PAU Institute for Water and Energy Sciences (incl. Climate Change)

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Master Dissertation

Submitted in partial fulfillment of the requirements for the Master degree

in

Water Engineering

Presented By

Seifeldin Ahmed Mohamed Abdalla

Developing a Technique for Rainwater Collection from Rooftops to Alleviate the Water Shortages in Nyala City, Sudan

Defended on

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By

Seifeldin Ahmed Mohamed Abdalla

April, 2024

DEDICATION

“Success is not the result of a single person's efforts, but a tapestry woven by the support, guidance, and love of many”

I dedicated this work to:

my dear mother in loving of memory, your presence in my life was a blessing, and your love and guidance will forever be cherished, rest in peace.

my great father, thank you for being a pillar of strength for me and family during this difficult time.

my brother Osman Ahmed for unconditional support and love you are my pillar. my loving family, whose unwavering support and encouragement have been a constant source of inspiration throughout this journey.

DECLARATION

I, **Seifeldin Ahmed Mohammed Abdalla**, solemnly declare that this thesis is the result of my original and independent research work. To the best of my knowledge and belief, it represents my own personal effort and does not contain any plagiarized content. I further affirm that any data, materials, or findings obtained from other publications and sources, which have been used in this thesis, have been duly acknowledged and referenced in accordance with the accepted academic standards and guidelines. I take full responsibility for the accuracy, integrity, and authenticity of the information presented in this thesis. Furthermore, I understand the consequences of any misconduct or violation of academic ethics and assure that this work has been conducted with the utmost honesty and sincerity.

Seifeldin Ahmed Mohammed Abdalla		22th, March, 2024
Student	Signature	Date

Certified by:

Prof. Abdelkrim Khaldi	Khaldi	22th, March, 2024
Supervisor	Signature	Date

ABSTRACT

Water scarcity and access to safe drinking water are pressing global challenges aggravated by climate change. This research addressed the specific case of Nyala City in West Sudan, where water shortages occur during the summer due to declining groundwater levels. The study was aims to develop a comprehensive rainwater harvesting system as a potential solution to alleviate water scarcity in the city. The research objectives involved investigating the social and cultural factors that influence the acceptance and adoption of rainwater collection, designing an efficient sand filtration system to ensure water quality, evaluating the effectiveness of the filtration system in eliminating contaminants and pathogens, and analyzing the economic viability of implementing the proposed system. Data for this study were collected through structured questionnaires and interviews conducted with the local community experiencing water scarcity and the relevant staff of the Water Corporation responsible for water supply. Additionally, rainfall data spanning the period of 2011-2020 were obtained from Climatic Research Units (CRU data) and Nyala Shape file from Data-Interpolating Variational Analysis Geographic Information System (DIVA-GIS). The research findings indicate significant variations in rainfall patterns across different regions of Nyala City. These findings were instrumental in informing the design of the rainwater harvesting system, which incorporates five filtration layers, including coarse sand, charcoal, and gravel, to effectively filter and enhance the quality of collected rainwater. To provide practical insights, two case studies were presented: Elshahid Hamza Basic School and a residential house. These case studies illustrated the layout and components of the rainwater harvesting system, emphasizing the integration of plastic tanks and PVC pipes for efficient collection, storage, and distribution of rainwater. Furthermore, calculations were performed to estimate the annual water harvesting potential for the case study buildings based on the roof area and average rainfall. The economic viability of the proposed rainwater harvesting system was analyzed, taking into account the costs associated with materials, installation, and maintenance.

Key words:

water scarcity, sand filtration, rainwater harvesting system, social factors, economic viability

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I would like to extend my sincere thanks to the participants who willingly shared their time and insights through questionnaires and interviews, providing valuable data and perspectives that greatly enriched this research. Lastly, I am deeply grateful to my family, colleagues, friends for their unwavering love, understanding, and encouragement. Their constant support and belief in my abilities have been a source of inspiration and strength. I acknowledge and appreciate the contributions of all individuals and organizations mentioned above.

However, any errors or shortcomings in this research are solely my responsibility. Thank you all for your invaluable contributions and support in making this research project possible.

LIST OF ABBREVIATIONS

AM	Abstraction Million
BCM	Billion Cubic Meter
BIM	Building Information Modeling
BSMY	Basin Storage Million Year
CAD	Computer-Aided Design
CM	Centimeter
CRU	Climatic Research Units
DIVA	Data-Interpolating Variational Analysis
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
IDW	Inverse Distance Weighted
KM	kilometers
MSL	Mean Sea Level
NETCDF	Network Common Data Form
PPM	Part Per Million
PVC	Polyvinyl Chloride
PAR	Percentage of Abstraction to Recharge
USD	United State Dollars
UM	Underflow Million
RWH	Rainwater Harvesting
RWHS	Rainwater Harvesting System
SDG	Sudanese Pound
RM	Recharge Million
SAR	Sodium Adsorption Ration
2D	Two Dimensional

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CHAPTER (1)

1 . INTRODUCTION

1.1 Background Information

Rainwater harvesting has been practiced for thousands of years in various parts of the world, serving as a simple and time-tested technique to meet residential water requirements [1]. This method involves collecting rainwater from a roof-like surface and storing it in tanks, cisterns, or reservoirs. Recognized as one of the oldest and most straightforward approaches to ensure a local water supply, rainwater harvesting has been widely adopted in South Asia and many other nations [2]. However, the pressing challenges of water scarcity and safe drinking water access have gained global attention due to the changing climate and the precarious state of water resources. Sudan, like many other countries, faces these critical issues. In Nyala City, located in West Sudan, water shortages intensify during the summer months. This situation arises from multiple factors, including the continuous pumping of groundwater to meet the city's demands, rising temperatures leading to increased evaporation exacerbated by climate change, and the lack of alternative water resources such as surface water or desalinated water. Moreover, the available groundwater is under mounting pressure due to domestic, irrigation, construction, and livestock use. The community also lacks awareness and education on water conservation and its crucial role in achieving sustainability[3], [4]. The research approach focuses on collecting rainwater from rooftops as a means to alleviate the water shortages. In addition to the technical aspects, the study will investigate the cultural acceptance of this proposed system, design and develop an efficient sand filtration system for rainwater, and analyze the economic viability of its implementation. The economic assessment will consider the costs associated with sand filtration and evaluate the potential economic benefits for the community. By undertaking this research, the study seeks to contribute not only to resolving Nyala City's water crisis but also to the broader understanding of rainwater harvesting techniques, cultural factors influencing their adoption, and the economic considerations associated with their implementation. Through community engagement and the integration of innovative technologies, this study aspires to establish a model for sustainable water resource management that can be replicated in similar regions.

1.2 Problems Statement:

As a result of the ever-changing climate and the precarious state of water resources, global challenges arising from water scarcity and access to safe drinking water have emerged. Sudan is one of many nations currently grappling with these pressing issues. Particularly in Nyala

City, West Sudan, during the summertime, people face water shortages as a result of decreasing groundwater levels due to continued pumping of groundwater to meet the needs of the city. Increased temperatures are caused by increased evaporation and are influenced by climate change. Lack of access to alternative water resources such as surface water river, desalinated water, and increasing pressure on available groundwater for domestic, irrigation, construction, and livestock use. Lack of awareness and education in the community about water conservation and its importance for sustainability.

1.3 Acknowledge Gap:

These previous works were very clear about rainwater harvesting from rooftops and discussed the must-have sides of rooftops, starting with catchment area, slope, rooftop types, and materials. Something that was not discussed deeply, the filtration system of collecting rainwater, how it looks, what type of use it has, and the efficiency of it in removing contaminants, was taken as a research gap.

1.4 Main Objective:

The main goal of this study is to develop a technique for collecting rainwater from rooftops in order to alleviate the water shortages in Nyala City.

1.4.1 Specific Objectives:

- To Investigate the cultural acceptance of this proposed system by considering community perceptions of water quality sources for drinking water.
- To Design and develop harvesting equipment with a sand filtration system for rainwater that is collected directly from rooftop houses.
- To Evaluate the effectiveness of the sand filtration system in eliminating contaminants and pathogens from rainwater collected.
- To Analyze whether implementing this system is economically viable by considering costs associated with sand filtration and potential economic benefits for the community.

1.5 Research Questions:

- What are the social and cultural factors that may influence the acceptance and adoption of the rainwater collecting from rooftops?
- What are the key design considerations for developing an efficient and effective sand filtration system for rainwater collected from a house's roof?

- How successful is the sand filtration system in eliminating contaminants and pathogens from rainwater collected from a house's roof, and what are the factors that affect its effectiveness?
- What are the economic costs associated with designing, developing, and implementing the sand filtration system for rainwater collection?

1.6 Working Hypothesis

- Social and cultural factors significantly influence the acceptance and adoption of rainwater collection from rooftops.
- There are specific key design considerations that significantly affect the efficiency and effectiveness of a sand filtration system for rainwater collected from a house's roof.
- The sand filtration system is successful in eliminating contaminants and pathogens from rainwater collected from a house's roof.
- The economic costs associated with designing, developing, and implementing harvesting equipment with the sand filtration system for rainwater collection are significant and may vary based on certain factors.

1.7 Significance of the study

The significance of this study is highly relevant because it focused on addressing critical water scarcity issues, adapting to the local context, considering cultural factors, and exploring technological and economic aspects. It aligned with the urgent need for sustainable water solutions in Nyala City while offering insights that can be valuable to researchers, policymakers, and communities facing similar challenges worldwide. The purpose of this study was to develop a technique for collecting rainwater from rooftops in order to alleviate the water shortages in Nyala City.

1.8 Scope and Limitations of the Research

As a limitation, it is important to acknowledge the significant impact of the ongoing conflict in the country on research activities and data accessibility. The inherent instability and safety risks arising from the conflict have posed considerable challenges to conducting research effectively. Also, Researcher have faced difficulties in accessing reliable and up-to-date data, which can potentially compromise the accuracy and validity of their findings. Furthermore, the stabilization of material prices used in rainwater due to the war can limit the ability to obtain necessary resources for research purposes.

CHAPTER (2)

2 Literature Review

This research presents a comprehensive plan for collecting rainwater from rooftops in order to alleviate the water shortages in Nyala City. Here are some previous papers that dealt with a similar topic:

2.1 Previous works related to this topic

[1] This paper presents a method for evaluating the performance of catchment areas under both average historical rainfall conditions and a severe (El Nio-induced) drought. The survey data from Ifalik's rainwater catchment can be used to gain insights into the performance and reliability of the systems, such as by running a daily water balance model to estimate the performance of the systems under another severe drought, and constructing design curves that provide combinations of roof catchment area and tank volume that satisfy a specified level of reliability. The paper also provides ideas about how these systems might perform under drought conditions. The paper provides design curves that can be utilized to assess the reliability of the system in meeting the water needs of the community. The paper also shows other methods for constructing design curves for the rest of the regions.

[5] the research it provides a detailed analysis of sustainable water management involving rooftops as catchment areas. It provides data on Indonesia's average annual rainfall, especially Jakarta, and discusses the potential for rainfall harvesting. The materials, slope and size of the roof of the rainwater harvesting system are also discussed, and the impact of the rainfall intensity on the roof area as a catch area is also studied. At the end of the day, this paper provides the advantages and disadvantages of using the roof as a rainwater basin, as well as recommendations for future sustainable water management.

[6] this research detailed description of the climate of the study area, the discussion of the common rainwater harvesting techniques used in Ghana, the identification of the issues and challenges of implementing RWH in Ghana, the analysis of the influence of different types of house occupancy on RWH, the examination of the impact of inaccurate land boundaries on RWH, the evaluation of the quality of water produced through RWH systems, and the conclusions and recommendations drawn from the study.

[7] This article started by developing a method to calculate the roof runoff coefficient at the residential plot level, which involves a simple random sampling, a supervised classification of the roof types, and the calculation of the predominant roof type. Utilizing GIS techniques to

look at the spatial distribution of rainwater catchment potential, using the Getis-Ord General G spatial association statistic. discussing the economic and environmental viability of RWHS, as well as the factors that influence the profitability of their installation. suggesting that only 17.7% of the rainwater collection potential is located in hot-spot areas, and that the installation of RWHS in single-family housing is easier and offers more potential uses. demonstrating that the increase in water prices in Mediterranean coastline municipalities, due to compliance with the cost recovery principle of the Water Framework Directive, will enable reducing the amortization period of RWHS.

[8] the articles Firstly, it provides a detailed overview of the current water scarcity situation caused by rapid urbanization and proposes a viable solution in the form of rainwater harvesting and storm water harvesting from runoff. Also, in the methodology for designing a rooftop rainwater harvesting system, including how to identify the catchment area, calculate the total water demand and rainwater harvesting potential, and select the appropriate components of the system. Thirdly, it uses a rational formula to calculate the runoff coefficient, which is taken from the manual of artificial recharge of ground water, Government of India Ministry of Water Resource Central Ground Water Board. Finally, the paper provides detailed analysis of the design of a recharge well, including how to determine the concentration time and the maximum amount of water stored in a recharge well in the longest rainfall period.

[9] this paper provides overview of the water situation in Odisha, as well as the benefits of implementing a rainwater harvesting system. It also detailed the filter units used in the evaluation and explained the data collection process in catchment areas. Also contains a detailed analysis of the data collected, and provides results and discussion on the design of rooftop rainwater harvesting in Gandhi Institute for Technology. Finally, he outlines the necessary steps to ensure clean water supply, and tests the water quality to ensure it meets World Health Organization guidelines.

[10] the author of this paper start by analysis of the potential of rainwater harvesting in Jordan, its use of data from population census and population growth rate to create three scenarios by which Jordan's population numbers in 2025 and 2030 were predicted, its calculation of the optimal tank size for total demand per household and flushing consumption, its estimation of the total cost of the optimal tanks for each governorate, its calculation of the potential water harvesting in the Swieleh District of Amman Governorate using an equation, its approximation of the total cost of installing a rainwater harvesting system for a hypothetical building, its

discussion of the potential benefits of rooftop rainwater harvesting, and its implications of the costs associated with rooftop rainwater harvesting for water supply management.

[11] the article firstly started by installed a rainwater harvesting system on the roof of the Dhaanish Ahmed College of Engineering. It includes data from weather reports and NASA's climate survey to accurately calculate the average annual rainfall for the campus region. It also provides an analysis of the runoff coefficient value and the total water demand of the college. Furthermore, it outlines the two main rainwater harvesting techniques, surface runoff harvesting and rooftop, and the components of consideration for rainwater harvesting such as the catchment area and carrying capacity of the system, as well as the climatic range, the cost of open water, the area and height of the buildings, the calculation of discharge, the time of concentration, and the pressure filters. Finally, it provides a conclusion that the Dhaanish Ahmed College of Engineering, Chennai campus could store a total of 58,427.43 m3 of water throughout the year, eliminating water shortages during the dry months when the monsoons don't arrive.

[12] this paper discusses the implementation of a rainwater harvesting technique for Chhadvel Korde Village in Maharashtra. The paper offers a top-stage view of the strategies, design, and effect of rainwater harvesting systems accomplished at some stage in the world and cites. many studies on the implementation of water harvesting strategies in one-of-a-kind elements of the arena. Additionally, this paper affords a populace evaluation of the village’s preservation and facility requirements and describes the techniques for collecting data on rainfall for Chhadvel Korde Village. Moreover, the paper elaborates on the layout of the pipes that might be used for rainwater harvesting technique implementation and describes the benefits of rainwater harvesting implementation and percolation pits within the village.

