Project Title: "Enhancing conjunctive management of surface and groundwater resources in selected trans-boundary aquifers: case study for selected shared groundwater bodies in the Nile basin"

Component 1: "Furthering knowledge and understanding about availability of groundwater resources in the selected aquifers underlying watersheds in the sub-basins of the Eastern Nile and the Nile Equatorial Lakes"

SADA Report for the Gedarif-Adigrat Aquifer System

Final Report

Professor. Gamal Abdo

International Consultant

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LIST OF ABBREVIATIONS

BCM	Billion Cubic Meters
CASZ	Central Africa Shear Zone
CBO	Community Based Organization
CSA	Central Statistics Agency
DEM	Digital Elevation Model
EASH	Water Sanitation and Hygiene
FAO	Food and Agricultural Organization
FDG	Focus Group Discussion
GEF	Global Environmental Facility
GIS	Geographic Information System
GOPE	Gedaref Organization for Peaceful Coexistence
GWWD	Groundwater and Wadis Directorate
HCED	Higher Council for Environmental Development
HQ	Headquarter
IC	International Consultant
IOM	International Organization of Migration
JICA	Japan International Cooperation Agency
LU/LC	Land Use/Land Cover
MAF	Ministry of Agriculture and Forestry
MCM	Million Cubic Meter
MEM	Ministry of Energy and Mining
MOAR	Ministry of Animal Resources and Fisheries
MOWR	Ethiopian Ministry of Water Resources
MWRI	Ministry of Water Resources and Irrigation
NBI	Nile Basin Initiative
NC	National Consultant
NGO's	Non- Governmental Organization
NILE Sec	Nile Basin Secretariat
RWU	Regional Water Bureaux
SADA	Shared Aquifer Diagnostic Analysis
SDGs	Sustainable Development Goals
SMA	Sudan Meteorological Authority
TBA	Trans-boundary Aquifer
TDS	Total Dissolved Solids
UCWR	UNESCO Chair in Water Resources-Omdurman Islamic University
UNDP	United Nation Development Program
UNESCO	United Nation for Education, Science and Culture Organization
UNIECF	United Nations International Children's Emergency Fund
UNO	United Nation Organizations
UofK	University of Khartoum
WEF	World Food Program
WES	Water and Environmental Sanitation
WMO	Water Meteorological Organization
WRC	Water Research Centre - UofK

EXECUTIVE SUMMARY

This is the Shared Aquifer Diagnostic Analysis (SADA) report for the Gedaref- Adigrat groundwater basin shared between Sudan and Ethiopia. The report serves as a baseline fact-based representation of the current status of the aquifer including its geologic and hydro-geologic characteristics, groundwater availability and use, surface-groundwater interaction, socio-economic aspects, groundwater governance and policies, groundwater management challenges, climate change impacts and trans-boundary threats, as well as identification of key gaps and threats to the management of groundwater resources. The study was largely a review of secondary existing/archived historical datasets and information with limited primary field data collection involving both technical and social science approaches. The collected data was harmonized to characterize the aquifer across the two-shared countries for information management. The technical data gathering methodology included a review of datasets and previous works and information to characterize the physical aspects of the aquifer including areal extent and architecture, hydraulic properties and storage, physiography, climate, vegetation, soils and geology. Social sciences methodology included, in-depth interviews; focus group discussions; field observation; key stakeholder mapping; reviews of reports, manuscripts and official documentation.

The climate in the study area ranges from arid to semiarid in the Sudan side to tropical savannah in the Ethiopian side with distinct dry and rainy seasons. Rainfall exceeds 1000 mm/year in the Eastern side of the study area with a decreasing trend towards Sudan to about 600 mm/y at Gedaref and even more decreasing to 470 mm/y at Showak at the north-eastern part of the study region. Monthly potential evapotranspiration greatly exceeds monthly precipitation throughout the year except during the months of June, July and August when rainfall exceeds evapotranspiration and when surface runoff and aquifer recharge takes place.

The impact of climate change on water resources was studied. The results of analysis showed an increasing trend in surface temperature of 4 to 4.5 ^{O}C by the end of the century in the business as usual scenario (RCP 8.5) and 2.0^{O}C increase for the conservative RCP4.5 scenario. Results also show a significant increasing trend of annual rainfall in the study area and increasing number annual rainy days. However, annual average evapotranspiration is expected to increase by 35 mm/year. It can be concluded that there is a significant change in the various climatic parameters as a result of climate change but overall, no serious hazard and impact on surface water resources and groundwater recharge are expected since increase in evapotranspiration is compensated by increase in rainfall.

The socio-economic situation in the study aquifer has also been studied. Most of the population depends on rain-fed agriculture which employs about 90 percent of the working force. The farming system of the study area is largely characterized by crop-livestock production system (mixed farming systems). Though the study area enjoys huge land resources, relatively high rainfall levels and rich animal resources, the population in the study area continues to suffer from high levels of poverty, food insecurity and poor social indicators. The relatively high incidence of poverty has generally been attributed to the region's constant vulnerability to environmental hazards and disasters, conflicts and instability, and particularly the deterioration of the agricultural sector in recent years. Specifically, the study region suffers from high susceptibility to natural disasters, acute shortage of potable water supply and sanitation facilities, high illiteracy and unemployment rates, lack of health services, and political conflict and displacement.

The aquifer represents an invaluable resource of strategic importance for domestic water supply for major cities, towns, and rural communities in the study area. The geology of the aquifer is basically Nubian which rests unconformably on the basement complex rocks and is overlain and/or intruded by basaltic rocks that originated from volcanic eruptions. Groundwater occurs within the sandstone formation as well as the fractured and weathered zones of the Basalt under unconfined and semi-confined conditions. The aquifer is recharged from rainfall at the area out-cropping the water bearing formation and from seasonal runoff. According to the groundwater flow directions, the Gedaref aquifer is also recharged through subsurface groundwater flow from the Ethiopian side of the aquifer. Water quality is reported to be fresh in the Gedaref sandstone formation parts of the basin where TDS values range between 400 and 500 ppm are recorded while higher values of TDS greater than 800 are recorded within the basalt formation.

The shared aquifer supports about 3.3 million people as well as more than 12 million livestock heads in Gedarif and Adegrat areas. Total annual actual water supply is estimated at about 23 MCM/year compared to actual demand of about 146.5 MCM/year. This reflects the huge gap between water supply and demand in both sides of the aquifer. Preliminary assessment reveals that the Gedaref-Adigrat aquifer has huge groundwater storage potential which is estimated at about 104 BCM and an annual natural recharge of about 128 MCM/year which represents only about 1% of the available excess runoff. Therefore, there are huge opportunities for enhancing the natural recharge through artificial recharge techniques and for the development of the available groundwater storage to satisfy the future expansion in the demand.

Stakeholders' analysis in Gedaref-Adigrat aquifer has been conducted. The analysis included identification of stakeholders, their classification (primary or secondary), their interest and level of influence on the proposed project. Primary stakeholders refer to people, groups, and institutions affected positively or negatively by the proposed or implemented groundwater management activities or decisions. Secondary stakeholders refer to people, groups, and institutions that are important intermediaries in the groundwater management project implementation process. 154 different stakeholders have been identified in Gedaref and Adigrat groundwater trans- boundary. The Stakeholders groups include state and local government water resources management institutions, water providers, water users, legislative bodies and regulators, policy makers, civil societies, women and youth groups, external and local NGOs (Service delivery) and financing organizations. The status and role of each stakeholder in connection to SADA project in terms of interest and influence have been clearly indicated. However, details with regards to degree of their engagement in water resource development and management, operation areas and type of activities for each partner, expectations from the groundwater management activities and the type of help that could be provided by stakeholders in the process of groundwater management and planning are not available and this needs further investigation.

The groundwater governance and policy issues in the Gedarif-Adegrat aquifer have also been studied. There are institutional and policy gaps at the national, state and local levels. Theses gaps are recognized in terms of inadequate institutional structures, lack of coordination, fragmentation and overlap of responsibilities among stakeholders, shortages of technical and managerial qualified personnel, and inadequate funding and logistic support, in addition to in-effective legal and regulatory frameworks. Also there is on trans-boundary institution for groundwater management of the shared aquifer and there is poor consideration to groundwater resources as compared to surface water. There is a need for policy harmonization and negotiation between Sudan and Ethiopia and formulation of binding regulations on the sustainable use of shared groundwater resources.

The study identified the gaps that hinder the sustainable management of the Gedarif-Adegrat aquifer as well as the major trans-boundary risks that should be considered by Sudan and Ethiopia .The gaps identified are water supply shortage, water quality and sanitation gaps, lack of monitoring and adequate information base, governance and policy gaps and technical capacity gap. Trans-boundary risks were also identified which include climate change, pollution and water quality deterioration, land degradation due to LULC changes, loss of biodiversity, poverty, political conflict and displacement.

The study concluded with some recommendations for the sustainable management of the shared aquifer which are:

- Establishment of a trans-boundary monitoring network
- Establishment of groundwater data and information exchange platform between Sudan and Ethiopia at national and local levels and introducing adequate administrative institutions for data collection and information dissemination.
- Establishment of capacity building programs at various levels including the community on shared groundwater resources management and ways to reduce potential competition and conflict. Training needs identified include groundwater modelling, trans-boundary monitoring, international groundwater policies and laws, trans-boundary groundwater conflict management, isotope techniques and water harvesting and management of groundwater recharge (MAR)
- Development of groundwater model for the shared aquifer to investigation alternative joint management scenarios.
- Establishment of a joint coordination committee between Sudan and Ethiopia for the joint management of the Gedaref-Adigrat aquifer.

1. INTRODUCTION

1.1. Project Background

Rising demands from global population growth, rapid urbanization, intensification of agricultural production, as well as increasing industrialization will require growing reliable quantity and quality of water. To meet these increased demands, policymakers, natural resource managers, and planners have to stop focusing solely on surface water and consider conjunctive uses of both surface water and groundwater resources. Groundwater resources can represent an economical, reliable, and sustainable contribution to water challenges. Furthermore, these resources are naturally less vulnerable and more resilient to external influences, such as floods and droughts, than surface waters. These extreme hydrological events can have devastating impacts on human life, generate an economic loss, and increase poverty and deprivation. Besides that, floods and droughts frequency is increasing due to the effects of climate change. Aquifers often offer opportunities for reducing the impact of these hydrological extremes and contribute to establishing emergency water supplies. Currently, there is increasing attention towards this precious water resource to overcome the water scarcity and high water demand in economic sectors. Groundwater resources are preferable to water resources that can be used efficiently and effectively for human and industrial consumption. This resource is viable to use for the required purpose because of the following major reasons:

1) It has a high natural storage capacity.
2) The water quality is good compared to surface water.
3) It is applicable to build infrastructure for poor communities and people living in arid and semi-arid areas (Adelana, MacDonald, Abiye, & Tindimugaya, 2008).

Further, it has high reliability in the case of inter-annual seasonal variation compared to surface water (Calow, MacDonald, Nicol, & Robins, 2010). Hence it is an important water resource that can be used for different activities.

Groundwater has always been essential for human needs and development throughout Africa, and this is the case in the Nile River Basin. Up to 75% of the population of the basin uses groundwater as the main drinking water source, and groundwater is important for rural livelihoods, livestock rearing and urban water supply. Trans-boundary aquifers (TBAs) underlie about 40% of the Nile Basin (NBI, 2006). According to available literature, most of these aquifers are in areas of high storage and high yield. Groundwater resources in TBAs in the Nile Basin is thus of importance for the development of the basin. Yet only a few TBAs have been studied in detail in an international context; the most important of these is the Nubian Sandstone Aquifer shared between Egypt, Sudan, Libya, and Chad. As pressures on groundwater resources increase with economic development, population growth and climate change, it is increasingly important to understand the potential and management practices of TBAs in the Nile Basin. TBAs may be subject to conflicts of interests because of unequal resource partitioning and different management capacities within the social, economic, and environmental contexts of the sharing countries. However, cooperation provides the opportunity for cross-border dialogue and data sharing for better evaluation of the shared resource and more equitable and sustainable use of those resources. Trans-boundary cooperation on water issues has increased tremendously within the last few decades. Yet the challenges are expanding ever more rapidly due to growing demand for freshwater resources in all water-using sectors, decreasing availability of safe water resources due to pollution and climatic changes which are expected to increase the variability of the hydrological cycle and thus lead to less reliable water supply patterns.

Until recently, groundwater had not been given the necessary consideration as an integral part of water resources development in the Nile Basin. As part of its role to promote joint development, protection and management of the common Nile Basin water resources, the Nile Basin Initiative (NBI) has initiated a basin wide project entitled "**Enhancing conjunctive management of surface and groundwater resources in selected trans-boundary aquifers: a case study for selected shared groundwater bodies in the Nile basin**". The project is being implemented by the Nile Basin Secretariat (Nile Sec) in collaboration with the United Nations Development Programme (UNDP) with funding from the Global Environment Fund (GEF). The project focuses on management of trans-boundary groundwater aquifers and is considered as an excellent opportunity for building and expanding the knowledge of groundwater resources of the Basin and for enhancing its role to meet the ever increasing demand for water for different purposes. Lack of good understanding and clear knowledge of the trans-boundary impacts could lead to potential threats such as deterioration of water quality, irrational water use with the potential to harm biodiversity, land degradation processes, or even trans-boundary conflict.

1.2. Project Objective

The project objective is to enhance knowledge and capacity for sustainable use and management of trans-boundary aquifers and aquifers of regional significance in the Nile

Basin. The project will also contribute to aid the national achievements and reporting of water-related Sustainable Development Goals (SDGs) and will be supportive to environmental protection whilst enhancing the socio-economic development of the basin's population. Specific objectives are to:

- Improve knowledge and understanding of groundwater resources in the Nile Basin;
- Strengthen overall water resources management nationally and basin-wide;
- Respond to climate change impacts through effective risk-reduction adaptation measures , e.g. conjunctive use and management of surface water and groundwater;
- Ensure a healthy ecosystem and strengthened livelihood.

The project comprises the following five (5) components:-

Component 1: Furthering knowledge and understanding about availability of groundwater resources in the selected aquifers underlying watersheds in the sub-basins of the Eastern Nile and the Nile Equatorial Lakes.

Component 2: Development of action plans on groundwater resources governance, management, and protection for inclusion in national, sub-basin frameworks, also including consideration of surface water/groundwater resources conjunctive use.

Component 3: Targeted pilot projects to explore conjunctive use of surface and ground waters, and links to biodiversity conservation and climate change adaptation.

Component 4: Further strengthening capacity to address groundwater issues at the national and regional levels.

Component 5: Communications and awareness raising.

The current study involves Component 1 on furthering knowledge and understanding about availability of groundwater resources in the selected aquifers underlying watersheds in the sub-basins of the Eastern Nile and the Nile Equatorial lakes. Three aquifer areas were chosen for the current intervention, namely the Gedaref-Adigrat aquifer shared between Ethiopia and Sudan; the Kagera aquifer shared among Burundi, Rwanda, Tanzania and Uganda; the Mt. Elgon aquifer shared between Kenya and Uganda. The aquifers are located in diverse ecological zones ranging between arid, semi-arid and tropical. This assignment will aim at fostering current mutual understanding for the groundwater flow regime and mechanism of recharge, policies, management systems, community engagement and sustainable development plans for effective utilization and protection from over abstraction, depletion and pollution.

1.3. Consultancy/Assignment Objectives

1. To undertake a Shared Aquifer Diagnostic Analysis (SADA) and produce a report that serves as baseline fact-based representation of current status of the aquifer development; threats; use/abstraction; surface-groundwater connection, socio economic aspects, with gender engagement as well as climate change impacts and associated extreme climate events.
2. To support preparation of the harmonized and a standardized groundwater knowledgebase (geo-data base and maps) for the Gedarif-Adegrat aquifer system by providing data in the relevant formats.

1.3.1. Consultancy Scope

1. Develop conceptual framework and plan the SADA study.
2. Identify the data needs and tools/resources required
3. Supervise national consultants from Sudan and Ethiopia who will collect relevant information on groundwater management in the countries, and specifically, data and information for the Gedarif-Adegrat aquifer.
4. Carry out a review of the existing data and/or prior hydrogeological related assessment reports that are available;
5. Conduct analysis of the aquifer;
6. Provide assessment reports, including hydrogeological maps with recommendations for suitable groundwater interventions as adaptive measures based on the findings of the assessments.
7. Provide an updated knowledge/information with maps of groundwater distribution and availability by conducting groundwater assessments for the Gedarif-Adegrat shared aquifer.
8. Conduct two aquifer level workshops in the shared aquifer area in Sudan and Ethiopia. Workshop participants are to be selected maintaining gender balance involving national and regional stakeholders. In carrying out the above tasks, the consultant is expected to work very closely with local staff in Kenya and Uganda, of the national/local authorities to ensure skills transfer/capacity building.

9. Conduct two regional validation workshops in Sudan and Ethiopia to be delivered by the consultants. National Focal Institution will coordinate local level engagement of stakeholders.

1.4. Objective and Scope of the Report

This is the final Shared Aquifer Diagnostic Analysis (SADA) report for the Gedaref- Adigrat groundwater basin shared between Sudan and Ethiopia. It discusses the outcome of component 1; of the project which provides the basis for the other four components. The report serves as a baseline fact-based representation of the current status of the aquifer including its geologic and hydro-geologic characteristics, groundwater availability and use, surface-groundwater interaction, socio-economic aspects, trans-boundary threats, groundwater governance and policies, groundwater management challenges, as well as and climate change impacts. The report provides updated knowledge/information based on existing data with maps of the groundwater basin characteristics, distribution and availability of groundwater storage and recharge with recommendations for sustainable groundwater management based on the findings of the assessments. Most of the information presented in this report is based on the reports submitted by the national consultants.

1.5. Approach to SADA Study

For the preparation of the SADA study of the Gedaref–Adigrat aquifer, the Nile Sec has hired a Technical National Consultant (NC) for technical data gathering and a social National Consultant for the socio-economic and environmental data gathering from each of Sudan and Ethiopia as well as an International Consultant (IC). The IC identified the data needed for the SADA assessment, supervised NCs in collecting relevant information on groundwater management in the two countries, reviewed and commented on the individual reports submitted by the NCs. The IC is to conduct the analysis of the aquifer and provide the SADA report. In carrying out the various tasks to develop the SADA report, the IC worked closely with the NCs of the technical and socio-economic data gathering. Also, consultation and coordination with stakeholders including local staff and local authorities were made to ensure information exchange, skills transfer and capacity building. The IC provided guidance to the NCs in all stages of their work through regular online meetings and short progress reports. Also a focal person representing the focal institution was identified to facilitate the work of the National Consultants and help with data collection and organization of workshops and other activities of the study.

The study was largely a review of secondary existing/archived historical datasets and information with limited primary field data collection involving both technical and social science approaches. The collected data was harmonised to characterise the aquifer across the two-shared countries for information management. The technical data gathering methodology included a review of datasets and previous works and information to characterise the physical aspects of the aquifer including areal extent and architecture, hydraulic properties and storage, physiography, climate, vegetation, soils and geology. Social sciences methodology included, in-depth interviews; focus group discussions; field observation; photography; key stakeholder mapping using the snowball technique, or chain referral; reviews of reports, manuscripts and official documentation; and identification of key threats to the management of groundwater resources.

1.5.1. Technical Data Gathering

This activity included primary desk work consisting of collection of existing data and literature and compilation from the available literature and previous studies and analysis. Field visits were carried out to collect more information from the field. Technical data included but was not limited:

- Delineated aquifer boundaries in Sudan and Ethiopia and development of GIS shape files which were combined to give one shape file for the shared aquifer. This provided the base map for all analyses.
- LU/LC, DEM, Soil and drainage maps.
- Geology, hydro-geologic characteristics including types of water bearing formation and groundwater occurrence.
- Well inventory including well lithology, groundwater levels, well yield, water quality and actual pumping.
- Trends in groundwater availability (eg declining water table, groundwater pollution, degradation of recharge zones, etc).
- Pumping test data.
- Surface hydrology including climatic data and surface runoff.
- Sources and amounts of recharge.
- Existing groundwater development policies.
- Governance mechanisms at national and cross-border levels.
- Legislation and institutional arrangements for groundwater management.

- The status on monitoring and identification of key gaps in current monitoring infrastructure in both countries.
- National groundwater development plan.
- Ongoing projects/programs with specific reference to the aquifer areas.
- Training and capacity building needs at different levels including community.

1.5.2. Social and Environmental Data Gathering

This data included:

- Stakeholders mapping and their involvement in groundwater management.
- Socioeconomic characteristics of the aquifer areas (eg drinking water coverage, customary water management practices, livelihood activities and conditions)
- Current water use (drinking water, livestock watering, rangeland watering, industry, mining, wildlife water sourcing, urban water supply sourcing, multiple uses, etc).
- Gender analysis and their role in groundwater management

1.5.3. Data and their Sources

Most of the data for the preparation of this report was provided by the National Consultants However, some data gaps were encountered which were filled from available open sources. Table 1-1 shows the data types used and their sources

Primary data collection was conducted through field visits and measurements of groundwater parameters. Also interviews and focal group discussion (FGDs) with local respondents using a set of guiding questions were conducted. During the FGDs, local community participants were organized into user groups depending on their main livelihoods or economic activities Further, local communities were structured or categorized into gender groups specifically the youth groups, and women groups.

Secondary data on technical and socio-economic issues were collected through primary desk work consisting of collection of existing data and literature and compilation from the available literatures and previous studies and analysis. More information from the field was also collected as well as data from internet sources.

Table 1-1: Data Types used and their sources

No.	Data type	Source
1	Administration areas and boundaries, Population data	Africa geo-portal, study reports, field visits
		Polygon feature classes (https://data.humdata.org/)
2	Climate data	Sudan meteorological authority, open sources, study reports
3	Geology	African geological portal, study reports,
4	Hydrogeology	Global hydrogeology maps, study reports
5	Borehole data, depth, water level, productivity etc.	Groundwater authority, study reports, field observation
6	Water quality	Groundwater authority, study reports, field observation
7	Water use	Groundwater authorities, field visits, study reports
8	Social data	Study reports, field visits, interviews, FGDs
9	Groundwater governance, policies	Water authorities, study reports
10	Surface & groundwater monitoring data	Water authorities, field visits, study reports
11	Water Utilities data	Water authorities, field visits, study reports
12	Lu/Lc, topography, soil maps	from NASA Shuttle Radar Topographic Mission (SRTM) and other open sources
13	Pumping test data	Groundwater authorities, study reports

1.5.4. Formation of Geo-Database

A Geo-Database system was formulated for the Gedaref-Adigrat aquifer which included primary data from field measurements, secondary data from archived previous study reports, papers and open source data from international sources.

The data was aggregated and harmonized for the aquifers on both sides and a GIS information base was developed with data layers covering different aspects such as hydrological, hydrogeological, physiographical environmental and social aspects.

1.5.5. Workshops

The following workshops were conducted:

- Two aquifer level workshops in the shared aquifer area in Sudan and Ethiopia. The purpose was to validate the data that has been collected, enhance the visibility of the project, and more collect information for the SADA particularly water uses, governance issues and possible trans-boundary risks and challenges. Workshop participants were selected maintaining gender balance involving national and regional stakeholders.

- Two regional validation workshops in Sudan and Ethiopia delivered by the consultants.

The following workshop is planned to be conducted:

- A regional SADA validation workshop with participants from both countries will be conducted either in Sudan or Ethiopia to discuss and validate the findings of the SADA analysis.

1.5.6. Modelling

Under a separate consultancy, a regional groundwater model will be developed for the aquifer to provide a technical basis for evaluating trans-boundary risks. The conceptual model of the aquifer will be developed based on the available hydrological and hydrogeological information. Participation of the national consultants and national experts from stakeholder's institutions will be ensured. The model will be calibrated against water level information. A water balance study of the Gedaref-Adigrat aquifer will be conducted with quantified recharge, outflows, and withdrawals. The model will then be used to investigate the consequences of different management scenarios for the aquifer with focus on the trans-boundary impacts and risks as well as projection of ground/surface water availability and identification of action plans for pilot projects for GW/SW conjunctive use under climate change stress and population increase pressure up to the year 2050. The results could be used as a basis for a trans-boundary agreement for win-win sustainable aquifer utilization between Sudan and Ethiopia.

Figure 1-1 summarizes the approach and methodology followed for the SADA analysis.

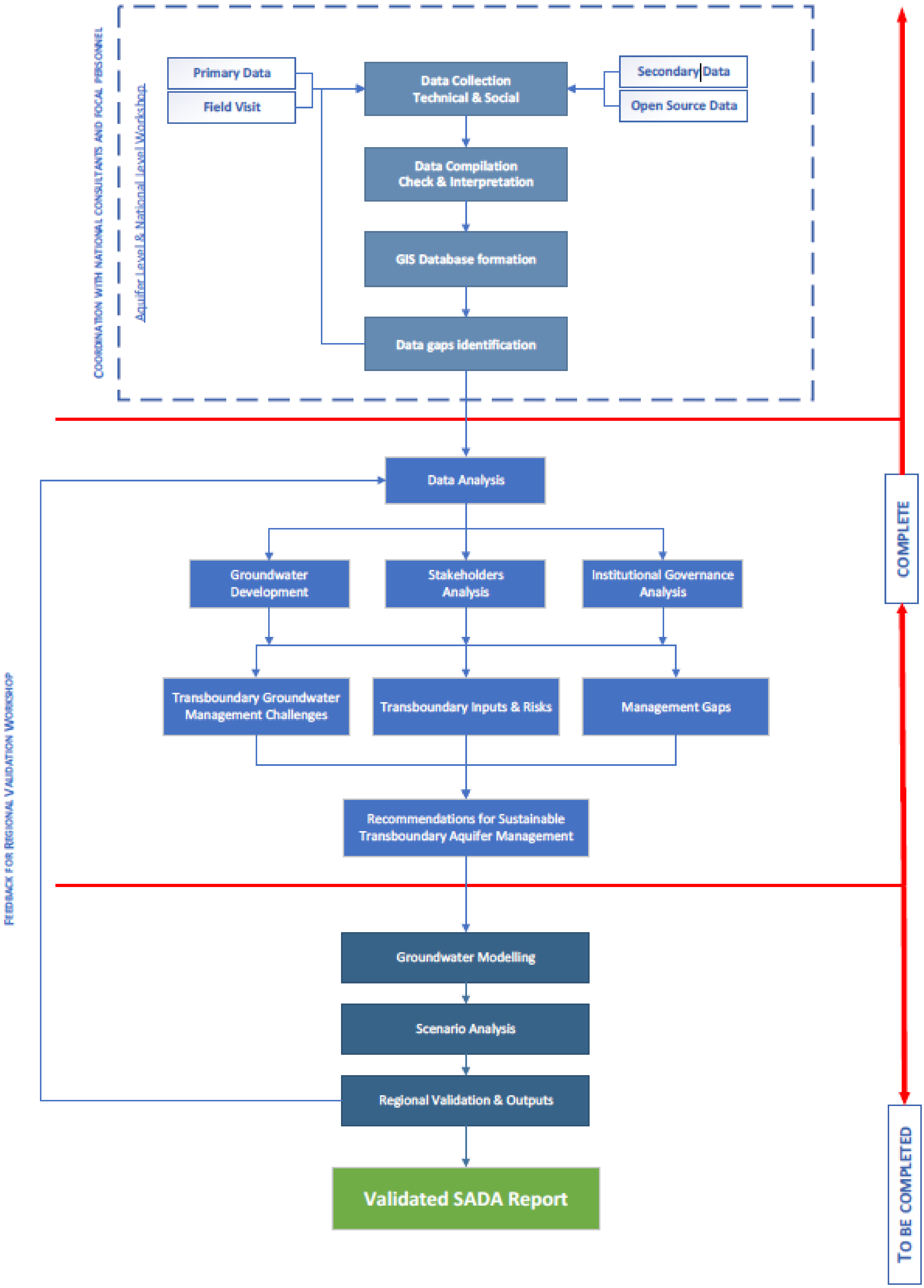

Figure 1-1: Approach and Methodology for the SADA Analysis

2. CHARACTERISTICS OF GEDAREF-ADIGRAT AQUIFER

2.1. Introduction

The Gedaref-Adigrat basin considered in this study is shared between Sudan and Ethiopia (Figure 2-1). The basin is one of the rift basins in Sudan and Ethiopia that has been formed due to reactivation of the Central African Shear Zone (CASZ). It has an area of about 55000 Km²; about 23000 Km² of it lies in Sudan and 32,000 Km² in Ethiopia. The area within Sudan represents about 30% of Gedaref State. The aquifer represents an invaluable resource of strategic importance for the socioeconomic development in both countries. Groundwater has been used as the main source for domestic water supply for major cities, towns, and rural communities. It is expected that the current demand for groundwater will increase due to population growth, climate change, and economic development which will all have a huge impact on the availability of aquifer resources in both countries. Therefore, it is necessary to comprehensively assess the availability of the groundwater resources potential for cooperative development and optimum utilization for mutual benefits of the two countries.

