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Surface Water Availability and Demand Analysis: Implication for Enhancing Water Resource Planning at Shabelle Basin in Southern Somalia

By

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In

Integrated River Basin Management

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Declaration

I, **Ahmed Mohamed Hassan,** hereby submit a thesis entitled **"Surface Water Availability and Demand Analysis: Implication for Enhancing Water Resource Planning at Shabelle Basin in Southern Somalia"** in partial fulfillment of the requirement for the award of an MSc Degree in Integrated River Basin Management by the Institute of Water and Environment at Mekelle University. 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

Shabelle river is one of two perennial river in Somalia which flow through the southern part of the country, freshwater resources in basin, are particularly important for irrigation, as well as domestic and industrial water supply. Increased agricultural water demand, the accelerated population growth and the infrastructure that collapsed disparity of rainfall, distribution make production of sufficient food and to contribute the ecological sustainability on flow, are going to greatly exacerbate. The complexity of future water resources management in what is already a water-stressed catchment.

Being able to assess the ability of the catchment to satisfy potential water demands is crucial in order to plan for the future and make wise decisions. In this study, current water demand and scenario analysis approach was used in conjunction with the Water Evaluation And Planning model, in order to assess the impacts of possible water demands on the water resources of the Shabelle catchment in 2040. For each scenario, the water resource implications were compared to a 2014 “baseline.” The model enabled analyses of unmet water demands,

The model result shows that approximately 90% of irrigation water demand has been met and the trends in water demand for the agriculture will not have significant impacts on the current scenarios. in the high growth scenario is the most sensitive of changes especially for agricultural development in the basin, for all the scenarios the water demands increase, producing greater shortfalls, therefore A tight control of the growth in future demands is essential, and to embrace more efficient management of the available water resource.

Keywords: Cropwatt model, Water demand, WEAP model, river Shabelle, surface water and scenarios.

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List of acronym and abbreviation

BCM	Billion Cubic Meter
CropWat	Crop Water Requirement
Deyr	October to November, minor wet season
EC	European Commission
FAO	Food and Agriculture Organization of the United Nations
FSAU	Food Security and Assessment Unit
GWP	Global Water Partnership.
Gu	April to June, major wet season
Hagaa	July to September dry and cool season
L/c/d	Litre Per Capita per Day
Jilaal	Dry season from December to March
KM	Kilometer
MM3	Million cubic meters
MM	Millimeter
maddas	Customary Water Use Association
MoA	Ministry of Agriculture
MoNP	Ministry of National Planning
MoWR	Ministry of Water Resources
PPP	Public Private Partnership
PET	Potential Evapotranspiration
SEI	Stockholm Environment Institute
SWIMS	Somali Water Sources Information Management System
SWALIM	Somalia Water and Land Information Management
UNDP	United Nations Development Programme
UN	United Nation
WEAP	Water evaluation and Planning
WUA	Water User Association

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CHAPTER 1: INTRODUCTION

1.1 Background

Water is a basic necessity for sustaining life and development of society. With the Increasing population including urbanization, economic growth, industrial production, agricultural and livestock production, demand for water has increased rapidly over the years (GWP, 2000). Population growth and economic development put constant pressure on the eco-systems of water resources (Alcamo et al., 2007). There is also a strong positive correlation between water demand and urbanization or population growth (Malmqvist and Rundle, 2002).

Increase in water demand has reduced water availability during dry seasons and has as well increased water conflicts in the watersheds. Unless properly managed, increasing demand of the scarce water resources by different sectors will strongly affect all users and the environment (Hellström et al., 2000).

Somalia has only two perennial rivers, the Juba and the Shabelle, both of which flow through the southern part of the country but originate in neighboring countries principally Ethiopia. Technically, the Shabelle is a tributary of the Juba and as such constitutes a single basin, but since flows from the Shabelle join the Juba only very rarely and even then result from localized rainfall the rivers are effectively separate (Gadain and Muchiri, 2011).

The water resources of the Juba-Shabelle basin are particularly important for irrigation developments in Somalia, as well as for domestic and industrial water supply. Statistics from Ministry of Agriculture (1988) indicate that a maximum of 2230 km^2 of land was irrigated, 1100 km^2 of which was under flood recession irrigation and the remainder under gravity and pump irrigation. The potential irrigable area of Somalia is 5000 km^2 (FAO, 1995).

Although the basins provides the greatest freshwater resources in Somalia, it is characterized by hydrological water deficit and seasonal gap with low river flow (Gadain and Basnyat, 2007). Moreover, the local accessibility to water is restricted mainly due to political instability, deteriorated or lacking infrastructure as well as lacking means to deal with flood variability (Basnyat, 2007).

Water use in Shabelle basin during the last two decades was more of traditional with little scientific support thereby causing poor water use and management. The population of the basin, which continues to increase fast due to high growth rate resulting from natural birth and migration, is also heavily depleting the natural resources. According to UNDP (2005). The estimated annual growth rate was 2.7% per annum and migration to urban areas is expected to increase with annual rate of 0.88%.

The poor management of water resources, the increasing competing water demand for livelihood and lack of strong administration and coordination among sectors is expected to exasperate the water scarcity challenges of the basin (Gadain and Basnyat, 2007). This implies there is a need for proper water resources use and development. This requires empirical evidences on current and future water availability and demand in Shabelle basin. However, the study on this issue is scanty in the basin. This research aims to address this gap and provide sufficient information on water demand as well as the supply potential of the basin which are important for decision makers engaged in water related sector.

1.2 Problem Statement

Increased agricultural water demand in the Shabelle basin has resulted in increased surface water abstractions and is contributing to the imbalance between water demand and supply, during the low river (Basnyat and Gadain 2009). Growth in population, increased economic activities and improved standard of living has led to increased demand and competition for freshwater resources in Shabelle basin. In span of 17 years between 1988 and 2005 it was estimated that migration to urban areas has increased population by 15% with annual rate of 0.88%. Small scale farmers and pastoralist immigration to the basin are mainly from neighboring regions of Gedo, Bay and Bakool (UNDP, 2005).

Decrease in rainfall, increased agricultural and domestic water abstraction, poor water management aggravates the problem with more intensity during the recent time because of lack of proper water resources management plan. However, no effort has been made to assess the water supply and demand situation of the basin and identify the major challenges of water resource planning.

This study was initiated to assess the current and future surface water availability and demand situation in Shabelle basin, analyze its implication for enhancing water resource planning in the basin and lay foundation for the development of sustainable water use and management plan. Such study will contribute to the economic development and improvement of the living environment of Shabelle basin.

1.3 Objective of study

1.3.1General objective

This study intended to assess the current surface water availability and demand situation within Shabelle basin, and project the implication based on current and future scenario. It also tried to analyze how the basin could respond to major stresses of demand and supply in terms of water availability in the present and future.

1.3.2 Specific objectives

The specific objectives of the study were:

1. To assess current situation of river Shabelle in terms of water availability, demand and water resource planning.
2. To assess the impact of possible water demand on the water resources of Shabelle basin by 2040.

3. To identify the major bottlenecks in proper water resources planning and management.

1.4 Research questions

The study tries to address the following research questions:

1. What are the current situation of river Shabelle in terms of water availability, demand and water resource planning?
2. What will be the impact of possible water demand on the water resources of Shabelle basin by 2040?
3. What are the major bottlenecks in water resources planning and management of the basin?

1.5 Significance of the study

This research will lead to conflict avoidance with a better economic development and better plan in order to balance the projected amount of demand and supply. As highlighted in this study, WEAP modeling has an important role to play in evaluating the possible impacts of different development options and scenarios. Furthermore, the result from the analysis will be used in order to propose the alternative suitable technical and non-technical means in order to reduce water demand, particularly in Shabelle basin. The Scenarios has been conducted in this study as a useful contribution to greater understanding of what may happen in the basin, having implication to development.

1.6 Scope and limitation

This study was carried out in Shabelle catchment particularly in southern Somalia. This is covers the local uses of water resources to the domestic, livestock and agriculture to build future scenarios to enables the possible impact of water resource

In Somalia, there are still challenges regarding data and information management. However, one might argue, the obvious reason for this problem is the prolonged civil unrest in the country for the past 24 years, which led to disappearance of most water resource information. Since the government of Somalia has been collapsed, estimating domestic, agricultural water demand and use at catchment level for district/villages areas in southern Somalia is problematic owing to the lack of measured data. These information was not sufficient though on how much water is abstracted via the different sources.

However, the study also was limited in a data on various parameters in Shabelle catchment, stream flow for downstream and tributary data were not available, and this made it a bit hard to expressly ascertain the exact degree to which water resources in the sub-catchment were threatened.

CHAPTER 2: LITTEARTURE REVIEW

2.1 Water resource

2.1.1 Surface water availability in Shabelle river

In Webi Shabelle tropical areas for Ethiopia, the annual water yield of a basin is primarily dependent on the amount of annual rainfall the basin receives. The Wabi Shabelle basin receives relatively low mean annual rainfall of about 425 mm as compared to most of Ethiopian basins. The annual runoff coefficient is also very low (0.04) as compared to the Abbay basin (0.21). The basin water yield is only 0.53 $l/s/km^2$ while in the Abbay basin annual the yield is 8.63 $l/s/km^2$ (MoWR, 2005).

However the mean flow at Gode is 3387 Mm^3, which reduces to about 2769 Mm^3 at Burker indicating the loss of water between Gode and Burker. The arid catchment between Gode and Burkur (about 22 000 km^2), has no contribution to the Wabi Shabelle river. Ephemeral tributaries found in this zone originates from area with very low rainfall (150 – 300 mm annually), and do not join the Wabi Shabelle river in the form of surface flow, but spread in the vast alluvial plains (MoWR, 2005b).

The large flood plain, which stretches from Kelafo to Mustahil, at border Ethiopia-Somalia is about 600 km^2, and about 140 km^2 of these plains are flooded throughout the year and form a permanent swamp, estimated loss by evaporation alone is 560 Mm^3(MoWR, 2005b).

An annual loss of about 650 Mm^3 from Gode to Burkur due to evaporation and seepage over a vast flood plain. The MoWR Ethiopia estimated that on average about 788 Mm^3 of water is lost annually along 230 km long stretch between Gode and Burkur (MoWR, 2005b). Downstream of the Somalia-Ethiopia border, discharges reduce progressively in Shabelle rivers due to the lack of any significant flow contribution inside Somalia and because of natural losses evaporation and infiltration (FAO, 1969).

The largest local catchment tributaries inside Somalia join Shabelle river on the lift bank between Giglei and Elo Geibo namely the uebi lehelei, Webi Boho and webi Gaantole at Buloberde. These Streams have the typical characteristics of hills torrents in arid areas, that's infrequent heavy flood flows of short duration. 1968 the major streams together with smaller streams in this contributed less than 10% of total annual flow recorded at Buloberde (FAO, 1969). In the middle Shabelle the length of river doesn't receive local runoff from surface water but inflow from groundwater occur in the lower part of the reach during the period of high flows considerable flood spillage.

However between Mahdaweyne and Jowhar the length of river has suffering from flood over spill and bank damage due narrow of river, the maximum flood flow 160 m^3/s just above the Jowhar is reduced to 106 m^3/s by the time the flow reach Balad. A flood flow less than 170 m^3/s at Buloberde will have its major spillage losses occurring between Jowhar and Blacad it is properly that considerable recharge of the groundwater aquifer extending towards the coast takes place between Hawadle and Blacad the river Length is 53Km.

In the downstream the river at Afgoi seepage occur in the bank of the river and supports the major irrigation schemes along the river, however the flow has extremely reduced when its reach the most suitable irrigated land.

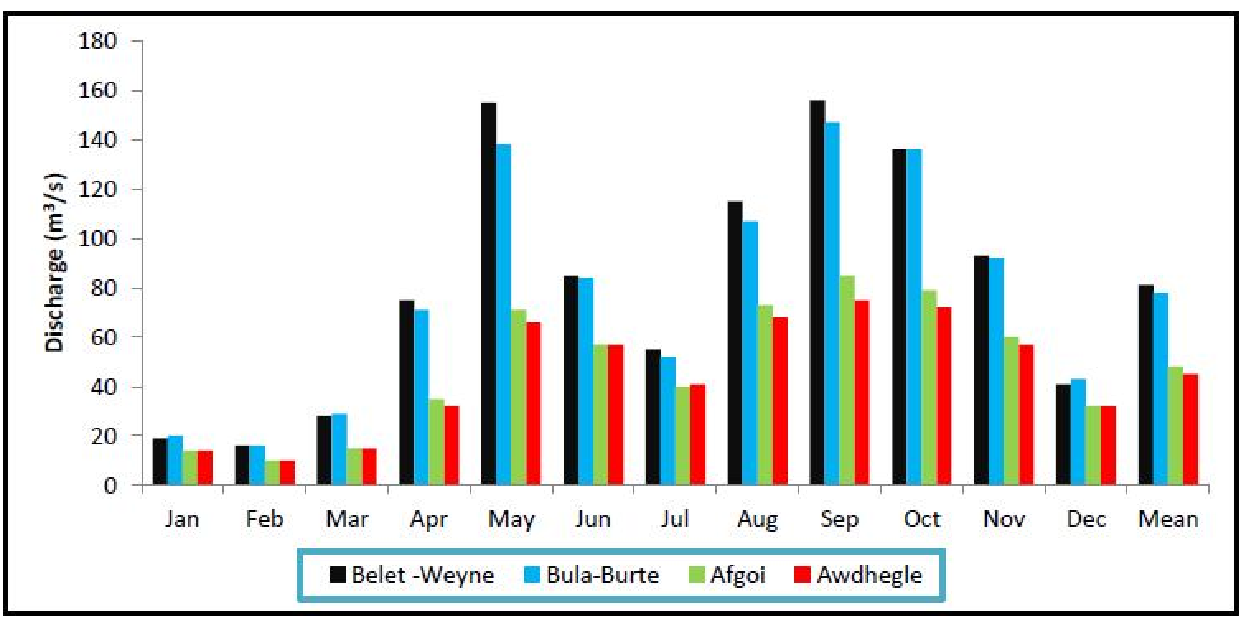


Figure 2.1:Average Monthly discharge in Shabelle rive for selected station (1963 to 1990)

2.1.2 Agriculture water demand in southern Somalia

Somalia is a water-scarce region where water is distributed unevenly in time and space. Crop production is largely limited to South Somalia's alluvial plains and inter-riverine area of the Bay region where 90% of production was obtained (Basnyat, 2007). The exploitation of natural resources for agricultural production is limited due to insecurity, displacement of communities, degraded irrigation infrastructure and lack of technical support, inputs, marketing and market access (SWALIM, 2011).

However the basin has been facing an enormous challenge on how to allocate, use and protect in this limited water resource. Food Security Analysis Unit (FSAU) estimates that after the civil war that lasted through most of the 1990’s, the annual cereal production was about 300,000 tones covering 50% of the annual requirements (590,000 Tonnes) and before the break of the civil war in 1990 it was 62% of the average production (480,000 tonnes).

The importance of irrigation in the Shabelle basin has been recognized many generations back according to the pre-war irrigation system was anchored by commercial estates, serving both domestic markets (rice, sugar) and international markets (bananas, citrus) and smallholder farmers who cultivated cereal crops.

Till around 1990, Somalia produced about 80% of its own cereal requirement and exported bananas and citrus to Europe, mainly to Italy, (SWALIM, 2011). Commercial fruit production, however suffered after the collapse of the central Government in 1991 and was further damaged by the El Nino floods in 1997 and the loss of the European preferential banana market in 2001 (SWALIM, 2011).

2.1.3 Access to irrigation water

The occurrence of accessibility in water is precondition, but infrastructure and management practices are necessary to provide ground or surface water to the specific places and needs.
However the accessibility is regulated by local customs, holding that the right to use water for irrigation only depends on access to land along the river (Muthusi, 2007). Pumps are regarded as legitimate ways to increase the amounts of abstraction, hence the use is limited merely by technical restrictions. No official approval or registration (licensing) and respective extraction control.

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, 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 (Gadain and Muthusi, 2007).

Twice per year farmers usually have to desist a section of the main canal as well as their distributaries, non-compliance being fined, fights over water are usually settled by elders (Gadain and Muthusi, 2007).

2.1.4 Types of Irrigation in southern Somalia

Irrigation along the Shabelle is complex and comprises of the following systems:

Controlled irrigation systems: served by large primary canals (greater than 2.5 m wide approximately) controlled by barrages or a weir from the rivers. Such systems can or should be able to provide for irrigation throughout the year, or if the land is further downstream at a minimum during the Gu and Deyr rain seasons. Such canals appear to require heavy equipment for their maintenance. There are also other small primary canals (less than 2.5 m wide approximately) controlled by barrages or weirs on the river. Such canals can be maintained using manual labor without the need for heavy machinery.

Uncontrolled (informal) irrigation systems: served by canals (direct intake canals) directly from the river with no, or limited control by barrages and weirs, thus water is only available in these canals at periods of high river flow. Essentially they serve as supplementary irrigation of crops, which are largely grown under rain fed conditions.

Water availability will normally be greater (over a longer period) on the Gu season than in the Deyr season. Many of these canals are short and could easily be maintained by the use of hand labor.

Pumped irrigation systems: In both rivers, the Juba and the Shabelle, there are large schemes where the water is supplied by large pumps and then distributed through a canal network. Elsewhere, individual farmers and farmer-groups use (or used) small pumps to access water directly from the river or canals. However such schemes appear to have particularly been affected by the security situation, with the looting of pumps.

2.2 Municipal water use and demand

The total water use by the domestic and municipal sectors in the Shabelle basin during last decades was estimated to be 533.3 Mm^3/y (Basnyat, 2007). Including the agricultural which is the most consumes, these amount of approximately 32.3 Mm^3/y was used in the municipal water use includes usage for domestic, public, livestock, and commercial needs. The average water supply per capita is estimated with 20 liter per day (l/d) and 50 l/d for the rural and the urban population respectively are assumed Muthusi et al. (2007) and this figure is not the real average of consumption because the losses of water are not considered.

The total water consumption for domestic purposes in the Shabelle basin has not been estimated these may include loss rates for the various districts and the above mentioned supply rate. These data may be important to know the overall loss or unaccounted for water rate ,the loss rate in un piped, unaccounted for water rate in piped areas includes physical losses at the source, in the main transmission system and distribution network, unregistered connections and meter losses.

However domestic water consumption rates were grossly estimated varies with an average of about 50 l/c/d (SWALIM, 2007), these estimated domestic water consumption rates are substantially lower than the WHO minimum value of 100 l/c/d.

2.2.1 Groundwater abstraction and distribution

Estimating domestic water demand and use at catchment level for rural areas in southern Somalia is problematic owing to the lack of measured data. There is no information though on how much water is abstracted via the different sources, not even for single abstraction points (Basnyat, 2007). SWALIM Experts estimated that rural water demand in Somalia, to be the range of 20 to 25 liters per capita per day concerning the access to groundwater, the different types of access, their implications and frequencies are listed in Table 1.0 below and Figure 1.0.

Illustrates that the number of source types utilized by the different user groups in Southern Central Somalia (Mugo and Gadain, 2009). While shallow wells are mainly utilized in the rural areas, the urban population usually abstracts water from shallow wells and boreholes. In urban areas springs are barely used while the rural populations rely on them more frequently to meet their water needs. Dug wells and boreholes are experience a much higher use in the rural than in the dams, unfortunately the study by Muthusi, Mugo and Gadain 2009 did not specify the type of dams registered.

Table 2.1:Types of Commercial domestic water delivery

Type	Suitability
Piped Water Supply	Urban Context, Mostly Private Operation
Public Standpoints/Wells	Urban Poor and Rural Context; Low cost water provision; small amounts; requires quality upgrade at delivery; large numbers of service providers reduce the dependence on one source
Donkey Cart Delivery	Refill water storage of households that are not connected to the piped system
Water Tankers	Refill water storage of households that are not connected to the piped system

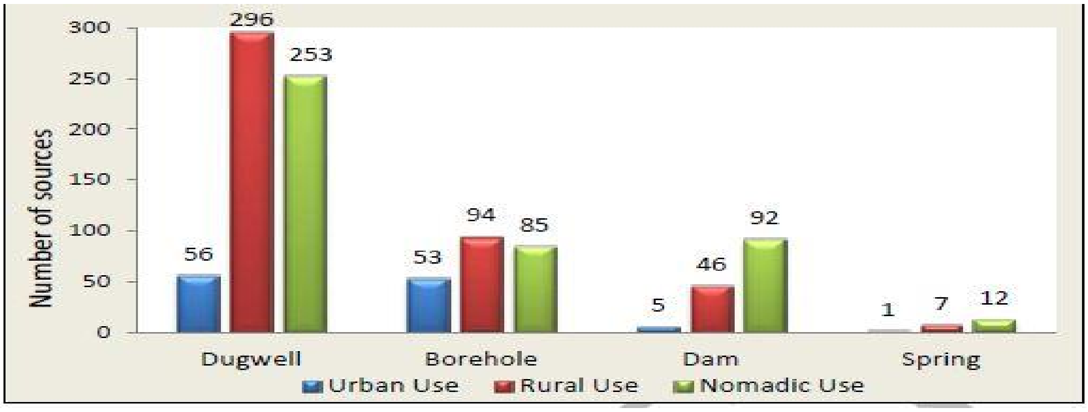


Figure 2.2:Number of water source and types for different users groups (Muthusi,Mugo And Gadian 2009)

2.2.2Urban private wells

Urban private wells show better maintenance than communal wells and water distribution is determined by the local supply and demand situation, often run by public private partnerships (PPPs) and regulated via market mechanisms (Basnyat, 2007). The coverage of piped water supply in urban areas is rather low so donkey carts and trucks are common means of supply (EC, 2002 and Basnyat, 2007).