[13] this paper first of all, it proposes the usage of low-effect development and rainwater harvesting systems to gather roof runoff for garage and deliver, as well as to reduce runoff and offer smooth and drinkable water. Secondly, it highlights the want for cultural reforms and recognition to elevate public information approximately the need of water conservation and safety. Thirdly, it emphasizes the importance of know-how quit-person prioritizing alternatives in responding to growing water constraints and scaling up change water shipping systems. Fourthly, it discusses the fee of installing a rainwater harvesting machine and how it could quickly be recovered in 3 to four years. Finally, it discusses the ability of rainwater harvesting and its sustainability, as well as the want for government subsidies to improve machine accessibility and infection prevention or treatment systems for RWH.

[2] the paper includes a comprehensive analysis of the motivations and aims of Rooftop Rainwater Harvesting (RRWH) of BIET Campus -Lucknow, the discussion of traditional knowledge, skills, and materials used for the system, an evaluation of the feasibility of a rainwater harvesting system, an examination of the essential components necessary for successful implementation, a discussion of filter design to improve efficiency and efficacy, and calculations to accurately account for the expected volume of collected water. Additionally, the paper has drawn on other research to enable its findings, and it has provided a future direction or recommendation for increased awareness and adoption of rainwater harvesting systems.

2.2 Description of Sudan

Sudan is a country in northeastern Africa located between longitudes 22–38° East and latitudes 10–22° North. It’s bordered from north by Egypt, on the east by the Red Sea, Eritrea, and Ethiopia, on the south-by-South Sudan, on the west by the Central African Republic and Chad, and on the northwest by Libya represented in figure 2-1, [14]. After Algeria and the Democratic Republic of the Congo, it is the third biggest country in Africa with a landmass of 1.88 million km2. Prior to South Sudan's 2011 separation, which resulted in a 24.7% reduction in its land area, Sudan was the biggest country [15]

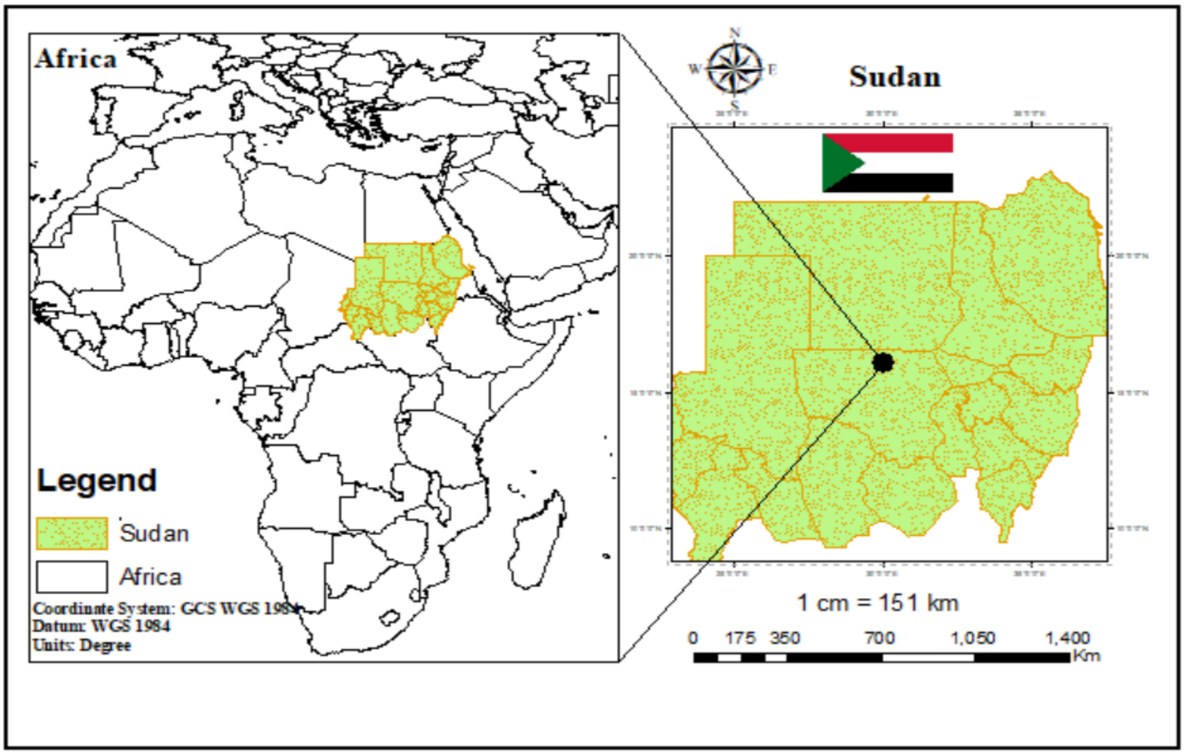


Figure 2- 1: Sudan Map

2.3 Water resources in Sudan

Sudan has an abundance of water resources, including groundwater, rainfall, and the Nile system. An estimated 84 billion m³ of surface water resources are available, with yearly rainfall ranging from nearly nonexistent in the desert, scorching north, to over 1600 mm in the tropical south. The total quantity of groundwater is estimated to be 260 billion m³, but only 1% of this amount is being utilized. Water-resources assessment in Sudan is not an easy challenge due to a lack of knowledge, a variety of degrees of freedom for the variables, poor measurements, and parameter uncertainty. However, Sudan could be divided into three regions based on seasonal water availability: (a) the rainy regions (equatorial tropical zones, which have water availability all year round; (b) areas with seasonal water availability; and (c) the areas with water deficits all year round, which make up more than half of Sudan[16]. Sudan has a variety of water resources, including groundwater and surface water. The Sudanese economy depends heavily on these resources for a number of industries, including home consumption, industry, and agriculture[17]. Also, water resources can be classified as conventional and non-conventional. Conventional water resources include surface water permanent rivers, seasonal streams, lakes, and khors, rainwater, and groundwater (renewable or fossil aquifers and permanent storage). Non-conventional water resources include reuse of sewage water, recycling of agricultural drainage water, and desalinization of seawater [18]

2.4 Conventional Water (surface water)

2.4.1 Rainfall

Rainfall has a significant impact on ecology and socioeconomics in Sudan, and there are two distinct seasons with high rainfall: the "Kireef" season in the summer and the "Hagay" season in the winter. Thermal uplifting occurs within slender conventional currents, resulting in clouds characterized by exceptionally heavy rainfall. These clouds have the remarkable ability to reach extraordinary heights and depths while their horizontal expansion remains limited. In tropical countries like Sudan, the primary rain-producing clouds belong to the vertically developing category, primarily cumulus and cumulonimbus types. Rainfall occurs either through isolated rainstorms or groups of rainstorms. In the latter case, numerous cumulonimbus clouds may align, forming distinct lines known as line storms or line squalls. Thermal uplifting leads the moist southwesterly winds to encounter the zone of upper easterlies, which move in opposition to the surface winds, initiating the northeastern lightning phenomenon locally referred to as "Abbadi. [17]. Sudan receives an estimated annual rainfall of approximately 440 billion cubic meters. The southernmost regions experience the highest rainfall rates, reaching around 800 mm per year. However, as we move towards the north, precipitation gradually decreases. The driest areas are found between Khartoum, where the annual rainfall is approximately 120 mm, and the border with Egypt, where rainfall is nearly nonexistent. In the northern part of Sudan, the rainy season is relatively short, and rainfall is sporadic and scattered. Generally speaking, the winter season lasts from November to April, while the summer season runs from May to October. Numerous variables, such as Sudan's terrain, geographic position, and the existence of multiple weather systems, affect the country's rainfall distribution[19] . The comparison of mean rainfall for the years 1990–2000, 2000–2010, and the long mean rainfall (1960–2010) in many areas in Sudan is displayed in Figure 2-2.

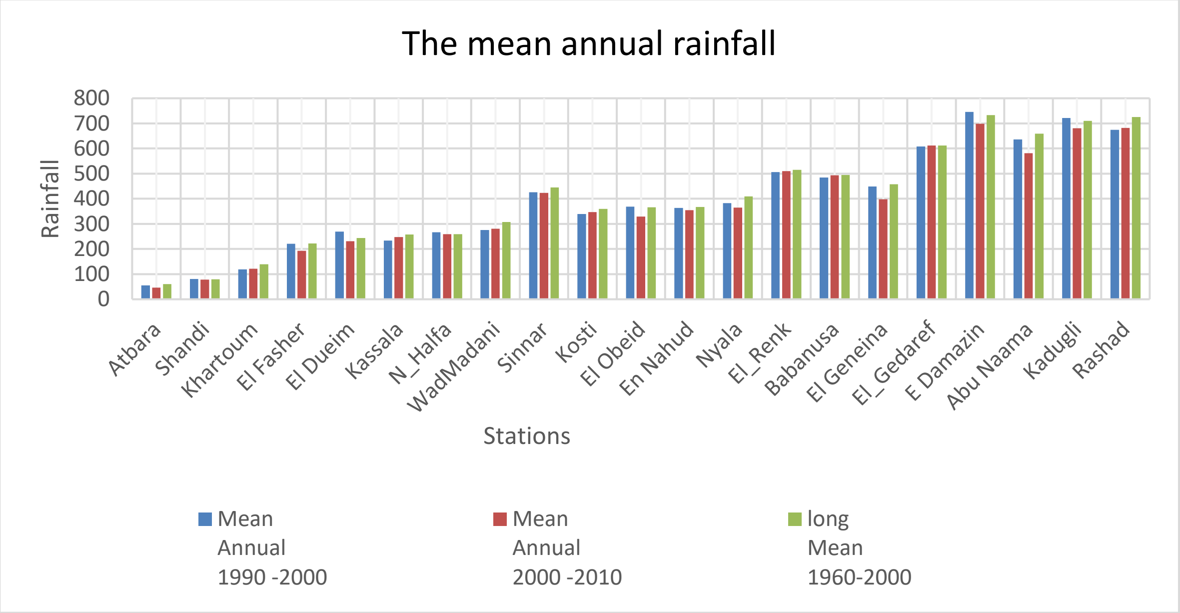


Figure 2- 2: the mean annual rainfall in different cities in Sudan[20]

also, its expansive plains, which are predominantly clayey in the Eastern, Central, and Southern regions while sandy in the North. However, the Kordofan and Darfur regions boast mountainous terrain. Notably, the southern areas of Sudan experience relatively greater levels of rainfall compared to the northern regions, as shown in figures 2-3a and 2-3b, [21].

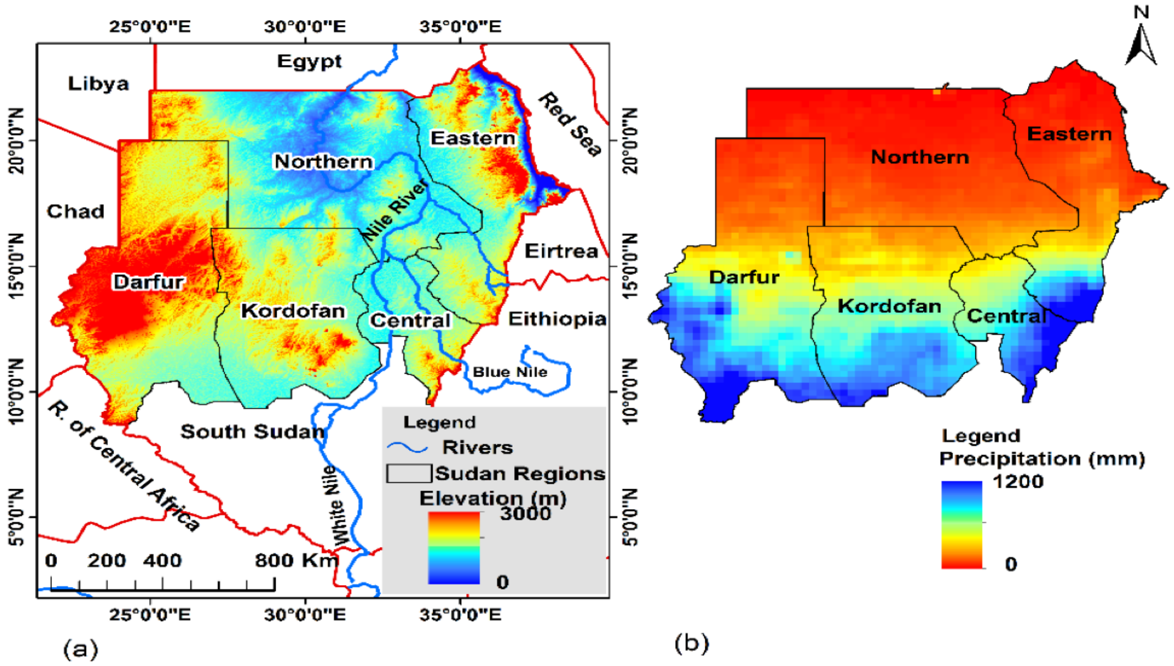


Figure 2- 3a–3b: map of elevation and distribution of rainfall in Sudan from 2001–2011 [21]

2.4.2 The Nile River

The Nile, renowned as one of the world's most prominent rivers, holds great significance. It holds the distinguished title of being the longest river globally and is often referred to as the "father" of African rivers. Originating south of the Equator, it gracefully meanders northward, coursing through northeastern Africa until it reaches its ultimate destination, the Mediterranean Sea. Stretching across approximately 4,132 miles 6,650 km, it encompasses a vast drainage area estimated at 1,293,000 miles 3,349,000 km. Encompassing portions of Tanzania, Burundi, Rwanda, the Democratic Republic of the Congo, Kenya, Uganda, South Sudan, Ethiopia, Sudan, and Egypt, its basin showcases remarkable diversity as shown in Figure 2- 4. The Nile finds its farthest source in the Kagera River, located in Burundi. Converging harmoniously, the Nile forms from three primary streams: the Blue Nile and the Atbara, which gracefully descend from the Ethiopian highlands, and the White Nile, whose headstreams gracefully flow into Lakes Victoria and Albert. The Blue and White Nile join in Khartoum, the capital city of Sudan, to form the main Nile, which flows from Khartoum down to the high Aswan Dam Reservoir in Egypt. This confluence marks a major geographical and cultural landmark for Sudan [14], [22].

