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INSTITUTE OF WATER AND ENVIRONMENT

Modelling Water Resource System for Effective Water Allocation of Juba Basin in Southern Somalia

By

Abdullahi Hassan Hussein

A thesis

Submitted in Partial Fulfilment of the Requirements for the Master of Science Degree In Integrated River Basin Management

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DECLARATION

I, **Abdullahi Hassan Hussein,** hereby present for consideration by Institute of Water and Environment at Mekelle University, my dissertation in partial fulfilment of the requirement for the Degree of Masters in **Integrated River Basin Management (IRBM)** which is entitled **Modelling Water Resource System for Effective Water Allocation of Juba basin in Southern Somalia**. I sincerely declare that this thesis is the product of my own efforts. No other person has published a similar thesis and study which I might have copied, and at no stage will this be published without my consent and that of the **Institute of Water and Environment**.

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ABSTRACT

Water demands in basins of Sub-Saharan Africa and in other parts of the world are increasing due to rapid urbanization, poverty and food insecurity, growing energy demands and climate change. The region's primary economy is agriculture and there is need to increase water uses for both consumptive and non-consumptives e.g. food and hydropower production, therefore water allocation among competing water users are urgently required to avoid a water-based conflict, overutilization of the rivers' scarce water resources, and address the challenges facing the basins common forms of resource management. The overall objective of this study was to model and evaluate the water resources system for effective water allocation of Juba basin in Southern Somalia in a sustainable manner for social, economic and environmental benefits. The WEAP model has been used throughout the world to analyse a diverse set of water management issues for small communities and large managed watersheds alike, therefore WEAP model was used for analysis and all data requirements by the model was collected from different sources. The model was set up for a current account year in 2014 and last year of scenarios in 2055. The water resources system of the basin were modelled and evaluated while giving consideration for existing and planned developments in relation to current and future water demands among multiple water users in the basin. Current situation of water demands among water users were modelled and the result indicated that all demands satisfied fully, even though the remaining river flow for months January, February and March were almost zero after deduction. Three scenarios for future water demand were created namely reference, scenario one and scenario two therefore unmet demands were encountered during dry months and increase of water demands year to year due to expansion of irrigated area, population growth and urbanization. WEAP demand management approach for efficiency irrigation of 10%, 20% and 25% were applied in short, medium and long term in scenario two respectively and a significant reduction compared with scenario one water demands were observed. Based on the result, water allocation strategies were identified such as water storage using dams and other structures to get balance of supply and demand while integrated water resources management and coordination and cooperation among riparian states are recommended. Further researches on groundwater availability as an alternative water sources to meet the unmet demands were also suggested.

Key words: Modelling, Water allocation, WEAP, Scenario, Demand, Supply

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ACRONYMS

AfDB	African Development Bank
BCM	Billion Cubic Meter
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DSS	Decision Support System
EFA	Environmental Flow Assessment
EU	European Union
FAO	Food Agriculture Organization of the United Nation
FSNAU	Food Security and Nutrition Analysis Unit
GHA	Greater Horn of Africa
GIS	Geographic Information System
GWP	Global Water Partnership
IDPs	Internal Displaced People(s)
IGAD	Intergovernmental Authority for Development
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IWRM	Integrated Water Resource Management
LGP	Length of Growing Period
MCM	Million Cubic Meter
MDGs	Millennium Development Goals

MoA	Ministry of Agriculture
MoLR	Ministry of Livestock and Range
MoNP	Ministry of National Planning
MoNR	Ministry of National Resources
MoWE	Ministry of Water and Energy
NAPA	National Adaptation Programme Action for climate change
NWC	National Water Centre
RIBASIM	River Basin Simulation Model
SEI	Stockholm Environment Institute
SRTM	Shuttle Radar Topography Mission
SWALIM	Somalia Water and Land Information Management
SWAT	Soil and Water Assessment Tool
UN	United Nation
UNDP	United Nation Development Programme
UNESCAP	United Nations, Economic and Social Commission for Asia and the Pacific
UNFPA	United Nations Population Fund
UN-HABITAT	United Nations Human Settlements Programme
USGS	United States Geological Survey
WASP	Water quality Analysis Simulation Program modeling system
WB	World Bank
WEAP	Water Evaluation and Planning
WRAP	Water Rights Analysis Package

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CHAPTER 1: INTRODUCTION

1.1. Background of the study

Water is the most essential element to life on Earth, sometimes scarce resource and yet fundamental for a living. It is also essential for both agriculture in many regions of the world and means to achieve sustainability in production systems. Maximizing net returns with the available resources is of the utmost importance, but doing so is a complex problem, owing to the many factors that affect this process (e.g. climatic variability, irrigation system configuration, production costs, and subsidy policies). Many regions are facing formidable freshwater management challenges. Allocation of limited water resources, environmental quality and policies for sustainable water use are issues of increasing concern (Uitto, 2004).

Overexploitation of water resources continues to be the greatest constraint on sustainable agricultural development, an important factor to poverty alleviation. Water has been recognized as an essential component of food security (UNWATER, 2006), with the World Summit on Sustainable Development in 2002 drawing more attention to the importance of water resources management in meeting the Millennium Development Goals (UN, 2002).

In the context of a river basin, allocation priority becomes important when the full water rights of all water users cannot be supplied. A prioritized system allows the water managers to take control over the water use in a river basin by allocating water in a preferred order. This preferential order could be based on regional or national objectives (Weragala, 2010).

In the context of water management, decision makers in the arid and semi-arid states face a question about how much water should be allocated among competing uses. Around one-fifth of the world's population currently lives in water scarce areas, and more than two-thirds will live in areas with physical or economic water scarcity by 2025 (UN WATER, 2007).

Water resources management becomes increasingly critical and as new, local and national sources of water become scarce, limited, expensive and difficult to exploit. Many countries in the arid and semi-arid regions that are facing water crisis will be increasingly forced to consider the possibilities of utilizing the water that is available in river basins.

Water allocation has received considerable attention in the recent past years by the scientific community. Qubaa et al. (2002) discussed the optimal allocation of water between market uses but did not directly consider management to maximize benefits from the distribution of water among consumptive and non-consumptive uses.

Ward and Lynch (1996) developed ‘An Integrated Optimal Control Model’ that maximized the social benefits arising from allocating reservoir (river basins) water among lake recreation, in stream recreation and hydroelectric power generation uses. They showed an optimal management policy could yield more net benefits than the historical management policy.

The demands for fresh water from basin water users cannot be fully satisfied beyond the capacity of a river basin. However, it is possible to manage the supplies and demands in a manner to minimize the losses to each user. Unfortunately, most of the river basins in the developing countries are poorly managed, causing social and economic losses to basin water users. Examples of such situations are abundant throughout the developing world.

In Somalia, Water resources management and development was highlighted as one of the three key program areas, under which a number of priority adaptation activities were identified in Somalia National Adaptation Programme of Action to Climate Change (NAPA). GWP (2015) indicated that increased conflicts and hostilities due to competition for water between communities and amongst the pastoralists in Somalia. Therefore, water allocation is very crucial in Somalia, particularly the perennial rivers, Juba and Shabelle river basins which are the breadbasket of majority of the Somali people who live in Southern Somalia (MoNR, 2013, AfDB, 2014).

In Somalia, achieving most of the Millennium Development Goals (UN 2000) such as alleviating poverty, eradicating hunger and providing basic sanitation, directly depends on access to a sustainable water supply, whereas the demand for water resources has been rapidly increasing in recent decades due to population growth, urbanization, dietary changes, and irrigation expansion (FAO-SWALIM, 2012; MoNR, 2013).

Juba basin in Southern Somalia facing many challenges including water scarcity, population growth, urbanization, climate change and lack of water resource management that may result conflict among water users, therefore holistic water management approach is required (MoNR, 2013; Elmi, 2014).

In contrast to increasing variations in water supply due to the expected global warming (IPCC 2007), the demand for water resources has been rapidly increasing in recent decades due to population growth, urbanization, dietary changes, industrial development and irrigation expansion (Vörösmarty 2000).

The GHA or IGAD sub-region suffers from severe effects of climate change and challenges of common sharing water resources. The recurring and severe droughts and floods have caused widespread famine, ecological degradation, poverty and economic hardships in the region. The impacts of climate change have been more severe because of inadequate water management facilities and practices, erratic and unpredictable rainfall patterns, and high ambient temperatures (ADB, 2010).

The IGAD Member States recognize the strong nexus between water reliability – or, in the worst-case scenario, scarcity – and conflicts. They recognize that central to the well-being of the population is access to reliable quantities of water of sound quality and predictable availability. Since much of the water resources of the region originate in well-watered areas and flow through increasingly arid areas crossing national administrative boundaries, a key element for transboundary water management in the region is sustainable and equitable resource development, use and management, backed by adequate policy and legal frameworks at the regional, basin/aquifer and national levels.

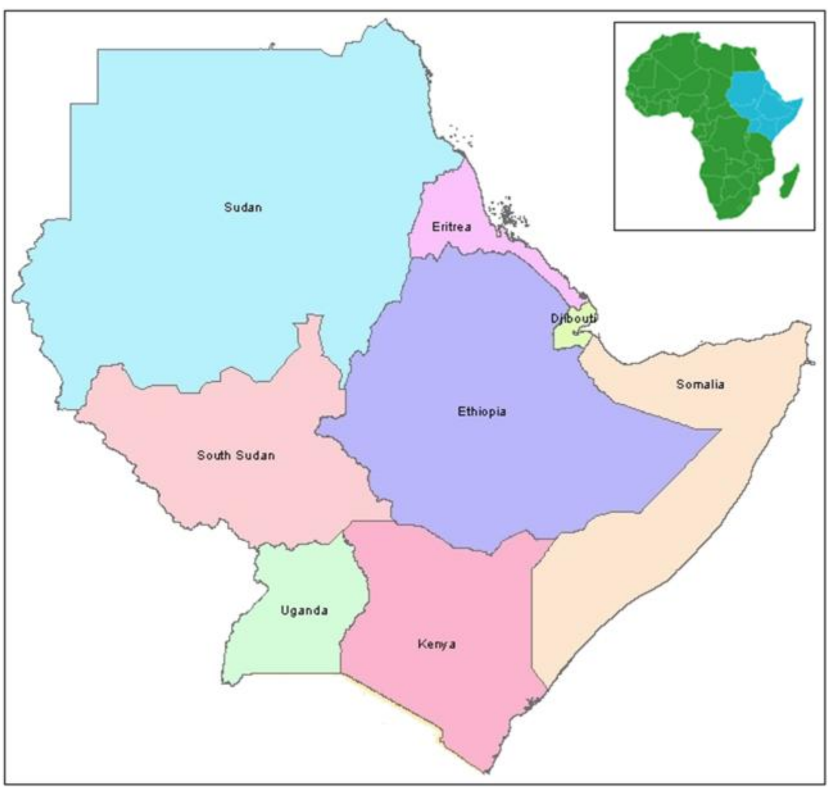

Figure 1.1: IGAD sub-region member states.

1.2. Problem statement

Approximately 30% of total global land area comprises populated arid and semi-arid areas and water shortages are a major obstacle to social and economic development in these areas including Somalia.

Water demands in basins of Sub-Saharan Africa and in other parts of the world are increasing due to rapid urbanization, poverty and food insecurity, growing energy demands and climate change (Faurès and Santini, 2008).

The Juba basin in the Horn of Africa is a transboundary river basin shared by Ethiopia, Kenya and Somalia. It is estimated that over 90% of the flows in Juba River within Somalia is contributed by the catchment outside Somalia. The Horn of Africa is water scarce regions which are vulnerable to hydrological variations and have already joined to the list of countries that are facing water scarcity.

The region's primary economy is agriculture and there is a desperate need to increase water uses for food, hydropower production and other uses, therefore water allocation among competing water users are urgently required to avoid a water-based conflict, overutilization of the rivers' scarce water resources, and to address the challenges facing the basins common forms of resource management.

Water resources are limited in Somalia both in quantity and quality hence effective water allocation becomes particularly important as demand exceeds supply. Inadequate water resources management is the most important constraint towards addressing the vulnerability of Somalia to disasters due to adverse climatic conditions. Somalia is lacking know-how to properly manage its available water resources. Effective water allocation among water users in Juba basin will enable Somalia to control better manage its water resources and no study related water allocation has been done.

In Somalia, water allocation among water users is very crucial and important in order to avoid conflicts among water users, adopt sustainable mechanisms of water resources management and improve the life standard of the people through effective and efficient water use therefore this study will focus on how the available water resources in the basin are allocated efficient and sustainable manner among multiple use.

1.3. Objective of the study

1.3.1 General Objective

The overall objective of this study was to model the water resources system for effective water allocation of Juba basin in Southern Somalia in a sustainable manner for social, economic and environmental benefits.

1.3.2 Specific objective

The specific objectives of the study were:

- To evaluate the capability of the Juba basin water resource to fulfill the current and future water demands among multiple water users
- To identify strategies and mechanisms for efficient utilization of available water resources of Juba basin
- To recommend the way forward regarding the care, protection and efficient use of water through Integrated River Basin Management

1.4. Research Questions

- Can Juba basin water resource fulfil existing and future water demands to all water users?
- What are the strategies and mechanisms for efficient utilization of available water resources in Juba basin of southern Somalia?
- What are the ways forward at the basin level towards ensuring effective and efficient water utilization, current, for sustainable water resource availability in the future?

1.5. Significance of the study

The study will assist the decision and policy makers, administrators, planners and water resources professionals, who are responsible for management of water resources, to assist them in formulating and implementing effective and efficient water allocation systems in Somalia to better manage the water demand and supply cases and better understand the behaviour of the system of water allocation of Juba river basin in Southern Somalia in the present and future situation.

It will also help all relevant stakeholders at ground level to use water resources efficient and sustainable manner while giving consideration social, economic and environmental benefits.

1.6. Scope and Limitation of the study

1.6.1 Scope of the study

The study had been drawn from the field of integrated River Basin (water resources) Management and concerned with the modelling of water resources system for effective water allocation of Juba basin in southern Somalia.

1.6.2 Limitation of the study

This study focuses on surface water and does not take into account groundwater due to lack of detail information and data.

Because of security reasons, accessibility of the whole study area was very limited, only the upstream part of the Juba basin was accessible while agricultural area are more concentrated and found in the downstream part of the basin. The security situation is still fragile and getting access to the study area still limited.

Data limitation was another major challenge that has been faced due to lack of updated data for some necessary data that are required to be updated ones therefore available data was used while faced limited data problems.

In Somalia, there are still challenges regarding data and information management. Although centralized database management is a good practice in the field of research, the country has not yet been able to achieve this, even with the growing rate of knowledge of information and communication technology. However, one might argue, the obvious reason for this problem is the prolonged civil unrest in the country for the last two decades, which led to disappearance of most water resource information that was collected before the civil war.

However, in 1991, the hydrometric network and river gauging stations have totally collapsed with no monitoring or collection of water level data in the Juba sub-catchments.

Somalia Water and Land Information Management (SWALIM) under FAO are trying to recover lost information from all available sources and re-establish data collection networks since early 2001, parts of the Somali pre-war hydrometric network have been reinstated by the SWALIM. Two gauge stations in upstream and middle stream in Luuq town and the Bardere town along Juba basin have been reinstated respectively, although the recent data at Luuq compare reasonably well with the pre-war data, in contrast to Bardere where there are some notable differences that needs to be done further analysis.

1.7. Structure of the thesis

This thesis is structured into five chapters. A brief summary of each chapter is given below:

Chapter one: Introduction

This chapter gives a general overview of the subject matter to be studied, justification and problem statement of why it is studied, general and specific objective and how the objectives can be achieved through research questions, significant, scope and limitation of the study as well as thesis structure.

Chapter 2: Literature review: This chapter discusses the water resources management aspects in Somalia and theories related water allocation principles, mechanisms and rights by describing the theories of water resources management and allocation and overview of different water allocation models and their availability and access, data input requirements and key outputs.

Chapter 3: Methods and Materials: This chapter gives a brief description of the study area, methods of data collection and analysis, software and materials used in the study.

Chapter 4: Results and Discussion: This chapter deals with the result and discussion of the study which emphasize water resources system and modelling current and future water demands prioritizing and setting water allocation system with different scenarios.

Chapter 5: Conclusion and Recommendation: Conclusion summarizes the main result findings of the research in view of the research objectives and describes the general field. Recommendation shows what should be done based on the research findings and suggest further researches.

CHAPTER 2: LITERATURE REVIEW

2.1 Water Resources Availability and Use in Africa

The average rainfall for African continent is about 670 mm per year, but the spatial and temporal distributions are very varied. Due to high rates of evaporation, renewable water resources constitute only about 20 percentage of total rainfall on average. In the Sudano-Sahelian and Southern African sub-regions, renewable water resources constitute only about 6% and 9% respectively. African water resources are also characterized by the multiplicity of transboundary water basins. They cover 64% of the continent's land area and contain 93% of its total surface water resources. There are about 80 Transboundary River and lake basins in Africa and over 38 transboundary aquifers. Groundwater is the main source of drinking water for more than 75% of the African population. Withdrawals of water are estimated to be about 3.8% of total annual renewable water resources. These withdrawals are used mainly for agriculture at 85% of the total, for community water supply at 9% and for industry at 6%. Therefore, there is a high potential for development of Africa's renewable water resources, although this potential can be realized only in certain areas because abundant renewable water resources are not distributed evenly over the continent.

The competition for limited resources is a direct consequence of the pressure within pastoral communities. Easing the water and pasture constraints would greatly reduce the often vicious competition for access to natural resources. Inadequate access to water is arguably the most binding of the constraints that pastoralists face. The GHA region has scarce water resources. The mean annual rainfall is low for more 76% of the area, sometimes as low as below 50mm per annum. There is, therefore, strong competition for water among multiple users: domestic, industrial, agricultural (including irrigation and livestock), and the need for a residual for the environment. The main thrust of development programmes is to meet the needs of multiple users. Sustainable approaches to water sector development in general and for pastoral areas in particular, require a comprehensive approach.

Key Water Challenges:

The key water resource challenges facing Africa can be summarized as:

1. Ensuring that all have sustainable access to safe and adequate water supply and sanitation services to meet basic needs;
2. Ensuring that water does not become the limiting factor in food and energy security;
3. Ensuring that water for sustaining the environment and life-supporting ecosystems are adequate in quantity and quality;
4. Reforming water-resource institutions to establish good governance and an enabling environment for sustainable management of national and transboundary water basins and for securing regional cooperation on water-quantity and water quality issues;
5. Securing and retaining skilled and motivated water professionals;
6. Developing effective systems and capacity for research and development in water and for the collection, assessment, and dissemination of data and information on water resources;
7. Developing effective and reliable strategies for coping with climate variability and change, water scarcity threats, and the disappearance of water bodies;
8. Reversing increases in man-made water-quantity and quality problems, such as overexploitation of renewable and non-renewable water resources and the pollution and degradation of watersheds and ecosystems;
9. Achieving sustainable financing for investments in water supply, sanitation, irrigation, hydropower, and other uses and for the development, protection, and restoration of national and transboundary water resources;
10. Mobilizing the political will, creating awareness, and securing commitment among all with regard to water issues, including appropriate gender and youth involvement.

2.2 Water Resource Management in Somalia

2.2.1Water Allocation and Rights in Somalia

Somalia is classified as a chronically water scarce country. Over 90% of the arid and semi-arid land areas have extremely limited access to water resources. There are two main sources of water in Somalia: Surface water, in rivers, springs and as rain, and ground water, in aquifers of various depths. The two rivers, Juba and Shabelle, are in the south of the country and both originate in the

Ethiopian Highlands from where they draw the bulk of their water (Basnyat, 2007**;** Petersen. et.al, 2012).

There was no effective legislation in Somalia governing the access to, allocation and use of the country's water resources. According to traditional local custom the right to use river water for irrigation in Juba River depends only on access to land along the river. Anyone who purchases a pump and owns or has the right to use land along the river can pump from the Juba. No approval or registrations are required and no charges are levied. Such a situation encourages water misuse and wastage that could also result in degradation of the resources and ecosystem of which it is a part. In the dry season, the lack of water allocation mechanism also result in water being pumped in the upper reaches for irrigation seasonal crops while the same water is badly needed in the lower reaches for the perennial crops of sugarcane, banana and rice. Water stress and low yields are the inevitable results. To overcome this unsatisfactory situation, a number of FAO mission visited Somalia and a draft national water resource law was prepared in 1984 while the proposes law appears to be comprehensive in terms of water rights, improvement should be considered in the following areas:

- Sectoral water allocation: water allocation to perennial crop diversions being presently accorded a higher priority than water use efficiency and needs of annual or seasonal crops.
-Water pricing policy: there is allowance for price differentiation, but no adequate criteria for use of this mechanism to implement allocation policy, e.g. to favour efficiency users. Also water fees could cover only recurrent costs for water delivery, but not capital investment cost.
-Water management, administration: the law would simulate administrative inefficiency and higher costs by creating a large administration without regulating the principles and process for its structuring.
-Omissions: the proposed law does not contain several key issues, including the status of water user groups, and the body of law which will settle and enforce disputes and rulings.

Implementation of the law has been slow and establishment of the National Water Centre (NWC) and the Juba basin master plan have been achieved before the civil war broke out in Somalia but unfortunately due to civil unrest till now no implementation of the master plan and all the government intuitions collapsed while the government is engaged in security issue currently.

2.2.2 Water Management Structure in Somalia

Despite the lack of substantive water legislation, the Somali Government nonetheless manages to maintain a certain amount of coordination water management through an entity known as the National Technical Committee. This body includes members from the Ministries of Mineral and Water Resources, Planning, Agriculture, Livestock Forestry and Range, Health, and Juba Valley Development among others. Further, the Committee deals in its agenda with water and water-related issues (including the question of water legislation).

Rather, because of the scarcity of Somalia's water supplies and the great distances which frequently separate water sources from each other, it is indispensable to ascertain what needs or potential needs are dependent upon each water source. Only with such information can the sectoral allocation of water between agriculture, domestic users, livestock and industrial users be undertaken. The same applies to such matters as an emergency action to be taken during times of drought, requiring water conservation measures to stretch very limited resources, and measures to control and prevent the transmission of waterborne diseases. It is important that such measures be prescribed in the law as integral parts of the plan.

The absence of a water policy and the unavailability of easily accessible water data in Somalia have other consequences as well. It appears that no complete register of water diversions from any river system or aquifer is maintained in the country. Nor is there any firmly fixed scheme of priorities that is applied to users. Thus, it is impossible to give protection to prior water rights; further, there is no clear consensus as to what kind or kinds of uses should be preferred when water becomes scarce. The result, in times of shortage settled farmers, who developed perennial crops such as banana with irrigation water, have recently found their diversions curtailed as a result of sharing with newcomers who may use river water, not to irrigate other perennial crops, but annual cash crops instead.

Theoretically, this structure is meant to operate at the local level, in order to take care of and informally resolve conflicts between and among individual users.

Available water supplies can be allocated among the domestic, livestock, agricultural, commercial and industrial sectors on a district-by-district basis if successful gathering data about 1) the availability of water from each water source and 2) the various water needs that can be supplied from each source. If sectoral water allocation is undertaken, monitored and enforced - especially in accordance with a scheme of priorities that determines the order of restriction or termination of water use in the event of shortage then conflicts between water users are more likely to be resolved. At least, disputes between perennial crop farmers' and cash crop farmers or between farmers and livestock owners can be settled. Whether disputes between individual water users within each sector can be prevented or resolved will depend upon the effectiveness of the regulatory system.

The mechanisms for coordinated water development and management in Southern Somalia existed in relevant legislation, especially the National Water Resources Law of 1984. This law ensured the regulation of access to and use of the Juba waters. Water legislation institutionalized water management through laws that regulated functioning of the institutions involved. This arrangement established the ways in which water could be exploited nationally, and endowed organizations with certain resources and the authority to facilitate development and efficient utilization of water resources. The Committee dealt with water and water-related issues, including water legislation. The administration of water development in the Juba Valley rested with the Ministry of National Planning and Juba Valley Development (Agrar-Und Hydrotechnic GMBH, 1990; Basnyat, 2009).

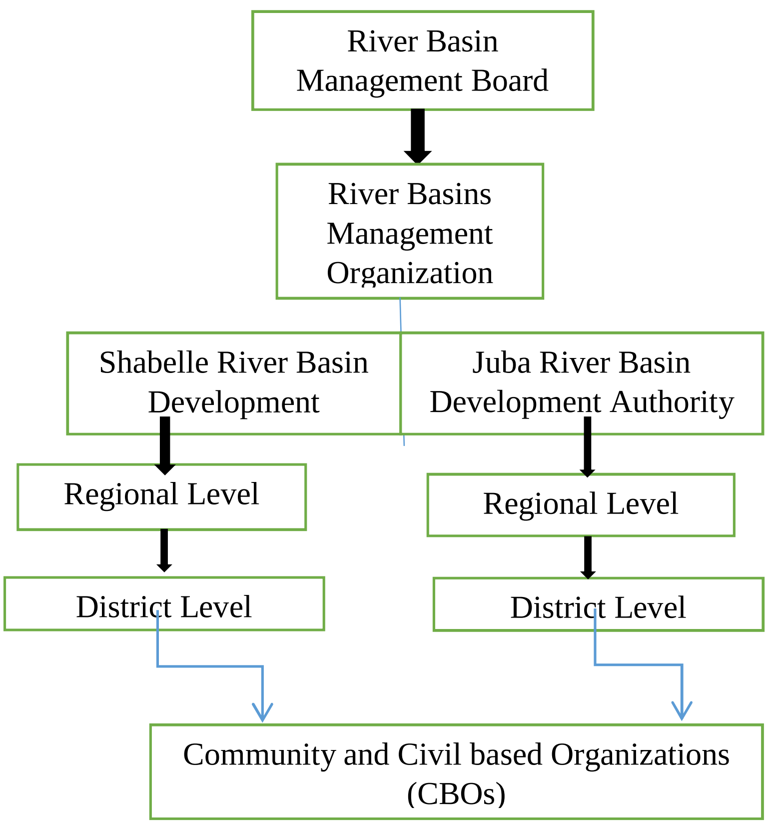

Figure 2.1 :Proposed River Basin Management in Somalia.

2.3 Principles and Mechanisms of Water Allocation

Basin water allocation planning is typically undertaken to achieve a series of overarching objectives including equity, environmental protection, and development priorities, balancing supply and demand and promoting the efficient use of water.

The basic principles for the allocation of water resources are efficiency, equity, and sustainability, with the aims of pursuing the maximum benefit for society, the environment and the economy, whilst maintaining fair allocation among various areas and people (Jin et.al, 2007).

Sustainable economic development in arid and semi-arid areas depends heavily on sustainable water resource management, defined by Loucks (1995) as “water resource systems designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity.” The rational distribution of water resources requires a complex balance between demand and supply, and over time (annual, inter-annual, or even generational), in various economic sectors (Yamout and El-Fadel, 2005), especially across sub-areas in arid and semi-arid climate zones (Just and Netanyahu, 1998).

From the institutional point of view, pricing or marketing is one of the instruments used to allocate water resources (Fisher et al., 2002; Dalhuisen and Nijkamp 2002), while tariffs form a complicated sub-system to be further optimized. The requirements for (and economics of) water distribution are much studied. Saving and recycling water), have all been investigated in recent years for ecological purposes (Chen, 1995; Baird and Wilby, 1999; Cheng 2002a and 2002b), water technology (Loschel, 2002), water-related macro-and microeconomics (Roger et al. 1993; Wang et al. 2000), ecological protection with least economic cost (Yang et al., 2003) and policy games (Slobadan and Hussan, 1999; Hamilton et al. 2002).

Water allocation does not mean merely the right of certain users to abstract water from sources but also involves other aspects. Table 2.1 lists a number of activities involved in a comprehensive and modern water allocation scheme.

Table 2.1: Elements of water allocation

Element	Description
Legal basis	Water rights and the legal and regulatory framework for water use
Institutional base	Government and non-government responsibilities and agencies which promote and oversee the beneficial use of water
Technical base	The monitoring, assessment and modelling of water and its behaviour, water quality and the environment
Financial and economic aspects	The determination of costs and recognition of benefits that accompany the rights to use water, facilitating the trading of water
Public good	The means for ensuring social, environmental and other objectives of water
Participation	Mechanisms for coordination among organizations and for enabling community participation in support of their interests
Structural and development base	Structural works which supply water and are operated, and the enterprises which use water

Source: UNESCAP (2000)

The overall objective of water allocation is to maximize the benefits of water to society. However, this general objective implies other more specific objectives that can be classified as social, economic and environmental in nature as shown in Table 2.2. As can be seen in this table, for each classification, there is a corresponding principle: equity, efficiency and sustainability, respectively.

Table 2.2: Objectives and Principles of water allocation

Objective	Principle	Outcome
Social objective	Equity	Provide for essential social needs: • Clean drinking water • Water for sanitation • Food security
Economic objective	Efficiency	Maximize economic value of production: • Agricultural and industrial development • Power generation • Regional development • Local economics
Environmental objective	Sustainability	Maintain environmental quality: • Maintain water quality • Support instream habitat and life • Aesthetic and natural values

Source: UNESCAP (2000)

Equity means the fair sharing of water resources within river basins, at the local, national, and international levels. Equity needs to be applied among current water users, among existing and future users, and between consumers of water and the environment.

Since equity is the state, quality, or ideal of being just, impartial, and fair, and different people may have different perceptions for the same allocation (Young, 1994). It is important to have pre-agreed rules or processes for the allocation of water, especially under the situations where water is scarce. Such agreements and methodologies should reflect the wishes of those affected sufficiently to be seen to be equitably and accountably applied.

Efficiency is the economic use of water resources, with particular attention paid to demand management, the financially sustainable use of water resources, and the fair compensation for water transfers at all geographical levels. Efficiency is not so easy to achieve, because the allocation of water to users relates to the physical delivery or transport of water to the demanding points of use. Many factors are involved in water transfers, one of which is the conflict with equitable water rights. For example, a group of farmers should have permits to use certain amounts of water for irrigated agriculture.

However, agriculture is often a low profit use; some water for irrigation will be transferred to some industrial uses if policy makers decide to achieve an efficiency-based allocation of water. In this case, farmers should receive fair compensation for their losses.

Sustainability advocates the environmentally sound use of land and water resources. This implies that today's utilization of water resources should not expand to such an extent that water resources may not be usable for all of the time or some of the time in the future (Savenije and Van der Zaag, 2000).

2.4 Water Demand and Allocation

Water allocation is essentially an exercise in allocating available water to demanding users. In order to make wise operational decisions regarding solutions to sharing water in a river basin or watershed, a fundamental scientific understanding of how the limited available water resources can be shared efficiency is required.

The demand of a water use is determined by social, economic and environmental needs (number of households, hectares of irrigated areas and crop types, minimum stream flows, etc.) and the water use rate of each activity. Where resources are restricted compared to demands, as for irrigation in some regions, conflicts can arise among competing users.

Water allocation is the process of sharing a limited water resource among various regions and competing users. It is a process made necessary when the natural distribution and availability of water fails to meet the needs of all water users – in terms of quantity, quality, timing of availability, or reliability. In simple terms, it is the mechanism for determining who can take water, how much they can take, from which locations, when, and for what purpose.

Historically, access to water has been regulated to meet a wide range of social objectives, including agricultural production, economic development, public health and – more recently – environmental protection. Examples of water-sharing rules and arrangements date back to the times of the ancient civilizations of Babylon, Rome and China.

As water scarcity has increased globally, water allocation plans and agreements have taken on increasing significance in resolving international, regional and local conflicts over access to water. With water now a limiting factor in food production and economic growth, a vital input to power generation, and with the rapid decline in the health of aquatic ecosystems, how water is allocated has taken on increasing significance.

Allocation objectives have evolved over time, and different approaches have emerged to calculating, defining and managing water resources. Ultimately, though, water resource allocation has remained the process of deciding who is entitled to the available water. Fundamentally, this consists of:

1. Determining how much water is available for allocation. This can include assessing different locations, different sources (such as groundwater and surface water), for different times of the year, or under different climatic conditions.
2. Determining how that water should be shared between different regions and competing users: who should be entitled to what? The water allocation process may distinguish between different administrative or geographic regions, different sectors, and (ultimately) individual water abstractors and users.

2.5 Conflicts and Conflict Management among Water Users

Freshwater scarcity seems to be an under-estimated and under-discussed resource issue facing the world today. It is obvious that the world's water demand grows every year in order to meet up with its increasing population. Exacerbated by climate change and increasing demand, freshwater scarcity is creating security concerns in some parts of sub-Saharan Africa, especially in the semi-arid region.

Increasingly, growing water demands lead to competing water uses and also cause conflicts e.g., between domestic and agricultural uses, agriculture and industry, agriculture and fisheries, upstream and downstream, highland and lowland, and rural and urban areas. In water scarce environment, competition for available water resources between many different water users is likely to become intense. If adequate measures to improve water use efficiency and to conserve this scarce resource are not taken, water security would be a critical challenge and has already become a challenge in many places.

Competition over natural resources, including water, is often viewed as a driver of conflict and has emerged as a key component in many current and past conflicts. However, disputes over water, whether scarce or abundant, do not always result in violence. In fact, the management of water often brings parties together and encourages cooperation; it can be an integral factor in conflict prevention, peace building, and reconciliation processes. Since fresh water is irreplaceable and indispensable to life, a valuable and contested resource requires careful, conflict-sensitive management to ensure that it will continue to fulfill its purposes over the long term.

In recent times, access to water and grazing land has become more competitive and has led the farmers and pastoralists into violent conflicts on a regular basis. This is a worrisome trend because both have coexisted inter-dependently for centuries, sharing the same fields for farming and grazing with a manageable level of tolerance and accommodation.

Konczacki (1978) and Jacobs (1980) posited that freshwater scarcity and insufficient rainfall are causes of social and economic ruins, conditions that leave the pastoralists at the mercy of the sedentary society of predominantly farmers. The same scarcity makes rain-fed farmers to expand their farms into cultivable pastoral land, which, according to Catterson (1990), brings about displacement of pastoralists. Because of limited land, the pastoralists and the farmers are constantly competing for the scarce resources. Untold hardship is increasingly experienced by those who become migrants as a result of desert encroachment as thousands of farmers and their families have already been forced to move off land that has become barren (Murray, 2007; Oyetade, 2007).

Raleigh and Urdal (2009) opined that freshwater scarcity appears to exert a somewhat stronger effect, increasing the risk of conflict to six percent for areas with very high levels of scarcity. Hence, there will be pressure over scarce resources, which if not managed well will increase the risk of conflict.

Achieving the goal of food security in Sub-Sahara Africa has to contend with the fact that some of the world's most water-scarce countries are located in the region. Research carried out by the International Water Management Institute (IWMI) shows that almost all countries in Africa would face either absolute or economic water scarcity in 2025. In the first case, countries will simply not have sufficient water resources to meet their projected agricultural, domestic, industrial and environmental needs, even if water is used with the highest feasible efficiency and productivity.

Increasing competition for available fresh water resources means that countries are obliged to make hard choices in developing and allocating water between agriculture and other uses. If water allocations to agriculture are reduced and instead diverted to sectors considered to be more lucrative, prospects for increasing food production, which even now is hard-pressed to keep pace with population growth, may be further undermined.

Recurrent droughts, water scarcity due to low flow of river water, lack of irrigation maintenance infrastructures, interacting with other social and economic factors have resulted in conflicts among farmer water users. These conflicts have increased in their frequency and intensity and in the magnitude of the destruction caused by them, threatening the very livelihood of the majority the rural population (Adger and Brookes, 2001; Tarhule and Lamb, 2003).

Water conflicts can be managed mostly through consensus building, decision support/modeling tools and interventions for conflict management. To manage conflict well, there are several conflict management strategies. Five strategies from conflict management theory for managing stressful situations are: (i) collaborating (win/win); (ii) compromising (win-some/lose some); (iii) accommodating (lose/win); (iv) competing (win/lose); (v) avoiding (no winners/no losers).

2.6 Approaches and Models for Water Allocation

The purpose of a water management model is to prepare a water allocation plan that takes into account the needs of the different water users/stakeholders in a basin. In addition, a water management model is useful in considering the impacts of different future scenarios (changes in hydrology, management decisions, socioeconomic changes etc.) on the entire system. The model is then used to test the impacts of proposed mitigation measures like changes in water allocation to a given sector, changes in sector priorities or bulk water transfers in and out of a basin (IGAD, 2011).

Models are increasingly becoming indispensable tools for planning, design and management of hydrologically related infrastructure. A model is an imitation of reality that stresses those aspects that are assumed important and omits all properties considered to be unnecessary. According to Singh (1995), a model is a systems methodology approach and helps to define and evaluate numerous alternatives that represent various possible compromises among the conflicting groups, values and management objectives and trade-offs.

From the point of view of sovereignty of river basins, models and algorithms can be grouped and classified into two basic categories as simulation and optimization models according to modelling techniques.

Simulation and optimization models have been formulated to handle prior water rights allocations (Wurbs, 1993). The conventional simulation models, in the sense that no formal mathematical Programming algorithms are used, such as the Water Rights Analysis Package (WRAP) (Wurbs, 2001) or MIKE BASIN (DHI, 2001), first calculate naturalized flows covering all time steps of a specified hydrologic period of analysis for all nodes, then subsequently distribute water to demands according to priority order in turn for each time step. At each priority step within the water rights computation loops, water is allocated to nodes with the same priority from upstream to downstream. If a source is connected to many demands with the same priority, water is allocated simultaneously by proportion to those demands.

New water availabilities of all nodes should be updated after each allocation. Since no optimization technique is used, simulation models cannot achieve optimal outcomes over multiple periods.

Linear programming and network flow models have been used extensively to model prior water rights allocation. Many models are formulated as weighted sum multi-objective optimization problems in terms of linear programming, where the weights reflect the priorities or importance of objectives (Diba, *et al.*, 1995). Certain types of models are also formulated as linear minimum-cost network flow problems and solved by network flow algorithms, in which the negative cost coefficients represent the priorities or the importance of the link flows.

The most commonly used method is the minimum-cost capacitated pure network-flow model, which can be solved using efficient linear programming algorithms such as the out-of-kilter algorithm (Wurbs, 1993). The pure flow network is a circulatory network having no storage at nodes and no gain or loss in the links, which can be converted from a river basin network by adding some pseudo accounting nodes and links for carry-over storages, reservoir evaporation and channel losses. Models utilizing this type of algorithm include ACRES (Sigvaldason, 1976), MODSIM (Labadie *et al.*, 1986), WASP (Kuczera and Diment, 1988), CRAM, DWRSIM (Chung *et al.*, 1989), and KOM (Andrews *et al.*, 1992).

Models for public allocation are either simulation or optimization models that treat water as a public property. In the past decades, many mathematical simulation and optimization models for water quantity, quality and/or economic management have been developed and applied to problems at both the subsystem level and the river basin level, such as reservoir operation, groundwater use, conjunctive use of surface water and groundwater, and irrigation and drainage management (McKinney *et al.*, 1999).

2.6.1 Simulation and Optimization Models

Keep in mind that, the classification of simulation and optimization models is according to modelling techniques, and the purpose of this section is to review them from the perspective of modelling techniques rather than from water rights systems or water allocation mechanisms.