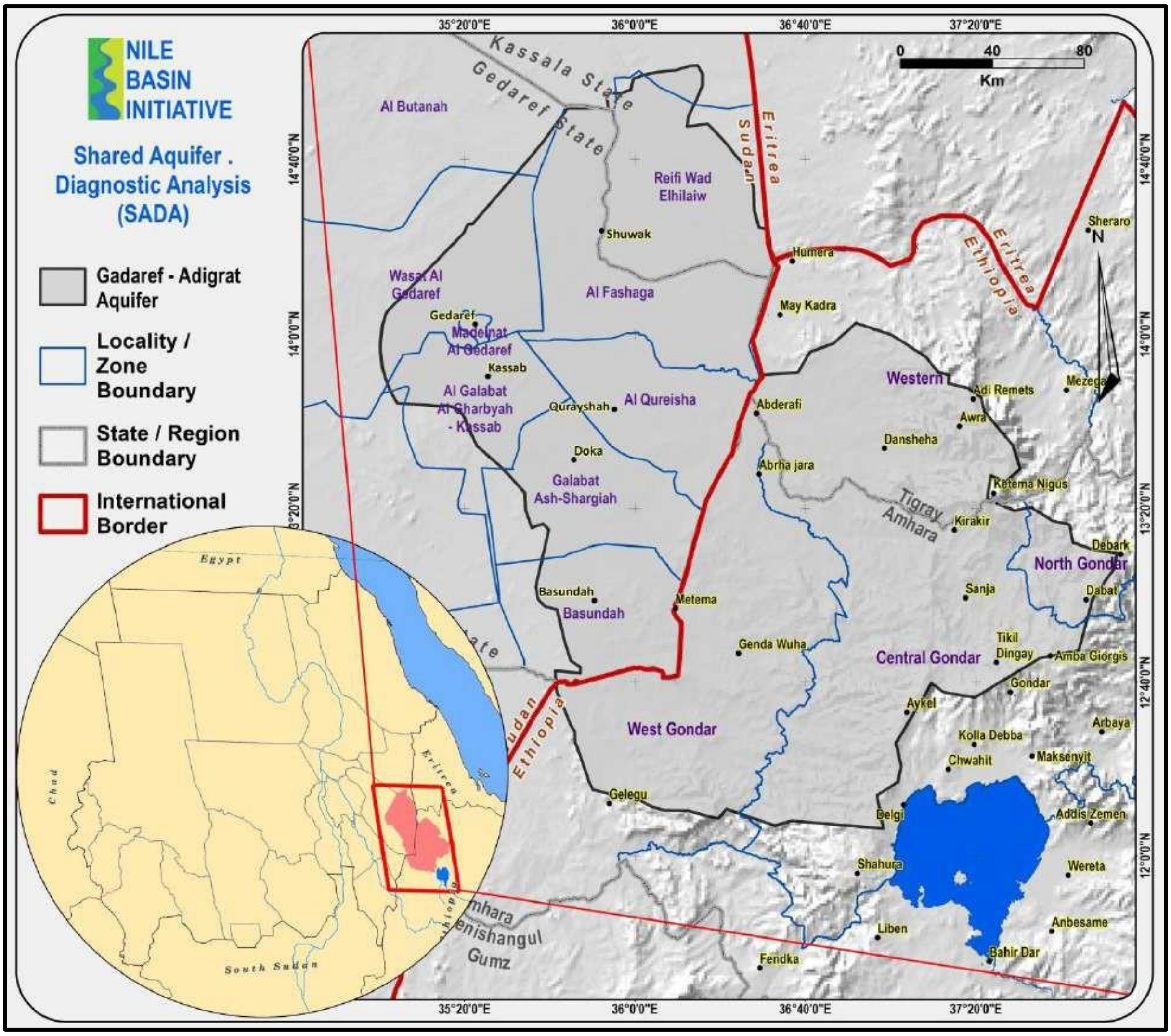

Figure 2-1: Administrative Units and Main Towns within Gedaref-Adigrat Aquifer

On the Ethiopia side, 14 districts lie within the aquifer in North Gondar and Western Tigray administrative zones. They are shown in (Table 2-1) together with the population in each district. In Sudan, the aquifer covers seven localities within Gedaref State. Table 2-2 shows the seven localities, their headquarters and population numbers. The administrative units in Sudan and Ethiopian side of the aquifer as well as major towns are shown in Figure 2-1.

Table 2-1: List of Districts and Population within the Project Study Area in Ethiopia

No	Region	Zone	District	Population
1	Amhara	North Gonder	Alefa	185,357
2	Amhara	North Gonder	Chilga	240,67
3	Amhara	North Gonder	Dabat	159,091
4	Amhara	North Gonder	Debarq	174,589
5	Amhara	North Gonder	Dembia	295,423
6	Amhara	North Gonder	Gondar Zuria	254,420
7	Amhara	North Gonder	Lay Armacheho	171,857
8	Amhara	North Gonder	Metema	123,235
9	Amhara	North Gonder	Quara	102,055
10	Amhara	North Gonder	Sanja	97,824
11	Amhara	North Gonder	Wegera	240,346
12	Amhara	North Gonder	Kafta Humera	107,105
13	Tigray	W.Tigray	Tsegede	116,876
14	Tigray	W.Tigray	Welkait	156,115
Total				**2,184,293**

Table 2-2: Localities, Headquarters and Population within the Study Area in Sudan

No	Locality	HQ	Population
1	Gedaref	Gedaref town	483,131
2	Gedaref Central	Gedaref town	200,215
3	El Galabat West	Kasab	164,670
4	El Galabat East	Doka	2032 57
5	Fashaga	Alshowak	126, 379
6	El Goreisha	El Goreisha	149,436
7	Gedaref	Basunda	127,431
Total			**1,544,519**

The population numbers in the Ethiopian and Sudan sides of the aquifer are 2,184,293 and 1,124,883 respectively. Figure 2-2 shows the population settlements and Figure 2-3 shows the population density in both sides. It can be observed that higher number of settlements and population density is observed in the Ethiopian side of the aquifer. Generally, high population density is observed in the eastern and south-eastern parts of the study area in Ethiopia and around main towns in Sudan. The population density is based on population number per kilometer square area. The data obtained show that the population densities in the Sudan and Ethiopian sides of the aquifer are on the average 49 persons/Km² and 68 persons/ Km² respectively.

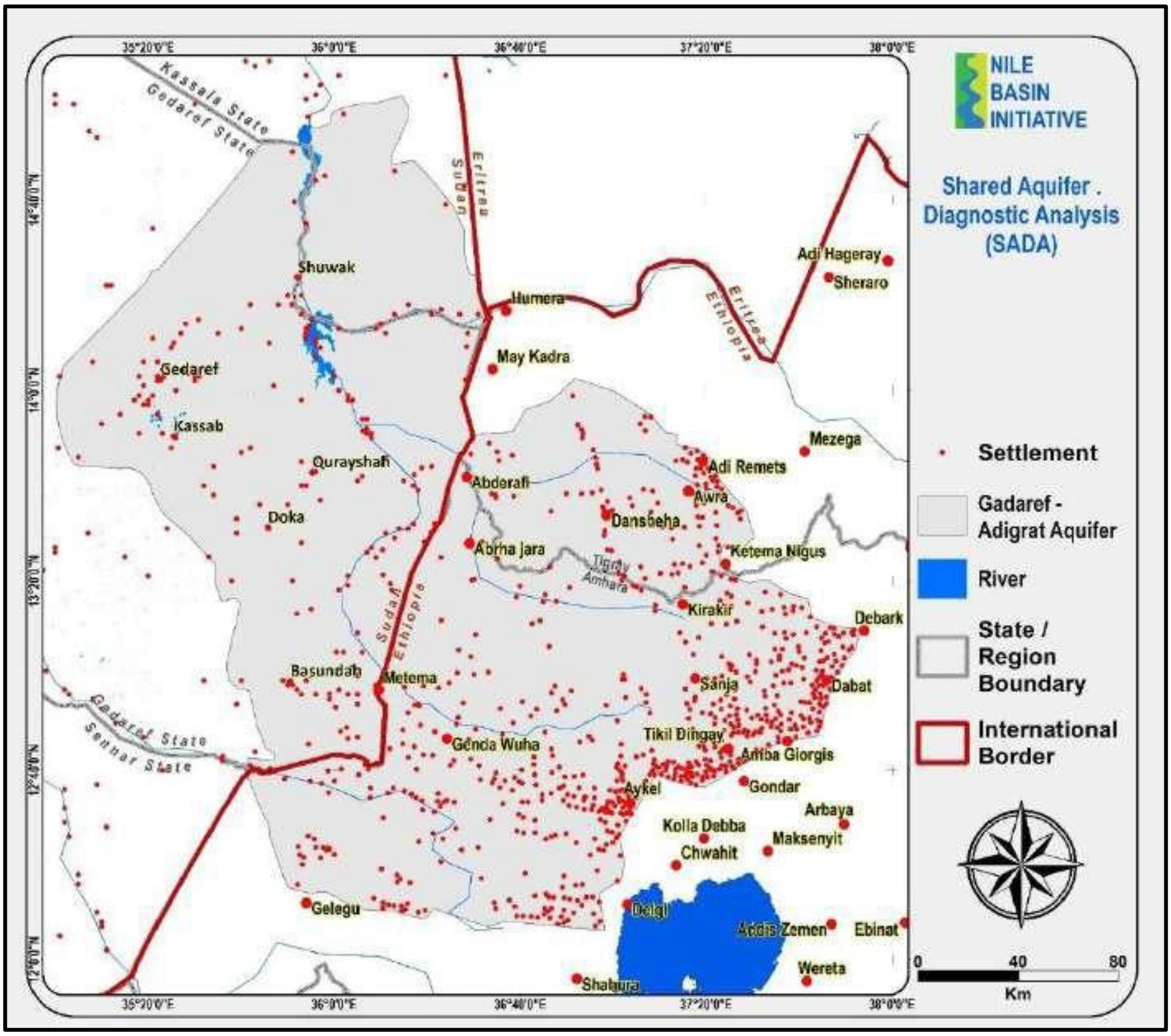

Figure 2-2: Settlements in the Gedaref-Adigrat Aquifer

The main watersheds that are contributing to the study area are River Atbara and River Rahad. The name Adigrat is coined with the Gedaref, because of the name Adigrat or Adigrat sandstone which comprises thick sequences of cross-bedded sandstone with intercalations of the aquifer is given later in this chapter.

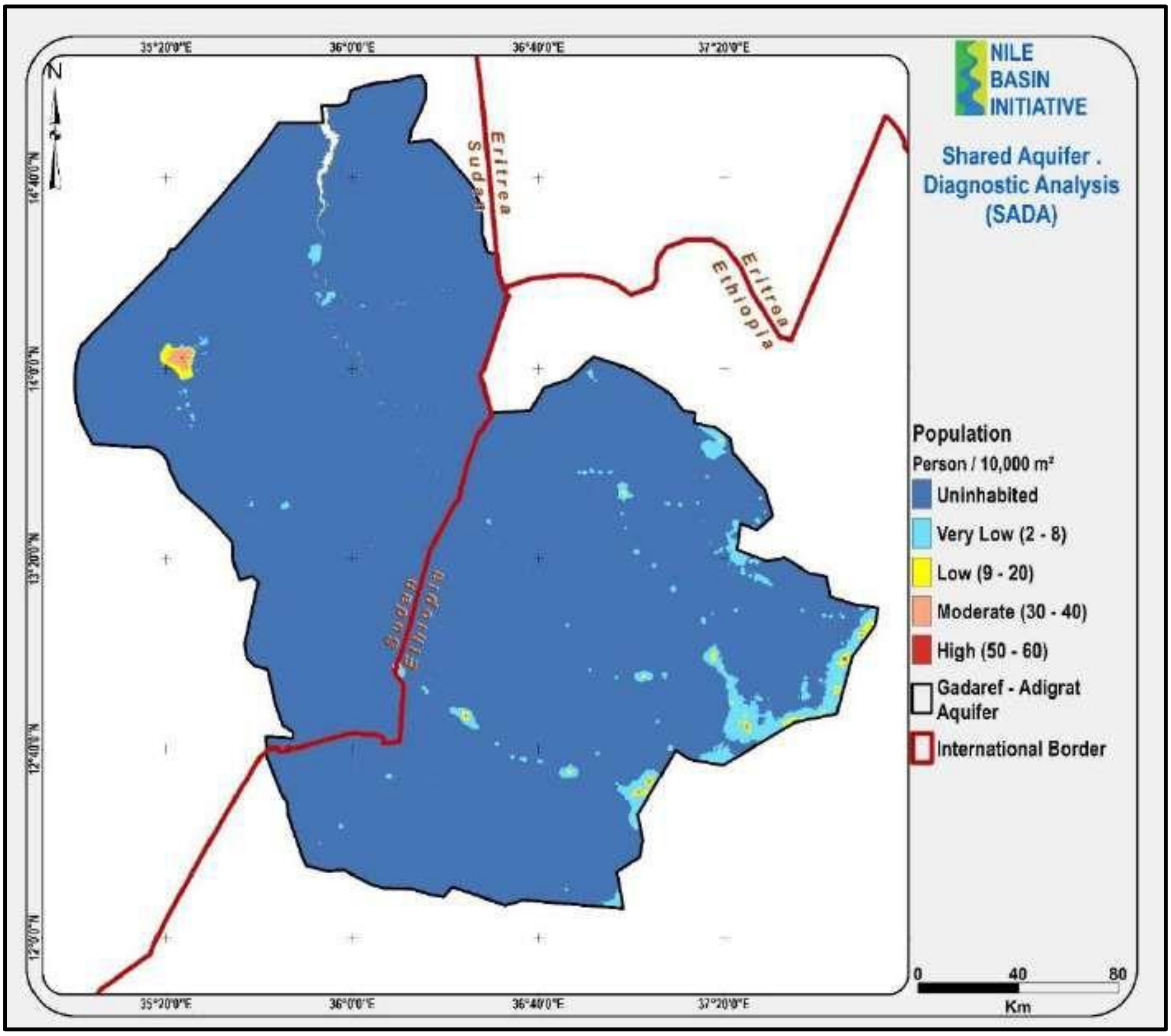

Figure 2-3: Population Density in the Gedaref-Adigrat Aquifer

2.2. Climate

The climate in the study area ranges from arid to semiarid in the Sudan side to tropical savannah in the Ethiopian side with distinct dry and rainy seasons. Average annual maximum temperature ranges between 30 C0 and 40 C0 with higher maximum temperature in the Sudan side. Average annual minimum temperature ranges between 10 C0 and 20 C0 with cooler weather in the Ethiopian side of the basin. Figure 2.4 shows the annual average maximum and minimum temperatures which indicate clearly that the Ethiopian side of the basin is generally cooler in terms of maximum and minimum temperatures.

The mean annual rainfall at six meteorological stations in the study region is shown in Figure 2-5. The data for the Sudan side were obtained from the Sudan Meteorological Authority while that for the Ethiopian side was obtained from open source due to lack of actual measured rainfall data. As can be seen, the rainfall in the Ethiopian side is higher exceeding 1000mm/year.

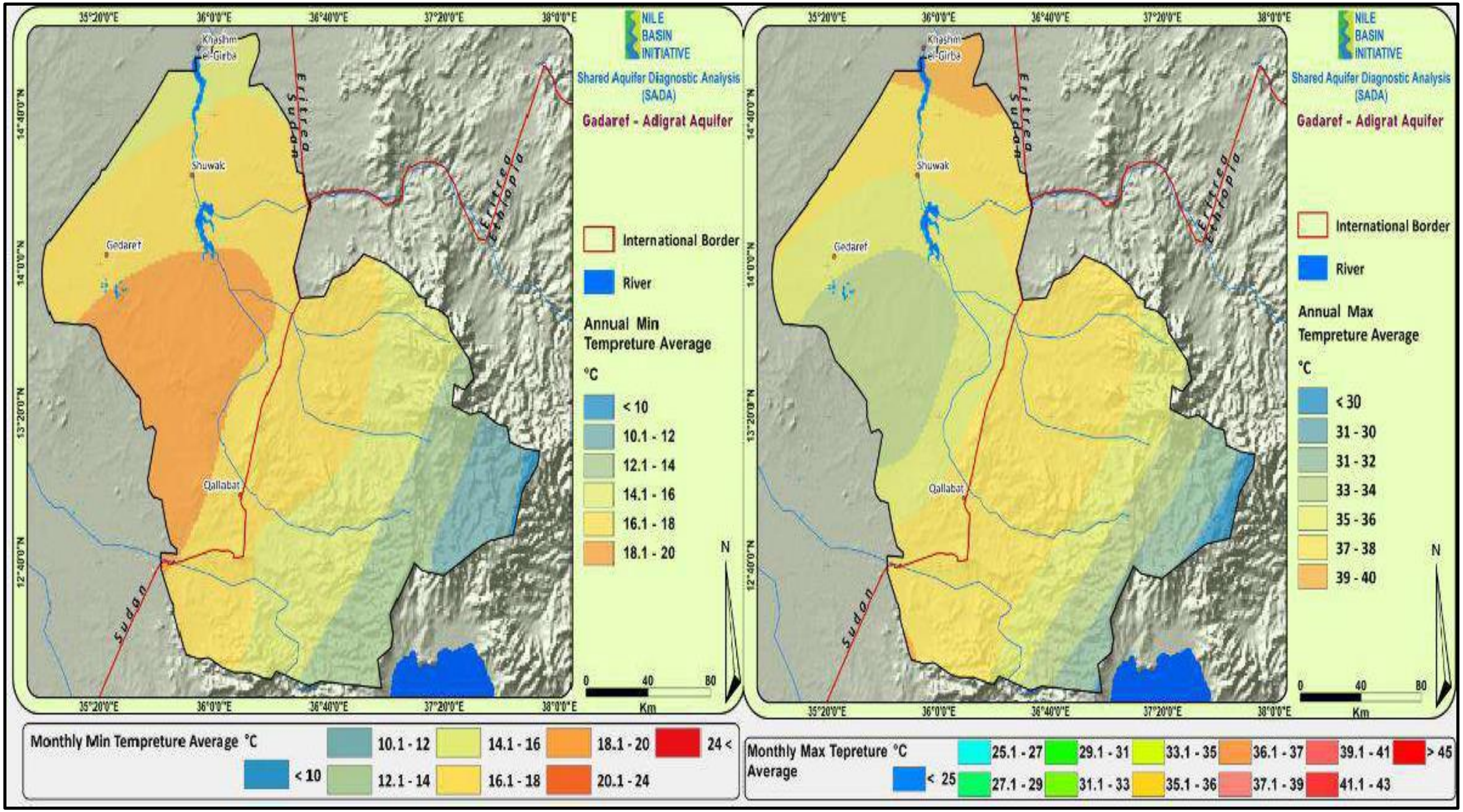

Figure 2-4: Average annual minimum (left) and maximum (right) temperature in Gedaref - Adigrat Aquifer

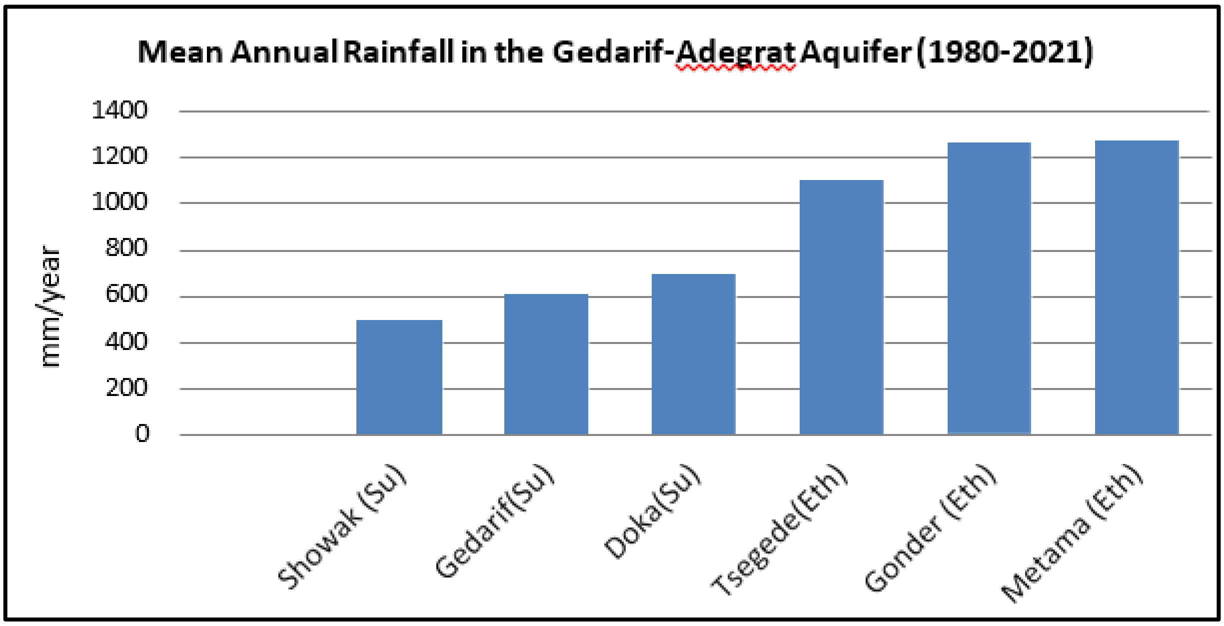

Figure 2-5: Mean Annual Rainfall at Six Meteorological Stations in the Gedaref-Adigrat Aquifer

In the south of the study region in Sudan, at Doka, average rainfall reaches 690 mm/y. Further to the North, the average rainfall decreases to about 600 mm/y at Gedaref and even more decreasing to 470 mm/y at Showak at the north-eastern part of the region. Figure 2-6 shows the average annual rainfall over the study basin together with monthly average rainfall. Again, the higher rainfall in the Ethiopian side can be seen as well as the decreasing trend of average annual rainfall towards the Sudan side. Figure 2-6 shows that the bulk of the rain falls in the period from July to September with its peak in August.

Table 2-3, Table 2-4, Table 2-5 and Table 2-6 show the monthly average rainfall and evapotranspiration in four selected stations, Gedaref, Showak, Gondar and Tesgede and Figure 2-7 and Figure 2-8 show the monthly values for Gedaref and Gondar as examples. The results show that the monthly potential evapotranspiration greatly exceeds monthly precipitation in the four stations throughout the year except during the months of June, July and August. It is estimated that out of the total rainfall in the Sudan and Ethiopian side, about20 % and 45% is excess water available for runoff and infiltration during the three months of the year respectively. The higher percentage of excess water at the Ethiopian side is attributed to the higher rainfall and higher slopes compared to the Sudan side of the basin.