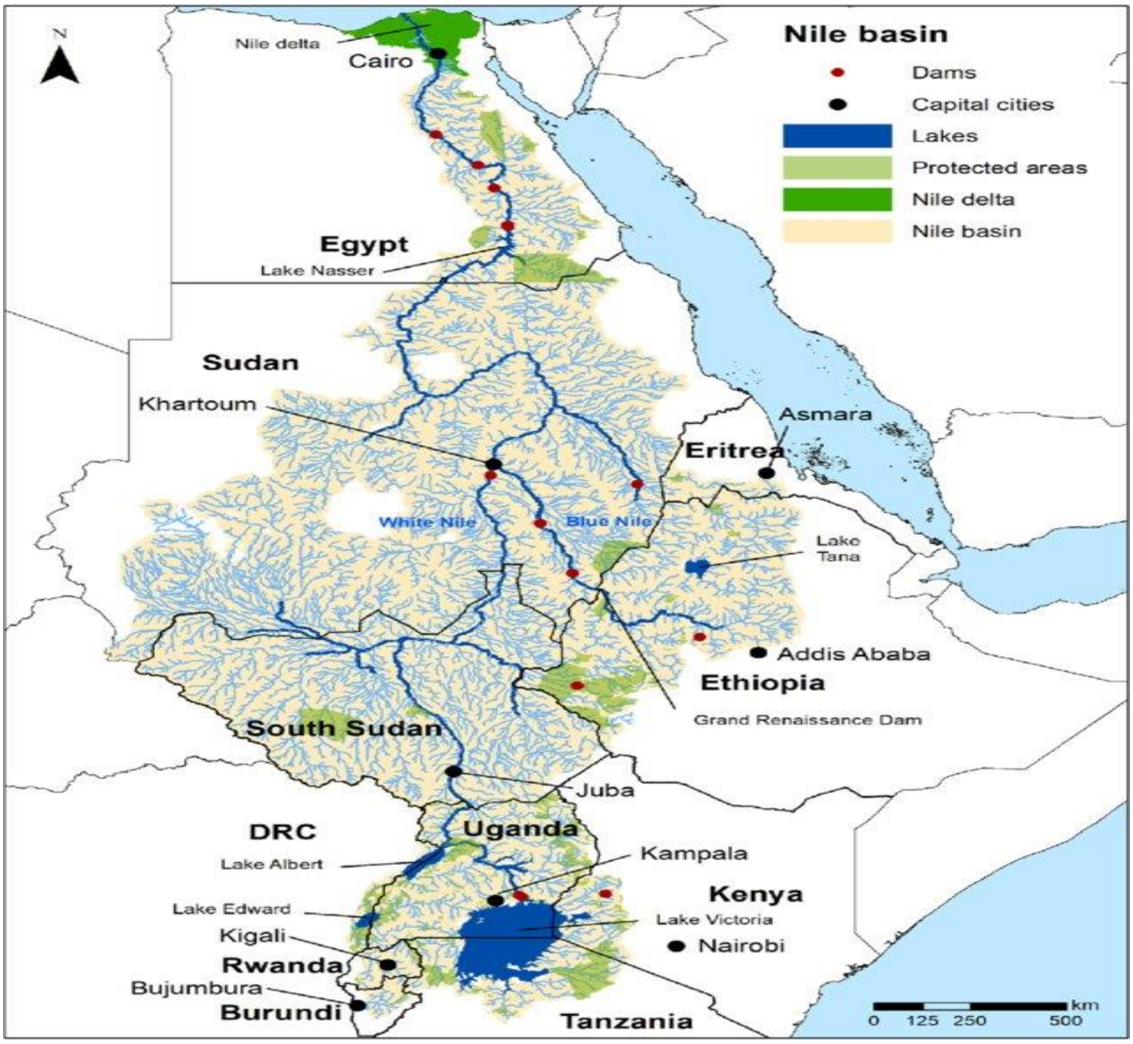


Figure 2- 4: Map of River Nile countries and their tributaries s[23]

The river Nile tributaries:

2.4.3 Blue Nile:

The Blue Nile originates from the Ethiopian Plateau at an elevation of 2,000 to 3,000 meters above mean sea level (m.s.l.), which is widely recognized as its source. It has carved a deep gorge through the Ethiopian Plateau, reaching depths of up to 1,200 meters below the surrounding terrain. The riverbed contains several rock outcrops, with the last ones located a few kilometers south of Roseires, approximately 1,000 km from its source beyond Lake Tana, known as the Damazin rapid. Near the western border of Ethiopia, the Blue Nile emerges from the plateau and flows northwest into Sudan at an altitude of 490 meters above sea level. Just before crossing the border, the river enters a clay plain, spanning approximately 735 km until it reaches Khartoum. It is at this point that the Blue Nile converges with the White Nile, forming the main stem of the Nile River. The average slope of the river from Lake Tana to the Ethiopian frontier is approximately 1.6 m/Km, while from the frontier to Khartoum, the slope decreases significantly to about 15 m/Km. Two significant tributaries, the Dinder and Rahad rivers, join the Blue Nile between Sennar and Wad Medani. Both of these rivers originate from the Ethiopian Plateau, approximately 30 kilometers west of Lake Tana, and during the dry season, they become seasonal streams reduced to pools. The Blue Nile Basin, including the Dinder and Rahad Basins, covers an area of 324,530 square kilometers. The majority of these catchments are located in Ethiopia. The flow of the Blue Nile reflects the rainfall patterns in the Ethiopian highlands, with distinct flood and low flow periods. The flood period, or wet season, spans from July to October, peaking in August-September, while the low flow, or dry season, occurs from November to June [18]

2.4.4 White Nile:

The total annual average supply of the White Nile system, measured at Jebel Aulia Dam, is 30.9 BCM. Daily flow varies from 54 million m^3 in April to 114 million m^3 in November. The Bahr El Ghazal basin system contributes 14 million m^3 annually, but substantial losses occur in swamps, resulting in only 0.5 BCM reaching the White Nile. These swamps cover an area of 40,000 square kilometers and experience an annual rainfall of 900 mm and an evaporation rate of 1200 mm. The Bahr El Jebel Basin supplies an annual average of 29 M m^3 at Mongalla, but due to significant losses in the Bahr El Jebel swamps, only 14.7 BCM m^3 reaches Malakal. The Bahr El Jebel swamps cover an area of 7,000 square kilometers. The Sobat Basin at Malakal provides a total annual average supply of 13.7 BCM, with daily discharge ranging from 8 million m^3 in April to 66 million m^3 in November. Water losses due to spillage into swamps in this basin amount to 4 BCM annually in the Baro tributary and another 4 M m^3 in the Machar marches, covering an area of 20,000 square kilometers and experiencing annual rainfall of 800 mm. [18].

2.4.5 The Atbara River:

The Atbara River, the final tributary of the Nile, joins the Main Nile approximately 320 kilometers downstream of Khartoum. It stretches for 880 kilometers and has a catchment area of 112,400 square kilometers, with the majority located in Ethiopia. The primary tributary of the Atbara is the Setit River, with a catchment area of 69,000 square kilometers. The Atbara exhibits more pronounced seasonal flow variations compared to the Blue Nile. In its first 300 kilometers, the river has a steep slope of approximately 5 meters per kilometer, leading to a significant sediment load relative to its flow volume. The steep slope and small catchment area of the river contribute to rapid runoff from the upper catchments, reaching the Sudanese border within one to two days[18]. Rainfall in the central Africa Plateau, including the Equatorial Lakes region, and the Ethiopian highlands serves as the primary source of the Nile system and other seasonal streams like Gash and Baraka. It is important to highlight that the Ethiopian highlands contribute approximately 86% of the Nile River's flow through its main tributaries (Blue Nile 59%, Baro-Adobo 14%, and Tekezze-Atbara 13%), while the equatorial lakes contribute 14%. During the flooding period from July to October, more than 90% of the Nile flow originates from Ethiopia, with less than 10% originating from the Equatorial Lakes. Sudan occupies about 44% of the Nile basin, and approximately 80% of Sudan's territory lies within the Nile basin. Between the years 1891 and 1959, several international agreements were established to regulate the relationships among the countries involved. These agreements, as highlighted in Figure 4 -5,

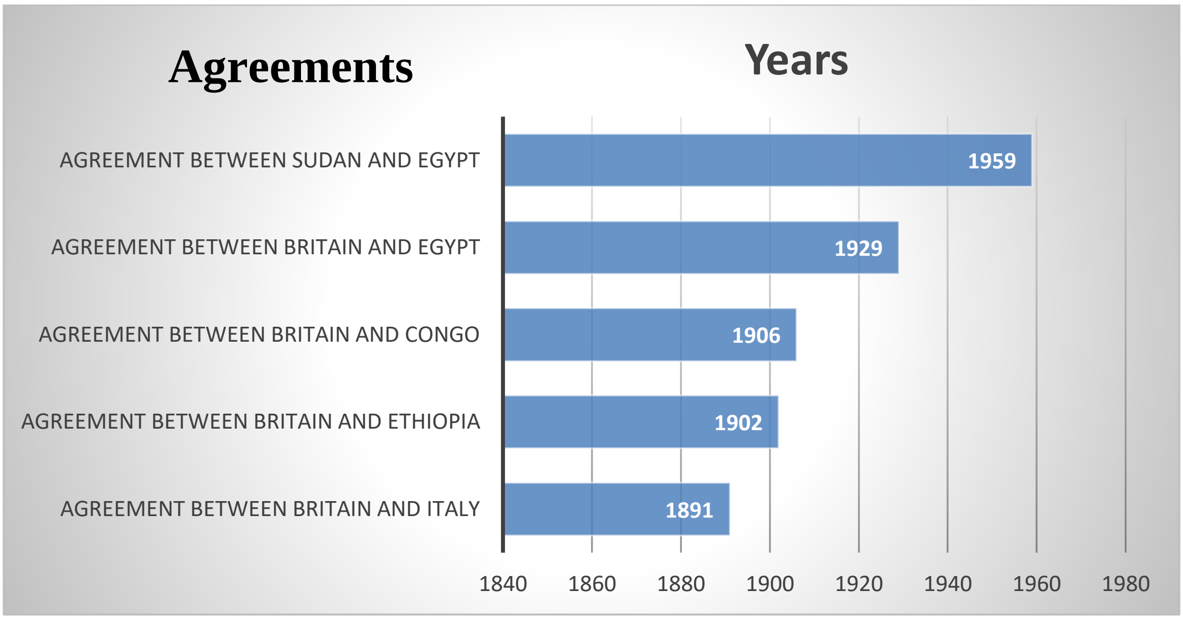


Figure 2- 5: Nile River Agreements [18]

The initial Nile Water Agreement between Sudan and Egypt was signed in 1929. Under this agreement, Egypt was granted the right to utilize 48 billion cubic meters (BCM) of water per year, while Sudan was only granted the right to access 4 BCM per year. Notably, the treaty did not assign any water usage rights to Ethiopia and imposed restrictions on Uganda, the United Republic of Tanzania, and Kenya, prohibiting them from utilizing the waters of Lake Victoria. According to the 1959 Nile Water Agreement between Egypt and Sudan, Sudan's allocated share of Nile water is 18.5 BCM per year, measured at Aswan (or 20.5 BCM per year, measured at Sennar). Egypt, on the other hand, is entitled to a corresponding share of 55.5 BCM per year [18], The figure below represents the Nile discharge at Dongola in BCM from 1987 to 2006 as shown in Figure 2- 6.

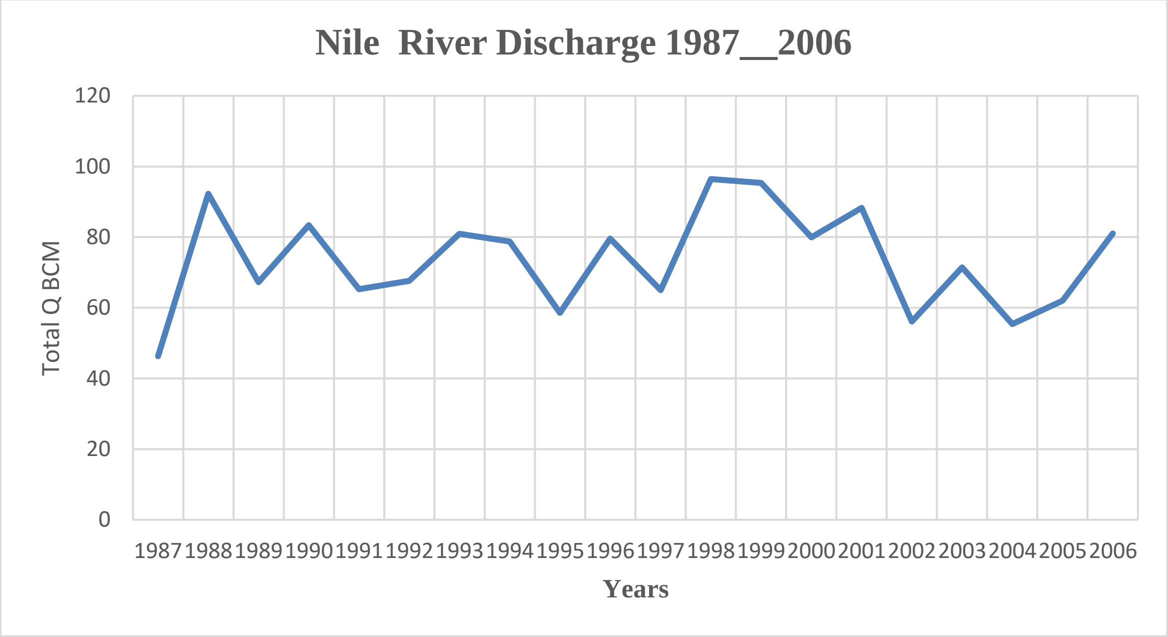


Figure 2- 6: Nile River total discharge in billion cubic meters (1987–2006) [17]

2.4.6 Lakes and seasonal streams:

Sudan is blessed with several lakes and seasonal streams that play a vital role in the country's ecosystem, supporting biodiversity and providing essential resources for both humans and wildlife. These water bodies, including lakes and streams, are distributed throughout the country, with some located along the Nile and others in more distant regions [17]. Seasonal Streams:

Wadi Howar: Wadi Howar is a seasonal stream in Sudan, considered a remnant of the Yellow Nile, an ancient tributary of the Nile. This stream highlights the historical significance of waterways in the region, showcasing the dynamic nature of Sudan's water resources, [17]

2.5 Groundwater:

Groundwater holds immense significance in Sudan, as it is the most crucial resource in the country. Approximately 80% of Sudan's population relies on groundwater for their livelihoods throughout most of the year. It is widely distributed, covering approximately 50% of the country's area. The depth of groundwater varies from 40 to 400 meters, and the total dissolved solids range from 100 to 2000 ppm. The Sedimentary Nubian Sandstone and Umm Ruwaba Formation are the primary aquifers in Sudan. In addition to its importance for human and livestock water supply, groundwater plays a crucial role in maintaining the environment. It sustains stream flows, supports wetlands, and contributes to the growth and survival of vegetation, among other things[18] . In the northern part of Sudan, where rainfall is scarce and the region is predominantly desert, wells serve as the primary sources of water. As one moves southwards, a tropical continental climate prevails, except in the extreme south, where the climate is described as continental equatorial. Both of these climate zones experience a distinct dry season, which becomes more intense and prolonged as one moves towards the northern region. The current minimum annual water requirements for human and animal consumption in the rural areas of Sudan are estimated to be 275×10^6 m3. Out of this amount, 23.2% is provided from groundwater sources. Additionally, it is estimated that about 1,381×10^6 m3 of water recharge occurs from the major basins annually. However, due to various challenges such as lack of proper policies, technical manpower, inadequate knowledge, and the absence of appropriate research to develop new technologies and approaches, only 143×10^6 m3 of this recharged water is actually used [24]. The groundwater basins in Sudan exhibit a range of geological formations, which can be categorized into simple and complex forms. These formations contribute to the diverse hydrogeological characteristics of the basins across the country. Here is an overview of the groundwater basins in Sudan and their associated geological formations: (Nubian Sandstone Formation): Six basins are located within the Nubian Sandstone Formation. (Nubian/Umm Rwaba Formation): Two basins are found within the Nubian/Umm Rwaba formation. (Alluvial Deposits): Eight basins are associated with alluvial deposits. (Umm Rwaba Formation): Two basins are situated within the Umm Rwaba formation. (Nubian/Basalt Formation): Two basins are present within the Nubian/Basalt formation [18], [25]. Types of groundwater basins or geological information on groundwater in Sudan:

2.5.1 Nubian Basin:

The Nubian basin, which covers approximately 28.15% of the country's area, is a significant water resource in Sudan. The water in this basin is known for its high quality and is suitable for both human and animal consumption. The Nubian basin is shared with neighboring countries Egypt, Libya, and Chad [18] . The transboundary Nubian aquifer, which spans an area of 2 × 10^6 km2, is shared among Egypt (38%), Libya (34%), Sudan (17%), and Chad (11%). Egypt and Libya possess the majority of the aquifer's water resources, while Chad and Sudan have a smaller share. This distribution reflects the varying levels of water availability and utilization among the countries sharing the Nubian aquifer [25], [26].