Due to losses in the network and illegal connections, the unaccounted for water (UFW) is estimated at an average of about 50%, indicating that half of the piped water is 'lost and remains unbilled' for the service provider (EC, 2002).

Furthermore, the billing efficiency of many suppliers is low and due to customs and traditional hierarchies many larger consumers e.g. the public administration but also mighty private customers are supplied with water free of charge (EC, 2002).

Hence also in the urban context, traditional norms and power positions determine how far and at what cost water demands are being met. The price per cubic meter for piped water in 2002 was about 0.61 US$ compared to 0.78 US$ for water sold at kiosk standpoints and an average of 2.1 US$ per cubic meter supplied by water trucks (EC, 2002).

2.2.3 Rural water source

In rural area like wells and boreholes are typically administered by community management committees, led by elders or the village chiefs (Basnyat, 2007). Traditional norms and male authorities hence decide on the validity of the water demands within their community. They determine the water distribution as well as the procedures of operation and maintenance (Basnyat, 2007).

The decisions of the committee are made on behalf of the community, usually without their consultation for the community the water is typically free of charge. Revenues are collected from external herders by an operator, generally there are no records on the amounts of water distributed nor on the revenues collected.

The revenues are usually envisaged to cover operational costs and infrastructure-reinvestments (Basnyat, 2007). But the effectiveness and efficiency of operation and maintenance strongly depend on the particular well operator. While men are usually in charge of commercial wells, women frequently administer wells serving domestic purposes. Commercial wells are usually in a better state since water sales are dependent on outsiders buying water to satisfy livestock demands.

Although trained women were found to perform better in management and maintenance of community water sources than men, they conventionally do not participate in decision making regarding the management of water sources.

For outsiders or for users of private wells water prices may limit the access and regulate the demand, where salinity and bitterness of water are high fresh tasting water is sold at high prices, this was for instance the case in the Burhakaba and Dinsor district (Bay region) where 200 liters were sold for 1 -2.5 USD in 2007, which was five to fifteen times higher than average water prices (Basnyat, 2007).

2.3 Environmental water demand

Apart from the domestic, livestock and agricultural water use, other important uses of water include industry and the environment, there is no data available on these uses. One vital consideration for the use of the river flows in Shabelle is the environmental water requirements that need to be maintained in the river for aquatic as well as other environmental uses. The swamps that the Shabelle river feeds would have an important ecological value in terms of sustaining the ecosystem as well as recharging the groundwater aquifers of the area.

The many small fresh water lenses and shallow wells along the dunes and eastern coastal areas are likely to be affected if there any changes in the flows to the swamps any future study or investigation should have to consider these water requirements. The assessment of environmental water requirements is done by a range of methods based on simple statistical hydrological indices, one such methods is flow duration curve, the flow duration relationship shows the frequency or percentage of time that stream discharge falls within various ranges (Wurbs et al, 2002).

Naturalized flows or present day historical flow data over specific durations are usually used in the flow duration analysis. In some cases the 90 % flow (Q90) may be set as the minimum environmental flow, The 90 % flow is the flow that is equaled or exceeded 90 percent of the time.

2.4 Water resource management

Water resources planning and management was generally an exercise based on engineering considerations in the past. Nowadays, it increasingly occurs as a part of complex, multi-disciplinary analysis that brings together a wide range of individuals and organizations with different interests, technical skills, and options (Yates et al., 2005). Successful planning and management of water resources requires application of effective integrated water resources management (IWRM) models that can solve the encountering complex problems in these multi disciplinary investigations (Loucks, 1995; Laín, 2008).

Water resource planning and management processes aided IWRM models have become more common, however generic tools that can be applied to different basin settings are frequently difficult to use because of the complex operating rules that govern individual water resource systems (Watkins and McKinney, 1995). IWRM models which can incorporate and operate hydrology and management processes at the same time are needed to help planners under different reality cases and management options (Yates et al., 2005). These IWRM models must be effective, useful, easy to use and adaptive to planners' priorities.

The best approach for IWRM models is to develop a straightforward and flexible tool to assist rather than to substitute the skilled water professionals the users of the model (SEI, 2011). WEAP is a new generation of water planning and management software, and the powerful capability of today's personal computers can easily use it everywhere to access to the appropriate tools.

2.5 CROPWAT Software and Applications

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. It is a practical tool that is used to carry out standard calculations for reference evapotranspiration, crop water requirements and irrigation requirements (Berejena et al, 2007). CROPWAT uses the recommended FAO Penman-Monteith method for estimating crop evapotranspiration.

This model has been used in several studies to determine crop water requirements, Mtshali (2001) applied CROPWAT to determine crop water requirement for sugarcane in Swaziland and acknowledged that estimates from the model were more realistic than the estimates derived from pan evaporation and pan factor coefficients. In Somalia CROPWAT was applied to assess the potential and actual crop water use of selected cropping patterns in the two districts of Jowhar and Jilib Along Juba-Shabelle (Besneyat, 2007).

Determination of crop water requirements is important to establish whether the source of water can satisfy the demand (Makadho et al, 1989). These authors established from the crop water requirements (CWR) areas that can be irrigated from a given amount of water following a given cropping programme.

In similar study conducted in Zambia on promoting water use efficiency revealed that allocating water based on crop water requirement reduces water demand as opposed to allocating water based on a fixed quantity. In a related study on equitable water allocation (Mtshali, 2001) concluded that using crop water requirement in water allocation gives room to accommodate new water right applicants.

2.6 WEAP model Software and application

WEAP model was created in 1988 as a flexible IWRM tool for the current water supply and demand system evaluation and future scenario exploration (WEAP, 2014). It has a long history of development and use in the water-planning field. The first application of WEAP was in 1989 to study on the water development strategies and water supply and demand analysis for the Aral Sea region in 1989 with the sponsorship of SEI (Raskin et al., 1992). The version of WEAP at that time had several limitations, such as an allocation scheme, demand sites priorities and water allocations (Raskin et al., 1992).

Because of these deficiencies, WEAP introduced major advances, including a modern Graphic user interface and a robust solution algorithm to solve the water allocation problem. Moreover, WEAP integrated hydrologic sub modules such as a conceptual rainfall-runoff model, an alluvial groundwater model, and a water quality model (Yates et al., 2005). WEAP software has been supported to water planners from global organization and institutions, especially, freely transferred to governmental and academic users from developing countries, and WEAP has been applied in many countries and river basins over two decades (WEAP, 2014).

Johnson, W. K. 1994 applied WEAP for accounting of water supply and demand in the upper Chattahoochee River Basin of Georgia, to illustrate the capability of WEAP, to provide a document for WEAP users how the program is applied in a multiple use river and reservoir. (Purkey, Moench & Axelrad 1998) used WEAP in the groundwater banking feasibility study in California by analyzing hydrology, legal & institution, operation and economics, (Strzepek et al. 1999) introduced new methods of linking IWRM models (WATBAL for water supply, CERES, SOYGRO, CROPWAT for crop and irrigation model ling, and WEAP for planning and water demand forecasting) with climate change scenarios for the study of future water availability in the U.S. Cornbelt's agriculture.

Water demand management scenarios (saving water by individual users with three options 10%, 20%, and 30%) for diverse climate situations (dry years to normal years) at the Steelpoort Sub basin of the Olifants River in South Africa was tested by using the WEAP model (Lévite, Sally, & Cour, 2003). Even though there are some limitations of the WEAP model like as a water year method, the user friendly model and its interfaces make easy for discussions and dialogue on water management among decision makers and local stakeholders, and for the promotion of public awareness and understanding of key issues and concerns (Lévite, Sally, & Cour, 2003).

The application of WEAP models to major agricultural regions in Argentina, Brazil, China, Hungary, Romania, and the US, was analyzed by simulating future scenarios about climate change, agricultural yield, population, technology, and economic growth (Rosenzweig et al., 2004).

Climate change projection using global climate models (GCM) simulations indicates eventually larger changes in the 2050s and beyond, but the water for the agricultures is sufficient in most of the water rich areas (Rosenzweig et al., 2004). Northeastern China shows the most stressed in water availability for agriculture and ecosystem services both in the current state and in the climate change projections (Rosenzweig et al., 2004).

The study about water evaluation and the planning system in Kitui-Kenya clearly demonstrated that WEAP is a powerful framework in the evaluating of current and future options of water resources, and evaluation can be performed within a few minutes by adding more accurate data to increase the accuracy of the analysis and validation of results (Van Loon & Droogers, 2006).

To help decision makers and stakeholders, Integrated Decision Support System (DSS) for pollution control in the upper Litani Basin of Lebanon was developed by using WEAP, and this DSS was effectively used in projection of three future scenarios for the water quality conditions in the basin (Assaf & Saadeh, 2006). As population growth, urbanization, and current policies and water management practices give stresses on water resources and urban infrastructure, urban water management tools are becoming essential for urban water planners to see the overview of their water system (O'Connor, Rodrigo, & Cannan, 2010).

Urban water systems can be improved by reducing water demands, increasing water recycling and reuse, creating alternative water supply sources from storm water/rain water, providing water quality to end user needs, and implementing multipurpose and multi-benefit infrastructure to achieve environmental goals (O'Connor, Rodrigo, & Cannan, 2010).

WEAP was also applied as an urban water management tool in the study of water resources and city sustainable development of Heng Shui City in China (Ojekunle, 2006). This study pointed out that the availability and reliability of data are very important and must be analyzed carefully with good judgment, and the adoption of water demand management gives opportunities during normal hydrological years but not in dry years.

This study explored and evaluated the future scenarios concerning about high population growth, high technology, demand management, using the water year method, demand disaggregation, and supply preferences, (O'Connor, Rodrigo, & Cannan 2010) studied the total water management for urban water resources in the City of Los Angeles by using real data and WEAP model, to assist the planners and decision-makers in the development of management techniques to improve urban systems.

This WEAP model simulated water supply reliability, total life cycle costs, water quality, and a number of other environmental indicators by using strategies such as increasing water conservation, expanding water recycling and reuse, grey water/storm water recharge, rainwater harvesting, integrating water supply (O'Connor, Rodrigo, & Cannan, 2010).

This study could provide opportunities for achieving multi-benefits urban system goals that would not exist in single purpose, traditional planning. According to the WEAP literature provided in the official website, WEAP is applied effectively in multi-criteria in IWRM field all over the world, including water supply and demand management issue in river basin to achieve multi-benefit goals.

2.6.1 Scenario analysis with WEAP model

WEAP model as described above allows for the analysis of various global change and water management scenarios. Scenarios are self-consistent story-lines of how a future system might evolve over time. These can address a broad range of "what if" questions like what if population increases? what if ecosystem requirements are tightened.

This allows us to evaluate the implications of different internal and external drivers of change, and how the resulting changes may be mitigated by policy and/or technical interventions. For example, WEAP can be used to evaluate the water supply and demand impacts of a range of future changes in demography, land use, and climate. The result of these analyses can be used to guide the development of adaptation portfolios, which are combinations of management and/or infrastructural changes that enhance the water productivity of the system.

In many basins around the world increasing water demand is leading to the overexploitation of limited water resources and more frequent and more pronounced periods of extreme water scarcity (Falkenmark and Molden, 2008,). Modeling can be used to determine possible implications of water demands and provide a useful contribution to how the water resources of the Shabelle basin in Somalia might be best utilized in the future.

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Shabelle river rises in the high plateau of eastern Ethiopia and has total drainage basin area of about 300km^2 two third of which are within Ethiopia. The total length of the river is over 2,526 km with approximately 1,290 km within Ethiopia.

In normal years, Shabelle river derives over 90% of its flow from Ethiopian plateau. The catchment area of Shabelle in Ethiopia is about 200 km^2 including the extreme Fafan tributary which may not contribute flow in some years See Figure 3.1 (Elmi, 2002).

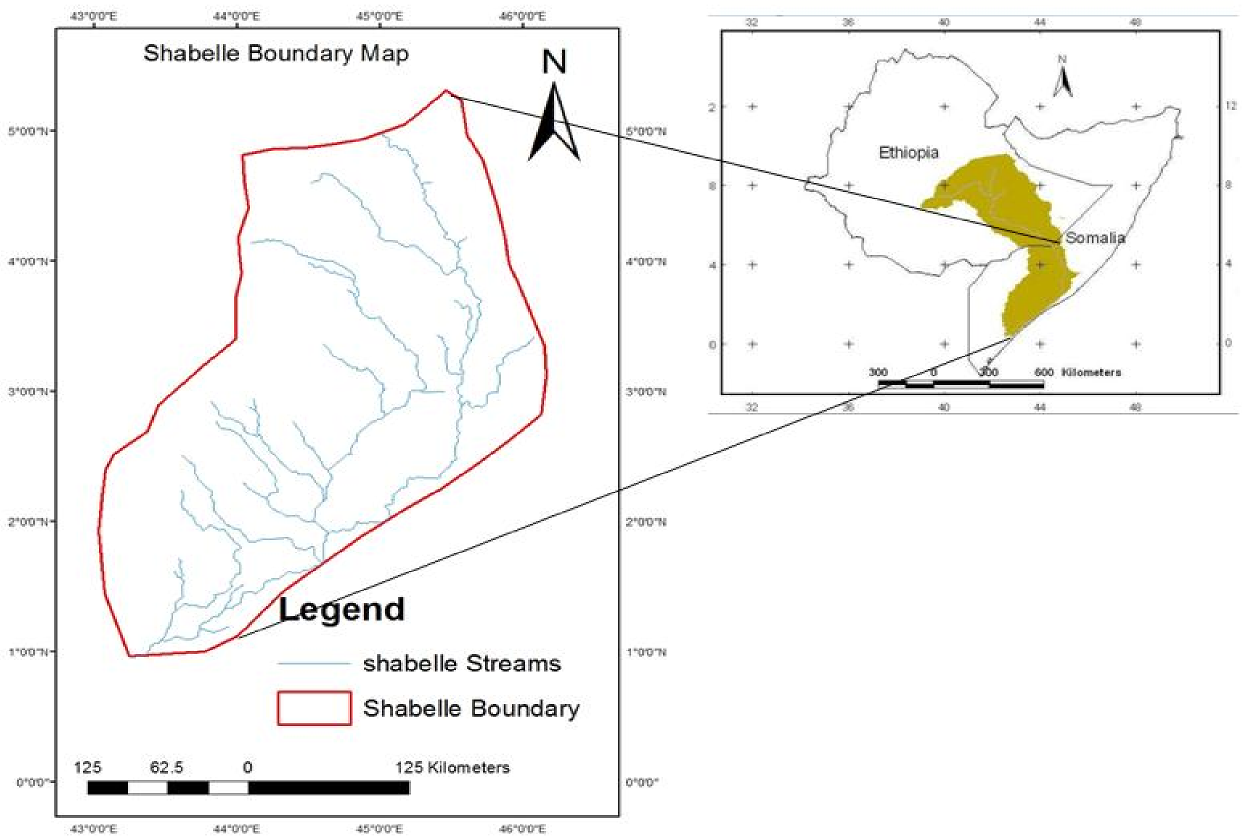


Figure 3.1: Geographical location in Shabelle river (source: MWR)

The Shabelle river flows south-eastwards to the Somalia border at the border town of Ferfer. There it turns south to Balcad near Mogadishu, where it turns southwest and continues roughly parallel to the coast from which it is separated by a range of sand dunes (Elmi, 2002). The river does not normally enter the Indian Ocean, but into a depression area where it is finally lost in the sand in southern Somalia feeding an ecologically sensitive area and recharging areas of groundwater aquifers. Only with exceptionally heavy rains does the Shabelle river break through to join of Juba river and thus succeed in reaching the Indian ocean (Elmi,2002). However, it could be safely said that the swamps sustain the freshwater available in the aquifers which meets the water needs of the coastal towns and settlements in the south.

3.1.2 Physical Characteristics

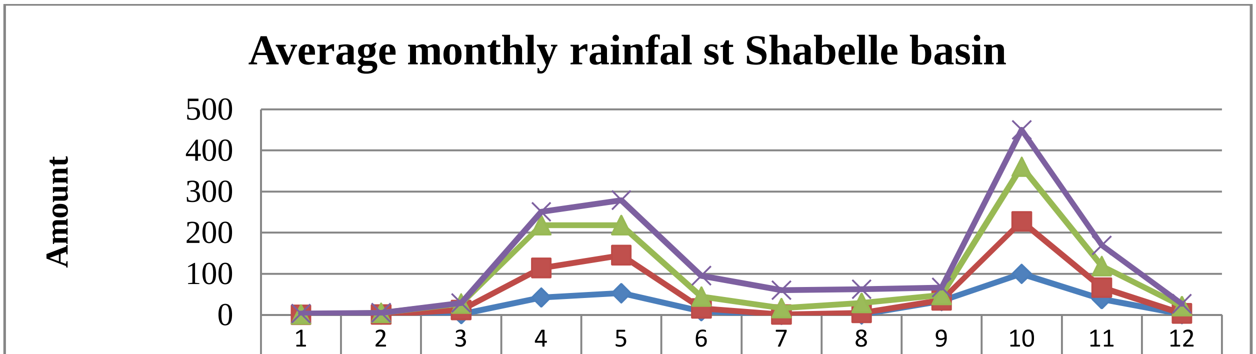
3.1.2.1Climate

The climate of the Shabelle river basins is mainly determined by the northeasterly and southeasterly winds of the Inter-tropical convergence zone (ITCZ) over the Ethiopian highlands, resulting in tropical arid to dry and sub-humid conditions (Oduori, et *al* 2007b). The annual movement of the ITCZ gives rise to four different seasons which are Jilaal, Gu, Hagaa and Deyr, the Gu and the Deyr are the rainy seasons in Somalia, whereas Hagaa and Jilaal mark the dry seasons in the country.

The Gu season runs from April to June and is with about 60 % of the annual precipitation in the major rainy season for the entire basin area. The Deyr season lasts from October to November and amounts for 20 – 30 % of the annual precipitation (Oduori, et al 2007b). Jilaal is the first dry season of the year lasting from December to March causing very hot and dry conditions. Hagaa, the second dry season runs from July to September causing littoral showers at the coast side, but dry and cool conditions in the hinterland.

Rainfall

Rainfall in the Shabelle river basin varies considerably from the headwaters to the terminal sections. The upper catchments of Shabelle river basin within the Ethiopian highlands receive rains in the range of 1300-1800 mm/year (Guleid et al, 2007). The middle catchment areas around the Somalia and Ethiopia border being in the leeward side of the highlands, receives less rain (e.g. 330 mm/year in Beladweyne). There is a significant increase in annual rainfall moving towards the coast (e.g. 500-700 mm/year within the lower Shabelle), (Figure 3.2). Orographic and coastal influences lead to a high variation in rainfall in the region. However, the mean annual rainfall for the Shabelle basins is between 300 mm/year and 500 mm/year. As the rainfall in Shabelle catchments varies significantly from year to year, it causes severe droughts every seven to ten years (FAO, 2005).



	1	2	3	4	5	6	7	8	9	10	11	12
Afgoi	2.4	0	1.37	32.78	60.76	50.93	43.42	33.4	18.22	89.62	50.4	5.9
Jowhar	0.8	4.4	15.8	104.2	73.35	29.05	15.45	24.15	12.85	133.3	52.55	17.65
BuloBerde	0	0	10.23	71.7	92.2	6.55	0.85	4.15	2.05	127.1	27.96	1.72
Beledweyne	0	0.5	1.45	41.95	52.6	8.65	0	0.6	33.3	99.65	38.05	1.55

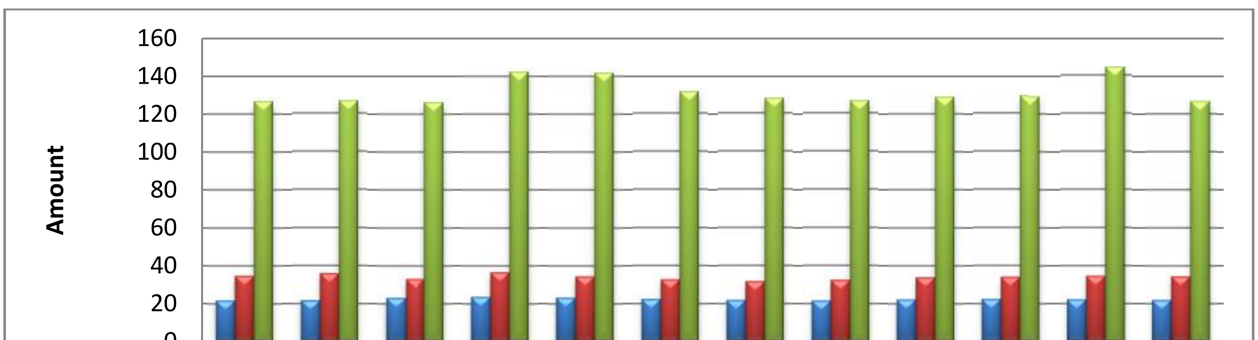
Figure 3.2: Average monthly rainfall in river Shabelle

Temperature and potential evapotranspiration

Air temperatures are influenced by altitude and by the strength of seasonal winds. In the first dry season (Hagaa) days are often cool and cloudy throughout Somalia, with light showers in areas close to the coast, in the second dry season (Jilaal) days are hot and dry.