Actually, they have been applied in modelling water allocation under various water rights regimes, water agreements and institutional mechanisms.

i. Simulation Models

Simulation models simulate water resources behaviour in accordance with a predefined set of rules governing allocations and infrastructure operations. They are used to model water quantity, quality, economic and social responses for a set of alternative allocation scenarios.

Comprehensive river basin simulation systems emerge with the rapid development of information technology. Traditional simulations are enhanced with interactive and advanced graphic user interfaces, allowing on-screen configuration of the simulations, and display of results. Water Ware, developed by a consortium of European Union-sponsored research institutes (Jamieson and Fedra, 1996a, b), integrates Geographic Information System (GIS) functions and incorporates embedded expert systems with a number of simulation and optimization models and related tools. For addressing water allocation, conjunctive use, reservoir operation or water quality issues, MIKE BASIN couples the power of ArcView GIS with comprehensive hydrologic modelling to provide basin-scale solutions (DHI, 2001).

ii. Optimization Models

Optimization models optimize and select allocations and infrastructure operations based on objectives and constraints. These models must have a simulation component to calculate hydrologic flows and constituent mass balance. However, the simulation models coupled in optimization water allocation generally have to be rudimentary in order to possess reasonable numerical calculation ability and time constraints.

Whereas the assessment of system performance can be best addressed with simulation models, optimization models are more useful if improvement of the system performance is the main goal (McKinney *et al.*, 1999).

Agricultural use is an important factor in water allocation, since irrigation water demand generally consumes most of the water available in a region. Amir and Fisher (1999) introduce an optimizing linear model for analysing agricultural production under various water quantities, qualities, and timing, pricing and pricing policies. The model serves as the “agricultural sub-model” (AGSM) incorporated into their Water Allocation System (WAS). AGSM is formulated at the level of a district. Its objective function is the net agricultural income of the district, which is maximized by selecting the optimal water consuming activities.

Fisher (1997), in this procedure, the decision variables is the land areas of different activities, because of the significant capabilities of reservoirs to handle irrigation, hydropower generation and flow adjustment for ecological use and controlling flood and drought, many models governing the reservoir operations and water allocation have been developed and designed a stochastic dynamic programming model for the operation of irrigation reservoirs under a multi-crop environment.

The model considers stochastic reservoir inflows with variable irrigation demands and assumes the soil moisture and precipitation to be deterministic. The demands vary from period to period and are determined from a soil moisture balance equation. An optimal allocation process is incorporated into the model to determine the allocations to individual crops during an intra-seasonal period whenever competition for available water exists among the crops. Thus, the model integrates the reservoir release decisions with the irrigation allocation decisions with respect to each crop in each period.

Due to the complexity of water allocation at the regional or basin level, three-level or three-layer optimization models based on an economic efficiency criterion are proposed by Reca *et al*. (2001a, b) and Shangguang *et al*. (2002). Level one model optimize irrigation timing for a single crop; level two models optimize water and land resources allocation for the cropping pattern on an irrigation area scale, which estimate the optimal benefit function for agricultural uses at different areas; level three models optimize water allocation among all types of demanding uses on a hydrologic system (region or basin) scale. The overall optimization model is defined in a deterministic way, assuming that the climatic variables and inflows to the system are known. To take into account the stochastic character of these variables, the optimization processes are repeated for such scenarios (Reca *et al*., 2001a).

iii. Integrated Simulation and Optimization Models

Simulation and optimization models can be complementary tools to solve water allocation problems with competition over scare water resources. Although detailed simulation models cannot be coupled within the optimization process, they can be used to assess the feasibility of the water allocation policies determined by optimization models, with regard to infrastructure operations and the water resources system responses under extreme conditions (Fedra *et al*, 1993; Faisal *et al.*, 1994).

Since its development, Water Evaluation and Planning model, WEAP model has been widely applied around the world in various IWRM projects with diverse objectives. WEAP is a modelling tool for water planning and allocation that can be applied at multiple scales, from community to catchment to basin (Yates et al., 2005a, b; Sieber, Swartz, and Huber-Lee, 2005).

Each model has its own methodology in water allocation: Prior appropriation, priority allocations, penalty systems, ranking and giving weights are some of the methodologies used. Some of these models are basically appropriate for surface water allocation in river basins and to facilitate water managers in the planning and decision making process. In addition, some of models are appropriate for analysis of reservoir operations, infrastructure planning and assessment, preparation of regulations and guidelines, ecosystem studies, evaluating agricultural practices, incorporate with groundwater analysis models, etc.

Basically all the models need meteorological data, river inflows and water demands of different users as input data. For the simulation models the operating policy also needs to be given as an input data. Other input data varies (e.g. reservoir characteristics, hydropower operating rules, water quality data, economic data etc.). Outputs of the models describe the impacts of the operating policies and satisfaction of different water users in the basin.

2.7. Applications of the Water Evaluation And Panning (WEAP) Model

The Water Evaluation and Planning (WEAP) model was used developed by the Stockholm Environment Institute-Boston, Tellus Institute, U.S.A. It is an integrated Decision Support System (DSS) designed to support water planning that balances water supplies and multiple water demands. WEAP incorporates issues such as allocation of limited water, environmental quality and policies for sustainable water use, unlike the conventional supply oriented simulation models. It gives a practical integrated approach to water resources development incorporating aspects of demand, water quality and ecosystem preservation (SEI, 2012).

WEAP is a river basin simulation model with geo-spatial capabilities that is capable of simulating the allocation on water throughout a river basin based upon a user specified time step. WEAP is a laboratory for examining alternative water development and management strategies. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (Yates et.al, 2005).

WEAP can address a wide range of issues, *e.g.*, sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and stream flow simulations, reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, vulnerability assessments, and project benefit-cost analyses.

One of the strengths of WEAP is that it is adaptable to whatever data is available to describe a water resources system. That is, it can use daily, weekly, monthly, or annual time-steps to characterize the system's water supplies and demands. This flexibility means that it can be applied across a range of spatial and temporal scales. Indeed, WEAP has been used throughout the world to analyse a diverse set of water management issues for small communities and large managed watersheds alike. WEAP operates always in an optimization water allocation mode, based on priorities set for each demand site. This makes WEAP unique in comparison to other water allocation tools (SEI, 2012).

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The current accounts provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Alternative sets of future assumptions are based on policies, costs, technological development and other factors that affect demand, pollution, supply and hydrology. Scenarios are constructed consisting of alternative sets of assumptions or policies. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

Since the first version of the model was developed in 1990, it has been applied in a lot of research work conducted in quite a number of basins in different countries in worldwide. The Map below shows a selection of WEAP projects from different regions of the world:

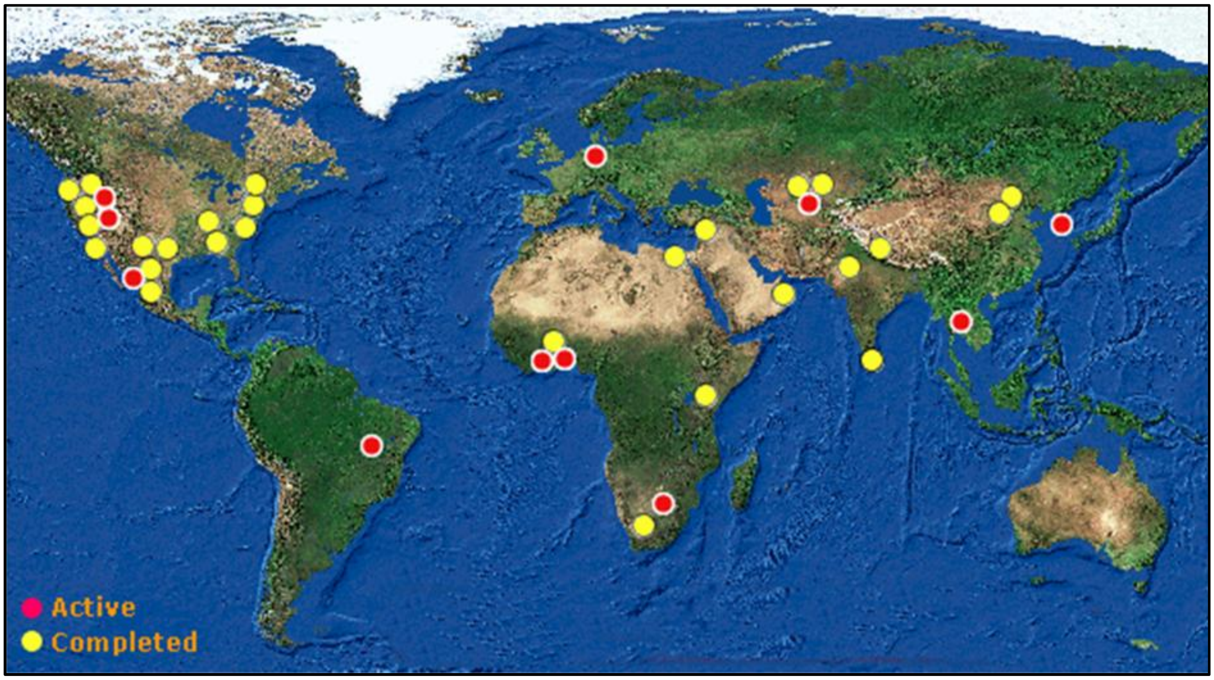

Figure 2.2: WEAP projects from different region of the world. SEI (2012

In Africa, WEAP model has been applied in different part of the continent specifically; it has been applied to Lake Naivasha in Kenya to develop an integrated water resource management plan for economic and ecological sustainability (Alfara, 2004).

In South Africa, it was applied on water demand management scenario in a water stressed basin. In the River Basins in Zimbabwe and Volta in West Africa, it was used for Planning and Evaluating groups of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security tools. In Ethiopia, WEAP model was used for evaluation of current and future water resource development in the Blue Nile and Awash basin for water allocation. Also, WEAP has been applied in complex situations such as the Aral Sea to evaluate water resources development policies.

CHAPTER 3: METHODS AND MATERIALS

This chapter discusses the description of the study area, methods of data collection and analysis, materials and software used.

3.1 Description of the study area

3.1.1 Location

The Juba Basin lies roughly between 38^o 1' and 46^o 0' east of the Prime Meridian and between 0^o 15' and 7^o 28' north degree of the Equator. The altitude of the Juba Basin ranges from a few meters above sea level at Indian Ocean to over 3,000 meters above sea level (a.s.l.) in the Ethiopian highlands. The total catchment area of the Juba Basin at the mouth of the river near Kismayo is about 221,000 km^2, 65% of which is in Ethiopia, 30% in Somalia and 5% in Kenya. The total length of the Juba River is about 1,808 km (measured on the longest tributary), of which 804 km lies in Ethiopia and 1,004 km lies in Somalia.

The Juba River originates from the Ethiopian Highlands, where three large tributaries, the Genale, the Dawa and the Weyb (Gestro), meet near the border with Somalia to form what is known the Juba River inside Somalia. Tributaries of the Genale River originate from the southern flanks of the Bale Mountains, and from the Sidamo Mountains in the north-west. The Dawa River originates in the Sidamo Mountains while Weyb River originates from the northern parts of the Bale Mountains. The Dawa River forms part of Ethiopia-Kenya border. Along its final reach, the Dawa tributary marks also the Ethiopia-Somalia border. Within Somalia the Juba basin covers the administrative regions of Gedo, Bay, Bakool, Middle Juba and Lower Juba.

The basin includes also the Lag Dera sub-basin which is mostly in Kenyan territory. The Lag Dera sub-basin contains several tributaries joining in Somalia. These include the Ewaso Nyiro tributary originating from Mount Kenya, at an altitude of about 5195 m a.s.l. Within the sub-basin, there is a large transboundary aquifer, the Merti, stretching over the Kenya-Somalia border. The Merti aquifer contains large amount of unexploited groundwater of about 84000 Mm^3.

Rivers Genale and Dawa flow in deep valleys until they reach flatter and broader areas along their respective flood plains at elevations below 400m a.s.l. However, Weyb River flows mostly in a wide valley with intermitted deeply incised reaches along its course. The Weyb converges with Genale near the Somalia border at Dolow, before joining Dawa shortly downstream. The joint channel downstream of this point is the main Juba River. After entering Somalia, the river continues to flow south-easterly until it reaches the town of Luuq, from which point it flows gently towards south and into the Indian Ocean.

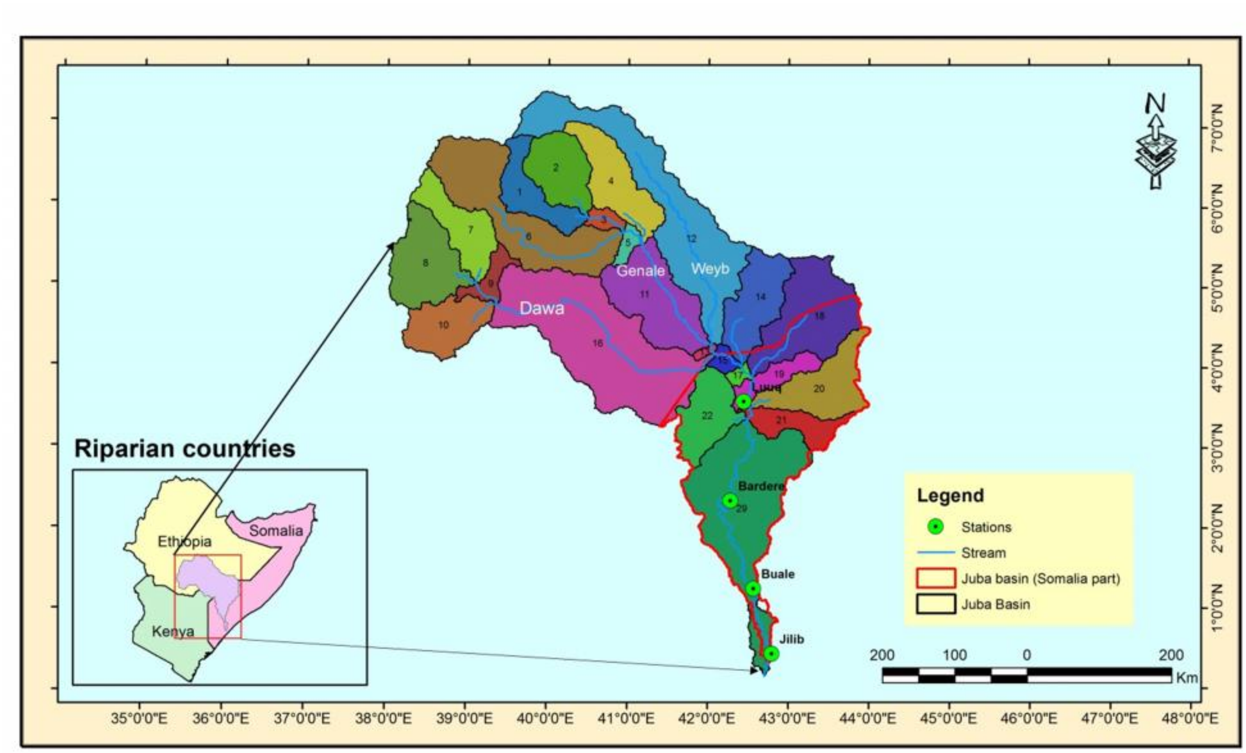

Figure 3.1: Location Map of the study area

3.1.2 Population (Human and Livestock)

Human population

The last estimated population done in 2014 has been collected from the Ministry of National Planning, the Federal Republic of Somalia. The population estimation survey is the first extensive household sample survey to be carried out among the Somali population in decades.

The previous last information available on population is from a census conducted in 1975, which published limited results; the results from another population census conducted from 1985 to 1986 were never released into the public domain. Since then, even though development agencies attempted to compile reliable data on population and socioeconomic statistics, such efforts collected data limited to thematic data sets. To fill this crippling gap, the Somali authorities decided to carry out a survey to collect information on the Somali population, among other details. The United Nations Population Fund (UNFPA) collaborated with donors and other UN agencies and took up the lead role to support the Somali authorities in undertaking the Population Estimation Survey.

Table 3.1: Estimated Population in Somalia

	Population	
Estimated Population	**12,316,895**	**%**
Urban	5,216,392	42.4
Rural	2,806,787	22.8
Nomadic	3,186,965	25.9
IDPs	1,106,751	25.9
Population Distribution		
Male	6,244,765	50.7
Female	6,072,130	49.3
Urban-Male	2,598,926	49.8
Urban-Female	2,617,466	50.2
Rural-Male	1,439,176	51.3
Rural-Female	1,367,611	48.7
Nomadic-Male	1,663,775	52.2
Nomadic-Female	1,523,190	47.8
IDPs-Male	542,888	49.1
IDPs-Female	563,863	50.9

Source: MoNP, Somalia, 2014

Livestock population

Livestock rearing is an important source of income for the people in southern Somalia, the demand for water for the livestock is considered vital. The people of the basin practice a sedentary lifestyle. As they are involved in both agriculture and livestock rearing, the percentage of cattle is higher in this region compared to that of camels and sheep/goats than in the northern region of Somalia. The livestock are taken often to the rivers for watering. In fact, during the dry season, there occasions of conflicts between the nomadic populations who bring their livestock to the rivers and the local people living in the riverine areas, because the livestock destroy or eat the crops that are grown in the riverine areas.

According to the FSNAU (2012) there is a current national trend of increasing livestock keeping (cattle, camel, sheep/goats).

Table 3.2: Livestock distribution in Southern Somalia

Region	**Cattle**	**Camel**	**Sheep**	**Goat**
Middle Shabelle	443, 420	235,140	411,360	937,020
Lower Shabelle	43, 940	336,070	113,930	260, 280
Banadir	25,530	1140	7,720	24,710
Bay	116,080	415,230	71,150	260, 280
Bakol	296,000	220,230	102,160	356,590
Gedo	612,900	899,270	622,620	943,540
Middle Juba	424,860	252,300	31,130	937, 030
Lower Juba	999,450	254,640	87,170	165,280

Source: Ministry of Livestock, Forestry and Rangeland, department of planning and statistics, Mogadishu (cited by Muse, 1997 and Basynt, 2007)

3.1.3 Climate

The climate of the Juba river basin is arid to semi-arid and is determined by the northward and southward movement of the Inter-Tropical Convergence Zone (ITCZ) across the Equator.

In Juba basin, like many other parts of the country, experience four distinct seasons: *Gu* Main rainy season (March/April to June), *Hagaa* Hot and windy season (July– September), *Deyr* Short rainy season (September/October – November) and *Jilaal* Very dry and cool season (December – February/March).

In most areas of Somalia this results in two rainfall seasons - the *Gu* as the zone passes northwards and the *Deyr* as it moves south. In both cases, rain is produced from the moist air derived from the Indian Ocean, in the southerly air stream. The north-easterly winds, emanating from Asia and Arabia, produce little significant rain. It is generally considered that rainfall is the most important meteorological element affecting life in Somalia. In particular, variation from season to season, and variations within the season are what determine the successes of agricultural activities.

The movement of the ITCZ also causes distinct changes in the wind direction throughout the year. When the ITCZ is to the south, the winds are from the northeast and when it is to the north the winds are from the southwest. This 1800 shift to the southwest occurs gradually as the ITCZ passes over, spanning approximately between March-July, and then returning to the north-east winds by December. While there are some regional variations, this pattern is dominant across the whole country.

Wind speeds average between 0.5 - 10 m/s, with the highest wind speeds occurring in the Northern Plateau. While the strongest winds occur between June and August, the weakest winds generally occur as the ITCZ passes over the Equator in April to May in southern Somalia.

Luuq; in Gedo region near the border with Ethiopia, has the highest mean temperature in the country, at over 30° C. Most inland areas of southern Somalia are only slightly cool with the north coast also almost having similar temperatures. Temperatures along the southern coast are lower than those of inland areas. In the north, temperatures are correlated with altitude, with a lapse rate of 6.5° C per 1000 m. Average monthly temperatures reach as high as 41° C in March mainly around Bardere and Luuq.

Greater contrasts between daily maximum and minimum temperatures occur in inland areas compared to those at the coast. However, these contrasts are generally small in comparison to those which might be expected for the desert environments. Hutchinson and Polishchouk (1989) attribute this to the relatively high humidity across the whole country.

There are few records of evaporation and the values which have been reported in various studies to vary between about 1000-3000 mm/yr. In general, evaporation is greater than precipitation across the country, but there are localized areas in southern Somalia, around Jilib and Baidoa, where for a few months of the year higher rainfall than evaporation may be experienced. This occurs at the beginning of both the *Gu* and *Deyr* seasons, thus allowing crop growth to commence. The total evaporation generally increases from south to north, with the highest annual evaporation occurring on the north coast. The time of greatest evaporation also varies across the country, being the middle of the year in the north, and the beginning of the year in south and central regions. However, the contrast is great in the north with only minor changes in evaporation throughout the year in the south.

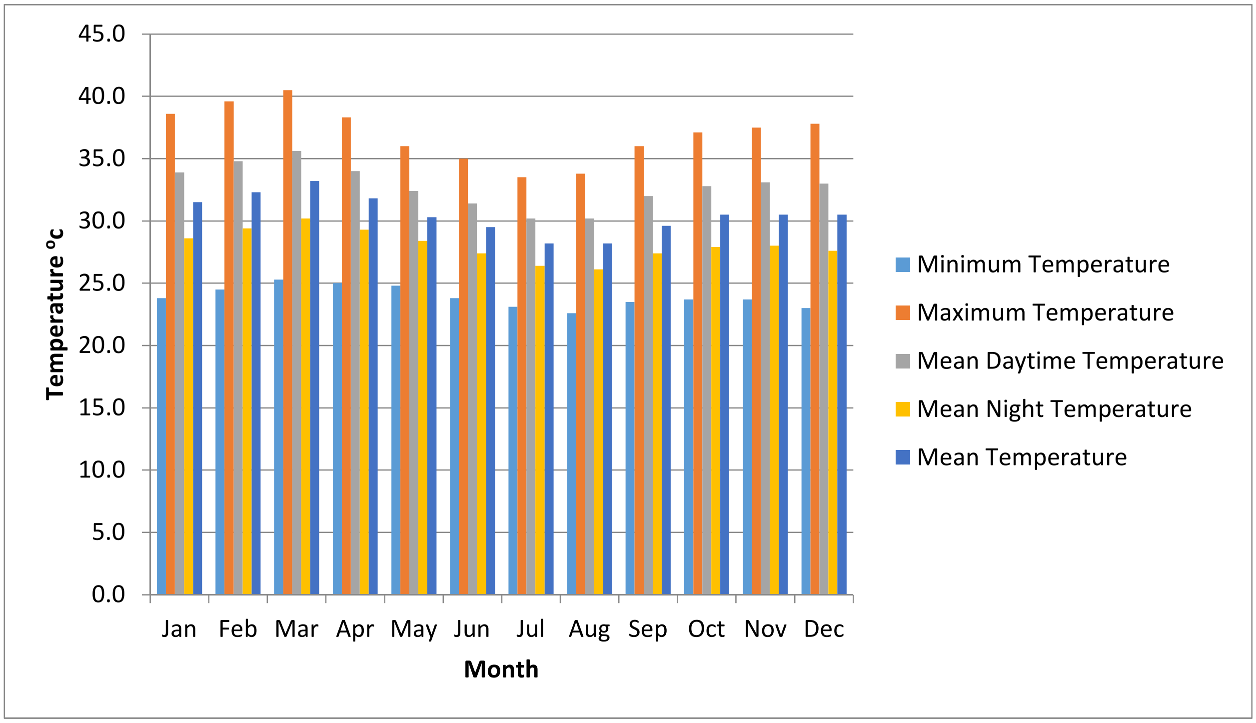

Figure 3.2: Temperature trends at Luuq station of Juba basin (own illustration based on FAO climwat data)

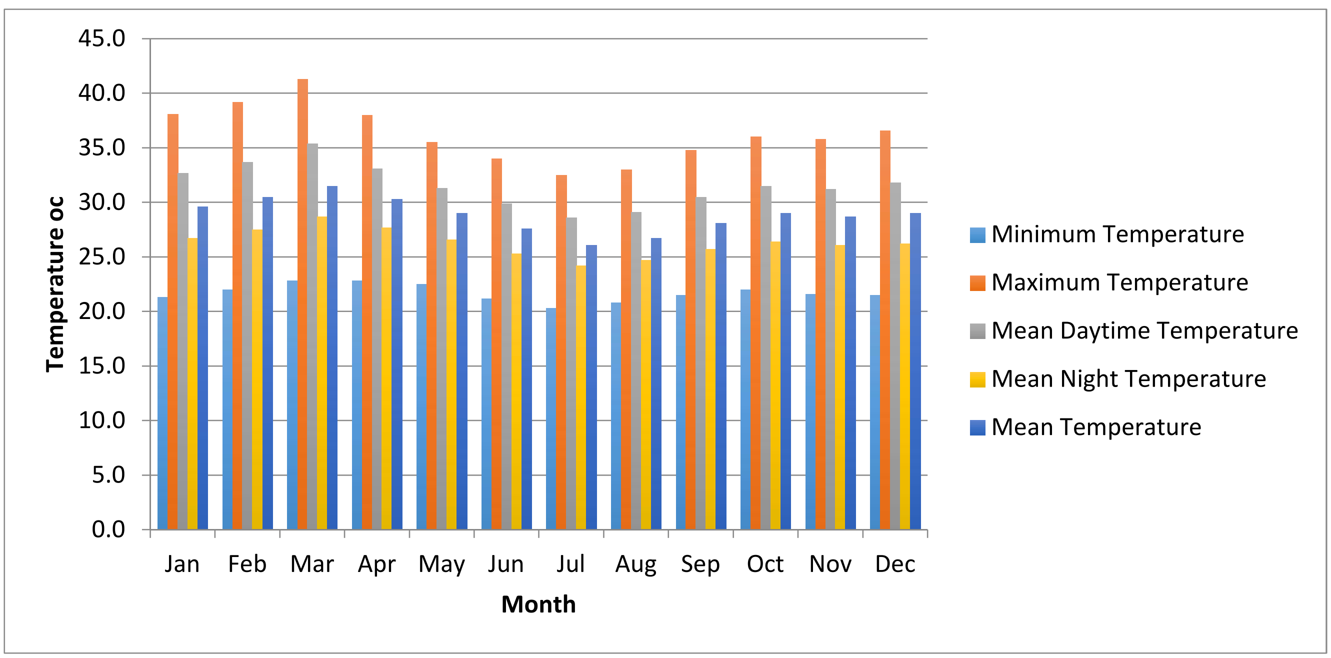

Figure 3.3:Temperature trends at Bardere station of Juba basin (own illustration based on FAO climwat data)

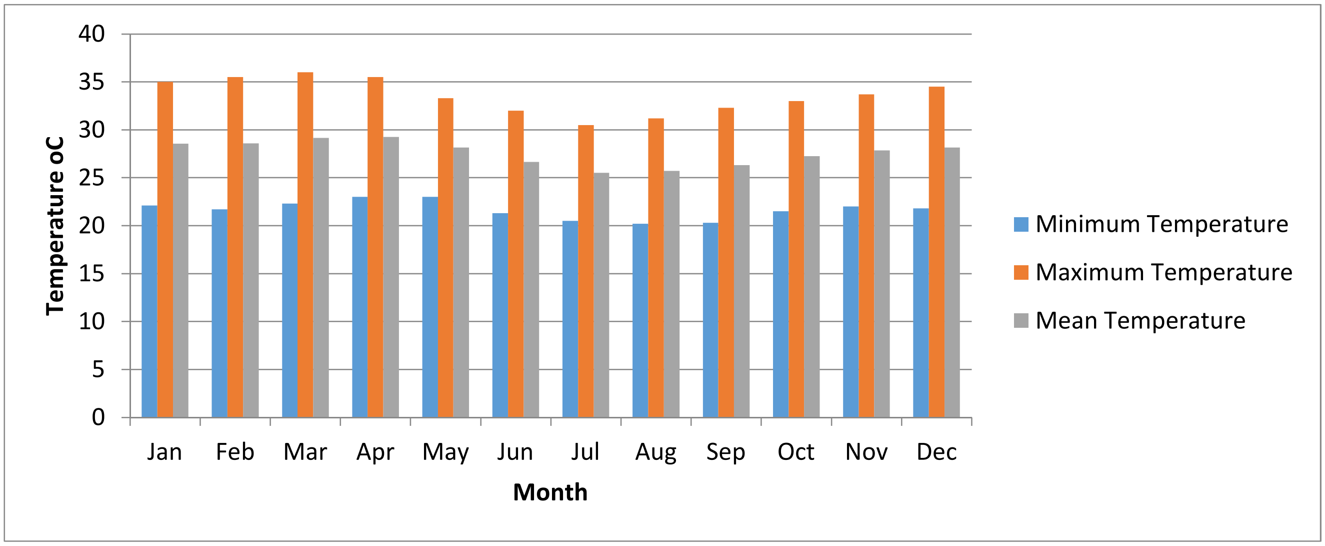

Figure 3.4:Temperature trends at Jilib station of Juba basin (own illustration based on FAO climwat data)

Rainfall in the basin is low and erratic with a bimodal annual pattern. The Ethiopia highland in the upper catchment area receives more rain. The middle catchment areas around Somalia and Ethiopian border, being in the leeward side of the highlands, receive less rain. There is an increase in annual rainfall as one move towards the coast.

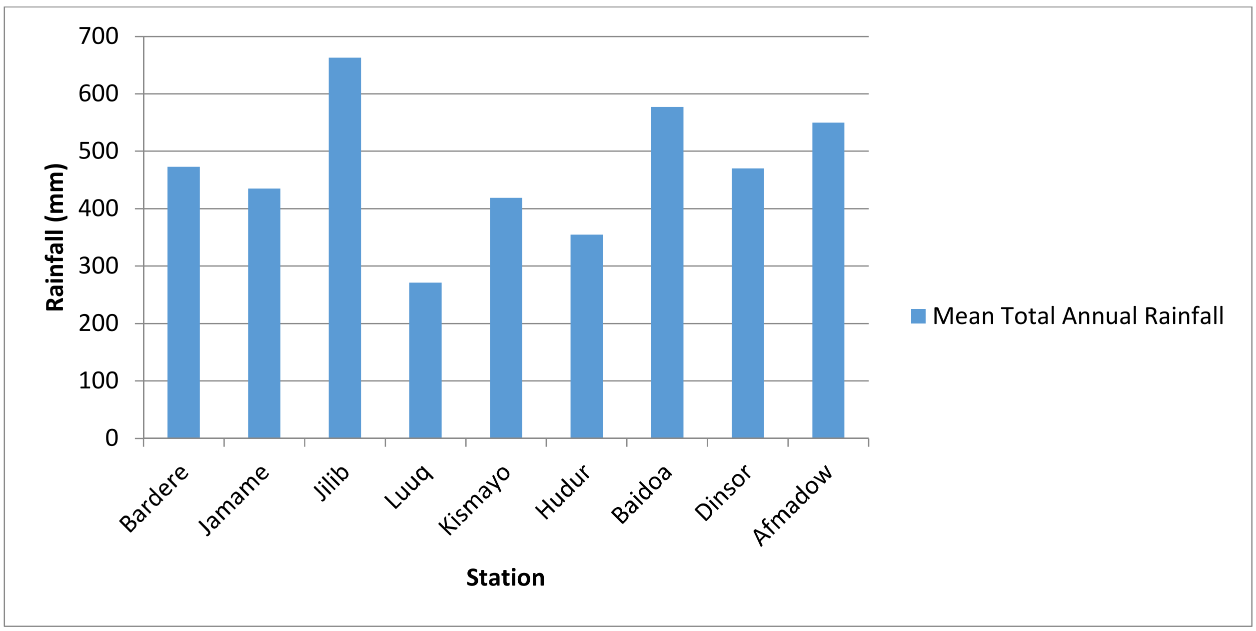

Figure 3.5:Mean annual rainfall of stations in Juba basin

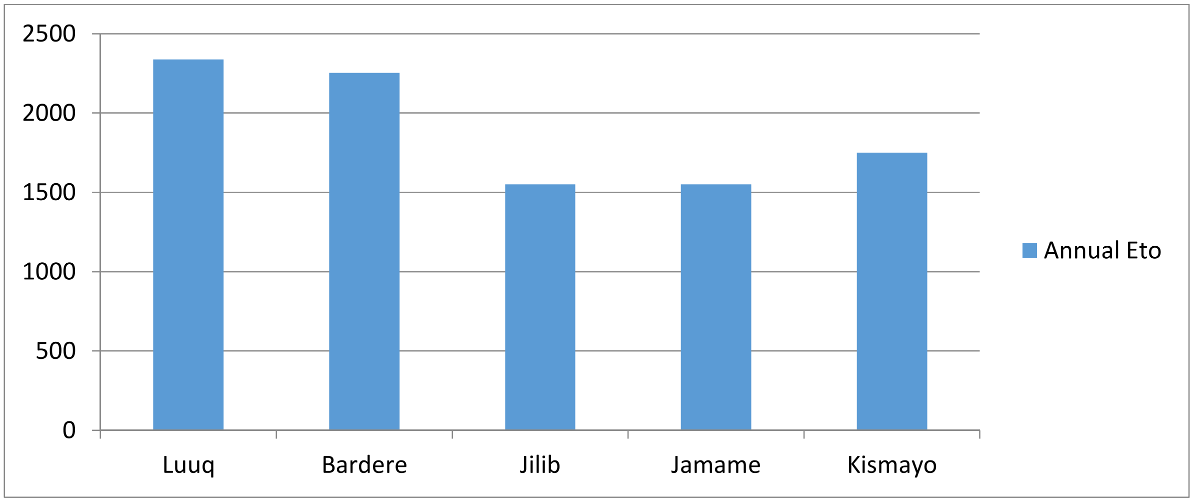

Figure 3.6:Annual ETO of different stations in the basin

Potential evapotranspiration is variable in basins, ranging from 1500 mm per year in the mountains to 1750 mm per year in the south, and being highest at over 2000 mm per year on the border (Hutchinson and Polishchouk, 1989).

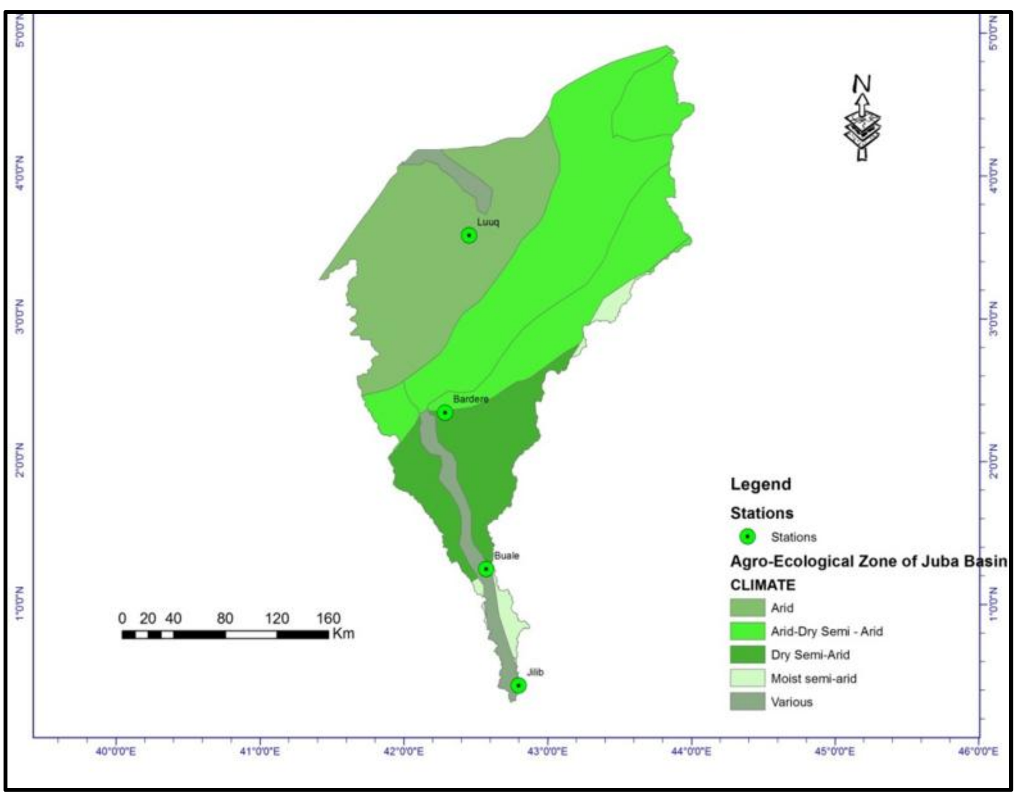

Figure 3.7: Agro-ecological zone for climate of Juba basin

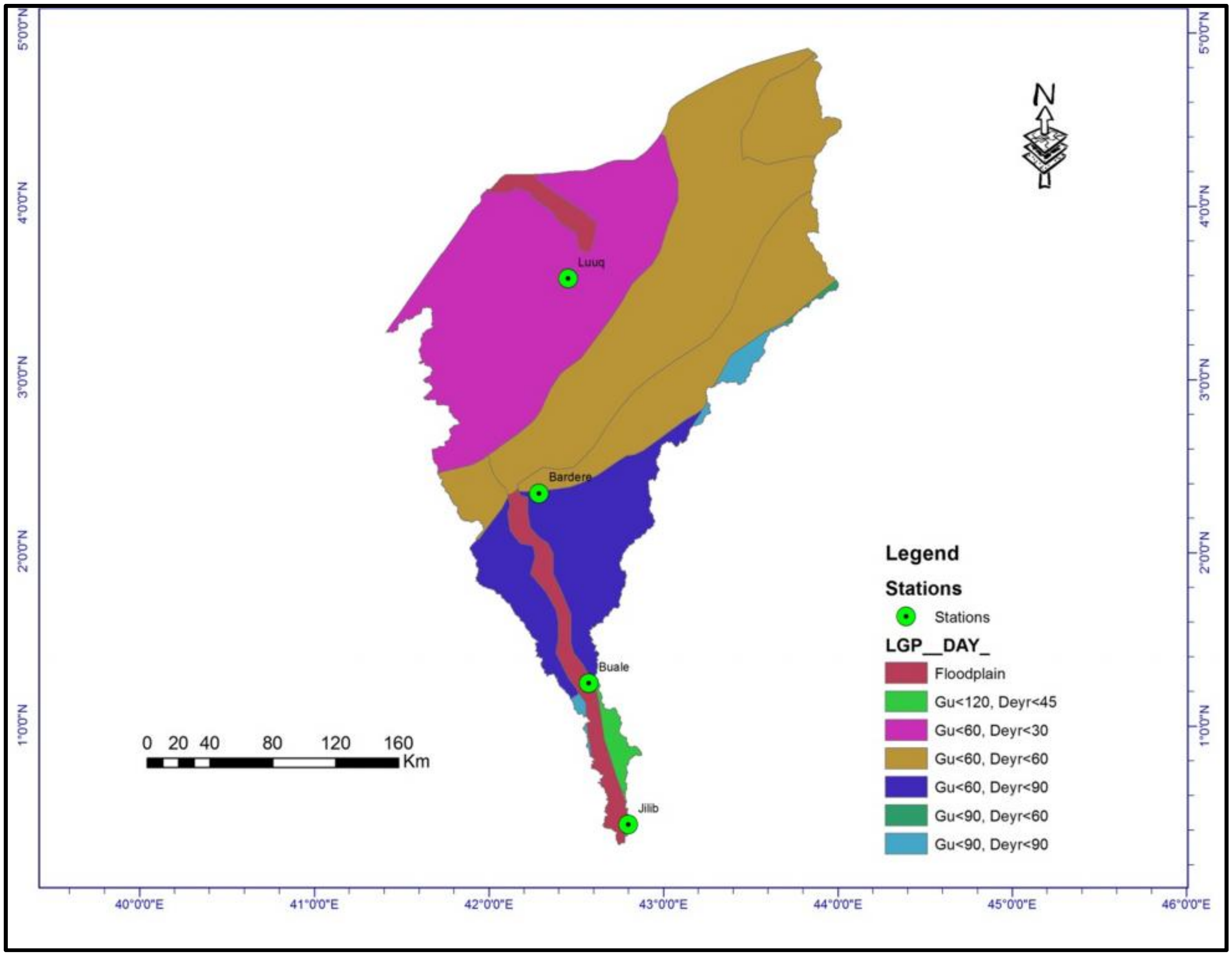

Figure 3.8:Agro-ecological zone for LGP

3.1.4 Water Resources System

The Juba and Shabelle are the only perennial rivers in Somalia. They are also the only rivers where long-term hydrological data are available. Based on streamflow data from 1963 to 1990, the long-term mean annual flow volumes in the Juba River at Luuq and at Jamama are 5.9 and 5.4 BCM, respectively.