2.5.2 Sahara Nile basin:

The basin stretches from North Kordofan State to the Egyptian border, spanning a total area of 27,398 square kilometers. It is geographically separated from the Sahara Nubian basin by a basement ridge that extends in a northeastern direction. The water level exhibits a gradient, starting at 10 meters near the Nile and gradually decreasing as one moves away from the source of recharge. In the central part of the basin, the water depth reaches a maximum of 25 meters. Groundwater within the basin moves from south to north, with a variable velocity ranging from 0.44 to 1.46 meters per year. The primary sources of recharge include the River Nile and the underflow from the Blue Nile Basin. Analyzing the water quality, it is observed that the total dissolved solids in this basin range between 200 and 400 parts per million (ppm). Furthermore, the salinity of the water increases as one moves away from the groundwater recharge source [18]. The aquifer near the Nile, the saturated thickness of the aquifer ranges from 100 to 500 meters. Mudstone layers in the aquifer are typically more than 200 meters thick. These mudstone layers are commonly found between depths of 50 and 500 meters. The mudstone layers appear to be consistent in the area adjacent to the Nile, specifically 7 meters south of Ed Damer and extending in a southern direction down to latitude 16°45". As the aquifer extends away from the Nile, it becomes semi-confined due to the presence of the mudstone layer [25], [26].

2.5.3 Central Darfur Basin:

The Central Darfur basin encompasses the central region of Darfur and the western part of North Kordofan. Its southern extension reaches the Tagabo-Maidob groundwater divide and is linked to the Baggara Basin in the south, covering a total surface area of 52,924 square kilometers. The water quality within the basin exhibits total dissolved solids ranging from 100 to 400 parts per million ppm. In the northern section, the water quality is notably good, with some locations registering levels not exceeding 80 ppm. However, in the Jebel Hilla area in the southern part of the basin, salinity reaches up to 1800 ppm [18]. The water level in the basin varies from 25 to 100 meters below the soil surface. Groundwater movement predominantly occurs from the north to the southeast, with a velocity ranging from 0.3 to 6.0 meters per year. The saturated thickness of the aquifer ranges from 100 to 350 meters. The annual recharge volume is estimated at 47.6 million cubic meters. The basin is connected to the Baggara Basin in its southern part, with an estimated outflow of 12.8 million cubic meters. The amount of water under permanent storage is reported to be 794 million cubic meters, and the abstraction rates stand at 5.63 million cubic meters per year[26] [24], [25].

2.5.4 Nuhud Basin:

The basin, situated in the central part of Northern Kordofan State, is distinctively separated from the Nubian Sandstone. Encompassing an area of 6,798 square kilometers, it exhibits a chemical water quality characterized as low, with total dissolved solids hovering around 500 parts per million (ppm). The aquifer's saturated thickness ranges from 150 to 250 meters, contributing to an estimated annual recharge of 15.4 million cubic meters. The water level within the basin varies from 75 to 100 meters below the soil surface, with the water quality reported. Groundwater flow direction is observed from west to east, carrying a velocity between 1.0 and 2.75 meters per year [24],[25], [26]

2.5.5 Sag El Na'am Basin:

This basin encompasses a trough along Wadi El Ku, situated 40 kilometers south of El Fashir, the capital of North Darfur State, covering an area of 2,678 square kilometers. It is linked to the central Darfur Basin through a narrow passage. The water within this basin exhibits good chemical quality, characterized by low total dissolved solids ranging from 80 to 500 parts per million (ppm). The Sodium Adsorption Ratio (SAR) falls within the range of 1.08 to 3.5. The depth of the water level in the basin varies from 50 to 1000 meters [28]. At the fringes of the basin, the water is under free water table conditions. In contrast, in the central part, where the mudstone layer is typically 15 meters thick, the water level is under semi-artesian pressure. Groundwater movement is observed from north to south and southeast, with velocities ranging from 1.0 meters per year in the southern part to 25 meters per year in the central and eastern parts. The saturated thickness of the aquifer spans from 500 to 2000 meters. Although the basin is being developed for irrigation purposes, the economic feasibility of irrigation is uncertain due to the deep-water levels. However, for various reasons, it is estimated to be profitable[25], [26]

2.5.6 River Atbara Basin:

The River Atbara Basin extends northward to the Abu Haraf water divide, reaching up to the Atbara River and covering an expansive area of 23,896 square kilometers. Bounded by the River Nile to the west and the Basement to the east, this basin exhibits diverse geographical features. The water level in the basin varies, starting from just a few meters near the Nile and River Atbara, gradually decreasing as one moves away from the source of recharge, ultimately reaching depths of up to 100 meters. The saturated thickness of the aquifer exhibits regional variation. In the northern and western parts of the basin, it measures around 100 meters, while in the central part, where a mudstone layer of 50 to 250 meters is present, the saturated thickness reaches up to 500 meters. The construction of the Khashm El Girba dam in the upper part of the river Atbara has altered the flow dynamics in the lower part, making it seasonal and restricted to floods. This transformation has significantly impacted the lives of the citizens, prompting a necessity for the development of groundwater resources. The groundwater resources have the potential to irrigate some 100,000 feddans, emphasizing the increasing importance of sustainable water management in the region [24][25]. Table 2-1 shows the groundwater potential of the Nubian Basin.

Table 2- 1: Groundwater Potential of the Nubian Basin [24],[26]

Ground Water Basin	**U.M.m3**	**R.M.m3**	**B.S.M. Y**	**A.M.m3**	**P.A. to R.m3**
Nubian Basin	7.3	136	5500	7.4	5.44
Sahara Nile Basin	20.6	20.6	9740	1.2	5.82
Sahara Nubian Basin	12.8	47.6	794	5.6	11.82
Central Darfur Basin	1.5	15.4	136	2.5	16.49
Nuhud Basin	1.3	14.8	134	1.5	9.89
Sag El Na'am Basin	3.7	23	-	0.5	1.9

2.5.7 Umm Rwaba Basin:

The Umm Ruwaba basin encompasses the Umm Ruwaba graben within the White Nile rift. This basin is confined by faults and extends in a southeast direction. The formations carrying water in this subbasin closely resemble those in the Bara basin, with the exception that the Mesozoic aquifer is semi-confined and lacks definition, unlike the Bara basin. Interestingly, the Mesozoic aquifer is limited to the Kosti area alone, and surprisingly, it is dry even in close proximity to the White Nile, with thicknesses exceeding 200 meters [24]. Sudd Basin the Sudd Basin holds the distinction of being the largest basin area in Sudan, extending southward from South Sudan. Covering a large area of 365,268 square kilometers, this basin is a key player in Sudan's hydrogeology. Two major basins, the Baggara Basin in the western part and the Eastern Kordofan in the central part of Sudan, are connected to this aquifer, contributing to its outflow and recharge. The Sudd Basin operates as a closed basin, receiving water flow from the Bagara basin north of Bahar El Arab and the Umm Ruwaba basin north of the Rank area, along with groundwater from the Sudd Basin itself flowing towards its central part. In the central region of the basin, groundwater levels intersect with the surface contours of lower elevations, indicating potential discharge to streams and lakes in the Sudd area. Approximately 200 million cubic meters of groundwater flow into the central part of the basin, with a significant portion believed to discharge to the surface. Groundwater levels in this area are near the surface, ranging from 10 to 25 meters. Groundwater movement towards the central part of the basin is observed, with velocities ranging from 0.1 to 1.8 meters per year, reflecting a slower pace compared to other basins. Abstraction rates stand at 1.8 million cubic meters, and the saturated thickness ranges from 100 to 3000 meters [18] . highlight the significant contribution of the White Nile and surface flow during the rainy season as the main sources of recharge for this basin table 2-2, [24],[26]

Table 2- 2: Groundwater potential of the Umm Rwaba Basin [24]

Ground Water Basin	U.M.m3	R.M.m3	B.S.M. Y	A.M.m3	P.A. to R.m3
Sudd Basin	50.8	341	11000	1.9	0.54
Eastern Kordofan	2.3	15.8	1710	4.5	28.31

2.5.8 Nubian/Um Rwaba Basin:

Baggara Basin: The Baggara Basin spans nearly the entire area of southern Darfur and the western part of southern Kordofan, covering an extensive 141,316 square kilometers. The chemical quality of the basin varies due to the presence of Nubian and Umm Ruwaba formations. In the eastern and western parts, the total dissolved solids are low, ranging from 100 to 400 parts per million (ppm), while in the central region, they reach up to 800 ppm. The water level within the basin varies from 30 to 75 meters, with the deepest water levels found in the central part of the aquifer. The saturated thickness of the aquifer varies from 100 to 2000 meters. Groundwater movement is observed from the north, east, and west towards the central part of the aquifer. From there, the groundwater flows in a southeastern direction towards the Sudd Basin. Velocities range from 0.13 to 1.75 meters per year. The annual recharge is estimated at approximately 155 million cubic meters, with the basin storage capacity reported to be 7110 million cubic meters. Abstraction rates from the basin are around 11.9 million cubic meters. The primary sources of recharge are from the northern and eastern directions, as well as through superficial deposits and wadi fill deposits [18] . Blue Nile Basin: The Blue Nile Basin covers the region between the River Rahad and the Blue Nile, extending northwest along the Blue Nile up to Khartoum. It is bordered by the Abu Haraf water divide to the northeast and the White Nile to the west, encompassing an area of 75,808 square kilometers. The chemical quality of the water varies, with low total dissolved solids along the Blue Nile ranging from 300 to 500 ppm. Water levels in the basin range from a few meters near the river to a maximum of 50 meters away from the stream. The basin's storage capacity is approximately 70.9 million cubic meters per year as shown in table 2-3, [18][25], [26]

Table 2- 3: Groundwater Potential of the Nubian/Um Rwaba Basin [24]

Ground Water Basin	U.M.m3	R.M.m3	B.S.M. Y	A.M.m3	P.A. to R.m3
Baggara Basin	22.7	154.6	7110	11.9	7.71
Blue Nile Basin	10	70.9	2270	21.6	30

2.5.9 Nubian / Basalt Basin:

a) Gadaref Basin: The Gadaref Basin spans the central part of Kassala State, covering an area of 28,016 square kilometers. The water chemistry in this basin is noteworthy, displaying good quality with low total dissolved solids ranging from 400 to 500 parts per million (P.P.M.). Water levels in the basin vary from 50 to 75 meters, and the water flows in a northwest direction with a velocity of 0.3 to 3 meters per year. The basin's storage capacity is approximately 700 million cubic meters per year. The annual recharge is reported to be 41.7 million cubic meters, while the abstraction rate stands at 1.2 million cubic meters per year. The saturated depth of the aquifer ranges from 200 to 500 meters. The primary source of recharge is seepage into the sandstone formation from the River Setit, a branch of the River Atbara. Additionally, the basin receives underflow from adjacent basins at the borders, estimated at 12 million cubic meters per year [24][25].

Table 2- 4: Groundwater Potential of the Nubian/Basalt Basin [24]

Ground Water Basin	U.M.m3	R.M.m3	B.S.M. Y	A.M.m3	P.A. to R.m3
Gadaref Basin	6.1	41.7	700	4.2	10.14
Shagara Basin	10	1.1	4.5	0.7	64.22

2.5.10 The Alluvial Basins:

The major alluvial basins are formed by seasonal streams, known locally as "khors." These streams experience runoff for no more than three months per year. However, during this relatively short period, the runoff is significant, leading to a complete recharge of the aquifers after the rainy season. The alluvial deposits in these basins are notable for their high transmissivity values and storability figures. The relatively shallow depth of these aquifers has enabled the local inhabitants to develop their own technology for extracting water, particularly for irrigation purposes. These basins hold historical significance as they are considered the oldest known cultivation centers that rely on groundwater resources [24],[25]. Table 2-5 represents the total groundwater availability in Sudan.

Table 2- 5: Groundwater availability in Sudan [24]

Ground Basin	Area Km2	Quality of water by BCM	Annual average recharge million m3
Nubian basin	637073	12600	1008
Umm Ruwaba basin	660957	4150	586
Nubian/Basalt Basins	3.42	325	325
Alluvial basins	-	2.5	1800
Total	-	16757	4109

2.6 Rainwater harvesting in Sudan:

The scarcity of water resources in some areas of Sudan constitutes a major factor that limits the implementation of development plans and programs. In the early twenty-first century, water was still one of the most serious problems facing the Arabs. American expert Thomas Nave says: “Water in the Middle East is an economic issue.” political and social, and extends to become a potential source of conflict, which makes it have a military dimension. This is in addition to the increase in population size rates, which requires a simultaneous increase in the amount of fresh water. This is why water has become a constant concern for all countries in the world, and it is no longer talked about as it was in the past. Rather, this concern has been termed "water security." And then it became an issue. a wish with multiple dimensions, represented by the economic dimension, the geographical dimension, the political dimension, and the dimension Moreover, development in various areas of life has led to an increase in per capita consumption of water. What is rainwater harvesting? What is the importance of rainwater harvesting? Definition of water harvesting: The term "water harvesting" refers to any morphological, chemical, or physical process carried out on the ground in order to benefit from rainwater, whether directly by enabling the soil to store the largest possible amount of rainwater falling on it or reducing the speed of excess runoff. The main element of rainwater harvesting techniques is the ratio between the area of runoff and the area of collection [28].

2.7 Previous studies about rainwater in Sudan

The use of water harvesting technologies in Sudan back years, perhaps to the last three centuries. It is used to a limited extent for small-scale agricultural purposes and also for drinking purposes for humans and animals. Many types of simple water harvesting technologies have been used. Most of them are no longer practiced in the villages of Kordofan and Darfur in central and western Sudan. The methods used at that time included digging basins in clay or hard ground whose permeability was very low. They were locally called (fulah) and were in a circular or oval shape, household utensils, and making rooftops. Rainwater harvesting techniques are also used for agricultural use for the purpose of irrigating crops, by creating terracing barricades, especially in mountainous and high-altitude areas, in the states of Darfur in western Sudan, or by creating drains of greater width and depth, which are mainly spread in many locations in Sudan, including agricultural lands in irrigated projects. outside the agricultural cycle. Staircase farming technology is considered one of the oldest waters harvesting and soil conservation systems in the world. In the Middle East, it is said that these technologies were developed by the Phoenicians, and then their use spread to the North African region, and from there they moved to western Sudan, especially since Sudan has witnessed large migrations from groups of countries bordering North African countries [28]. There are many types of rainwater techniques used in Sudan, and still:

2.7.1 Earth Dams:

This technique consists of building earthen dams as wide as the valley streams to divert water according to the contour to the largest area of land to provide the opportunity for the soil to be saturated with water and increase its capacity. for agriculture for a longer period[28].