The hottest period is in March and April, temperatures vary with the seasons, with the mean annual temperature ranging from 23°-30°C, a maximum temperature of 41°C in March and a minimum temperature of 24°C in July (Oduori, et al 2007b). In Somalia the relative humidity is high in the areas near the major rivers ranging from about 70-80%, away from these rivers the air becomes much drier (Oduori, et al 2007b). Relative humidity is also higher in the coastal areas, where it usually exceeds 87% (Oduori, et al 2007b). The weather is hot and calm between the monsoons (part or whole of April and part or whole of September). In the Jilaal periods, prevailing winds are strong and blow in heavy dust storms from the Arabian Peninsula.

To some degree, weaker winds occur during the intermonsoonal periods of April/May and October/November and wind speed average varies from 2 m/s to 6 m/s (Basnyat, 2007). Potential evapotranspiration is consistently high throughout the study area. The highest potential evapotranspiration occurs in the northern areas of Hiraan regions, where it exceeds 2000 mm per year while the rest of the area is between 1500 to 2000 mm per year. The annual rainfall is usually far below potential evapotranspiration and there is a significant moisture deficit at most stations for most of the year (Oduori, et al 2007b).



	1	2	3	4	5	6	7	8	9	10	11	12
Min Temp	21.8	21.8	23.07	23.57	23.25	22.47	21.9	21.55	22.22	22.37	22.15	21.95
Max Temp	34.75	36	33.05	36.57	34.4	32.7	31.77	32.45	33.9	34.02	34.5	34.42
PET	126.7	126.6	126.3	142.3	141.9	131.3	127.8	126.4	129	129.1	144.3	126.6

Figure 3.3: Temperature and potential evepotranspiartion

3.1.2.2 Geology

The study area is characterized by the outcropping of the metamorphic basement complex, made up of migmatites and granites. Sedimentary rocks such as limestone, sandstones and gypsiferous are present and an extensive, wide system of coastal sand dunes basaltic flows are present in the northwestern part of the study area. From a tectonic point of view, the study area is characterized by a fault system lying parallel to the coast in the alluvial part of the Area of Interest (AOI), and by a system of northwest-southeast oriented faults in the metamorphic basement complex. Some late tertiary fluvio-lagunal deposits occur on the part of the southern Shabelle, consisting of clay, sandy clay, sand, silt and gravel. Recent fluvial deposits are common alongside the Shabelle, consisting of sand, gravel, clay and sandy clay. A wide coastal dune system occurs along the coast (Alim, M. S, 2007).

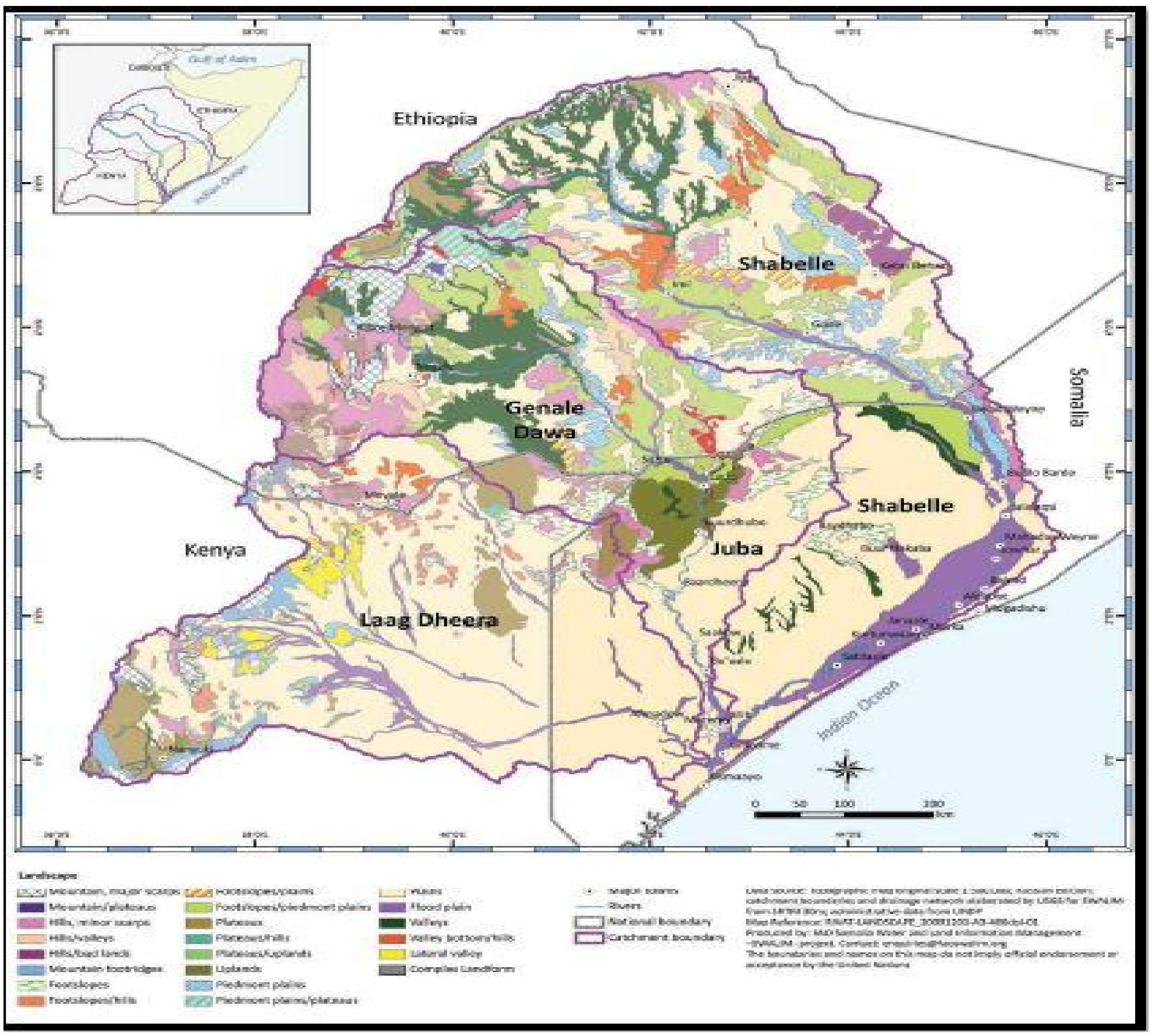


Figure 3.4: Lithology in Shabelle basin. Source; (SWALIM, 2010).

3.1.2.3 Soil

The study area is dominated by the presence of the distal portion of the main perennial rivers of the Shabelle river, Because of the predominance of alluvium, many soils comprise layers of deposited materials because of the semi-arid climate Figure (3.5), have been little-affected by normal soil-forming processes. Despite their variability most soils share the characteristics of heavy texture and low permeability with a tendency to poor drainage, (Carbone & Accordi, 2000).

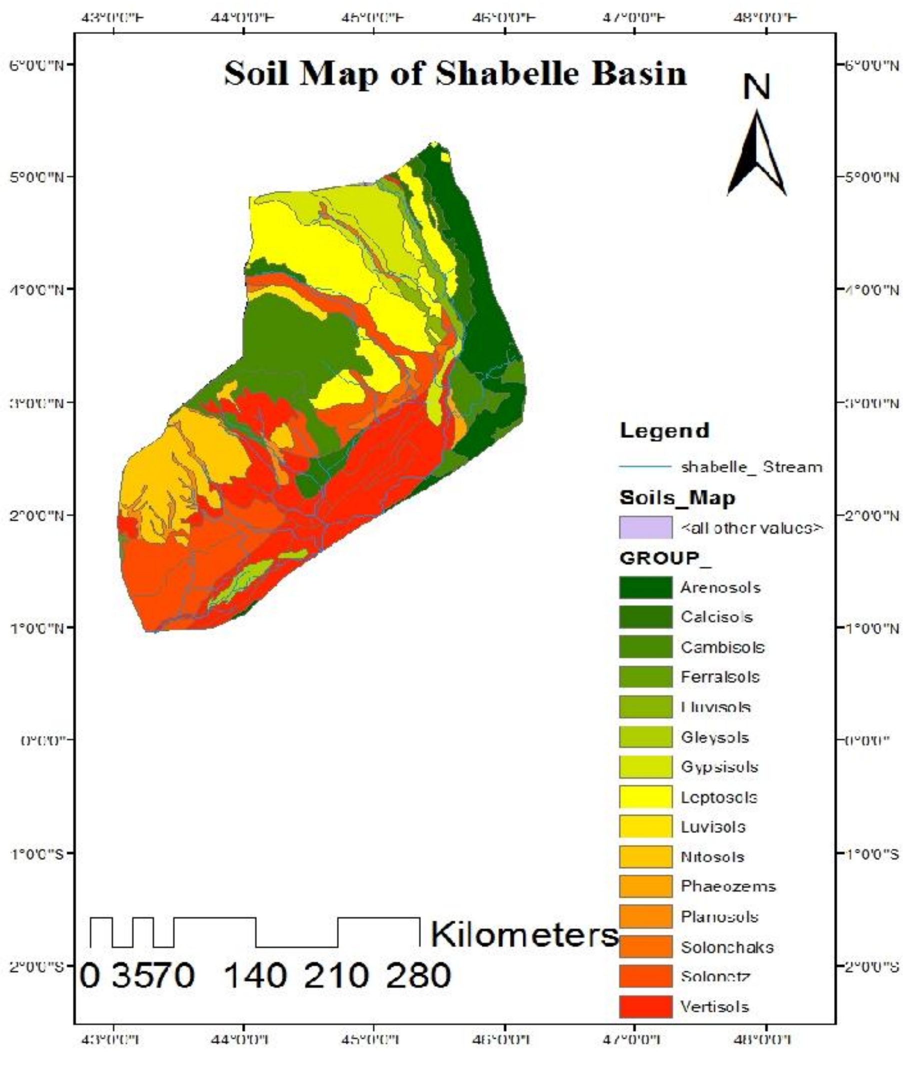


Figure 3.5**:** Soil map of river Shabelle

3.1.2.4 Topography of river Shabelle

On the upper catchment which the Shabelle river rises on the eastern flanks of the eastern Ethiopian plateau this river basin has a lowest elevation of 184 m, and a highest elevation of 4182 m. About 47% of the basin is below 500m, about 41% is between 500 to 1,500m, 12% is between 1,500 to 3,000m and less than 1% is above 3,000m, (Elmi 2002).

Within Somalia, the catchment in the highest elevation is 800m, mainly in upper Shabelle (Hiiran Regional see figure, 3.6) and the lowest elevation -4 below the seas level, normally the catchment has same characteristic

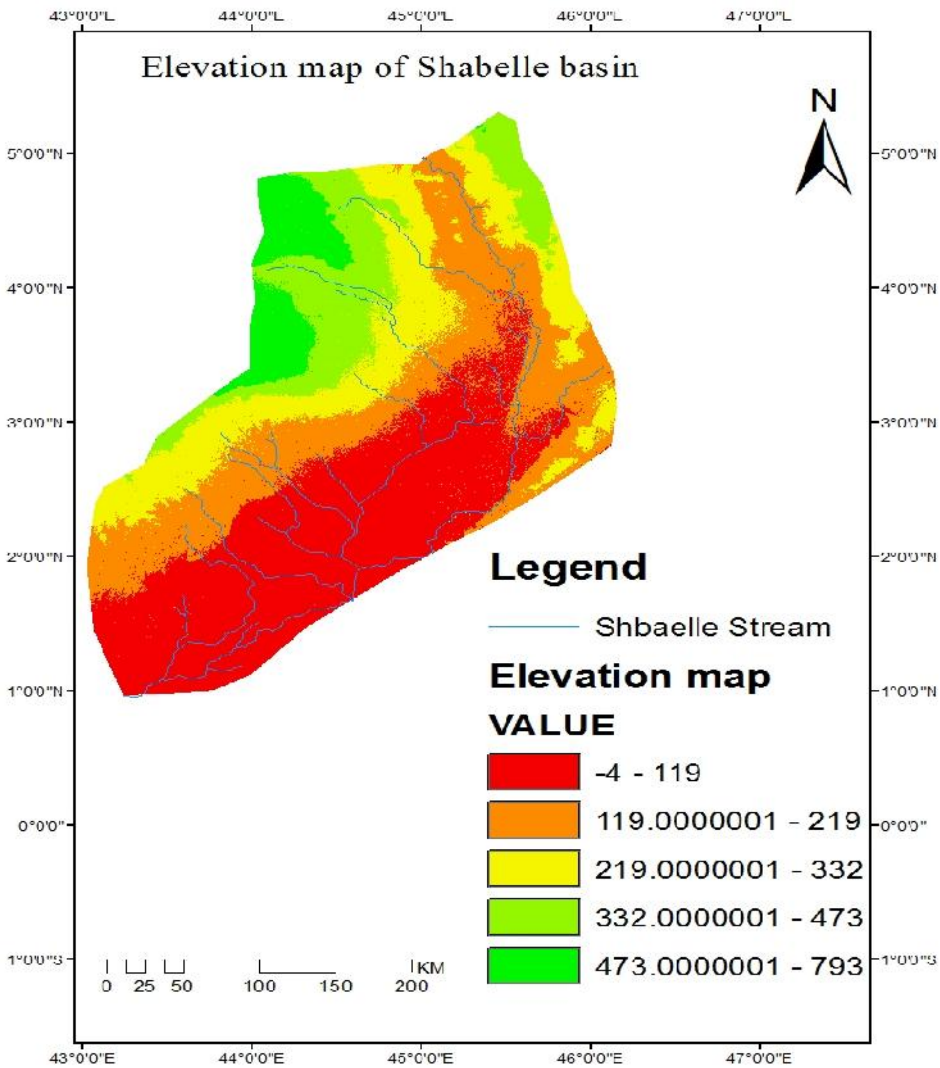


Figure 3.6: Topography map in Shabelle river

3.1.2.5 Land use and land cover

Land use and land cover in the study area consists mainly of natural vegetation. Other cover types include crop fields (both rain fed and irrigated), urban and associated areas (Settlement/Towns and Airport), Dunes and Bare lands and Natural water bodies. The natural vegetation consists of riparian forest, bush lands and grasslands. Woody and herbaceous species include Acacia bussei, A. seyal, A. nilotica, A. tortilis, A. senegal, Chrysopogon auchieri var. quinqueplumis, Suaeda fruticosa and Salsola foetida, (GTZ, 1990).

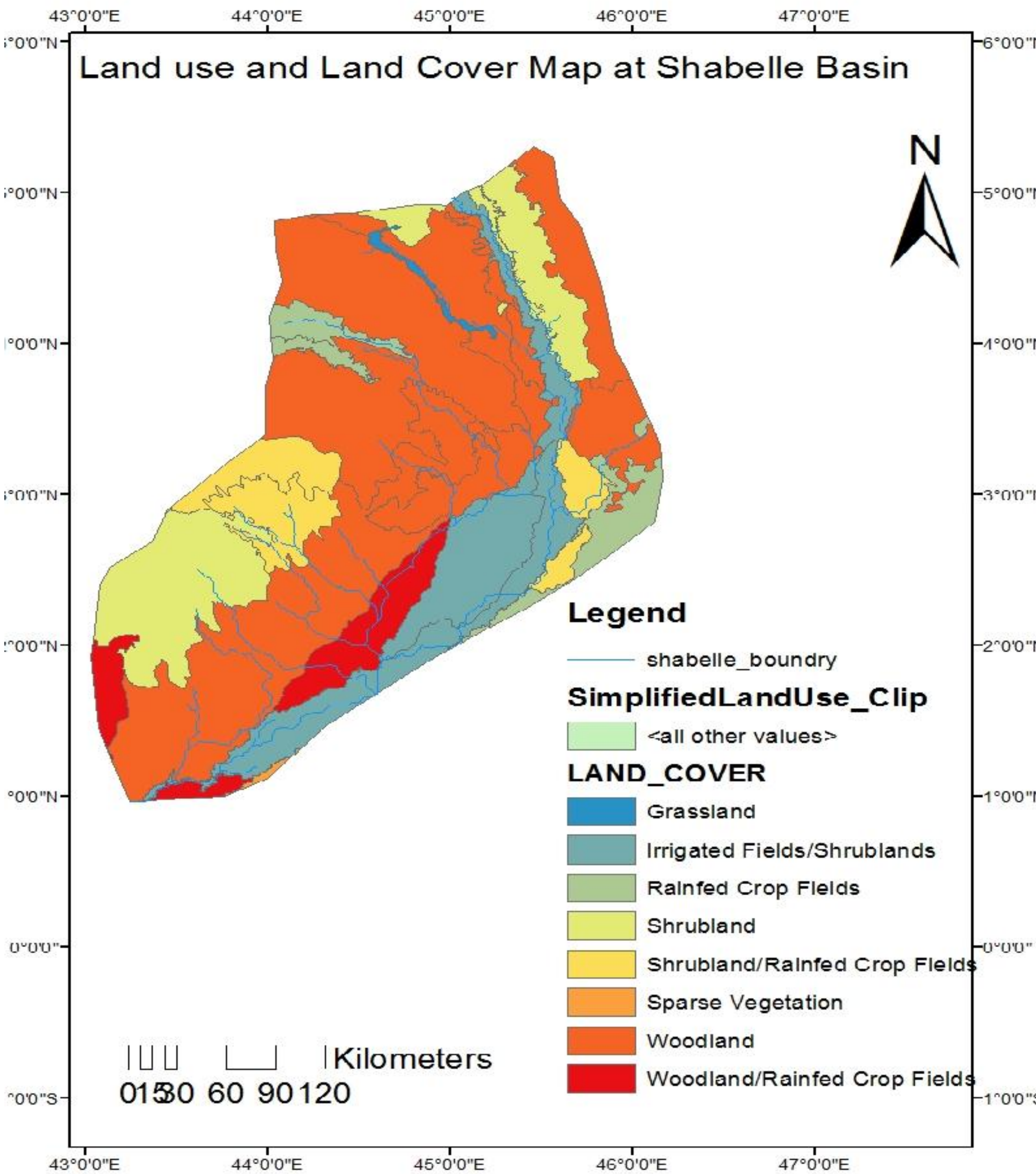


Figure 3.7: Land use and land cover at Shabelle river

Land under controlled irrigation for small-scale irrigation, crops grown include maize, sesame, fruit trees and vegetables, while large scale plantations include sugarcane, bananas and fruit trees such as guavas, lemons, mangos, papaya, etc. This land use class includes agriculture entirely dependent on rainfall. Crop growing under this category of land use is done twice a year, in the Gu and Deyr seasons. Crops include sorghum, millet, maize, groundnuts, cowpeas, mung beans, cassava and other minor crops.

Rangelands in the Shabelle catchments are used as grazing areas by pastoralists, mostly by goat, sheep, cattle and camels. Livestock ownership is private but grazing lands are communal, making it very difficult to regulate range use. Rangelands are used for transhumance strategies by herders (Shaie, 1977). Land cover associated with this land use includes forest, bush lands and grasslands (GTZ 1990).

Farmers in these river valleys are settled, and practice animal husbandry in conjunction with crop production. They tend to keep lactating cattle, a few sheep and goats near their homes, while non-lactating animals are herded further away in a manner similar to the herding of nomadic stock. However Rain-fed and irrigation-dependent farmers keep relatively small numbers of livestock, mainly cattle and small ruminants. Animal feed is obtained from natural vegetation and crop residues, while watering of animals is from rivers during the dry season, crop residues are used to provide forage to non browsers, such as cattle and sheep. Numerous reservoirs provide water in the wet season and also serve as alternative water sources to rivers. Groundwater is also an important source of water for livestock, other sources including hand-dug wells, swamps, creeks and boreholes.

3.1.3 Socio-economic Condition

3.1.3.1 Major Economic Activity

The general feeling was that around 80% of the population in Shabelle basin is engaged in livestock, agricultural and fisheries sectors, one of the major objective in government of Somalia is to provide employment to the whole labor Force. Somalia is a large country of nomadic and semi-nomads with agricultural population, the expansion of the industrial and service sectors and opportunity for employment was rapidly growing in urban area (1988, MoA).The export of livestock is the principal means for providing foreign currency for the import of capital goods and consumption commodities (livestock sectors, 1981).