There are considerable flow variations within a year as well as from one year to another. As the reliability of flow available is important for the design and planning of water resources, flow duration curves for the locations where long-term data are available from 1955 to 1990 and 1963 to 1990 at Luuq and Jamame respectively. For example, the flows exceeding 50% and 90% of the time in Juba at Luuq are 152 m^3/s and 12 m^3/s, respectively. In the downstream gauged location in Juba at Jamame, the 50% and 90% flows are 144 m^3/s and 10.3 m/s.

Water quality of Juba River is a matter of concern since both the human and livestock populations use the river water for direct consumption. There was very little water quality data available for the two rivers. The only available long-term data was for Juba at Mareera where electrical conductivity (EC) values were available for the period, 1977 to 1990. It is observed that the salinity in the river rises during the *Jilaal* season and peaks during *Gu* flood season (Basynt, 2007).

In the headwaters of the Juba river basin, where rainfall is generally high and losses are relatively low, surface water resources are abundant. In the middle sections, as rainfall decreases and becomes less frequent, losses increase and runoff is highly localized and seasonal, the rivers themselves still carry considerable volumes of water during most of the year. Downstream of the border, discharges reduce progressively, the flow being reduced by evaporation, infiltration, consumptive use, and by over-bank spillage when the stage is high.

There is no comprehensive data available on groundwater occurrence, groundwater abstractions or respective safe yields in the Juba basin. In addition, the mechanisms of groundwater recharge are not known, but infiltrations associated to the river flows are considered the main component of inflows. To obtain more information regarding the local groundwater resources seems to be a priority action for the near future considering the projected reduction in surface water availability.

3.1.5 Hydrogeology

The aquifers in the study area are of the richest in the country in terms of groundwater resources. However, there are no comprehensive data available on either groundwater occurrence or abstractions in the Juba and Shabelle sub-catchments. The mechanisms and rates of groundwater recharge are also not precisely identified. Recharge is through infiltration from direct rainfall and infiltrating surface water from the two rivers and their tributaries. The storage and movement of groundwater are therefore most likely to follow the very coarse boundaries of the major river basins (Basnyat, 2007). The following are the description of the four main aquifers in the Juba and Shabelle sub-catchments:

Basement Complex Aquifer: this aquifer was found in the Buur area and is one of the well-defined hydrogeological areas in the study area (Figure 2-9). The rocks found in this aquifer are mostly granites, quartzite, micashists and marble. Recharge occurs mainly with rainfall and from runoff water along *toggas*.

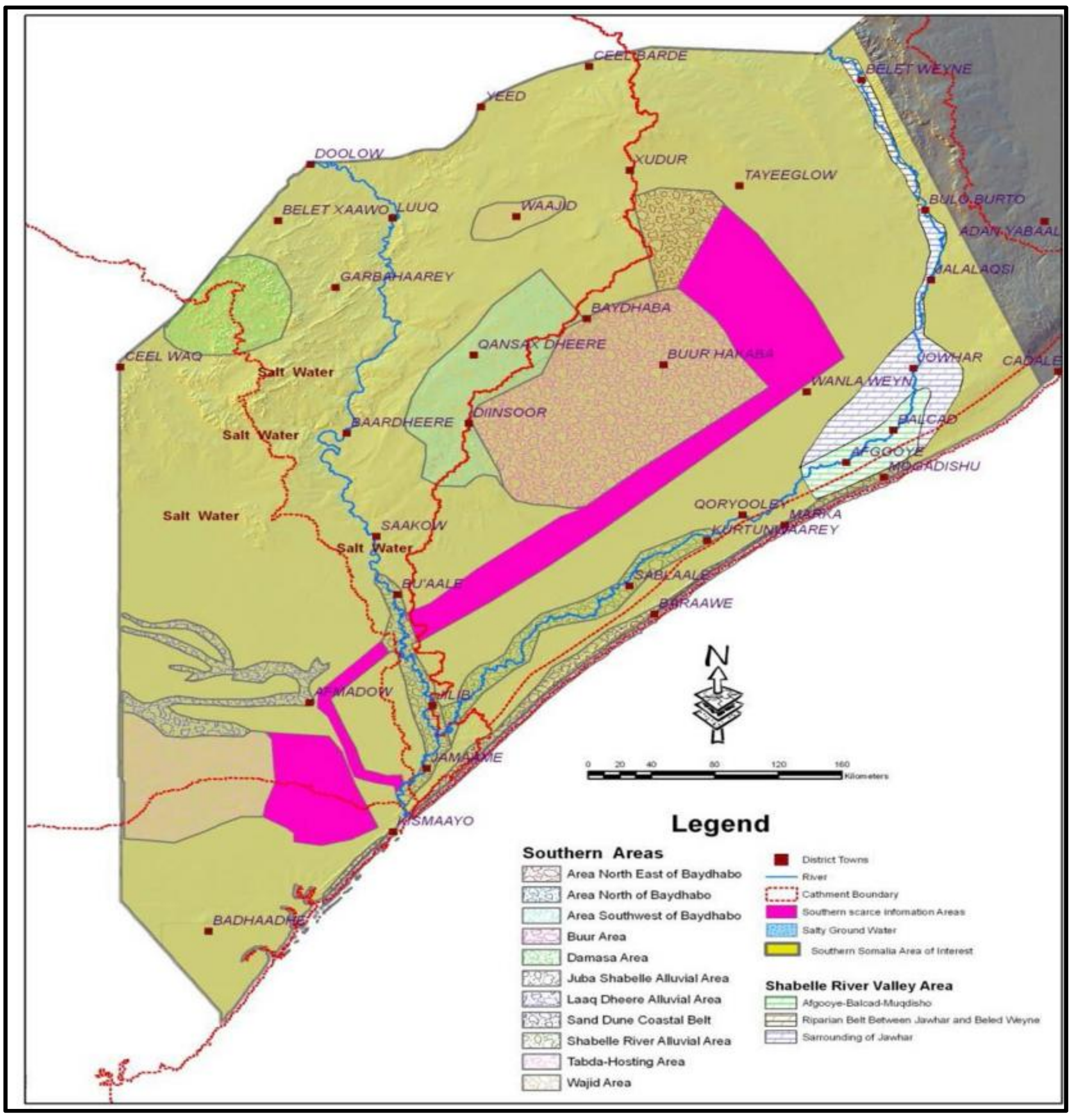

Figure 3.9: Potential groundwater resource areas in the Juba-Shabelle Basin in Southern Somalia. (Source: Faillace, and Faillace 1987)

Little recharge also occurs in large areas covered by black alluvial clay. Much of the groundwater was found along the *toggas* in alluvial deposits and weathered basement, where recharge conditions are good. The groundwater bodies are small and discontinuous, most of which are locally recharged. Small amounts of water can also be found in the rock fractures, although salinity of the water is generally high.

Huddur-Bardheere Aquifer: in this basin, recharge occurs along the Baydhabo escarpment through the joints of stratification and the Karstic areas through the sinkholes where rainfall and runoff water infiltrates rapidly (Faillace and Faillace, *1987*). Recharge is good at the areas covered by the Baydhabo Jurrasic limestone, and almost zero at the areas covered by residual clay which is impermeable. Underground flow starts from the Baydhabo plateau and continues in the northeast and northwest direction. In the upper parts of the Juba valley, groundwater flow is from east to west and from north to south.

Coastal Aquifer: is also another significant aquifer in the southern part of the country. Recharge of groundwater in the coastal basin occurs as a result of direct rainfall, infiltration from the Juba and Shabelle rivers, and regional flow from Kenya, runoff and subsurface flow from the basement complex.

The Juba River Basin is characterized by the outcropping of the metamorphic basement complex, made up of migmatites and granites (Oduori, et *al* 2007b). Sedimentary rocks such as limestone, sandstones, gypsiferous limestone and coastal sand dunes are also present in the study area. Basaltic flows are found in the north-western part of the study area (Venema and Vargas, 2007). Between the two rivers of Juba and Shabelle, there is a large outcrop of crystalline rocks belonging to the African basement, which is formed by granite, marbles, quartzite, gneiss and paragneiss (Oduori, et *al* 2007b). Some late Tertiary fluviolagunal deposits occur on the Lower Juba plain, consisting of clay, sandy clay, sand, silt and gravel. Recent fluvial deposits are common alongside the two rivers, consisting of sand, gravel, clay and sandy clay (Venema and Vargas, 2007). Other recent alluvial deposits occur in small valleys in Gedo and Bakool regions and in the Buur area, consisting of gravelly sand or red sandy loam materials. The coastal zone is characterized by various alluvial, marine and Aeolian deposits of the Quaternary (Thiemig, 2009).

Mountains ranging from 900 m up to 3,000 m are found in the Ethiopian Highlands, in the eastern part of the Juba basin. This landscape type is mainly characterized by exposed hard rock. The southern part (Upper Juba) is formed by impervious basement rock and tertiary volcanic formations, made up of magmatites and granites (Thiemig, 2009). The evolution of the Juba and Shabelle catchments is closely linked to the development of the Great Rift Valley, as they occupy most of its eastern flank (Oduori, et *al* 2007b). The uplift of the Ethiopian highlands and the deposition of thick volcanic and sedimentary rock formations have determined the geological setting in which the two river basins have evolved (Hadden, 2007).

3.1.6 Soil and Land use

The types of soil vary according to climate and parent rock. The arid regions of northeastern Somalia have mainly thin and infertile desert soils. The limestone plateaus of the interfluvial area have fertile, dark gray to brown, calcareous residual soils that provide good conditions for rain-fed agriculture. The most fertile soils in Somalia are found on the alluvial plains of the Jubba and Shabeelle rivers. These deep vertisols (black cotton soils) have a high water-retention capacity and are mainly used for irrigation agriculture.

There are also large areas of dark cracking clays (vertisols) in the southern part of Somalia that appear to have a higher water-holding capacity than the generally sandy soils found elsewhere. According to both the FAO and USDA soil taxonomy, a vertisol is a soil in which there is a high content of expansive clay known as montmorillonite. This soil forms deep cracks in drier seasons or years.

When irrigation is available, crops such as cotton, sorghum and rice can be grown. Vertisols are especially suitable for rice because they are almost impermeable when saturated. Rainfed farming is very difficult because vertisols can be worked only under a very narrow range of moisture conditions: they are very hard when dry and very sticky when wet.

The main soil types in the study area are Petric Gypsisols, which feature a substantial secondary accumulation of gypsum, and Lithic Leptosols, which are very shallow (< 25 cm) due to limitation by underlying consolidated material (Thiemig, 2009). Along the upper reaches of the

Juba River, extensive limestone outcrops, with localized sandstones, marls and gypsum determine soil development.

The soils in the alluvial plains are characterized by stratified fluvial deposits which, because of the semi-arid climate, have been little-affected by soil-forming processes. Despite their variability, most of these soils share the characteristics of heavy texture (clay) and low permeability, with a tendency to poor drainage (Venema and Vargas, 2007).

FAO SWALIM conducted a detailed soil survey for the riverine areas of the two river basins. They have been classified as Vertisols and Fluvisols mainly. The hilly terrain and associated pediments, piedmonts and erosion surfaces predominantly have shallow and stony soils of medium texture (loamy), classified as Leptosols, Regosols and Calcisols. Pockets of deep Cambisols and Luvisols also occur. The soils of the dune complex are sandy and classified as Arenosols.

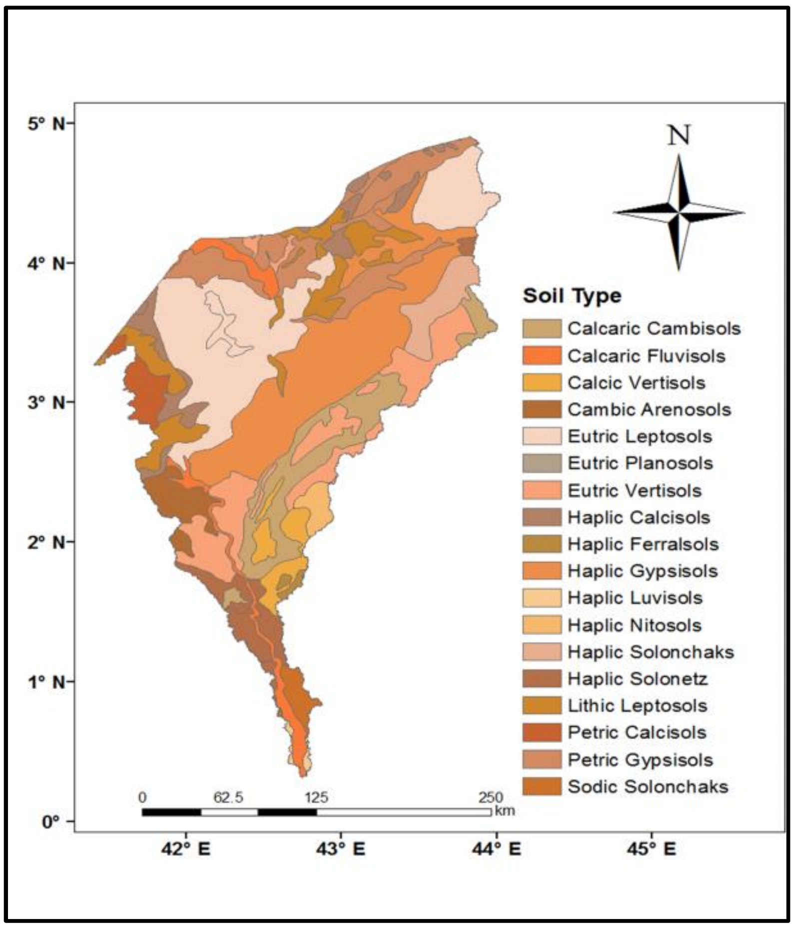

Figure 3.10: Soil Type of Juba basin

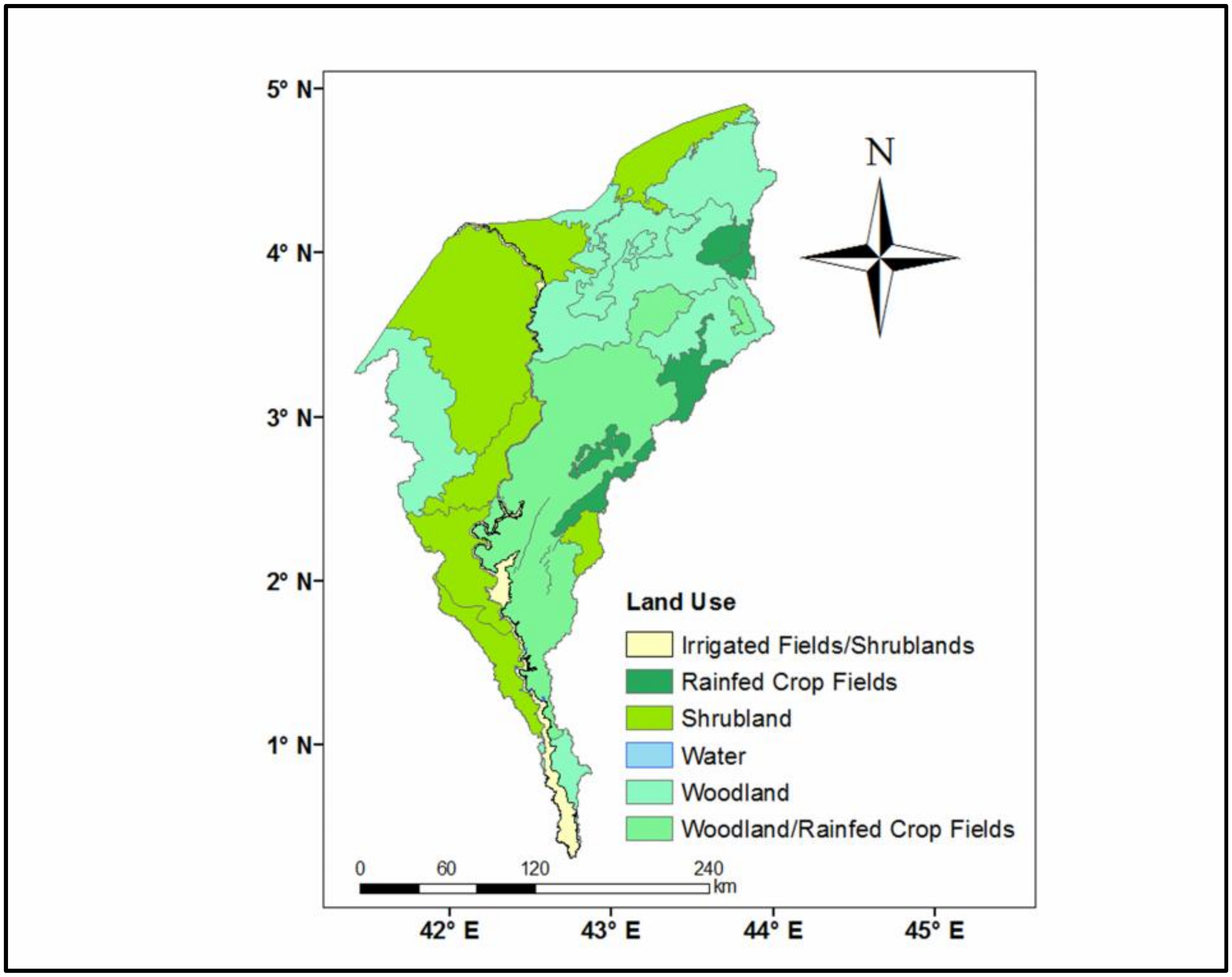

Figure 3.11: Land use of the study area

3.1.7 Livelihood

The livelihood of the Juba basin community depends mainly on agriculture (both rain-fed and irrigated) and livestock.

In Somalia, agriculture and livestock are the backbone of the economy of the country and the livelihood of most of the people depends on these two sectors. Because of semi-arid climate condition, drought and flood are more common and always have an impact on livelihood of the communities in Juba basin. Droughts have also caused displacement of the population in the horn of Africa, including Somalia, where displacements have also been induced by civil unrest droughts.

3.2 Methods of Data collection

For this study, data has been taken partly from the literatures both past and recently studies done in the Juba basin particularly focusing on water related studies and partly from databases mainly the one of FAO-SWALIM and government agencies offices were considered.

3.2.1 Research Design

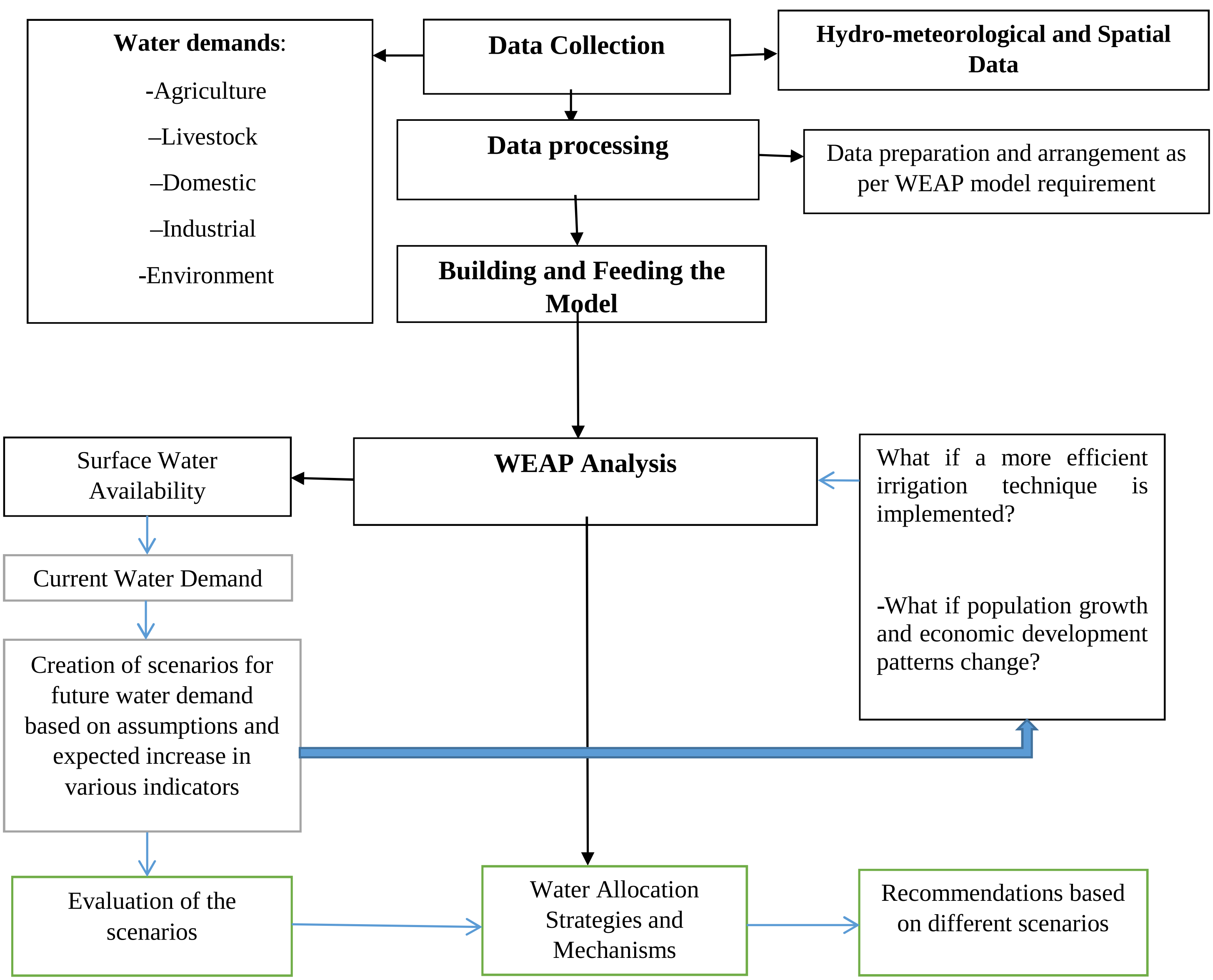

Figure 3.12:Research design or Flow chart

3.2.2 Climate data

The climate data used in this study were obtained from FAO-SWALIM and mean long term climate data were extracted from ClimWat software developed by FAO in 2006 for the purpose to obtain the long term climate data in different part of the world easily. CLIMWAT 2.0 offers observed agro climatic data of over 5000 stations worldwide distributed including Somalia as shown figure 3.13. CLIMWAT 2.0 has been produced in two versions; one containing the worldwide database and the second in which the databases are divided by continent.

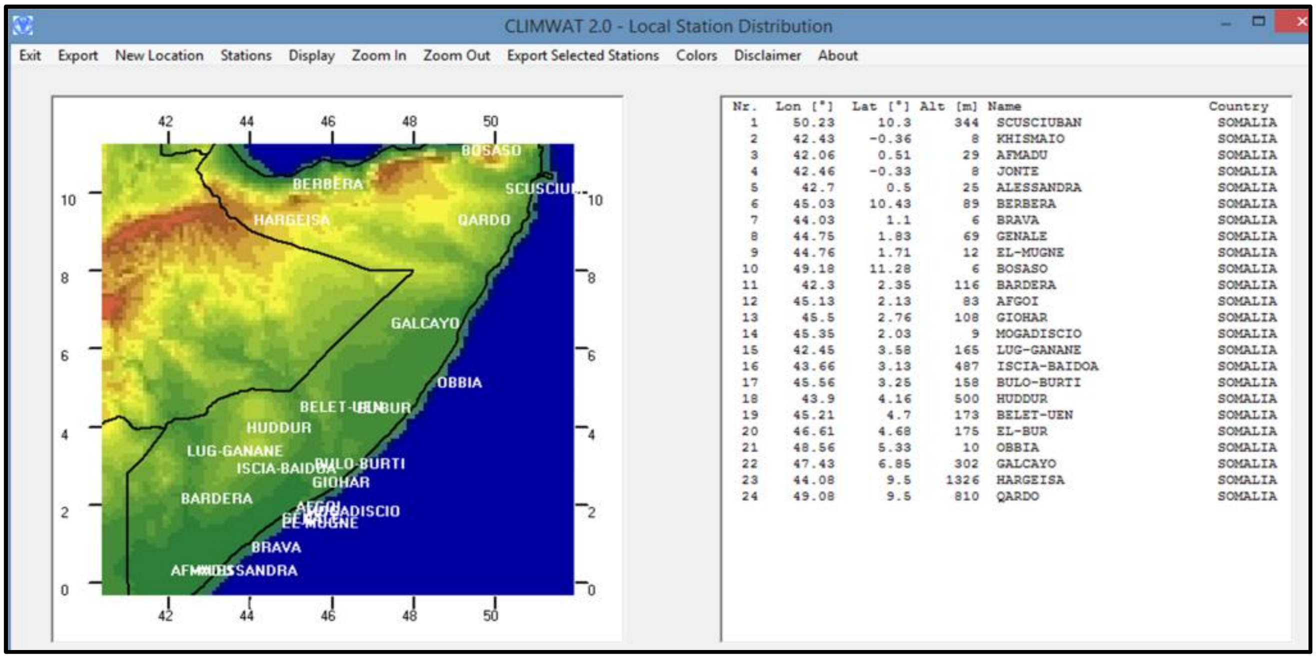

Figure 3.13: ClimWat stations in Somalia.   Source: FAO, 2006

CLIMWAT provides long-term monthly mean values of seven climatic parameters, namely:

- Mean daily maximum temperature in °C
- Mean daily minimum temperature in °C
- Mean relative humidity in %
- Mean wind speed in km/day
- Mean sunshine hours per day
- Mean solar radiation in MJ/m2 /day
- Monthly rainfall in mm/month
- Monthly effective rainfall in mm/month
- Reference evapotranspiration calculated with the Penman-Monteith method in mm/day.

3.2.3 Hydrologic data

Hydrology data is an important aspect of modelling in water resources system and helps in understanding how it operates under a variety of hydrologic conditions. Daily river discharge and river level data were collected from the current functional stations in the study area starting from 2002-2014 and obtained a long term river flow collected from 1963-1990 along the basin . In addition, a long term river flow of the upper catchment at Ethiopia-Somalia border gauged station at Dolow Ado on Genale Dawa river basin (known Juba River in Somalia) were obtained for the year 1973-2002 and this flow was used as input to WEAP in order to understand the water resources system of the upstream part of the Ethiopia based on monthly and yearly average.
Every hydrological and water resource model has its own way and format to accept data, WEAP is a very flexible model which takes daily, monthly and annual data. However, average monthly data were used for running the model. The collected daily discharge from gauging stations along the basin was aggregated to monthly average river flow and fed to WEAP in a CSV format.

Based on the river flow, four different scenarios were developed and classified as baseline scenario (2014), short term (2015-2025), medium term (2026-2040) and long term scenarios (2041-2055) and each scenario upstream planned developments and water demands to multiple water users were given consideration based on the master plan of Genale Dawa which was mentioned how the future flow looks like if the planned developments are implemented while the reduction of the monthly average river flow at border of Ethiopia-Somalia are estimated to be 12.2%, 14.8% and 19.8% in medium scenario (2012-2022), high scenario (2022-2037) and prospective scenario respectively (MoWE, 2007). The reduction of the flow at the end of each scenario was based on throughout the year from the initial year of the scenario to the last year.

Table 3.3: Yearly Mean Flow at Dolow Ado (Ethiopia)

Scenario	Flow m^3/s	Volume Bm^3/y	Reduction from the base case (%)	Scenario Description
A	207.47	6.54		Original state of the basin for base period 1973-2002 (Natural flow conditions)
B	206.80	6.52		Base case (2005) with existing schemes

C	186.27	5.87	9.9%	Low scenario(2007-2012)
D	184.10	5.80	12.2%	Medium scenario (2012-2022)
E	179.48	5.66	14.8%	High scenario (2022-2037)
F	171.23	5.39	19.8%	Perspective scenario (2037+)

Source: Ethiopian MoWE (2007)

However, this estimation was applied to the observed river flow at Luuq where water resource planning of Juba basin are always applicable therefore monthly average of the Luuq station from 2002-2014 as the baseline flow were used and developed the monthly average river flow of the short term plan (2015-2025), medium term plan (2026-2040) and long term plan (2041-2055) based on the strategic plan of the Ministry of Agriculture, Somalia.

In Somalia, when the former government collapsed in 1991 all the functional gauged stations along Juba basin were destroyed and become non-functional due to civil war, but fortunately in the mid of 2001, some stations were resumed and reinstalled by FAO-SWALIM therefore from 1991-2000 no data are available and is difficult to fill such big gap which is 10 years. Hence, for this study Luuq station river flow data of year 2002-2014 was used as the headflow input to WEAP because of its accuracy while Bardere river flow was observed to be more exceptional than Luuq (H. A. Houghton-Carr, et.al, 2011).

According to H. A. Houghton-Carr, et.al, (2011) it is indicated that the recent data at Luuq compare reasonably well with the pre-war data, in contrast to Bardere where there are some notable differences. These results indicate a suspected problem with the post-2001 data at Bardere. The flows at Bardere, particularly the low flows, are too high, and it is unlikely that this is caused wholly by local storm runoff. It is possible that the Bardere rating has shifted; also, the datum adjustment applied to the water level measurements should be checked. He concluded that the post-2001 data at Luuq on the Juba are most reliable, whilst at the other stations there are some issues with the data that need to be addressed before these data can be fully utilized.

Henry (1979) indicated that gauge stations operated on the Juba River at different times at Luuq, Bardere, Kaitoi and Jamame, only the one close to the Somalia border with Ethiopia which is Luuq station are acceptable since, as the case of the Juba river catchment within Somalia contributes no significant flow of the stream.

Basnyat et.al (2009), mentioned that Luuq flow is important for getting actual river flow amounts from the source and planning activities such as water resource planning, estimating peak flow and develop flood warning strategies in southern Somalia and indicated that the average river flows along the river decreases from upstream to the downstream parts, although the catchment areas increase. These could be due to various factors, which include the following:

1. There is little contribution from the catchment areas in Somalia, due to both arid climatic conditions and undefined drainage network and density. Only during high rainfall periods do the tributaries contribute flows to the main river.
2. The bank full condition occurs frequently when floodwaters spill over the riverbanks and flood the vast flood plains laterally as one move downstream. The peak flows in the downstream areas thus reduces and hence the total annual volume. The river channel becomes wider as it flows downstream.
3. During the low flow periods, there is significant water diversion to irrigate the lands in the riverine areas along the Juba and Shabelle rivers. In addition, very little water returns to the river as return flow.
4. As the river traverses through arid climate conditions, the potential evapotranspiration is very high compared to rainfall. The evaporation from water in the flood plains is high too.
5. Since the river slope is also very gentle, there is a lag of 2 to 3 days for the water to travel from the upstream to downstream points, where evaporation is quite high.
6. The river water is recharging the aquifers along the course of the river which reduces the flow downstream. In addition, due to the topography and hydro-geological conditions, it can be safely said that there is very little base flow contribution from groundwater aquifers in the Somali catchments.

3.2.4 Sectoral Water Demands

Sectoral information of data were collected from different sources in order to evaluate and fully understand the current and future water demands in relation with the available supply of Juba basin in southern Somalia.

The most important water resource in the study area is Juba River, which determines the ecosystem of the riverine area. The river itself is a habitat for fish and wildlife and it interacts with the riparian lands through the regular seasonal floods. In addition, it recharges the groundwater storage although not much is known about these mechanisms in detail.

Man has always made use of the river as a source of water for meeting domestic and animal watering needs and for cultivating crops. Before the civil war broke out in Somalia in 1991, the water for Juba was being used for generating electricity through Fanole barrage and for providing the basis for modern irrigation agriculture.

i. Agricultural water demand

As per the WEAP model data input requirement, irrigated area, type of crops and seasons of cultivation are important. Current irrigated areas of Juba basin are estimated to be 15000 ha only which mostly are in downstream part of the basin) FAO-SWALIM, 2012). This is due to all irrigation schemes collapsed during the civil war and mostly irrigation projects along the river owned by the state while at present no state projects are running and the government focuses on stability and security instead of implementation of projects.

Based on the Master plan of the Juba basin, crop water requirement of all the crops grown in the study area in a selected three different climate stations of the basin in upstream, middle-stream and downstream have been used in this study and the average CWR were observed to be 13404 m^3/ha/year as presented in figures 3.14, 3.15 and 3.16 respectively.

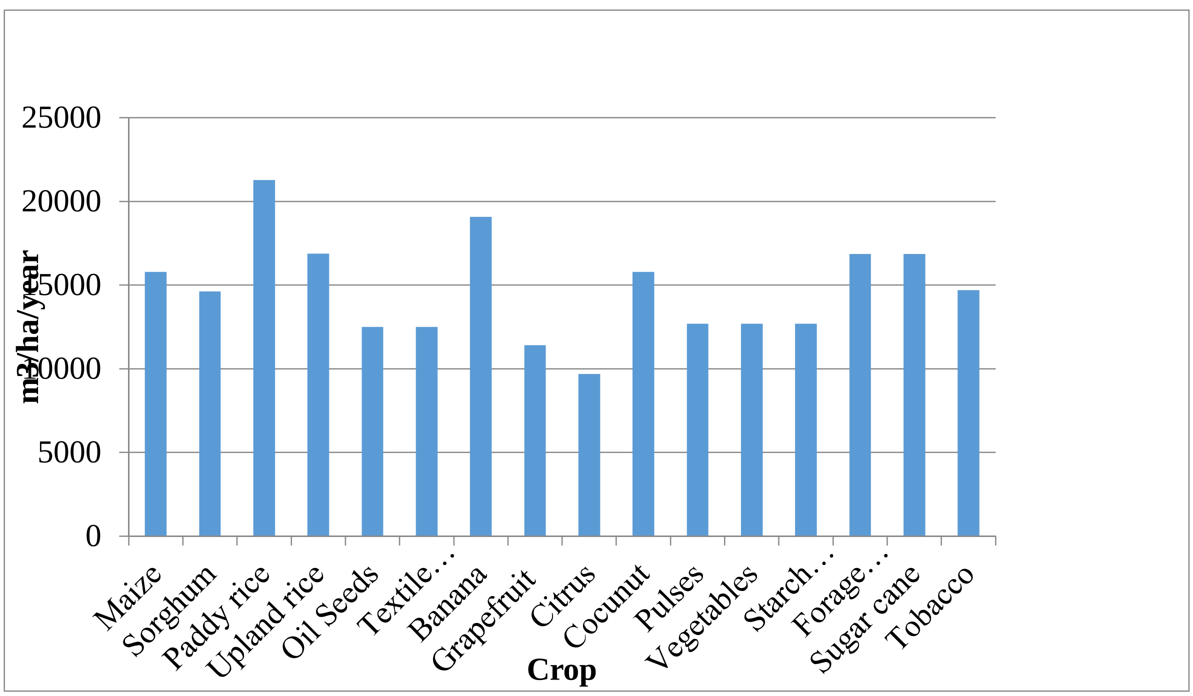

Figure 3.14: Crop water requirement at Luuq station

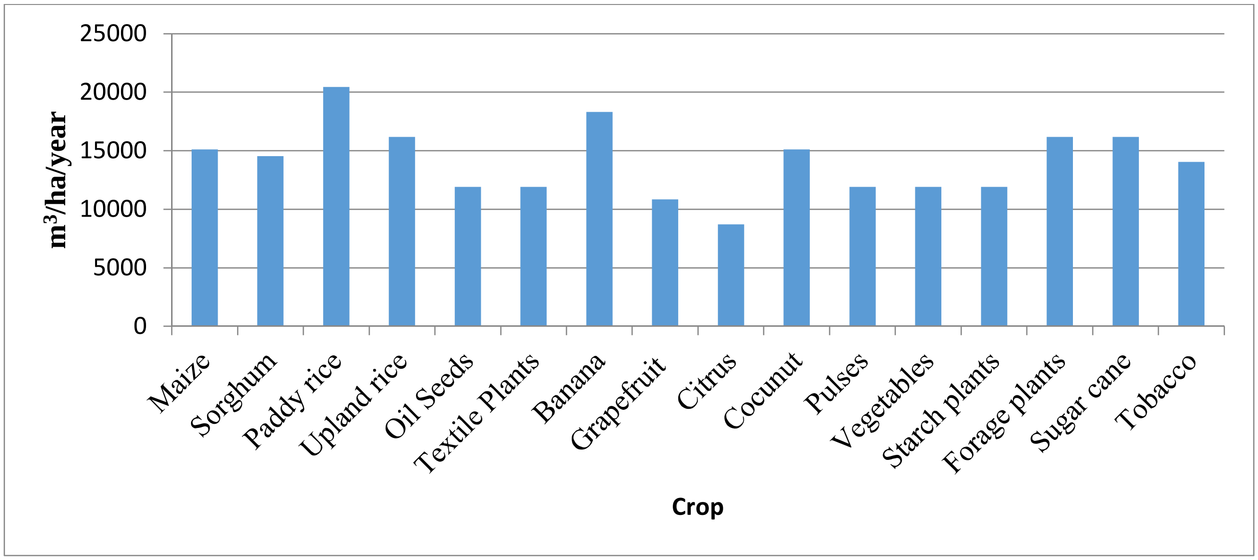

Figure 3.15: Crop Water Requirement at Bardere Station

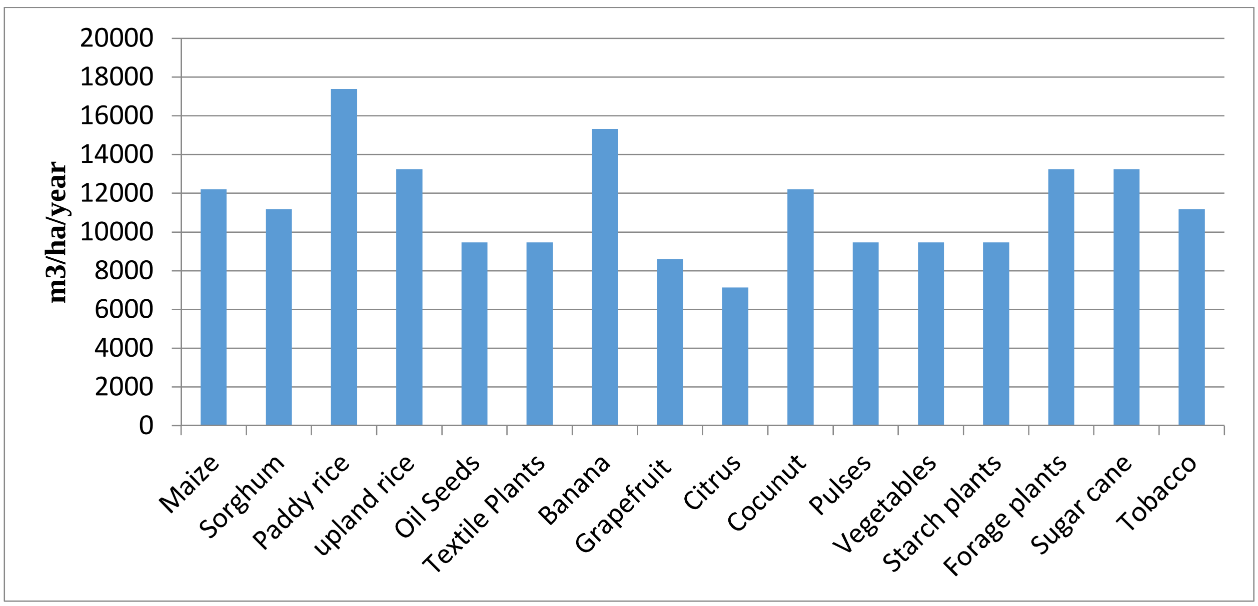

Figure 3.16: Crop water requiremnt at Jilib station

ii. Livestock Water Demand

The only available data on regional livestock numbers is a pre-war record from 1988, based on data by the Ministry of Agriculture (Basnyat, 2007). Livestock water demand has been based on FAO livestock standard water demand in semi-arid regions, particularly sub-Sahara Africa and applied 40 litres, 7 litres and 25 litres per head of cattle, sheet/goat and camel per day respectively.