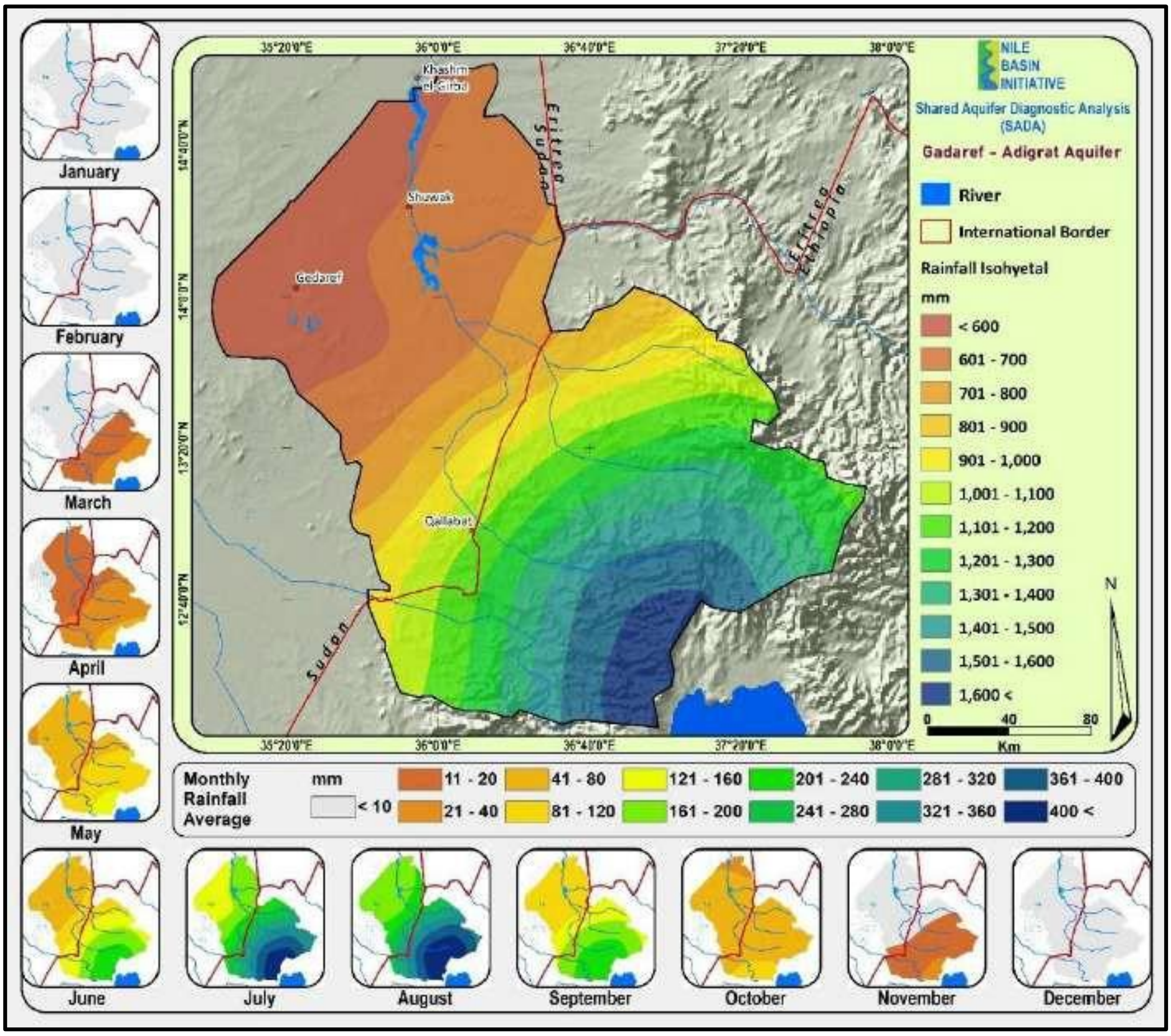

Figure 2-6: Mean Annual and Monthly Rainfall in the Gedaref-Adigrat Aquifer

Table 2-3: Average Monthly Rainfall Vs Evapotranspiration at Gedaref (1980-2020)

Month	Rainfall(mm/m)	Evapotranspiration (mm/m)	Excess rainfall (mm/m)
Jan	0.95	4.24	0.00
Feb	0.91	2.67	0.00
Mar	1.66	3.05	0.00
Apr	7.33	9.33	0.00
May	17.90	25.38	0.00
Jun	76.52	66.95	9.57
Jul	168.78	109.86	58.92
Aug	206.36	144.90	61.45
Sep	94.66	145.33	0.00
Oct	20.59	84.90	0.00
Nov	2.94	26.57	0.00
Dec	1.52	7.85	0.00
Total			**129.94**

Table 2-4: Average Monthly Rainfall Vs Evapotranspiration at Showak (1980-2020)

Month	Rainfall(mm/m)	Evapotranspiration (mm/m)	Excess rainfall (mm/m)
Jan	0.91	5.10	0.00
Feb	0.78	3.52	0.00
Mar	1.32	3.52	0.00
Apr	6.19	6.76	0.00
May	26.84	25.29	1.56
Jun	56.97	62.38	0.00
Jul	129.12	106.52	22.59
Aug	168.13	145.90	22.23
Sep	76.68	145.90	0.00
Oct	17.11	75.62	0.00
Nov	2.77	20.57	0.00
Dec	1.14	7.00	0.00
Total			**46.38**

Table 2-5:Average Monthly Rainfall Vs Evapotranspiration at Gonder (1980-2020)

Month	Rainfall(mm/m)	Evapotranspiration (mm/m)	Excess rainfall (mm/m)
Jan	2.95	36.45	0.00
Feb	4.14	20.28	0.00
Mar	18.05	30.25	0.00
Apr	22.00	43.45	0.00
May	80.00	143.65	0.00
Jun	175.95	142.44	33.51
Jul	316.67	165.37	151.3
Aug	336.95	195.87	141.08
Sep	152.05	255.02	0.00
Oct	66.33	218.41	0.00
Nov	25.00	132.54	0.00
Dec	6.50	72.247	0.00
Total			**325.89**

Table 2-6: Average Monthly Rainfall Vs Evapotranspiration at Tsegede (1980-2020)

Month	Rainfall(mm/m)	Evapotranspiration (mm/m)	Excess rainfall (mm/m)
Jan	1.90	24.518	0.00
Feb	1.81	14.547	0.00
Mar	5.71	14.365	0.00
Apr	20.38	22.1	0.00
May	70.71	59.618	11.092
Jun	158.38	141.7	16.68
Jul	274.86	174.135	100.725
Aug	321.05	184.47	136.58
Sep	185.10	198.276	0.00
Oct	47.38	166.712	0.00
Nov	4.67	72.371	0.00
Dec	3.85	36.725	0.00
Total			**325.89**

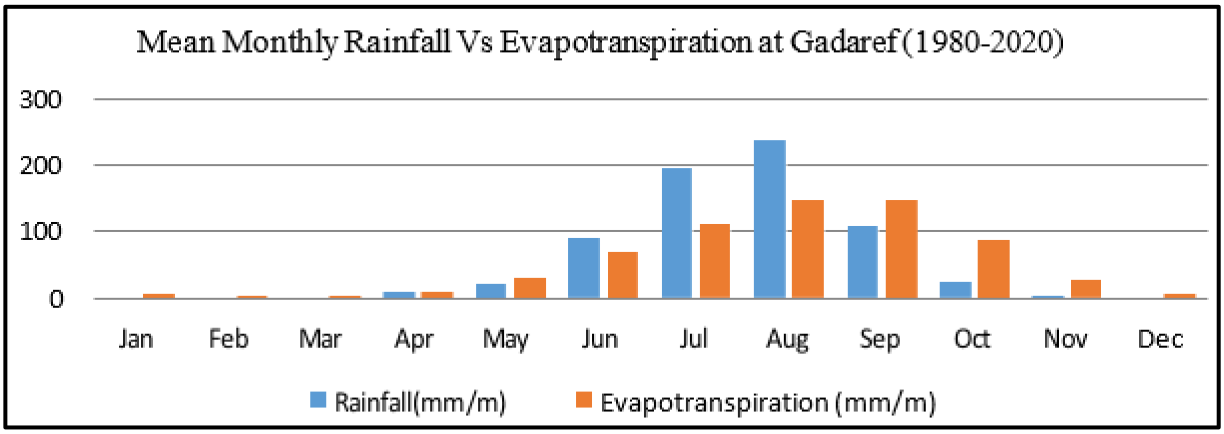

Figure 2-7: Mean monthly Rainfall and Evapotranspiration at Gedaref (1980-2020)

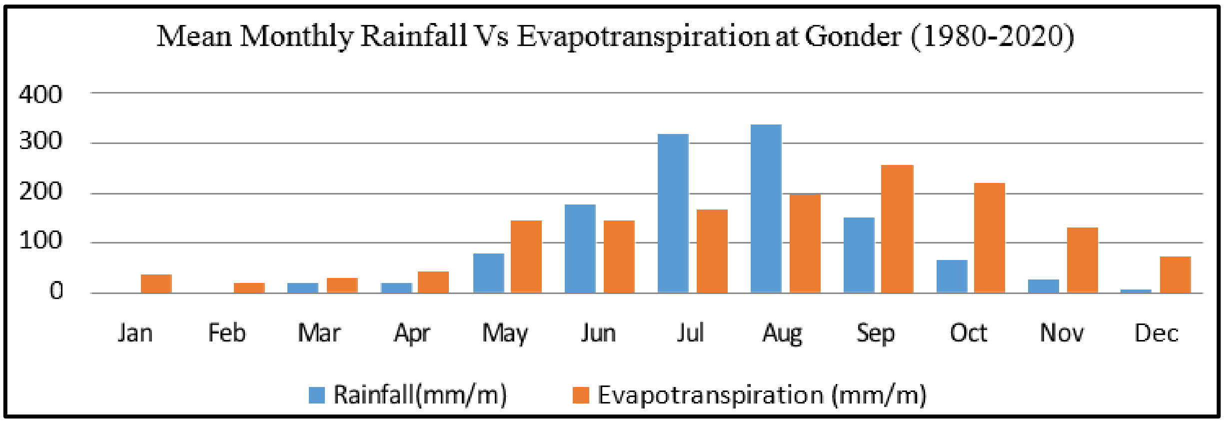

Figure 2-8: Mean Monthly Rainfall and Evapotranspiration at Gondar (1980-2020)

2.3. Topography and Drainage

Figure 2-9 shows a topographic map of the Gedaref-Adigrat basin. The topography features very high ridges along the eastern boundary of the basin in Ethiopia and low ridges on the western side in Sudan with the interior of the basin sloping mildly in a north-west to north direction in the same path of Atbara River. The elevation of the basin changes from a height of more than 3000 meters in Ethiopia to about 400 meters at the northern boundary in Sudan.

All the area in Ethiopia drains towards Sudan. The major drainage system crossing the basin is River Atbara and Rahad River. River Atbara has two major tributaries, upper Atbara which originates from Ethiopia and Setit which originates from Eritrea. Estimated annual flow of the River Atbara is about 11 BCM/year. The area west of the Gedaref - Gallabat ridge drains to the Rahad River by several Wadi systems the most significant of which is Abu Fargha Wadi. River Rahad has a total annual discharge of 1.1 BCM/year, and it runs over the southern part of the aquifer in Ethiopia.

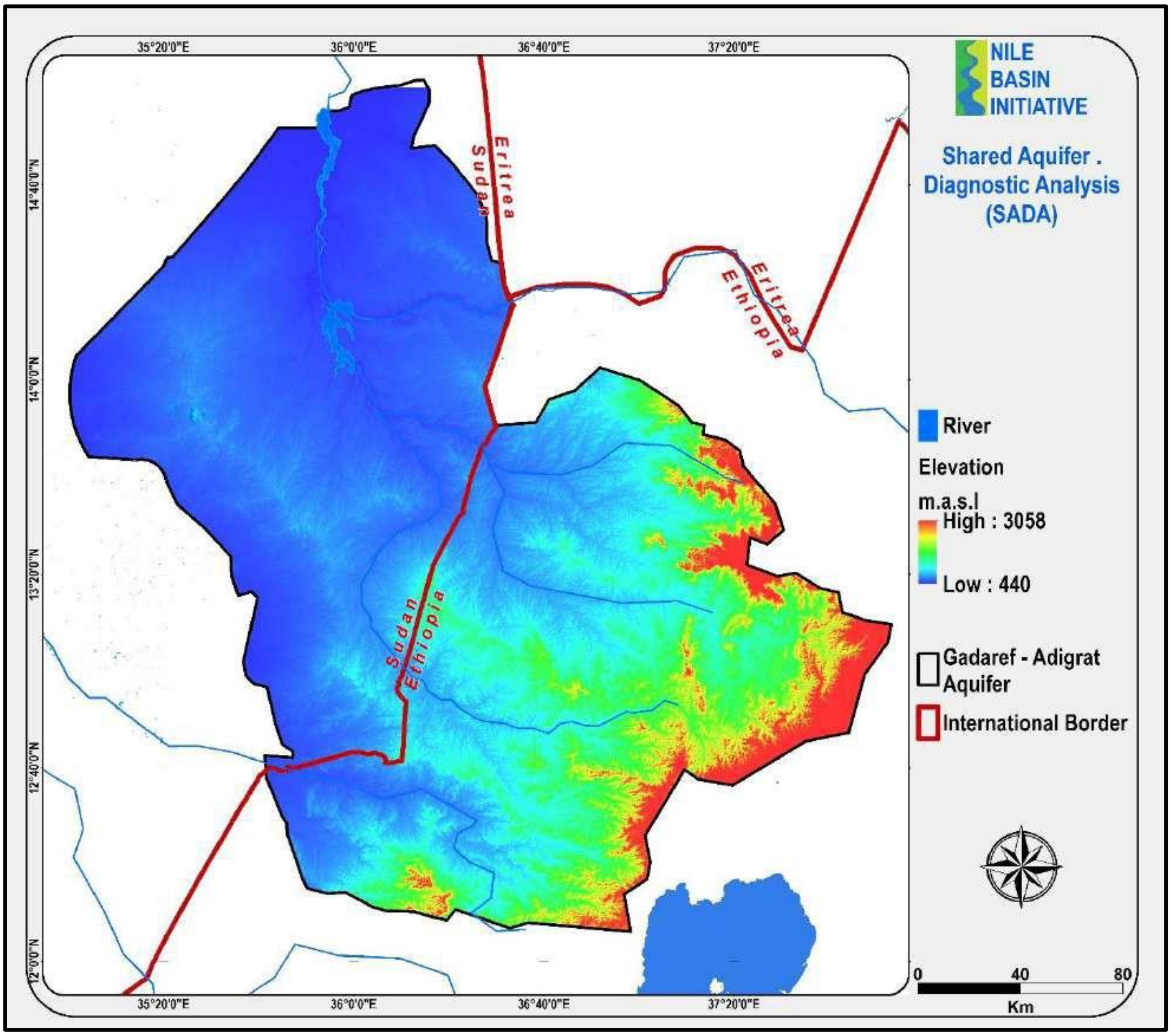

Figure 2-9: Topography and Drainage in the Gedaref-Adigrat Aquifer

Two major Sudanese dams lie within the study area in Sudan, namely Khashm Algirba and Upper Atbara dam complex which are both multipurpose for irrigation and hydropower generation. The Upper Atbara dam complex completed in 2019 has a storage capacity of 3.7 BCM, reservoir surface area of 250 Km² and total reservoir length of 120 km. Khashm Algirba dam built in 1964 had an initial storage capacity of 1.3 BCM which has now decreased to one third as a result of siltation. It has a reservoir surface area of 125 Km² and a length of 80 Km. The lakes of both reservoirs and the river reaches crossing the basin constitute sources of groundwater recharge to the aquifer. However, the quantity of recharge is not known, and this needs further studies.

2.4. Land use/Cover

The LU/LC classes defined in the study area are (Figure 2-10):

1. Natural vegetation, which is the dominant land cover in the area, as well as shrub/tree woodland cover which is confined to valleys, along watercourses and depressions.

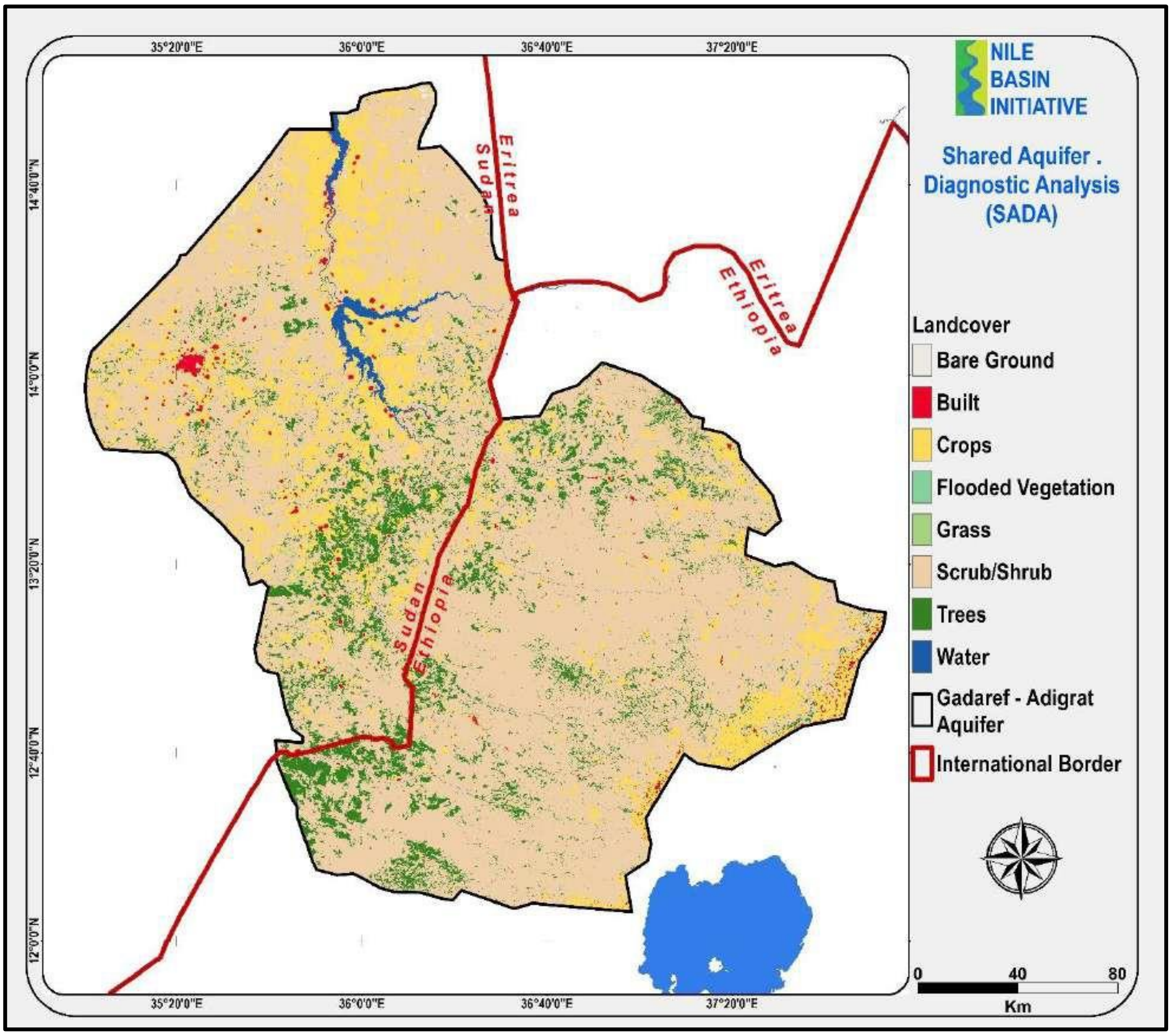

Figure 2-10: LU/LC in the Gedaref-Adigrat Aquifer

2. Agricultural which represents areas under rain-fed mechanized farming. Crops cultivated in this area include sorghum and sesame.
3. Bare land or exposed non-vegetated areas formerly under cultivation and now abandoned due to degradation.

2.5. Geology and Hydrogeology

The geology of the Gedaref – Adigrat basin is illustrated in Figure 2-11 and can be summarized from younger to older as given in Table 2-7.

Table 2-7: Geologic Formations and their Age in the Gedaref-Adigrat Aquifer

Formation	Age
Recent Deposits	Quaternary to recent
Volcanic Rocks (basalts)	Tertiary
Nubian Sandstone Formation	Mesozoic
Basement Complex	Pre Cambrian - Cambrian

The Basement Complex is of Pre-Cambrian age and comprises Schists, Gneiss and Granite in the Sudan part of the study basin , the Nubian Sandstone formation constitute a sequence of inter-bedded sandstones and mudstones laid down in a depositional environment that is dominated by multiple braided channels, bars and floodplain. The formation rests unconformably on the basement complex rocks and is overlain and/or intruded by basaltic rocks that originated from volcanic eruptions. Recent deposits comprise the unconsolidated clays, silts and sands of Quaternary age. Based on available lithological data from boreholes in Gedaref aquifer, the sandstone formation is divided into three sandstone units separated by claystone confining beds (Omer, 1978).

Groundwater occurs within the sandstone formation as well as the fractured and weathered zones of the Basalt under unconfined and semi-confined conditions. The basement complex has limited groundwater potential except in areas where there are fractures that allow groundwater recharge. The thickness of the saturated layer ranges from 200 to 500 m and the depth to water ranges from 50 to 75 meters. The aquifer is recharged from rainfall at the area out-cropping the water bearing formation and from seasonal runoff. According to the groundwater flow directions, the Gedaref aquifer is also recharged through subsurface groundwater flow from the Ethiopian side of the aquifer. Water quality is reported to be fresh in the Gedaref sandstone formation parts of the basin where TDS values range between 400 and 500 ppm are recorded while higher values of TDS greater than 800 are recorded within the basalt formation.

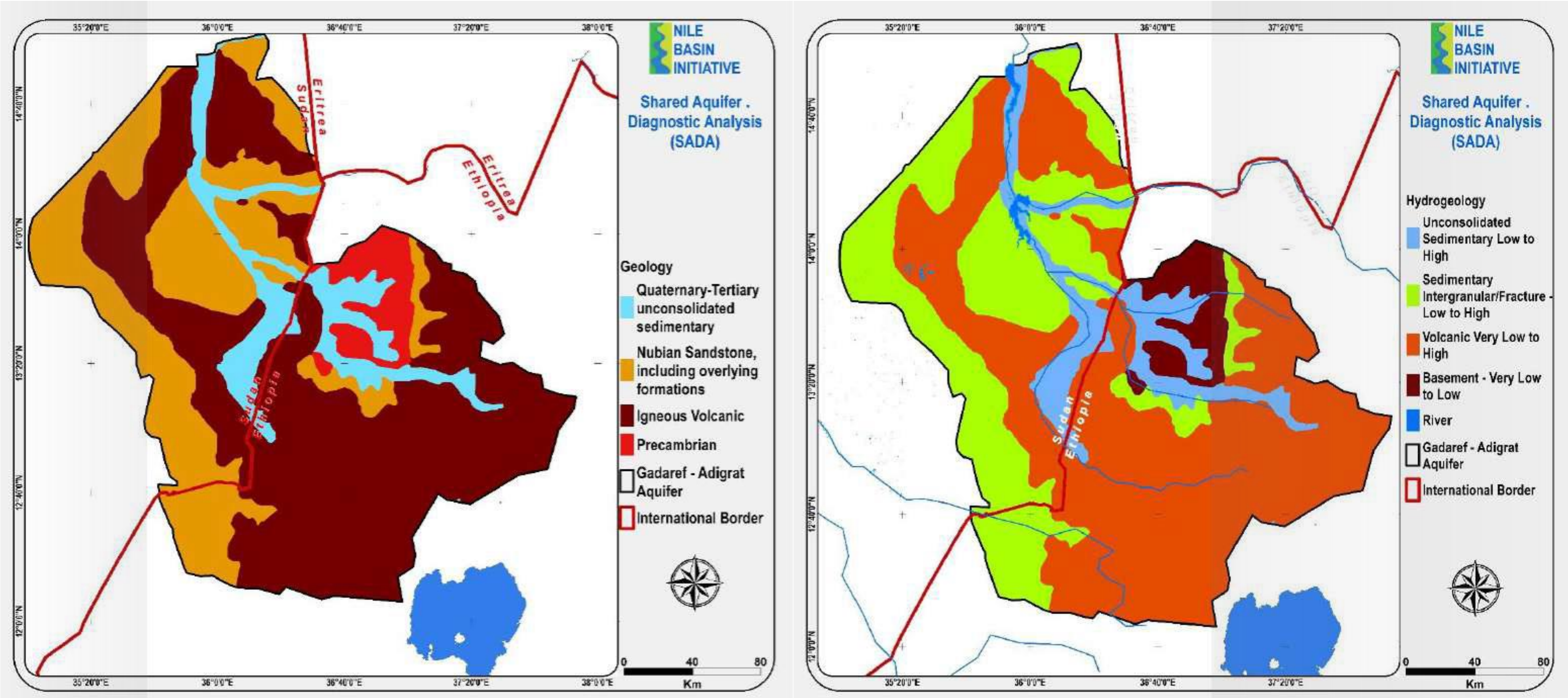

Figure 2-11: Geology (left) and hydrogeology (right) of the area.

The highly cemented Adigrat Formation has low primary porosity, and the top part has been altered by heating by Cenozoic volcanism. Fracturing has created secondary porosity and permeability. The emergence of springs at the contact of the Adigrat sandstone and the overlying volcanic rocks is indicative of the low permeability of the Adigrat formation. The

Adigrat aquifer is typically 200 to 1000 m thick and is unconfined to semi-confined. The water table is usually 200 to 400 m deep; typical borehole depth is 300 m. The Adigrat aquifer has moderate productivity and good water quality (Kebede, S. et al (2018)).

2.5.1. Permeability and Porosity Distributions in Gedaref-Adigrat Aquifer

The permeability and porosity distributions in the study area are shown in Figure 2-12 and Figure 2-13respectively.

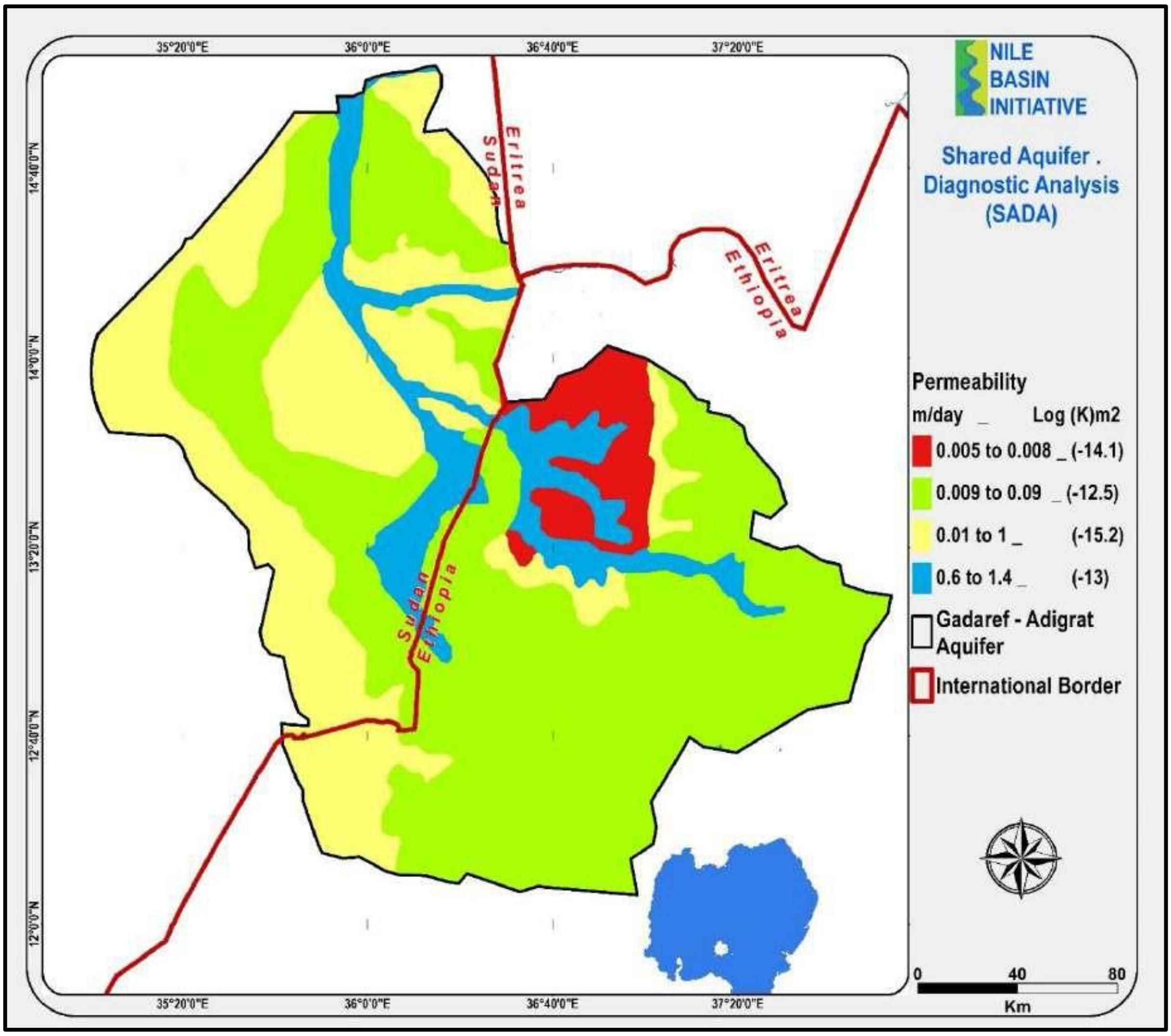

Figure 2-12: Permeability Distribution in Gedaref-Adigrat Aquifer

The data are obtained from high-resolution global lithology datasets that clearly differentiate fine and coarse-grained sediments and sedimentary rocks. These data output is useful to further understand and integrate the groundwater dynamics. The permeability is expressed in geometric mean logarithmic permeability (log K m^2) (Huscroft, Gleeson, Hartmann, & Börker, 2018), and in m/day for different types of aquifer formation based on values available in the literature. The porosity is expressed in %.