The livestock, agricultural and fisheries sectors form the fundamental base of Somali economy, us they provide livelihood for over 80 percent of the country labor force, they generate foreign exchanged as well as catering for a balanced and regular food supply of the Somali food.

3.1.3.2 Demography

The last population estimation survey in Somalia, estimated that total population in urban, rural, nomadic areas and camps for IDPs in the 18 pre-war regions was 12,316,895 (MoP and UNFPA, 2014). Out of the total population, 42 percent (5,216,392) were living in urban areas and 23 percent (2,806,787) were living in rural areas. The nomadic population constituted 26 percent (3,186,965) and the internally displaced persons made up 9 percent (1,106,751) of the population.

However, these total of population the river Shabelle is 2,238,940, lower Shabelle is the largest population of about (1,202,219). The total population in the basin has increased significantly compared to previous estimates, 52 percent (1.164, 249) of the total population comprised males and 47.6 percent (1,065,735) were female. Lower Shabelle was home to the most Somalis living in rural areas at 25.8 percent of the total population and 9.3 percent of all internally displaced.

3.1.4 Research methods

3.1.4.1 Model selection and calibration

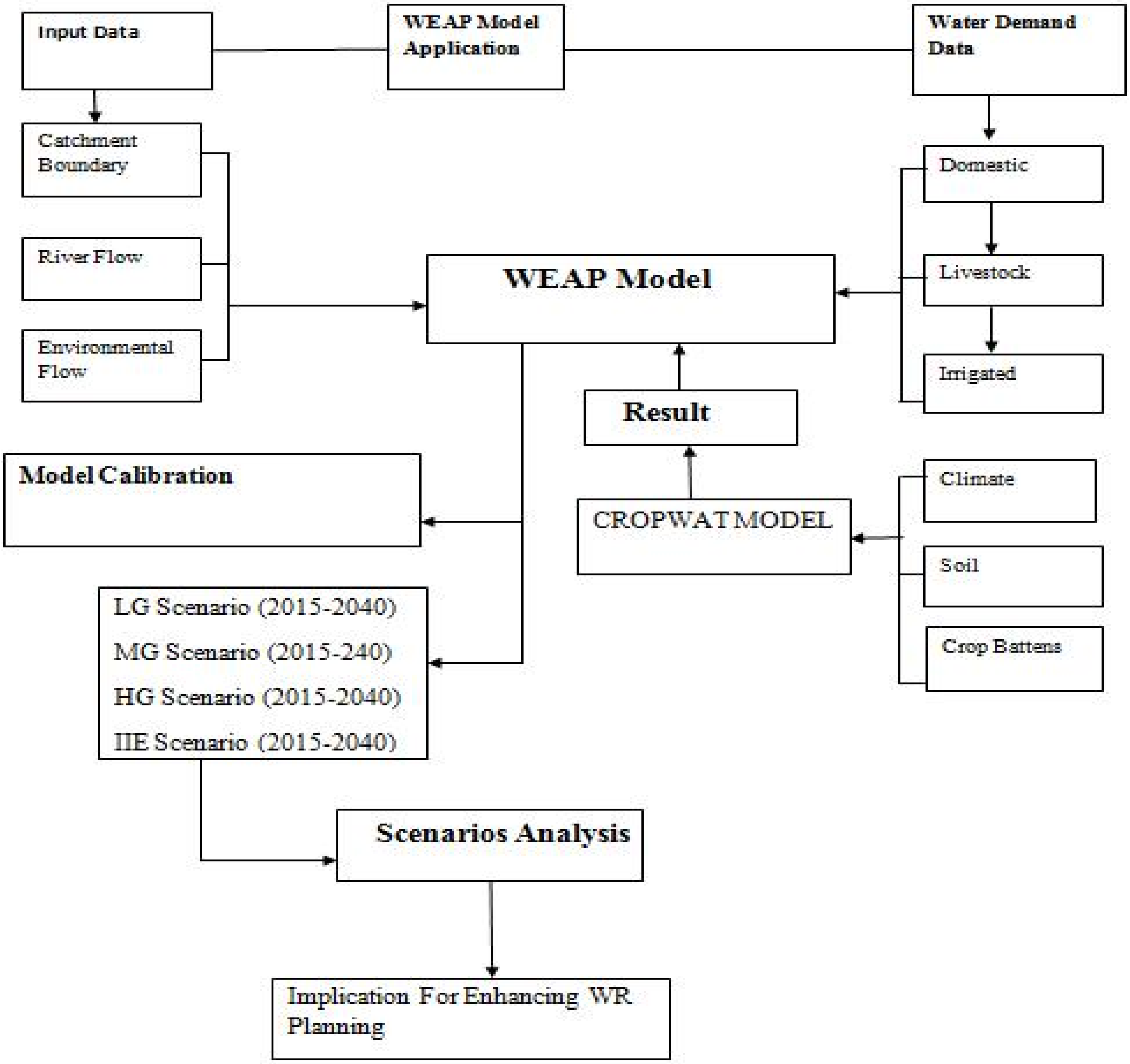


Figure 3.8: Research design flow chart

Water evaluation and planning system (WEAP Model Setup)

The Water Evaluation and Planning Integrated Water Resources Management (IWRM) model (WEAP) seamlessly integrates water supplies generated through watershed- scale hydrologic processes with a water management model driven by water demands and environmental requirements and is governed by the natural watershed and physical network of reservoirs, canals and diversions.

The WEAP model was developed by the Stockholm Environment Institute (SEI) and can be downloaded from www.weap21.org. It is a general multipurpose, multi- reservoir simulation program which determines the optimal allocation of water for each time step on the basic principle of water balance accounting.

The model provides a comprehensive flexible and user-friendly framework for planning and policy analysis. WEAP has an integrated approach of simulating both the natural inflows and engineered components of water system. This allows the planner access to a comprehensive view of the factors that must be considered in managing water resources for present and future use.

This enables us to predict the outcomes of the whole system under different scenarios, and carry out comparisons between the different alternatives to evaluate a full range of water development and management options (SEI, 2005). Based upon the following criteria, WEAP was selected to perform water resources management modeling for the Shabelle river basins.

The model can be used at different levels spatially and temporally, The mode is easy to use with a friendly interface, the model has been successfully used in many national and international applications, the model is able to simulate hydrology, groundwater utilization, surface-groundwater interactions, and wastewater treatment, the model has in-built capability to build and compare scenarios, the model is based on priority based water allocation system and can therefore be used in negotiation situations, the model can enable stakeholders to get involved in management procedures through interactive data driven model.

This helps increase public awareness and acceptance, the model enables users to have interactive control over data input, editing, model operation and output display.

Model calibration

The aim of calibration is to adjust the parameters so that the model solutions fit the observations in an optimal fashion (Yates et al. 2005b). WEAP has a calibrations includes a linkage to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy (WEAP, 2014). You can use PEST to help calibrate one or more variables in your WEAP model which can be particularly useful when using the Soil moisture method of catchment hydrology.

The complexity of water allocation models and the fact that they are required to simulate human behavior (to reflect changes in demand) in addition to WEAP model processes means that model calibration and validation is extremely difficult and has often been neglected in the past (McCartney and Arranz, 2007). in this study of calibration the WEAP model involves the comparison of simulated and observed flows. Accordingly observed stream flow data at gauging station in Buloberde were used for calibration. Naturalized stream flows from the selected station were compared to the simulated results of the model.

3.1.4.2 Primary data collection and analysis

Stream flow data

After the outbreak of the civil war in Somalia, all of the hydrometric and weather stations that were operated by the Ministry of Agriculture (MoA) fell into disrepair or were looted. SWALIM started rehabilitating the hydrometric network in 2002. The staff gauges that were rehabilitated by SWALIM and installed from March 22 to April 4, 2002. An effort was made to fix the new staff gauges, the gauge station of river Shabelle were maintained before the war by the hydrometric project of the Ministry of Agriculture. To date, two stations have been reinstated measuring the river flow at Shabelle.

Flow data was collected from Somalia water land and information management (SWALIM) and stream flow is an important aspect of modeling a water system and helps in understanding how it operates under a variety of hydrologic conditions.

Data available for the river were obtained from two gauging stations located at the main river, namely, Buloberde and Baledweyne. The mean monthly flow data from the gauge station of Buloberde river which is largest tributary joined Shabelle were used for the model.

Estimation of environmental flow

In Somalia, the minimum environmental flow has not been established as is the case in many African countries where less than 10% of mean annual runoff is allocated to the environment. This was determined from the available 11 year in river flow, the flow duration curve is one of the common methods which are used in determining environmental flows using the 90% flow (Q90*)* as the minimum environmental flow.

In this study, Q90 was used to determine the minimum flow which is exceeded 90% of the time (Siwale, 2008). The basic time unit used in preparing a flow duration curve was determined by sorting average monthly discharges for period of record from the largest value to the smallest, involving a total of n values. The sorted daily discharge values are assigned a rank (M) starting with 1 for the largest and the probability of exceedance (P) calculated as follows.

P = 100 * [M / (n + 1).

Calculation of Crop Water Requirements

Crop water requirement have been computed using CROPWAT 8.0 software. The inputs for the calculations were considering climatic data from the nearest weather station to Afgoi catchment (See Table 3.1). The soil characteristics for the representative zones mainly clay loam are dominated in lower Shabelle (Vargas, 2007).

There were several types of cropping patterns practiced when the irrigation infrastructure was operated. The cropping patterns for the irrigated agriculture in the Shabelle river consist of fruit trees, maize, groundnuts, tomatoes, sesame, cow pea, vegetables and banana. (Basnyat, 2009).

However, in order to estimate the irrigation potential, Banana crop were considered since one of the most crop cultivation in lower Shabelle.

Table 3.1: Climate and potential evapotranspiration data for Afgoi (FAO-SWALIM)

Month	**Max Temp**	**Min Temp**	**Humidity**	**Wind Speed**	**Sun Shine**	**Solar Radiation**	**ET0**
	(0C)	**(0C)**	**(%)**	**(Km/day)**	**(Hours)**	**(MJ/m2/d)**	**(mm/day)**
Jan	33.5	21.6	77	345.6	7.9	20.6	5.65
Feb	34	21.7	83	354.2	9.3	23.6	5.84
March	35	23	81	319.7	8.9	23.5	6.03
Apr	34.2	23.5	83	216	7.5	20.8	5.06
May	32.7	23.1	87	216	6.5	18.4	4.25
June	31.2	22.6	89	259.2	6.2	17.3	3.85
Jul	30.5	21.5	84	259.2	7.9	19.9	4.4
Aug	31.1	21.5	85	259.2	8.2	21.3	4.68
Sep	32	21.7	82	259.2	8.5	22.5	5.16
Oct	32.2	22	82	233.3	7.6	21	4.89
Nov	32.2	21.7	78	172.8	6.7	18.9	4.5
Dec	33	21.6	77	276.5	6.6	18.3	4.97
Average	**32.6**	**22.1**	**82.3**	**264.2**	**7.7**	**20.5**	**4.94**

3.1.4.3 Secondary data collection and analysis

Water Demand for Commercial Irrigation

The outbreak of the civil war affected the main irrigated areas including essential irrigation infrastructure was destroyed, data on irrigated areas in the Shabelle rivers are scarce although there is a large area of land suitable for agriculture in the river areas (SWALIM, 2007). The availability of water is a constraint for irrigation study by (Basnyat, 2007) estimated an irrigated area of Shabelle is 50,000 ha these data was collected from SWALIM.

Domestic water demand

Domestic water demand encompasses all domestic-type water requirements in urban and rural areas. Per capita water demands shows that 25 l/d and 50 l/d for rural and the urban population (Basnyat, 2007). There are three (3) regional under the Shabelle catchment namely Hiiraan (upper basin), middle Shabelle (middle Basin) and lower Shabelle (downstream), the study was covered the entire regional see in table 3.2 below.

However these population data were input as the activity levels to be multiplied by the annual per capita water use rate in order to obtain the total annual water demand. A growth rate of 2.7% percent (UN, 2005) was assumed for the entire basin and the "Growth from" function of the model was used to compute the current population for each demand site. The method is based on the given population and per capita water consumption as shown in equation.

Water Demand = Per capita water consumption (l/d) x population.

Table 3.2:Population numbers in the Shabelle river by regional (Minister of planning 2014)

Regional Basin	Urban Population	Rural Population
Hiiran upper Shabelle	132,379	388,146
Middle Shabelle	166,308	349,728
Lower Shabelle	318,722	883,497
Total	617,409	1,621,371

Livestock water demand

Water for livestock is an essential basis for subsistence and development of the Somali population and its main the source of income which majority of population directly engaged in livestock production (FAO and EU, 2004). The estimated livestock population and water demand data has been taken from FAO-SWALIM Database, Livestock water requirement has been compiled in sub-regional, in order to simulation the study.

Table 3.3 gives the details of livestock surface water requirement used in the simulation studies, different types of livestock water requirements have been clubbed together and indicated as single demand node in the model. The performance of this analysis in annual water use rate were indicators of (FAO standard of sub-Saharan Africa) if water demand 40, 7 and 12 litter per day per cattle, sheep/goat and camel was used. The method was given Livestock for per capita water consumption as shown in equation.

Water Demand = Per capita water consumption (l/d) x livestock population

Table 3.3:Livestock Population in River Shabelle (SWALIM-FAO)

Regional	Cattle	Camel	Sheep/Goat
Hiiran Upper Shabelle	200,750	530,960.00	1,865,740.00
Middle Shabelle	443, 20	235140	1,348,380
Lower Shabelle	43, 940	336070	3,748,210

3.1.4.4 Scenario specification and evaluation

I Current account water demand

Under the current account available water demand in four main water use sectors were simulated in the WEAP model. The catchment has at least four demand categories: domestic, agriculture, livestock and environment. in Somalia domestic water demand is the top priority fallowed by livestock, agriculture and environmental have given least priority this classification was derived from the general classification in the Government.

Demand	Priority
Domestic	1
Livestock	2
Agricultural	3
Environment	4

Table 3. 4: Priority demand for water

The input data requirement in WEAP model was building the area by adding GIS based raster and vector maps to the projected area, the background vector data was added from a shape file format. This format was created by GIS software once the area is open the years, time steps and units are set. In this study the current accounts is set to be year 2014 with the last year scenarios to year 2040, the time steps per year is set to be 12 and the time step boundary to “based on calendar month”, starting with the month of January.

The current accounts year is chosen to serve as the base of the model and all system information (for instance demand and supply data) is the input into the current accounts. The current accounts is the dataset from which the scenarios are built, the “current scenario” carries forward the current accounts data into the entire project specified (2015-2040), river path is drawn in WEAP by clicking on the “River” symbol in the element window.

The direction of the flowing river is built from the headwater (Buloberde) of the main river, the input data for the model in main river was used at Buloberde station, since it's the largest local catchment tributary join the Shabelle river (FAO,1969).

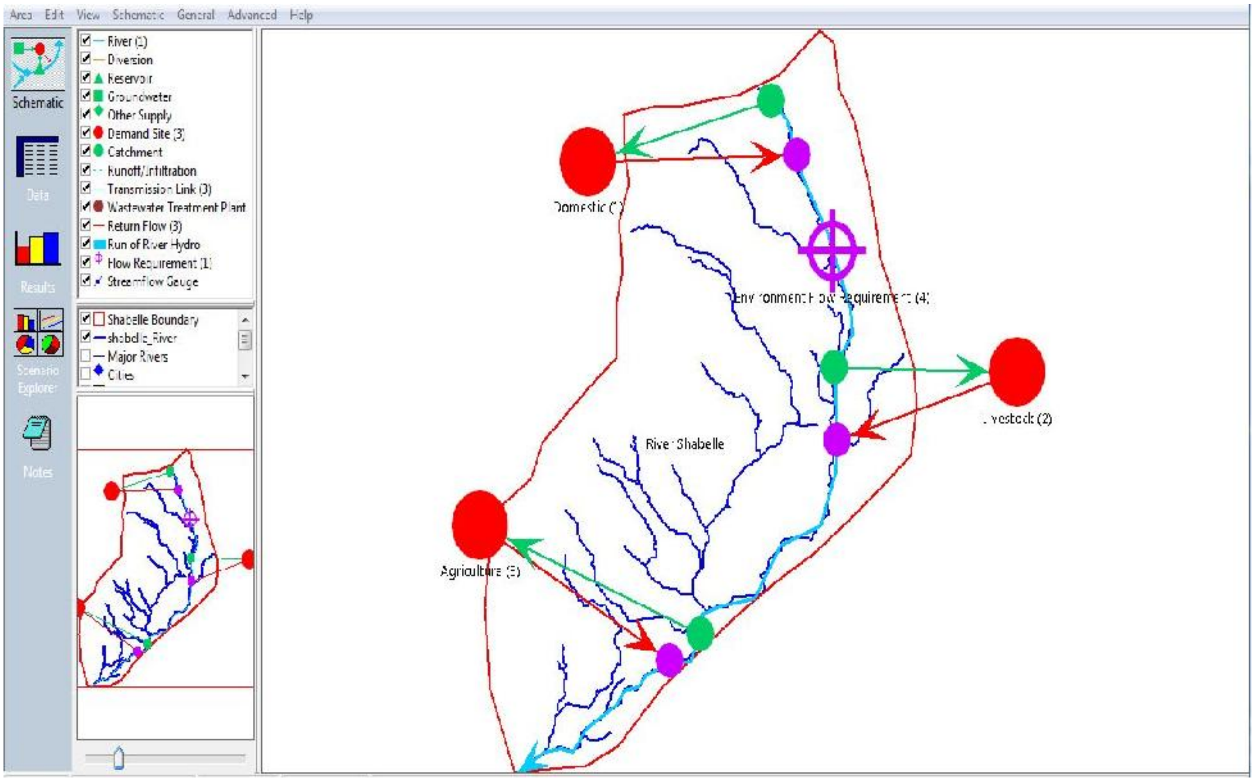


Figure 3.9: Catchment boundary in WEAP model

II Creation of Scenarios

Water demand analysis in WEAP is either by the disaggregated end-use based approach of calculating water requirements at each demand node or by the evapotranspiration based irrigation demand in the physical hydrology module. Demand calculations for domestic, livestock and agricultural entities were based on a disaggregated accounting for various measures of social and economic activity such as population served, livestock population and agricultural production units these are referred to as the activity levels.

The activity levels were multiplied by the water use rates of each activity defined as water use per unit of activity, each activity level and water use rate was individually projected into the future using exponential growth rate function.

WEAP calculates water mass balance for every node and link in the system on a monthly time step, water is dispatched to meet in stream and consumptive requirements subject to demand priorities, supply preferences, mass balance and other constraints (SEI, 2005).

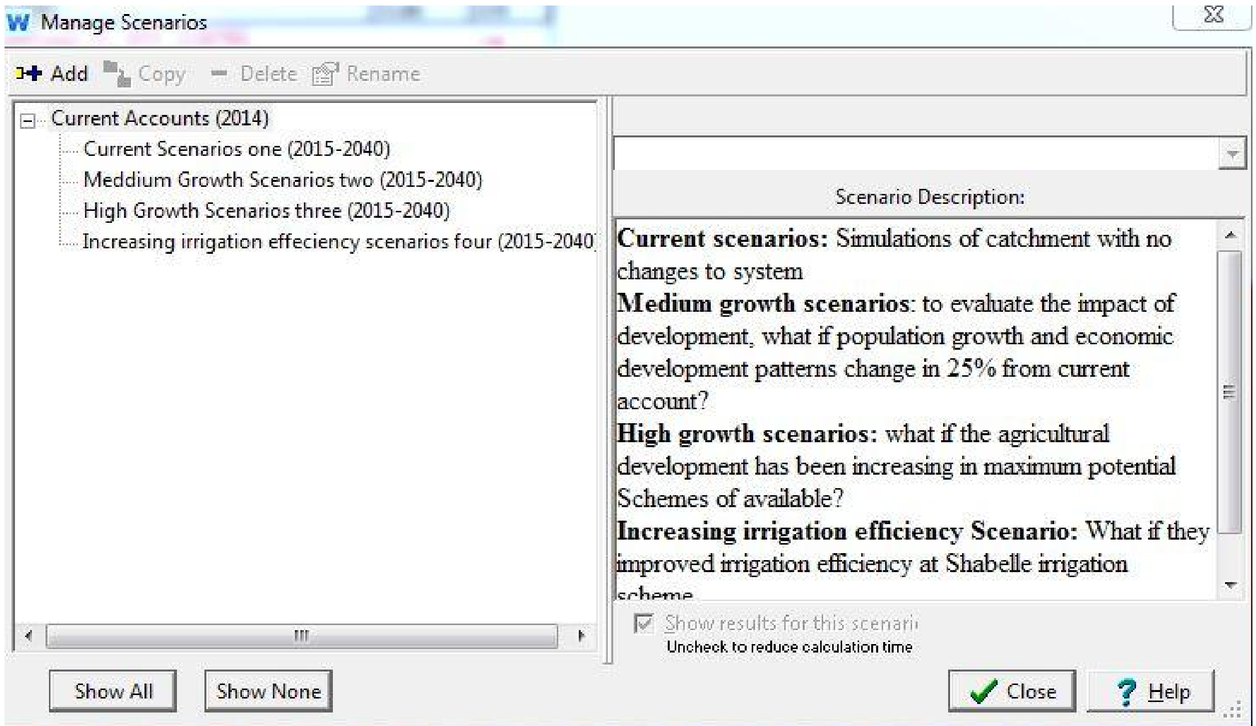


Figure 3.10: Scenarios creation in WEAP

Current scenarios

Reference scenario also known as a default scenario or business-as-usual scenario, is established from the Current Accounts, which represents the basic definition of the current system including the specification of supply and demand data for the first year of the study on a monthly basis, to stimulate likely evolution of the system without intervention (SEI, 2011). Current scenario carried out entire project specified (2015-2040), the current data into the entire time horizon in which no changes are imposed and serves as a point of comparison for the other scenarios in which changes are made in the system data.