2.7.2 The Excavation System (Hafirs):

Hafirs have been known for a long time, especially in societies that live in semi-arid environments. Hafirs are considered artificial reservoirs and are always dug under the surface of the earth and in soil that, mostly, does not allow for water leakage or is treated to be hard or solid. This method is used to store rainwater in small tanks, and the engineering sector has been able to develop it until it has become an engineering technique suitable for harvesting rainwater despite drinking and evaporation losses Figure 2-7. The benefit from hafir water may reach more than 60% if it is maintained periodically and if it is implemented according to engineering specifications and under technical supervision. The use of rainwater harvesting in Sudan is to provide water for drinking purposes, mainly in hafir. The majority of hafirs are created around residential complexes in villages and some large cities in Sudan, such as Al-Obeid, which was the capital of the Greater Kordofan region, where it depends mainly on such despicable things. There are also excavators of larger sizes and capacities; they were created for Arab men to benefit from drinking animals, and these are found more in the regions of Butana in eastern Sudan, North Kordofan, and Darfur[28]

Figure 2- 7: Hafirs technique in some areas of Sudan [29]

2.7.3 Baobab Tree (Tabaldi trees):

Sometimes it is used to hollow out the stems of some trees, such as the baobab tree in Kordofan, as this tree is considered one of the most important tools for storing rainwater in this region, in addition to producing good fruits. The baobab tree is found in abundance in western Sudan, and it is one of the largest and tallest trees in the world. Its height may reach 25-30 meters, and its trunk diameter reaches 11 meters. This tree lives for more than a thousand years, and the baobab tree is bare of leaves for a period of time. 9 months a year, and the leaves begin to appear at the beginning of autumn. The trunk is hollow from the inside and can hold about 45 people, as shown in Figure 2-8. The people in western Sudan use it as a water store to collect rainwater. It holds about 10,000–25,000 liters of water, which the residents use during the drought period, which extends for more than 5 months[29].

Figure 2- 8: Harvesting water from Baobab trees in Sudan [29]

2.7.4 Collection from the roofs of houses:

This is done by making sloped roofs for houses or creating what are called roofs figure 9, which serve two purposes: the first purpose is to drain rain from the roofs of houses, while the second purpose is to drain rain from the roofs of houses. The second is to collect rainwater and store it in containers to use for various purposes. Figure 2-9 shows Rainwater from rooftops in some areas of Sudan.

Figure 2- 9: Rainwater from rooftops in some areas of Sudan [29]

2.8 Water policies and regulations in Sudan

The policies and regulations governing water resources in Sudan are primarily established by the Federal Ministry of Water Resources and Irrigation. Additionally, other federal ministries, such as the Ministry of Agriculture and the Ministry of Environment, Natural Resources, and Physical Development, also contribute to water management efforts. Several key governmental and non-governmental organizations are involved in water resource management in Sudan. As summarized below, the acts are very regulatory in nature, and with the exception of the Environmental Health Act, they offer little guidance on the efficient, productive, and sustainable use of the limited water resources of Sudan [30][31]. Here below are the policies and acts of Sudan:

2.8.1 Irrigation and Drainage Act 1990:

Provision: Any work related to irrigation or drainage requires a permit from the Ministry of Irrigation and Water Resources. Licensees must notify the Ministry when drawing water for irrigation from various sources.

2.8.2 Gash Development & Utilization Act 1992:

Provision: Provides guidance on licensing for abstraction and digging of shallow wells, water fees, and prevention of water resource pollution.

2.8.3 Water Resources Act 1995:

Provision: A major institutional reform covering Nile and non-Nilotic surface waters, as well as groundwater. establishes the National Water Resources Council and requires a license for any water use.

2.8.4 Groundwater Regulation Act 1998:

Provision: Mandates the Groundwater and Wadis Directorate as the sole government technical organ for developing and monitoring wadis and groundwater. Issues with permits for constructing water points.

2.8.5 Gezira Scheme Act 2005:

Provision: transferred irrigation and farming responsibilities from professionals to farmers. It aims to ensure farmers' rights to participate in planning and implementation, manage irrigation operations through water users' associations, and freely manage production and economic aspects.

2.8.6 Public Water Corporation Act 2008:

Provision: Gives authority to the central government for national planning, research, development, and investment in the water supply sector.

CHAPTER (3)

3 . Materials and Research Methods

3.1 Study area location:

Nyala is a city located in southwestern Sudan, specifically in the Darfur historical region. Situated at an elevation of 673 meters, Nyala serves as the capital of the state of South Darfur. It borders North Darfur State to the north, West Darfur State to the west, the Republic of Central Africa to the southwest, South Sudan to the south, and West Kordofan State to the east figure3-1. The city has a rich history and is known for its various industries and trading activities. Nyala is home to industries that produce textiles, processed food, and leather goods. Also, the city serves as a trading center for gum Arabic, a valuable commodity. In addition, Nyala has terminus ends for both roads and railways, facilitating transportation and trade. Nyala is home to branches of the Agricultural Bank of Sudan and the People's Cooperative Bank. Following the outbreak of violence in Darfur in 2003, Nyala became a haven for refugees [14], [31]

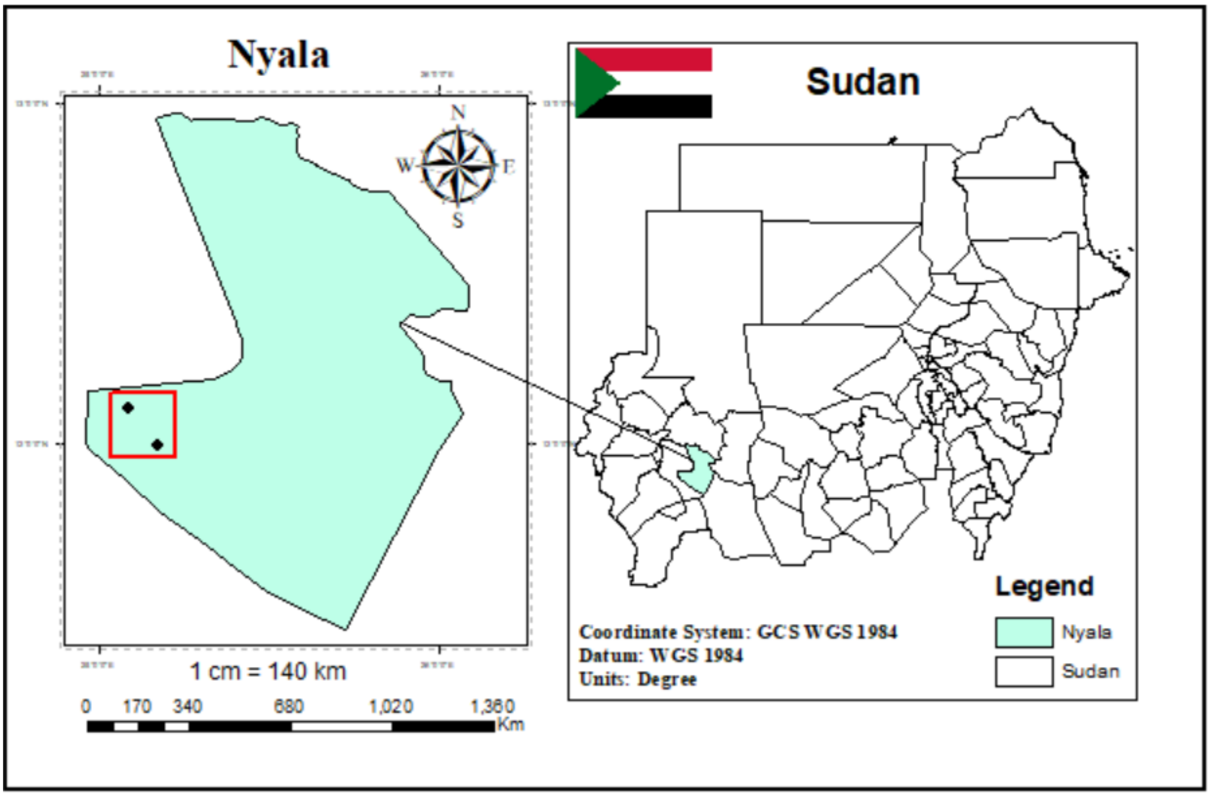


Figure 3- 1: Research Area Map of Nyala City

3.2 Temperature

The average yearly temperature in Nyala is approximately 31 ºC, which is slightly higher than the average temperature in Sudan. Throughout the year, temperatures typically range from around 13°C to 38°C. The hottest month in Nyala is May, with an average high temperature of around 38.33 °C and a low temperature of 24 °C. The hot season lasts for about 2 months, starting on March 20 and ending on June 1, with average daily high temperatures above 37 °C. On the other hand, the cool season spans approximately 2 months, from July 13 to September 15, with average daily high temperatures below 32 °C. [32] , [14].

3.3 Rainfall

In terms of precipitation, Nyala receives an average of about 66 mm annually. The wetter season lasts for approximately 3 months, starting on June 21 and ending on September 26, during which there is a greater than 29% chance of a given day being a wet day. August is the month with the highest number of wet days, averaging around 17 days of precipitation. Wadi Nyala, located in Nyala City, Sudan, receives an annual runoff of approximately 75 million cubic meters during the rainy season, which typically falls between June and November. Some of this runoff is received from Jebel Mara, located about 90 kilometers northwest of Nyala City. Jebel Mara is known for its relatively small but reliable rainfall, even during drought years. According to a United Nations Environment report, the estimated annual rainfall in Nyala is 384 millimeters per year. This rainfall contributes to the runoff that replenishes Wadi Nyala. From 1978 to 2007, Wadi Nyala remained the primary source of recharge for the shallow aquifers in the area. These aquifers play a crucial role in providing groundwater for various water users, including the displaced people in the region. Wadi Nyala's importance as a water source is significant, as it supports the water needs of the local population and serves as a vital resource in an area where water access is essential [32], [33].

3.4 Soil Cover and Vegetation

The northern and west central areas of Nyala have sandy soils; the central region is characterized by clay soils; and the southern part is covered by laterite soils. Topographically, it’s characterized by a gentle dip from west to east within the watershed, and the area is part of the basement complex, which is a rocky region. Additionally, the topography is covered by alluvial sediment. The vegetation is characterized by thorn bushes and low trees, with large areas having sparse vegetation coverage. However, there is a concerning phenomenon of vegetation degradation due to continuous tree cutting and overgrazing [33].

3.5 Water access

Water access in Nyala City has been facing a significant challenge due to various factors such as limited infrastructure, population growth, and the impact of conflict and displacement, including the lack of adequate water supply systems. To address this, the South Darfur Water Corporation has been working on projects like the Nyala drinking water project, which aims to increase the water supply by drilling underground wells and establishing a pipeline. Water shortages have been a recurring problem in Nyala City, especially during periods of low rainfall. The city relies primarily on groundwater as a source of drinking water. However, it is important to note that the city's drinking water supply is not solely dependent on groundwater. also receives a portion of its drinking water supply from the valley. However, there is a recurring water crisis in Nyala, as the valley tends to dry up at the beginning of January each year. This issue cannot be resolved solely through rainfall or the Nyala Baggara Basin project. The city has experienced an acute lack of drinking water, leading to difficulties for the residents. Unfortunately, the shortage of drinking water is expected to persist until the water supplies are replenished by rainfall [33]. In an effort to ensure the safety of drinking water, studies have been conducted to assess the bacteriological quality of water sources in Nyala City. These studies have revealed the presence of bacterial contamination, including total coliform, fecal coliform, and fecal enterococci, in various water sources, except for designated water points. This highlights the importance of addressing water quality issues to safeguard the health and well-being of the population[32]

3.6 Data Collection Methods

3.6.1 Questionnaires and interviews

For the research objectives, a questionnaire and interview were used to gather information from two key groups: the community of Nyala, which has been experiencing water scarcity, and the Water Corporation staff responsible for water supply. It’s provided a holistic understanding of the water scarcity issue and potential solutions. The questionnaire was aimed at capturing the perspectives and insights of both groups regarding the acceptance of rainwater techniques as a solution to water scarcity and the implementation of a sand filtration system. By considering the costs and economic benefits for the community, the questionnaire aimed to gather valuable data that helped in applying the rainwater technique.

3.6.2 Geographic Information System (ArcGIS)

3.6.2.1 Definition and history

ArcGIS is a suite of software products developed by the Environmental Systems Research Institute (Esri) that provides a comprehensive platform for spatial analysis, data management, and mapping. It is widely used in various industries and sectors for its capabilities in handling geographic information. ArcGIS allows users to create, analyze, and visualize spatial data, perform advanced geospatial analysis, and publish the results as services that can be accessed through web applications, mobile devices, or other desktop software. [34], [37].

3.6.2.2 Data input in Arc GIS Version 10.8

Rainfall data for the period 2011–2020 were obtained from Climatic Research Units (CRU data) at https://crudata.uea.ac.uk/cru/data/hrg/. and the Nyala Shape file was downloaded from the Data-Interpolating Variational Analysis Geographic Information System (DIVA GIS) at https://www.diva-gis.org/gdata. Subsequently, the data processing steps outlined in Figure 3-2 were applied to analyze the long-term trend over a period of 10 years.

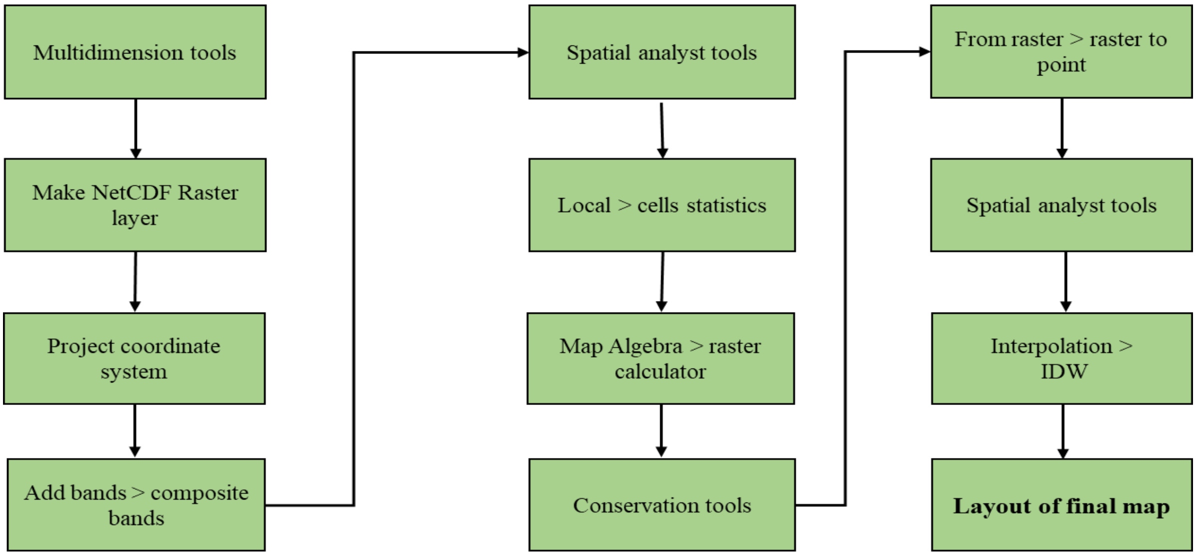


Figure 3- 2: Long-Term Period Rainfall Data Process

3.6.3 Computer-aided design Software (AutoCAD)

3.6.3.1 Definition and history:

AutoCAD, developed by Autodesk Inc. is a software program for computer-aided design (CAD). Its initial release took place in 1982, and it has since gained widespread usage as one of the most popular CAD applications worldwide. AutoCAD empowers users to generate, modify, and document both 2D and 3D designs and drawings. This robust design and drafting tool offer a comprehensive array of features to facilitate the creation and editing of digital drawings. It boasts a user-friendly interface, an extensive assortment of drawing and editing tools, 2D and 3D modelling capabilities, as well as tools for annotation, documentation, and collaboration. [36].