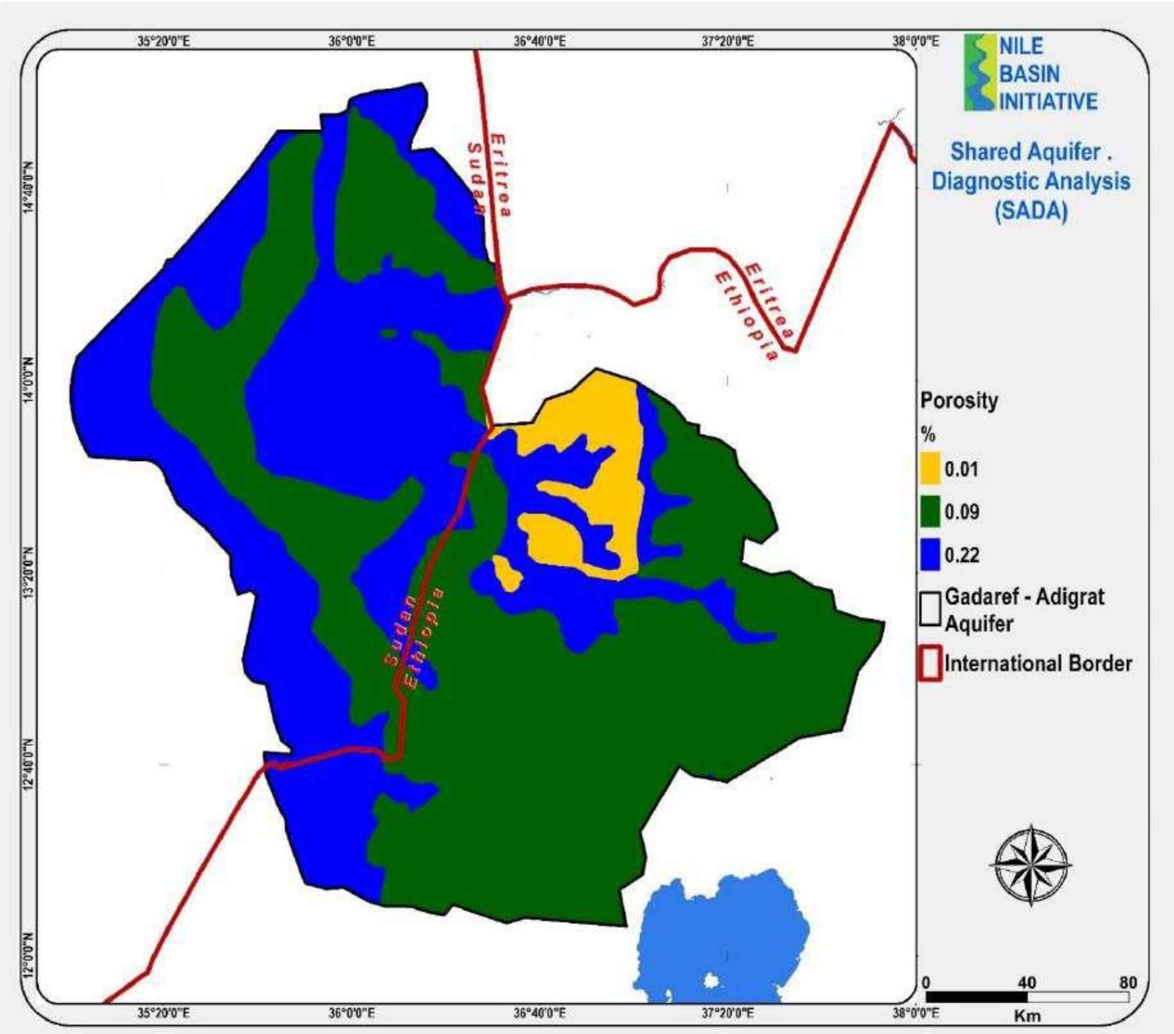

Figure 2-13: Porosity Distribution in Gedaref-Adigrat Aquifer

2.5.2. Groundwater Storage in Gedaref-Adigrat Aquifer

The storage distribution within the aquifer in mm is shown in Figure 2-14. The data were obtained from a 5 km resolution grid that presents groundwater storage in Africa in mm (http://ihp -wins.unesco.org/layers/groundwater_storage_processed:geonode:groundwater_ storage processed). This parameter was estimated by combining the saturated thickness and effective porosity of the aquifer. Calculations revealed that the total storage volume in the Gedaref- Adigrat aquifer is huge and amounts to about 104 BCM. This storage is distributed between Gedaref and Adigrat parts as 34.5 BCM and 69.5 BCM respectively.

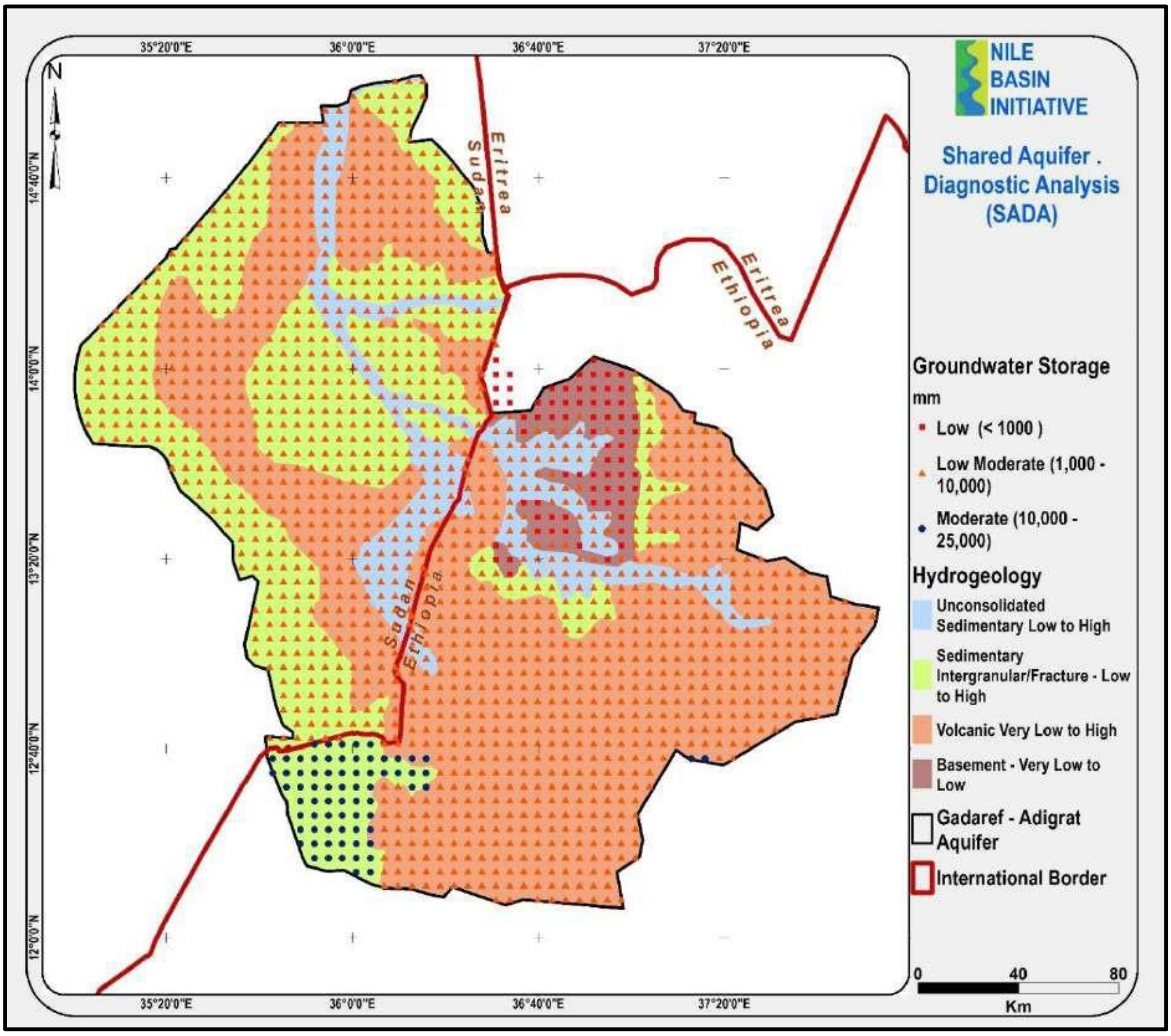

Figure 2-14: Groundwater Storage Distribution in Gedaref-Adigrat Aquifer

2.5.3. Water level Distribution and Groundwater Flow Directions

Borehole locations inside the project area as provided by the National consultants are presented in Figure 2-15. The groundwater level distribution relative to mean see level was obtained by subtracting the depth to water from the top elevation. The water level distribution is also shown in Figure 2-15, as well as the general groundwater flow directions. It can be seen that the general direction of groundwater flow is from Ethiopia to Sudan, which implies that some subsurface flow takes place from Adigrat aquifer to Gedaref aquifer. It should be mentioned that most of the borehole data in the Adigrat side lie in the periphery of the project area where most of the people are living (Gondar Zuria and nearby cities). Borehole information in the border area between Gedaref and Adigrat is not available and could not be collected by the National consultants due to security issues.

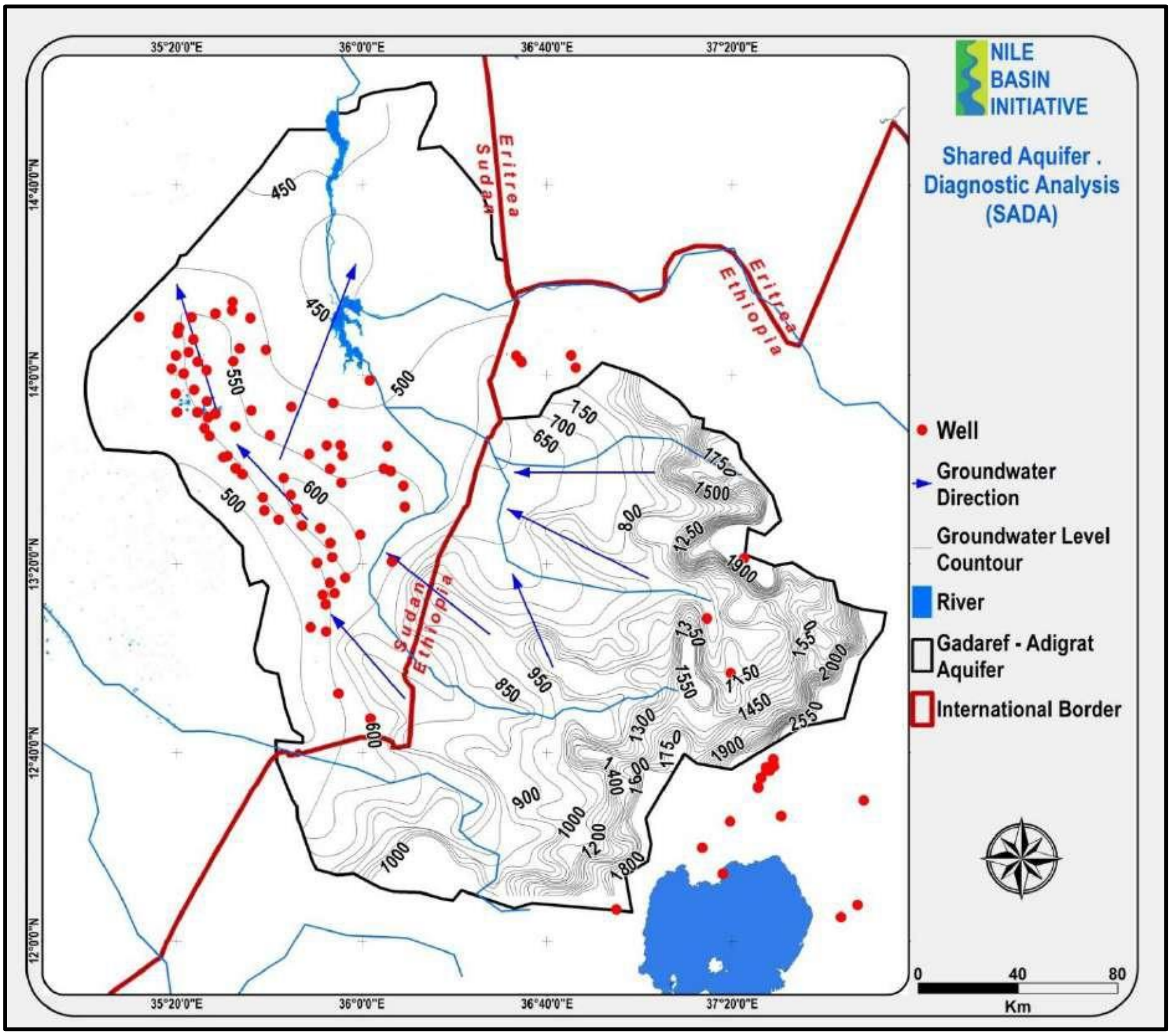

Figure 2-15: Groundwater Level (a.m.s.l) Distribution in Gedaref-Adigrat Aquifer and Flow Directions

2.5.4. Groundwater Productivity of the Gedaref-Adigrat Aquifer

The groundwater productivity map is shown in Figure 2-16 which indicates what borehole yields can reasonably be expected in different hydrogeological units. In the Gedaref aquifer, the yield information was obtained from borehole data provided by the Gedaref groundwater authority.

In the Adigrat side, data is obtained from open source groundwater productivity distribution maps (Data source: Source-Based upon mapping provided by British Geological Survey © NERC 2012). Sample observed data were also collected during a field visit. The results show that high borehole yield ranging from 5 to 20 l/s can be obtained from the sandstone formation, while medium productivity up to 5 l/s can be obtained from the volcanic basalt aquifer. The alluvium and basement complex have generally low productivity.

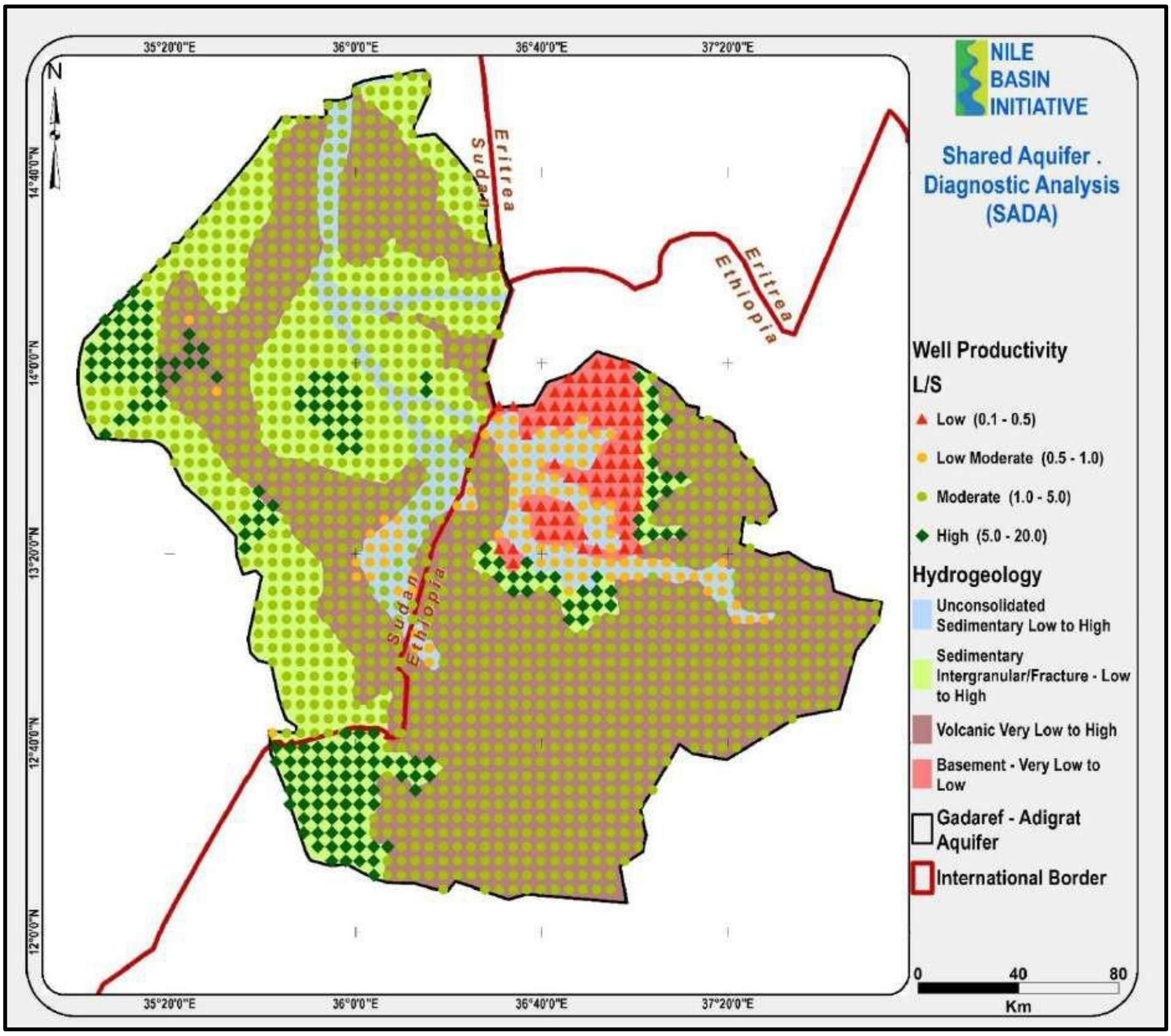

Figure 2-16: Groundwater Productivity in the Gedaref-Adigrat Aquifer

2.5.5. Groundwater Recharge in Gedaref-Adigrat Aquifer

Accurate estimation of groundwater recharge is a most important requirement for long term management of any groundwater system. Recharge can take place from direct infiltration of rainfall, leakage from rivers, streams, irrigation canals, etc. or by artificial recharge. Unfortunately, there is no information in the Gedaref-Adigrat aquifer to support correct estimation of recharge. In the present study, recharge is assumed to take place from rainfall only provided that rainfall is in excess of evapotranspiration and the soil moisture conditions allow water to pass downwards to recharge the aquifer. In a recent study in Toker aquifer, Eastern Sudan, Shigidi et al (2021) estimated groundwater recharge as 1% of effective rainfall; that is rainfall in excess of evapotranspiration. In the absence of information, the figure of 1% is used in the Gedaref aquifer. In the Adigrat aquifer, this figure is taken as 0.6% since the area is relatively steeper and hence a smaller percentage of runoff takes place as recharge. However, this needs further investigation. Figure 2-17 shows the recharge distribution within the Gedaref-Adigrat aquifer and Table 2-8 shows the annual recharge estimates as well as the runoff for the aquifer. The total annual recharge is 128.1 MCM/year distributed between Gedaref and Adigrat as 47.3 and 80.8 respectively.

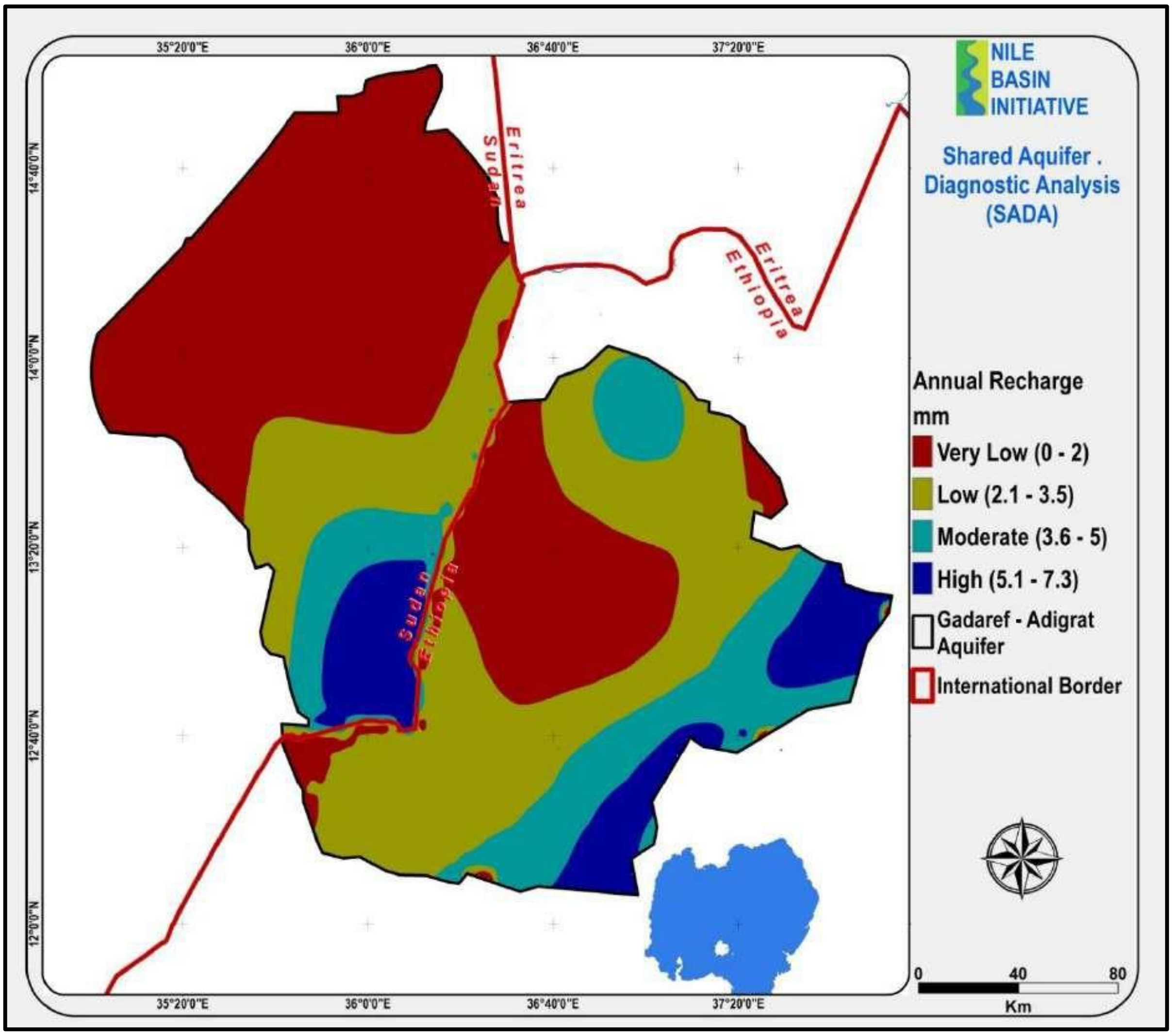

Figure 2-17: Recharge Distribution within the Gedaref-Adigrat Aquifer

Table 2-8: Annual Recharge Estimates for the Gedaref-Adigrat Aquifer

Item	Gedaref	Adigrat	Total Aquifer
Runoff (mm/year)	107.50	489.70	597.20
Recharge (mm/year)	0.93	1.40	2.33
Runoff (BCM/year)	5.91	26.93	32.85
Recharge (MCM/year)	47.30	80.80	128.10

2.5.6. Water Quality in Gedaref Aquifer

The total dissolved solids (TDS) values are available only for boreholes within the Gedaref Aquifer. The TDS distribution is shown in Figure 2-18. The TDS distribution within the whole aquifer will be developed when data from the Adigrat side become available. Water quality is generally fresh in the Gedaref parts of the basin where TDS values ranging between 400 and 500 ppm and higher values of TDS greater than 800 are recorded within the basalt formation.

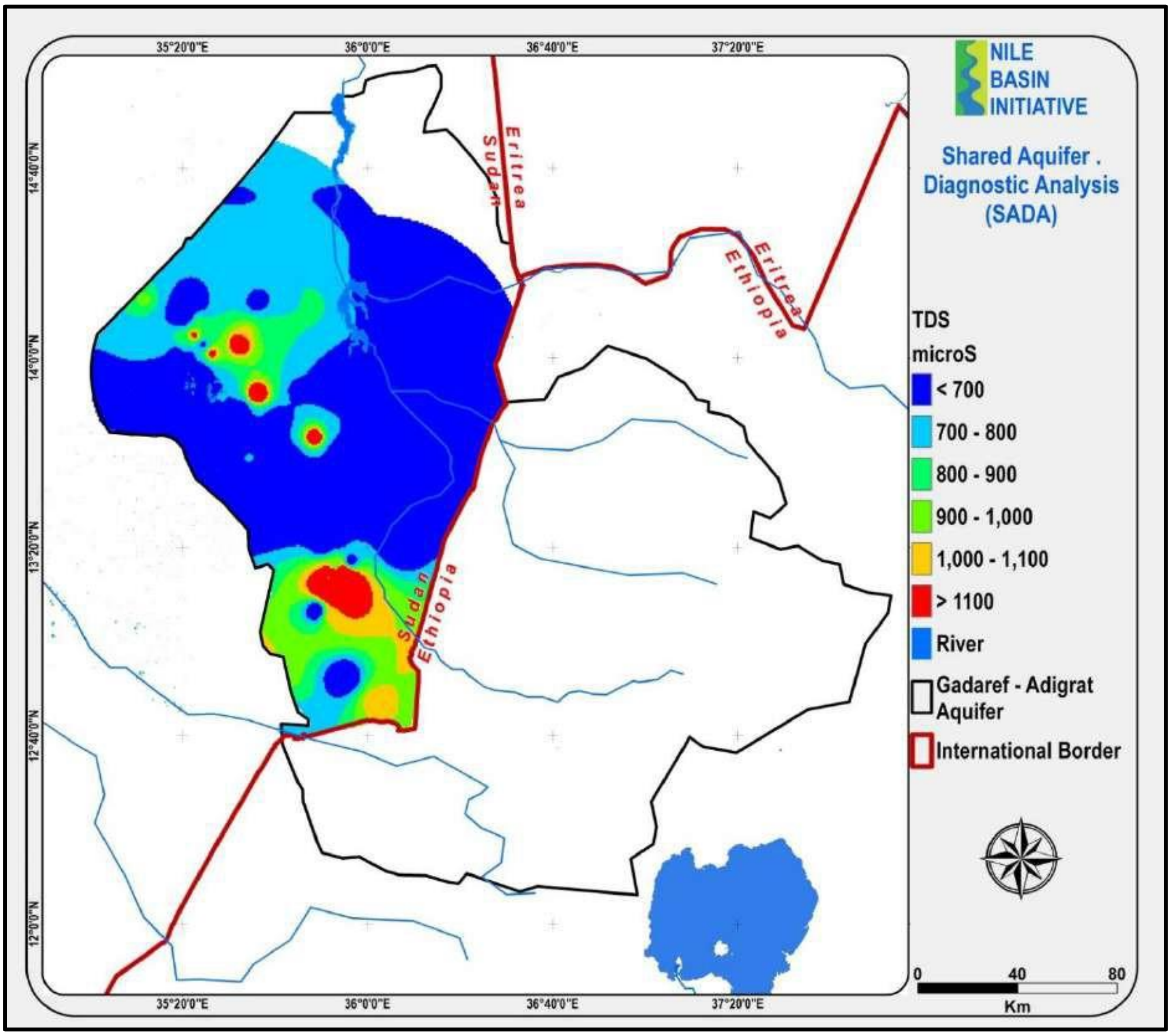

Figure 2-18: Total dissolved solids distribution in Gedaref aquifer

2.6. Groundwater Development in Gedaref-Adigrat Aquifer

In general, groundwater is the most important source of domestic water supply in the aquifer area, especially in arid and semi-arid parts of it. It is estimated that about 85% of the domestic water supply and livestock watering is from groundwater. Groundwater abstraction for irrigation is limited since agricultural activities in the area are mostly rain-fed. Groundwater is developed by open shaft wells, driven wells and boreholes.