In this study current scenario was applied to analyze the situation of Shabelle river without any development in of the system except the population growth rate 2.7% per annum (UN, 2005). And the only estimation published by international Bank for reconstruction and development (IBRD, Prewar) the annual growth rate livestock is estimated 2%.

Medium Growth (MG), scenario

after analyzing the possible impact in current scenarios WEAP was configured in medium growth scenarios, these scenario is to evaluate the impact of a population growth rate and extended irrigated area for Shabelle basin.

Medium growth (MG) scenario we assumed by what if population growth in terms both rural and urban are growing 2.9% and livestock 2.2% per annum, in this scenarios has been changed 25% in the standard of life and economically when you compare the scenarios 1 and these determined by due to the livestock and population of Somalia has become increasingly dependence upon the industry in 2040 for medium growth rate, the production of animals to meet both export and internal demand has raising and come almost entirely from nomadic and semi nomadic sectors of the community, compare the current scenario which very low production and no existing the industrial in the basin. The standard of people has a raising and annual water use rate of people has been increasing which reach 70 (l/d) per person.

Irrigated area where agriculture production in Shabelle is increased by land reclamation and the rehabilitation of irrigation infrastructure along the Shabelle river. Data on agricultural production, area, yield and crops patterns have improved. An effective machinery for this scenarios be created by the institutional responsible, pricing policy in agriculture needs to be thoroughly reviewed in the light of cost of production , incentives to farmers, marketable surplus and the need for ensuring self-sufficiency in food. These determination will cause by the irrigated area from current scenarios will be growing 2.7% from the scenrios1 and is reach 135000 ha by the year 2040.

Higher growth (HG), scenario

In this scenarios also we called worst scenarios, generally high growth scenarios we assumed by the urban and rural water development had been improved by the performance of commercial and eradicating the poverty situation as well as improving national food self sufficiency. By the same time, the rate of urban population has been increased from the rural area of the country to the big town, therefore annual growth rate increase by 3.2% per annum, annual water use rate raising 100 (l/d) per person, is two times when you compare in the current scenarios.

60% of Somalia population are engaged livestock especially in the domestic sectors, giving increased attention to animal production for instance and rehabilitated the animal production department was established by 1974. The case of animal production and the policy will be improving by productive of livestock of the country both for meat and milk these productive through management and feeding genetic will be improved.

The result of this will increase the livestock numbers, and more land has become accessible for grassing several type of grassing reserves were developed, also there had been increased commercialization and hence livestock off-take had been increased, the annual growth of livestock will be 2.5% per annum, compared the current scenarios which is 2%

Agricultural water demand in the pre-war irrigation system was anchored by commercial estates, serving both domestic markets (rice, sugar) and international markets (bananas, citrus), and smallholder farmers who cultivated cereal crops (SWALIM, 2011). Till around 1990 Somalia produced about 80% of its own cereal requirement and exported bananas and citrus to Europe mainly to Italy. Commercial fruit production mainly was located in river Shabelle while the government has been developed in 9 barrages which was 195,242 ha, irrigated area. Based on that we assume Somalia has rehabilitated the pre war barrages which is 195,242 ha. the extended area is gives more than four times in the current scenarios.

No	Names	Command area/ ha
1	Saabuun	50 942
2	Balcad	10 000
3	Janaale	67 440
4	Mashallaay	27 000
5	Qoryooley	26 800
6	Falkeerow	4 120
7	Kuntunwaarey	5 000
8	Sablaale	940
9	Hawaay	3 000
Total		**195, 242**

Table 3.5: Pre war barrages along Shabelle river (SWALIM, 2011).

Irrigation efficiency scenario

This scenario was modeled to assess the impact of improved irrigation efficiency when the three scenarios was developed in the catchment. The main focus is put on water used for irrigation because irrigation the biggest user of available water (80%), it was adopted that from the increased technology and improving the water demand scenario, where the irrigation efficiency will be improving and a measured by water lost through seepage, leakages absorption and dead storage from the canal system, in this scenarios of over 90% is normally considering well constructed canal and schemes should be achieved 90%. The irrigation management can be of then measuring distribution efficiency, application field and management losses incurred through seepage, wastage, incorrect allowance got response time and travel time, and incorrect gate operation canal system.

Simulation of environment and river flow

In the annual discharge of the river Shabelle we assumed that the currently amount of river flow will be constant up to three scenarios, also the minimum environmental flow requirement will be constants in the three scenario since there is no reliable projection in reservoir we can increase or reduce in the environmental flow.

CHAPTER 4 : RESULTS AND DISCUSSION

4.1 Current water supply and demand

4.1.1 Surface water potential and annual discharge in Shabelle river

The Shabelle river mean annual runoff at Beledweyne is estimated at 2,500 Mm^3, and Bulo-berde 2,900 $Mm^{3,}$ with higher proportion of runoff coming from Ethiopia. Accordingly to Basnyat and Gadain (2009), over 90% of the total volume runoff is generated from Ethiopian part. Contribution of Somalia for Shabelle basins is less than 10% because of low rainfall in the area (FAO, 1969). A result of 11 year river flow records (2003 to 2014) shows that there is inter-annual variability in annual discharge with peak flow registered in 2006, while the smallest flow recorded on 2004. About 50% of observation period shows runoff discharge below the average, the river channel capacity varies from location to location.

The channel capacity of Shabelle around at Beledweyne city Ethiopia border, is approximately 400 m^3/s (Basnyat and Gadain, 2009). Flows are generally decreasing from upstream locations to downstream (Divas, 2007)**.** With some marginal increase during the rainy seasons in some downstream locations due to contribution from the Somali catchments (Basnyat, and Gadain, 2009). The monthly average flows decrease along the river Shabelle with water being lost through extraction, evaporation and over-bank spillage and not much contribution to flows from the Somali catchment areas (Basnyat and Gadain 2009).

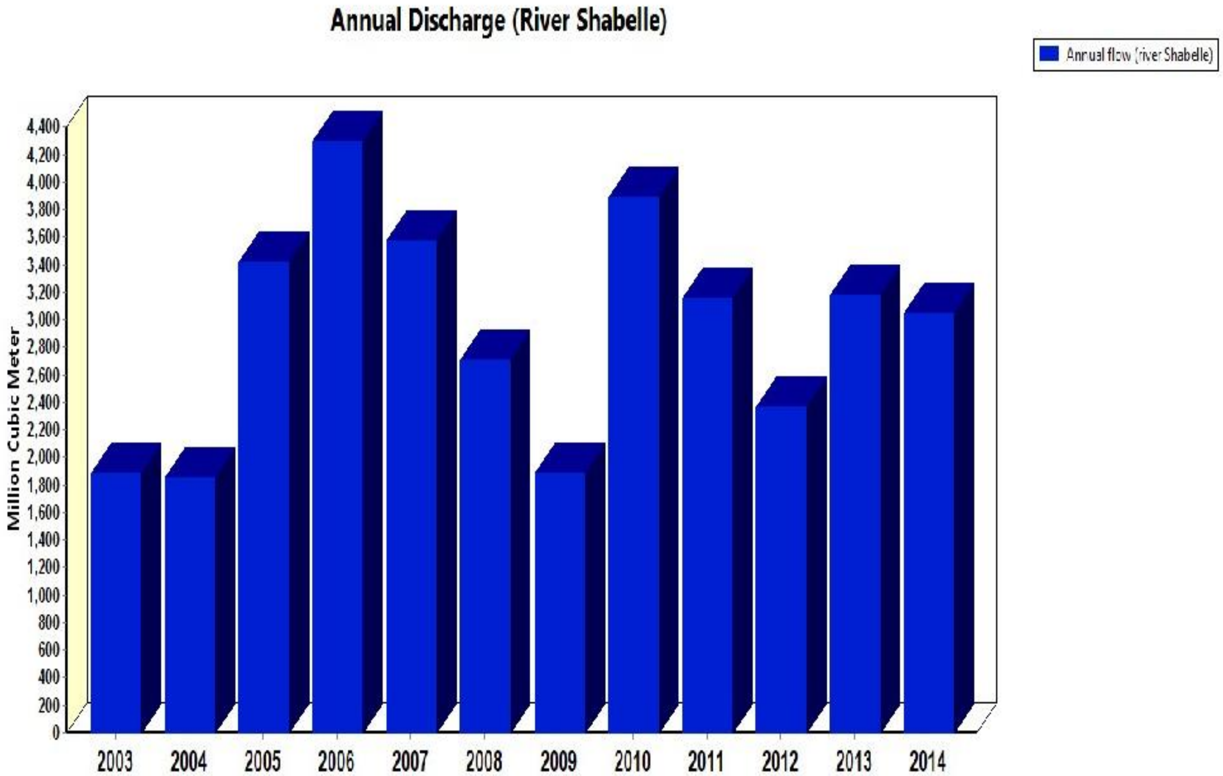


Figure 4.1: Annual flows of Shabelle river

The flow of the Shabelle river is characterized by extreme seasonal and inters annual variability, at Beledweyne Ethiopian-Somalia border. Annual flow varies from approximately 80 m^3/s to 90 m^3/s, also mean monthly flow varies considerably. For example, more than 80% of the flow occurs during the wet season in May and October while only 4% of the flow occurs during the dry season December to March.

There is also more extremely reduction in (summer Season) minimum flow at border, about 19.0 Mm^3 of flow occurs in December to January due to more evaporation and low rainfall at whole catchment. On the other hand, the flow increases in April to June where up to 874.9 Mm^3 of discharge was measured due to heavy flood from in the border of Ethiopia and significant localized contribution. Similarly, about 848.2Mm^3 flow was recorded in the months of October/November. This shows that the two rain seasons contribute much of the flow for Shabelle river (80%).

4.1.2 Model calibration result

Calibration of the model means adjusting some parameters in such that there is good match between the simulated and observed data at selected stations. Observed data is required for calibration of the model and sufficiently long continuous observed data is not available for any site in the basin. Calibration of the WEAP model was based on the flow at the gauging stations at Buloberde it was done for the period 2003-2014, WEAP simulation results entirely depend on the quality of the input data e.g., river discharge, groundwater recharge, urban and agricultural demands, (Holger Hoff, 2011).

The accuracy of the model is assessed by simulated and observed stream flow, results from figures 4.2 below it can be observed that the simulated and observed flows are comparable in Shabelle rivers, there is good match between simulated and observed flow values, and the mean R-squared value is 0.922.

An observed and simulated flow of the current situation data, the graph shows that the simulated is fitting well in the observed data and the model performance are perfect and provides a good estimate.

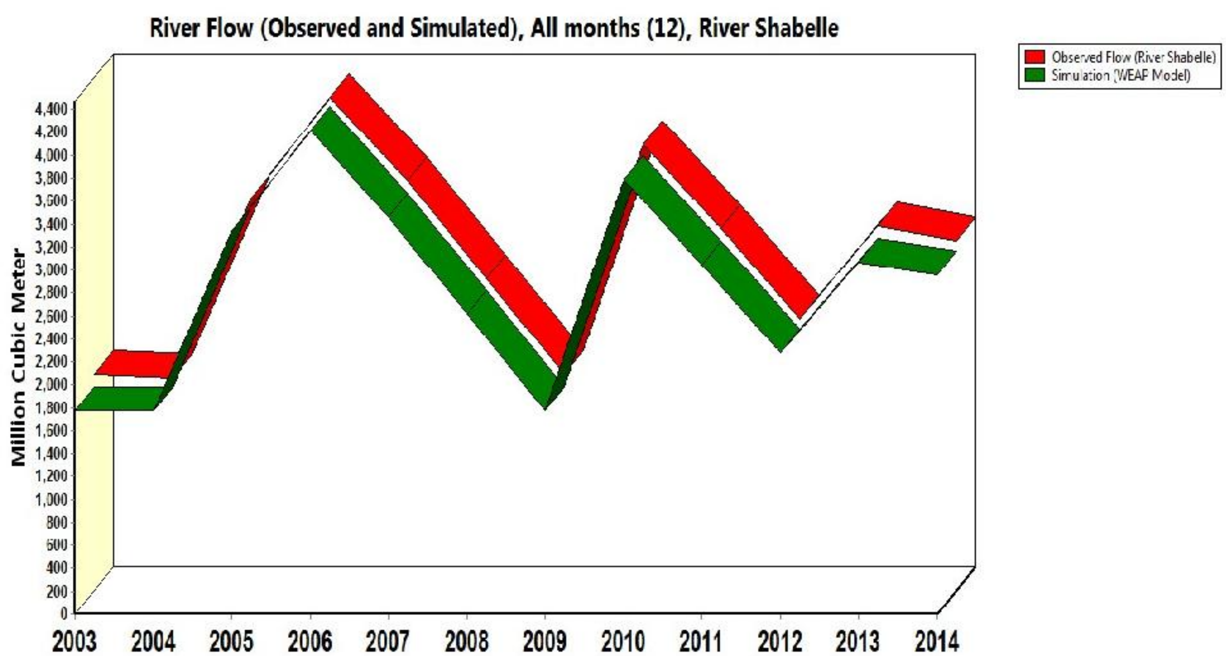


Figure 4.2: Observed and simulated stream flow in Shabelle river

4.1.3 Environmental flow requirement

In order to maintain the ecological services as well as the natural channel habitat associated to the historic flow regimes of the Shabelle Rivers, a certain reserve flow has to be maintained and could be considered as a sectors demand on its own (Abdalle and Gadain, 2007).

From the figure 4.3 the 90 % flow was estimated as $4.132m^3$/sec, this flow is equivalent to 10.7 Mm^3 per month and max annual is 290 Mm^3.This calculation was done assuming 10% environmental flows. Similarly Petersen and Gadain, (2012) considered 10 % environmental reserve flow which is equivalent to 240 Mm^3 to assess annual water demands by environmental needs. The average of monthly demand coverage is depend on the river flow during the high flow of river in (rain season) the flow has meet in the environmental water demand in the low River flow in (dry Season) which is Jan, to March is need to Priorities in the environment which can be alarm in unmet water demand.

Environmental water needs for sustaining specific ecosystem are given priority with regards to water allocation under many recent pieces of water legislation implemented in Africa, (Wallingford, 2003). In Tanzania, laws and policies were developed recently that gave priority of water use to river ecosystem once basic human needs are met (Dunbar et al, 2004). However environmental flows have not been established for Shabelle catchment, figure 4.3 the result shows that the current water demand it must be kept in mind, that environmental demands are partly satisfied.

In Shabelle, the annual environmental satisfaction of a basin is primarily dependent on the amount of annual runoff the basin receives. Semiarid of Somalia the Shabelle basin considering minimum annual environmental requirement of about 290 Mm^3 as compared to Juba basin, 1200 Mm^3. during dry season the annual runoff is also very low (19 Mm^3) as compared to the juba basin (200 Mm^3). However in the study of Petersen, G, and Gadain, (2012) indicate that environmental flows vary from year to year depending on river flow where it ranges from between 10% to 15% of the annual flow ,In dry seasons less than 10% of the natural river flow.

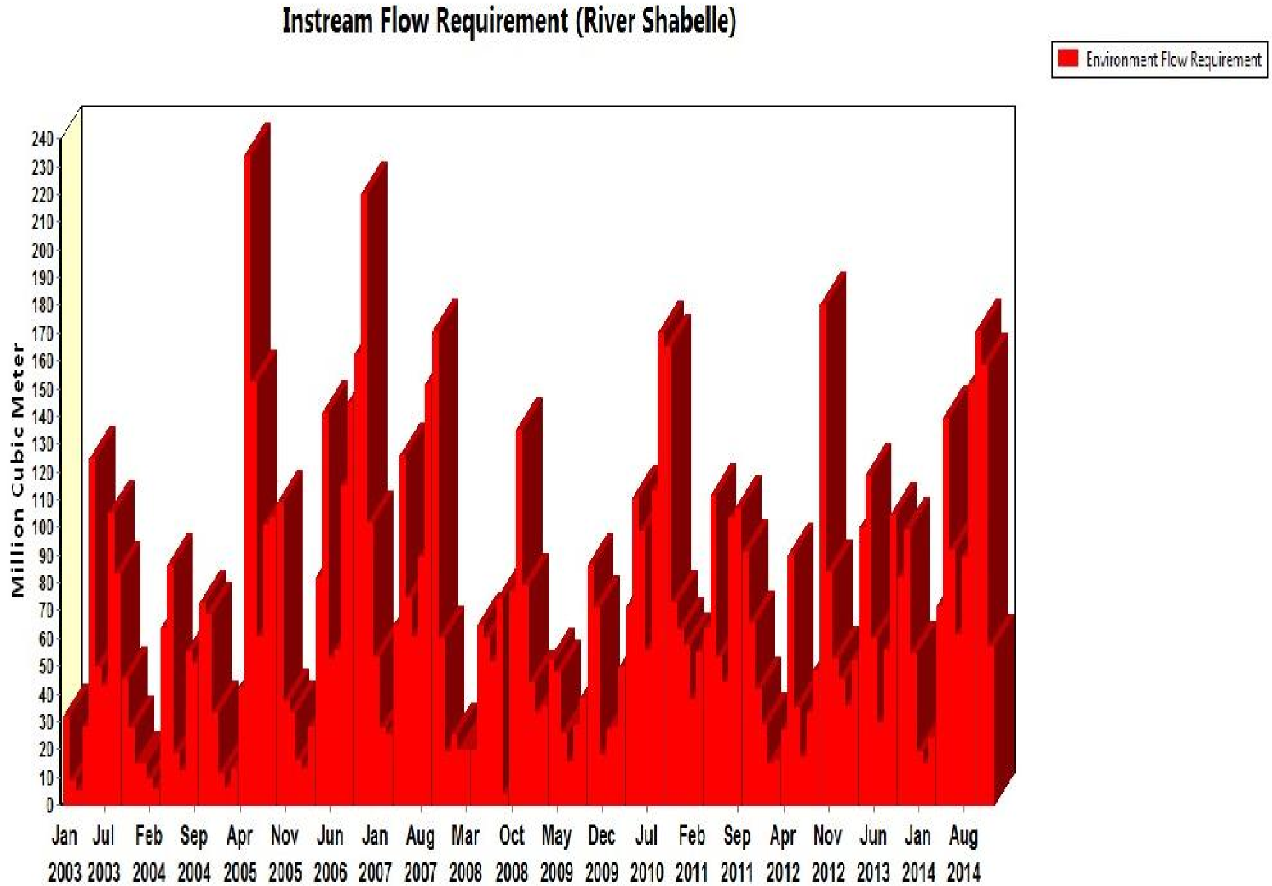


Figure 4.3: Environmental flow requirement

4.1.4 Domestic, livestock and irrigation water demand

4.1.4.1 Current monthly agricultural water demand

Before the collapse of the central government the Irrigation department at the ministry of agriculture managed all irrigation schemes infrastructure operation and maintenance, currently agriculture which is the main occupation of the inhabitants in the basin is primarily water demand for Irrigation.

The FAO CROPWAT software has been used to determine crop water requirements at Afgoi station (lower Shabelle basin), the annual irrigation demands are 13,435m^3 per ha, along the Shabelle river given in existent irrigation schemes. irrigated crops growing in the schemes the study was give consideration the annual perennial growing in the schemes which is banana.

In terms use of the rivers similarly Basnyat 2007 has been used CROPWAT the result shows that, the annual irrigation water demand 11,830m³/ha, at Middle Shabelle (Jowhar).