3.6.3.2 Input data in AutoCAD 2023

All the data were available in the program, just tools for drawing the shape of a school, house, and rainwater harvesting system were drew by using AutoCAD (2D), and the most tools that were used were polyline, arc line, a circle, line, circle, trim, joint, mirror, offset, fillet, move, rotate, hatch, rectangle, text, pan, and zoom.

Arc: The arc tool used for drawing curved lines, used to create rounded corners, arches.

Circle: used to for drawing circles and creating circular objects like windows or water tanks.

Polyline: This tool used for drawing lines with multiple segments, creating walls, boundaries.

Line: The line tool used for drawing straight lines for creating edges or outlines.

Trim: The trim tool helps for removing unwanted parts of lines, arcs or other elements.

Mirror: mirror tool, used for creating a mirrored copy of an object which is helpful.

Offset: The offset tool used for creating parallel lines or curves at a specified distance.

Fillet: The fillet tool helps for creating rounded corners between two lines or arcs.

Hatch: The hatch tool used for fill enclosed areas with patterns or solid colors.

Join: The join tool used for connecting separate lines or arcs to create a single continuous object.

CHAPTER (4)

4 . Results and Discussion

4.1 Rainfall

Figure 4 -1 presents a comprehensive overview of the long-term rainfall patterns in Nyala from 2011 to 2020. The map divided into different regions to represent varying levels of rainfall. The color scheme utilized in the figure aids in distinguishing between the maximum, minimum, and average rainfall values for each region, the southwestern part of the city, highlighted in blue, experienced the highest amount of rainfall during the observed period, with an annual precipitation of approximately 533 mm. On the other hand, the northeastern region, depicted in red, received the lowest amount of rainfall among all the points in Nyala, with an annual average of around 402 mm. For representing the average rainfall across all points in Nyala during the specified period, a color gradient ranging from light green to green is employed, this color gradient signifies the varying intensity of rainfall throughout the city, the average annual precipitation across Nyala was calculated to be 471 mm.

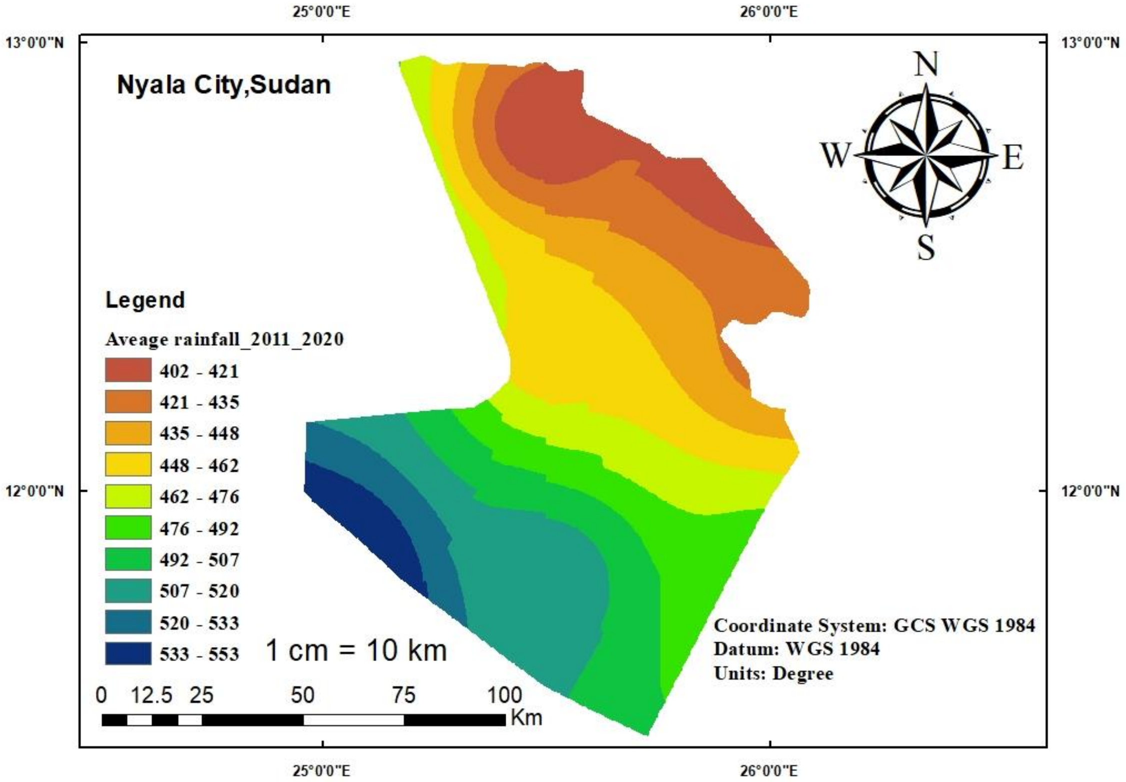


Figure 4- 1: the long-term rainfall 2011_2020 for Nyala City

4.2 Rainwater System

Figure 4-2 represents the rainwater harvesting system, which is composed of five layers, the first layer is coarse sand for removing larger particles and sediment from the rainwater, the charcoal layer is purposed to adsorb organic compounds, chemicals, odors, and some heavy metals, improving the quality of the filtered water. Also provided by gravel (5, 10, and 25 mm) to provide stability and support to the other filtration layers, distributing the flow of water evenly, preventing channeling, and ensuring effective filtration and net between each layer.

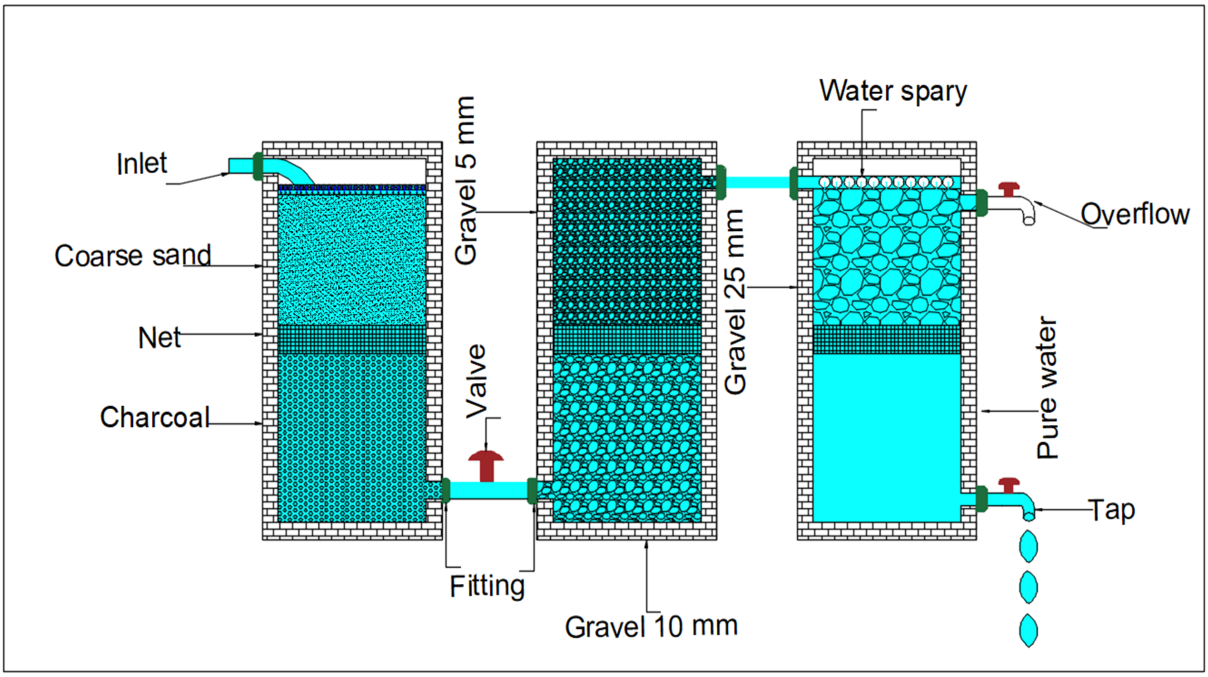


Figure 4- 2: Sand filtration System for rainwater harvesting

4.3 Rooftops building

4.3.1 Elshahid Hamza Basic school

Elshahid Basic School, established in 1975, is considered one of the oldest basic schools in the Texas area. Figure 4-3 displays the layout of the school, which has successfully graduated numerous generations of students. Elshahid school consists of four classrooms, each measuring 60 m^2 in area, an office with an area of 48 m^2 and roof were constructed from concert. All the structures have the same elevation of 6 m. Also, the school is equipped with a rainwater harvesting system, comprising of two plastic tanks, the first tank is dedicated to the rainwater system, has a total capacity of 500 liters and the second tank serves as a water storage unit with a capacity of 5000 liters. To collect rainwater, PVC pipes are connected from the rooftop to the tanks to drain off the roof top water with suitable size, this pipe is joined with the first flush pipe. And it was connected to the storage tank to store the rainwater, from the calculations, it is found that the PVC pipe of 120 mm is effective to convey water from roof to the storage tank, valves and taps are installed to regulate and control the water flow. Additionally, a net is installed between the rooftop and the pipes to prevent debris and other materials from entering the system.

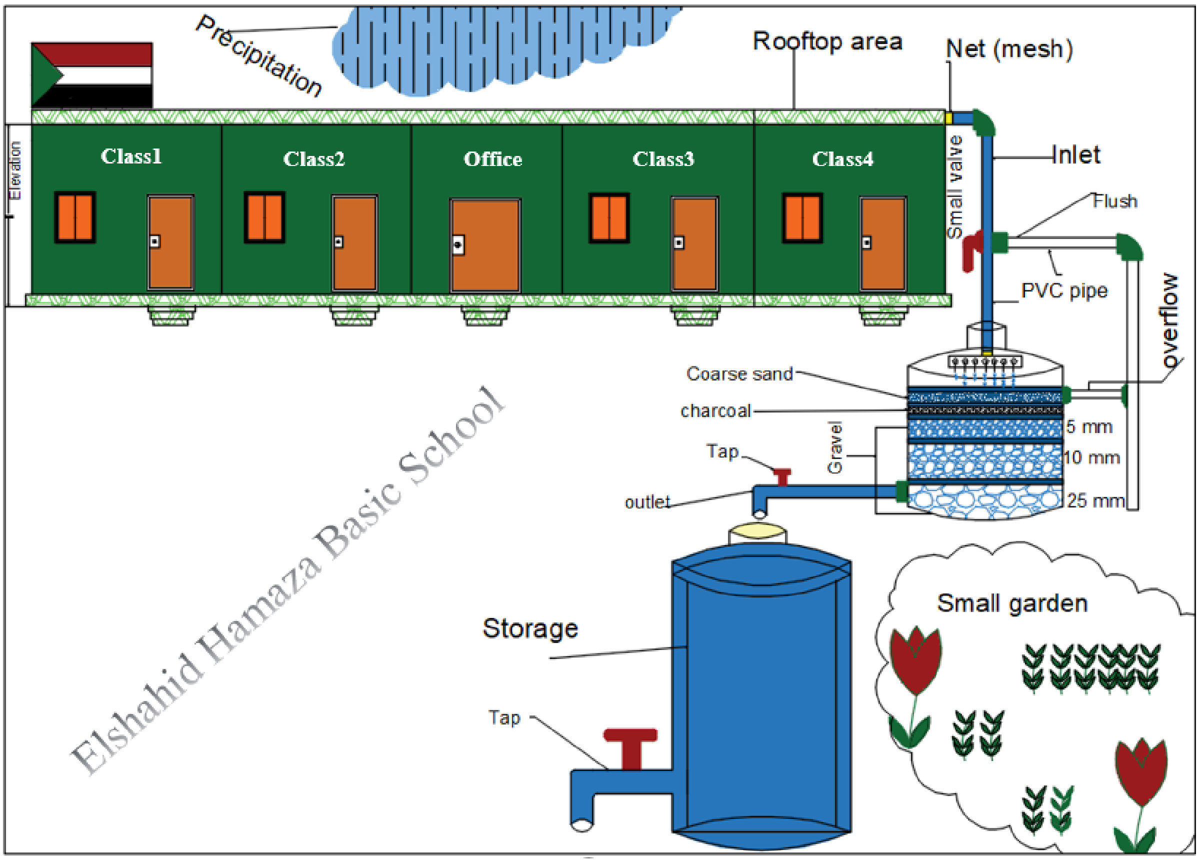


Figure 4- 3: Elshahid Hamza Basic School with rainwater system

4.3.2 Residential house

The residential house comprises from a room, a veranda and the roof were constructed form corrugated iron sheet as shown in figure 4-4, with the room having a rooftop area of 16 m^2 and the veranda covering 12 m^2, the room is elevated at 4 m, while the veranda sits at a height of 3 m. To facilitate water management, the house is equipped with two tanks, the first tank is dedicated to the rainwater system has total capacity 500 liters, while the second tank serves as a water storage unit Has capacity 2000 liters. Also, the PVC pipes connected from rooftop to the tanks, this pipe is joined with the first flush pipe allowing for the efficient collection and distribution of water, a net is installed between the roof and the pipes to prevent debris from entering the system, ensuring a clean and reliable water supply.