Table 3.4: Livestock Population of Juba Basin and their water demands

	Cattle		Camel		Sheep & Goat	
Region	Head	m^3/day	Head	m^3/day	Head	m^3/day
Gedo	612,900	24,516.00	899,270	22,481.75	1,566,160	10963.12
Middle Juba	424,860	16,994.40	252,300	6307.5	968,160	6777.12
Lower Juba	999,450	39,978.00	254,640	6366	252,450	1767.15
Bakol	296,000	11,840.00	415,230	10,380	321,020	2247.14
Bay	116,080	4,643.20	220,230	5505.75	458,750	3211.25

According to the FSNAU (2012), there is a current national trend of increasing livestock keeping (cattle, camel, and sheep/goats. Similarly, no current livestock projections are available therefore pre-war livestock projection which was stated to be 2% was used for future projection. This data were obtained from the Ministry of Livestock, Forest and Range, the Federal Republic of Somalia. For estimation of livestock water demand, FAO livestock water demands standard in semi-arid regions have been used for the different types of the livestock available in the study area.

iii. Domestic Water Demand

In order to model the current and future sectoral water demands among multiple water users, current information and future projection are necessary therefore in this study total current population with an annual population growth rate were obtained from the Ministry of National Planning, the Federal Republic of Somalia (2014).

According to the Ministry of National Planning in 2014, the total populations of the basin both urban and rural were estimated to be 2520041 people with 2.7% (UNDP, 2005) annual growth rate. In reference scenario, it was assumed that the annual growth rate to be constant without change while other developed scenarios which were based on 'what if questions' assumed that annual growth rate to be 3% in scenario one and scenario two. As a general guideline, a standard of 50 litres per capita per person per day (lpcd) for urban population and 20 litres per capita per person per day for rural consumption was used.

Commercial and Institutional Water Demand (CIWD)

In addition to domestic water use, water requirements in the urban include the normal needs of the community for public schools, clinics, hospitals, offices, shops, restaurants and hotels. The water demand for commercial and institutional needs is usually linked directly to the population; and has been taken as 5% of the domestic demand.

Industrial Water Demand (IWD)

There is no data available on industrial water use or demand in the basin. The respective needs are probably relatively small though, since the agro-pastoral sector is the dominant occupation (UNDP, 2008) and none of the available field reports assigned any importance to it. But even if the industry does not abstract major water quantities, discharges of pollutants could have severe impacts on the water quality, polluting large quantities of water and making them unsuitable for any other use.

However, in this study, Industrial water demand was linked to domestic water demands, although the industry is not usually linked directly to the population. But for the purpose of planning, currently it is assumed to use 10% of domestic water demand due to lack of data and cannot be neglected. Before the outbreak of the civil war in Somalia, there were industries in the basin and the most important one was Marere Sugar factory, established as an autonomous agency in 1977, was a great economic significance of the country. The main objectives of Marere sugar factory were: (i) to supply sugar for the country in substitution of the imported product, (ii) to create employment for Somalis, (iii) to create a sound infrastructure to benefit the neighbouring farming areas. The Project employs 5000 persons; this number was expected to increase if the full development of the Project was achieved. However, due to current civil unrest no operational factory and no available industry water demand data in the study area.

Total Daily Demand (TDD)

The total daily demand is taken to be the combined total of the domestic, commercial, institutional and industrial water demands.

Total Daily Demand = Demands for Domestic + Commercial & Institutional + Industrial.

iv. Environmental Flow Requirement

In order to maintain the ecological management services and the natural channel habitat associated to the historic flow regimes of the Juba River, a certain reserve flow has to be maintained and could be considered as a sectoral demand on its own (Petersen and Gadain, 2012).

A Minimum Flow Requirement defines the minimum monthly flow required along a river to meet water quality, fish & wildlife, navigation, recreation, downstream or other requirements. Depending on its demand priority, a flow requirement can be satisfied before, after or at the same time as other demands on the river (SEI, 2012). The FDC Shift function in WEAP was used to estimate the recommended streamflow in a modified stream, by uniformly reducing (shifting) the natural (unregulated) flow duration curve by a fixed number of percentile places, and further disaggregating it into a complete time series of modified flows. FDCShift is one of several possible approaches to calculating environmental flows, and should be considered a "low confidence" method. The shift was calculated according to the following procedure:

1. The Flow Duration Curve (FDC) was calculated from the original ("No Change") streamflow time series specified by the ReadFromFile parameter.
2. For each flow value *Q* in the original streamflow time series, calculate its percentile *P* in the FDC: $P = 100 * Rank / (N + 1)$, where *N* is the number of data points and *Rank* is the rank order (from *1-N*) of *Q* in the flow duration curve (flows in decreasing order). *Rank* = *1* is the highest flow; *Rank* = *N* is the lowest flow.
3. Calculate a new percentile *P'* by shifting *P* the number of steps according to the Environmental Management Class parameter (A-F, corresponding to a shift of 1-6 steps). A shift of one step corresponds to moving from one number to the next larger number in the following list of percentiles: 0.01%, 0.1%, 1%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 99%, 99.9% and 99.99%. For example, a shift of 2 places (B: Slightly Modified) would mean that a 60% flow would be reduced to a 80% flow, and a 90% flow would be reduced to a 99% flow.

3.2.5 Spatial data

Shape files of Digital elevation Model (DEM), land use, soil type and agro-ecological zone were collected from the FAO-SWALIM database. The DEM was used to generate the boundary of the study area by using ARCSWAT in ARCGIS. These shape files also uploaded into WEAP system and used for schematic view of the study area.

3.3 Methods of Data Analysis

3.3.1 Data Analysis

Based on the availability of the model with its capabilities for analysis and works in any environment, data was analysed by using WEAP model version 3.43 to allocate the available limited water in an efficient and sustainable manner among domestic including industrial, agriculture, livestock and environment in Juba basin of southern Somalia.

3.3.2 WEAP Model for Data Analysis

WEAP is a river basin simulation model with Geo-spatial capabilities that is capable of simulating the allocation of water throughout a river basin based upon a user specified time step while also it is a modelling tool for water planning and allocation that can be applied at multiple scales, from community to catchment to basin (Yates et al., 2005a, b; Sieber et al, 2005).

Surface Water Resource

WEAP model was used to evaluate and analyses the surface water resources available in Juba basin based on the observed river flow of Ethiopia-Somalia border (1973-2002) and at Luuq station for Somalia side (2002-2014). The flow data was input to WEAP system in order to know the available water resources in monthly and annual bases. WEAP rainfall runoff model was used to understand the contribution of Somali part to the basin. Land use (Area and Kc,), climate((Precipitation, Effective precipitation and ETo) Where Kc- crop coefficients and ETo is the reference crop evapotranspiration was input data to the WEAP to simulate the runoff.

Modelling Current and Future Water Demands among water users

Current and future water demands to domestic (including industrial, commercial and institutional), agriculture, livestock and environmental flow requirement were analysed using WEAP model. The steps below were followed for current situation water demands and scenario analysis:

1. Definition of the study area and time frame: The setting up of the time frame includes the last year of scenario creation (last year of analysis) and the initial year of application. The study area was defined and set its boundary by adding the vector layer of Juba basin which has been prepared using ArcGIS 10.1 to the WEAP system because WEAP reads vector shapefile format of WGS1984 projection. Therefore, this study the time frame was set from 2014 and the last year of the scenario was set to be 2055 based on availability of the current, projected and planned development in the basin to all water sectors.

2. Creation of the current account which is more or less the existing water resources situation of the study area. Under the current account available water resources and various existing demand nodes are specified. This is very important since it forms the basis of the whole modelling process. This can be used for calibration of the model to adapt it to the existing situation of the study area.

The Current Accounts represent the basic definition of the water system as it currently exists. The Current Accounts are also assumed to be the starting year for all scenarios. The Current Accounts include the specifications of supply and demand for the first year of the study on a monthly basis.

In this study, as mentioned above the year 2014 were the initial year while last year of scenario were set to be 2055 therefore all the collected current information on both water supply and demand were the data input to the current accounts.

3. Creation of scenarios based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated for running the model.

In this study, three scenarios were developed namely reference scenario or business as usual scenario, scenario one for water demands and scenario two for water allocation. The scenarios were used to address a lot of "what if situations", like what if population growth and economic development pattern change, and what if more irrigation efficiency technology applied.

4. Evaluation of the scenarios with regards to the availability of the water resources for the study area. Results generated from the creation of scenarios can help the water resources planner in decision making, which is the core of this study. WEAP uses scenarios as a way to evaluate different water allocation schemes, given water demand and associated priorities.

All the three scenarios were evaluated and possible solutions were listed down to avoid water based conflict among water users and strategies for balancing supply and demand were suggested.

WEAP Schematic

The Schematic View is the starting point for all activities in WEAP. It is formed from the setup "area". It defines the physical elements comprising the water demand-supply system and their spatial relationships, the study time period, units and the hydrologic pattern. The graphical interface is used to describe and visualize the physical features of the water supply and demand system (SEI, 2012). The system formed is a spatial layout called the schematic. GIS Vector Layers were added as overlay or background on the Schematic as shown figure 3.18.

Demand Sites

A demand site is defined as a set of water users that share a physical distribution system that are all within a defined region or that share an important withdrawal supply point (Sieber et al., 2005). Demand sites used in this study are classified in to three main demand sites domestic demand which were included industry, commercial and institutional water demands, agriculture and livestock. Each demand site has a transmission link to its source and where applicable a return link directly to a river.

Annual Activity Levels

The annual demand represents the amount of water required by each demand. Losses, reuse, and efficiency are accounted for separately. Water consumption of each demand site was calculated by multiplying the overall level of activity by a water use rate based on monthly variation of each demand site. Activity Levels are used in WEAP's Demand analysis as a measure of social and economic activity.

Annual Water Use Rate

The Water Use Rate is the average annual water consumption per unit of activity. WEAP displays the denominator to emphasize that this is a rate per unit, not the total amount of water used. In this study, annual water use rate per person, per hectare and per head of livestock were calculated and converted in to m^3 per annum and provided as input to the WEAP system.

Monthly Variation

WEAP performs a monthly analysis from the first month of the current account year through the last month of the last year. The current accounts year is usually the most recent year for which reasonably reliable and complete data are available and from which future demand projections can be made. The current accounts year data comprise the current accounts, which all scenarios use as the basis for their projections.

Monthly variation is important and it has been based on the monthly requirement of each demand sites for example, domestic and livestock water use may remain constant throughout the year, while agricultural water demand vary considerably from month to month based on crop water requirement and cultivation period. If the demand is constant throughout the year, the monthly variation should be left as a blank. Otherwise, the percentage of annual water used in each month has to be entered. The twelve monthly coefficients must sum to one hundred percentages. If demand does not vary, all months are assumed to use the same amount, according to the number of days in the month. For example, the default annual share for January is 31/365=8.49%, whereas February is 28/365=7.67%. Depending on the setting in basic parameters, either the monthly variation is the same for all branches underneath a demand site or each branch within a demand site can have a different monthly variation. Monthly variation of agriculture water demand was based on monthly irrigation requirement of all crops in the study area.

Demand Sites Schematic Development

The create-area menu option was used to create the Project Area. GIS-based vector boundary, river shape files for the Juba River Basin were imported to the Project Area to orient the system and refine the area boundaries. This provided the outline for the Schematic which is the view used for system configuration. The major river water courses were digitized, starting from a source going downstream. Monthly average head flow data of Luuq station was entered using the WEAP data tree, e.g. minimum environmental flow requirement (to meet the ecological needs), return flow, stream gauge and transmission link for demand sites and supply source. Demand sites were entered at the schematic and demand priorities set based on the master plan of Juba basin for water allocation priorities. Demand priorities represent the level of priority for allocation of constrained resources among multiple demand sites. Demand sites with the highest priorities will be supplied first. For each demand site, the Annual Activity Level, Annual Water Use Rate and Consumption were entered to be used in calculating the water demand. Different levels of disaggregation were created for each demand site, e.g. domestic demand, livestock demand, agricultural demand and environmental flow requirement as shown the final demand site schematic map of figure 3.17:

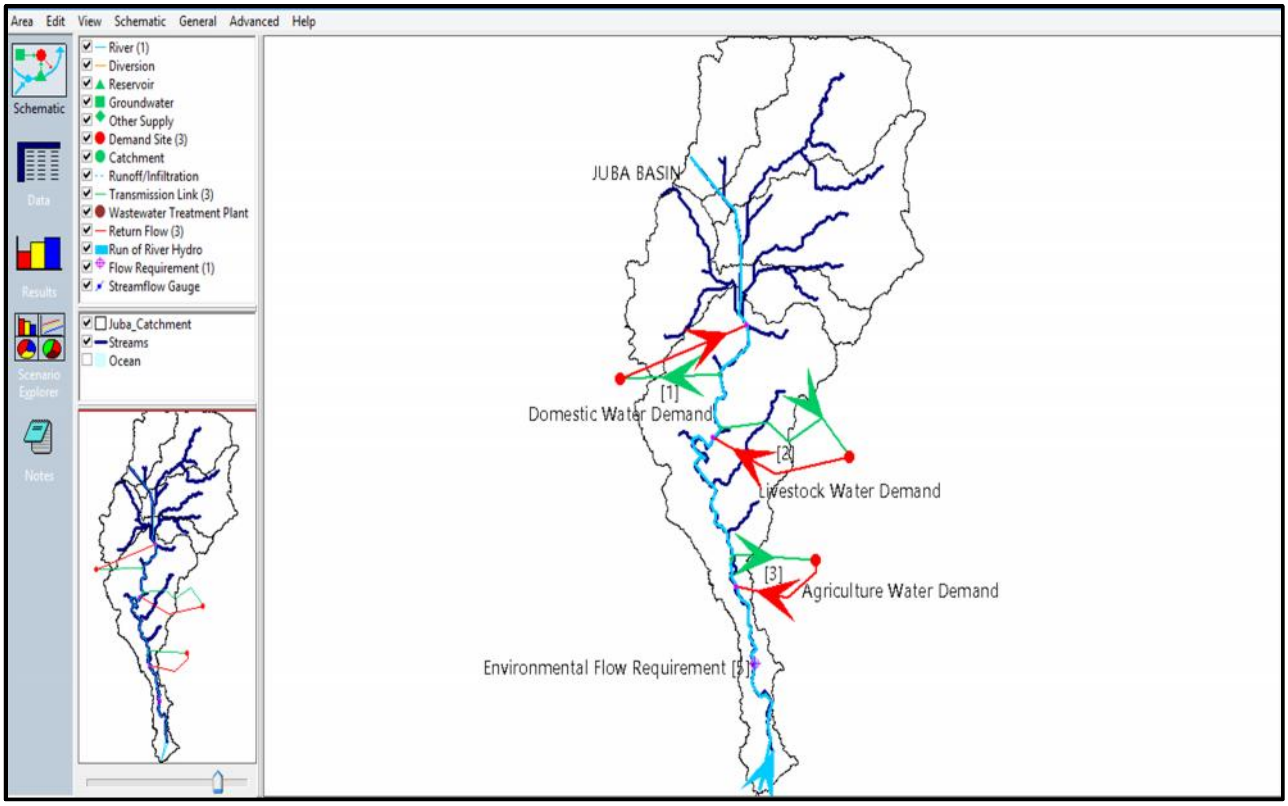

Figure 3.17: WEAP schematic view of Juba basin

Priorities for Water Allocation

WEAP uses a linear programming technique to solve the water allocation model; priorities (1 to 99) were used to classify demands. 1 represents highest priority demand node and 99 represents the lowest priority demand node. A Demand-Priority- and Preference driven Approach used presents a robust solution algorithm to solve the water allocation problem.

A standard linear program is used to solve the water allocation problem whose objective is to maximize satisfaction of demand, subject to supply priorities, demand site preferences, mass balances and other constraints.

Two user-defined priority systems are used to determine allocations from supplies to demand sites: Demand Priorities and Supply Preferences. Demand Priority determines the demand site's priority for supply. Demand sites with higher priorities are processed first by the WEAP Allocation Algorithm. Reservoir priorities default to 99, meaning that they will fill only if water remains after satisfying all other demands. Many demand sites can share the same priority. These priorities are useful in representing a system of water rights and are also important during a water shortage (SEI, 2012). Supply Preferences indicate the preferred supply source where there is more than one source to a demand site. Using the demand priorities and supply preferences, WEAP determines the allocation order to follow when allocating the water. The allocation order represents the actual calculation order used by WEAP for allocating water.

In Somalia, as it has been mentioned in the proposed Somalia National Water Law in 1984 and the master plan of the Juba Basin, which was developed in April 1990 by the ministry of Juba valley development, the following priorities were set:

a. Domestic and livestock uses, highest priorities
b. Irrigation, second priority
c. Commercial and Industrial uses, third priorities
d. Others (filling reservoir, etc.)

In this study, the above priorities were adopted in order WEAP to understand which demand sector should be given the first, second, third and the least one. Although industrial water demand was linked to domestic water demand due to lack of data.

On the other hand, currently no operational reservoir in Juba basin that is why no consideration has been given in reservoir operations and expected in the future therefore environmental flow requirement were given consideration to keep the needs of ecological system of the basin.

Scenario Analysis

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent storyline of how a future system might evolve over time in a particular socioeconomic setting and under a particular set of policy and technology conditions (SEI, 2012). Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts. Scenarios can address a broad range of questions. An important concept of WEAP is the distinction between a reference or "business as usual" scenario and alternative policy scenarios (Raskin et al., 1992). The "business-as-usual" scenario incorporates currently identifiable trends in economic and demographic development, water supply availability, water-use efficiency and other aspects. No new water conservation measures or supply projects are included in the "business-as-usual scenario. This scenario provides a reference against which the effects of alternative policy scenarios may be assessed. In any study the current water accounts and the reference or "business-as-usual" scenarios are outlined based on the continuation of current patterns. Population growth as demand driving variable is relied on for this purpose. "What-if" scenarios based on the reference scenario are then introduced.

The following scenarios were developed based on current situation and future water demands to domestic, agriculture and livestock as well as environmental flow requirement.

- Reference scenario
- Scenario one for sectoral water demands
- Scenario two for water allocation strategies

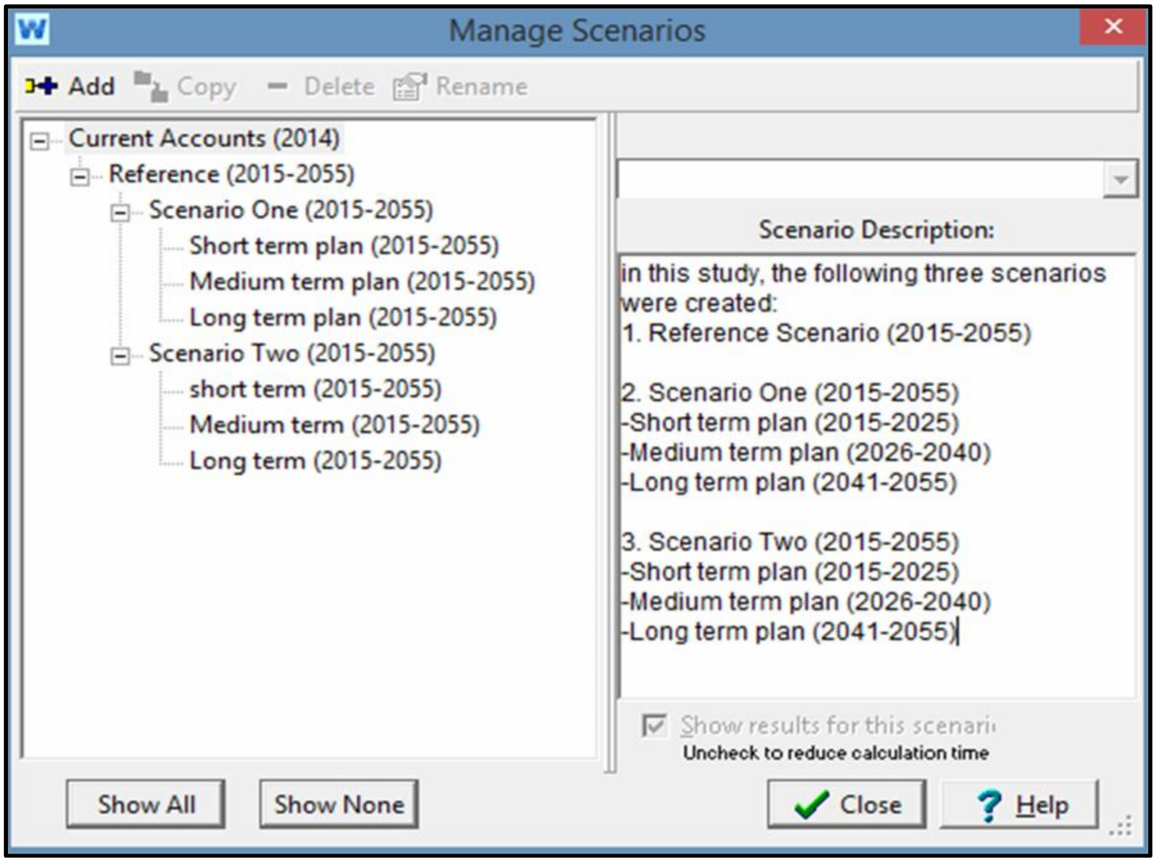

Figure 3.18: Scenario description

In all the three above scenarios, domestic and livestock water demands were calculated based on daily water consumption per person and per head of livestock therefore for livestock population in all the scenarios annual growth rate of 2% were used and constant daily water use rate based on current situation while 2.7% and 3% annual growth rate were used for human population projection in reference and scenario one and two respectively.

On the other hand, agricultural sector were based on current and planned irrigated area in different scenarios as described well in table 3.5.

Table 3.5: Summary of created scenarios on agricultural sector

Scenario	Current and Planned Irrigated area (Ha)	Crop Water Requirement (m^3/ha/year	Demand Management for efficiency irrigation (%)
Reference Scenario (2015-2055)	15,000	13,404	
Scenario one for water demand (2015-2055)			
Short term plan (2015-2025)	73,210	13,404	
Medium term plan (2026-2040)	170,000	13,404	
Long term plan (2041-2055)	221,000	13,404	
Scenario two for water allocation strategies (2015-2055)			
Short term plan (2015-2025)	73,210	12,063	10
Medium term plan (2026-2040)	170,000	10,723	20
Long term plan (2041-2055)	221,000	10,053	25

3.3.3 GIS software

The first step in doing any kind of hydrologic modelling involves delineating streams and river basin, and getting some basic river basin properties such as area, slope, flow length, stream network density, etc. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain processing. In this study, **ArcGIS** 10.1 was used for mapping and to geo-reference the collected information and create spatial database. **Arc-Hydro** and **Arc-SWAT** tools which are GIS extension tools were also used to process a DEM and to delineate the whole of Juba basin river basin and sub-watershed, respectively.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Evaluation of Water Resource System of Juba basin

Planning and allocation of water resources to different uses within the basin is one of the basic activities of water resource management to fill the gaps in water use, drought and flood protection, environmental stability and increasing agricultural production. This has been based on the procedures of the water use and allocation to determine water requirements and allocations for domestic, livestock, agriculture and industrial use at each stage of the development plan.

This analysis takes into account of the increasing demands for water resulting from an expanding population and irrigation area under cultivation, and has then balanced these requirements with the abstractions needed for other consumptive and non-consumptive uses.

In this study, the water use and allocation modelling was restricted to surface water resources only. Groundwater resources have not been considered in this analysis, because information on groundwater availability on its extent, location, recharges rates, safe yields, and current amounts of abstraction, basic quality and purpose of use (sectoral shares) are not available in the basin. If groundwater data becomes available in the future, it can easily be linked to the surface water model through the WEAP's groundwater MODFLOW.

In this study, the year 2014 served as the "current account" year. The current account year is chosen to serve as the base year for the model, and all system information (e.g., demand, supply data) is input into the current accounts. The current account is the dataset from which scenarios are built. Scenarios explore possible changes to the system in future years. The reference scenario carries forward the current accounts data into the entire project period specified (here, 2014 to 2055) and serves as a point of comparison for other scenarios in which changes may be made to the system data, e.g. population number increase based on an annual growth rate or reducing annual water use per hectare due to demand side management and technology.

This year is chosen because of the availability of the data both water supply and water demand therefore in order to understand the available and reliable water resources of Juba basin both monthly average and yearly, river flow of upstream, Ethiopia and downstream, Somalia were used and this will enable decision makers to plan the basin in a holistic approach by observing clearly the long term trends of the river flow and how the basin water resources system changes from time to time in order to avoid the recurrent drought and the frequency flood that always occur in the whole basin.

Figure 4.1 and 4.2 show trends of the river flow of 1973-2002 (30 years) of Genale Dawa both annual and monthly average in order to understand the past and how the river flow changes from month to month and year to year from one scenario to another in order to understand past water resources system in the basin as the result of river basin planning and allocation for both upstream and downstream of Juba basin.

To model the river flow system of the basin in both upstream and downstream of the catchment to be well understood the capability of the basin based on monthly and yearly available water, the monthly average flow of 1973-2002 of Dolo Ado station at Somalia-Ethiopia border was used as WEAP input headflow both annual and monthly average of 30 years river flow and presented the figures 4.1 and 4.2 respectively

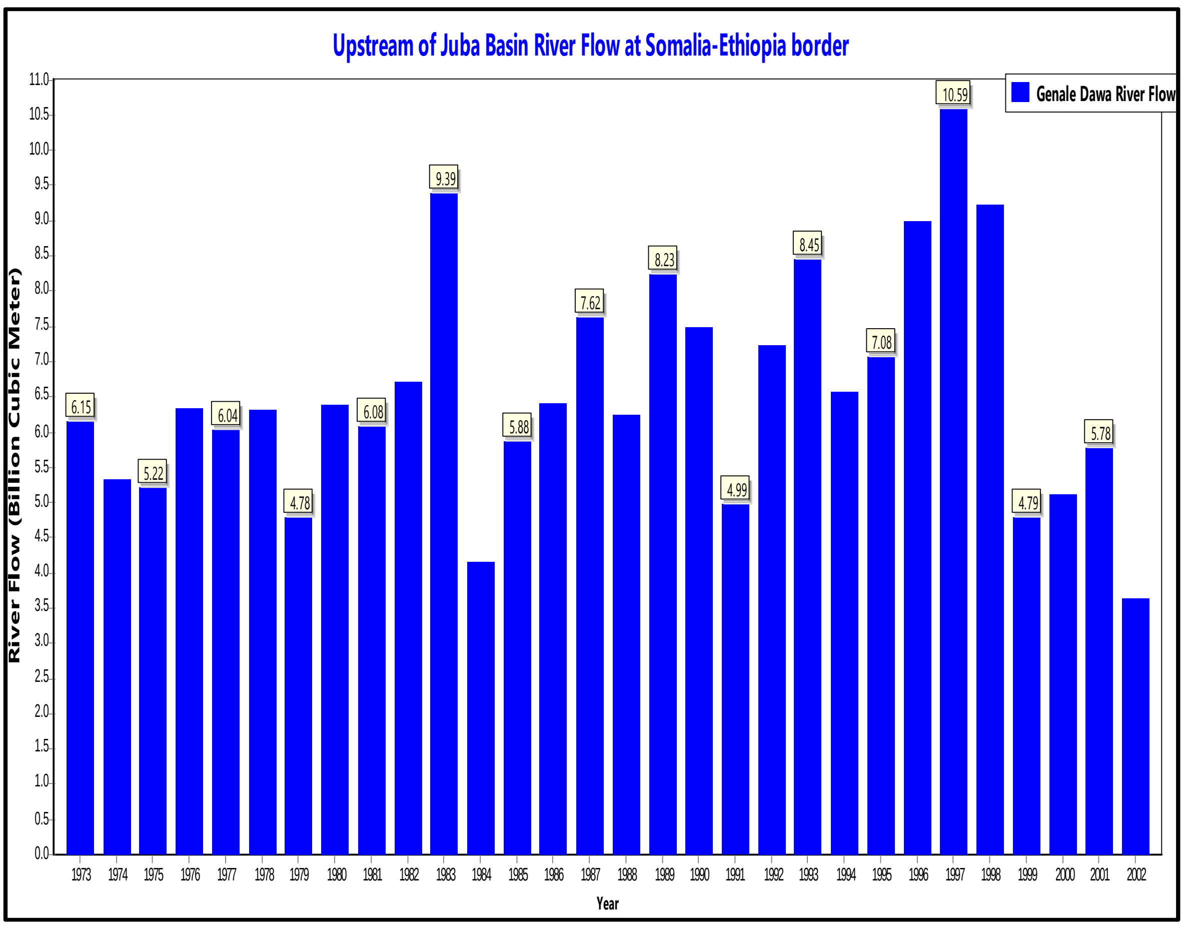

Figure 4.1: Annual river flow of Genale Dawa at the border of Somalia

Figure 4.1 shows the annual river flow of 30 years from 1973-2002 and observed that the average annual river flow to be 207.5 m3/s or 6.5 BCM. As figure 4.1 indicates the average wet years observed were 1983, 1996, 1997, 1998 and 1993 whereas the dry years were observed in 1979, 1984, 1999, 1991 and 2002.

As a result of MIKE BASIN simulation used by the Ministry of water and Energy in 2007, the yearly flows were inspected to be the following:

Gadain et.al (2009) mentioned that in recent years, two major flood events in 1997/98 and 2006 were experienced in the Juba basin and indicated that these floods had a tremendous impact on the environment and the population. Almost the entire Juba valley was inundated and agricultural crops were destroyed. The floods also caused land degradation and increased soil erosion with consequent silting of irrigation barrages.

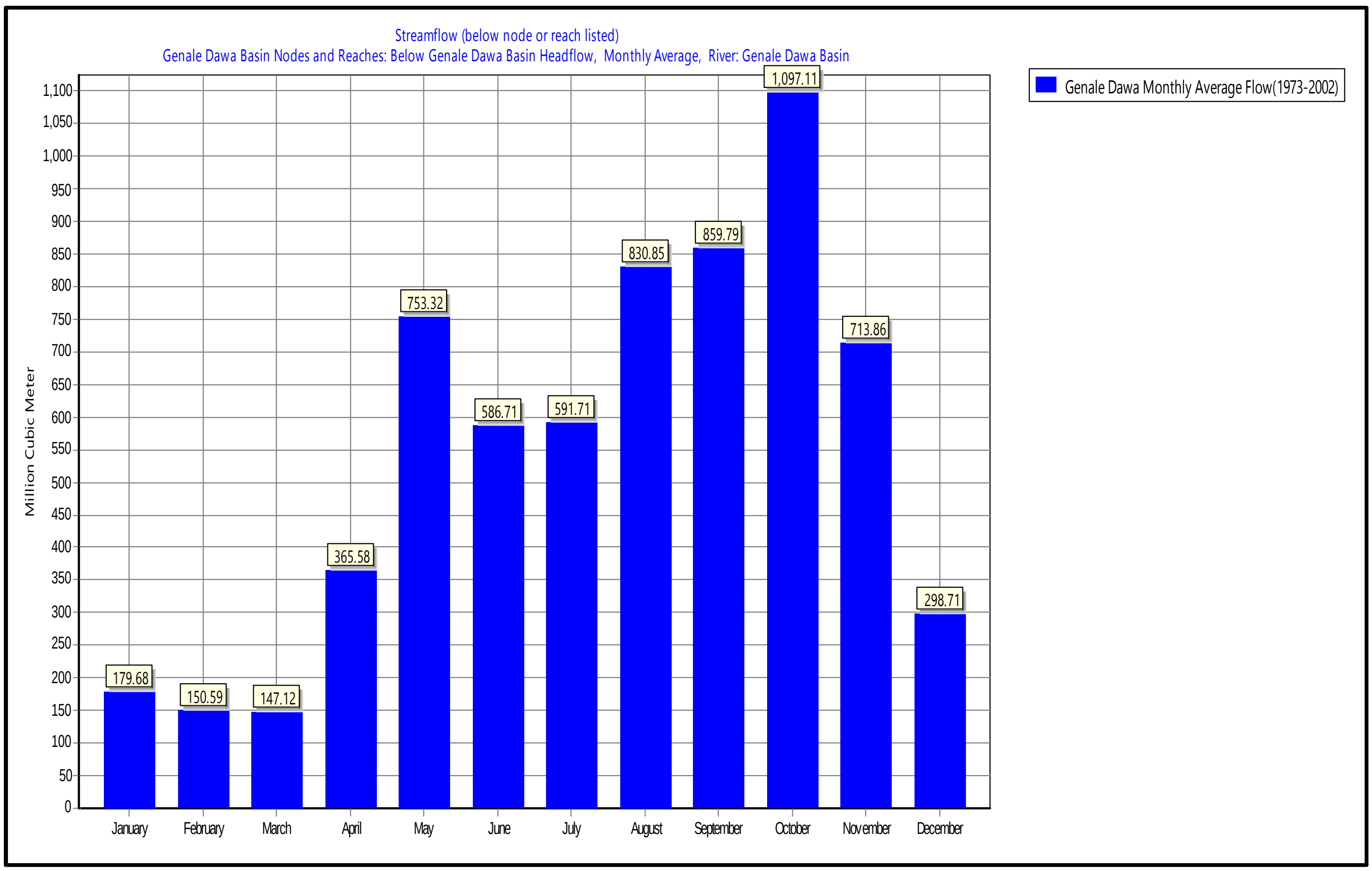

Figure 4.2: Monthly average river flow of Genale Dawa from 1973-2002 at border to Somalia

For the upper Juba catchment, the Ministry of Water Resources and Energy of Ethiopia (2007) also issued a master plan revealing the gradual implementation of irrigation and dam projects to increase the water supply for the local population. The year 2005 has been chosen as the reference (base case). The 'low scenario' (2007-2012) assumes the implementation of medium-scale irrigation projects while the 'medium scenario' (2012-2022) comprises a major hydroelectric power plant (HPP GD3) as well as medium-to-large-scale irrigation schemes. The 'high scenario' (2022-2037) assumes almost full irrigation development and the so-called Genale HPP cascade. Finally, there is a 'full development scenario' (2037+), assuming full irrigation, water supply and hydropower development in the basin therefore in this study, which has been conducted the downstream of the Juba river basin (known Genale Dawa in the upstream) were considered all the upstream development and multiple water sectors use due to transboundary basin shared by Somalia, Ethiopia and Kenya.

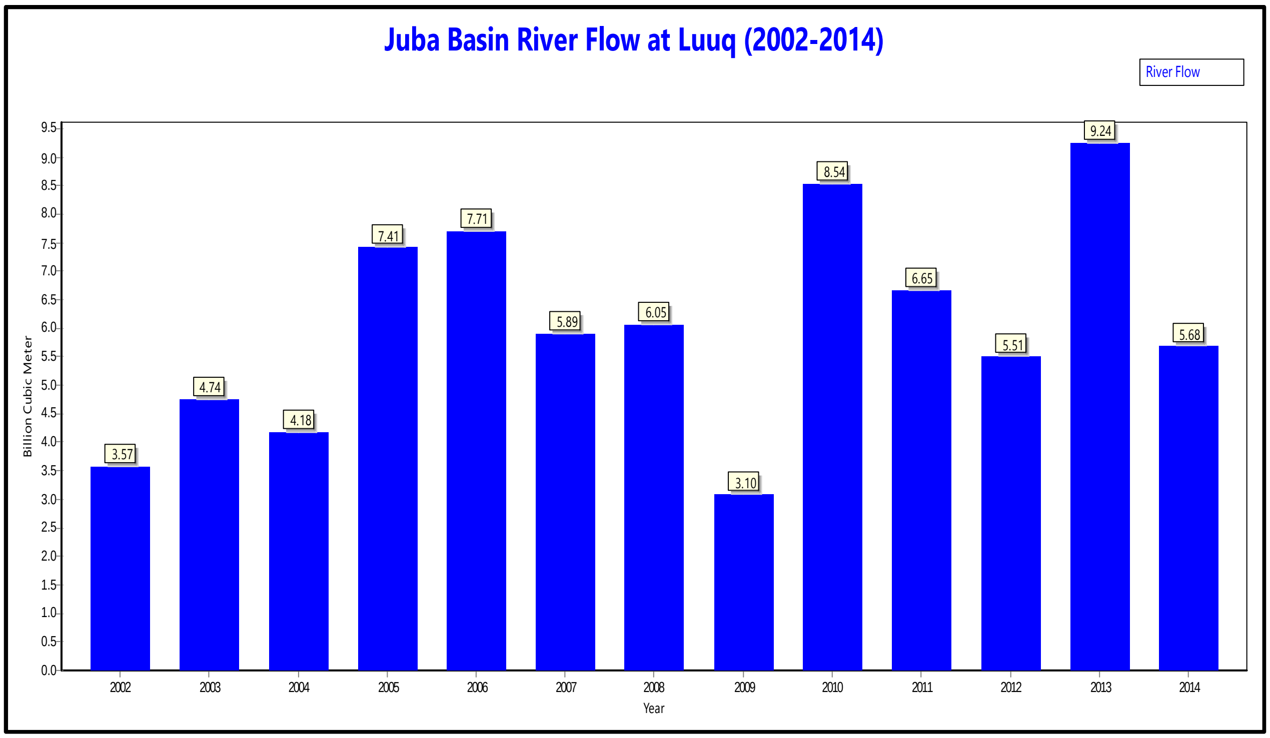

Figure 4.3: Annual river flow of Juba River at Luuq (2002-2014)

Based on the results of the runoff analysis from 2002 up to 2014, it has been observed that the year 2009 was the lowest discharge year and 2013 was the maximum discharge this makes the range of the discharge between 3.10-9.24 BCM while the mean discharge among all the years was observed to be 6 BCM.