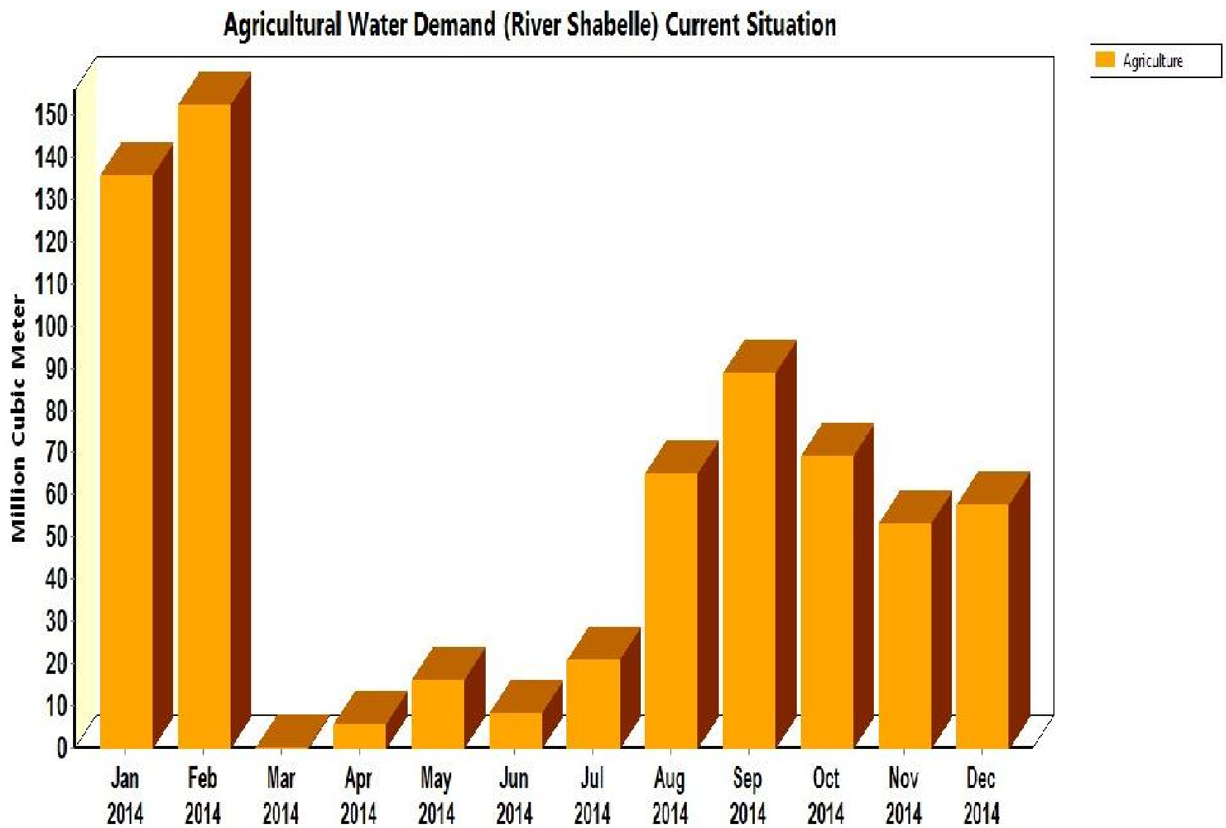


Figure 4.4: Irrigation water requirement

Agriculture in Shabelle catchment is the largest consumer of surface water in the current annual water demand, based on the result of CROPWAT estimated, the annual agricultural water demand in Shabelle basin is 671.7 Mm^3 in total irrigated area. But satisfying the annual water demand for commercial irrigation within the Shabelle catchment is unlikely particularly in the months of Jan and Feb. For these reasons according the result of WEAP model irrigation water use accounted for only January in135 Mm^3, Within the WEAP model the irrigation water demand varied from month to month based on rainfall, during wet years the irrigation demand was reduced and during dry years it was increased.

However the result of table 4.1 indicate that the irrigation water demand showed variation within the months where higher demand was observed in the month of January and February, on the other hand during the wet season which includes May, June, July and October there is sufficient flow which can satisfy the irrigation demand of the crop, during dry season the irrigation water demand has been greater than the river flow because of monthly variation in crop water requirement.

In contrast to this study, Basnyat, (2007) found water demand of 591,500 Mm^3 for Shabelle area. However, the same author reported that during the wet season there is sufficient flow which satisfies the seasonal demand, this result is in line with present finding. However most of the agricultural production is taking place in the middle and lower river basin where the crop water demands has been determined using the same climatic parameters. The result of both studies didn't show much difference because of under similar climatic conditions and with similar cropping patterns.

Agriculture Area (50,000 ha)	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Sum**
Irrigated water demand (Mm^3)	135.6	152.1	0.0	5.7	16.1	8.0	20.6	64.9	88.9	68.9	53.2	57.6	671.7

Table 4.1: Currently in monthly Irrigated demand

4.1.4.2 Domestic and livestock water demands

The current water demand for domestic in the basin is estimated at about 26.1 Mm^3 for Shabelle river, and has been estimated total population of 2,238,780 (2014). Over the last year from 2005 to 2014 the population growth rate of the study area at 2.7% per annum (UNEP, 2005), however the domestic water demand are much difference when you compare the livestock because of number of livestock since is the highest camel in the world, exacerbated by livestock markets according to the FSNAU (2012). There is a current national trend of increasing livestock keeping (cattle, camel, and sheep/goats).

Table 4.2 : Current domestic water demand of the study area

Regional	Urban (Mm^3)	Rural (Mm^3)	Total
Hiiran	3.54	2.42	5.96
Middle Shabelle	3.04	3.19	6.23
Lower Shabelle	5.82	8.06	13.88
Total	12.4	13.67	26.07

Currently the total livestock population in Shabelle basin is 9,168,145 and 44.6 Mm^3 in annual water demand see table (4.3), these increased livestock population will put a large strain on already limited water resource and greatly increased livestock sector water demand. The model result indicates that during the wet season there is usually enough water to meet the demand, however during the dry season there is water stress in many areas of the middle/down of the basin.

However in this result showed that the domestic and livestock have got sufficient water demand and there's no unmet demand, According Balint, Z. et al, (2011). When water demand is not met locally the communities, they migrate with their livestock to long distant areas for many hours and fetch unsafe and unreliable water from undeveloped sources. However domestic water utilization in the urban centers there is a mechanism for household connections of water mainly through utility companies, in the rural areas communities fetch water directly from the source and during dry periods through water trucking.

Table 4 3: Current livestock water demand of the study area

Livestock/regional	Cattle	Sheep/Goat	Camel	Total (Mm^3)
Hiiran	5.93	6.72	4.33	16.98
Lower Shabelle	1.64	13.12	2.7	17.46
Middle Shabelle	1.65	6.53	2.03	10.21
Total	9.22	26.37	9.06	44.65

4.1.5 Annual water demands along the Shabelle River

To date Somalia has utilized very little of the Shabelle water partly because of its inaccessibility, and major irrigation schemes collapsed during the civil war and the consequence of El Nino Flood 1997/1998 also the loss of the European preferential banana market in 2001 (Gadain and Muchiri, 2011). Still agriculture is the largest demand and the major crop production schemes of the country, It must be kept in mind that especially domestic, livestock and environmental demands are partly satisfied, the river flow has been set in direct relation with the sectors demands for the purpose of this analysis the river flow has been taken as 988.4 Mm^3, according to the annual water demand gauged station, located at the Buloberde. Based on the annual water balance as illustrated in the table 4.4 there seems to be some room in unmet water demand for development agricultural in Shabelle basin. However it must be considered that environmental water demands could be much higher since a relatively low share (Basnyat and Gadain, 2009).

Also the table above discriminate between the sectors water demand in Shabelle river respectively, domestic and livestock demands have not been extracting much water. However the analysis of agricultural water demands provided a glimpse at the disproportional use of the Shabelle river as compared to the other sectors demand. Since is the basin over populated and mostly engaged agriculture to the Shabelle river, the result shows that at least 70% of the total water demand is related to the agriculture concerning the livestock, domestic and environmental demands have minor shares in water consumption.

Table 4.4 : Total monthly water demand in along river Shabelle

Month	Water demand (Mm^3)					Naturalized flow (Mm^3)	Unmet demand (Mm^3)
	Agriculture	Domestic	Livestock	Environmental	Total		
Jan	135.6	2.2	3.7	7.07	148.57	70.7	71
Feb	152.1	2.0	3.4	5.95	163.45	59.5	98
Mar	0.0	2.2	3.7	8.83	14.73	88.3	-
Apr	5.7	2,2	3.6	27.63	36.93	276.3	-
May	16.1	2.2	3.7	52.03	74.03	520.2	
Jun	8.0	2.2	3.6	35.41	49.21	354.1	-
Jul	20.6	2.2	3.7	16.54	43.03	165.4	-
Aug	64.9	2.2	3.7	21.32	92.12	213.2	-
Sep	88.9	2.2	3.6	33.49	128.19	334.9	-
Oct	68.9	2.2	3.7	36.86	111.66	368.6	-
Nov	53.2	2.2	3.6	37.7	96.7	377.0	-
Dec	57.6	2.2	3.7	21.31	84.81	213.1	-

There's water shortage which was not sufficient to meet water demand currently the unmet water demand doesn't significant impact in all other sectors which is 170Mm³. During dry season the flow has less than 800Mm³ and total annual water demand are 1038 Mm³. However these shortages are linked the low river flow and monthly variation of crop water demand, table 4.4 show that in monthly of January and February apparently there is water shortage.

However, the result indicates that the monthly variation of agricultural water requirement in the January and February was not sufficient, there will be alarm the risk of failure in irrigated agriculture, and little correlation between the water requirements of crops and crop production in Shabelle.

The contrast Basnyat 2007 has found that certain agricultural activities become unprofitable due to the relationship between their water requirements, cost of production and their market price, with more than three million in the Shabelle basin depending on food aid (EC, 2004). However the result show that it necessary to build reservoir which can apparently satisfied during the low river flow, although many survey of the Shabelle river valley with Somalia has revealed no attractive on stream storage reservoir sites.

According to SWALIM-FAO on most of the small irrigation schemes with canal committees and water use association exists in the schemes, but there's no clear patterns of water allocation right and fees. On the result of this study confirm that if the river Shabelle water resources are developed/rehabilitated prewar barrages to cater for irrigation, and they improved the irrigation efficiency of new technology, it would be possible to attain the annual agricultural demand enough both for domestic consumption as well as for external markets.

4.2 Future water availability under different scenarios

4.2.1 Scenarios 1:current trend up to 2040

Scenario analysis enables the answering of ‘what if’ questions in a water system, the current trend up which is as usual scenario or is the base scenario that uses the actual data to help in understanding the best estimates about the studied period. The objective of a current scenario is to bring an understanding of the current trend other scenarios are built with variations on the demand or supply side (Eric Akivaga). The current scenario which the current account year as 2014 is extended to the ‘future’ (2015-2040).

The annual current trend up in livestock and domestic is significant growing by the year 2040, the total population of domestic and livestock reach 19,000,000 million. Figure 4.5 shows an increasing trend across the basin demand (arising because of increased the number of population in the basin, the annual water demand in livestock and domestic occur (125 Mm^3). It's clear dominance the agricultural water use without intervening over domestic and livestock demands.

Since the objective of this scenarios to present and evaluate the possibility of significant without intervening the irrigated agriculture, in this scenarios does not seems to be any obvious reason to reject the broad lines of the above reasons as it doesn't appear to be likely that water use.

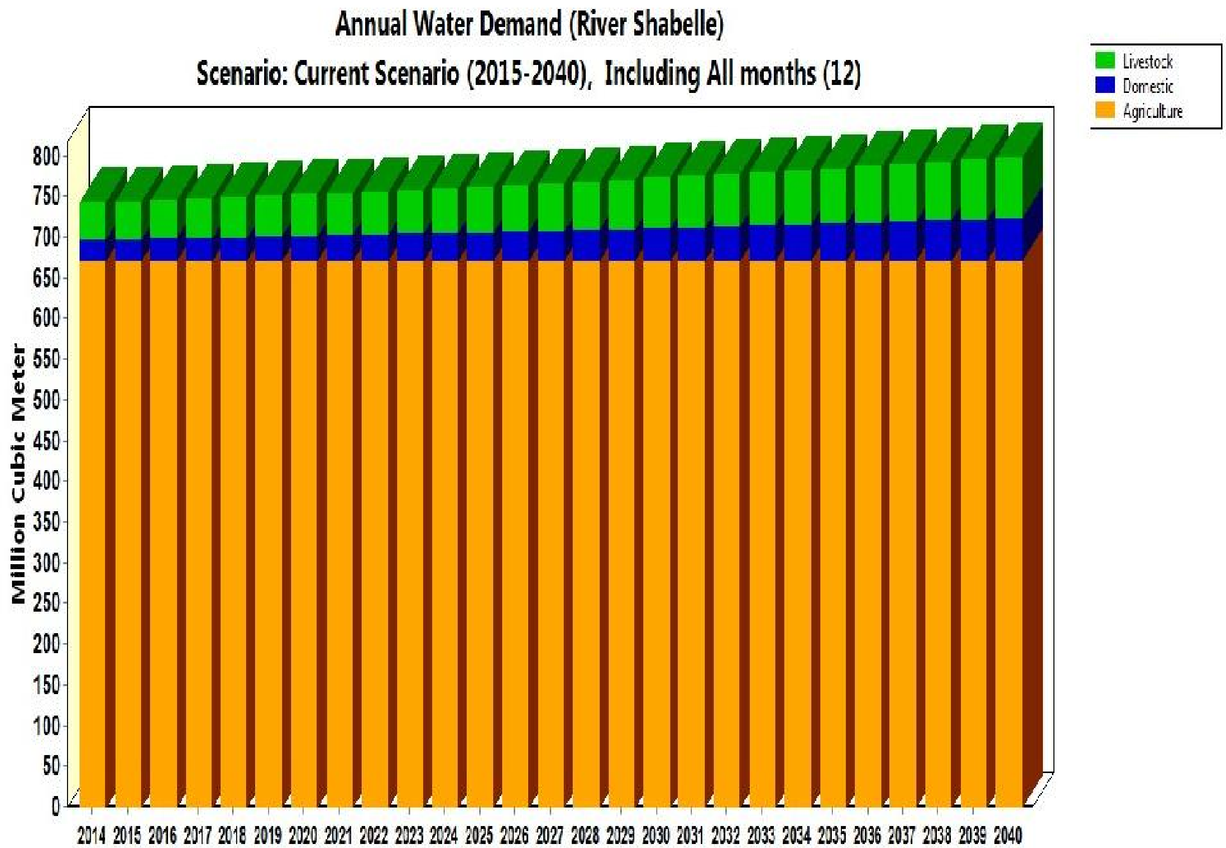


Figure 4.5: Future water demand based on current scenarios

For simulation river flow that annual river discharge in currently is 2.9 BCM, at Buloberde and the annual environmental flow is 290 Mm^3 which is exceeded 90 % of the time. With the assumption of these though the environmental demands are even slightly greater comparing the domestic and livestock with the annual total demands.

The current scenario is showed by the highest unmet water demand is irrigation scheme the water shortages occur often between Jan to Feb, of most years. Therefore demand site satisfaction is maximized subject to the mass balance supply preferences, demand priority and other constraints. In the result of Figure (4.6), all Demand are met except for Agricultural demands, however the average monthly demand site coverage is more than 90% except for the month of Feb therefore no acute domestic and livestock water shortage in the catchment.

The analytical comparison of the Agricultural, domestic and livestock population water demands reveals that the annual water demand of 1086 Mm^3 by the year 2040, This scenario shows that agricultural water demand consumes more than the total water demand for domestic, livestock and environmental use. This is actually the case of where greater than 64% of total annual water demand is used for agriculture.

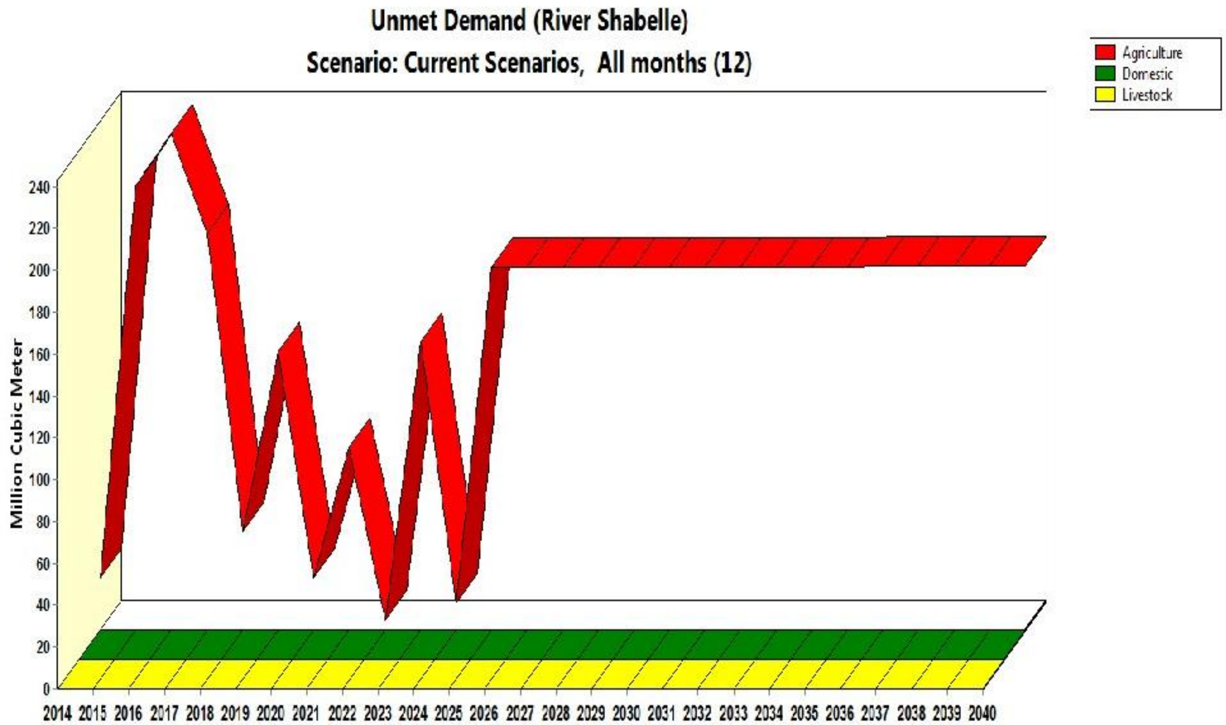


Figure 4.6: Figure unmet water demand based on current scenarios

Table 4.5: Total annual water demand in current trends

	Agricultural	**Domestic**	**Livestock**	**Environmental Flow**	**Total water**
Annual Activity	50,000 ha	4,357,752.3	12,707,055		
Water demand	671 (Mm^3)	52.7(Mm^3)	73.2(Mm^3)	290 (Mm^3)	1086 (Mm^3)
Unmet demand	240 (Mm^3)	-	-	-	

4.2.2 Scenario II: medium growth up to 2040

Assuming a general medium growth scenario for 2040, where agricultural production in Somalia is increased by the rehabilitation of irrigation infrastructure along the Shabelle river 135 000 ha (annually water demand is 1,814 Mm^3) the population in the Shabelle river has been grown to almost 4, 575, 450, (in 2040) annual water demand is 85 Mm^3, the annual growth rate we assume that 2.9% per annum. The livestock of the basin has become increasingly which is reach that 15,796, 245 million population and annual growth rate 2.2% per annum the annual water demand is raising (76 Mm^3 per year). Environmental flow demands stay the constant (annually 290 Mm^3 for the Shabelle River).

The total water demand reveals that the water demands in the Shabelle basin under medium growth assumptions would make up 68 % of the Shabelle stream flows, but again a comparison for the sector demand in performed in order to reveal the differences in developments and their impacts on the basins, as above, domestic and livestock demands are little abstraction assigned to the rivers.