2.6.1. Adigrat Aquifer

Table 2-9 shows the current daily and annual groundwater abstraction for human consumption in the different districts in the Adigrat side of the aquifer as well as the actual demand. The total annual abstraction is estimated as 10.55 MCM/year, while the total annual demand for human consumption is estimated as 11.15 MCM/year. Therefore, the groundwater abstraction represents about 95% of the current human demand. However, if the livestock demand is included, the percentage coverage is much less. Table 2-10 shows the total water demand including the livestock watering demand. As can be seen the total annual demand is about 87.4 MCM/year. Therefore, the current abstraction represents only about 12% of the demand. Part of this deficit is met from surface water sources such as ponds, springs, excavations, and seasonal water courses.

Table 2-9: Current groundwater abstraction in the Adigrat side of the aquifer *"source: Sintayehu, 2021 Report B"*

No	District name	Daily GW abstraction (m^3/day)	Annual GW Abstraction (m^3/year)	Annual Human Demand (m^3/year)
1	Alefa	1853.57	676553.1	845691.5
2	Chilga	27.7855	10141.71	12677.14
3	Dabat	1590.91	580682.2	725852.9
4	Debark	1745.89	637249.9	796562.5
5	Dembia	2954.23	1078294	1347868
6	Gondar Town	4819.3	1,770,000	1160791
7	Lay Armachew	1718.67	627314.6	784143.4
8	Metema	3402	1,241,730	562259.9
9	MIrab Armacho	364.6	133079	166348.8
10	Quara	1020.55	372500.8	465626.1
11	Tach Armacho	978.24	357057.6	446322
12	Takusa	1400.9	511328.5	639160.6
13	Tegede	803.89	293419.9	366775
14	Wegera	2403.46	877262.9	1096579
15	Qafta Humera	1071.45	391079.3	488849.2
16	Tsegede	1168.76	426597.4	533246.8
17	Welqayet	1561.15	569819.8	712274.9
Total Annual in the project area			**10,543,155**	**11,151,028**

Table 2-10: Human and livestock demand in Adigrat aquifer *"source: Sintayehu, 2021 Report B"*

District Name	Daily Human Demand (M³/d)	Daily Livestock Demand (M³/d)	Total daily Demand (M³/day)	Total Annual Demand (M³/year)
Alefa	2316.96	204.39	2521.35	920293.22
Chilga	34.73	21072.52	21107.26	7704148.10
Dabat	1988.64	6904.09	8892.73	3245847.14
Debark	2182.36	2256.39	4438.75	1620145.28
Dembia	3692.79	238.52	3931.30	1434926.07
Gondar Town	3180.25	50.28	3230.53	1179144.15
Lay Armachew	2148.34	7221.94	9370.28	3420151.23
Metema	1540.44	38730.27	40270.71	14698809.90
MIrab Armacho	455.75	11378.12	11833.87	4319363.84
Quara	1275.69	23991.60	25267.29	9222561.69
Tach Armacho	1222.80	20267.48	21490.28	7843952.78
Takusa	1751.13	11517.90	13269.02	4843192.90
Tegede	1004.86	19137.77	20142.63	7352060.48
Wegera	3004.33	3721.01	6725.34	2454748.65
Qafta Humera	1339.31	15539.62	16878.93	6160808.90
Tsegede	1460.95	16077.40	17538.35	6401496.82
Welqayet	1951.44	10631.93	12583.37	4592930.51
Total				**87,414,582**

Human demand estimation in Table 2-9 and Table 2-10 is based on population projection for 2021 and a daily per capita of 10 l/p/d. The total livestock population is based on available information on the regional livestock population. The daily water consumption per livestock is assumed to be 32 l/c/d which is based on the average data obtained from previous studies (Sintayehu, 2021 Report B).

2.6.2. Gedaref Aquifer

Generally, Gedaref state is known by its severe shortage of water supply. According to available information, the population access to basic safe domestic water supply is only 28%

compared to Sudan overall average (Hilal, 2021 Report B). Groundwater in Gedaref region is used almost only for domestic and livestock water supplies. Apart from the scattered village-owned wells, two well fields are constructed to supply the main city of Gedaref with its need for drinking water. These are the Azaza and Abu-Naga well fields. Azaza well field lies about 10 km northwest of the Gedaref city. The aquifer system in Azaza basin is developed mainly in the Gedaref sandstone Formation. Azaza well field has a total of 16 wells with depths ranging between 127 m and 194 m. Only five boreholes are currently working with a pumping rate of 3000 m³ /d. Abu-Naga Basin lies near Abu-Naga village 14 km south-west of the Gedaref. The well field consists of 20 wells with depths ranging between 135 m and 296 m, only 8 wells are currently working. The total abstraction from the 8 working wells is 3000 m³/d.

Table 2-11 shows the rural and urban population numbers for the localities within the Gedaref aquifer as well as the available daily water supply and actual demand in m³/day. The demand is based on 20 l/p/day for rural areas and 50 l/p/d for urban areas. The population is based on the Sudan 2008 population census projected to 2021.

Table 2-11: Available Daily Water Supply and Actual Demand in m³/day in Gedaref Aquifer "*Source: Hilal, 2021 Report B &Gedaref State Water Corporation*"

Locality	Urban Population	Rural population	Available Water Supply (Urban) m³/day	Available Water Supply (Rural) m³/day	Total Available Water Supply m³/day	Actual Demand m³/day
Gedaref	483,131	0	16704	0	16704	24156.55
Gedaref Central	0	200215	0	884	884	4004.3
El Galabat West	0	164670	28	2700	2728	3293.4
El Galabat East	67685	135572	192	692	884	6095.69
Fashaga	72219	144160	3200	4428	7628	6494.15
El Goreisha	0	149436	84	4622	4706	2988.72
Basunda	0	127431	64	1108	1172	2548.62
Total	**623,035**	**921,484**	**20,272**	**14,434**	**34,706**	**49,581.43**

As can be seen from the Table 2-11, the available water supply represents about 70% of the demand. This demand, however, does not include the livestock watering demand which is discussed below. Livestock statistics between 2008 and 2016 are available from which the growth rates for the Cattle, Sheep, Goats and Camels were calculated as 2.19%., 3.05%, 3.05% and 0.84% respectively. Accordingly, the livestock number was projected up to 2021 as shown in Table 2-12and Table 2-13 shows the livestock water demand for the year 2021 based on the p/c/l/day shown in the table obtained from previous studies (WRC, 2017).

Table 2-12: Livestock Population in Gedaref Area (2008-2021)

Animal Species	Cattle	Sheep	Goats	Camels	Total - livestock
2008	1,273,180	1,183,000	853,168	615,000	**3,924,348**
2016	1,544,691	1,565,610	1,129,103	659,242	**4,898,646**
2017	1,578,630	1,613,436	1,163,595	664,772	**5,020,433**
2018	1,613,314	1,662,723	1,199,140	670,349	**5,145,527**
2019	1,648,761	1,713,516	1,235,772	675,972	**5,274,022**
2020	1,684,986	1,765,861	1,273,522	681,643	**5,406,012**
2021	1,722,008	1,819,804	1,312,426	687,361	**5,541,599**

Table 2-13: Livestock water demand in Gedaref area (2021).

Livestock	Population	Demand (l/c/d)	Daily demand m^3/day
Cattle	1,722,008	35	60,270
Sheep	1,819,804	8	14,558
Goats	1,312,426	5	6,562
Camels	687,361	45	30,931
Total	**5,541,599**		**112,322**

From the results shown, the annual human water demand is about 18 MCM/year and the livestock annual demand is 41 MCM/year, therefore the total annual demand is 59 MCM/year. As the current total available water supply is 12.7 MCM/year, it represents only about 22% of the demand. This reflects the severe shortage of water supply in the area.

A summary of the water supply situation in the Gedaref-Adigrat aquifer is shown in Table 2-14

Table 2-14: Summary of Water Supply and Demand in MCM/year in the Gedaref-Adigrat Aquifer

Item	Gedaref	Adigrat
Human demand	18	11.15
Livestock demand	41	76.3
Total demand	59	87.45
Available water supply	12.7	10.55
Supply/Demand	**22%**	**12%**

2.7. Groundwater Monitoring Status in Gedarif-Adigrat Aquifer

In Sudan, groundwater level monitoring is carried out by the monitoring department of the GWWD in several large aquifers of interest. Unfortunately, Gedaref basin has not been included in the GWWW monitoring network. Generally, there is a big gap in groundwater monitoring in Sudan. The existing network covers only about 5% of the required network. The network is not working properly due to the lack of financial resources and it does not enable the accurate assessment of groundwater situation in the large groundwater basins.

Similarly, there is no ground water monitoring network in the project study area in Ethiopia. There might be multiple reasons for this: namely, the region or the study area has been in a political conflict in the last decades and recently the instability extended beyond the region. Furthermore, budget and skilled human power on ground water management have also contributed to limited ground water monitoring activities.

2.8. Groundwater Management Capacity in Gedarif-Adigrat Aquifer

There is a real gap in Sudan and Ethiopia in institutional and human resources capacities at various levels to plan, implement, manage, monitor and evaluate groundwater projects. The capacity gap is recognized in terms of inadequate effective structures, shortages of technical and managerial qualified personnel, and inadequate logistic support. In view of the current water supply shortage, growing demands for water, and adaption to climate change in the project area, there should be a well-built capacity, to deal with water resources management in a sustainable manner within the framework of an integrated water resources management approach. Therefore, training and capacity building are highly needed to meet the above challenges in the project area.

2.9. Issues of Trans-Boundary Concern

Trans-boundary issues of primary concerns in the Gedarif-Adegrat aquifer can be summarized as:-

2.9.1. Possible Changes in the Groundwater Flow Regime

Groundwater abstraction can create steep hydraulic gradients toward production wells in the two sides of the aquifer. Over time, these develop into widespread cones of depression which are superimposed on regional hydraulic gradients. Water level analysis showed that the groundwater flow direction takes place from the Ethiopian side towards Sudan. Large scale abstraction on one side has the potential risk of reversing the flow directions in some areas. This SADA study involves the development of a groundwater model for the aquifer to provide a technical basis for evaluating such trans-boundary risks. The model will be used to investigate the consequences of different management scenarios for the aquifer and their impacts on the groundwater flow regime. The results could be used as a basis for a trans-boundary agreement for win-win sustainable aquifer utilization between Sudan and Ethiopia.

Other emerging groundwater management issues include the rapid change in groundwater use from non-commercial use (drinking water for people and cattle) to use of groundwater for commercial purposes (mining, fish ponds, industries etc). These observations are remarkable in all the aquifer areas, and could impact the water quantity and quality in the future.

2.9.2. Land Degradation

Several studies have been conducted on both sides of the aquifer to assess the impacts of land use and land cover (LU/LC) changes in the study area by using multi-temporal Landsat data for different periods in time. The results showed that a significant change of LU/LC patterns has occurred during the previous three decades within the study area. The major trends were drastic conversions of natural vegetation and forest areas into large-scale mechanized rain-fed agriculture and progressive loss and degradation of rangeland and forest areas in Eastern Sudan (Muna and Hussein, 2019). Teshome et al (2019) studied the trends and drivers of land LU/LC cover change in Western Ethiopia. The result shows that forest was the dominant LU/LC type with significant reduction of 22% between 1978 and 2016. Expansion of agricultural land was the major driver showing a radical increase of 28 % over the 38 years of the study period.

Also the impact of LU/LC changes on the selected soil properties in Gedarif region was studied by Biro et al, 2013. Various soil properties such as texture, bulk density, organic matter, soil pH, electrical conductivity, sodium adsorption ratio, phosphorous and potassium were analysed. The results revealed a significant change in the physical and chemical properties of the soil resulting in land degradation, which in turn has led to a decline in crop productivity. Other studies in Gedarif area have shown that the average cereal yields are declining, with sorghum and millet yields having dropped from 350 kg/feddan in the late 1950s to under 200 kg/feddan in 2016/17 (UN Environment, 2020).

2.9.3. Pollution and Water Quality Deterioration

In the study area there is no proper sewage system and on-site disposal systems (septic tank + injection well, and pit latrines) are predominant. They are often poorly designed, located and constructed. In such an environment, bacteriological contamination and other pollutants could readily find their way to groundwater and degrade its water quality. This is particularly true in areas mostly lie over shallow unconfined or semi-confined aquifers. Several studies to assess contamination have been conducted in many areas Sudan including Gedarif area. Results of chemical and bacteriological analysis of samples from boreholes within many towns show gross total and fecal coliform bacteria, and/or Nitrate pollution (SNCIHP ,2000). This is to be expected since almost all disposal wells and pit latrines tap the groundwater table, and they are often located very close to production wells within a distance of 10 to 20 m. In most cases water is provided to the community without treatment. This situation will definitely aggravate the incidence of water borne diseases and can worsen hygiene and sanitation status of the community.

Pollution from agricultural chemicals is also another threat in the study area. Since the introduction of agricultural chemicals in in the 1950s, their application has intensified and expanded considerably in agricultural schemes and private vegetable and horticultural farms in many areas in Sudan and Ethiopia including Gedarif area. A total of about 200 active ingredients are registered in Sudan in over 600 different formulations which could also be a sources of contamination to both surface and groundwater sources

2.9.4. Biodiversity and Ecosystem Sustainability

The study area is home to a variety of ecosystems and habitats in four major ecological zones namely semi-desert, woodland savannah, flood region and mountain vegetation. However, biodiversity is threatened by various factors, including loss of habitat through deforestation and mechanized farming. As has been discussed, farmers have been continuously expanding the land under cultivation at a rate of 3.71 per cent per year at the expense of forest areas to compensate for the falling crop yields (UN Environment, 2020). Also declining water levels in the aquifer and impairment in water quality can logically lead to damage or loss of ecosystem function and biodiversity. Furthermore, these ecosystems rely on the surficial waters that are the most vulnerable to environmental change, either natural or human- caused. The very existence of these ecosystems depends on the supply of the aquifer water and the integrity of these ecosystems depends on the quality of available water.

No detailed studies on the impact on ecosystem and biodiversity are available. However, protecting these ecosystems and preserving them is a significant trans-boundary challenge in the management of the aquifer that requires further studies and the establishment of a proper monitoring system.

2.9.5. Poverty and Poor Social Indicators

Though the study area enjoys huge land resources under rain-fed mechanized farming, relatively high rainfall levels and rich animal resources, the population in the study area continues to suffer from high levels of poverty, food insecurity and poor social indicators. The relatively high incidence of poverty has generally been attributed to the region's constant vulnerability to environmental hazards and disasters, conflicts and instability, and particularly the deterioration of the agricultural sector in recent years. Specifically the study region suffers from high susceptibility to natural disasters acute shortage of potable water supply, high illiteracy and unemployment rates, lack of security and increased tension between farmers and nomads.

2.9.6. Political Conflict and Displacement

Repeated armed conflict in the border area resulted in lack of security and high flux of refugees from Ethiopia to Sudan. The influx of arrivals from Ethiopia are hosted in refugee camps which lack basic needs like food, shelter, adequate sanitation and safe water. The situation is very challenging especially during the rainy season. Locating the sources of drinking water nearby the overflowing and abandoned latrines presents a serious threat for the transmission of sanitation, hygiene, and WASH-related infections such as cholera and hepatitis E.

2.9.7. Climate Change

Climate change analysis conducted within this study shows an increasing trend in surface temperature of 4 to 4.5 ^{O}C in the business as usual scenario (RCP 8.5) and 2.0^{O}C increase for the conservative RCP4.5 scenarios. Results also show a significant increasing trend of annual rainfall in the study area and increasing number annual rainy days. However, annual average evapotranspiration is expected to increase by 35 mm/year. It can be concluded that there is a significant change in the various climatic parameters a result of climate but generally, no serious hazard and impact on surface water resources and groundwater recharge are expected. More detailed discussion on climate change analysis and impact is given in the following chapter.

3. CLIMATE CHANGE ANALYSIS IN GEDARIF -ADIGRAT AQUIFER

3.1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods” (IPCC 2014 and 2018). General circulation models (GCMs) are types of climate models which employ a mathematical model of the general circulation of a planetary atmosphere or ocean. GCMs are used for weather forecasting, understanding the climate, and forecasting climate change

3.2. The Representative Concentration Pathway (RCP)

A Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory. Originally, four pathways were used for climate modeling and research namely; RCP2.6, RCP4.5, RCP6, and RCP8.5. They describe different climate futures, all of which are considered possible depending on the volume of greenhouse gases (GHG) emitted in the years to come. Since. The following paragraphs describes each RCP.

RCP 1.9: is a pathway that limits global warming to below 1.5 °C, the aspirational goal of the Paris Agreement.

RCP 2.6: is a "very stringent" pathway. It requires that carbon dioxide (CO2) emissions start declining by 2020 and go to zero by 2100. It also requires that methane emissions (CH4) go to approximately half the CH4 levels of 2020, and that Sulphur dioxide (SO2) emissions decline to approximately 10% of those of 1980–1990. RCP 2.6 is likely to keep global temperature rise below 2 °C by 2100.

RCP 4.5: is described by the IPCC as an intermediate scenario. Emissions in RCP 4.5 peak around 2040, then decline. According to specialists’ emission scenarios are biased towards exaggerated availability of fossil fuels reserves; RCP 4.5 is the most probable baseline scenario (no climate policies) taking into account the exhaustible character of non-renewable fuels.

RCP 6.0: emissions peak around 2080, then decline.

RCP 8.5: emissions continue to rise throughout the 21st century. Since AR5 this has been thought to be very unlikely, but still possible as feedbacks are not well understood. RCP8.5, generally taken as the basis for worst-case climate change scenarios, was based on what proved to be overestimation of projected coal outputs. It is still used for predicting mid-century (and earlier) emissions based on current and stated policies.

3.3. Study Area

Climate data for the Aquifer area was acquired from The World Climate Research Program (WCRP) Coupled Model Inter-comparison Project (CMIP5). The study considered the climate parameters; Temperature, Precipitation and Evapotranspiration. RCP4.5 and RCP8.5 were considered. CMIP5 encompasses data from 34 Global Circulation Models (GCM). Data series for each parameter in the study contained a monthly aggregated mean calculated from the results of all CMIP5 models for the period from 1950 to 2100.

3.4. Average Temperature at Surface (tas)

By the middle of the 21st century (year 2050) it is projected that the study area will experience an increase in temperature of about 1.5°C in both RCP scenarios. Yet, by the end of the century it is expected to reach 4.5°C for RCP8.5 and not to cross the 2.0°C limit for the RCP4.5 (Figure 3-1)

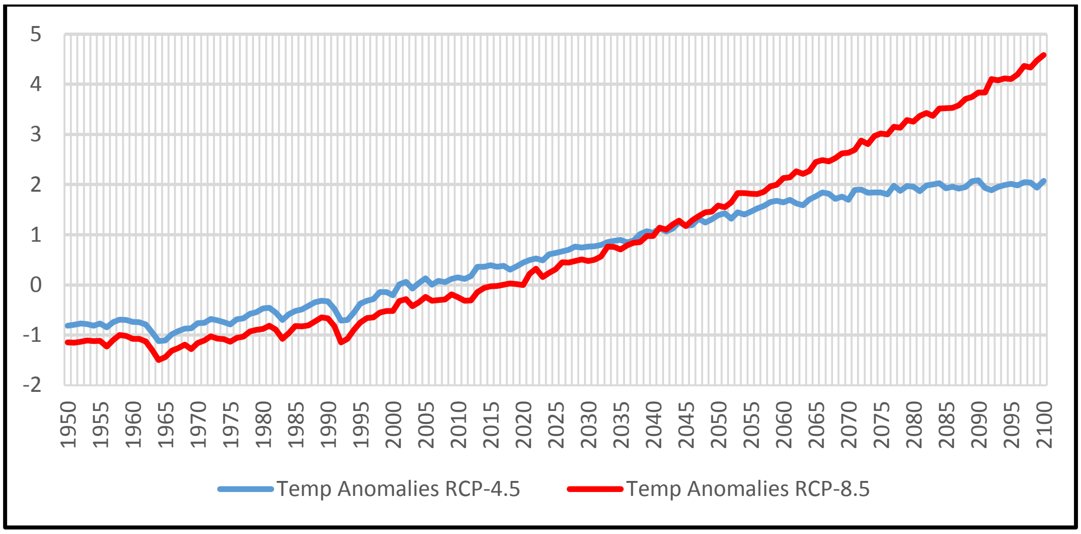

Figure 3-1: Impact of Climate Change on Temperature

3.5. Precipitation (Pr)

- RCP8.5 shows a significant increase in annual rainfall yield (Figure 3-2).

- Anomalies show that both scenarios predict almost the same anomalies range until the year 2050 when a drastic deviation between the two scenarios occurs. Ending with a 40mm difference between the two scenarios (Figure 3-3).
- Number of rainy days is expected to increase by the end of the century confirming the noticed amount of rainfall. The average annual number of rainy days is expected to increase to 21 days/year for RCP8.5 in comparison to 17 days for RCP4.5. (Figure 3-4)
- Annual cycle of rainfall pattern is predicted to be the same peaking at August.

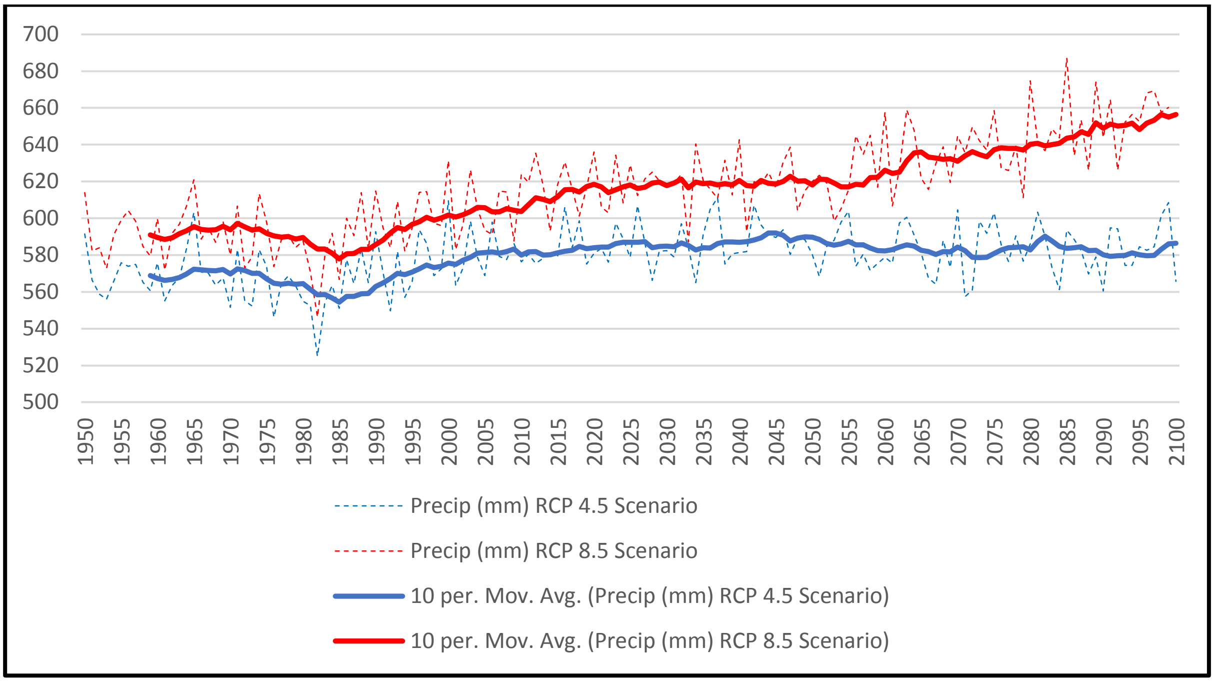

Figure 3-2 Impact of Climate Change on Annual Rainfall

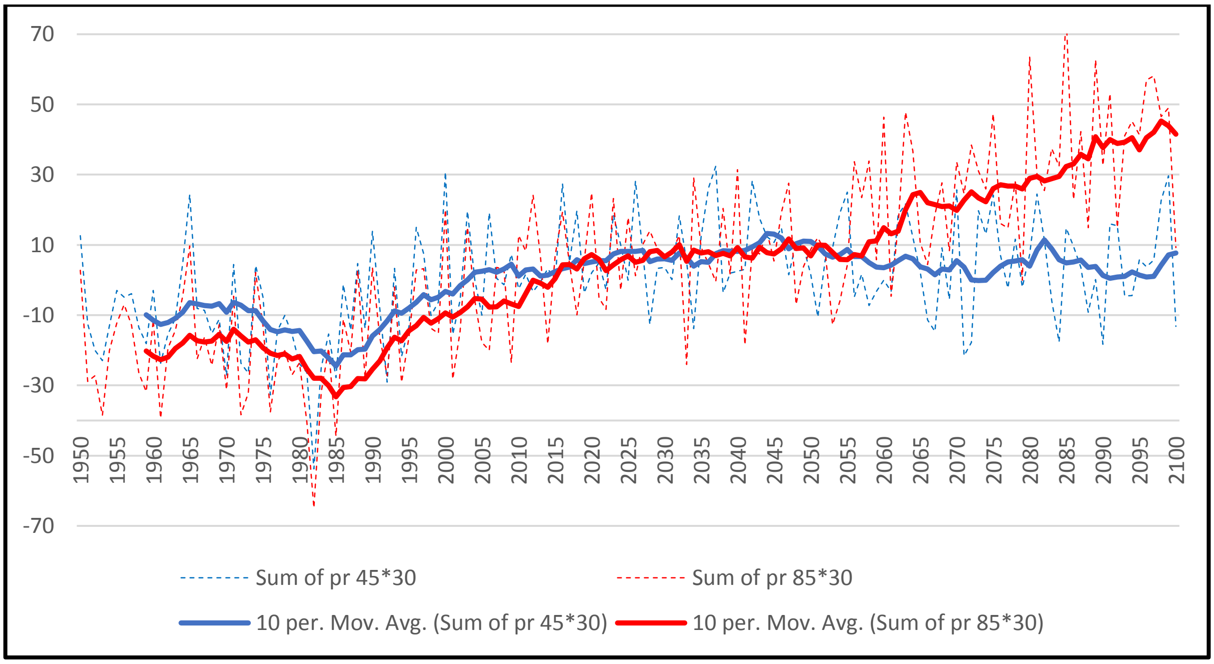

Figure 3-3 Impact of Climate Change on Annual Rainfall Anomalies

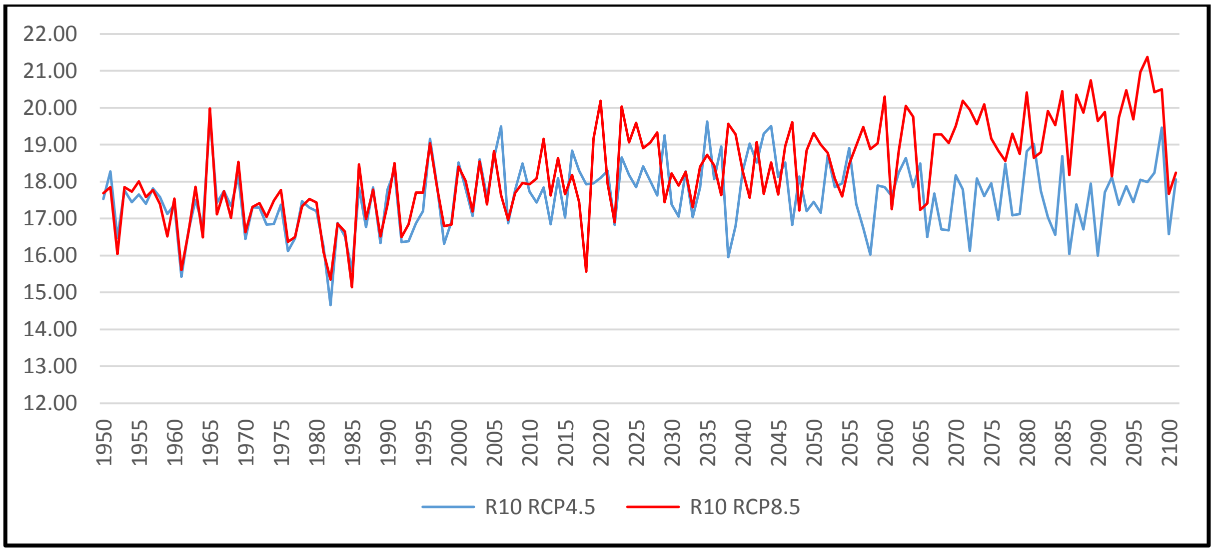

Figure 3-4: Impact of Climate Change on Annual number of rainy days >10mm

3.6. Evapotranspiration

- Annual average evapotranspiration in the study area is showing a 35mm increase through the study period for RCP8.5. Half of that is reached by the year 2050 and the trend continues until the end of the century (Figure 3-5, Figure 3-6).
- RCP4.5 is showing no considerable increase in evapotranspiration through the study period.
- Annual cycle of evapotranspiration limits is expected to be the same through the whole century for both scenarios.