In line with the most recent publications (Basnyat and Gadain, 2009), the annual river flows of Juba basin have been quantified as 5.9 BCM. According to Musgrave (2002), the river flows in

Somalia are almost entirely dependent on the rainy seasons in the Ethiopian highlands and estimated that as much as 95% of the annual flow originates from Ethiopia. This implies that the more the rainfall in upstream, the more the river flow is high and the less rainfall, the more the water resources available in the basin is estimated to be low while the contribution of Somalia part are very less due to climate condition.

Basnyat and Gadain (2009) indicated that the flow of the Juba basin in Somalia mainly depends on rainfall and runoff in Ethiopia while Climate change models project that especially the pastoral areas of Ethiopia and Somalia will become drier due to lower rainfalls (IUCN, 2006; EC, 2004). At the same time, drought and flood events are predicted to become extreme and more frequent along the Juba River (EC, 2004; HLC, 2008).

However, Changes of climatic (and other) conditions occurring in Ethiopia would therefore have a significant impact on water availability in the Somali part of the Juba basin. Alterations in temperature and precipitation in Somalia would also modify the regional agricultural water use in terms of irrigation requirements and crop water demands. Lower rainfalls imply a greater reliance on river or groundwater and hence the climate change impacts on river flows are of central importance to the analysis of local water availability.

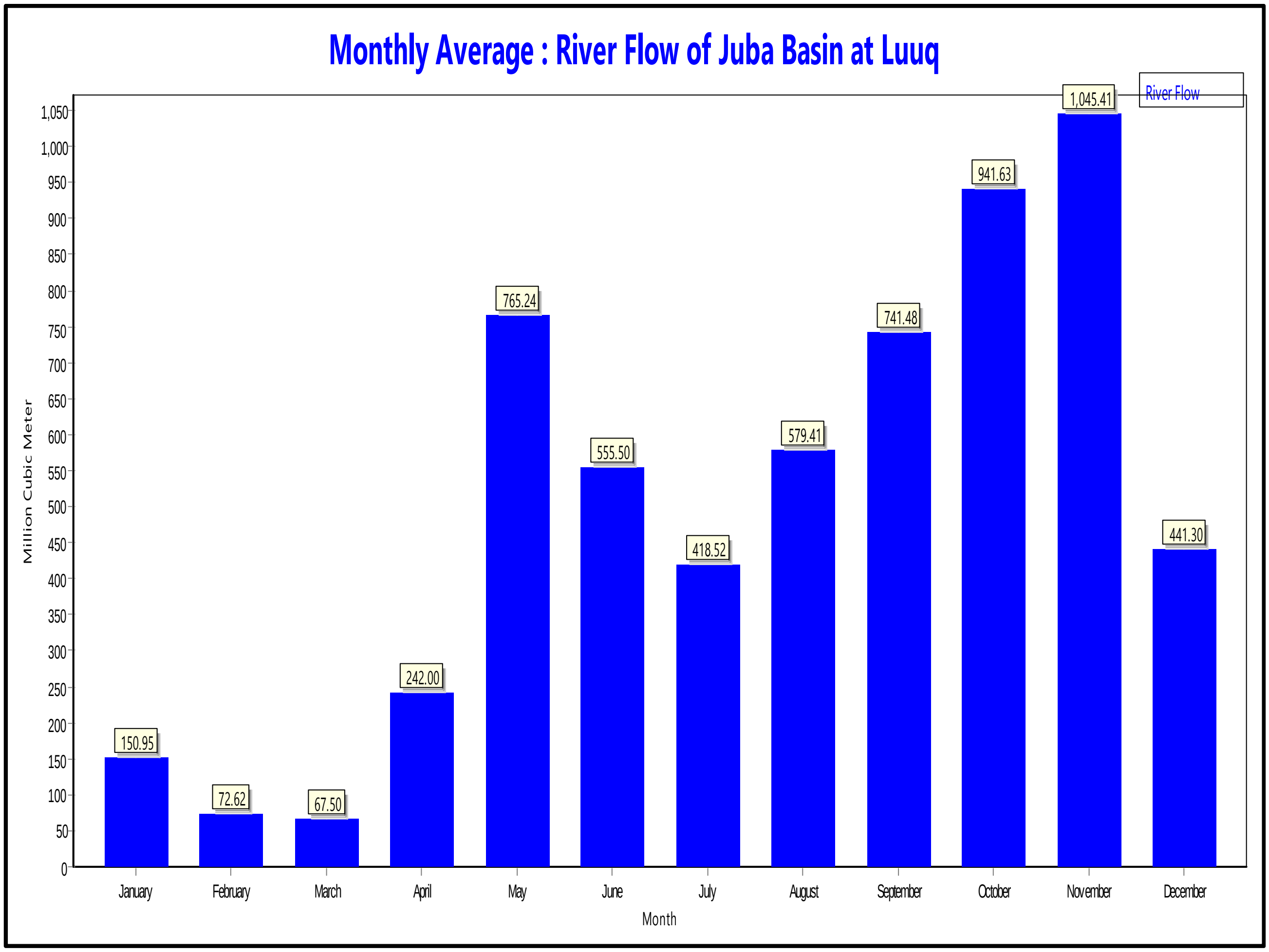

Figure 4.4: Monthly Average river flow of Juba River at Luuq (2002-2014)

Figure 4.4 shows that the monthly average of the 13 years river flow and it has been observed that months March, February and January were the lowest months respectively while November and October were the highest discharge because of the rainy season of the basin both upstream and downstream of the basin.

In Somalia, frequency flood and drought are common due to fluctuation; within a year, mostly floods occur during the rainy seasons and vise verse drought during dry month while water demands differ due to monthly variation requirement in the basin.

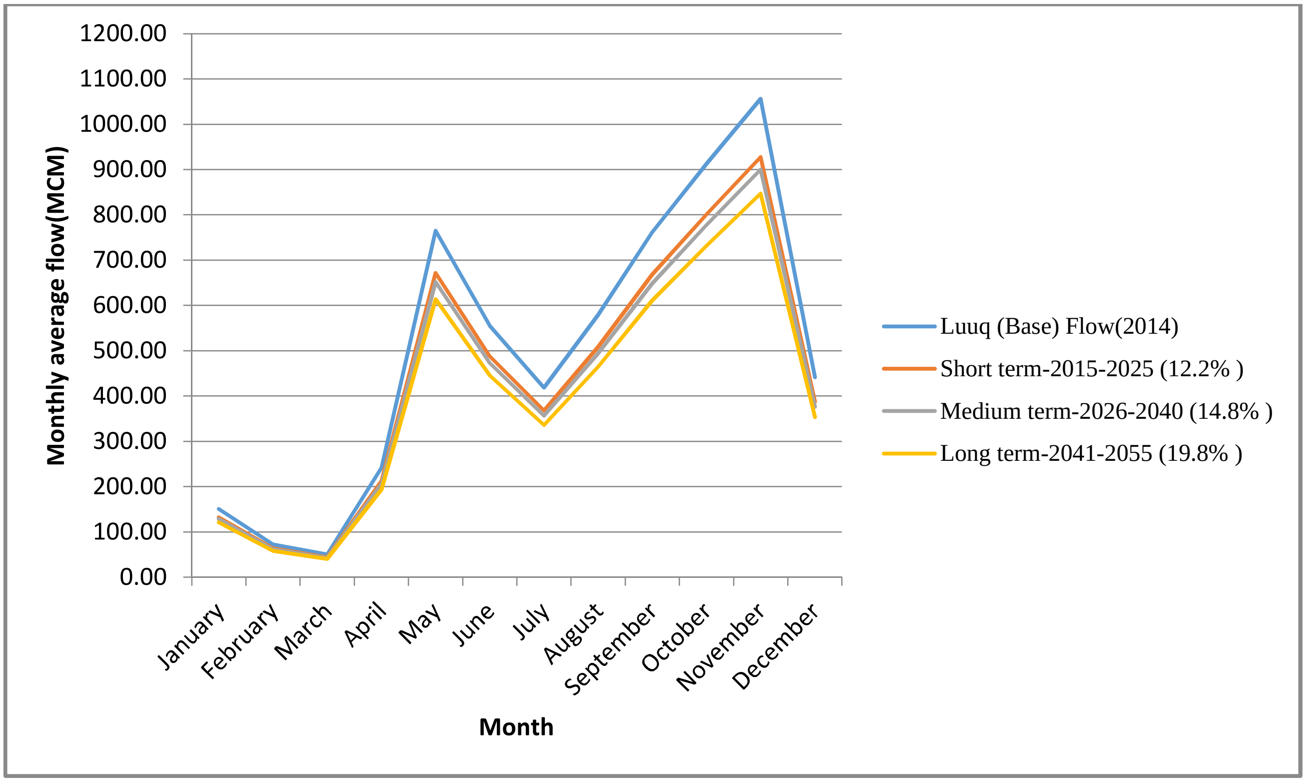

Figure 4.5: Monthly Average River flows in different scenario at Luuq (2014-2055)

Figure 4.5 presents the monthly average river flow trends of Luuq station from 2014 to 2055 and how the flow look like from the base case year to the last year of this study if the planned projects are implemented accordingly.

Based on the planned projects both upstream and downstream of the Juba basin in relation with the availability of water as well as the livelihood of the region which depend on agricultural sector, water resources management particularly balancing water demand and supply are very crucial.

4.2 Modelling Rainfall-Runoff

WEAP Rainfall runoff simulation was used in order to understand the contribution of Somalia to the basin and the results are presented below:

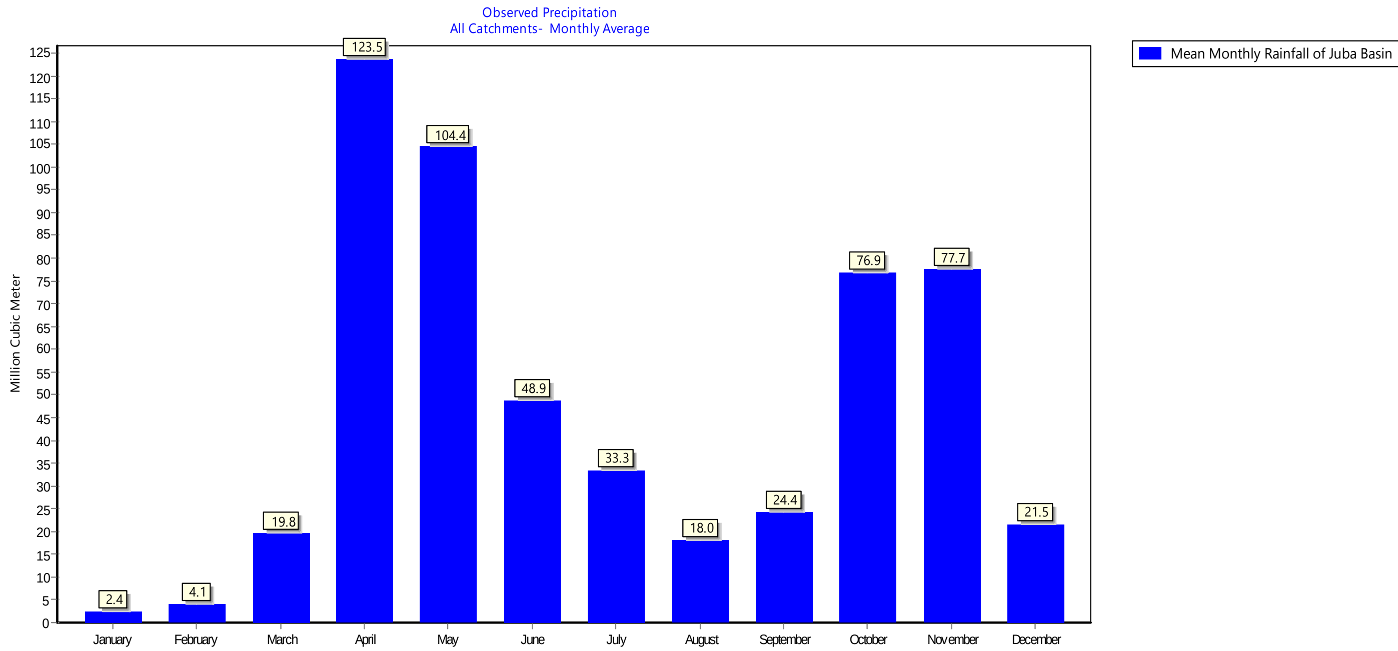

Figure 4.6: Monthly average observed rainfall from the study area

Figure 4.6 shows that the mean monthly rainfall in Juba basin was observed to be 554.8 mm which can be said less than 10% of the total available flow.

In Somalia, there are four main seasons around which pastoral and agricultural life revolve. From January to March is the Jilaal, the harshest dry season of the year. The main rainy season, referred to as the Gu, starts from April to June. From July to September is the second dry season, the Haga. The Dayr, which is the shortest rainy season, lasts from October to December.

Although the basin evinces the greatest freshwater resources in Somalia, it is hydrologically water deficient and there are seasonal gaps with low river flows (IUCN, 2006; Muthusi, Mahamoud, Abdalle and Gadain 2007; Basnyat 2007).

In line with Kammer (1989) indicated that the average annual rainfalls for the Juba basin is about 550 mm, Rainfall in juba basin varies considerably. Annual rainfall is lowest on the Ethiopia–Somalia border at around 200 mm, and increases both downstream, to around 500–600 mm at the coast.

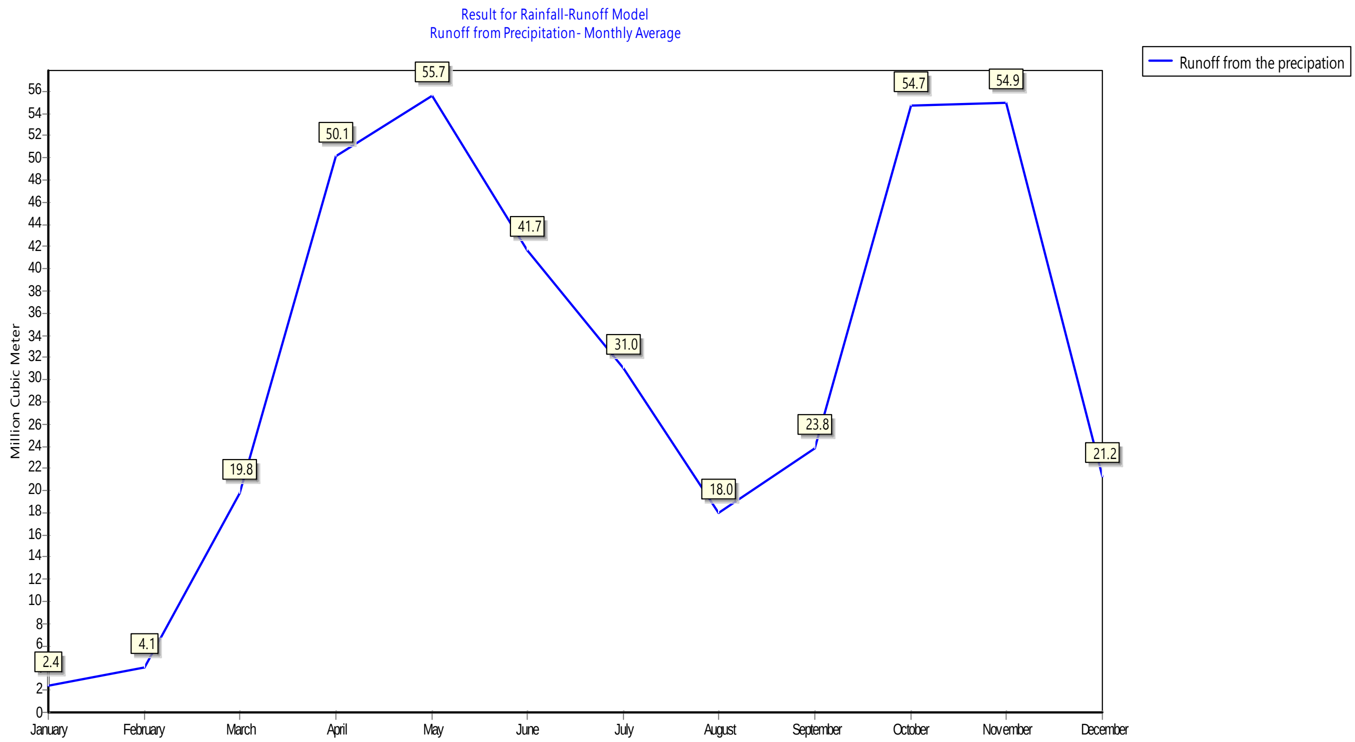

Figure 4.7: Runoff from the rainfall

Figure 4.7 shows that the runoff from the precipitation to be 377.4 MCM which can be estimated 6% of the total flow available in the basin. This indicates that the contribution of Somali part is not significant. In line with findings of Musgrave (2002), he indicated that about 95% of the runoff originated from the upstream of Ethiopian highlands.

Sebhat (2011) mentioned that the runoff contribution in Somalia is nearly negligible because the region has arid climatic condition, undefined drainage network and densities. He concluded that the role of Juba river in all sub basins have less impact on long-term annual water balance. This may happen due to less or nearly negligible surface runoff contribution from each sub basins in Somalia and sub basins areas are so big compare to the river cross section that contribute for evaporation.

Long-term water balance in the sub basins indicates that the Juba basin has less impact on the evaporation in all sub basins. The actual evaporation mainly depends on sub basins rainfall. This is due to less or close to zero values of the surface runoff contribution from each sub basins in Somalia.

4.3 Comparison of Observed and WEAP simulated flow

The complexity of water allocation models and the fact that they are required to simulate human behaviour (to reflect changes in demand) in addition to physical processes means that model calibration and validation is extremely difficult and has often been neglected in the past (McCartney and Arranz, 2007).

WEAP includes a linkage to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations. PEST is particularly useful when the WEAP soil moisture method of catchment hydrology is used.

In PEST, there are three different types of observations to which WEAP calibration can be done: Streamflow, Reservoir storage and Catchment snowpack. For example, PEST compares the streamflow gauge data entered in the Data View, with streamflow results for the node immediately upstream of the gauge. For Reservoir storage, PEST compares the reservoir storage data entered in the Observed Volume variable for the reservoir in the Data View, with the reservoir storage results. For Catchment snowpack, PEST compares the snowpack data entered in the Snow Accumulation Gauge variable for the catchment in the Data View, with the Snow Accumulation results for the catchment.

Refsgaard (1996) indicated that model calibration can be manual, automatic and a combination of the two methods. Therefore, in this study PEST for automatic calibration was not used due to lack of data such as reservoir operation where currently no reservoir in the basin as well as soil moisture method for WEAP rainfall runoff model was not applied because of the runoff from upper catchment of the basin in Ethiopian highland.

According to Verdonac et.al (2009), two kinds of analysis can be carried out for the model calibration in monthly and annual flow comparison, and flow frequency comparison. Calibration is done through physical observation. The comparison can be made for downstream stations where river flows are calculated by simulation, with head flows directly entered to the WEAP system. The method consists in the comparisons month-by-month, or year-by-year, between the simulated values and observed data. As shown figure 4.8 and 4.9, observed and WEAP simulated flow hydrograph were compared and seen physically their fitness therefore this implies that there is significant relation between observed and WEAP simulated flow.

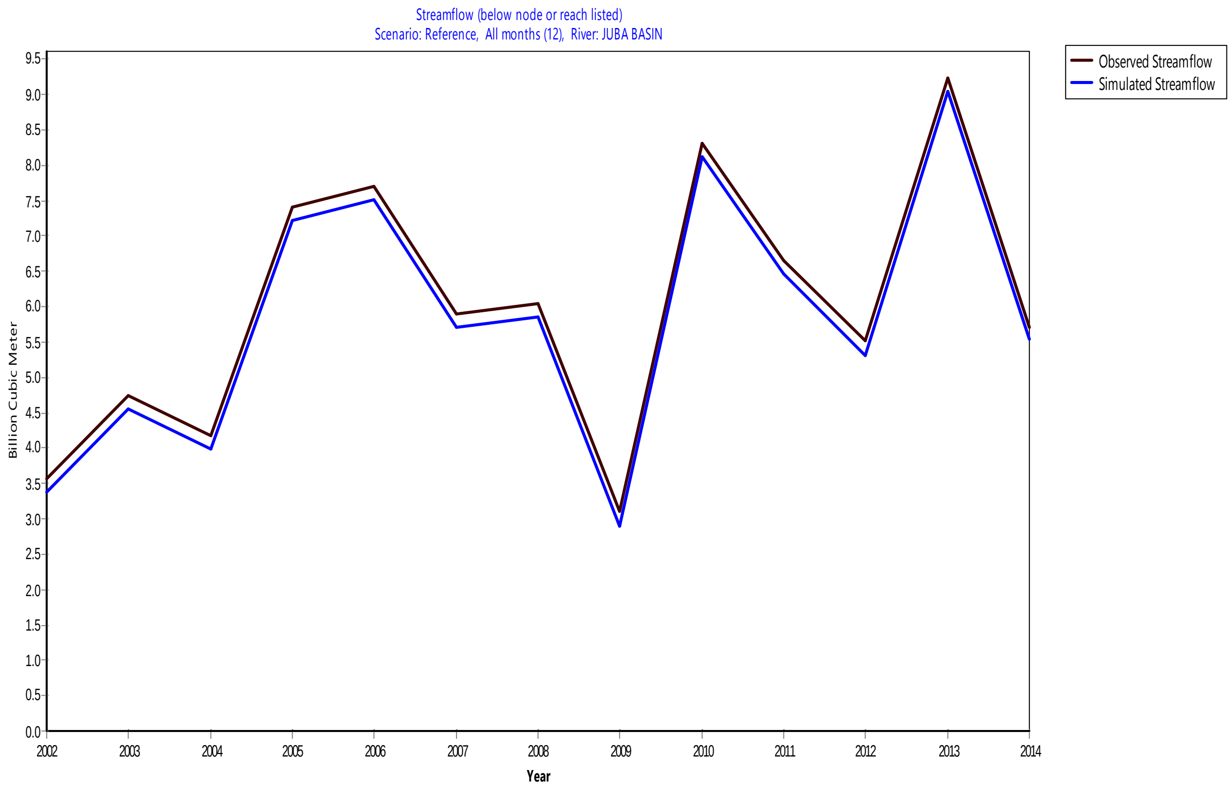

Figure 4.8: Annual Observed and WEAP simulated streamflow

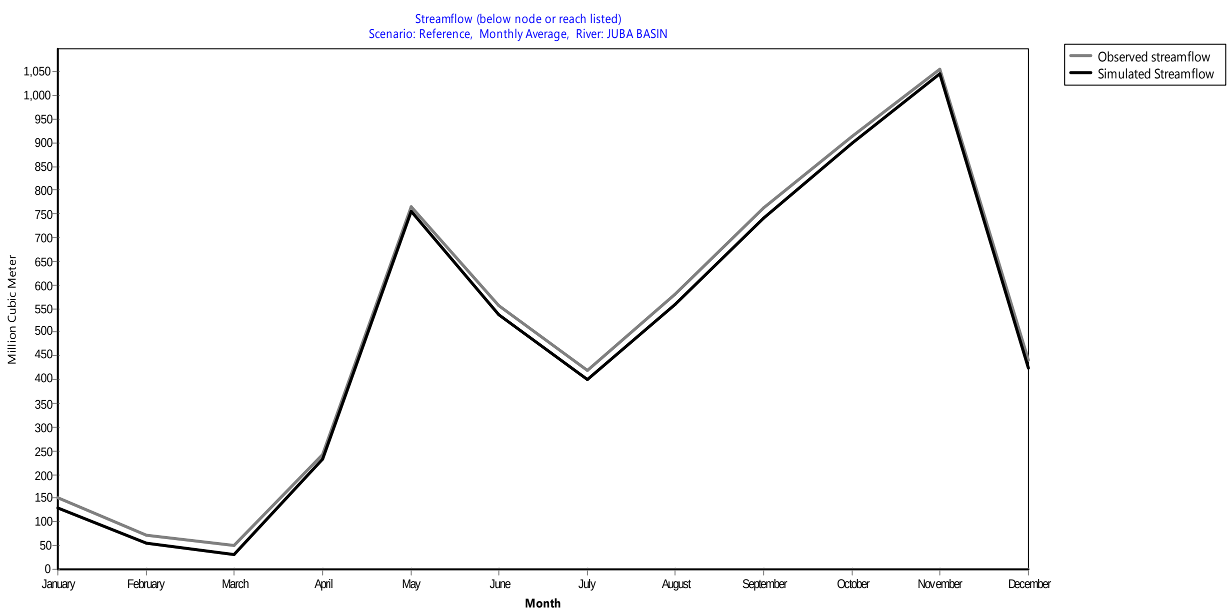

Figure 4.9: Monthly average Observed and WEAP simulated streamflow

4.4 Modelling Current Situation of Water Demand

4.4.1 Water demand for Domestic, Agriculture and Livestock

Current situation of water demand and supply from 2002-2014 of all water users was modelled before any scenario was developed in order to know the current water resources system of the basin and water demands to domestic, agriculture and livestock. Therefore monthly average of available water in relation to demand was done.

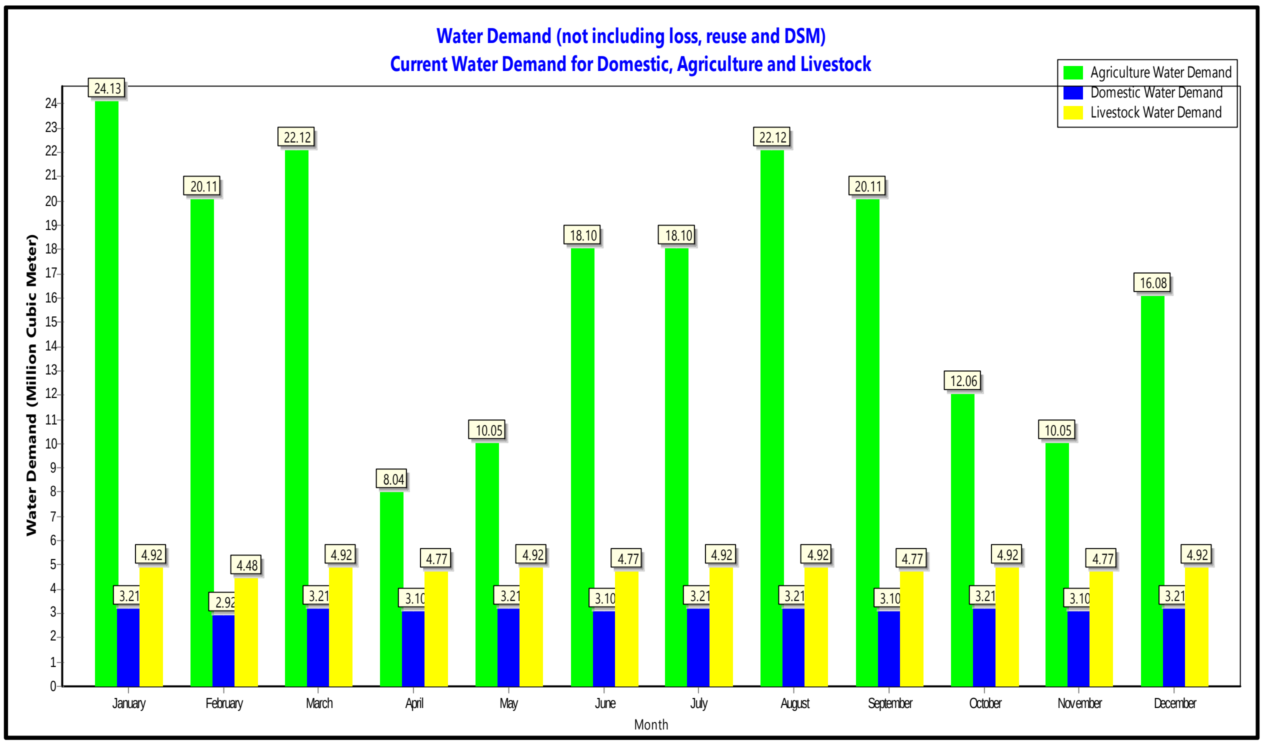

Figure 4.10: Monthly average current water demands for agriculture, livestock and domestic (2002-2014)

Figure 4.10 indicates that agriculture is the major water use in the basin. Current agricultural water demands are 201.1 MCM while domestic and livestock water demands are 37.8 MCM and 58.0 MCM respectively this makes that the current annual total water demands of agriculture, livestock and domestic in the basin excluding environmental flow requirement are 297 MCM.

In line with the findings of FAO-SWALIM in 2012, although all irrigation schemes and infrastructures collapsed during the civil war still agriculture was the major water use among others.

Based on the crop water requirement per hectare multiplied by the current irrigation area that was estimated to be 15000 ha, current agricultural demands are observed to be 201.06 MCM. Monthly variation based on monthly crop water requirement mentioned in the master plan of the Juba valley development was applied.

4.4.2 Environmental flow requirement

The flow duration curve has been used to calculate the environmental flow requirement and 20% of the total flow were allocated as environmental flow requirement , therefore as mentioned figure 4.12, the months January, February and March are the last months that the environment flow requirement is allocated less due to low flow while other water users like domestic and livestock have been given the highest priorities as mentioned in the master plan of the Juba basin as well as the international standard of water use.

A basic flow duration curve measures high flows to low flows along the X-axis . The X-axis represents the percentage of time (known as duration or frequency of occurrence) that a particular flow value is equaled or exceeded. The Y-axis represents the quantity of flow at a given time step, associated with the duration. Flow duration intervals are expressed as percentage of exceedance, with zero corresponding to the highest stream discharge in the record (i.e., flood conditions) and 100 to the lowest (i.e., drought conditions).The sustained flow of a river is considered at a target of 90% of the flow duration curve used to sustain environmental flows (Richter et al., 2003). However, the flow duration curve was used to determine the environmental flow requirements in the Juba basin in southern Somalia as shown figure (4.11)

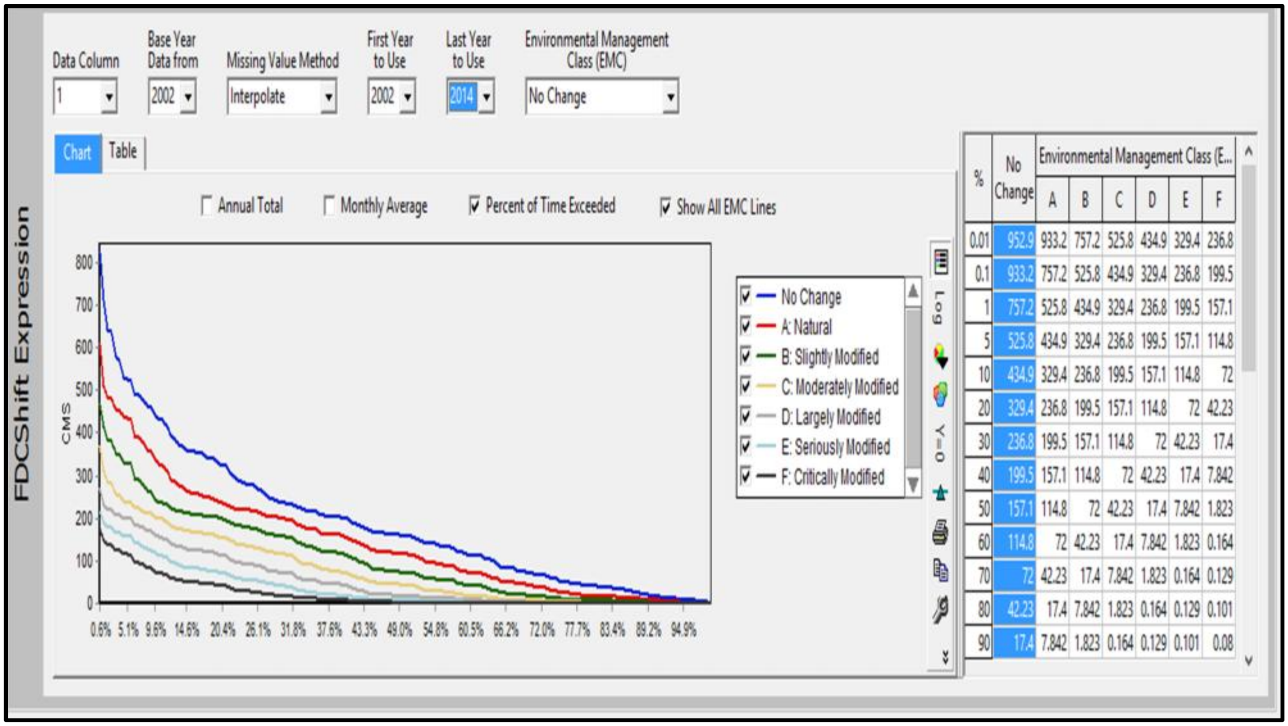

Figure 4.11: Environmental Management Class for Juba basin

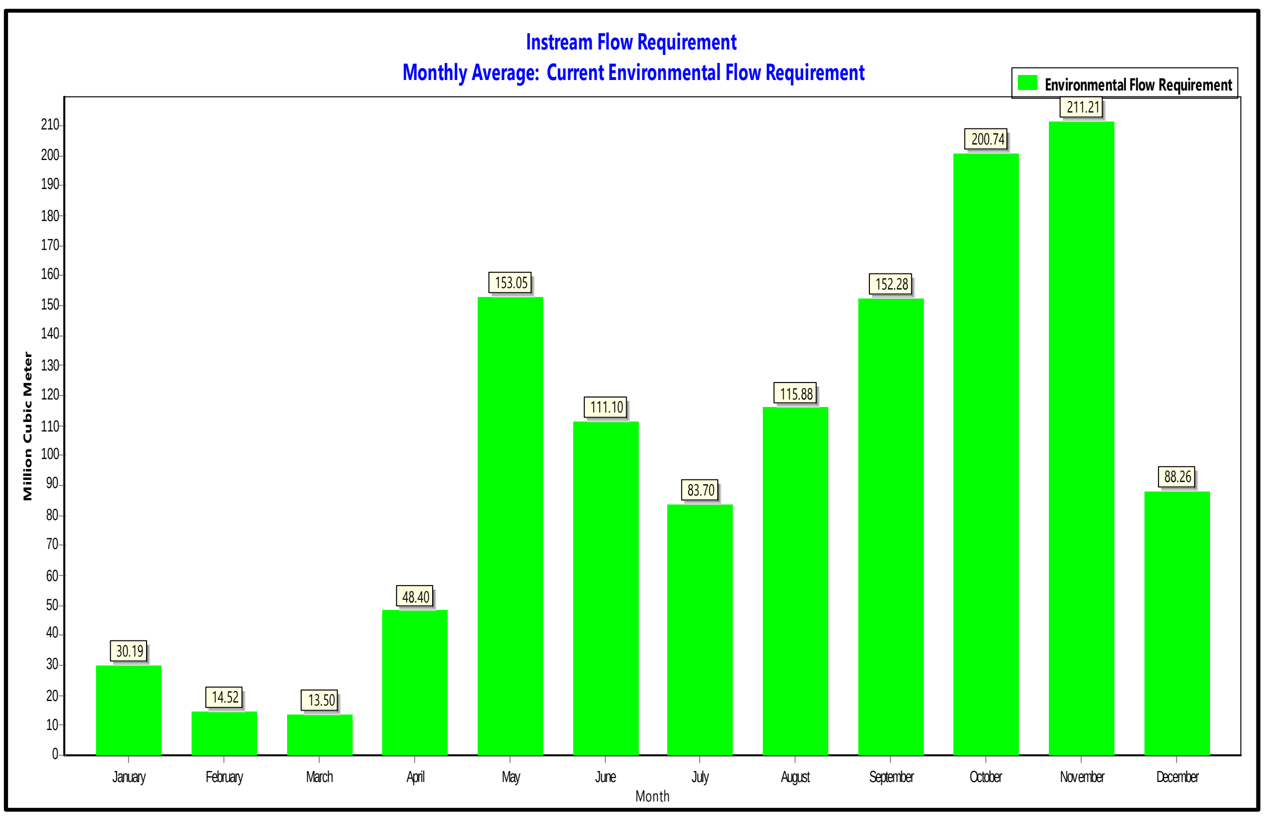

Figure 4.12: Current Environmental flow requirement (2002-2014)

Figure 4.11 shows that the flow duration curve expression at different stage of environmental management class from no change to critically modified. As the figure 4.12 indicates the current annual environmental requirement were observed to be 1222 MCM or 1.2 billion cubic meters.

IGAD (2014) mentioned that some countries in the IGAD region and East Africa, such as Kenya and Tanzania, have policies and laws that give priority in water use, or reserve water, to river ecosystems once basic human needs are met. Given the shared nature of most water resources in the region, this approach should be followed in all Member States of IGAD.

Figure 4.12 shows that how the environmental flow requirement was allocated based on the river flow of the basin as it has been indicated months of the low river flow, such as January, February and March, the environment was allocated less because of other sector water demands which have been given priorities. The environmental inflow requirement has been applied 20% of the total flow based on the available flow in the basin.

4.4.3 Current sectoral water demands

Current water demands among multiple water users, including the environmental flow requirement were modelled and the result indicated that current total water demands are 1500 MCM or 1.5 BCM. This indicates that the current water use is low compared to the current average supply available which has been observed to be 6.0 BCM.

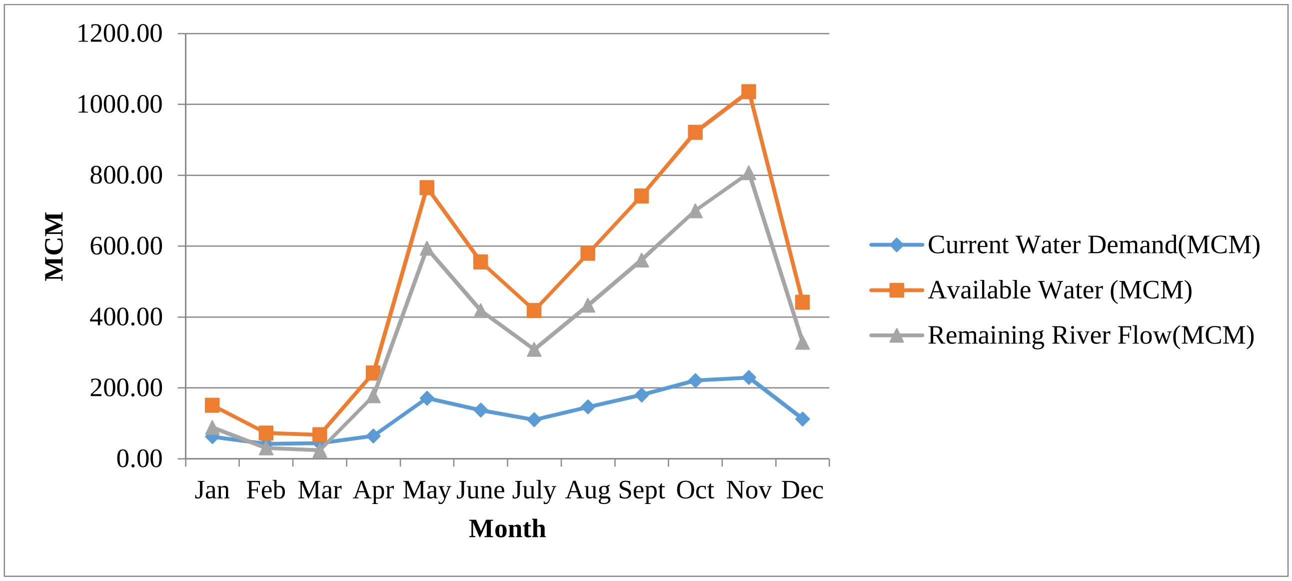

Figure 4.13: Current water demands of agriculture, domestic, livestock and environment

Figure 4.13 shows that all sectoral water demands have been met and no unmet demands were encountered in the current situation, although the months of January, February and March are the lowest available water resources, particularly in March which is the hottest month in southern Somalia, the remaining river flow in March is 23.75 MCM and in February is 30.5 MCM while 88.5 MCM in January.