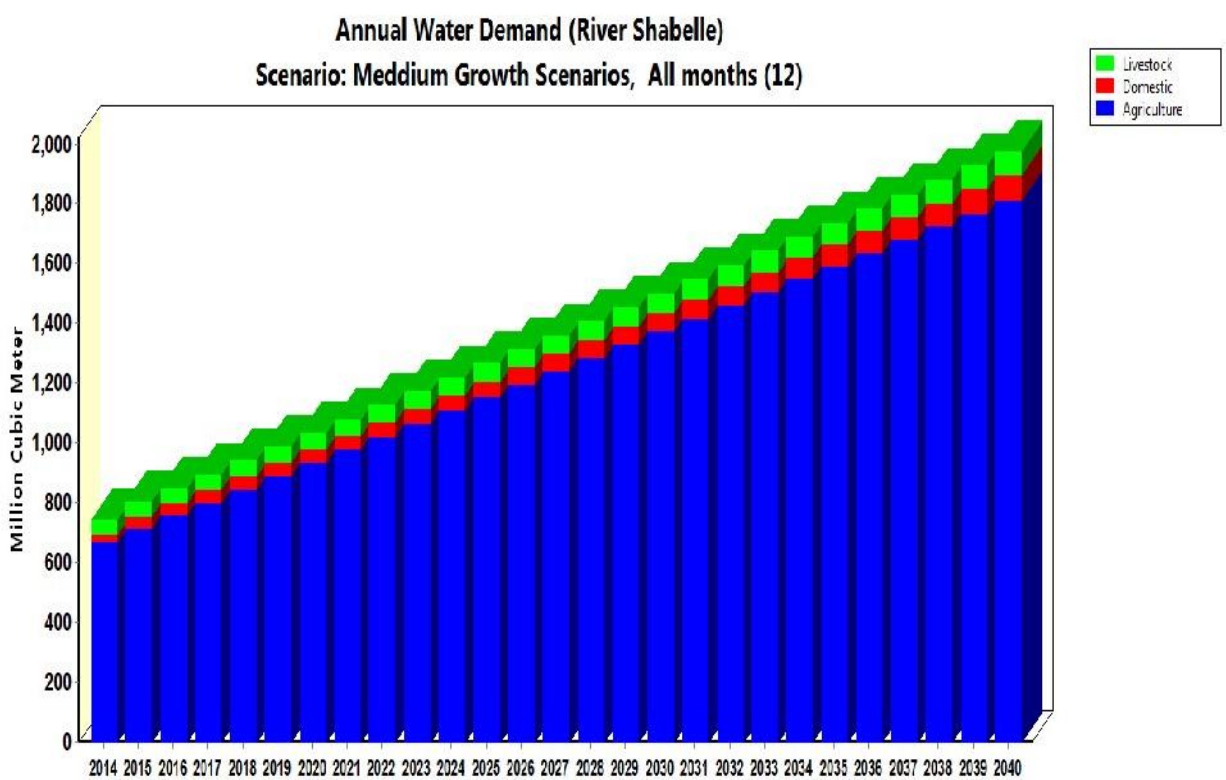


Figure 4.7: Future water demand based on medium scenarios

It must be highlighted at this point again, that there is extremely trends of demand in agricultural development and hence assumes quite high water demand and has envisioned correspondingly high absolute abstractions from the rivers, these at some point might surpass the available river flows in this scenarios for the Shabelle river for instance in the total water demands of 2265 Mm^3 have been abstracted from the total annual stream flow of 2900 Mm^3, and the 635 Mm^3 reaming to the river.

The unmet water demand are much higher in this scenarios, the dry season demands and supplies are not balanced, however the analysis show that the situation of the unmet water demand in monthly have been selected (December, to March). Average of monthly projections for river flows were selected the highest unmet water demand in February. The result in this scenarios shows that considering the flow at the Buloberde gauge station, the unmet demand during the February are hence projected as 380 $Mm^3$for Shabelle River, and the total unmet water demand is 700 Mm^3, due to the agricultural developments and demand variation some monthly flow are achieved in the medium growth scenario, hence the dry season the unmet water demand are relatively high as compared the rain season. However extended the development in these scenarios with the increasing of agricultural development no flow regulation will be happening in the Shabelle.

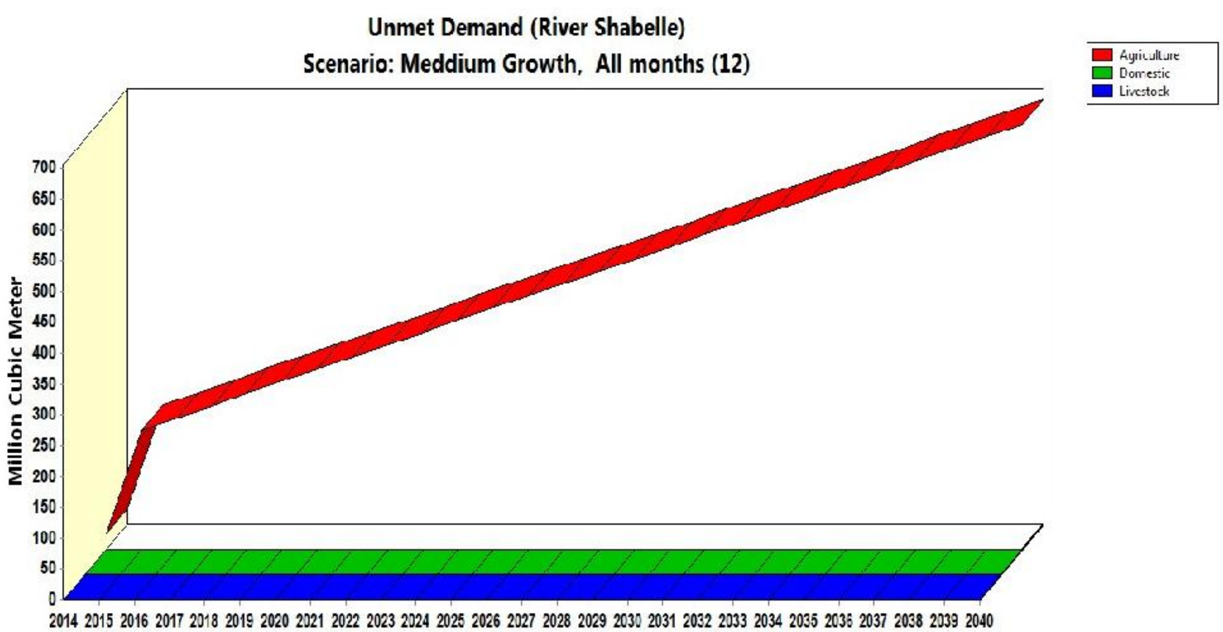


Figure 4.8: Unmet water demand based on medium scenarios

In the Shabelle basin the domestic, livestock and environmental water demands make up about 17 % of the total water demand according to this scenario, the agricultural water demands in the Shabelle basin make up 82 % of the total annual demand, is due to the fact that the highest crop water demands occur during Dec, to Feb.

Nevertheless the gap in the water balance is alarming and demonstrates the limits of the river flow especially in the dry season, even if domestic and livestock demands were entirely satisfied from ground water the deficit would not be covered in ecological river flow, only if agriculture abstractions would be reduced agricultural demands could be maintained without threatening the environmental reserve flow.

Table 4. 6 : Future water demand in medium growth scenario and remaining river flow

	Agricultural	**Domestic**	**Livestock**	**Environmental Flow**	**Total water**
Annual Activity	135,000 ha	4,575,450	12,707,055	-	-
Water demand	1,814 (Mm^3)	85 (Mm^3)	76 (Mm^3)	290 (Mm^3)	2265(Mm^3)
Unmet demand	700 (Mm^3)	-	-	-	

4.2.3 Scenario III: High growth up to 2040

Assuming a high growth scenario for 2040, where

Based on our assumption we assume Somalia has rehabilitated the pre war barrages which is 195,240 ha, the irrigation infrastructure along the Shabelle river will demand more than the current flow of Shabelle at the border and achieving a maximum river water use, total water demand is (2,623 Mm^3). The population in the Shabelle basin has grown to almost 4, 920 439 million in 2040 and annual water demand raise (120 Mm^3 basin per year), livestock numbers in Shabelle basin has been growing 16, 997 228 Million 2040 (80 Mm^3 per year).

In this scenarios the negative result are not entire sustaining the river flow since not all Sectors demands are actually satisfied from the river, the domestic as well as livestock demands are partly satisfied by in this scenarios, eventually compensating the deficit of the total river flow would be reduced to a minimum in any case. And agricultural demands were in fact higher than the flow at border these developments have been crossed more than the total annual flow.

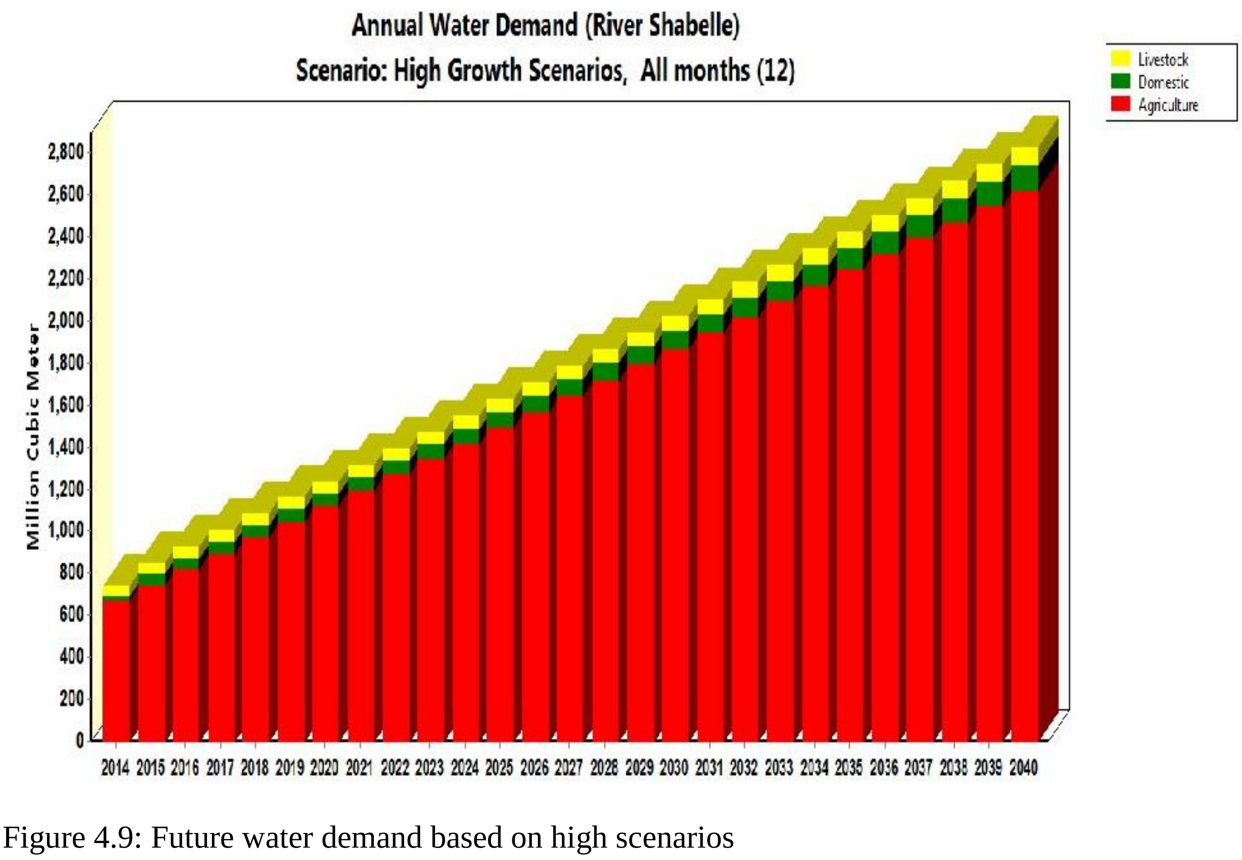


Figure 4.9: Future water demand based on high scenarios

In the high growth scenario agriculture is using about 85% of the total annual flow river, also the domestic demands have increased in absolute and relative terms In 2040, However they serve to reveal the consequences of certain development trends as well as the need for efficient utilization in order to respective development plans.

The demands in the Shabelle basin under the high growth scenario amount to about 97 % of the total river flows while in the certain development trends as well as the need for demands are far beyond the limits of supply. The deficit of 2800 Mm^3/year in the Shabelle basin corresponds to an annual flow of 2900 Mm^3/year.

Like in the agricultural scenario the planned water abstractions lay above the annual stream flows according to border measurements, the deficit at the stream flow would be amount to -150 Mm^3, even in wet seasons or in wet years river flows wouldn't be satisfied in sectors water demand at Shabelle basin. Concerning the unmet water demands under the high growth scenario, the available river flows at the Buloberde gauges station during the dry season are projected to be 1,150 Mm^3. Due to the agricultural developments the flow regulation in the Buloberde of Shabelle basin does not suffice though to supply the basin with any water during the dry season according to this result as mentioned above.

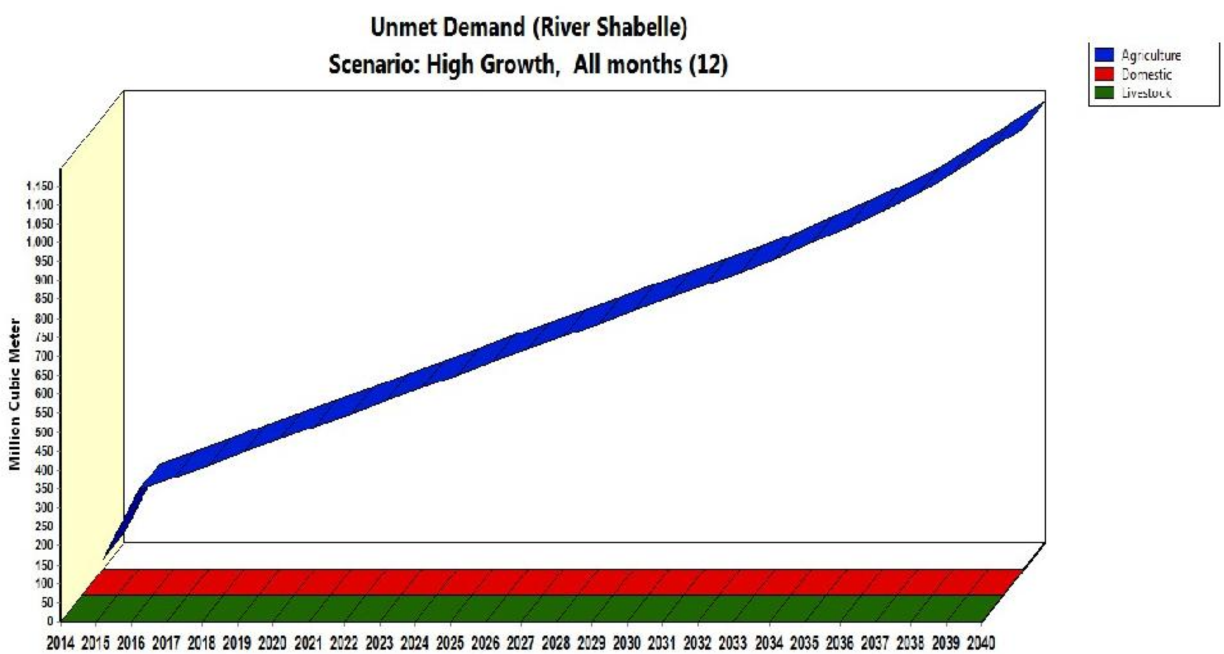


Figure 4.10: Unmet water demand based on high scenarios

The analysis reveals that, the full development of this scenario and high growth the population in the Shabelle basin would be unable to satisfy their basic water demands, such a development would potentially lead to waves of migration of the people and livestock towards to the major cities. Also there will be deterioration of irrigated agriculture along the Shabelle and hence that collapse of some of the major agricultural production zones within the basin, in ecological and limits water resource wouldn't be sustain their water needs of the population.

Table 4.7: Future water demand in high growth scenario

	Agricultural	**Domestic**	**Livestock**	**Environmental Flow**	**Total water**
Annual Activity	195,240 ha	4, 920 439	16, 997 228	-	-
Water demand	2,623 (Mm^3)	120 (Mm^3)	82.7(Mm^3)	290 (Mm^3)	3,116 (Mm^3)
Unmet demand	1,150 (Mm^3)				

4.2.4 Scenario IV: Improved irrigation efficiency

This scenario was modeled to assess the impact of improved irrigation efficiency when the annual water demand is greater than the currently river flow, It was adopted from the increased water demand scenario where the conditions of scenarios were imposed. It is proposed that if well managed surface irrigation methods, an overall irrigation scheme efficiency of 90% can be attained, this scenario based on assumption if they implement technologies which deliver water directly to the root zone, like drip irrigation these scenario was built to simulate irrigation efficiency of 90% at catchment irrigation scheme since the current scheme there's no efficiency existing.

By improving the irrigation efficiency averagely the highest amount of unmet demand for the irrigation scheme drops drastically from 315 Mm^3 to 145 Mm^3 (LG), from 700 to 320 in Mm^3 (MG) and 1,182 to 540 Mm^3 (HG). The demand coverage improves by an average of 7% (from 90% to 97%) in the (current Scenario), in The (MG scenarios) the demand coverage improves by an average of 18% from (74% to 91%); however in HG scenarios the coverage demand has improved 37% (from 43% to 80%).

However this scenario indicates that savings in irrigation water will significantly reduce water stress in all the other sectors in the catchment, it can also be argued that if certain apportionments or entitlements are given to users, then the water saved becomes extra amount of water available for irrigation. The supply of water for irrigation scheme in this scenario improved to above 74%, compared to above external water demand, it is clear from these scenarios that improved efficiency is imperative. In the context of water demand and equitable allocation of water resources in Shabelle catchment improved efficiency affects directly the availability of water for domestic and environmental flows, however the irrigation system required to meet this scenario is expensive but is more efficient.

Monthly	Current status Mm^3			Medium improvement by 2040 Mm^3			High improvement by 2040 Mm^3		
	Domestic	Livestock	Agriculture	Domestic	livestock	Agriculture	Domestic	Livestock	Agriculture
Jan	4.5	6.2	67.8	7.0	6.5	183.1	10.1	7.0	264.8
Feb	4.2	5.8	76.1	6.6	6.1	205.4	9.4	6.5	297
Mar	4.5	6.2	0.0	7.0	6.5	0.0	10.1	7.0	0.0
Apr	4.3	6.0	2.9	6.8	6.3	7.8	9.7	6.8	11.2
May	4.5	6.2	8.1	7.0	6.5	21.8	10.1	7.0	31.5
Jun	4.3	6.0	4.0	6.8	6.3	10.8	9.6	6.8	15.6
Jul	4.5	6.2	10.3	7.0	6.5	27.8	10.1	7.0	40.3
Aug	4.5	6.2	32.4	7.0	6.5	87.6	10.1	7.0	126.7
Sep	4.3	6.0	44.4	6.8	6.3	120	9.7	6.8	173.5
Oct	4.5	6.2	34.4	7.0	6.5	93.7	10.1	7.0	134.5
Nov	4.3	6.0	26.6	6.8	6.3	71.9	9.7	6.8	104
Dec	4.5	6.2	28.8	7.0	6.5	77.8	10.1	7.0	112.5

Table 4.8 : categories of improving in irrigation efficiency

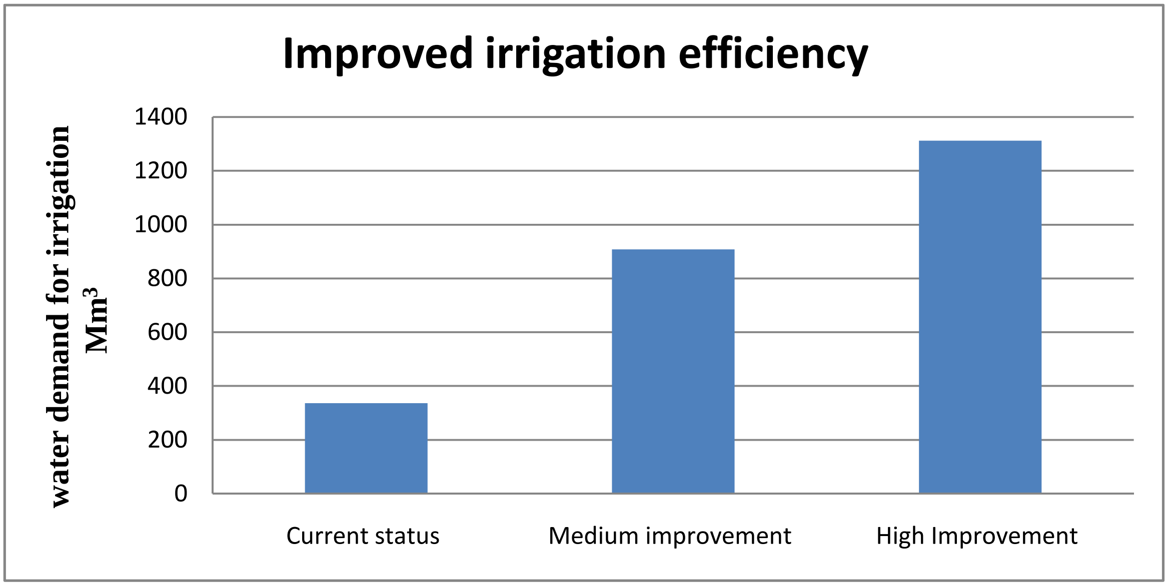


Figure 4.11: comparison of total water demand for improved irrigation efficiency scenarios

4.2.5 Summary and comparison with the scenarios for 2040

After analyzing the 2014 baseline data and the impact of the river flow, the WEAP model was configured for the current scenarios, MG and HG scenarios. The average annual unmet demands over the 25 years of hydrology were 144 Mm^3 (1.9% of the total annual demand), 425.8 Mm^3 (31% of the total annual demand) and 621.3 Mm^3 (34% of the total annual demand) for the current scenarios, MG and HG scenarios, the greatest shortfalls were experienced during the Jan and Feb where the river is low flow.

The environment flow requirement have met all scenarios but the most likely which can happened were Jan and Feb is a minimum river flow and is need to highly considerate the environment. For the HG scenario there was a shift in the worst year and the highest unmet demands were experienced during the January (278 Mm^3 and the normal river flow on that month were 70Mm^3).