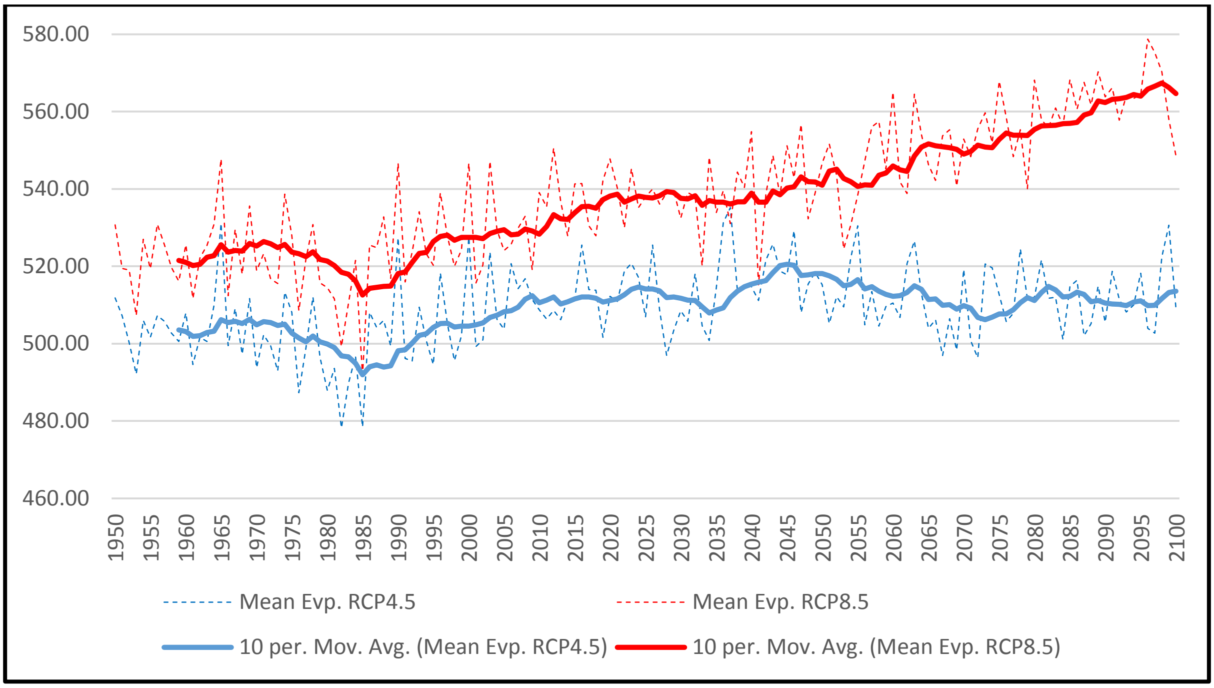

Figure 3-5: Impact of Climate Change on Annual Evaporation

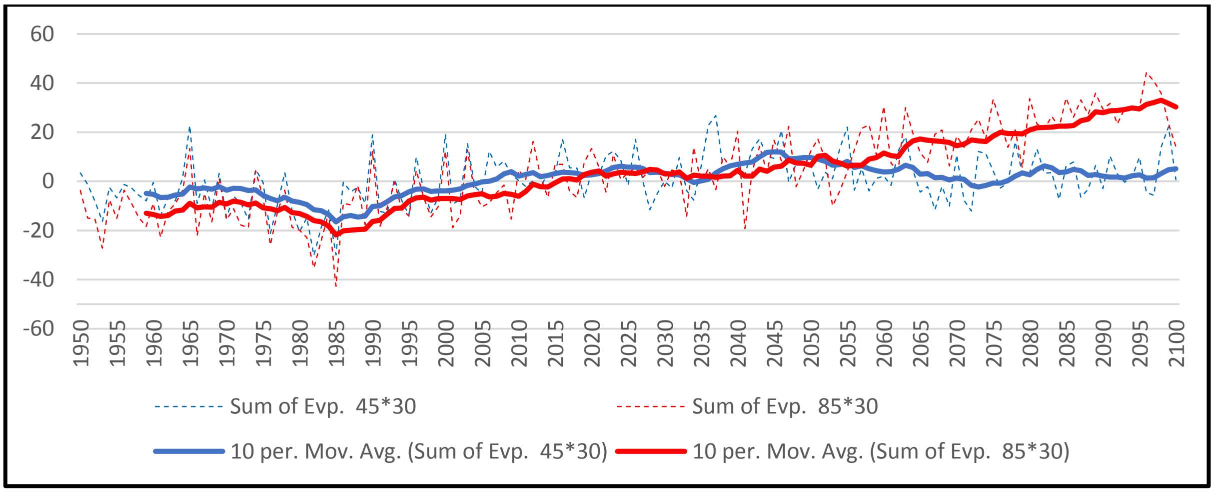

Figure 3-6: Impact of Climate Change on Annual Evaporation Anomalies

3.7. Conclusions

Climate change analysis using CMIP5 data shows the following:

- Increase in surface temperatures is expected of 4.0^{o}C-4.5^{o}C in the business as usual scenario RC P8.5 and not to cross the 2.0^{o}C limit for the RCP4.5.
- RCP8.5 shows a significant increase in annual rainfall yield. Anomalies show that both scenarios predict almost the same anomalies range until the year 2050 when a drastic deviation between the two scenarios occur ending with a 40mm difference between the two scenarios.
- The number of rainy days is expected to increase by the end of the century confirming the noticed amount of rainfall. The average annual number of rainy days is expected to increase to 21 days/year for RCP8.5 in comparison to 17 days for RCP4.5. However, the annual cycle of rainfall pattern is predicted to be the same peaking at August.
- Increase of 35mm annual average evapotranspiration is expected considering RCP8.5.
- It can be concluded that no serious hazard on water resources is expected as a result of climate change in the study area since the increase in evapotranspiration is compensated by increase in rainfall

4. SOCIAL AND ECONOMIC ASPECTS IN GEDAREF-ADIGRAT AQUIFER

4.1. Socioeconomic situation in Adigrat Aquifer

Most of the Adigrat aquifer lies within the North Gondar Zone, Amhara National Regional State. The zone is dominated by the agricultural sector, which employs about 90 percent of the working force. The farming system of the study area is largely characterized by crop-livestock production system (mixed farming systems). Out of the total rural agricultural holders, those who are engaged in crop production, livestock and both crop and livestock productions are estimated to be 16.07 %,8.58 % and 75.35 %, respectively. The proportion of population engaged in non-agricultural activities only is negligible, amounting to 1.8 percent. Of the total land area recorded in the region, the largest area is contributed by the Zone (29.85 %). The total land holding area under different land uses is estimated to be about 570,160 hectares, in the zone. Of this land, the area under annual crops accounts for 507,474 hectares (89%), land under permanent crops is estimated to be 2,347 hectares (0.4 %); grazing land amounted to be 12,312 hectares (2.2 %); fallow land is reported to be 37, 274 hectares (6.5 %); wood land amounted to be 441 hectares (0.1 %) and land for other uses is estimated to be 10,311 hectares (1.8 %). The average size of land holdings is 1.29 hectares. Livestock are also important in the farming system of the Zone. They serve as a source of draught power, transport, income, food, fuel and manure. The major animal species kept in the study areas are cattle, goats, sheep, and camels.

4.1.1. Water Supply

Most of the people found in the basin area get available water from different sources such as rivers, lake, unprotected springs, developed springs, hand dug wells, hand pump, shallow well and deep well. These water sources are also used for livestock and sanitation purposes. According to FGD with the community, the water from unprotected well, river, unprotected ponds and unprotected springs is provided without any treatment. This situation might aggravate the incidence of water borne diseases and can worsen hygiene and sanitation status of the community. Hence, urgent intervention of water supply schemes is needed for the socio-economic wellbeing of the community. As it was mentioned under health facilities, majority of the deadly diseases reported are easily preventable and curable. However, availability of pure water supply and provision of sanitation is the crucial aspect of public utilities. Most of the hand-dug wells are not well protected and the users should fetch the water through rope pumping (pulling). The well water is open at the top and exposed to different polluting agents.

Domestic water supply accessibility is the other issues that need important attention. According to FGD to identify the conditions of accessibility to households within the basin boundary from the water supply sources, most of them respond that the households use to collect domestic water within 5- 8 kilometres distance from home. The most prevalent water related, and water borne diseases in the basin that has direct impact on the agricultural work force (human being) are malaria, diarrhea, typhoid, dysentery and internal parasites. The majority of the informants disclosed that there is no management body for the available water supply scheme, proper distribution, and management and maintenance functions of the water points. Other challenges and constraints of water supply and sanitation in the basin are weak management system, limited or shortage of budget for water supply development, problem of maintenance and poor-quality construction of water points and shortage of chemicals for water treatment.

4.1.2. Cooperative Societies

Community based organizations such as cooperatives have socio-economic significance. One of the most important institutions in undertaking socioeconomic development in general and undertaking the problem of poverty in particular is cooperative societies. There are different types of cooperatives in the districts; the major ones are primary cooperatives, multipurpose cooperatives, consumers, saving and credit, general agriculture, non-agriculture cooperatives, etc.

The institutional assessment of the study has tried to cover the spatial distributions of rural cooperative societies especially those involved in agricultural activities such as agricultural services cooperatives, saving and credit cooperatives and irrigation cooperative societies that treat members in delivering services. This is because of their importance on promoting development and improving the rural way of life. It is becoming clearer and more acceptable that cooperatives, as economic enterprises and as self-help organizations, are acting a meaningful role in uplifting the socio-economic conditions of their members and their local communities.

4.1.3. Migration and Unemployment

Most of the daily workers come mainly from different parts of the neighbouring districts for search of better jobs, finding of their relatives, and search of farm lands, education and opportunities that they are not able to get in their place of birth. The main push factors of the migration of the people

in the basin are existence of unfavourable conditions in an area within the aquifer where one lives in, unavailability of jobs, few employment opportunities, and inadequate conditions such as lack of farmland, loss of wealth, natural disasters, poor housing, and war. Population increases, shortage of cultivable land, reduction of cultivated land productivity, climatic change are the main contributing factors for unemployment. In addition, the low development of industrial sector, service providing economic sectors and agriculture-based processing industry development also aggravate the rural unemployment rate and even the urban unemployment.

4.1.4. Child Labor

Children are engaged in all forms of paid work in factories services industries, shops and marketplaces and in houses hold chores. In such activities, the children are not supervised by the existing law, and as a result of these, they are subjective to hazardous working condition. Children under these forms of child labor are more or less self-employed due to various reasons. As has been observed in this study, child laborers along the street side are engaged mainly in marginal works such as shoe shiner, porterage, and street vending. However, there are other works in which street children perform less frequently compared to the above jobs. Government policies, unemployment and underemployment, non-conducive school environment and large family size also force children to engage in laborious work.

4.1.5. School Accessibility

The school accessibility for the rural population in the study area was assessed using different information sources including the sector level data from each administrative district and the results of focus group discussions. Most of the students in primary school walk an hour walking distance. The distance of secondary school from home is too far and schools are found only in the capitals of district. Due to the too far distance of the location of most of secondary school from home, the students require to walk averagely two and half-hours daily. There are also considerable numbers of households that can walk a greater number of hours to get the school system. Nevertheless, the education strategy of the country has undertaken to access the primary school system within 3 kilometres distance from home. Furthermore, due to lack of awareness of parents, poverty among the people, lack of budget and sources of income for the school, more than half of the students withdraw from school for business purposes and adult education is difficult due to poor understanding towards the importance of education.

4.1.6. Gender Issue

Ethiopia is rapidly changing in addressing women's issues. Over the last few decades, there has been a significant improvement in empowering women to take part in every sector of political, social and economic development. Enabling polices and strategic plans have been laid down by various Ministries and Office of the Prime Minister. The water resource policy issued in 2001 says: "Promote the full involvement of women in the planning, implementation, decision making and training as well as empower them to play a leading role in self-reliance initiatives." Regardless of enormous effort by the government to empower women, there exist a huge gap in women's participation in planning, execution and management of water resources development and management. The root causes of such under-representation are lack of capacity (skill, education and facilities) and cultural taboos. However, the gap is getting narrower and narrower from time to time.

4.2. Socioeconomic situation in Gedaref Aquifer

The state consists of ethnic groups representing different tribes. This diverse social structure has been formed due to migrations following the Mahdist revolution, which resulted in a multi-ethnic, multi-cultural society. Gedaref state is a distinguished agricultural area where mechanized farming schemes were introduced in 1954. About 70 per cent of the total mechanized farming in the Sudan is carried-out in Gedaref and two thirds of the state population works in the sector. The total arable land is about 8.6 million feddans, of which around seven million is used for cash crops like sesame, sorghum, beans, sunflowers, and citrus fruits, while livestock in Gedaref state is estimated at 7.6 million heads of cattle. Full dependence on rainfall for agriculture, characterized by severe annual fluctuation, still threatens people's livelihoods.

4.2.1. Social Indicators

Gedaref state's nutrition indicters are among the worst indictors as the global wasting percentage is above the emergency threshold (15 %), and stunting is also high (46 %). The state is among the worst performing ten states in Sudan when it comes to the practice of open defection as only 10% of Gedaref population has access to sanitation facilities, while only 28 % of the state population has access to safe drinking water. On the other hand, Gedaref has good immunization coverage and remarkable achievement in skilled attendance during deliveries. Education data shows that the net intake rate in primary education is 34 %, which is low compared to the national indicator. The state consists of ethnic groups representing different tribes.

4.2.2. State Water supply

The state population access to basic domestic water supply is 27.7 % compared with the Sudan overall average access of 68.0 percent. It is worth to indicate that out of the state population who have access to basic water supply only 6.2 % have access to safely managed water supply (piped into dwelling or compound) compared with overall Sudan average access of 36.9 %. The bacteriological water quality of the current improved water sources in the State is an issue which was evident during the latest large scale acute watery diarrhea epidemics in which some of the affected people were found to be drinking from improved water sources. It was found that the water contamination is at large resulted from the malfunctioning water sources design, disinfection process, storage, distribution, transportation and household handling.

4.2.3. Population Movement

Refugees and migrants represent a high proportion of the population of the state. Gedaref hosts around 100,000 refugees and it has been a safe haven for many migrants from different part of Sudan as seasonal agriculture labor. Gedaref supports services to refugees and migrants and responds to the needs of a steadily growing number of refugees in the border. The continuous conflict and tension in Ethiopia and Somalia forced many people to seek refuge in Sudan. Migration has a serious impact on children especially in the issues related to violence and trafficking.

4.2.4. Social Cohesion

In the past couple of years' social cohesion in Gedaref state has been affected and deteriorated due to tribal conflict in East Galabat locality. Conflict-sensitive programming is essential for improving social cohesion and resilience, empowering young people to lead development and play key roles as potential actors in their communities. Recent tension in the border between Sudan and Ethiopia and conflict around El Fashaga locality may affect stability in Gedaref state and may lead to new displacement. Strengthening the governmental and non-governmental response systems is crucial for an effective humanitarian response.

4.2.5. Indigenous Groups and Land use

The ethnic groups in the state are a mix of tribal groups diverse in culture, livelihood, and mode of survival. The majority of state population came from the different parts of the country and most of them settled in the productive and arable agricultural areas. The State is relatively rich in terms of natural resources and capacity for future investment and development especially on agriculture, livestock. Rural population lives in broadly scattered settlements to match the existing ecological conditions. In some cases, the settlements take the form of large central villages surrounded by small villages and nomadic camps. Population density tends to increase considerably in urban centres.

The small settlements size and the wide dispersal of rural population throughout the state make provision of basic social services as health, water supply, sanitation, and education extremely difficult and complicated. Urbanization is rapidly expanding due to deterioration of basic services at the rural areas over the last two decades. The population in the area suffered from hostile unfavourable environmental phenomena, such as recurrent droughts in some parts of the state in addition to the migration of thousands of droughts and war affected population from Ethiopia and Eretria

One of the most important changes that occurred in the Gedaref area has been without any doubt the expansion of large-scale mechanized rain-fed and irrigated farming that has radically transformed the ecological environment of the pastoral areas. The expansion of irrigated and mechanized agriculture was meant to change the nature of the area from a predominantly pastoral one into a rich agricultural one and to develop market oriented agriculture with cash crops such as cotton, sesame and sorghum. Therefore, the development of mechanized agriculture was made at the expenses of both traditional rain-fed agriculture and pastoralism.

4.2.6. Livestock in Connection to Pastoralists and Agro-pastoralists

The grazing pattern of livestock follows pastoral nomadic and semi nomadic systems, as well as settlement system in irrigated areas. The livestock suffers several problems including geographical and environmental marginalization of pastoralists. These problems coupled with improper distribution of water resources, seasonality of good pastures, and community ownership of pasture.

Livestock growth is extremely high and consequently this will put more pressure on the available water resources, therefore, future plans should consider these facts and focus more on surface water harvesting systems.

4.2.7. Indigenous Groups and Active Stakeholders

Gedaref Organization for Peaceful Coexistence (GOPC) has a very good reputation on the humanitarian response and recognized records in dealing with the different crises in the states. GOPC has good experiences working with ingenious groups along the borders between Sudan and Ethiopia. It is recommended that GOPC be engaged in this project to support the identification of the key water sector partners and state indigenous groups.

Youth organizations in Gedaref groundwater basin have big and effective participation in the organizations at the community level besides influencing the community decision making processes. They take the lead in developing action plans for communities in the state besides receiving a number of training activities to enhance the skills in management, technical expertise to build their current and future capacity. Youth focal names and contacts in 13 towns and villages can support the NBI in project implementation at present and in the future.

4.2.8. Gender Mainstreaming and Social Inclusion in the Management of Water Resources

In the water sector policies, and strategies, gender aspects have been incorporated in all documents to ensure that women have equal opportunities for realizing their full WASH related rights. However, the realties on the ground show that women participation and engagement in the sector consultation, planning and management is very limited and marginal. In the rural areas, women bear the impact of inadequate water access, as they are expected to walk long distances in search for water, which puts their safety security at risk in addition to taking care for the core tasks of their homes. The women participation in water WASH and other CBCs is low and regularly excluded from many key decisions making forums including traditional community structures, water committees, and governmental institutions.

5. STAKEHOLDER ANALYSIS IN GEDAREF-ADIGRAT AQUIFER

5.1. Introduction

A stakeholder is an individual or group or organization entity that have interest and can be affected by activity or decision made to the use and management of the resources. The purpose of this section is to identify the stakeholders for groundwater management in the Gedaref-Adigrat aquifer, describe their roles and involvement and assess their interest and relative power for the project success. In addition to the national stakeholders, international and regional stakeholders are described. Stakeholder analysis can help project management members understand the variety of stakeholders that have an interest and can play positive roles in groundwater resources development, use, and management, and the individuals that can have negative roles.

Stakeholders may be interested to use the groundwater, or they are concerned about the availability and its environmental impact, or they may have activities that can negatively affect the groundwater quality and quantity, and so on. Hence, stakeholders have to come together when developing and planning any activities that could impact the aquifer groundwater. Any management decision must be passed through consensus. Though stakeholders have different perceptions and actions on the groundwater use, there should be a common understanding that all parties participated in the decision process. Any activities on groundwater planning and management conducted without stakeholders, it would not be effective economically, socially, and politically. Therefore, stakeholders' analysis is very crucial for successful sustainable groundwater management as it has multiple advantages such as preventing conflict, promote social, economic, environmental, political conditions, and enhancing benefits.

5.2. Identification of Stakeholders

In this section, the different stakeholders from Governments at different levels to end-users, civil society, regulators, and donors, who are directly or indirectly affected by the groundwater management decision or activities, are identified, as well as those who have an interest in the resources use and the ability to influence the outcome

In order to identify the stakeholders, the following measure criteria are necessary to analyse:

- Who are the potential beneficiaries in groundwater management?
- Who are or might be negatively impacted by the GW management?

- Who are the supporters or opponents of changes to groundwater management systems?
- Are gender interests adequately identified and represented?
- Are there important stakeholders outside the project study area?

The identification of stakeholders is not only restricted to the groundwater system project boundary. The groundwater aquifer activities may have different socio-economic effects on local, national, and even potentially international stakeholders.

5.3. Assessment of Stakeholders` Interest

Assess stakeholder interests and the potential impact of groundwater management decisions on these interests. After, the key stakeholders have been identified; the possible interest that these groups or individuals may have in groundwater can be considered and analyzed. The following important questions are used to assess the interests of the different stakeholders:

- What are the stakeholder expectations from the groundwater management activities?
- What benefits are potentially to result for the stakeholder?
- What stakeholder interests' conflict with groundwater management goals?
- Which stakeholders may have different interests? Some stakeholders may have contradictory objectives and interests to groundwater management?
- What resources do stakeholders provide or help in the process of groundwater management and planning?

5.4. Assessment of Stakeholders` influence and Importance

Assess the influence and importance of the identified stakeholders. This step is used to categories the stakeholders according to their influence and importance. This refers to the stakeholders' influential power on groundwater resources management activities and decisions. This power is like formal control over the decision-making process or indirectly support and facilitate groundwater management and planning activities. The influence and importance of stakeholders determined using the following questions:

- Do the stakeholders have the power and status (political, social, and economic)?
- Do the stakeholders have control power over groundwater resources management?
- Do the stakeholders have an informal influence on the groundwater management activities or decisions?

- Do the stakeholders have importance to the successful implementation of groundwater management?

5.5. Stakeholders Mapping

Stakeholders Mapping is basically classifying stakeholders in four groups: -

1) High power and high interest.
2) High power and less interest.
3) Low power and high interest.
4) Low power and low interest.

According to the recommendations of Mendelow, A.L. 1998, the groups should be treated as follows to ensure the success of the project:

1) High power, with highly interested stakeholder group (Manage closely): These stakeholder groups or people must be fully engaged in the project and the greatest efforts to satisfy them must be made.
2) High power, less interested stakeholder or people (Keep Satisfied): Enough work should be put with this stakeholder group to keep them satisfied, but not so much that they become bored with the message.
3) Low power, highly interested stakeholder or people (Keep Informed): They should be adequately informed this to ensure that no major issues are arising. Stakeholders in this category can often be very helpful with the detail of the project.
4) Low power, less interested stakeholder or people (Monitor): Some effort should be made to communicate and monitor this stakeholder group without boring them with excessive communication.

5.6. Stakeholders Identification and Analysis Results

The stakeholders in Gedaref-Adigrat aquifer, their classification (primary or secondary), their interest and level of influence on proposed Program are given in Table 5-1. Primary stakeholders refer to people, groups, and institutions affected positively or negatively by the proposed or implemented groundwater management activities or decisions. Secondary stakeholders refer to people, groups, and institutions that are important intermediaries in the groundwater management project implementation process (e.g. NBI, World Bank, ADB, government line agencies, NGO's) 154 different stakeholder groups have been different in

Gedaref and Adigrat groundwater trans- boundary aquifer (94 in Adigrat and 60 in Gedaref basin). The stakeholders are basically primary and secondary stakeholders and partners who supposed to have direct and indirect influence and interest in the socioeconomic context of Gedaref and Adigrat in addition any other interventions or projects related water resources development and management. The Stakeholders groups include state and local government water resources management institutions, water providers, water users, legislative bodies and regulators, policy makers, civil societies, women and youth groups, external and local NGOs (Service delivery) and financing organizations.