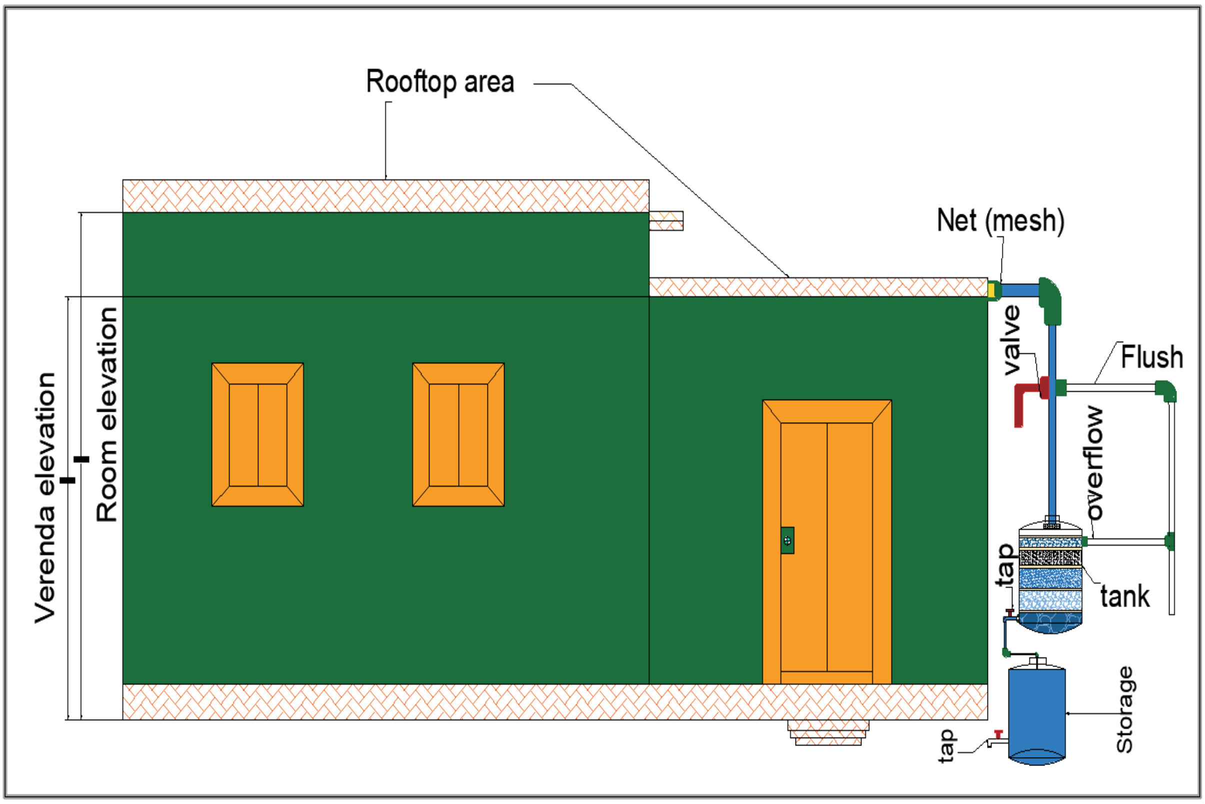


Figure 4- 4: residential house with rainwater system

4.3.3 Calculations

For calculating the rainwater harvest or drained this equation was followed:

$Q = R\times F \times A$ 4.1 [27]

Where: Q represents the amount of water that harvested (liter/year) and R represents run off coefficient this depend on the roof top type and F represents the average rainfall (471 mm/year) and A represents the area of roof building (m^2)

For Elshahid Hamza School:

Total Catchment area A = 4 classes + office = $4\times60+48 = 288\ m^2$

Run off coefficient R for concrete was taken 0.8 in this case

$Q = 0.8 \times 471\times 288 =$ **108,518** liter/year this the total amount of water collected yearly

For residential house:

Total catchment area A = veranda + room = $12 + 16 = 28\ m^2$

Runn off coefficient for corrugated iron sheet was taken 0.9 in this case

Q = 0.9 × 471× 28 = **11,869** liter/year this the total amount of water collected yearly

Each person needs around 1.5 to 3 liters for drinking daily according Harvard Medical School so here assumed that the basic school has 180 people (students 160, teaching staff 15, guards 5) so each person obtained 1.7 liter /day and for house 6 person so each person got 5.5 liter/day.

4.3.4 Cost and Maintenance

In terms of cost, cost-effective water filtration systems offer several advantages that make them accessible to everyone and the materials required for these systems are readily available, and many of them are even free, the only components that may need to be purchased are tanks, pipes, mesh, and valves shown in table 4-1.The key advantages of cost-effective water filtration systems are their simplicity in implementation, even without the assistance of engineers, also the installation process is straightforward, and with proper guidance, homeowners can set up the filtration system themselves. In terms of the maintenance the water filtration systems are also relatively easy with seasonal revisions of the tanks and pipes are recommended to ensure optimal performance. Additionally, regular cleaning of the sand, gravel, and charcoal used in the filtration process helps remove accumulated dirt and maintain the efficiency of the system.

Table 4- 1: the total cost of rainwater systems materials

Materials	**Price* (SDG)**	**The monthly income in Sudan ***
Tank 500 liters	20000	80000__500000 **SDG** month 1 **SDG** = 0.001 **USD**
Tank 2000 liters	40000	
Tank 5000 liters	80000	
PVC pipes	5000	
3 Valves +6 nets +4 fitting	95, 20,60	

* The monthly income and materials prices mentioned in this research are subject to change, starting from 2022. This change is attributed to the ongoing conflict, which has had a significant impact on the stability of the economic environment[37].

The total cost of the rainwater system for the school is 105,725 SDG in USD is (105.724 USD) and for single house is 65,725 SDG in USD is (65.725 USD)

CHAPTER (5)

5 . Conclusion and Recommendation

5.1 Conclusion

In conclusion, Sudan, as one of the countries grappling with economic water scarcity, particularly Nyala City, has been experiencing the detrimental effects of water shortage during the summer season for several years.

The long-term analysis of rainfall patterns 2011_2020 in Nyala has revealed that the southern region of the city receives a higher amount of rainfall about 553 mm compared to the northern region that received 402 mm and with average 471 mm, emphasizing the crucial role of rainfall quantity in rainwater harvesting. To ensure the quality of collected rainwater from rooftops, the implementation of a sand filtration system was essential, this system effectively eliminates small particles, bacteria, and odors, resulting in clean water suitable for human consumption. When considering the implementation of rainwater harvesting, the size of the rooftop area plays a significant role in determining the amount of rainfall collected.

In this case, the school has a total rooftop area of 288 m^2, while the house has an area of 28 m^2 with a total rainfall obtained 108,518 liters/year for the school and 11,869 liters/year for the house Consequently, the quantity of rainfall obtained varies accordingly, highlighting the importance of adapting storage tank sizes to match the received rainfall. The key advantages of cost-effective water filtration systems are their simplicity in implementation, even without the assistance of engineers, also the installation process is straightforward, and with proper guidance, homeowners can set up the filtration system themselves.

The purpose of this research was to develop a technique for collecting rainwater from rooftops in order to alleviate the water shortages in Nyala City to address these challenges, implementing rainwater harvesting techniques has proven to be a viable solution. Rainwater harvesting is widely regarded as one of the most effective methods of water conservation, requiring minimal effort and cost for implementation. Furthermore, it offers significant time and cost savings as the water is freely provided by nature and cannot be monetized. Overall, rainwater harvesting presents a practical and efficient approach to mitigate the water scarcity issues faced by Sudan, particularly Nyala City. By harnessing the natural resource of rainfall, this technique offers a sustainable solution that addresses both economic and environmental concerns.

5.2 Recommendations

- ✓ Regular maintenance of storage tanks and cleaning of rooftops gutters, downspouts are recommended to ensure they are free from debris, such as leaves and twigs, also to prevent the buildup of sediment, algae, or any other contaminants in the storage tanks, this maintenance ensures the stored rainwater and rooftops remain safe for use.
- ✓ Maintenance of the water filtration systems is relatively straightforward, with seasonal revisions of tanks and pipes being recommended to ensure optimal performance, these regular checks contribute to the sustained functionality and effectiveness of the rainwater harvesting system.
- ✓ Promoting education and awareness among users about the benefits of rainwater harvesting, proper maintenance practices and educate individuals on the importance of water conservation and responsible usage of harvested rainwater also recommended.
- ✓ Using the proper rooftop materials are suitable for rainwater harvesting also recommended, such as metal, clay, corrugated iron sheet and concrete tiles., these materials are less likely to release contaminants into the collected rainwater compared to materials like asphalt shingles.
- ✓ A first flush system to divert and discard the initial runoff from the rooftop, this initial runoff often carries dirt, dust, and pollutants, which can affect the quality of the stored rainwater. The first flush system helps improve water quality by redirecting this initial runoff away from the storage tanks.

6 . REFERENCES

[1] R. T. Bailey, A. Beikmann, M. Kottermair, D. Taboroši, and J. W. Jenson, "Sustainability of rainwater catchment systems for small island communities," *J Hydrol (Amst),* vol. 557, pp. 137–146, 2018, doi: 10.1016/j.jhydrol.2017.12.016.

[2] P. Kumar, P. Yadav, and S. Chaudhari, "REVIEW PAPER BASED ON THE ROOFTOP RAINWATER HARVESTING (RRWH) OF BIET CAMPUS – LUCKNOW," no. 04, pp. 6388–6395, 2023.

[3] "Sudan's water crisis and the women fighting back." Accessed: Feb. 27, 2024. [Online]. Available: https://www.unep.org/news-and-stories/story/sudans-water-crisis-and-women-fighting-back

[4] P. Tamagnone, L. Cea, E. Comino, and M. Rosso, "Rainwater harvesting techniques to face water scarcity in african drylands: Hydrological efficiency assessment," *Water (Switzerland),* vol. 12, no. 9, Sep. 2020, doi: 10.3390/w12092646.

[5] Y. Mariana and B. A. Suryawinata, "Sustainable water management: Roof as a rainwater catchment area," *IOP Conf Ser Earth Environ Sci,* vol. 195, no. 1, 2018, doi: 10.1088/1755-1315/195/1/012094.

[6] C. Andoh, S. Gupta, and D. Khare, "Status of Rainwater Harvesting (RWH) in Ghana," *Current World Environment,* vol. 13, no. 1, pp. 172–179, 2018, doi: 10.12944/cwe.13.1.17.

[7] R. Villar-Navascués, A. Pérez-Morales, and S. Gil-Guirado, "Assessment of rainwater harvesting potential from roof catchments through clustering analysis," *Water (Switzerland),* vol. 12, no. 9, pp. 1–14, 2020, doi: 10.3390/W12092623.

[8] S. sangita Mishra*, S. B.K., and H. J. Rao, "Design of Rooftop Rainwater Harvesting Structure in a University Campus," *International Journal of Recent Technology and Engineering (IJRTE),* vol. 8, no. 5, pp. 3591–3595, 2020, doi: 10.35940/ijrte.e6519.018520.

[9] S. R. Mohapatra, T. Dash, P. Choudhury, Prof. G. Mohanty, and Dr. S. Swain, "Review on Design of Rooftop Rainwater Harvesting in Gandhi Institute for Technology (GIFT), BBSR," *Int J Res Appl Sci Eng Technol,* vol. 10, no. 5, pp. 672–680, 2022, doi: 10.22214/ijraset.2022.42286.

[10] "EVALUATION OF ROOFTOP RAINWATER HARVESTING POTENTIAL IN JORDAN MASTER THESIS ENVIRONMENTAL ENGINEERING ANAS JARADAT Thesis Advisor Assist . Prof . Dr . ENES ÖZKÖK," 2022.

[11] A. A. Latheef, D. J. Aqram, A. M. Ashik, and M. H. M. Raihan, "International Journal of Innovative Analyses and Emerging Technology A Project Report on the Construction of a Rooftop Rainwater Harvesting System for a College," no. July, 2023.

[12] S. R. Nadupuru and M. Shewale, “Rain Water Harvesting Technique Implementation for the Chhadvel Korde Village, Maharashtra,” *E3S Web of Conferences*, vol. 405, 2023, doi: 10.1051/e3sconf/202340504033.

[13] K. Bañas, M. E. Robles, and M. Maniquiz-Redillas, “Stormwater Harvesting from Roof Catchments: A Review of Design, Efficiency, and Sustainability,” *Water (Switzerland)*, vol. 15, no. 9, 2023, doi: 10.3390/w15091774.

[14] “Sudan | History, Map, Area, Population, Religion, & Facts | Britannica.” Accessed: Nov. 23, 2023. [Online]. Available: https://www.britannica.com/place/Sudan

[15] S. Development, *Sudan First State of Environment and Outlook Report 2020*. 2020.

[16] A. M. Omer, “Water resources management and sustainabledevelopment in Sudan,” *International Journal of Water Resources and Environmental Engineering*, vol. 2, no. 2, pp. 190–207, 2010.

[17] الدكتورجودة فتحي, “موارد مياه السودان واستخدامتها البشيريه.”

[18] A. K. Basheer, “PROSPECTS OF SUSTAINABLE UTILIZATION OF SUDAN WATER RESOURCES,” no. December 2008, 2016, doi: 10.13140/RG.2.1.1732.9041.

[19] F. Water, “Sudan water resource.” [Online]. Available: https://water.fanack.com/sudan/water-resources-in-sudan

[20] N. Abduel, H. Mohamed, H. Mohamed, F. Osman, and S. Zaki, “Rainfall Changes in Central Sudan Between 1960 - 2010 Rainfall Changes in Central Sudan,” vol. 2, no. January 2014, 2021.

[21] K. M. Elhag and W. Zhang, “Monitoring and Assessment of Drought Focused on Its Impact on Sorghum Yield over Sudan by Using Meteorological Drought Indices for the,” pp. 1–21, 2018, doi: 10.3390/rs10081231.

[22] “Nile River.” Accessed: Feb. 26, 2024. [Online]. Available: https://education.nationalgeographic.org/resource/nile-river/

[23] J. R. Allan *et al.*, “Navigating the complexities of coordinated conservation along the river Nile,” *Sci Adv*, vol. 5, no. 4, pp. 1–12, 2019, doi: 10.1126/sciadv.aau7668.

[24] J. S. Birks and C. A. Sinclair, “The Democratic Republic of The Sudan,” *ARAB Manpower*, pp. 297–314, 2020, doi: 10.4324/9781003074489-18.

[25] A. M. Omer, “Focus on groundwater in Sudan,” *Environmental Geology*, vol. 41, no. 8, pp. 972–976, 2002, doi: 10.1007/s00254-001-0476-9.

[26] R. Salama, “Rift basins of the Sudan,” *Sedimentary basins of the world*, pp. 105–149, 1997, [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1874599797800093

[27] S. R. Ali and R. K. Jain, “Rain Water Harvesting System for College of Engineering, Teerthanker Mahaveer University, Moradabad,” *Int J Innov Res Sci Eng Technol*, vol. 03, no. 08, pp. 15649–15657, Aug. 2014, doi: 10.15680/ijirset.2014.0308077.

[28] A. M. Elhassan, “حصاد المياه في السودان,” no. December, 2018.

[29] H. Fish and C. Shenyi, “Water resources management.,” 1986.

[30] E. , Mulder and F. , van Steenbergen, “Sudan Water Policy Review and Analysis,” no. November, 2021.

[31] Mohammed Ishag Altaib Gomma, “Challenges and Opportunities of Water Safety Planning Implementation in Nyala, South Darfur State, Sudan (2017),” *עלון הנוטע*, vol. 66, no. 2017, pp. 37–39, 2018, [Online]. Available: https://www.fairportlibrary.org/images/files/RenovationProject/Concept_cost_estimate_accepted_031914.pdf

[32] F. Hall, “Challenges Facing Groundwater Management in Sudan Gamal Abdo and Abdin Salih Department of Civil Engineering, Faculty of Engineering, University of Khartoum,” no. February, pp. 17–20, 2012.

[33] “Water resources program in the Sudan Nyala water resources study”.