The remaining river flows are the river flows after the deduction of all demands, although loses have not been included and observed water shortage during dry months as mentioned above while other months observed that there is a surplus of water after deduction of all water demands among multiple water users.

However, this result revealed that March, February and January are the months when water use conflicts may likely to occur between pastoralists and farmers due to high demands from different water users and not only those based on the basin but others outside of the basin also always occupied in the riverine areas particularly pastoralists who always move from place to place looking for water for their livestock and good grazing system during dry period of Somalia which is called Jilal and number of water users at this time is not well known therefore competition of the available water are very high thus creates water based conflicts among water users particularly farmers and pastoralists.

Although the current water use in the basin is very less due to current situation of Somalia where the major irrigation schemes collapsed during the civil war and El Nino flood 1997/1998 (Houghton-Carr et.al 2011), agriculture still is the main water consumer according to Basnyat (2007) as a result of this, water allocation management at grass root level are necessary in order to avoid water based conflicts and overutilization of the available water resources during critical time of low flow period.

In line with the findings of Gadain (2012), concluded that there seems to be some room for development at upstream as well as within the Somali Juba basin because of the current available water, although Somalia part more than half of the existing irrigation schemes collapsed during the civil strife where current even the security of the basin is very fragile.

4.5 Scenario Analysis

At the heart of WEAP is the concept of scenario analysis. Scenarios are self-consistent story lines of how a future system might evolve over time in a particular socioeconomic setting and under a particular set of policy and technology conditions. Using WEAP, scenarios can be built and then compared to assess their water requirements, costs and environmental impacts. All scenarios start from a common year, for which is established current account data.

In this study, the following scenarios were developed and all water users in the basin were given consideration based on existing information and planned development activities in the basin described in the Juba basin master plan and the current strategic plan of the Ministry of Agriculture, the Federal Republic of Somalia and other line ministries.

1. Reference or Baseline scenario
2. Scenario one: short term, medium term and long term
3. Scenario two: short term, medium term and long term

The above scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if a more efficient irrigation technique is implemented? Scenarios in WEAP encompass any factor that can change over time, including those factors that may change because of particular policy interventions, and those that reflect different socio-economic assumptions.

4.5.1 Reference or Baseline Scenario

Reference Scenario represents the changes that are likely to occur in the future without intervention or new policy measures. It is also known as business-as-usual scenario. Finally, “what-if” scenarios can be created to alter the Reference Scenario and evaluate the effects of changes in policies and/or technologies (SEI, 2012).

However, in this scenario no changes were made except for current annual growth rate of 2.7% and 2% have been applied to human and livestock population respectively as shown figure 4.14and 4.15 that are likely to occur and not depend on any intervention and policy change while the current irrigation area is assumed to be constant in this entire scenario. The annual water use rates among multiple water users are assumed to be constant, therefore a monthly average of water demand by each sector were modelled.

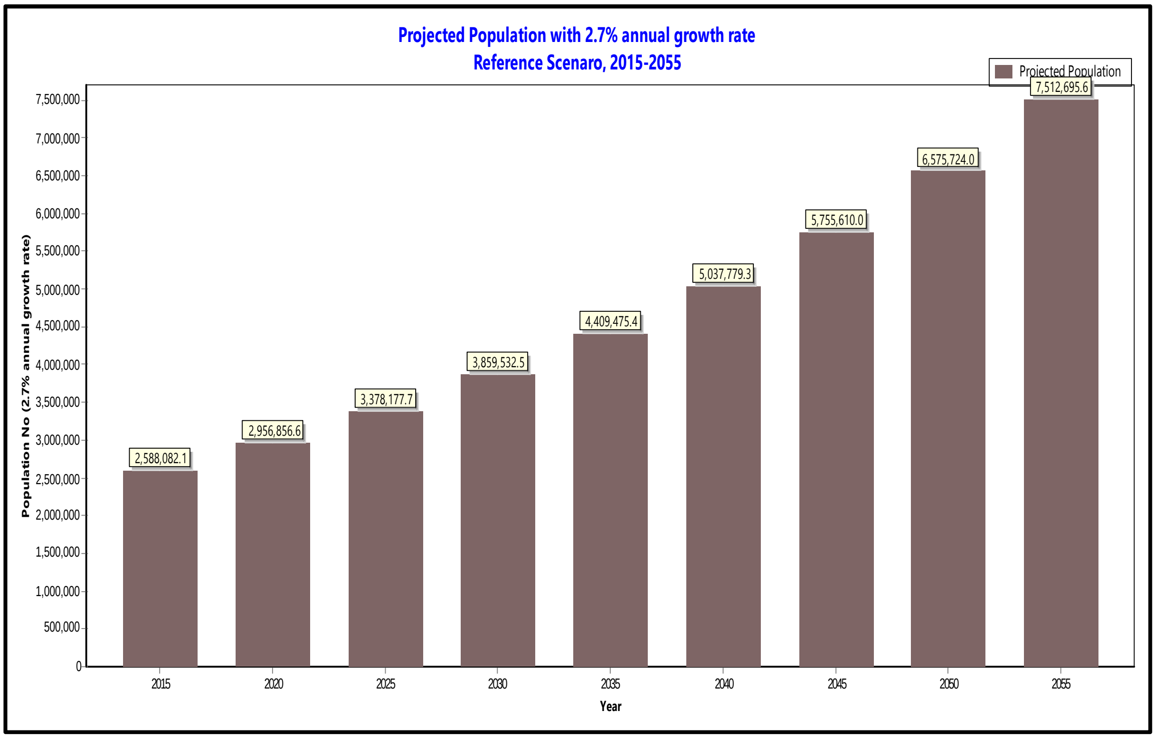

Figure 4.14: Projected Population with 2.7% annual growth rate of Juba basin (2015-2055)

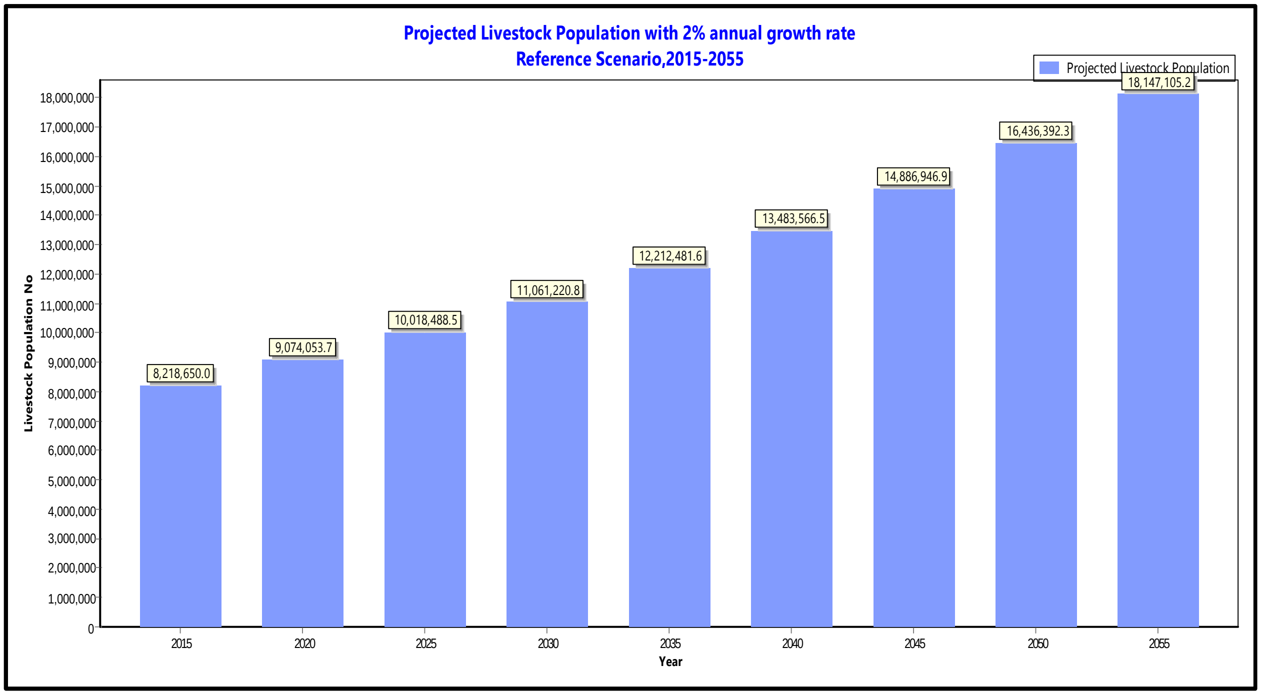

Figure 4.15: projected livestock population with 2% annual growth rate (2015-2055)

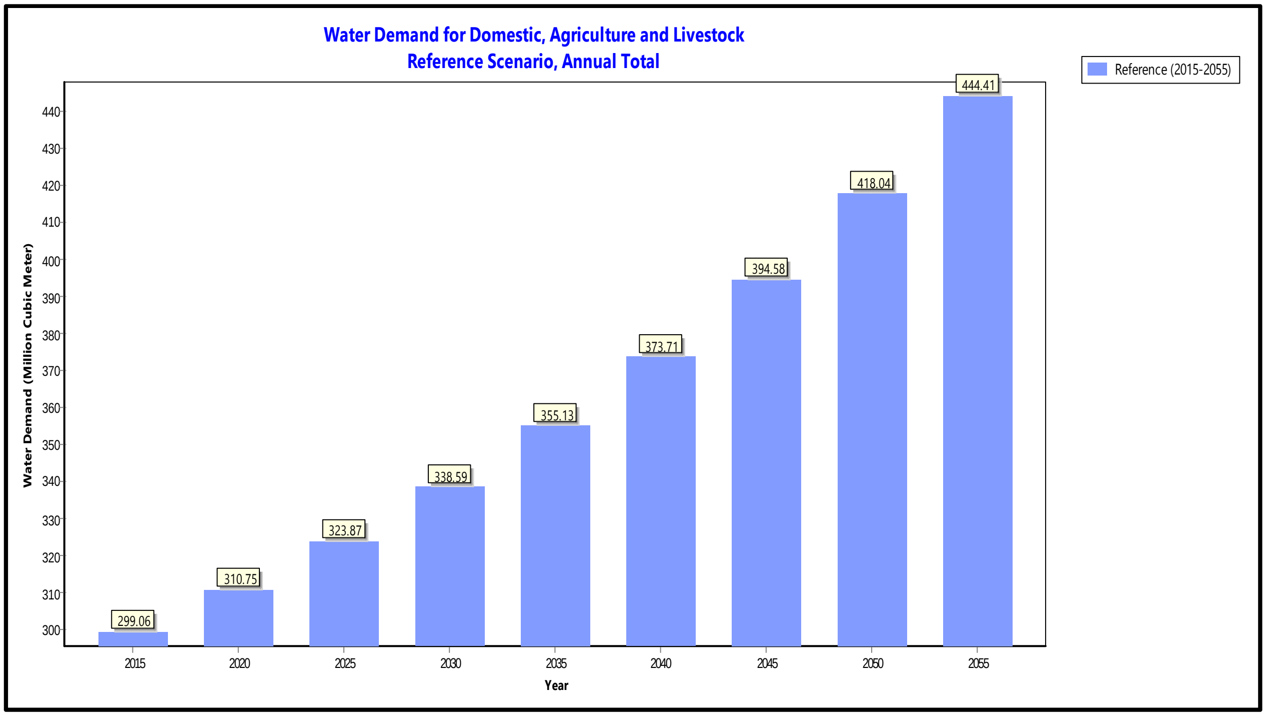

Figure 4.16: Annual Total water requirement for Domestic, Agriculture and Livestock in Reference Scenario (2015-2055)

Figure 4.16 shows that the annual total water requirement in 2015 until the last scenario year in 2055 for three demand sites, domestic, agriculture and livestock without intervention and change and observed that the annual total water requirement of agriculture from 2015-2055 to be constant while domestic and livestock water demands change with the increase of the population number.

The annual total water demand in 2015 are estimated to be 299.06 MCM while observed that 201.1 MCM required by agricultural sector out of 299.06 and 444.41 MCM in 2055, this indicates that the annual total requirement of domestic and livestock are very low as indicated in figure 4.17 whereas agriculture is the major water user even though current irrigated area is very limited compared to the potential irrigable land due to irrigation schemes collapsed during the civil strife in Somalia as a result of this most of the farmers depend on rainfed agriculture instead of irrigated agriculture.

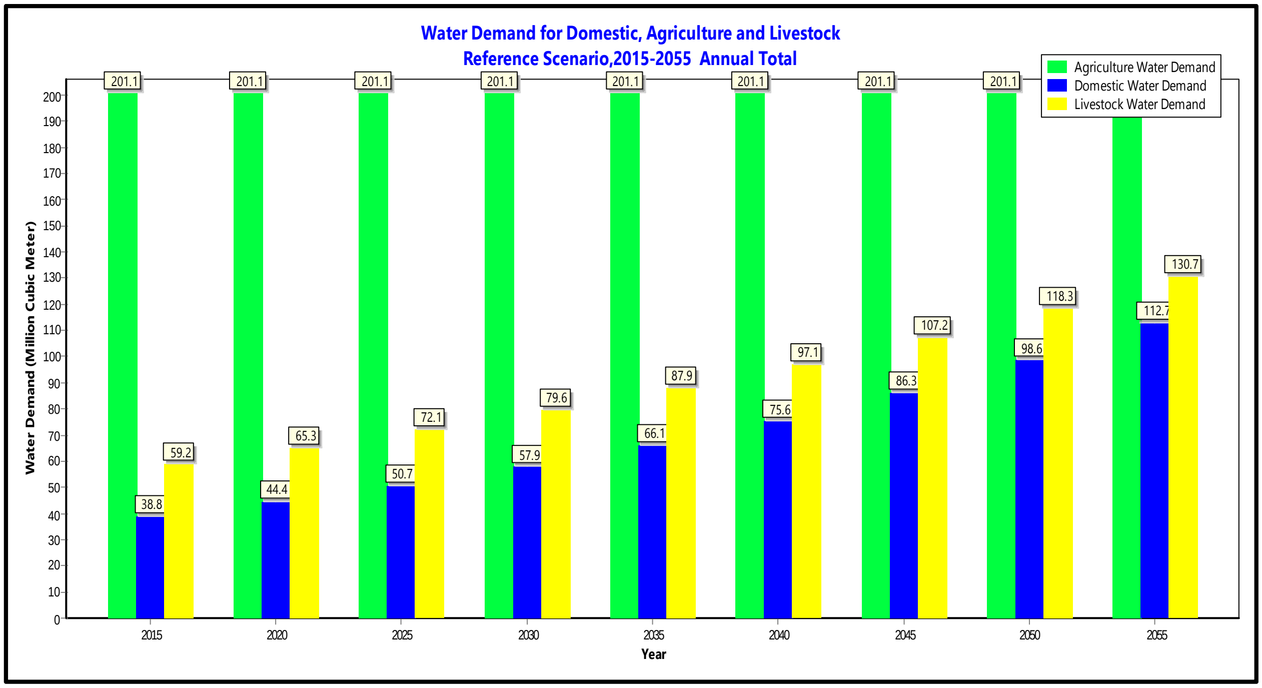

Figure 4.17: Annual water demand for domestic, agriculture and livestock in reference scenario (2015-2055)

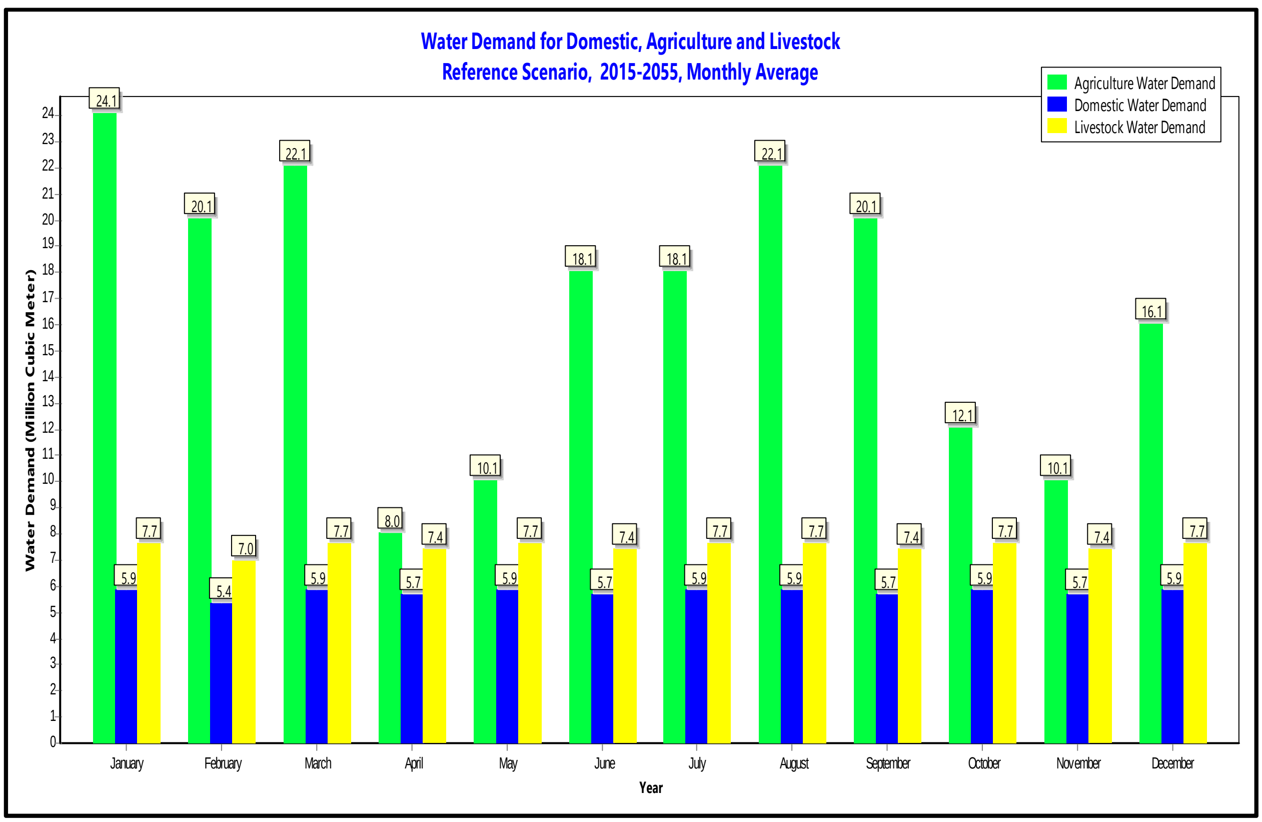

Figure 4.18: Monthly average water demand for domestic, agriculture and livestock in reference scenario

4.5.2 Scenario One: Sectoral Water Demands

This scenario, the previous irrigation projects along Juba basin were assumed to be resumed and the planned projects before the civil war broke out in Somalia based on the current strategic plan of Somali Government, particularly the Ministry of agriculture, therefore the plan has been classified into three phases short term plan (2015-2025), medium term plan (2026-2040) and long term plan (2041-2055). Thus, each plan both existing or current situation and future development were given consideration, for example 73,210 ha in 2025 in short term plan, 170,000 in 2040 for medium term plan and 221,000 ha in 2055 for long term plan.

However, in this scenario because of urbanization the water requirements per person per year have been giving consideration on the urbanization rate. According to Basnyat (2007) based on the Ministry of National Planning (1988) and UNDP (2005) indicated that there is a clear trend of urbanization. The increase in population that turned from rural to urban between 1988 and 2005 is 15%, corresponding to an annual increase of 0.88 %. Therefore, his finding indicated that the average per capita water demands are raising too, just based on a change in lifestyle and water supplies.

Annual domestic water demand with an annual growth rate of 3% was used in this scenario whereas livestock population of 2% annual growth rate was assumed that to be constant in all scenarios. The total human population number in 2025 will be estimated to be 3,488,326 if 3% annual growth rate is applied while annual water use rates of domestic water demand per person, including industrial, commercial and institutional which was linked to the population were assumed to increase 1% due to urbanization, industrial and economic developments of the Juba basin from the current figure 15 m^3/person per year in 2014 to 22.6 m^3/person per year.

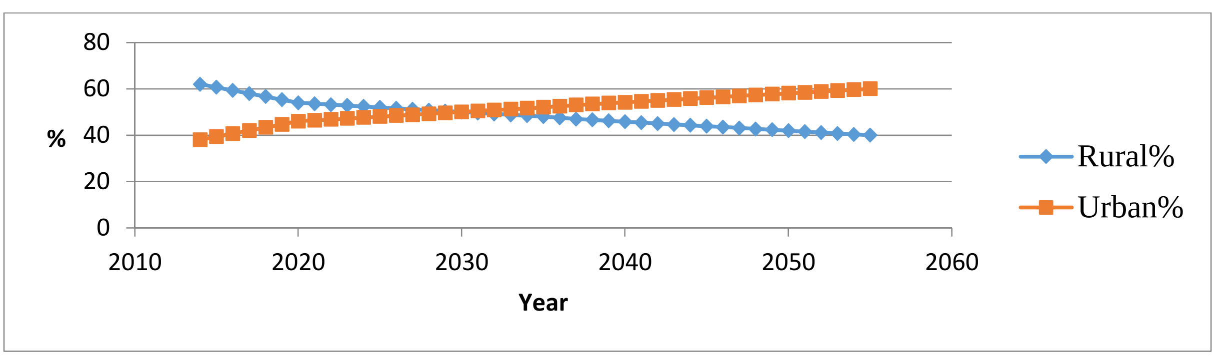

Figure 4.19: Rural and urban trends

Figure 4.19 indicates that the rural and urban will be 54% and 46% in 2020 and 48% and 52% in 2035 whereas 47% and 53% in 2037 and 40% and 60% in 2055 respectively. Figure 4.169 shows that the urbanization is very high and as it has been observed in 2030 will be the year of breakeven point that the percentage of urban and rural people will be the same 50% to 50% respectively and if the trend continue the urban people will be greater that the rural population from 2030 on therefore domestic water demand will also increase dramatically with the increase of urban population due to the water requirement in rural and urban population are totally different in line for the standard of the life.

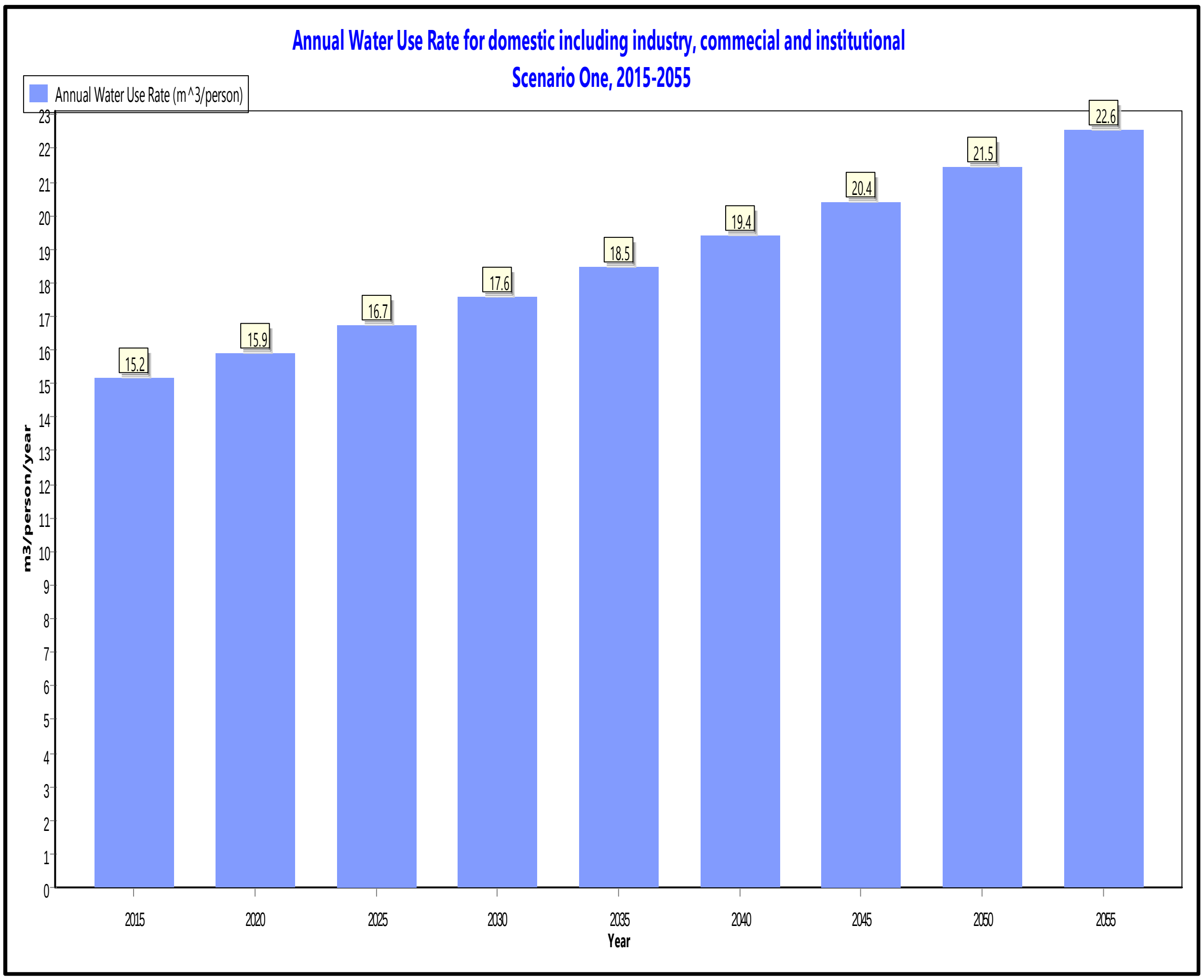

Figure 4.20: Annual water use rate for domestic

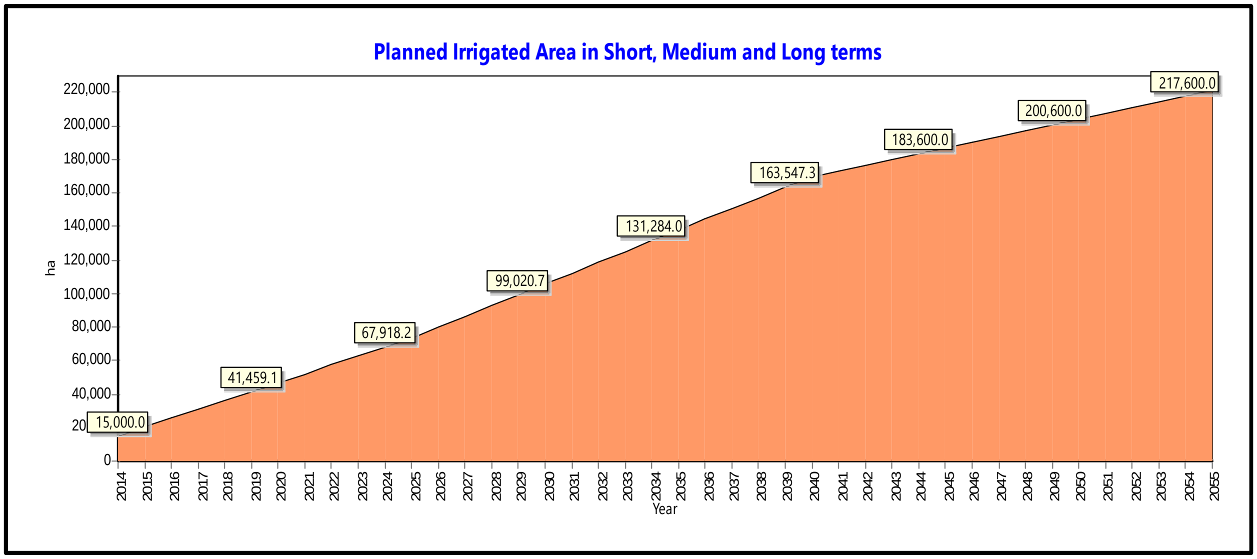

Figure 4.21: current and planned irrigated area (ha) of Juba basin

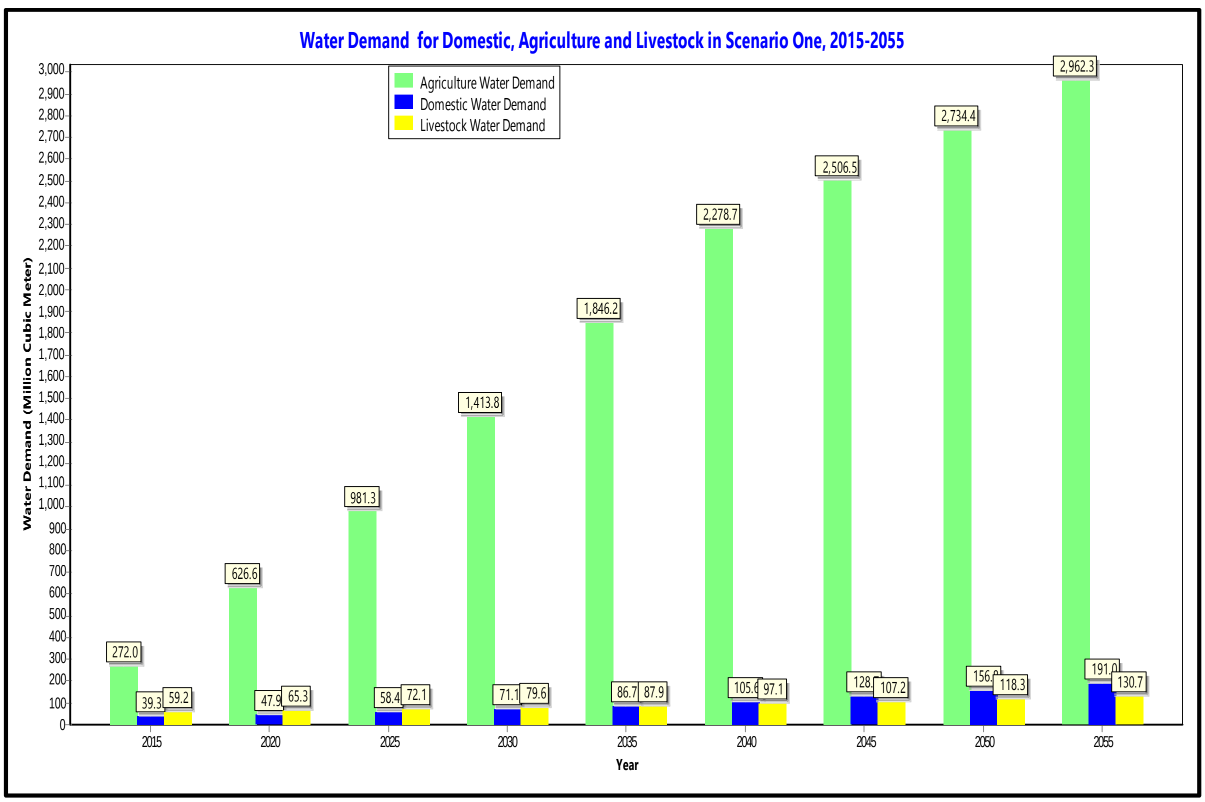

Figure 4.22: Water demand for domestic, agriculture and livestock in scenario one, 2015-2055

Figure 4.22 shows that agricultural sector demands high amount of water than livestock and domestic water requirements. In short term planning (2015-2025) in which 73, 210 ha is going to be achieved, therefore 981 MCM for agricultural water demands comparing to the current situation amount which is higher while in medium term planning and long term planning in 2040 and 2055 agriculture demands 2.3 BCM and 3 BCM respectively in the same time total water demand in the short term, medium term and long term in scenario one were found to be 1.1 BCM, 2.5 BCM and3.3 BCM respectively.

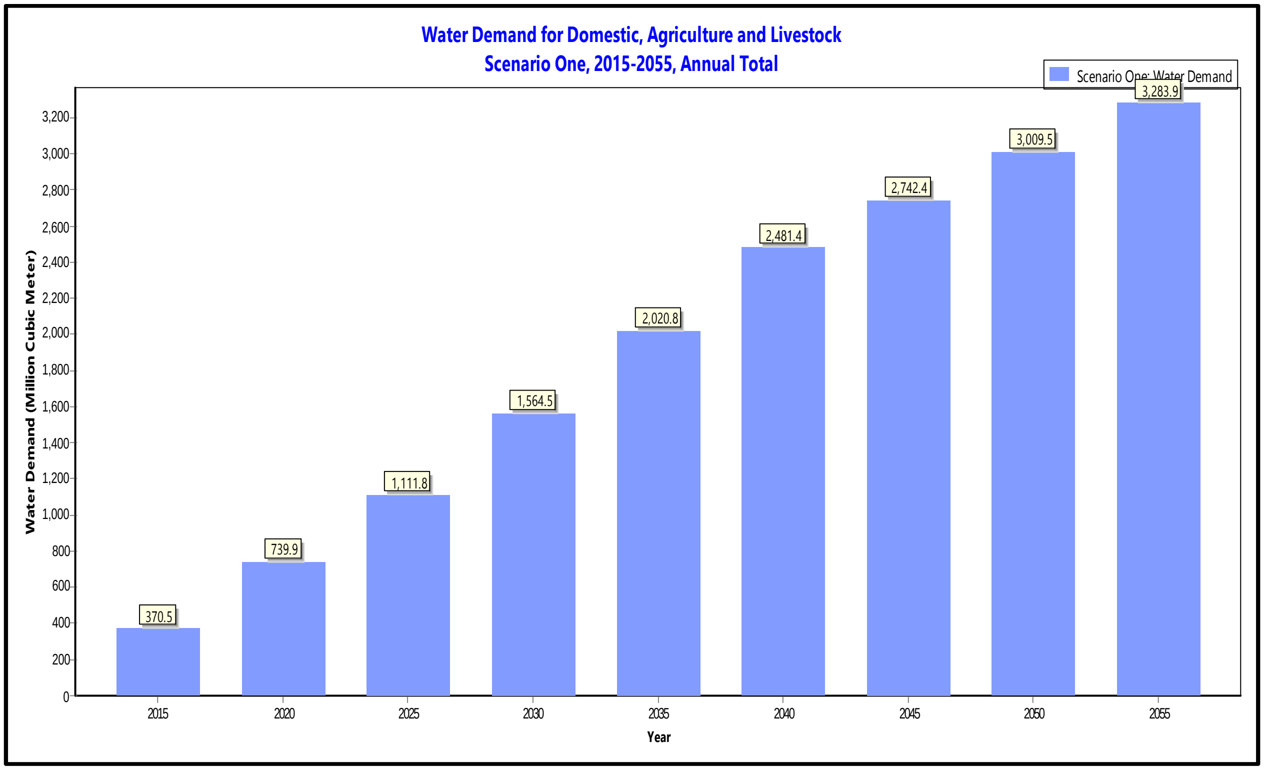

Figure 4.23: Annual Water demand for domestic, agriculture and livestock in scenario one, 2015-2055

Figure 4.23 presents five year interval annual total water demands of agriculture, livestock and domestic and observed that there is increase trends of water demands while the supply decreases based on the river flow data available and future prediction of reduction percentage at Somalia-Ethiopia border which was mentioned and well described in the master plan of Genale Dawa as shown figure 4.5 due to upstream sectoral water demands while the basin passes through drought prone areas in Ethiopia-Somalia border, Kenya-Somalia border and Ethiopia -Kenya border where many pastoralists live there.

Juba River, whose runoff originates from the Ethiopian Highlands and shared between Ethiopia, Kenya and Somalia and flow through drought prone areas that are inhabited by vulnerable pastoralist communities whose livelihoods are defined by the physical and developmental aspects of the rivers and affected by the underlying trans-boundary river management issues.