The status and role of each stakeholder in connection to SADA project and the forthcoming program (Enhancing Conjunctive Management of Surface and Groundwater Resources in Selected Trans-Boundary Aquifers) in terms of interest and influence have been clearly indicated in Table 5-1 and Table 5-2. However, details with regards to degree of their engagement in water resource development and management, operation areas and type of activities for each partner are not available and this needs further investigation.

Table 5-1: Stakeholder identification and analysis in the Adigrat Aquifer

No	Stakeholders	Primary	Secondary	Stakeholders' interest in the program	Level of Influence	Remark
A - Government authorities_ National Stakeholders						
1	Ministry of Water and Energy of Ethiopia (MoWIE)		✓	High	High	
2	Ministry of Health (MoH)		✓	High	High	
3	Ministry of Education (MoE)		✓	High	High	
4	Ministry of Agriculture and Rural Development (MoARD)		✓	High	High	
5	Agricultural Transformation Agency (ATA)		✓	High	Low	
6	Ethiopian Ministry of Mines and Petroleum (MoMP)		✓	Medium	High	
7	Ministry of Communications and Information Technology (MCIT)		✓	High	High	
8	Ethiopian Geological Survey of Ethiopia (EGS)		✓	High	Low	
9	Ethiopian national Meteorological Agency (ENAMA)		✓	High	Medium	
10	Ministry of Finance and Economic Development (MoFED)		✓	High	High	
11	Ethiopian Central Statistics Agency (CSA)		✓	High	Low	
12	Ministry of Environment, Forest and Climate change (MoEFCC)		✓	High	High	
13	Environmental Protection Authority (EPA)		✓	High	High	
14	Ministry of Foreign Affairs (MOF)		✓	High	Low	
15	Ethiopian Water Works Construction Enterprise (EWWCE)		✓	High	Low	
B- Regional _Stake holders						
Government Regional Administration						
16	Amhara Water, Irrigation and Energy Bureaus		✓	High	High	
17	Amhara Regional State Education Bureau		✓	High	High	
18	Amhara Regional State Health Bureau		✓	High	High	
19	Amhara Regional State Agricultural and Rural Development		✓	High	High	
20	Amhara Regional State Finance and Economic Development Bureau		✓	High	High	

21	Amhara Regional state Environment and Land management Bureau		✓	High	High	
22	Amhara Regional State Administration office (regional president office)		✓	High	High	
23	Amhara Regional State waterworks and design organization		✓	High	Low	
C- Zonal Stakeholder						
24	Government Zonal administration office(North Gondar)		✓	High	High	
25	Water, Irrigation and Energy office		✓	High	High	
26	Agricultural and rural development office		✓	High	High	
27	Education office		✓	High	High	
28	Health office		✓	High	High	
29	Environmental protection office		✓	High	High	
30	Land administrator office		✓	High	High	
31	Investment office		✓	High	High	
32	Women, Children and Youth Affairs office		✓	High	Medium	
33	Finance and economic development office		✓	High	High	
D - District Stakeholder (Aquifer area)						
Government district and city Administration						
34	District chief Administration office		✓	High	High	
35	Alefa,Chilga,Dabat,Debarq,Dembia,Gon dar Zuria,Kafta Humera,Lay Armacheho,Metema,Quara,Sanja,Tsege de,Wegera,Welkait		✓	High	High	
36	Water, Irrigation and Energy office		✓	High	High	
37	Agricultural and rural development office		✓	High	Medium	
38	Education office		✓	High	Medium	
39	Health office		✓	High	Medium	
40	Environmental and land administration office		✓	High	Medium	
41	Investment desk		✓	High	Medium	
42	Culture and Tourism desk		✓	High)	Medium	
43	Women, children, and youth office		✓	High	Medium	

44	Town water supply and sewerage Services		✓	High)	Medium	
E - Kebele level stakeholders						
Kebele and Community level chief administration						
45	Water users (household consumers community dwellers)	✓		High	Low	
46	Livestock herders(community)	✓		High	Low	
47	Farmers (tap water for irrigation and farm use)	✓		High	Low	
48	Religious institutions	✓		High	Low	
49	Cultural or traditional institutions	✓		High	Low	
50	Kebele administration	✓		High	Low	
51	Kebele development community	✓		High	Low	
F-Water Users						
52	Households, families, individuals	✓		High	Low	
53	Women and children	✓		High	Low	
54	School, hospitals	✓		High	Low	
55	Private enterprises	✓		High	Low	
56	Elders	✓		High	Medium	
57	Construction contractors, local builders/well drillers		✓	High	Low	
58	Local technicians/plumbers workers	✓		High		
G-NGO Stakeholders						
Non-Governmental Organizations (NGO) & Development Assistance Group (DAG)						
59	SNV Netherlands development organization		✓	High	Medium	
60	Plan Ethiopia		✓	High	Medium	
61	Oxfam GB In Ethiopia		✓	High	Low	
62	Norwegian Church Aid		✓	High	Medium	
63	International Water And Sanitation Centre		✓	High	Medium	
64	ORDA (local NGO)		✓	High	High	
65	Amref Health Africa		✓	High	Low	
66	Water Aid		✓	High	Medium	
67	World Vision		✓	High	Low	
68	Catholic Relief Services		✓	High	Low	

69	Austrian Development Cooperation		✓	High	Low	
70	Belgium Development Cooperation		✓	High	Low	
71	CIDA(Canada International Development Agency)		✓	High	Low	
72	Denmark Embassy		✓	High	Low	
73	DFID(UK)		✓	High	Low	
74	European Commission(EU)		✓	High	Low	
75	USAID(US)		✓	High	Medium	
76	GIZ		✓	High	Low	
77	UNDP		✓	High	Medium	
78	ADB(African Development Bank)		✓	High	Medium	
79	World bank (UN_Water)		✓	High	Medium	
H- Scientific Community Stakeholders						
National and Regional Academic Institute and Research centers						
80	Ethiopian Agricultural Research Institute		✓	High		
81	Amhara Agricultural Research Centers		✓	High	Low	
82	Gondar University		✓	High	Medium	
83	Debark University		✓	High	Medium	
84	Bahir Dar university		✓	High	Low	
85	Mekele University		✓	Medium	Low	
I- International Stakeholders						
International organizations/Institutes						
86	IWMI – International Water Management Institute		✓	High	Low	
87	IGRAC – International Groundwater Resources Assessment Centre		✓	High	Medium	
88	AGW-Net – Africa Groundwater Network		✓	High	Low	
89	GWP – Global Water Partnership		✓	High	Low	
90	IGAD		✓	High	Low	
91	NBI_NILE -SEC		✓	High	Low	
92	NBI_ENTRO		✓	High	Low	
93	FAO		✓	High	Low	

Table 5-2: Stakeholder identification and analysis in Gedaref Aquifer

No	Stakeholder	Primary	Secondary	Interest	Influence
National Stakeholders					
1	Ministry of Irrigation and Water Resources	✓		High.	High
2	Ministry of Production and Economic Development		✓	High	medium
3	Ministry of Education (MoE)		✓	medium	low
4	National Meteorological Corporation		✓	Medium	low
5	Groundwater and Wades Directorate (GWWD)	✓		High	low
6	Drinking Water and Sanitation Unit(DWSU	✓		High	low
State Stakeholders					
7	State Ministry of Planning and Public Utilities	✓		High.	High
8	State Ministry of Production and Economic Development	✓		High	low
9	State Ministry of Social Development		✓	low	low
10	Gedaref State Water Corporation	✓		High.	High
11	Gedaref State WES Project	✓		High.	High
Local Authorities					
12	El Galabat East	✓		High	medium
13	El Galabat West	✓		High	medium
14	Fashaga	✓		High	medium
15	Gedaref	✓		High	medium
16	Gedaref Central	✓		High	medium
17	Basunda	✓		High	medium
Main ethnic groups in Gedaref Basin					
18	More than 15 ethnic /tribal groups (listed in Annex)	✓		High	High
Civil Societies in Gedaref Sate					
19	Gedaref Organization for Peaceful Coexistence (GOPC)	✓		High	High
20	Alesha Forum			High	

21	White hand Association	✓		High	High
22	YataGedamon Imitative	✓		medium	low
23	Civil Laboratory			medium	low
24	Youth without Boarders	✓		High	low
25	Sord Organization	✓		High	High
26	Akishrag Organization	✓		High	High
27	Artistic	✓		high	low
28	Accidents Streets		✓	high	medium
29	Family Planning Association		✓	high	medium
30	Girls Student Assembly		✓	High	medium
31	Zakat Chambour,	✓		High	High
Key influential l Associations Groups in the Sate					
32	Farmers Associations	✓		High	High
33	Livestock Association	✓		High	High
34	Pastoralists Groups	✓		High	High
UN Agencies Presence in Gedaref Basin					
35	UNCHR	✓		High	High
36	UNICEF	✓		High	High
37	WHO	✓		High	High
38	WFP	✓		High	High
39	IOM	✓		High	High
40	ZOA	✓		High	High
41	MSF	✓		High	High
42	IRW	✓		High	High
43	COOPI	✓		High	High
44	WHH	✓		High	High
45	CIS	✓		High	High
Identification of Youth organizations Focal Persons in Gedaref Groundwater Basin					
46	Ali Doka+249 914421504	✓		High	High
47	Ibrahim Doka+249912351457	✓		High	High

48	Jabir Al-azaza Soqura+24907151246	✓		High	High
49	Al-azaza Soqura+24907151246	✓		High	High
50	Al-azaza Soqura+24907727277	✓		High	High
51	Awad Drin Basunda+24915047715	✓		High	High
52	Mahmoud Algerasha+24914402248	✓		High	High
53	Ibrahim City (1) +24993047870	✓		High	High
54	Al_ Sadig City (1) +24917221654	✓		High	High
55	City (1) +24962954758	✓		High	High
56	Sami City (5) +24901956971	✓		High	High
57	Alsuni Fathi AL_Garbeiya+24910381875	✓		High	High
58	Muzamil Showak+24122811511	✓		High	High

6. GOVERNANCE AND INSTITUTIONAL SETUP

6.1. Institutional and legal framework in Ethiopia

The lead institution in the management of water resources in Ethiopia is the Ministry of Water Resources (MoWR). However, there are other key players in the sector as shown in Table 6-1.

Table 6-1: Key institutions Involved in Water Management in Ethiopia

Project Cycle	Urban Water	Rural Water
Planning	MoWR (policy and strategy) Regional Water Bureaux (RWB) Towns (town administration)	MoWR Water Bureaux (RWB)
Decision Making	Council of Ministers (for major projects) Regional Council	Regional Council Zonal Offices of Water Community Organizations Households (wells)
Implementation	MoWR (large projects) RWB with zonal departments Contracts Consultants	RWB with zonal offices NGOs Contractors ESRDF Community Organization
Operation and Maintenance	RWB and line departments Towns water services (water board) MoWR for large rehabilitation works Contracting services to private sectors	Zonal offices for back- up support Community Organization
Monitoring and Evaluation	Bureau of water and line departments ESRDF Planning and Economic Department Research organizations Funding Agencies NGOs	

Source: (MoWR, 2002), MoWR (2001)

The principal water policy document in Ethiopia is the Comprehensive and Integrated Water Resources Management Policy issued by the MoWR in July 2000 (MoWR, 2002) This document sets out management policy on water resources in general and those that relate to water supply and sewerage, irrigation, and hydropower. It also describes policies on various cross-cutting issues, such as those dealing with groundwater resources, watershed management, water rights allocation, trans-boundary concerns, and technology.

As far as groundwater is concerned, the policies emphasize identifying the spatial and temporal occurrence and distribution of the country's groundwater resources and ensure its utilization for different water uses. It also stressed to exploit the groundwater not more than its sustainable yield. Moreover, the policy highlights the establishment of norms, standards, and general guidelines for the sustainable and rechargeable management of groundwater. In the technological and engineering aspect special focus is given to wells and drilling like standards and guidelines for the manufacture and import of drilling rigs, need to develop shallow wells at local levels, and promotion of indigenous technologies in groundwater development and utilization. Proclamation No. 197/2000 in the policy declares that "All water resources of the country are the common property of the Ethiopian people and the State". It gives the Ministry of Water Resources the authority to allocate and apportion water to all regions regardless of the origin and location of the resource. The proclamation lists a wide range of regulatory tasks among the powers and duties of the same Ministry.

Ethiopia has not only a federal-level water supply management organization but also regional-level water supply management units or organizations, each of which is connected with the federal ministry-level organization. The authorities, roles, or functions of the Ministry in relation to the water sector indicated above include:

- Facilitating the development of water resources;
- Determining the national availability of groundwater and surface water in terms of quality and quantity and from the results & findings of river basin studies;
- Deciding about conditions & methods for properly allocating and using trans-boundary water resources shared by multiple regional states;
- Engaging in studies and treaty negotiations to ensure the proper use of water resources flowing down adjacent to a border with a neighboring country;
- Ensuring the performance of studies and engineering design & construction works required for facilitating the expansion of medium and large dams;
- Operating & maintaining dams and other hydraulic structures whose construction was funded by the federal government.
- Collaborating & coordinating with relevant institutional stakeholders on quality requirements for each of different water uses;
- Helping increase access to drinking water and implement & coordinate a project funded by foreign aid (incl. loans); and
- Authorizing and regulating the construction and operation of water-related projects

6.1.1. Ethiopian Water Resource Policy on Groundwater

1) Identify the spatial and temporal occurrence and distribution of the country's ground water resources and ensure its utilization for the different water uses and provide special focus for those areas vulnerable to drought and water scarcity.
2) Ensure that the exploitation of ground water shall be based on abstraction of the maximum amount equal to the sustainable yield as determined by competent authorities and established regulatory norms.

3) Establish and develop norms, standards and general guidelines for sustainable and rechargeable management of ground water.
4) Foster conjunctive use of surface and groundwater as appropriate.
5) Promote implementation of appropriate technologies suitable for water deficient areas in order to mitigate water scarcity problems.

6.2. Sudan Government System

- Sudan is a federal country where there are three levels of authority - National level, State level and Locality level. The powers over land and natural resources including water resources are divided among the various levels as follows:
- At the national level, the federal organs exercise the powers of planning, legislation and execution on federal lands, natural resources, mineral and subterranean wealth, inter-state waters, national electricity projects, and disaster management
- The state organs within the boundaries of the state exercise powers over; state lands, natural resources, animal wealth, wildlife, non-Nile waters and electric power There is, at present, some ambiguity as to what constitutes state versus federal land. However, the interpretation is that any land that falls within a particular state's boundaries is land belonging to that state, unless it is explicitly attributed to a specific federal institution
- There are concurrent powers, where both federal (national) and state organs exercise powers on education, health, environment, tourism, industry and meteorology.

The Ministry of Water Resources and Irrigation (MWRI) is the lead of the water sector institution in Sudan. Relevant supportive or user ministries include; The Ministry of Agriculture and Forestry (MAF) The Ministry of Energy & Mining (MEM), The Higher Council of Environment and Physical Development. The functions o f M W R I includes: Water allocation system (water rights, licensing, and monitoring), regulations, standard setting, permitting (water & discharge), compliance, monitoring, sanctioning/ enforcement functions, pollution control function and specific water quality standards. The water provision is federal, but the foreign support control and distribution is central. The GWWD is central with regional offices all over the different states.

The main responsibilities of GWWD are groundwater assessment, management and provision technical consultancy and drilling supervision for proper groundwater resources development

6.2.1. Institutional Setup of the Groundwater Sector Governance System

1) Before 1956 groundwater belonged to the Soil Conservation and Land uses departments in the Ministry of Agriculture.
2) In 1957 treated as mineral within the Geological Survey of the Ministry of Mining and Energy.
3) In 1967 Groundwater Research section was established within the Rural Water Corporation in the ministry of Agriculture.
4) In 1996 the water resources gathered in the MIWR and different names were given to the groundwater institute; Non Nile Water General Directorate, Groundwater Directorate.
5) Since 2000 and forward, Groundwater and Wadis GWWD is one directorate out of the six general directorates in the Ministry of Water Resources. GWWD has always been an unstable, marginalized and low status institution.

6.2.2. Organizational Structure of the Water Sector Governance System

Most countries have decentralized water services provision to district and/or municipal governments and are in the process of decentralizing management of water resources to basin level. The efficiency and effectiveness of the decentralization process directly affects sectors governance. Key issues are the extent of decentralization and whether or not the responsibilities allocated to lower levels of government have been matched with the necessary authority and resources (financial, human and logistical).

Institutional arrangements for environmental governance in Gedaref state are characterized by the presence of a several number of institutions who have direct links to the issue of water resource management. Each of these institutions also relates to one or more institutions at the Federal level.

6.2.3. Water Management Policy

The Sudan has recently taken some major steps to organize the water sector. The first step was putting the monitoring, assessment, planning, management and development of all the surface and groundwater resources under MWRI. The second step was the formation of the National Council for Water Resources (NCWR), which includes representatives from all stakeholders of the wide water sector. The third step was the decentralization, privatization and active participation of users in the management and funding of the irrigated schemes.

Sudan has three pending draft versions of water policy: 1992, 2000, and 2008. The function is to manage surface water, groundwater and the Nile. Function also includes protection of the environment, the mitigation of drought and flood impacts. The goal of the policy is to address the sustainable and efficient water resources management as a foundation for national economic development. Priorities are drinking water, food security, sanitation and environment protection and negotiation and cooperation approaches for the management of the shared basins. The main policy principles are:

1) Water resources management affects everybody and should be undertaken with the participation of relevant stakeholders.
2) People are stakeholders for water use and the national government is the custodian of all water in Sudan for the equitable benefit of all in the public interest.
3) The gathering and management of accurate information for the recording and ongoing monitoring of water resources is essential for the proper development, management and protection of water resources.
4) The environment needs to be protected in order to ensure sustainable utilization for the present and future generation.
5) The development of water resources will be undertaken in order to maximize its benefits in the public interest whilst ensuring minimum adverse impact on the environment.
6) Public institutional arrangement at federal and state levels will be integrated, accessible, efficient and transparent whilst avoiding duplication of functions and responsibilities.
7) Water and water related issues are an integral part of the wider economy and have direct effects on many other sectors which require inter-departmental and inter-sectorial communication and co-operation

The long term strategies for groundwater resources emphasize that:

- Groundwater resources are an invisible part of the hydrological system, the national water balance and the natural resources base.
- Groundwater resources are a national property, the equitable use of which is common to all subject to national authority and control.
- Proper planning assessment, development and management of water resources cannot be achieved without strengthening the information base at the national and the states level.

- Present and future water users have a right of access to clean and unpolluted groundwater resources and un-degraded environment.
- Groundwater abstraction, particularly from alluvial and shallow aquifers, shall be based on recharge and safe yield concept.
- Sustainability of groundwater development, investment and supply services shall be planned for and considered as part of development and management policy of the water resources systems.

6.2.4. Sudan Water Legislations

Legislation is crucial to policy implementation. In most African states, the water sector's legal framework is a combination of related water resources, utilities, health and environmental laws and regulation dating back often to colonial times. Typically, their updating is a complex and on- going effort. Nevertheless, legislation forms the basis of institutional jurisdictions, water rights, regulation and conflict resolution. As a result of often out of date and poorly harmonized legislation, institutions overlap and often have conflicting interests and responsibilities, with the result that rights and regulations are difficult if not impossible to enforce. The governance assessment should include an assessment of the state of legislation and the degree to which it supports policy and provides for clear separation of stakeholder roles and responsibilities.

6.2.5. Regulations

The vast majorities of water sector regulators in Africa are not independent and cannot regulate without referring to government. Although several countries use informal regulation mechanisms such as performance agreements between service providers and authorities and maintenance of good customer relations, they usually fall short of requirements. In assessing the regulatory framework, the effectiveness of the following regulatory functions should be reviewed:

- Setting of tariffs and fair prices.
- Setting of standards for services and monitoring of providers
- Enforcement of regulatory decisions, standards and rules, assurance of compliance with acceptable accounting practices.
- Arbitration of disputes between service providers and consumers.
- Protection of customers from unfair practices; and,
- Promotion of competition and the prevention of abuse of monopoly power

- Many laws and regulations have been drafted over the years to deal with the use and protection of the water resources systems. Recently, the Groundwater Act. (2016) was developed and approved. The Act. named Exploitation of Groundwater Regulations (2016) aims to achieve sustainable management of groundwater aquifers and protection from degradation.

6.2.6. Institutional Assessment

Table 6-2 broadly characterizes the groundwater sector governance and identifies its main areas of risk.

Table 6-2: Assessment of the Groundwater Sector Governance

No	Function/Roles	Federal Level	State Level	Locality Level
A	administer/participate in local allocation/ access to groundwater	+	o	s
B	engage in preparation/implementation of groundwater management plans	o	+	x
C	facilitate shared access and use of groundwater facilities	o	o	s
D	promote/undertake demand reduction measures	+		
E	engage in recharge and retention measures	o	o	x
F	mobilize additional sources of water	o	s	
G	make/participate in binding rules on water use	o	s	x
H	implement groundwater protection measure	o		
I	settle groundwater resource disputes		+	x
j	negotiate and interact with other policy actors	o	x	x

+ Requires formalization of relationship with a local water resources regulatory agency
o Main implementer
s Support
x Requires juridical personality to be conferred on corresponding organization/association

7. Gaps Hindering Sustainable Management of Gedarif-Adegrat Aquifer

7.1. Introduction

This chapter summarizes the important gaps that have been identified in the Gedarif-Adegrat aquifer which should be considered by Sudan and Ethiopia for the sustainable management of groundwater. The gaps identified are:-

1. Water supply, quality and sanitation gaps
2. Lack of monitoring and adequate information base
3. Governance and policy gaps
4. Human capacity gap

These are further discussed below

7.2. Water Supply, Quality and Sanitation Gaps

- The study revealed that there is currently a huge gap between the water supply and demand in both sides of the aquifer. Water supply represents only about 22% of the demand for Gedaref and 12% of the demand in Adigrat.
- Also there is a gap in water with adequate quality. Ground water pollution has been reported in both Gedaref and Adegrat caused by both natural conditions and anthropogenic activities. Quality problems include high salinity, high fluoride, arsenic, nitrate and calcium in addition to bacteriological contamination.
- The study area suffers from inadequate sanitation facilities. There is also lack of water treatment and source protection leading to water borne diseases such as malaria, diarrhea, typhoid, dysentery and internal parasites.

7.3. Lack of Monitoring and Adequate Information Base

- This study reveals that systematic monitoring of groundwater quantity or quality in the Gedaref-Adegrat aquifer does not exist even at a local scale. Lack of monitoring may result in undiscovered problems such as declining groundwater levels and depletion of groundwater reserves, reductions in stream/spring base flows or flows to sensitive ecosystems such as wetlands, deterioration of groundwater quality and increased costs for pumping and treatment. The study also reveals a great gap in the human resources monitoring capacity. Accordingly, groundwater monitoring has been identified as of the priority areas of training and capacity building.

- Generally, there is a big gap in groundwater monitoring in Sudan. The existing network covers only about 5% of the required network and Gedaref basin is not included in the network. Similarly, there is no ground water monitoring network in the project study area in Ethiopia. There might be multiple reasons for this: namely, the region or the study area has been in a political conflict in the last decades in addition to limitation on budget and skilled human power on ground water monitoring. Accordingly there is no information base and data availability is minimal. Most of the data used in this assessment is open source.
- There is no information on aquifer lithology in some areas of the aquifer especially the trans-boundary area. Accordingly, there is lack of data regarding vertical thickness of the aquifer, aquifer cross section and vertical connectivity. Due to tectonic activities the Gedarif- Adegrat aquifer become a complex basin and with significant changes in thickness and water availability. Therefore, for better understanding it's very important conduct geophysical surveys in certain areas to detect the thickness/fractures and types of basalt flows and their variations.
- There is no historic water level data to support calibration of a groundwater model and also no pumping test data for estimation of hydrogeological parameters.
- Recharge is a very important parameter for sustainable management of the aquifer. There are no studies on the estimation of aquifer recharge from different sources. An attempt has been made in the present analysis to estimate aquifer recharge from rainfall in excess of evapotranspiration. However, this needs further studies when data on water level fluctuations become available.
- Ecosystem characteristics and health of biodiversity has not been a high priority in the Gedarif-Adegrat aquifer. Accordingly, there is no ecosystem monitoring and there is lack of awareness and poor understanding on how ecosystem change is impacting our natural resources and is vital for developing evidence-based policy and management.
- Pollution, Soil erosion, climate change and species extinction are just some of the most serious problems which have not been studied. The impacts of these problems are not only environmental; they also have huge economic consequences due to reductions in the provision of ecosystem services including clean water, productive lands.

7.4. Governance and Policy Gaps

- The groundwater governance is generally poor with real institutional and policy gaps at the national, state and local levels for the sustainable development and management of groundwater. Much of the focus is on surface water management.
- The gap is recognized in terms of inadequate institutional structures, lack of coordination, fragmentation and overlap of responsibilities among stakeholders, shortages of technical and managerial qualified personnel, and inadequate funding and logistic support, in addition to in-effective legal and regulatory frameworks, lack of policies, plans and knowledge of the groundwater system.
- There is on trans-boundary institution for groundwater management of the shared aquifer and there is poor consideration to groundwater resources as compared to surface water.
- There is lack of stakeholder engagement in groundwater management
- Policy harmonization and negotiation between Sudan and Ethiopia on shared groundwater resources does not exist. There is a need to create a platform between concerned stallholders to start a discussion and formulate binding regulations on the sustainable use of shared groundwater resources.
- There is limited awareness of groundwater resource and little understanding of groundwater use and importance compared to surface water at the community and intuitional levels.

7.5. Human Capacity Gap

There is a real gap in Sudan and Ethiopia in human resources capacities at various levels to plan, implement, manage, monitor and evaluate groundwater projects. In view of the current water supply shortage, growing demands for water, and adaption to climate change in the project area, there should be a well-built capacity, to deal with water resources management in a sustainable manner within the framework of an integrated water resources management approach.

Therefore, training and capacity building are highly needed to meet the above challenges in the project area. Table (Table 7-1) gives the training areas that are mostly needed, as have been identified in this study. Proposals for some training courses are given in Annex (1).

Table 7-1: Identified Training Needs in Sudan and Ethiopia

Sudan Training Needs	Ethiopia Training Needs
Regional groundwater modelling	Regional groundwater modelling
Groundwater monitoring with focus on trans-boundary monitoring	Trains-boundary water quality monitoring
Water harvesting (WH) and Management of groundwater recharge (MAR)	International and regional groundwater policies and laws
Community awareness and participation in planning and management of groundwater projects	Concepts and knowledge on trans-boundary groundwater conflict management
Data management and analysis using GIS	Use of isotopes for characterization of the groundwater system
Basics of water resources management and protection for community leaders, village committees, women and youth groups.	Water policy, laws, legislation and regulations for judiciary , senior state officials, relevant institutions including localities, civil societies and community leaders

8. CONCLUDING REMARKS AND WAY FORWARD

8.1. Concluding Remarks

1) The Gedaref-Adigrat aquifer shared between Sudan and Ethiopia represents an invaluable resource of strategic importance for the socioeconomic development in both countries. Groundwater has been used as the main source for domestic water supply for major cities, towns, and rural communities. It is expected that the current demand for groundwater will increase due to population growth, climate change, and economic development which will all have a huge impact on the availability of aquifer resources in both countries.