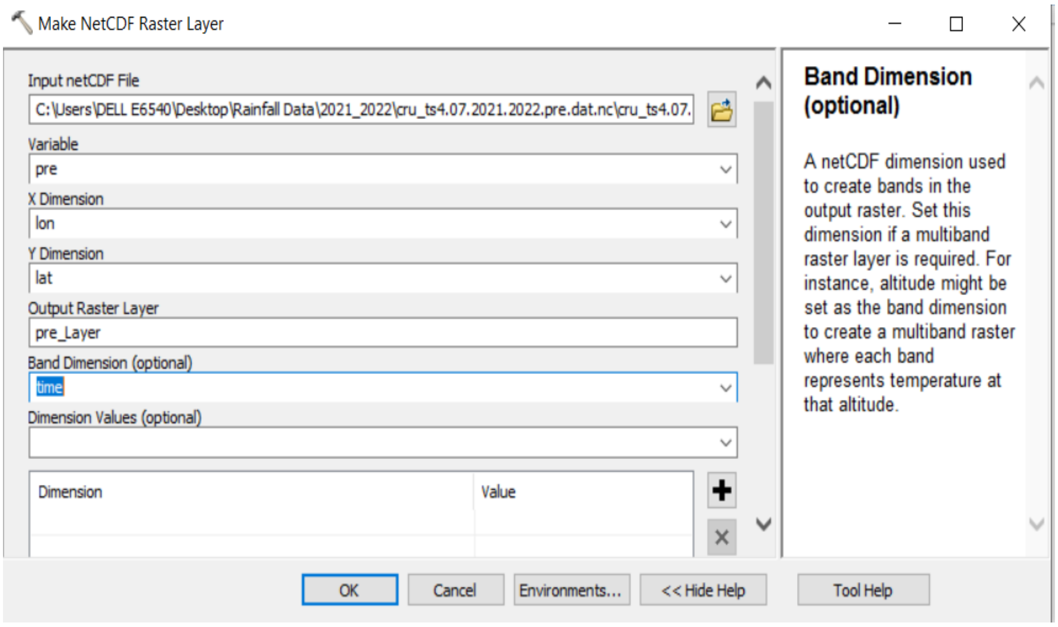
[34] D. J. Maguire, “ArcGIS: General-Purpose GIS Software,” *Encyclopedia of GIS*, pp. 1–8, 2016, doi: 10.1007/978-3-319-23519-6_68-2.

[35] S. Load *et al.*, “Introduction to ArcGIS 10.2,” pp. 1–26.

[36] C. M. D. Quiminsao and J. A. Sumalinog, “Factors Affecting the Students ’ Achievement and Attitude in Learning Factors Affecting the Students ’ Achievement and Attitude in Learning AutoCAD,” no. June, 2023, doi: 10.34104/ajeit.023.01300140.

[37] “Economic Indicators | List By Country.” Accessed: Mar. 21, 2024. [Online]. Available: https://tradingeconomics.com/countries

7 . Appendix



Make NetCDF Raster Layer

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Variable: pre

X Dimension: lon

Y Dimension: lat

Output Raster Layer: pre_Layer

Band Dimension (optional): time

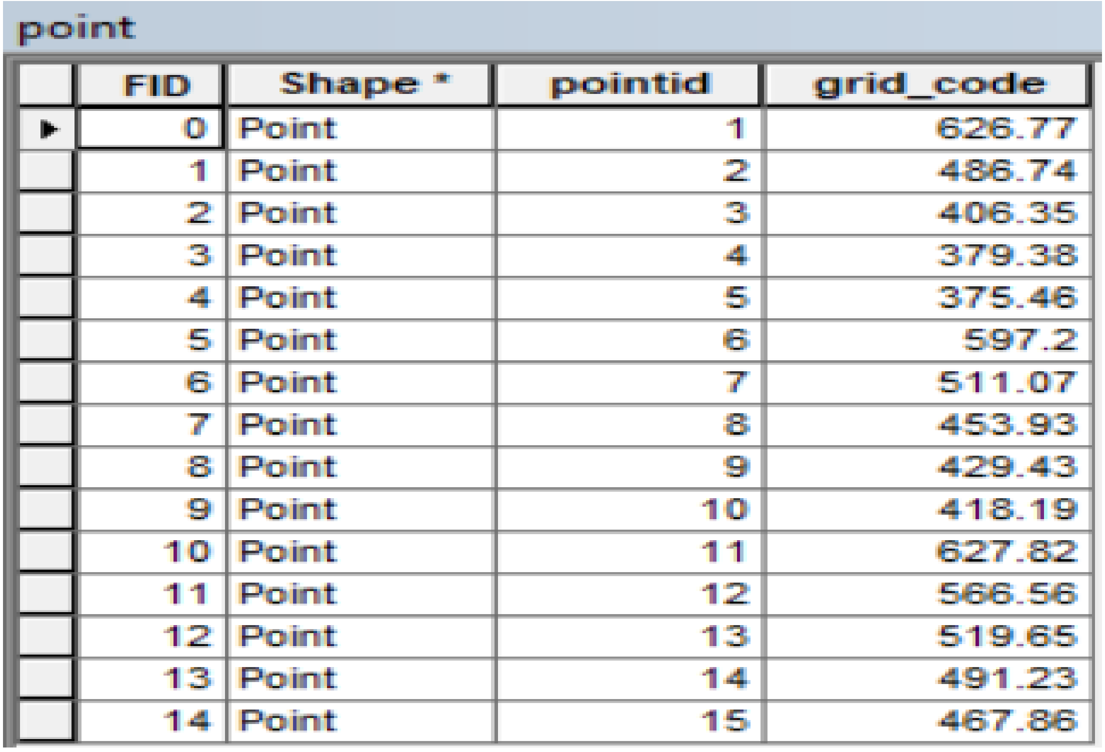
Dimension Values (optional):

Dimension	Value

Band Dimension (optional)

A netCDF dimension used to create bands in the output raster. Set this dimension if a multiband raster layer is required. For instance, altitude might be set as the band dimension to create a multiband raster where each band represents temperature at that altitude.

Figure 0- 1: NetCDF Raster



point

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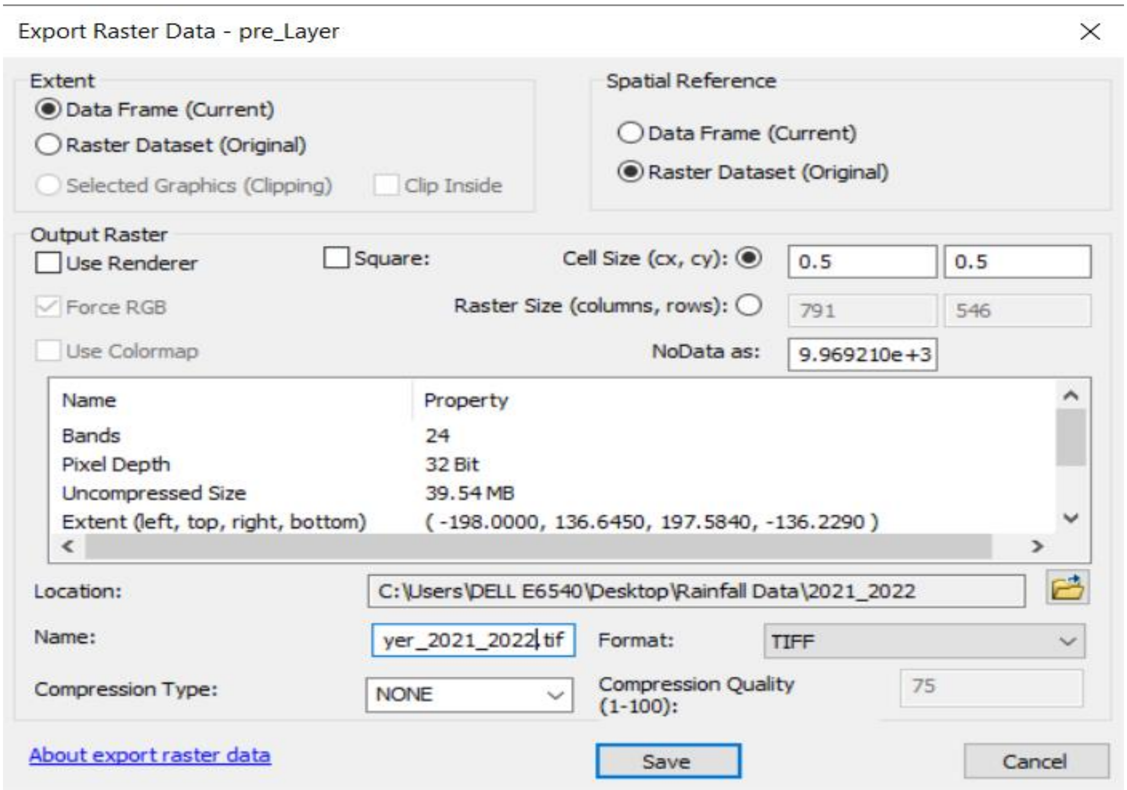
1	Point	2	486.74
2	Point	3	406.35
3	Point	4	379.38
4	Point	5	375.46
5	Point	6	597.2
6	Point	7	511.07
7	Point	8	453.93
8	Point	9	429.43
9	Point	10	418.19
10	Point	11	627.82
11	Point	12	566.56
12	Point	13	519.65
13	Point	14	491.23
14	Point	15	467.86

Figure 0- 2: Rainfall point



Export Raster Data - pre_Layer

Extent
● Data Frame (Current)
○ Raster Dataset (Original)
○ Selected Graphics (Clipping) ☐ Clip Inside

Spatial Reference
○ Data Frame (Current)
● Raster Dataset (Original)

Output Raster
☐ Use Renderer
☐ Square:
Cell Size (cx, cy): ● 0.5 0.5
☑ Force RGB
Raster Size (columns, rows): ○ 791 546
☐ Use Colormap
NoData as: 9.969210e+3

Name	Property
Bands	24
Pixel Depth	32 Bit
Uncompressed Size	39.54 MB
Extent (left, top, right, bottom)	(-198.0000, 136.6450, 197.5840, -136.2290)

Location: C:\Users\DELL E6540\Desktop\Rainfall Data\2021_2022
Name: yer_2021_2022.tif
Format: TIFF
Compression Type: NONE
Compression Quality (1-100): 75

Figure 0- 3: Raster Data

S I N A Stars

سينا ستارز

للصناعة و التجارة

خزانات مياة

قائمه اسعار خزانات الاستانلس ستيل
(ستار ستيل)

السعه	القطر	الارتفاع بالحامل	السعر
500لتر	76سم	170سم	5150ج
1100 لتر	106سم	170سم	7550ج
1500 لتر	106سم	195سم	9400ج
1800 لتر	120سم	185سم	9850ج
2000 لتر	120سم	210سم	10750ج
2500 لتر	120سم	235سم	14800ج
3000 لتر	152سم	210سم	17350ج
3500 لتر	152سم	235سم	20550ج
4000 لتر	152سم	265سم	22600ج
5000 لتر	152سم	310سم	26700ج
6000 لتر	152سم	360سم	32400ج
8500لتر	191سم	360سم	72250ج
10000لتر	191سم	410سم	82600ج

قائمه اسعار خزانات الاستانلس ستيل(الافقي)

السعه	القطر	الطول	الارتفاع	السعر
2000 لتر	120سم	150سم	180سم	18150ج
3000 لتر	120سم	150سم	270سم	23950ج
5000 لتر	152سم	182سم	290سم	35050ج
8500 لتر	191سم	220سم	320سم	77750ج
10000 لتر	191سم	220سم	370سم	88750ج

*الخزان معتمدمن(هيئه الابنيه التعليميه ، وزاره الصحه . المركز القومى للبحوث)

المركز الرئيسي ٧١ شارع جامعة الدول العربية – المهندسين ت : ٣٧٦١١٢٧٧٠ – ٣٧٦٢٢٨٠٣٤
تليفاكس : ٣٧٦١١٢٠٢٦ – ٣٧٦٠٣٧٩٧ – ٣٧٦١٥٦٢٠
الفرع ٧ ش الكوثر – من جامعة الدول ٣٧٦٢٢٨٠٣٤ – ٣٧٦١١٢٧٧٠
المصنع بنى سويف – بياض العرب – المنطقة الصناعية

Figure 0- 4: List of The Tanks Price

Figure 0-6: Elshahid Hamza Basic School from Google Earth

Figure 0-7: The Residential House from Google Earth

Questionnaires and interviews of cost and culture acceptance for rainwater technique and filtration system:

February _ March 2024

The main goal of this study is to develop a technique for collecting rainwater from rooftops in order to alleviate the water shortages in Nyala City 30 people were interviewed in this study involved water corporation staff and the citizens the questions are devolved by:

1. Personal Information for water corporation staff:

Name………………………………………………………………………………...

Department/Role……………………………………………………………………….

Years of experience in the water sector ……………………………………………….

Location……………………………………………………………………………….

2. Familiarity with Rainwater Filtration Systems:

a. Are you familiar with rainwater filtration systems?

- ○ Yes
- ○ No

b. Have you received any training or information about rainwater filtration systems?

- ○ Yes
- ○ No

c. How would you rate your knowledge level about rainwater filtration systems?

- ○ Very knowledgeable
- ○ Somewhat knowledgeable
- ○ Not very knowledgeable
- ○ Not at all knowledgeable

3. Perception of Rainwater Filtration Systems:

a. In your opinion, what are the potential benefits of implementing rainwater filtration systems?

b. Do you think rainwater filtration systems align with the goals and mission of the Water Corporation?

○ Yes, they align well
○ Yes, but there may be some conflicts
○ No, they do not align
○ Not sure

c. Are there any specific concerns or challenges you foresee in implementing rainwater filtration systems?

4. Cost Analysis:

a. How do you perceive the cost-effectiveness of rainwater filtration systems compared to traditional water supply systems?

○ More cost-effective
○ Equally cost-effective
○ Less cost-effective
○ Not sure

b. Are there any budgetary constraints or financial considerations that may impact the implementation of rainwater filtration systems?

5. Cultural Acceptance:

a. How do you think rainwater filtration systems would be culturally accepted by the community?

Highly accepted

○ Moderately accepted
○ Not very accepted
○ Not at all accepted

b. Are there any specific cultural factors that should be considered in promoting rainwater filtration systems?

6. Implementation and Training:

a. What resources or support would you need to successfully implement rainwater filtration systems?

b. Would you require any training or additional knowledge to work with rainwater filtration systems effectively?

7. Suggestions and Feedback:

a. Do you have any suggestions or feedback regarding the implementation of rainwater filtration systems within the Water Corporation?

Additional Information (optional):

a. Is there any additional information or comments you would like to provide?

Demographic Information of Nyala city citizens:

Age……………………………………………………………………………………….

Gender……………………………………………………………………………………

Occupation……………………………………………………………………………….

Location………………………………………………………………………………….

Cultural Acceptance:

a. Are you familiar with rainwater filtration systems?

- Yes
- No

b. Have you ever used or seen a rainwater filtration system?

- Yes
- No

c. Do you think rainwater filtration systems are culturally acceptable in the community?

- Yes, it is widely accepted
- Yes, but it is not widely accepted
- No, it is not accepted at all
- Not sure

d. What cultural factors do you think may influence the acceptance of rainwater filtration systems in the community?

Perception of Cost:

a. Do you believe rainwater filtration systems are cost-effective?

- Yes, they are highly cost-effective
- Yes, but they have moderate cost-effectiveness

- No, they are not cost-effective
- Not sure

c. Are there any specific cost concerns or barriers that prevent you from considering a rainwater filtration system?

Environmental Awareness:

a. How concerned are you about conserving water resources?

- Very concerned
- Somewhat concerned
- Not very concerned
- Not at all concerned

b. Do you believe rainwater filtration systems contribute positively to water conservation efforts?

- Yes, they are highly effective
- Yes, but their effectiveness is moderate
- No, they are not effective
- Not sure

Suggestions and Feedback:

a. Do you have any suggestions or feedback regarding rainwater filtration systems, their cultural acceptance, or cost-effectiveness?

Additional Information (optional):

Is there any additional information or comments you would like to provide?

Once again, thank you for your participation and for sharing your thoughts and experiences. We truly value your input and look forward to utilizing it to inform our decision-making process moving forward.