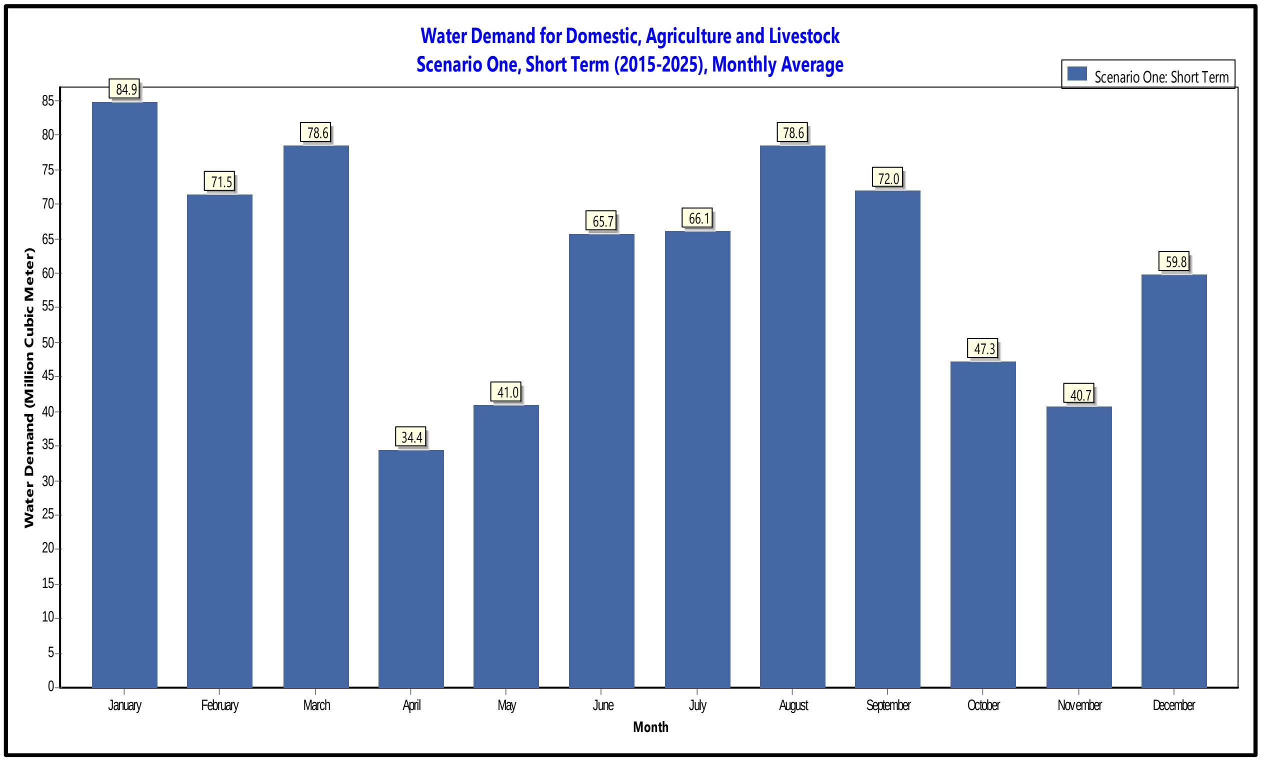

Figure 4.24: Monthly average water demand in short-term plan of scenario one (2015-2025)

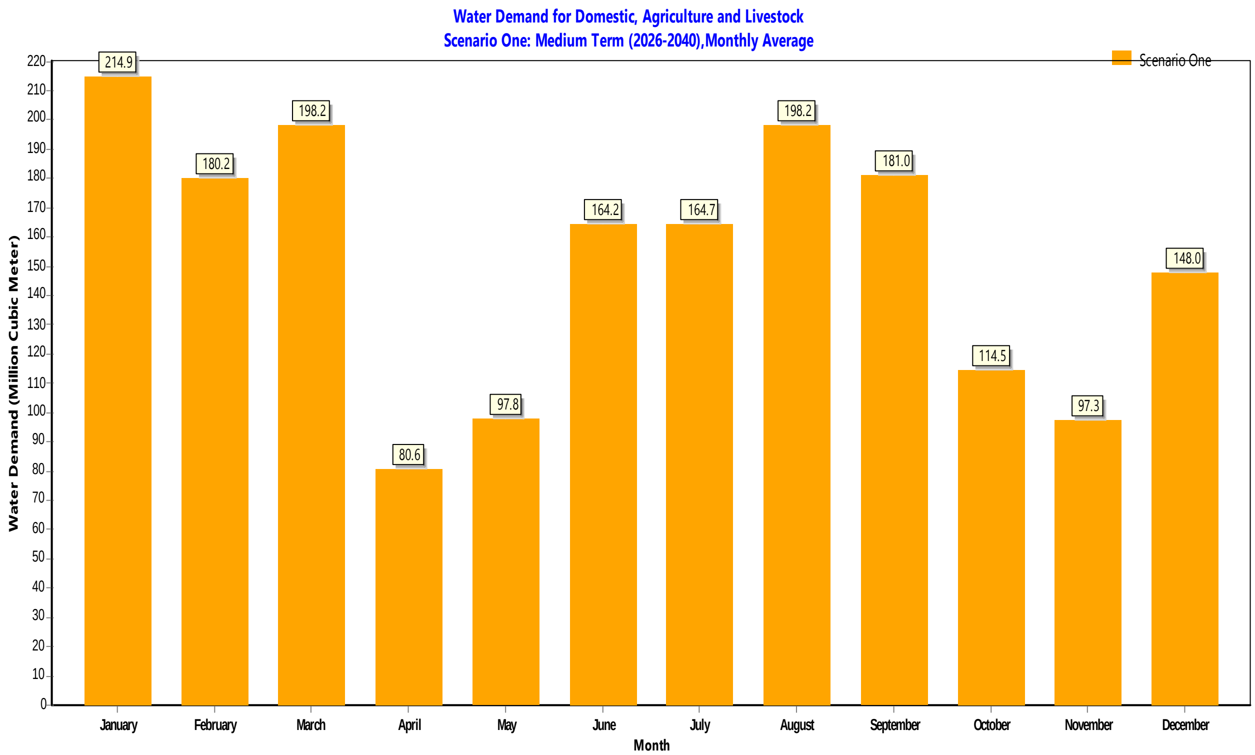

Figure 4.25: Monthly average water demand in medium-term plan of scenario one (2026-2040)

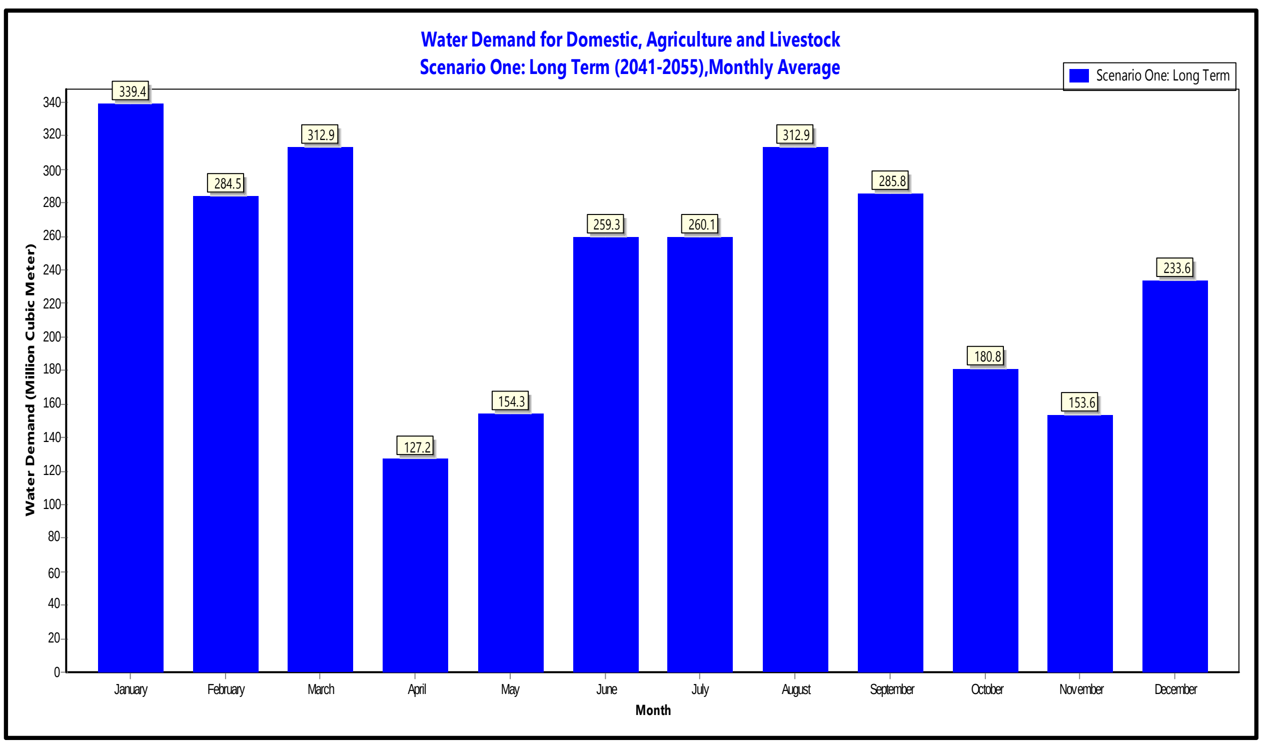

Figure 4.26: Monthly average water demand in long-term plan of scenario one (2041-2055)

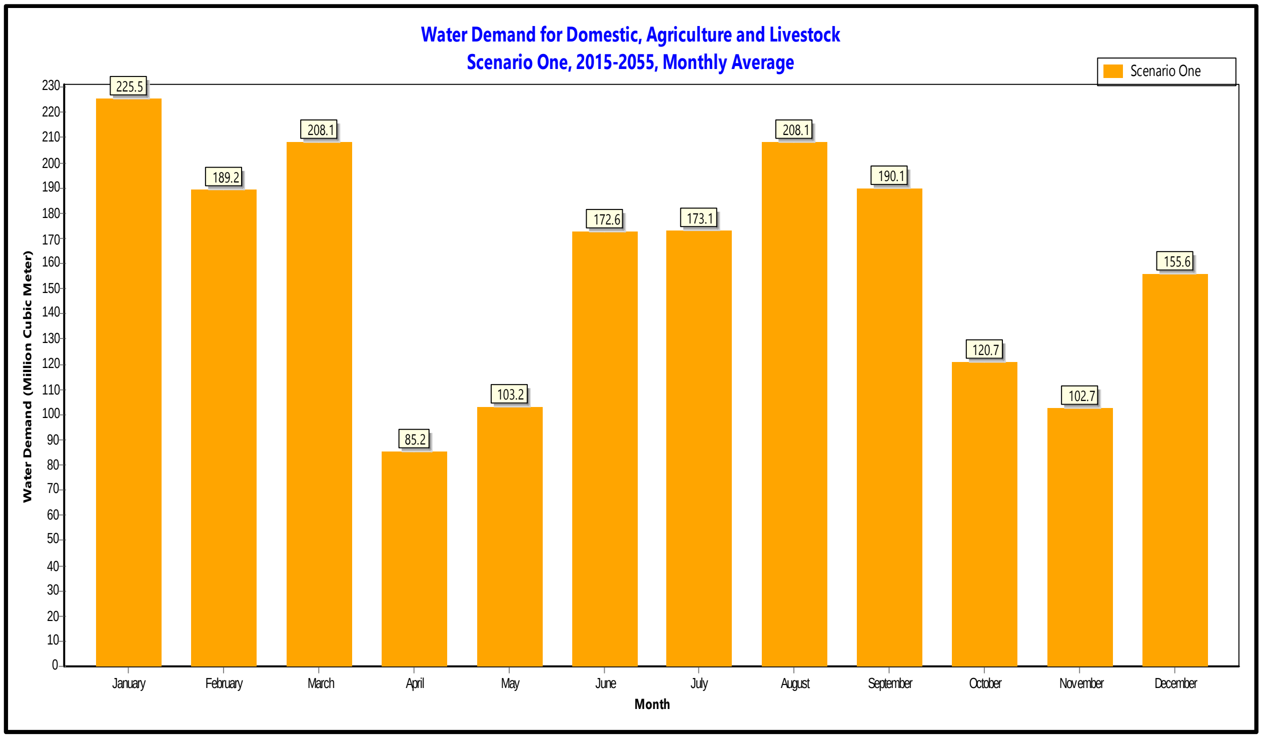

Figure 4.27: Monthly average water demand for domestic, agriculture and livestock in scenario one

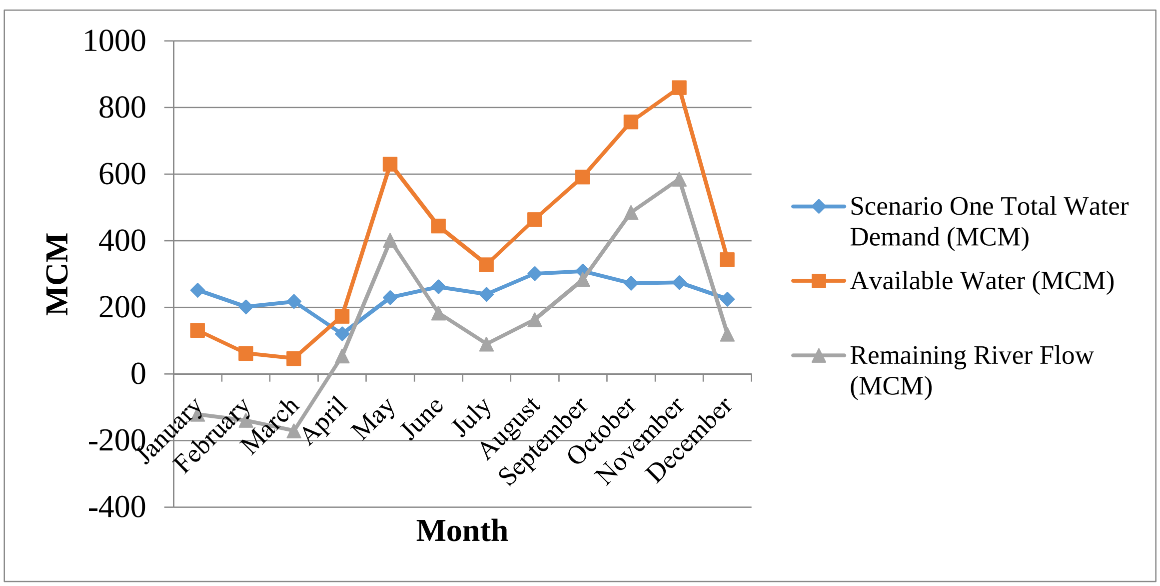

Figure 4.28: Monthly average inflow and outflow at scenario one (2015-2055)

4.5.3 Scenario Two: Water allocation Strategies

WEAP is unique in its capability of representing the effects of demand management on water systems. Water requirements may be derived from a detailed set of final uses or "water services" in different economic sectors. For example, the agricultural sector could be broken down by crop types, irrigation districts and irrigation techniques whereas an urban sector could be organized by county, city, and water district.

Industrial demand can be broken down by industrial subsector and further into process water and cooling water. This approach places development objectives providing end-use goods and services at the foundation of water analysis, and allows an evaluation of effects of improved technologies on these uses, as well as effects of changing prices on quantities of water demanded. In addition, priorities for allocating water for particular demands or from particular sources may be specified by the user.

Differing from the scenario one that was assumed fixed rate of 13404 m^3/ha and observed that agriculture consumes large amount of water compared to other sectors while unmet demand was encountered in months January, February and March.

However, in this scenario, demand management approach was applied in order to use the available water in the basin efficiency due to unmet demand by reducing in total monthly demand by 10%, 20% and 25% in short term, medium term and long term planning in scenario two respectively due to demand side management programs. This has been done by assuming that irrigation management applied shifting from high water demanding methods of irrigation to medium and low water demanding irrigation methods due to shortage of water.

Walker et.al (1987) mentioned that improving water use efficiency through modern irrigation technologies is considered an important activity toward saving water for non-irrigation off-stream and environmental instream uses. A large number of factors must be considered in making irrigation technology choices, including the location of the basin, its state of development, the water availability across the year, and the crop under consideration. Moreover, the irrigation technology considered needs to be compatible with other farm operations, including land preparation, cultivation, and harvesting, and the technology needs to be feasible from an economic, technical, and physical (topography and soil properties, for example) point of view.

Access to irrigation water is regulated by local customs, holding that the right to use water for irrigation only depends on access to land along the river (Mbara, Gadain and Muthusi, 2007). Pumps are regarded as legitimate ways to increase the amounts abstracted, hence the use is limited merely by technical restrictions.

No official approval or registration (licensing) and respective extraction control is currently required, having led to water misuse and wastage (Mbara, Gadain and Muthusi, 2007). Partly, local management committees have been established in order to regulate the use among the farmers, especially during times of a low river flow (Mbara, Gadain and Muthusi, 2007). Farmers sharing irrigation canals are often organized in so called *maddas*, which are customary water user associations (WUAs) (FAO, 2006). There are seasonal schedules for water allocations, gatekeepers, technicians controlling the discharge and assigning maintenance and repair duties among the members (Mbara, Gadain and Muthusi, 2007). Twice per year farmers usually have to desilt a section of the main canal as well as their distributaries, non-compliance being fined. Fights over water are usually settled by elders (Mbara, Gadain and Muthusi, 2007).

Improved efficiency irrigation technology was applied because of highly competitive among multiple water use where Juba basin is the main river of Somalia in terms of runoff, therefore this indicates that economic development of Somalia which depends on agriculture is based on Juba basin's water resources management if well utilized.

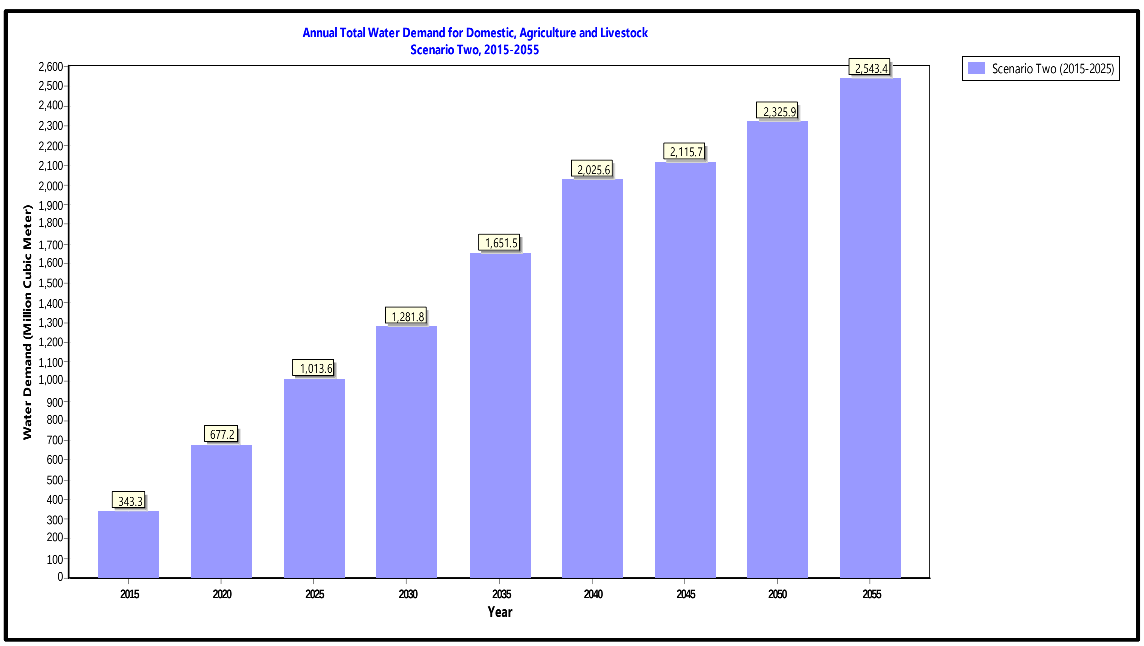

Figure 4.29: Annual water demand for domestic, agriculture and livestock in scenario two

In this scenario, changes have been made on agricultural water demand due to its high water demand therefore scenario of what if irrigation efficiency improved by 10% , 20% and 25% has been applied in short, medium and long term planning in scenario two in order to balance and reduce the high unmet demand that were observed in scenario one.

Figure 4.30, 4.31 and 4.32 present the water demand in scenario two in short, medium and long term plans after the irrigation efficiency mentioned above were applied while figures 4.34 and 4.35 show that the comparison among scenarios based on annual and monthly average respectively in order to understand the significant of water management strategies.

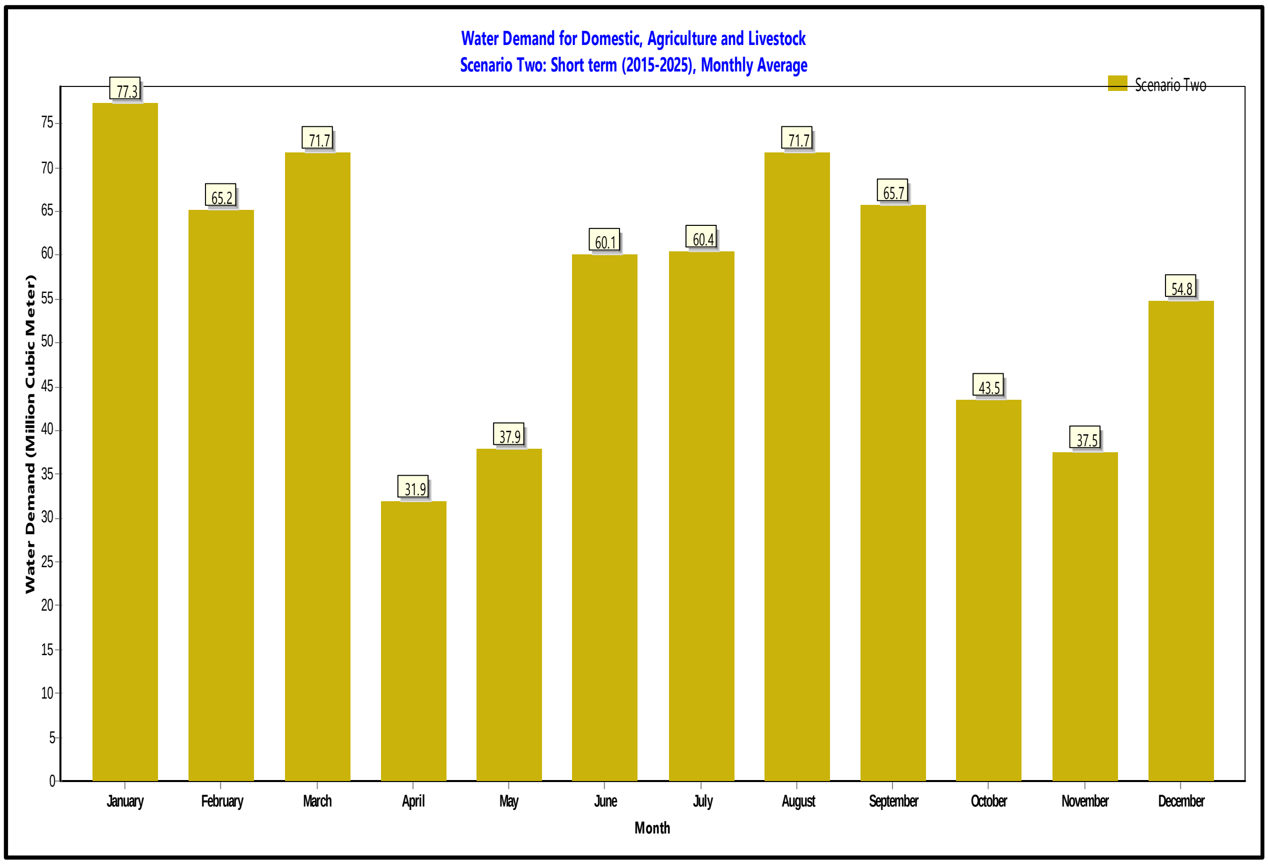

Figure 4.30: Monthly average water demand for domestic, agriculture and livestock in short-term plan of scenario two (2015-2025)

Medium term (2026-2040): Efficiency Irrigation Improved (20%)

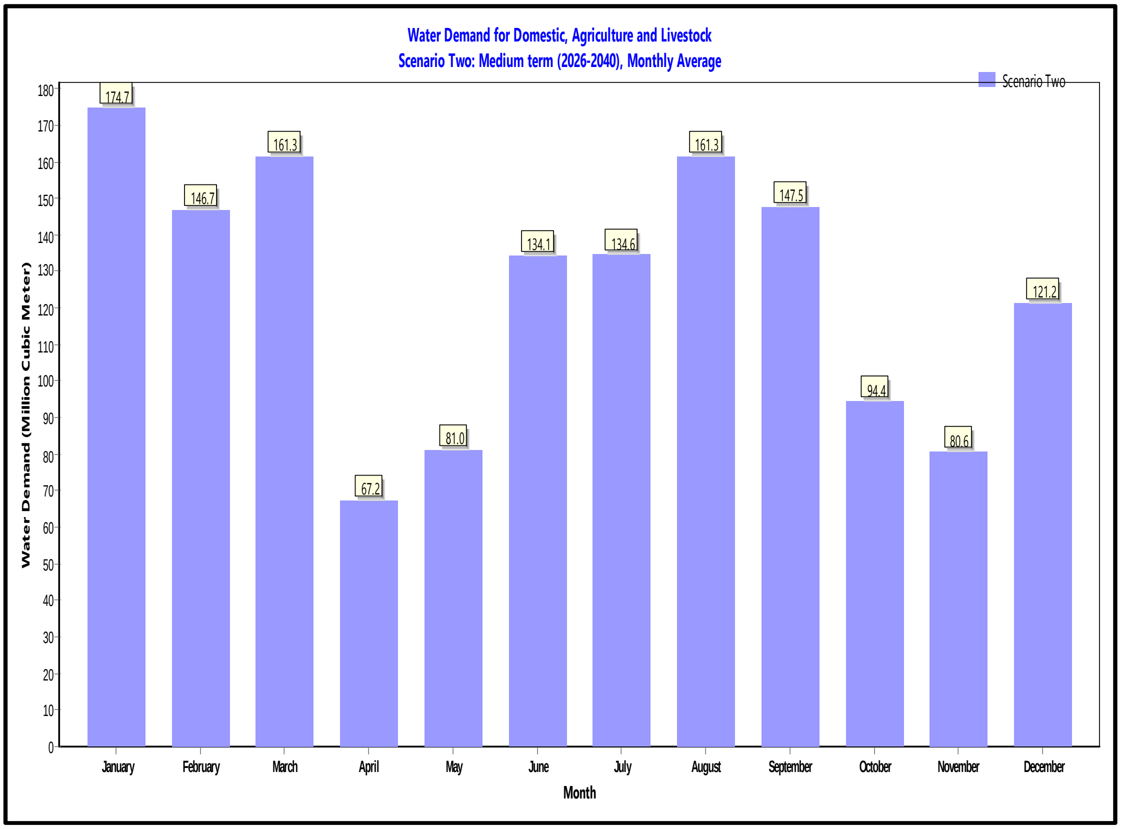

Figure 4.31: Monthly average water demand for domestic, agriculture and livestock in medium-term plan of scenario two (2026-2040)

Long term (2041-2055): Efficiency Irrigation Improved (25%)

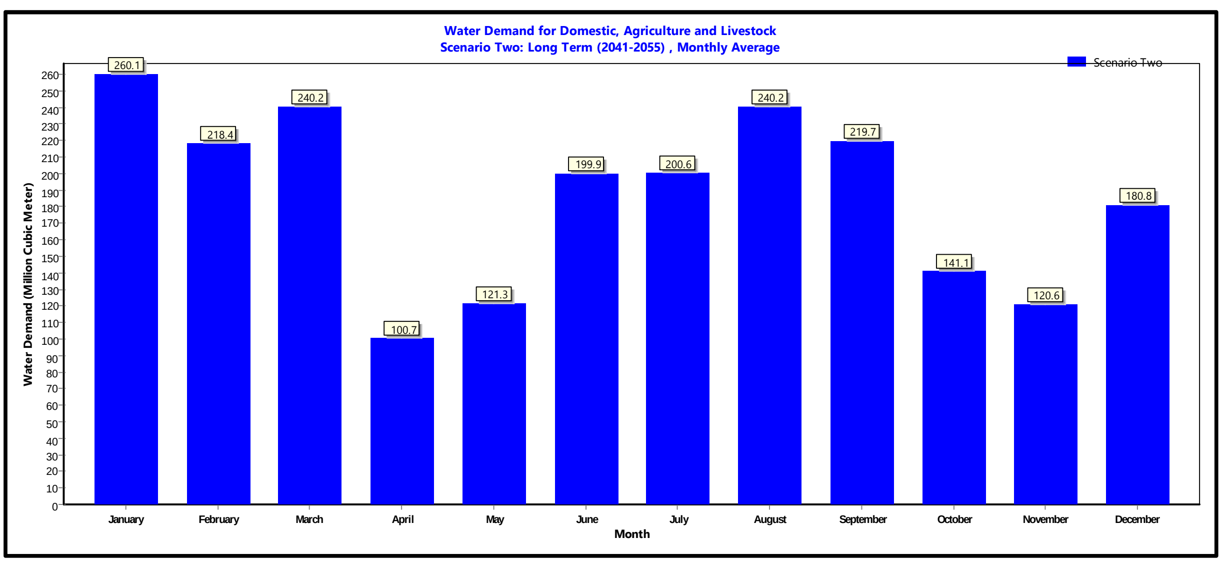

Figure 4.32: Monthly average water demand for domestic, agriculture and livestock in medium-term plan of scenario two (2041-2055).

Based on figure 4.26, 4.27 and 4.28, it can be concluded that improving irrigation efficiency would have a significant impact of demand management of the Juba basin due to agriculture is the major water user in the basin. As shown in figure 4.29 for comparison among scenarios, the unmet demand in scenario two reduced although there are unmet demands yet because of demand increasing from time to time.

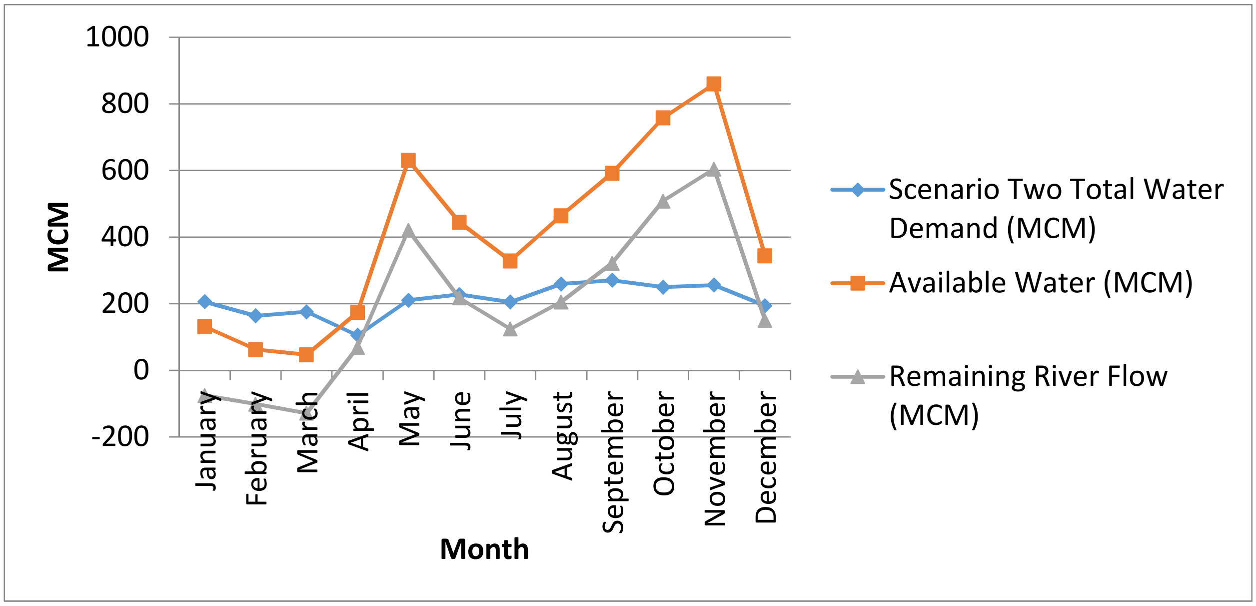

Figure 4.33: Monthly average inflow and outflow at scenario two (2015-2055)

4.5.4 Analysis of unmet demands in scenarios

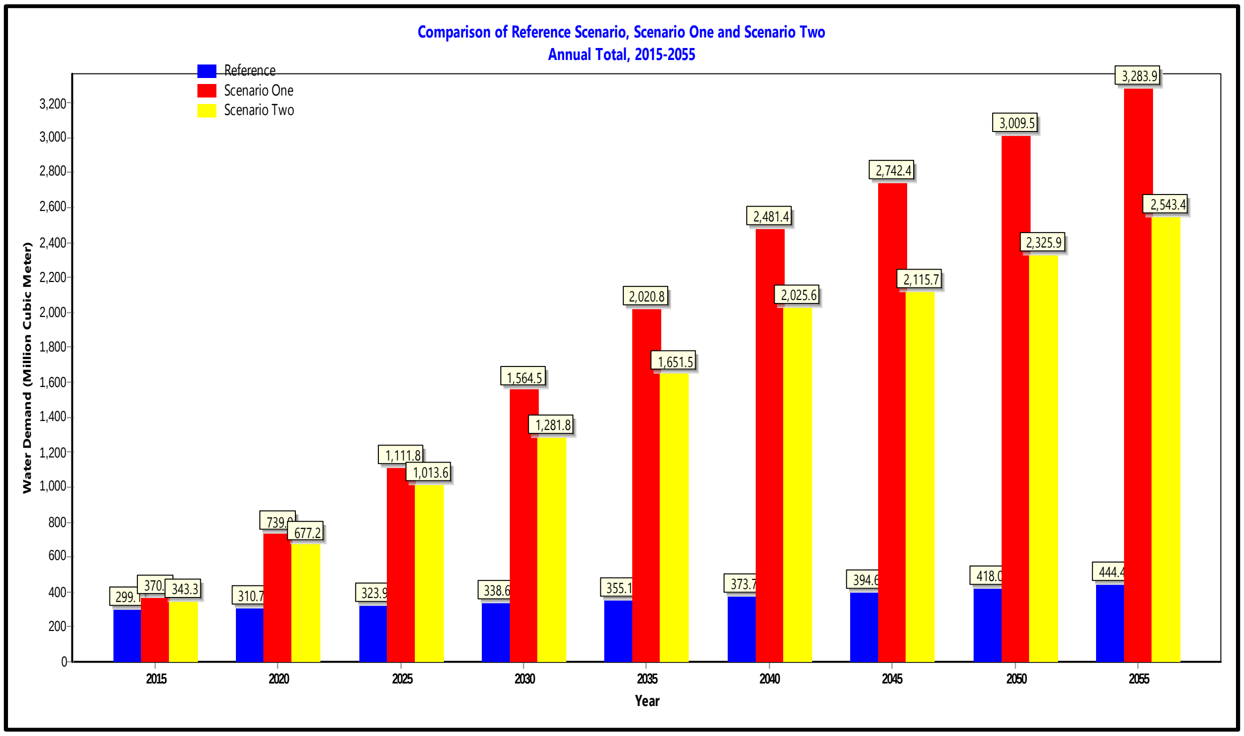

Figure 4.34: Comparison of annual water demand in reference, scenario one and scenario two (2015-2055)

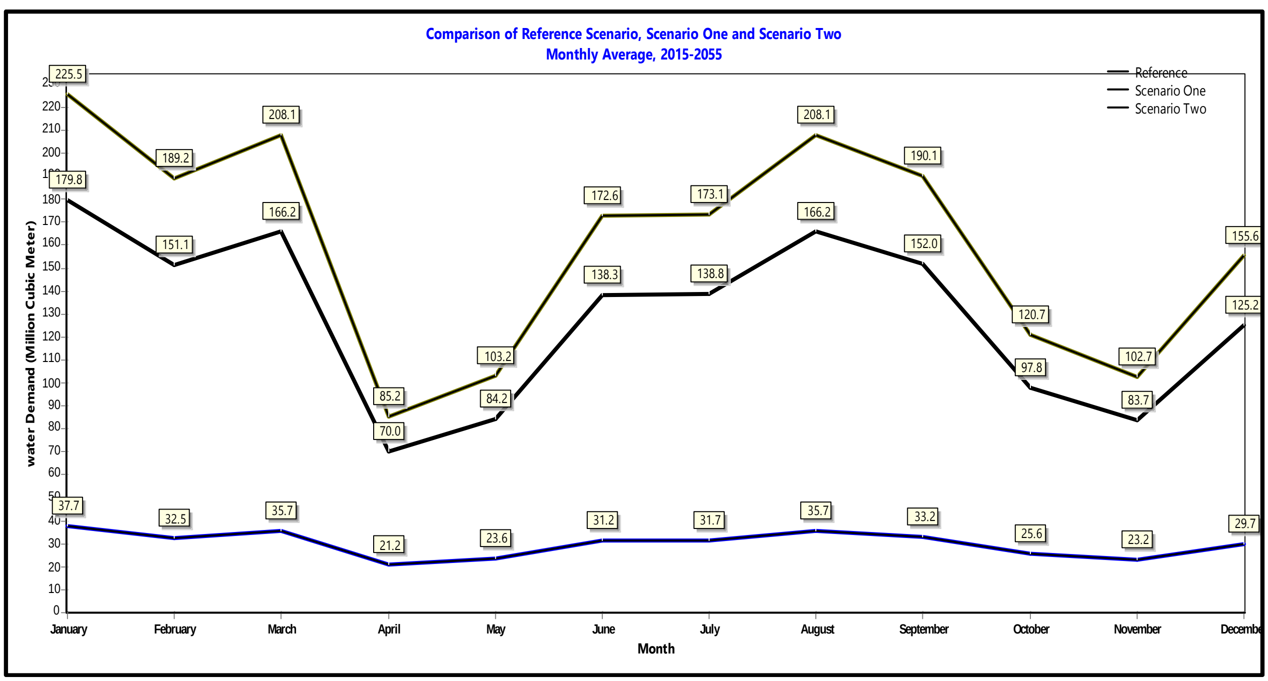

Figure 4.35: Comparison of monthly average water demand in reference, scenario one and scenario two

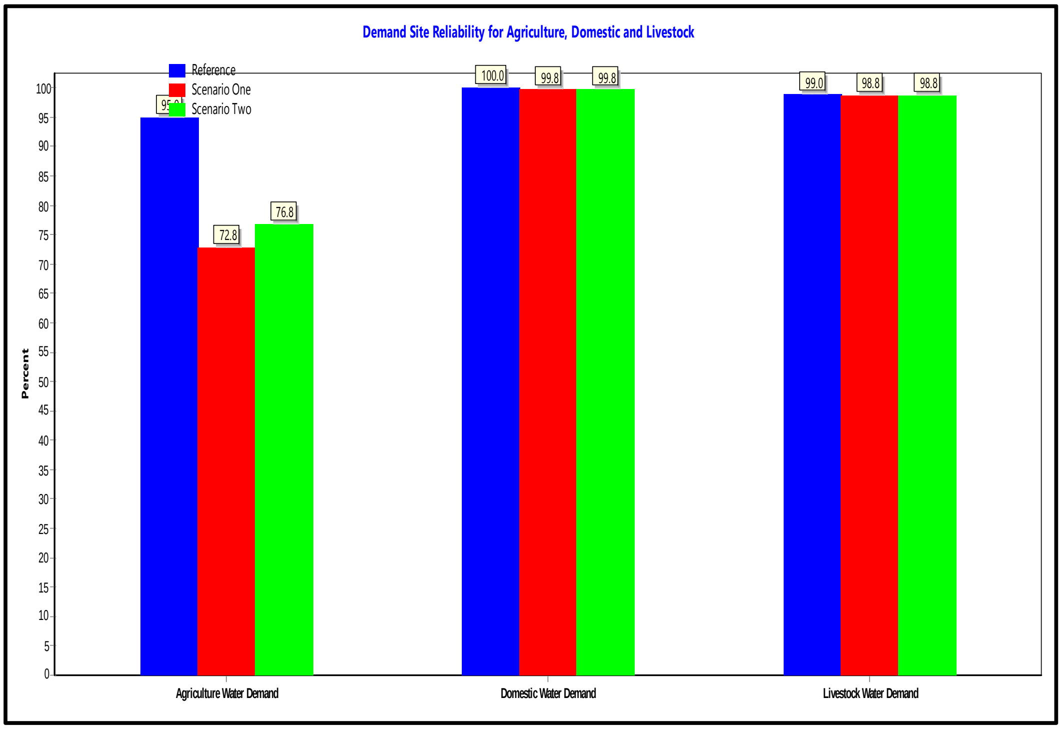

Figure 4.36: Demand site reliability for Agriculture, Domestic and Livestock in reference, scenario one and scenario two (2015-2055)

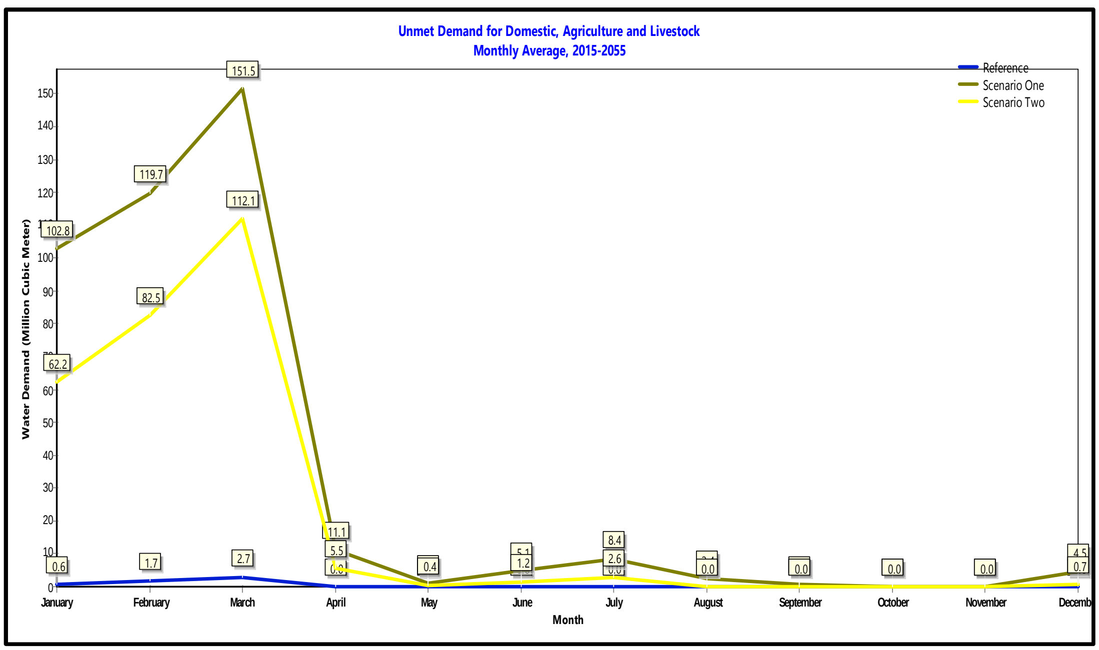

Figure 4.37: Monthly average Unmet demand for domestic, agriculture and Livestock in reference, scenario one and scenario two (2015-2055)

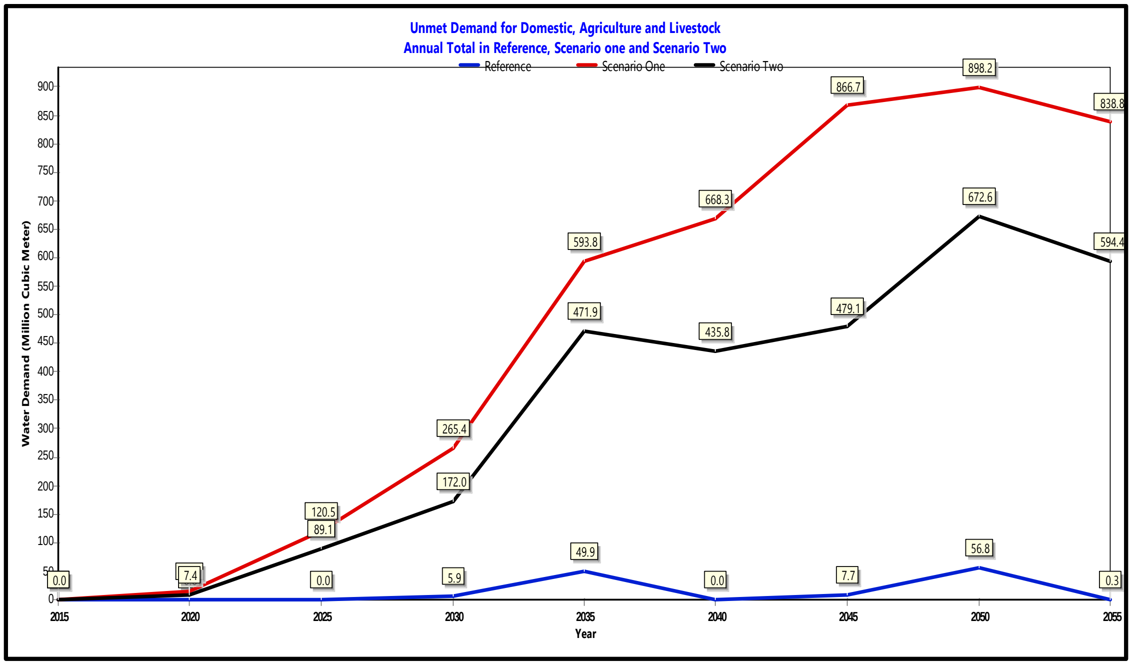

Figure 4.38: Annual Total Unmet demand for domestic, agriculture and Livestock in reference, scenario one and scenario two (2015-2055)

4.6 Water Allocation Strategies and Mechanisms

4.6.1 Supply Enhancement

In general, Supply enhancement includes increased access to conventional water resources through the construction of hydraulic structures aiming at regulating water supply and conveying water to the end user (dams and reservoirs; conveyance systems), as well as enhancing supply with treated wastewater, desalination and inter-basin transfers. Pollution control should also be considered a supply management option, as it increases the amount of water available for beneficial use, as well as for inter-basin transfer.