2) The main aquifer in the region is the Nubian sandstone commonly referred to Gedaref Formation. A secondary aquifer of low productivity is the weathered and fractured volcanic Basalt cutting through the Nubian formation. Water quality is generally fresh in the Gedaref parts of the basin but higher salinity is recorded within the basalt formation.

3) Preliminary assessment reveals that the Gedaref-Adigrat aquifer has huge groundwater storage potential. The storage potential is estimated as 104 BCM, distributed between Gedaref and Adigrat parts as 34.5 BCM and 69.5 BCM respectively.

4) Despite these great storage potentials, there is currently a huge gap between the water supply and demand in both sides. Water supply represents only about 22% of the demand for Gedaref and 12% of the demand in Adigrat.

5) Groundwater recharge to the aquifer is directly from infiltration of rainfall in excess of evapotranspiration. It is estimated that the groundwater recharge to the aquifer is 128.1 MCM/year, distributed between Gedaref and Adigrat parts as 47.3 MCM/year and 80.8 BCM/year respectively.

6) The current annual demand for domestic and livestock water supply is estimated as 146.4 MCM/year for the whole aquifer, while the total annual natural recharge is about 128.1MCM/year. Thus, the current recharge alone cannot satisfy the demand in future. In view of population growth, it is necessary to enhance groundwater recharge by using artificial recharge techniques using excess surface runoff in the area. Other surface water resources available in the area could also be developed through water harvesting to bridge the gap between supply and demand.

7) Results of climate change analysis showed an increasing trend in surface temperature of 4 to 4.5 ^{O}C by the end of the century in the business as usual scenario (RCP 8.5)

and 2.0^{O}C increase for the conservative RCP4.5 scenario. Results also show a significant increasing trend of annual rainfall in the study area and increasing number annual rainy days. However, annual average evapotranspiration is expected to increase by 35 mm/year. It can be concluded that there is a significant change in the various climatic parameters a result of climate but generally, no serious hazard and impact on surface water resources and groundwater recharge are expected.

8) Since the population in the project area is dependent on rain-fed agriculture, their socio-economic conditions are often negatively impacted by rainfall fluctuation and occurrence of frequent droughts. Socioeconomic indicators are among the lowest in terms of access to water supply and sanitation, health services, education and community participation in water projects especially women. Other social challenges in the area include poverty, child labou, political conflict, population movement, and refugees

9) The study identified the different stakeholder groups in Gedaref – Adigrat aquifer including state and local government institutions, water providers, water users, legislative bodies and regulators, policy makers, civil societies, women and youth groups, external and local NGOs and financing organizations. They are classified into primary and secondary stakeholders with varying degrees of influence and interest in the project. However, details with regards to the degree of their engagement are not available and this needs further investigation.

10) The assessment also reveals that there are a real institutional and human resources capacity gaps at the national, state and local levels for the sustainable development and management of the Gedaref-Adigrat aquifer. The capacity gap is recognized in terms of inadequate institutional structures, lack of coordination, fragmentation and overlap of responsibilities among stakeholders, shortages of technical and managerial qualified personnel, and inadequate funding and logistic support.

11) Trans-boundary risks were also identified which include climate change, pollution and water quality deterioration, land degradation due to LU/LC changes, loss of biodiversity, poverty, political conflict and displacement.

8.2. Way Forward Recommendations

1) Development of groundwater model and investigation of alternative joint management scenarios.
2) Establishment of capacity building programs at various levels including the community on shared groundwater resources management and ways to reduce potential competition and conflict.
3) Establishment of a trans-boundary monitoring network.
4) Establishment of groundwater data and information exchange platform between Sudan and Ethiopia at national and local levels and introducing adequate administrative institutions for data collection and information dissemination.
5) Establishment of a joint coordination committee between Sudan and Ethiopia for the joint management of the Gedaref-Adigrat aquifer.

9. List of References

Abate, K. A. (2013). Rural Water Supply and the Determinants of Productive Use of Water at Household Level: the Case of Metema Woreda, North Gondar, Amhara Region. Addis Ababa University.

Abdel Rahman, E. M. 1983: The geology of mafic-ultramafic masses and adjacent rocks south of the Ingessana igneous complex, Blue Nile Province, E. Sudan, M. Phill thesis, Ports month polytechnic, UK.

Abiye, T. A. (2010). An overview of the trans-boundary aquifers in East Africa. Journal of African Earth Sciences, 58(4), 684–691. https://doi.org/10.1016/j.jafrearsci.2009.10.003

Abraha, A. Z. (2009). Assessment of spatial and temporal variability of river discharge, sediment yield and sediment-fixed nutrient export in Geba River catchment , northern Ethiopia Amanuel Zenebe Abraha. KU Leuven.

Adam, E. G. 1987: Water Resources Evaluation of Gedaref Basin. PhD thesis, University of Khartoum, Sudan.

Adelana, S., MacDonald, A., Abiye, T. A., & Tindimugaya, C. (2008). Applied groundwater studies in Africa. In Applied Groundwater Studies in Africa. https://doi.org/10.1201/9780203889497

Ahmed, F. 1968: Geology of the J. Qeili, Butana, and Sileitat Es-Sufur igneous complexes, Nile valley, Central Sudan. M.Sc. thesis, University of Khartoum.

Akod, M. 1993: Confining floods of creek (khor) Abu Fargha, unpublished report.

Akod, M. 1996: Flood mitigation of Khor Abu-Farga, Gedaref area, first part. Unpublished report university of Khartoum.

Al Hardallu, Adlan (2002) Environmental Governance in Sudan . Chapter VI in Sus-tainable Development in Sudan: Ten Years After Rio Summit, A Civil Society Perspective. Ed . Hassan A . Abdel Ati . Proceedings of the National Civil Society Preparatory Conference 2-4 Octo¬ber 2001. Environmentalists Society, EDGE for Consultancy and Research and Heinrich Boll Foundation Regional Office Horn of Africa.

Alemayehu, T. (2006). Groundwater occurrence in Ethiopia. In Addis Ababa University. Retrieved from http://www.eah.org.et/docs/Ethiopian groundwater-Tamiru.pdf

Almond, D. C. 1984: Alkaline Basalt volcanism in north eastern Sudan, a comparison of Bayoda and Gedaref areas, Jour. of African earth Sci., Vol. 2, No. 33, p. 233-245.

Al-Shanti A.M.S: and Mitchell, A.H.G. 1976. Late Precambrian subduction and collision in the Al Amar-Idsas region, Arabian Shield, Kingdom of Saudi Arabia. Tectonophysics, 30, T41-T47.

Al-Shanti, A.M.S. and Roobol, M.J. 1979: A late Proterozoic ophiolite complexs at Jabal Ess in northern Saudi Arabia. Nature, 279, 488-91.

Asrie, N. A., & Sebhat, M. Y. (2016). Numerical groundwater flow modeling of the northern river catchment of the Lake Tana, Upper Blue Basin, Ethiopia. Journal of Agriculture and Environment for International Development, 110(1), 5–26. https://doi.org/10.12895/ jaeid .20161.380

Aswathanaraya U., 2005: Advances in Water Science Methodologies, 251p.

Babiker, I. M. 1977: Aspect of the ore geology of Sudan. Thesis, PhD, Univ. Cardiff. 227 pp.

Bakor, A.R., Gass, I.G. and Neary, C.R. 1976: Jabal Al Wask, northern Saudi Arabia: An Eocambrian back-arc ophiolite. Earth Planet. Sci. Lett., 30, 1-9.

Balek, J. 1989: Groundwater Resources Assessment,251p.

Bentor, Y.K. 1985: The crustal evolution of the Arabian-Nubian massive with special reference to the Sinai Peninsula. Precambrian Res., 28, 1-74.

Berhanu, K. G., & Hatiye, S. D. (2020). Identification of Groundwater Potential Zones Using Proxy Data: Case study of Megech Watershed, Ethiopia. Journal of Hydrology: Regional Studies, 28. https://doi.org/10.1016/j.ejrh.2020.100676

Biro, K, Pradhan, B, Buchroithner , F and Makeschi ,N, (2013), "Land Use/Land Cover Change Analysis and its Impact On Soil Properties in Gedarif Region, Sudan" , Journal of Land Degradation and Development 24(1), DOI: 10.1002/ldr.1116.

Bodegom, A. J. van, Gebremedhin, E., Linden, N. van der, & ... (2018). Report on the Nexus Humera case study in Ethiopia: Dutch Climate Solutions research programme. Retrieved from https://library.wur.nl/WebQuery/wurpubs/fulltext/477239

Brown, G.C., 1980: Calc-alkaline magma genesis: The Pan-African contribution to crustal growth. In: Alshanti, A. M. S. (ed.). Evolution and mineralization of the Arabian-Nubian Shield. IGA Bull. 3, 3, 19- 29.

Bussert, R. 1998: Die Entwicklung intrakratonaler Becken im Nordsudan. Berliner geowissenschaftliche Abhandlungen, Reihe A 196, 329pp.

Bussert, R., & Dawit, E. L. (2009). Unexpected diversity: New results on the stratigraphy and sedimentology of Palaeozoic and Mesozoic siliciclastic sediments in Northern Ethiopia. Zentralblatt Für Geologie Und Paläontologie, Teil I, 3(4), 181–198.

Calow, R. C., MacDonald, A. M., Nicol, A. L., & Robins, N. S. (2010). Ground water security and drought in Africa: Linking availability, access, and demand. Ground Water, 48(2), 246–256. https://doi.org/10.1111/j.1745-6584.2009.00558.x

Campbell, J. B. 1987: Introduction to remote sensing. New York, NY: Guilford Press. 551 p.

Chernet, T. (1993). Hydrogeology of Ethiopia and Water Resouces Development. Addis Ababa.

Chialvo, J. 1975: Contribution a la geologic du confluent Atbara Setit; Unpublished thesis, University of Grenoble, France.

Cramez, C. and Colo, J. F. 1984: Onshore Sudan, Gedaref area. Total-C.F.P., P6500/001, TEP/DE/GPH, Unpublished report.

CSA-Central Statistical Agency. (2011). Federal Democratic Republic of Ethiopia Central Statistical Agency. Agricultural sample survey report on livestock and livestock characteristics. STATISTICAL BULLETIN 2 (505), Addis Ababa, Ethiopia. Addis Ababa, Ethiopia.

Cuthbert, M. O. (2019). Groundwater reserves in Africa may be more resilient to climate change than first thought.

D.C. Van Enk (1978) Water Resources of the Gedaref Area.

Eisawi, A. and Schrank, E. 2009: Terrestrial palynology and age assessment of the Gedaref Formation. J. Afri. Earth Sci, 54, p. 22-30.

Eljah, M. A. 2008: Geology and geochemistry of El Tuwal ophiolitic complex and environs-East Central Sudan, 200p.

Elshafie, R.A: Lithology of UmRuwaba formation and its paleogeography in connection with water problem. Ph.D.Thesis.(In Russian).

Fitches, W. R., Graham, R. H., Hussein, I. M., Ries, A. C., Shackelton, R. M. and Price,

Gani, M. R. 2008: Stratigraphic and structural evolution of the Blue Nile Basin, Northwestern Ethiopia.

Garson, M. S. and Shalaby, I. M. 1976: Precambrian-lower Palaezoic plate tectonics and Metallogenesis in the Red Sea region. Geol. Assos. Canada, Spec. Paper, 14, 573596.

Gebremicael, T. G., Mohamed, Y. A., Zaag, P. V., & Hagos, E. Y. (2017). Temporal and spatial changes of rainfall and streamflow in the Upper Tekezē-Atbara river basin, Ethiopia. Hydrology and Earth System Sciences, 21(4), 2127–2142. https://doi.org/10.5194/hess-21-2127-2017

GRAS, the Geological Research Authority of Sudan, 2004. Geological map of the Sudan, scale 1:2000, 000, Khartoum. 10-Al, state of Algoas, Brazil. Pollen et Spores 17, 93 - 140.

Huscroft, J., Gleeson, T., Hartmann, J., & Börker, J. (2018). Compiling and Mapping Global Permeability of the Unconsolidated and Consolidated Earth: Global

Hussein, M. T. and. Adam, E. G. 1995: Water quality of the Gedaref basin, Sudan, Hydrological Sciences, 40, 2, p. 205-216.

Ibrahim, K. E. M. T. Hueeein and Gidoo, I. M. 1992: Application of combined geophysical and hydrogeological techniques to groundwater exploration. A case study of Showak-Wad Elhelew area, eastern Sudan.

James, M. 1983. Gedaref Water Supply and Solid Waste Disposal Feasibility Study- Sudan. A.I.D; United State Agency for International Development; Published report, 203p.

Kazmin, V. 1976: Ophiolites in the Ethiopian Basement. Ethiopian Inst. Geol. Surv. Note 35.

Kazmin, V., Shifferaw, A. and Balcha, T. 1978: The Ethiopian Basement: stratigraphy and possible manner of evolution. Geol. Resch., 67 (2), 531-546.

Kebede, S., Hailu, A., Crane, E., Ó Dochartaigh, B.É and Bellwood-Howard, I. (2018). Africa Groundwater Atlas: Hydrogeology of Ethiopia. British Geological Survey.

Khairalla, M. K. 1966: Study of the Nubian Sandstone Formation of the Nile Valley between the 14 N and 17 42 N with reference to the ground water geology. M. Sc. thesis, 283pp, University of Khartoum.

Khalaf Alla, O. M. and. Osman, M. A. 1986: Gedaref Water supply intake siltation problem. International conference on Water resources needs and planning in drought prone areas, Khartoum. p. 315-322.

Kheir OM. 1981. Contribution to the hydrogeology of the Gefaref Basin, Eastern Sudan. MSc Thesis, University of Khartoum

Kheiralla M. Kheiralla (1984), Summary of Groundwater Geology in Sudan.

Kroner, A. 1985. Ophiolites and the evolution of tectonic boundaries in the late Proterozoic Arabian - Nubian Shield of northeast Africa and Arabia. Precambrian Res.

Leta, S., & Mesele, F. (2014). Spatial analysis of cattle and shoat population in Ethiopia: Growth trend, distribution and market access. SpringerPlus, 3(1), 1–10. https://doi.org/10.1186/2193-1801-3-310

MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. É. Ó., & Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. Environmental Research Letters, 7(2). https://doi.org/10.1088/1748-9326/7/2/024009

Mengesha Admasu, A. K. and M. F. (2004). Sustainable Drinking Water Project In Dhana.pdf. Ethiopian Journal of Health Development.

Merem, E. C., Twumasi, Y. A., Wesley, J., Olagbegi, D., Crisler, M., Romorno, C., … Leggett, S. (2020). Issues in Transboundary Water Use in the River Nile Basin Area of Africa. World Environment, 10(2), 27–44. https://doi.org/10.5923/j.env.20201002.01

Merla, G., Abbate, E., Canuti, P., Sagri, M., & Tacconi, P. (1973). Geological Map of Ethiopia and Somalia, 1:2,000,000. In Consiglio Nazionale delle Ricerche Italy. Italy.

Michael 1979. Remote Sensing Applications Guide, Planning and Management Guide. 217p.

Mirghani, M. 2002: Concepts and Models for the Characterization of the West Gedaref Hydrogeologic System, Sudan.

MoARF (Ministry of Animal Resources and Fisheries (2006), Statistical Bulletin for Animal Resources, Issue No. 15-16, General Administration for Planning and Economics of Animal Resources, Animal Resources Economics Administration, Khartoum.

MoWR. (2002). Water sector development program 2002-2016. In The Federal Democratic Republic of Ethiopia.

Mula, A. G. and Omer M. K. 1983: A geophysical survey in Gedaref area. Unpublished Report, University of Khartoum.

Muna M. and Hussein M. (2017), "Rainfall Erosivity, Land-Use and Land-Cover Change Analysis for Gedarif Region, Sudan", International Journal of Water Resources and Arid Environments 6(2): 252-260, 2017, ISSN 2079-7079.

Nash. H.G (1979), Review of Hydrogeological and Groundwater Resources Studies in the Sudan.

National Water Corporation (2008). Sudan WASH Sector Country Status Overview, 2009-2010 International year of WASH in Sudan

Omer, M. K. 1978: Geologie des gres de Nubie du Soudan Central, Oriental et Septentrional. Genese, diagenese et paleogeographic. These, Universite Grenoble, France.

Pavelic, P. (2012). Groundwater availability and use in Sub-Saharan Africa: a review of 15 countries. In Groundwater availability and use in Sub-Saharan Africa: a review of 15 countries. https://doi.org/10.5337/2012.213

R. C., 1983. The Late Proterozoic ophiolite of the Sol.

Rekha, V. B., Thomas, A. P., Suma, M., & Vijith, H. (2011). An Integration of Spatial Information Technology for Groundwater Potential and Quality Investigations in Koduvan Ár Sub-Watershed of Meenachil River Basin, Kerala, India. Journal of the Indian Society of Remote Sensing, 39(1), 63–71. https://doi.org/10.1007/s12524- 010-0050-6

Richts, A., & Vrba, J. (2016) Groundwater resources and hydroclimatic extremes: mapping global groundwater vulnerability to floods and droughts. Environmental Earth Sciences, 75(10). https://doi.org/10.1007/s12665-016-5632-3

Sachse, A., Jakobs, L., & Kolditz, O. (2015). Hydrogeology. https://doi.org/10.1007/978-3-319-13335-5_2

Saghayron, E. 1996. Gedaref Water, Assessment of the current situation and future demands. Unpublished report, Ministry of Engineering affairs, The Gedaref State.

Seifu A. Tilahun, Amy S. Collick, M. A. (2010). Project of Learning and Communication of Water supply, Sanitation and Hygiene (WaSH) of Amhara region. Bahir dar.

Shigidi, A., Abdo, G. and Omer, M. (2021). Groundwater Assessment in Toker aquifer, Regional Water Harvesting Centre, Khartoum, Sudan

Singhal B.B.S and R.P Gupta 1999: Applied Hydrogeology of Fractured Rocks, Second Edition, 429p.

Stern, R.J. 1994: Arc assembly and continental collision in the Neoproterozoic East African Orogen: implications for the consolidation of Gondwanaland. Ann. Rev. Earth Sci., 22, 319.

Tadesse, K. (2004). Strategic planning for groundwater development in Ethiopia. Proceedings of the International Conference and Exhibition on Groundwater in Ethiopia: From May, 25-27 2004. Addis Ababa, Ethiopia: Proceedings of the International Conference and Exhibition on Groundwater in Ethiopia.

Tadesse, S., Milesi, J. P., & Deschamps, Y. (2003). Geology and mineral potential of Ethiopia: A note on geology and mineral map of Ethiopia. Journal of African Earth Sciences, 36(4), 273–313. https://doi.org/10.1016/S0899-5362(03)00048-4

Teshome, B., Motuma T,b , Kefyalew, S., and Kassac, H., (2019), “Trends and drivers of land use/land cover change in Western Ethiopia”, Journal of Applied Geography, Volume 104, Pages 1-94

The Federal Democrative Republic of Ethiopia. (2012). Growth and Transformation Plan (2010/11-2014/15). Addis Ababa, Ethiopia.

Tothill J.D. (ed.) (1948). Agriculture in the Sudan: A Handbook of Agriculture as Practiced in the Anglo-Egyptian Sudan. London: Oxford University Press.

UNEP (2020), “Sudan First State of Environment and Outlook Report 2020”, UNEP real-time data tools and platforms.

Vail, J. R. 1978. Outline of the geology and mineral deposits of the Democratic Republic of the Sudan and adjacent area. Overseas Geology and Mineral Resources. IGS, London, 49, 68 pp.

Warden, A. J., Kazmin, V., Kiesl, W. and Pohl, W. 1982: Some geochemical data of the mafic-ultramafic complex of the Tulu Dimitri, Ethiopia, and their genetic significance. Ost. Akad. Wiss., Math.- naturw. 191, 11-131.

WEDC. (2005). Domestic water suppl. in watsan.

Weldegerima, T. M., Zeleke, T. T., Birhanu, B. S., Zaitchik, B. F., & Fetene, Z. A. (2018). Analysis of Rainfall Trends and Its Relationship with SST Signals in the Lake Tana Basin, Ethiopia. Advances in Meteorology, 2018. https://doi.org/10.1155/2018/5869010

White Man, A. J. 1971: The geology of the Sudan Republic, Clarendon press Oxford. Wipki, M. 1995: Eigenschaften, Verbreitung und Entstehung von Kaolinlagerstatten im Nordsudan, Wissenschaftliche Schriftenreihe Geologie und Bergbau, Band 2.

Winter, T. C., Harvey, J. W., Franke, O. L., & Alley, W. M. (1998). Ground Water and Surface Water A Single Resource: Introduction. In Ground Water and Surface Water A Single Resource - U.S. Geological Survey Circular 1139.

Wipki, M., Germann, K., and Schwarz, T. 1993: Alunitic kaolins of the Gedaref region (NE Sudan). In: Thorweihe, U., Schandelmeier, H. (Eds.), Geoscientific Research in Northeast Africa, pp. 509-514.

World Health Organization and UNICEF. Progress on Drinking Water and Sanitation (2012) Update. United States: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation; 2018.

WRC (2017). Catchment Mapping of Water Resources Assessment in Darfur Region, UNEP, Sudan.

10.ANNEX 1: PROPOSED TRAINING COURSES

10.1. Proposed Training Course on Regional Groundwater Modeling

10.1.1. Background

One of the most important tools used for groundwater management is groundwater modeling. Modelling has played and will continue to play a great role in understanding the groundwater system and the flow dynamics within it and to solve many problems that are most critical to groundwater management. An important component of this SADA study is to develop a regional groundwater model for the Gedaref-Adegrat aquifer to provide a technical basis for evaluating trans-boundary risks. The model will be used to investigate the consequences of different management scenarios for the aquifer with focus on the trans- boundary impacts and risks. The modelling results could be used as a basis for a trans-boundary agreement for win-win sustainable aquifer utilization between Sudan and Ethiopia. A most widely used groundwater modelling software that has proved to be very effect in groundwater planning and management is MODFLOW. MODFLOW is very useful for good understanding of the groundwater system and its response to the proposed actions. This enables the decision-maker, to compare alternative management scenarios and hence the optimum decisions could be selected.

It has been highlighted in this study that there is lack of technical capacity in groundwater modeling in Sudan and Ethiopia. Consequently, groundwater modeling has been endorsed as one of the top priority areas for training and capacity building.

Course Duration and Contents

The course duration is 60 hours, 10 working days at 6 hours daily. Details of the course contents is given below;-

10.1.2. Mathematical Formulation of Groundwater Flow

- Explanation of the Groundwater flow equation.
- Involved parameters.
- Solution process using Finite Difference including discretization. Model formulation.
- model parameter substitution,
- Inclusion of boundary conditions and model solution.

10.1.3. Over view of Modflow and Formulation of Conceptual Models

- How to generate a conceptual model for a real world problem from available geological, hydrological and geological data.
- Features of Modflow and its capabilities.

10.1.4. Introduction to GIS and Data preparation for the Model

- What is GIS and how to use GIS for data input and display
- Data Display and Data Types (Vector, Raster, DXF….)
- Data conversion (Conversion form one data format to another)
- Basic Raster Data Analysis (With focus on DEMs)
- Basic Vector Data Analysis.
- ArcGIS/Modflow interface
- Preparation of data Layouts

10.1.5. Data Input to Modflow

- Aquifer Geometry
- Aquifer Layers
- Aquifer Parameters
- Aquifer stresses
- Aquifer Recharge
- Boundary Conditions

10.1.6. Model Processing using Modflow

- Solution of Steady and Transient Cases
- Defining Model Solution Options
- Model Output Display and Interpretation
- Mesh Refinement and Solution Convergence.
- Practical training

10.1.7. Model Calibration

- Calibration process
- Practical training

10.2. Proposed Training Module on Groundwater Monitoring

10.2.1. Introduction

Groundwater systems are dynamic and adjust continually to short-term and long-term changes in groundwater abstraction, climate and land use changes. Therefore regular and systematic monitoring of groundwater is necessary for its effective and sustainable management. Water-level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge. Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time, to develop ground-water models and forecast trends, and to design, implement, and monitor the effectiveness of ground-water management and protection programs.

This study reveals that systematic monitoring of groundwater quantity or quality in the Gedaref-Adegrat aquifer does not exist even at a local scale. Lack of monitoring may result in undiscovered problems such as declining groundwater levels and depletion of groundwater reserves, reductions in stream/spring base flows or flows to sensitive ecosystems such as wetlands, deterioration of groundwater quality and increased costs for pumping and treatment. The study also reveals a great gap in the human resources monitoring capacity. Accordingly, groundwater monitoring has been identified as of the priority areas of training and capacity building.

10.2.2. Course Duration and Contents

The course duration is 40 hours. The proposed course deals with various aspects of groundwater monitoring including:

- Groundwater monitoring objectives and types
- Trans-boundary groundwater monitoring
- Ecosystem monitoring
- Design of monitoring network and monitoring wells
- Monitoring parameters and methods of measurements including frequency of measurements
- Water quality sampling procedure
- Data quality assurance
- Data processing and reporting
- Field measurement exercises.

10.3. Proposed Training Course on Water Harvesting (WH) and Management of Artificial Recharge (MAR)

10.3.1. Introduction

Water harvesting (WH) and management of artificial groundwater recharge (MAR) have been identified as one of the priority areas for training and capacity building in the study aquifer. The technique is now receiving growing awareness and considerable worldwide attention as most suitable, practical and economical means to bridge the gap between water needs and available supply in many regions, in particular arid and semi-arid regions of the world . In addition to water supply augmentation, WH and MAR can also have great potential in protecting the natural environment from degradation. Due to the significant importance of the subject, many regional and international organizations are taking leading role in fostering the use of WH and MAR techniques and enhancing training and capacity building programs in the subject.

The available potentialities of the technique in the study area are great and promising where there are many alluvial aquifers underlying seasonal river systems. The present study revealed that the current natural recharge to the aquifer is only about 4 mm/year compared to about 500 mm/year of annual surface runoff (rainfall – evapotranspiration). In view of the current huge gap in water supply in the study area, coupled with the expected increase in demand due to population growth as well as climate change impacts, augmentation of the available water resources through WH and MAR is necessary.

10.3.2. Course Contents and Duration

The proposed training course will have a duration of 40 hours and will deals with various aspects of WH and MAR including:

- Studies needed for WH and MAR projects
- Meteorological investigations
- Hydrological investigations
- Hydrogeological studies
- Soil infiltration studies
- Topographic surveying
- Assessment studies using tools such as infiltration experiments, modelling, and use of RS/GIS techniques
- Planning of WH and MAR Schemes

- WH and MAR Techniques and Designs.
- Economic Evaluation of WH and MAR Schemes
- Monitoring and Impact Assessment.
- Operation and Maintenance
- Case studies
- Exercises