In this study, the following water allocation strategic options were identified in order to improve the water security system of Juba basin by balancing demand and supply among multiple groups of water sector while giving consideration the end user groups in the downstream part of the basin.

Building Dams and River Diversions

Building dams will have significance on the state of available water resources throughout the year and will be avoided water based conflicts among water users particularly farmers and pastoralists in the Juba basin of southern Somalia while constant water flow will be assured through balancing supply and demand.

In terms of use of the rivers, Elmi (2002) evaluated the significant impact in two transboundary rivers (Juba and Shabelle) on the survival of the Somali national economy, social, environmental well-being and security of the nation. He pointed out that several development projects like the Bardere Dam Project (BDP), which is the largest dam ever planned in Somalia, but it is unimplemented due to Somalia's internal problems.

According to Salman (2011), he mentioned that projected a 20–36% decrease in mean annual runoff due to abstraction and evaporation in Ethiopia based on the assessment done by the World Bank’s independent experts on planned Bardere Dam. The Bardere Dam and Water Infrastructure Project consisted of the construction of a multipurpose dam about 600 m long and 75 m high to regulate the flow of the Juba River, generate hydropower and control floods. The Project also included the construction of irrigation and drainage systems for about 5000 ha of land. The proposed Dam was located on the Juba River, 35 km upstream of the town Bardere in southern Somalia.

On the other hand, the existed diversions and barrages on Juba basin should be rehabilitated to regulate and ensure continuation flow and protection of flood in the prone areas of the downstream of the basin. For example, Fanole barrage, which had a capacity to pass 800 m^3/s. this barrage was planned in early of 1970's and constructed between 1977 and 1980. It had a powerhouse with low-head turbines, supplied a gravity diversion canal to the Fanole rice project, and to Homboy project as well as Juba sugar (Marerey) and Mogambo irrigation projects. Rehabilitation of diversions will have an impact regulation of flow whereby balancing supply and demand of the basin during low flow while avoiding water loss via flooding and draining water to the Indian ocean.

Conjunctive water use

Conjunctive use of surface and groundwater can be seen as one of the strategies of balancing supply and demand in the basin although the information regarding the local groundwater resources is not known but seems to be a priority action for the near future considering the projected reduction in surface water availability.

On-farm options

At farm level, Water resources can be improved efficiencies through better system design, regular maintenance and effective drainage, and equitable procedures for allocating water among farmers when there are shortages.

4.6.2 Demand Management

Demand management, in contrast, aims to raise the overall economic efficiency of water use, or to re-allocate water within and between sectors. The general aim of demand management is to maximize the benefits obtained from a given amount of water available to users, which could also include producing the same benefits from less water. In agriculture, this might involve producing more highly valued crops from irrigation or raising crop productivity, or reducing the consumptive use of water by minimizing evapotranspiration, or restraining the cropped area under irrigation.

In scenario one for this study indicates that high water demand in dry periods even if irrigation efficiency technology improved in scenario two still there are monthly gaps with low flow river flows where demand exceeds the supply due to existed and planned irrigated area of the basin.

Water availability to people, livestock and for agricultural use constitutes the basis of people's livelihoods and is a prime constraint for regional development (Gadain and Mugo, 2009). Although the basin evinces the greatest freshwater resources in Somalia, it is hydrologically water deficient and there are seasonal gaps with low river flows (IUCN, 2006; Muthusi, Mahamoud, Abdalle and Gadain 2007; Basnyat 2007).

However, if development of irrigation must be allowed for, and this is a policy decision, then some adjustment will be necessary in the plans for developing the Somalia reaches of the river. These adjustments may include a reduction of total area and/or modified cropping patterns and schedule seems to be important according to the volume and availability of water in the basin.

Intensive agriculture with advanced technology and modern agriculture can play a role for balancing demand and supply during water shortage periods by introducing drought resistant varieties through crop breeding and increasing the fertility of the soil both organic and inorganic fertilizers in order to maximize yield while minimizing the net cultivable land. This will be strategic for water shortage in Juba basin although capital and investment are precondition application for this technology.

Rainfed Agriculture Investment

There are several reasons to invest in rainfed agriculture as part of a water scarcity coping strategy, but the opportunities vary greatly from one place to another. Where the climate is suitable for rainfed agriculture, there is great potential to improve productivity where yields are still low, as is the case in many regions of sub-Saharan Africa (CA, 2007). Here, a combination of good agricultural practices (through management of soil, water, fertility and pest control), upward (inputs, credit) and downward (markets) linkages, combined with weather insurance schemes can go a long way in improving agricultural productivity with little impact on water resources.

In Juba basin, rainfed agriculture will be appropriate in some areas and suggested to promote in upstream part of the basin in Ethiopia where there is sufficient rainfall in order to compromise the downstream part of the basin where rainfall is very less and evaporation is very high due to adverse climate condition. Therefore, these can be achieved through cooperation and coordination among riparian states. It is in the semi-arid tropics that the issue of balance between irrigated and rainfed agriculture gets most attention. In these areas, relying on rainfed agriculture involves considerable climate-related risk. A range of water-harvesting techniques have been advocated for bridging short dry spells, and thus decreasing risk in rainfed agriculture (Wani, Rockström and Oweis, 2008; Faurès and Santini, 2008).

Elmi et.al (*2010*) stated that the Juba and Shabelle Rivers are international river basins in the Horn of African region. Ethiopia and Somalia have no past agreements on common utilization of the water resources in these two rivers and this may cause conflicts on water use in the future and influence the hydropolitics in the Horn of Africa.

Elmi (2014) indicated that since it is clear that the scarce water resources in the common rivers must be shared between the riparian states, the only assurance that no harm is done to the interests of any party lies in the process of collaboration and negotiation to facilitate the sustainable management and equitable utilization of the shared water resources.

According to the Ethiopian MoWR (2006), the regional and national water needs in Ethiopia call for concrete extensions of the current water use while regional development directly depend on agricultural sector.

However, even if the Ethiopian plans for total reduction of the river flow at the border of Somalia and Ethiopia would hold true as mentioned in the Genale- Dawa Master Plan based on different scenarios, the Somalia part of the catchment' available water resource would not be sufficient to the multiple water users in the basin. The result of this study indicates that there is scarcity of demand even considering different technologies that have better irrigation efficiency applied in scenario two because of high agricultural water demands therefore a mutual consultation as well as a coordinated planning would increase the development potential of the whole region while avoiding international conflicts. Furthermore, international donors financing the implantation of the master plan demand basic agreements between upstream and downstream parties: The World

Bank for instance expects commitment to their operational policy on international waterways, encouraging cooperation, goodwill, efficient use and protection (MoWR, 2006).

The Juba River has considerable potential as a source of irrigation water for agricultural development projects. There are perhaps three main constraints to the development of this basin: (a) a shortage of water in the river during the months January-April; (b) A tendency of the river to flood, especially during the months of October and November; (c) a lack of coordination and cooperation among riparian states.

Every water resource has upstream and downstream riparian and associated advantages and disadvantages often accrue depending on where they are physically located. For example, upstream diversions of water for agriculture or hydropower can have downstream impacts on local users, including effects on livelihoods and health therefore cooperation is important to avoid water-based conflict. Integrated approach for the development of water resources in the basin is necessary in order to meet the water requirements of all sectors to avoid competition and conflicts in water use and at the same time optimize the use of limited water resources.

IUCN (2006) mentioned that IGAD as a regional body could play an important role in respective cooperative efforts. While at present in 2015 IGAD developed a regional water resources policy that aimed at to promote closer cooperation in the equitable, sustainable and coordinated utilization, protection, conservation and management of transboundary or shared water resources in the IGAD region for poverty eradication, socio-economic development, regional integration, environmental sustenance and peaceful coexistence. The IGAD Member States would greatly benefit from an overall regional policy and legal framework under which bi- and multilateral agreements for specific river basins and groundwater bodies would be developed. This regional policy framework would also be a driver for the harmonization of national laws, regulations and institutional arrangements, which would facilitate the implementation of the international agreements.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The overall objective of this study was to model and evaluate the water resources system for effective water allocation of Juba basin in southern Somalia in a sustainable manner for social, economic and environmental benefits.

The mean annual flow of Juba basin at Luuq station was observed to be 6 BCM while the monthly average based on the observed flow from 2002-2014 indicates that January, February and March are the lowest months of available water resources in the basin.

This study shows that the Juba basin has capability to fulfil current water demands among multiple water users and no unmet demands were encountered although the current water use is very less due to current situation of Somalia where the major irrigation schemes collapsed during the civil war and the security of the basin still is fragile.

For future water demands, the result indicates that there is scarcity of demand even considering different technologies that have better irrigation efficiency of 10%, 20% and 25% in short, medium and long term in scenario two while significant reduction of monthly and annual total water demands were observed but still high unmet demands were encountered in months January, February and March. The study concludes that future water demands based on the planned activities in the basin both upstream and downstream will have an impact of meeting all demands due to expansion of irrigated areas, high population growth with urbanization, economic development and therefore holistic approach of integrated water resources planning and management has to be applied by the riparian states because of it is hydrologically water deficient and there are seasonal gaps with low river flows while sustainable use of limited water resources could be maintained.

However, this study suggests different water allocation strategic options including building dams and other diversions along the Juba River in order to get constant and regulated flow as well as some adjustment and modifications such as adjustments of crop patterns and a reduction of irrigated areas due to low supply in dry months and high supply in wet months and recognized that this will result in avoiding water based conflicts among multiple water users in the basin.

5.2 Recommendation

Based on the research findings, the following recommendations are listed:

1. Study on groundwater availability on its extent, location, recharges rates, safe yields, and current amounts of abstraction; basic quality and purpose of use (sectoral shares)
2. Dams and other river diversions should be built on Juba basin to improve water availability of the whole year and regulation constant flow because of its hydrology water deficits during dry months and surplus during wet seasons
3. Supply enhancement and demand management options must be improved to balance the supply and demand and avoid water based conflicts among multiple water users in the basin
4. Coordination and cooperation between riparian states as well as data and exchange information must be improved and application of integrated river basin management must be applied that will enable efficiency utilization common available water resources. Mechanisms that encourage a basin-wide agreement by the riparian states should be put in place to manage the common available water resources
5. Rehabilitation of exiting gauged and meteorological stations along Juba basin and reinstallation of new ones in the downstream part of the basin are recommended to understand well the water resources system of the basin and address the current lack of data.

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APPENDIX

Appendix A:

Table A-1: Annual Sectoral Water Demands for Domestic, Agriculture and Livestock

Water Demand (MCM) for sectoral water demands excluding Environmental Flow Requirement			
Year	**Reference (2015-2055)**	**Scenario One (2015-2055)**	**Scenario Two (2015-2055)**
2015	299.06	370.49	343.28
2016	301.29	444.19	409.88
2017	303.57	517.98	476.57
2018	305.91	591.85	543.35
2019	308.30	665.83	610.23
2020	310.75	739.90	677.20
2021	313.25	814.06	744.27
2022	315.81	888.34	811.45
2023	318.44	962.72	878.74
2024	321.12	1037.21	946.13
2025	323.87	1111.82	1013.64
2026	326.68	1202.10	988.53
2027	329.55	1292.51	1061.64
2028	332.50	1383.05	1134.88
2029	335.51	1473.72	1208.25
2030	338.59	1564.53	1281.76
2031	341.75	1655.48	1355.41
2032	344.98	1746.58	1429.21
2033	348.29	1837.83	1503.16

2034	351.67	1929.24	1577.27
2035	355.13	2020.81	1651.54
2036	358.68	2112.56	1725.99
2037	362.30	2204.48	1800.60
2038	366.02	2296.58	1875.41
2039	369.82	2388.87	1950.40
2040	373.71	2481.35	2025.58
2041	377.69	2533.12	1952.06
2042	381.77	2585.10	1992.65
2043	385.94	2637.30	2033.45
2044	390.21	2689.73	2074.48
2045	394.58	2742.39	2115.75
2046	399.05	2795.29	2157.26
2047	403.64	2848.44	2199.02
2048	408.32	2901.86	2241.04
2049	413.12	2955.54	2283.33
2050	418.04	3009.51	2325.90
2051	423.07	3063.77	2368.77
2052	428.22	3118.33	2411.93
2053	433.49	3173.20	2455.41
2054	438.88	3228.39	2499.22
2055	444.41	3283.93	2543.36

Appendix B:

Table A-2: Crop Water Requirement at Bardere station

Monthly Crop Water Requirement (mm) for Bardere Station														
Crop	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total mm**	**M^3/ha/year**
Maize	155.3	144.4	162.2	59.1	101	146.4	146.4	147.9	146.6	93	83.7	124.6	1510.6	**15,106**
Sorghum	146.2	135.9	152.2	50	91.8	137.8	137.7	189.2	137.9	83.8	75	115.6	1453.1	**14,531**
Wheat	146.2	135.9	152.2	50	91.8	137.8	137.7	189.2	137.9	83.8	75	115.6	1453.1	**14,531**
Paddy rice	201	186.9	209.9	104.9	146.7	189.4	189.3	191.4	189.6	138.8	127.2	169.6	2044.7	**20,447**
Upland rice	164.4	152.9	171.7	68.2	110.1	155	154.9	156.6	155.2	102.2	92.4	133.6	1617.2	**16,172**
Oil Seeds	127.9	118.9	133.6	31.9	73.5	120.5	120.5	121.8	120.7	65.5	57.7	97.6	1190.1	**11,901**
Textile Plants	127.9	118.9	133.6	31.9	73.5	120.5	120.5	121.8	120.7	65.5	57.7	97.6	1190.1	**11,901**
Banana	182.7	169.9	190.8	86.3	128.4	172.2	172.1	174	172.4	120.5	109.8	151.6	1830.7	**18,307**
Grapefruit	118.8	110.4	124	22.8	64.3	111.9	111.9	113.1	112	56.3	49	88.6	1083.1	**10,831**
Citrus	100.7	93.4	104.9	4.7	46	94.7	94.6	95.7	94.8	38	31.6	70.6	869.7	**8,697**
Coconut	155.3	144.4	162.2	59.1	100.9	146.4	146.3	147.9	146.5	93	83.7	124.6	1510.3	**15,103**
Pulses	127.9	118.9	133.6	31.9	73.5	120.5	120.5	121.8	120.7	65.5	57.7	97.6	1190.1	**11,901**
Vegetables	127.9	118.9	133.6	31.9	73.5	120.5	120.5	121.8	120.7	65.5	57.7	97.6	1190.1	**11,901**
Starch plants	127.9	118.9	133.6	31.9	73.5	120.5	120.5	121.8	120.7	65.5	57.7	97.6	1190.1	**11,901**
Forage plants	164.4	152.9	171.7	68.2	110.1	155	154.9	156.6	155.2	102.2	92.4	133.6	1617.2	**16,172**
Sugar cane	164.4	152.9	171.7	68.2	110.1	155	154.9	156.6	155.2	102.2	92.4	133.6	1617.2	**16,172**
Tobacco	146.2	135.9	152.6	50	91.8	137.8	137.7	139.2	137.9	83.8	75	115.6	1403.5	**14,035**

Table A-3: Crop Water Requirement at Luuq station

Monthly Crop Water Requirement(mm) for Luuq Station													
Crop	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total Annual mm**
Maize	158.9	148.2	138.7	45.1	120.8	152.7	154	153	150.9	107.6	93	155.8	**1579**
Sorghum	149.6	139.5	128.9	35.7	115.5	143.8	134	144	142	98.6	84.1	146.6	**1462**
Wheat	149.6	139.5	128.9	35.7	115.5	143.8	134	144	142	98.6	84.1	146.6	**1462**
Paddy rice	205.7	191.8	187.8	91.8	167.8	197.7	199.3	198	195.2	152.7	137.3	201.6	**2127**
Upland rice	168.3	157	148.5	54.4	130.2	161.7	163.1	162	159.7	116.7	101.9	165	**1689**
Oil Seeds	130.9	122.1	109.2	17	92.7	126	126.8	126	124.2	80.6	66.4	128.3	**1250**
Textile Plants	130.9	122.1	109.2	17	92.7	126	126.8	126	124.2	80.6	66.4	128.3	**1250**
Banana	187	174.4	168.2	73.1	149	179.7	181.2	180	177.5	134.7	119.6	183.3	**1908**
Grapefruit	121.5	113.4	99.4	7.7	83.3	116.8	117.8	117	115.4	71.5	57.5	119.1	**1140**
Citrus	128.8	95.6	79.8	11.2	64.5	98.8	99.7	99	97.6	53.5	39.8	100.8	**969**
Coconut	158.9	148.2	138.7	45.1	120.8	152.7	154	153	150.9	107.6	93	155.8	**1579**
Pulses	130.9	122.1	109.2	17	92.7	126	126.8	126	142.2	80.6	66.4	128.3	**1268**
Vegetables	130.9	122.1	109.2	17	92.7	126	126.8	126	142.2	80.6	66.4	128.3	**1268**
Starch plants	130.9	122.1	109.2	17	92.7	126	126.8	126	142.2	80.6	66.4	128.3	**1268**
Forage plants	168.3	157	148.5	54.4	130.2	161.7	163.1	162	157.7	116.7	101.9	165	**1688**
Sugar cane	168.3	157	148.5	54.4	130.2	161.7	163.1	162	157.7	116.7	101.9	165	**1687**
Tobacco	149.6	139.5	128.9	35.7	111.5	143.8	145	144	142	98.6	84.1	146.6	**1469**

Table A-4: Crop Water Requirement at Jilib station

Monthly Crop Water Requirement (mm) for Jilib Station														
Crop	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total mm	Total M^3/ha/year
Maize	153	139.9	154.4	8.1	40.3	86.9	90.4	143.5	140.9	74.2	86.2	103.3	1221.1	12211
Sorghum	144	131.7	145.4	0.5	31.4	78.6	82	135.1	132.6	65.4	77.6	94.4	1118.7	11187
Paddy rice	198	181.1	199.9	51.2	84.9	128.4	132.4	185.8	182.4	117.9	129.1	147.9	1739	17390
upland rice	162	148.1	163.5	16.8	49.3	95.2	98.8	152	149.2	82.9	94.7	112.3	1324.8	13248
Oil Seeds	126	115.2	127.2	17.7	13.6	62.1	65.2	118.2	116.1	47.9	60.4	76.6	946.2	9462
Textile Plants	126	115.2	127.2	17.7	13.6	62.1	65.2	118.2	116.1	47.9	60.4	76.6	946.2	9462
Banana	180	164.4	181.7	34	67.1	111.8	115.6	168.9	165.8	100.4	111.9	130.1	1531.7	15317
Grapefruit	117	107	118.1	26.3	4.7	53.8	56.8	109.8	107.8	39.2	51.8	67.7	860	8600
Citrus	99	90.5	99.9	43.6	13.1	37.2	39.9	92.9	91.2	21.7	34.7	49.9	713.6	7136
Cocunut	153	139.9	154.4	8.1	40.3	86.9	90.4	143.6	140.9	74.2	86.2	103.3	1221.2	12212
Pulses	126	115.2	127.2	17.7	13.6	62.1	65.2	118.2	116.1	47.9	60.4	76.6	946.2	9462
Vegetables	126	115.2	127.2	17.7	13.6	62.1	65.2	118.2	116.1	47.9	60.4	76.6	946.2	9462
Starch plants	126	115.2	127.2	17.7	13.6	62.1	65.2	118.2	116.1	47.9	60.4	76.6	946.2	9462
Forage plants	162	148.1	163.5	16.8	49.3	95.2	98.8	152	149.2	82.9	94.7	112.3	1324.8	13248
Sugar cane	162	148.1	163.5	16.8	49.3	95.2	98.8	152	149.2	82.9	94.7	112.3	1324.8	13248
Tobacco	144	131.7	145.4	0.5	31.4	78.6	82	135.1	132.6	65.4	77.6	94.4	1118.7	11187

Table A-5: River Flow (m^3/s) of Genale Dawa at Dolow Ado station

Year	Month	Natural Flow Condition (1973-2002)	Base case(2005)	Low scenario(2007-2012) 10% annual flow reduction
1973	1	52.14	51.96	41.22
1973	2	34.47	34.06	27.05
1973	3	24.68	24.44	16.33
1973	4	57.31	56.89	40.93
1973	5	184.57	183.7	161.36
1973	6	149.47	148.72	130.16
1973	7	201.68	201.04	188.85
1973	8	405.61	204.27	376.59
1973	9	409.38	407.82	378.2
1973	10	469.19	468.56	437.9
1973	11	257.29	256.72	230.52
1973	12	83.05	82.65	63.48
1974	1	46.67	46.48	34.9
1974	2	31.64	31.26	24.16
1974	3	46.67	46.28	35.77
1974	4	131.58	131.1	112.2
1974	5	186.46	185.59	163.86
1974	6	217.43	216.68	199.82
1974	7	259.44	258.81	246.73
1974	8	260.77	259.43	230.35
1974	9	390.88	389.32	358.48
1974	10	234.07	233.44	206.49
1974	11	166.68	166.12	141.84
1974	12	54.37	53.97	35.26
1975	1	28.31	28.16	16.86
1975	2	20.19	19.83	12.82
1975	3	12.64	12.3	4.18
1975	4	82.57	82.09	63.11
1975	5	181.01	180.14	156.05
1975	6	167.98	167.23	150.71
1975	7	213.12	212.48	194.97
1975	8	297.87	296.5	261.98
1975	9	308.59	307.03	274.93
1975	10	368.18	367.55	335.28
1975	11	218.91	218.34	191.72
1975	12	78.35	77.95	59.7

1976	1	47.12	46.97	36.22
1976	2	30.54	30.14	23.16
1976	3	17.28	16.99	7.97
1976	4	71.68	71.2	49.77
1976	5	346.98	346.11	318.45
1976	6	280.41	279.66	259.61
1976	7	262.61	261.97	251.72
1976	8	273.84	272.47	248.31
1976	9	285.49	283.93	252.36
1976	10	311.75	311.12	283.54
1976	11	375.06	374.49	347.96
1976	12	99.09	98.69	79.66
1977	1	67.49	67.31	55.75
1977	2	72.64	72.19	64.96
1977	3	64.02	63.64	54.22
1977	4	120.29	119.81	97.6
1977	5	187.62	186.75	162.35
1977	6	145.92	145.17	128.23
1977	7	190.23	189.59	172.85
1977	8	249.88	248.56	220.39
1977	9	270.98	267.46	239.56
1977	10	458.67	458.04	410.23
1977	11	337.88	337.31	298.64
1977	12	125.93	125.53	103.21
1978	1	67.26	67.08	55.31
1978	2	46.03	45.58	38.28
1978	3	47.34	46.96	37.13
1978	4	112.34	111.86	92.68
1978	5	192.95	192.08	168.21
1978	6	153.46	152.71	136.42
1978	7	199.15	196.51	179.15
1978	8	288.29	186.92	247.11
1978	9	325.83	324.32	291.34
1978	10	463.27	462.64	422.7
1978	11	337.67	337.1	380.62
1978	12	156.79	156.39	136.6
1979	1	84.84	84.66	73.23
1979	2	63.07	62.62	55.43
1979	3	62.02	61.63	52.7
1979	4	108.01	107.53	88.3
1979	5	218.27	217.4	192.49

1979	6	185.7	184.95	165.84
1979	7	159.11	158.47	147.05
1979	8	225.3	223.93	199.13
1979	9	228.13	226.57	197.62
1979	10	251.31	250.68	220.67
1979	11	154.52	153.95	128.25
1979	12	72.88	72.48	54.23
1980	1	49.27	49.09	38.21
1980	2	31.17	30.76	23.48
1980	3	36.21	35.89	23.86
1980	4	148.76	148.28	131.19
1980	5	347.29	346.42	324.74
1980	6	249.36	248.61	330
1980	7	272.77	272.13	262.34
1980	8	332.56	331.22	310.7
1980	9	330.97	329.41	301.22
1980	10	334.68	334.05	305.6
1980	11	210.4	209.89	183.75
1980	12	74.7	74.3	55.53
1981	1	41.72	41.54	30.3
1981	2	25.8	25.41	18.18
1981	3	50.36	49.97	37.21
1981	4	304.82	304.34	241.15
1981	5	325.77	324.9	300.89
1981	6	179.31	178.61	162.42
1981	7	205.7	205.17	193.24
1981	8	290.93	289.71	259.85
1981	9	316.52	314.96	279.6
1981	10	319.17	318.54	292.06
1981	11	171.11	170.59	145.79
1981	12	70.87	70.52	53.61
1982	1	43.04	42.86	32.07
1982	2	25.7	25.31	18.23
1982	3	39.46	39.16	30.25
1982	4	141.15	140.67	115.79
1982	5	336.59	335.72	370.97
1982	6	257.52	256.77	237.9
1982	7	214.53	213.89	203.27
1982	8	271.08	269.71	246.59
1982	9	311.35	310.5	283.6
1982	10	409.79	409.16	376.67

1982	11	327.41	326.84	300.71
1982	12	161.6	161.2	138.02
1983	1	83.91	83.73	71.77
1983	2	57.04	56.66	49.54
1983	3	41.93	41.66	32.81
1983	4	104.29	103.81	86.06
1983	5	283.19	282.32	258.31
1983	6	233.72	232.97	213.74
1983	7	242.1	241.47	230.29
1983	8	345.87	354.51	325.86
1983	9	702.59	701.04	661.69
1983	10	792.92	792.29	758.32
1983	11	519.86	519.29	492.1
1983	12	153.63	153.26	134.81
1984	1	122.98	122.8	112.06
1984	2	39.67	39.32	32.7
1984	3	26.37	26.12	17.43
1984	4	38.13	37.74	21.02
1984	5	101.58	100.73	77.68
1984	6	135.89	135.16	116.42
1984	7	115.96	115.32	104.84
1984	8	200.01	198.68	176.18
1984	9	332.12	330.56	295.36
1984	10	261.156	260.93	235.01
1984	11	140.95	140.48	116.55
1984	12	60.89	60.56	41.95
1985	1	28.99	28.85	17.7
1985	2	20.77	20.47	14.07
1985	3	17.26	17.01	7.49
1985	4	201.56	201.08	179.47
1985	5	491.24	490.37	464.46
1985	6	233.2	232.51	213.94
1985	7	222.69	222.06	211.92
1985	8	280.68	279.34	256.08
1985	9	227.16	225.78	197.58
1985	10	267.43	266.8	240.09
1985	11	160.65	160.09	135.41
1985	12	71.59	71.2	52.01
1986	1	31.32	31.18	18.91
1986	2	19.81	19.47	12.5
1986	3	26.15	25.79	16.98

1986	4	159.9	159.42	138.73
1986	5	348.5	347.63	319.24
1986	6	368.94	368.19	345.2
1986	7	277.97	277.33	265.06
1986	8	265.19	263.83	234.6
1986	9	382.63	381.07	350.54
1986	10	324.65	324.02	296.14
1986	11	142.62	142.08	117.99
1986	12	79.01	78.61	59.65
1987	1	30.87	30.75	19.5
1987	2	31.1	30.78	23.74
1987	3	51.49	51.1	40.87
1987	4	170.07	169.59	142.93
1987	5	596.99	597.12	558.45
1987	6	647.06	646.31	625.38
1987	7	236.03	235.47	225.76
1987	8	170.46	169.55	151.84
1987	9	198.95	197.39	170.22
1987	10	363.74	363.11	334.01
1987	11	312.14	311.57	284.64
1987	12	82.65	82.31	63.64
1988	1	45.48	45.3	33.83
1988	2	32.46	32.14	25.3
1988	3	29.89	29.64	20.77
1988	4	94.54	94.06	71.86
1988	5	203.17	202.3	181.09
1988	6	122.5	121.8	106.9
1988	7	265.66	265.02	248.97
1988	8	380.48	379.12	347.78
1988	9	291.25	289.69	256.02
1988	10	599.78	599.15	568.62
1988	11	220.85	220.31	194.76
1988	12	70.74	70.38	52.54
1989	1	46.92	46.74	35.74
1989	2	42.05	41.69	34.85
1989	3	37.19	36.89	28.07
1989	4	287.17	286.69	251.87
1989	5	324.38	323.52	298.68
1989	6	228.13	227.39	212.21
1989	7	293.76	293.15	271.6
1989	8	263.29	261.98	241.37

1989	9	461.19	459.63	429.77
1989	10	541.88	541.25	509.09
1989	11	318.79	318.22	291.32
1989	12	275.32	274.92	251.72
1990	1	137.44	137.26	125.55
1990	2	107.16	106.7	95.41
1990	3	223.71	223.32	208.69
1990	4	397.89	397.41	366.76
1990	5	308.88	380.01	287.31
1990	6	250.99	250.26	232.92
1990	7	214.41	213.77	203.64
1990	8	321.83	320.52	292.95
1990	9	286.04	284.48	257.46
1990	10	289.83	289.2	263.06
1990	11	188.3	187.23	162.88
1990	12	115.54	115.14	95.25
1991	1	68.05	67.91	56.51
1991	2	54.86	54.45	47.18
1991	3	48.31	47.95	37.76
1991	4	149.75	149.27	129.65
1991	5	186.79	185.92	164.03
1991	6	127.61	126.86	108.3
1991	7	180.8	180.16	162.47
1991	8	332.52	331.15	293.77
1991	9	324.67	223.11	297.11
1991	10	210.33	209.7	184.96
1991	11	116.4	115.86	92.25
1991	12	90.69	90.29	71.24
1992	1	66.7	66.52	55.1
1992	2	64.09	63.63	55.18
1992	3	57.32	57.01	47.42
1992	4	93.11	92.63	75.75
1992	5	156.35	155.48	133.65
1992	6	187.65	186.9	170.25
1992	7	210.13	209.49	196.97
1992	8	336.81	335.44	288.96
1992	9	315.78	314.22	283.93
1992	10	642.64	642.01	599.28
1992	11	472.43	471.86	442.3
1992	12	141	140.6	116.9
1993	1	110.02	109.84	96.35

1993	2	206.88	206.42	183.42
1993	3	86.82	86.52	77.57
1993	4	121.84	121.36	104.27
1993	5	571.81	570.94	546.37
1993	6	462.53	462.82	443.87
1993	7	280.77	280.13	266.37
1993	8	329.93	328.56	301.1
1993	9	265.9	264.34	234.84
1993	10	359.17	358.54	328.13
1993	11	316.35	315.79	285.39
1993	12	99.29	98.89	79.7
1994	1	67.27	67.09	55.74
1994	2	70.45	70.03	62.39
1994	3	48.49	48.16	39.14
1994	4	57.74	57.26	39.31
1994	5	197.35	196.48	175.7
1994	6	249.06	248.34	233.3
1994	7	298.69	298.05	281.53
1994	8	436.29	434.94	393.36
1994	9	328.23	326.67	295.94
1994	10	297.02	297.39	265.84
1994	11	239.11	338.54	195.03
1994	12	197.78	107.38	86.81
1995	1	63.58	63.4	52.52
1995	2	64.73	64.29	57.32
1995	3	85.81	85.46	74.13
1995	4	182.95	182.87	158.53
1995	5	309.79	308.92	285.69
1995	6	192.05	191.3	175.32
1995	7	188.66	188.02	174.66
1995	8	342.67	341.35	306.37
1995	9	397.22	395.71	356.1
1995	10	494.65	494.02	463.62
1995	11	258.16	257.59	228.33
1995	12	101.35	100.95	81.84
1996	1	65.03	64.85	53.39
1996	2	63.48	63.04	55.87
1996	3	58.03	57.7	49.04
1996	4	178.18	177.7	157.6
1996	5	650.38	649.51	624.27
1996	6	564.42	563.67	538.55

1996	7	412.79	412.15	392.19
1996	8	385.51	384.14	349.06
1996	9	402.2	400.64	371.01
1996	10	334.52	333.89	307.03
1996	11	184.51	183.94	459.7
1996	12	109.1	108.7	89.88
1997	1	64.75	64.57	53.38
1997	2	42.96	42.57	35.16
1997	3	33.79	33.46	24.94
1997	4	167.46	166.98	148.2
1997	5	171.22	170.34	147.25
1997	6	122.25	121.5	105.28
1997	7	213.78	213.14	200.51
1997	8	727.98	726.67	705.91
1997	9	679.08	677.52	649.64
1997	10	890.6	889.97	838.56
1997	11	649.44	648.87	610.36
1997	12	247	246.6	222.08
1998	1	244.05	243.87	223.02
1998	2	430.21	429.8	422.58
1998	3	201.18	200.84	191.17
1998	4	172.58	172.12	153.88
1998	5	259.04	258.17	238.47
1998	6	221.24	220.49	202.78
1998	7	262.47	261.83	246.56
1998	8	366.99	365.62	326.36
1998	9	316.61	315.07	282.17
1998	10	528.73	528.1	496.31
1998	11	412.36	411.79	383.35
1998	12	110.96	110.56	91.34
1999	1	60.03	59.85	48.52
1999	2	46.3	45.89	38.95
1999	3	65.54	65.15	54.83
1999	4	78.26	77.78	57.92
1999	5	166.7	165.8	144.09
1999	6	107.05	106.32	91.14
1999	7	157.81	157.17	138.9
1999	8	220.87	219.5	191.32
1999	9	207.35	205.79	175.04
1999	10	401.68	401.05	361.08
1999	11	237.47	236.9	209.19

1999	12	63.92	63.52	44.84
2000	1	32.04	31.89	20.82
2000	2	21.56	21.14	14.23
2000	3	16.36	16.04	7.61
2000	4	25.21	24.75	13.2
2000	5	249.15	248.28	225.65
2000	6	86.71	85.98	71.3
2000	7	116.51	115.87	103.11
2000	8	207.01	205.64	172.36
2000	9	197.4	195.84	165.03
2000	10	457.81	457.18	412.54
2000	11	408.02	407.45	376.86
2000	12	116.71	116.31	96.6
2001	1	56.75	56.67	45.27
2001	2	40.39	39.94	32.53
2001	3	47.06	46.67	37.28
2001	4	119.56	119.08	100.01
2001	5	191.21	190.34	166.56
2001	6	166.87	166.14	178.56
2001	7	158.79	158.15	143.28
2001	8	333.51	332.14	304.64
2001	9	332.14	330.58	295.36
2001	10	386.13	385.5	352.69
2001	11	268.19	267.62	240.78
2001	12	91.64	91.24	72.68
2002	1	58.54	58.36	46.63
2002	2	30.21	29.76	22.56
2002	3	44.49	44.1	34.31
2002	4	152.5	152.02	129.39
2002	5	162.46	161.59	140.62
2002	6	96.21	95.46	79.66
2002	7	99.41	98.77	87.94
2002	8	162.09	160.73	140.9
2002	9	124.61	123.15	97.04
2002	10	223.72	223.09	193.78
2002	11	138.8	138.23	112.39
2002	12	89.38	88.98	68.44