Table 4.9: Summary table of the 2014 data and 2040 scenarios

Water demand sectors	2014 Data Mm^3	Current trend up to 2040 Mm^3	Medium growth up to 2040 Mm^3	High growth up to 2040 Mm^3
Domestic	26.1	52	80	120
Livestock	46	70	75	83
Agriculture	670	670	1800	2,623
Environment	290	290	290	290
Total	1032.1	1082	2245	3116

Table 4.10: Comparison water demand and unmet demand

Monthly	Average monthly Demand			Average monthly unmet demand		
	Current scenarios	**MG scenarios**	**HG scenarios**	**Current scenario**	**MG scenario**	**HG scenario**
Jan	143.7	260.8	344.6	57.9	191.3	277.5
Feb	159.5	290.5	384.0	86.2	234.5	331.1
Mar	8.1	9.9	12.0	0.0	0.0	0.0
Apr	13.6	20.2	25.7	0.0	0.0	0.0
May	24.2	39.7	51.6	0.0	0.0	0.0
Jun	15.8	24.4	31.2	0.0	0.0	0.0
Jul	28.7	48.1	62.6	0.0	0.0	0.0
Aug	73.0	129.9	171.1	0.0	0.0	8.2
Sep	96.7	174.0	229.6	0.0	0.0	2.3
Oct	77.0	137.3	180.9	0.0	0.0	0.0
Nov	61.1	108.1	142.2	0.0	0.0	0.0
Dec	65.7	116.5	153.3	0.0	0.0	2.2
Total	**767.0**	**1,359.6**	**1,788.9**	**144**	**425.8**	**621.3**

Estimation of the above table shows that deficit occur at present during January and February for mean flow condition and that they can occur in all months except in May, June, Sep and October for flow 75 percent probability level. For the proposed development deficit would occur during five month in mean flow and seven month of flow leaving 75 percent probability occurrence. In order to satisfy the sectors water demand, some from regulation storage can be seen to be essential since annual flow considerable exceeds the future demand

At the proposed level of development severe deficit can be expected even in years of normal stream flow, these deficit are likely to be much larger than flow indicated by above in high growth scenarios since these imply highest deficit that overall irrigation efficiency can be attained even in the present irrigated area where there's unmet demand. Clearly if it intended to increase the total irrigated area from the present 50, 000 to 200,000 ha some major revision of the cropping patterns and their water requirement will be addressed and sophisticated irrigation methods introduced to raise the overall irrigation efficiency.

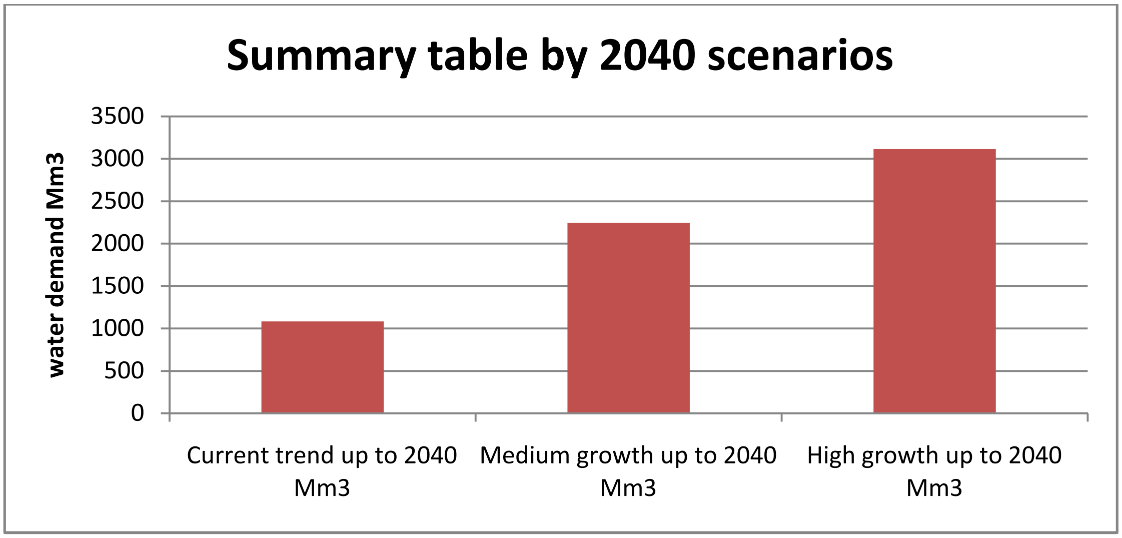


Figure 4.12: Comparison of total water demand by 2040 scenarios

Further extensions of perennial crops should be halted as their needs are much more difficult to meet than those of seasonal crops. It is reported that groundwater use cannot be restored to on a large scale, no one account the risk of exhaustion of the resource and not necessarily because of the higher cost but in view of the long term effect of salinity increase with water of the quality (Jean C. Henry, 1980).

The present view is that groundwater should be reserved to meet short period peak requirement when the stress on the surface water resource is felt most. Also Jean C. Henry, same study indicate that with irrigation efficiency of 45%, more than half the water extracted at headwork is lost, this lost is shared by aquifer recharge and evaportranspiration outside in the irrigation area wherever surface drainage is provided. Some though be given not only to the long term effect of this upon the groundwater system but also the possible reuse of any recoverable surface drainage, the quantities involved are large, more than the consumptive use, more than half the total volume of water that is distributed, it is understood that at present direct return of irrigation drainage the to the river in lawful.

It is clear that increased water storage in large barrages increases the area of land that can be irrigated and provided livelihood people; however the performance of that development will be curtailed as a consequence of shortage water. These results indicate the possible implications of one scenario in combination with different levels of water resource development, they illustrate how modeling can be used to determine possible implications of water demands and provide a useful contribution to the debate about how the water resources of the Shabelle basin in Somalia might be best utilized in the future.

However even ignoring the large degree of unquantifiable uncertainty associated with them, the results paint a complex picture in which there is no straightforward answer to the key question of whether investment in large-scale infrastructure should proceed. There is no win-win solution; the model results indicate that through provision of water for irrigation increased water storage behind large canals is likely to contribute the ecological sustainability on flow.

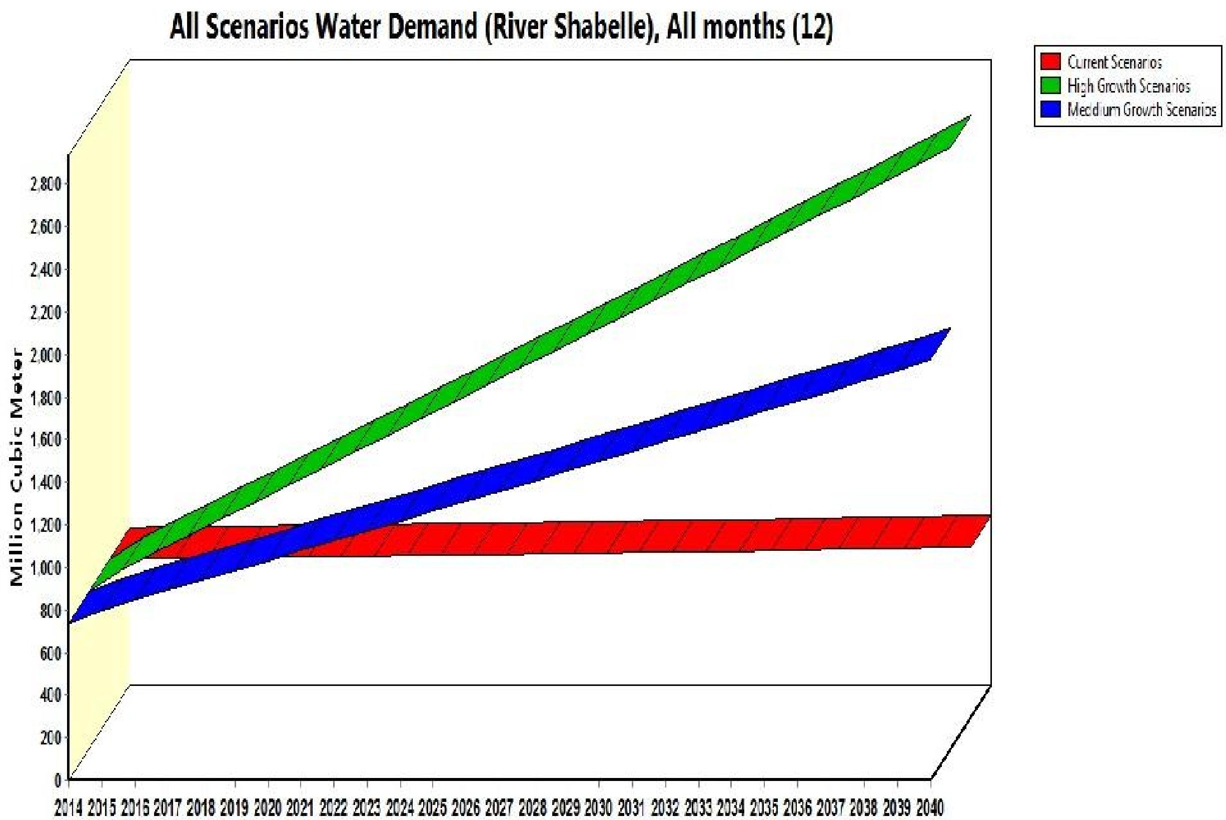


Figure 4.13: All scenarios in annual water demand

4.3. Strategies for improving water resource in Shabelle basin

4.3.1 Issue of Trans-boundary water resource management

Shabelle needs to shift towards an integrated policy for water management, where the policy will include all sectors for domestic, livestock, environment and agricultural water demand, and need to be focus on the integrated river basin management (IRBM) in whole catchment scale, figure 4.1 show that the annual water availability it depend the rainfall which falls in upstream of Ethiopia where the river flow varied from year to year. Shabelle river is necessary for joint management for cooperative between Ethiopia-Somalia partners and used to define equitable and efficient shares.

With the increasing activities in the Shabelle River Basin, it is expected that the sum of existing water uses and planned demands in the different countries will exceed available water resources in the Shabelle Basin and leading to shortages and potential disputes over the shared water resources. For example, Ethiopia is implementing large dams for hydropower generation and irrigation schemes, and Somalia has been developed several agricultural development projects Before the outbreak of the civil war in 1991, nine barrages were in built for the utilization of Shabelle river. In this regard, there is need to recognize the trans-boundary interconnectedness of the lives and livelihoods of the communities of the two countries that inhabit the Shabelle River Basin.

These development of the Shabelle River Basin is need to be entail closer cooperation between the affected countries in Ethiopia and Somalia and will ideally involve the coordinated utilization, protection and management of the shared water resources, through acknowledging their common languages, the natural resources that they share, their cross-border trade and the movements of people and livestock and consider the challenges of recurrent drought.

Both courtiers integrated approaches should be used as an approach to balance the use of water in various sectors the main important when an attempt is made to integration it can be potential opportunity, e.g. Regional economic cooperation and integration.

The contrast of this study Abdullahi Elmi 2014 has been raise the first potential opportunity, of integration of economic sectors in Ethiopia-Somalia such as agriculture and energy through water over cross-border cooperation. Second potential opportunity, Linking the rivers water to other economic sectors such as transport and trade, ports along the Somali coastlines which Ethiopia is desperate for as it lacks access to the sea could be linked to the rivers. The countries could mutually benefit, if the rivers run into Somalia without major consumptive uses in upstream Ethiopia in exchange to freely accessible ports for Ethiopia in the Somalia's coastlines (Elmi, 2014).

These development of political willing can also result from actions taken by regional economic communities, this initiative requires a strong cooperation of the administrations of the countries Ethiopia-Somalia. As a result, governments were stimulated to improve their national monitoring systems and better harmonization of two countries.

The catchment area of Somalia has been experienced consequence of poor water management over water resource extremely flood, pollution of rivers, destruction of catchment area, and water shortage of the river. Controlling water-related risks (floods, droughts, pollution) is more relevant than ever in a context of climate change that may aggravate the frequency of extreme events. The actions associated with this control (prevention, forecasting and protection) should be part of strategic planning on the scale of the trans-boundary basin. Once again, stakeholder participation and public consultation are needed.

It is important for countries to exchange information, especially hydro-meteorological data necessary for this control, and on the progress made in sectoral plans for controlling climate change impacts and management plans for droughts and floods. The information can be centralized by the trans-boundary basin organization.

Flood control is part of the IWRM concept. The slowing down of flooding dynamics in natural overflow channels (floodplains and wetlands) is effective and sustainable, including for the protection of downstream in Somalia, the control of human settlements in flood prone areas is an essential complement. From a development perspective, floodplain restoration helps to improve local livelihoods and reduced flooding risk is a major benefit for downstream countries communities.

4.3.2 Scenarios adaptation

A more rational allocation algorithm of scarce water is needed. This is primarily true in the agricultural sector where reducing the production of highly water-intensive crops can be accomplished by moving to more economically viable low water consuming plants, for food security, Shabelle therefore needs to explore the possibility of increasing overall irrigation efficiency in "virtual water" through addressing cropping patterns and their water requirement.

Also, fresh water use in agriculture should be reduced by implementing incentives that encourage more efficient water applications through adopting water-saving irrigation technologies and other farming techniques in strategies.

Increased reliance on treated wastewater in agriculture will also free up fresh water for use in other sectors. Before the collapse of the central Government, the irrigation department at the ministry of agriculture managed all irrigation schemes, infrastructure operation and maintenance, currently no official approval or registration (licensing) and respective extraction control, there is an obvious need for more efficient and effective water policies, metering of water use, and collection of water tariffs, enforcement of the surface water strategy policy and groundwater policies are particularly critical for achieving these objectives.

As shown in the irrigation efficiency in scenarios four (table 4.8), the results show that even if we apply technologies for improving irrigation efficient, surface water will not met irrigation water requirement, and is important for coordination in surface and groundwater in order to cover the monthly variation for unmet water demand.

The role of conjunctive use is particularly significant today, more than ever before, when there is growing need to satisfy the ever increasing water demand within the limited resources available while considering various social and environmental impacts of water utilization and protecting the resources for sustainability (Kifle Woldearegay, 2006)

Both surface water and groundwater are part of the hydrologic cycle and are interconncted. It is interesting to note that water resource utilization projects, from either surface or groundwater resources, tend to increase this interconnection.

However these conjunctive use of surface and groundwater therefore could help and address the issues related in water scarce during january and febuary and need to be considered as a key strategy for demand coverage and efficient utilization but groundwater recharge from surface water has to be improving, and using by integrated large scale for watershed management.

Stakeholder and civil society participation in water management and water conservation efforts must be encouraged through education and capacity building, and through making the political process more transparent and cooperative. It is exaggeration to suggest that Integrated River Basin Management be incorporated as a critical component of efficient and effective strategy to deal with water scarcity, and particularly for achieving high efficiency from using in increasingly scarce resource in Shabelle basin.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The overall objective of the study was to undertake surface water availability and demand analysis implication for enhancing water resource planning in Shabelle basin using the WEAP (Water Evaluation and Planning tool) approach.

Based on the findings of the study, the following conclusions were drawn:

Surface water availability in Shabelle catchment is (2900Mm^3 runoff) with the mean annual discharge is 93m^3/s at BuloBerde respectively, under the current water demand situation water demand for agricultural with 671.7 Mm^3 is the largest consumer of surface water followed by livestock 44.6 Mm^3, domestic water demand 26.1 Mm^3 and environmental water demands is 290 Mm^3. Currently the total annual water demand within the basin make up 30 % of the Shabelle river flow is sufficient to sustain all the water demands.

During the dry season the unmet water demand are much higher than 27%. There's no existing water allocation system which provide for community users in the catchment, except only, canal committees and water user associations exist in some areas but the entitlement to primary water use which is not even adequately quantified, the same applies for the environmental flows. In our ability to predict future water demand, we used three different scenarios of demand and trends that affect water resources on to each scenario.

The changes in water demand for the domestic, livestock, and irrigation will have significant impacts on the basin. The model simulations indicate that approximately 90% of irrigation demand has been met and the extending irrigated area will be broadly match the potential until the current scenarios of the 2015-2040.

However in the latter part of the scenarios in the medium growth 60% or less of the total irrigation demand will be met and only approximately 40% of annual water will be decline, in the high growth scenarios the water demand reach by (3,116Mm^3) is much more than what is available at the annual flow with Somalia (2900Mm^3).

The high growth scenario is the most sensitive of changes especially for agricultural development in the basin, the river flows in the high scenario cannot sustain the irrigation demand of Shabelle Irrigation scheme, therefore the scheme needs to embrace more efficient management of the available water resource, improved irrigation efficiency of the scheme improves overall demand coverage by 15% in all sectors.

5.2. Recommendations

Several recommendations can be derived from the results obtained and its analysis, it can be summarized as the following:-

1. Further development of the assessment model towards Shabelle basin is recommended in order to investigate the hydrological response and its consequences for the sake of the future water demand.

2. This study should be repeated for the same catchment in future using WEAP model after gathering adequate stream flow for downstream data levels at the study should focus on the domestic demand in by district within the basin to produce more realistic water resources availability scenarios.

3. It is also clear that the catchment is very vulnerable to drought situations; therefore there is an urgent need to increase reservoir, dams and weirs should be constructed along should River to improve water availability in the catchment during water scarcity.

4. Groundwater potential needs to be investigated and explored further to enable a more holistic investigation into the analysis of water management in this catchment, the possibility of using ground water for irrigation and water supply especially fear of water shortage problem in the monthly variation.

5. Scenarios analysis results from this study should be used in discussion among water planners, decision makers, and local authorities relating with management plans for the improvement of Shabelle river.

6. Consideration of the basin as unit for the integrated planning and management of water resources using an integrated approach between Ethiopia and Somalia.

7. Clearly, major adaptation will be needed in response for increasing water scarcity, especially in agricultural activities, adaptation may require.

- Major revision of the cropping patterns and their water requirement will be addressed and sophisticated irrigation methods introduced to raise the overall irrigation efficiency.
- Yet, drip irrigation systems are the most water-efficient as they deliver water directly to the root zone. Although this is an expensive technology and might need initial government or private investment, investment will pay off since drip irrigation is very effective at saving water, reducing evaporation and increasing crop yield.
- Night-time irrigation can substantially reduce water losses due to evaporation, soil moisture probes can also be helpful in optimizing irrigation through proper scheduling.

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APPENDIX A.a, Scenario I: Current trend up to 2040 for population Hiiran Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	132,379.0	388,146.0	2.41	3.19
2015	135,953.2	398,625.9	2.48	3.28
2016	139,624.0	409,388.8	2.55	3.37
2017	143,393.8	420,442.3	2.62	3.46
2018	147,265.5	431,794.3	2.69	3.55
2019	151,241.6	443,452.7	2.76	3.65
2020	155,325.1	455,426.0	2.83	3.74
2021	159,518.9	467,722.5	2.91	3.85
2022	163,825.9	480,351.0	2.99	3.95
2023	168,249.2	493,320.4	3.07	4.06
2024	172,792.0	506,640.1	3.15	4.17
2025	177,457.3	520,319.4	3.24	4.28
2026	182,248.7	534,368.0	3.32	4.39
2027	187,169.4	548,795.9	3.41	4.51
2028	192,223.0	563,613.4	3.51	4.63
2029	197,413.0	578,831.0	3.60	4.76
2030	202,743.2	594,459.4	3.70	4.89
2031	208,217.2	610,509.8	3.80	5.02
2032	213,839.1	626,993.6	3.90	5.16
2033	219,612.7	643,922.4	4.01	5.29
2034	225,542.3	661,308.3	4.11	5.44
2035	231,631.9	679,163.6	4.22	5.58
2036	237,886.0	697,501.1	4.34	5.73
2037	244,308.9	716,333.6	4.46	5.89
2038	250,905.2	735,674.6	4.58	6.05
2039	257,679.7	755,537.8	4.70	6.21
2040	264,637.0	775,937.3	4.83	6.38

APPENDIX A.b, Scenario I: Current trend up to 2040 for population Middle Shabelle Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	166,308.0	349,728.0	3.04	3.19
2015	170,798.3	359,170.7	3.12	3.28
2016	175,409.9	368,868.3	3.20	3.37
2017	180,145.9	378,827.7	3.29	3.46
2018	185,009.9	389,056.1	3.38	3.55
2019	190,005.1	399,560.6	3.47	3.65
2020	195,135.3	410,348.7	3.56	3.74
2021	200,403.9	421,428.1	3.66	3.85
2022	205,814.8	432,806.7	3.76	3.95
2023	211,371.8	444,492.5	3.86	4.06
2024	217,078.9	456,493.8	3.96	4.17
2025	222,940.0	468,819.1	4.07	4.28
2026	228,959.4	481,477.2	4.18	4.39
2027	235,141.3	494,477.1	4.29	4.51
2028	241,490.1	507,828.0	4.41	4.63
2029	248,010.3	521,539.3	4.53	4.76
2030	254,706.6	535,620.9	4.65	4.89
2031	261,583.7	550,082.6	4.77	5.02
2032	268,646.5	564,934.9	4.90	5.16
2033	275,899.9	580,188.1	5.04	5.29
2034	283,349.2	595,853.2	5.17	5.44
2035	290,999.6	611,941.2	5.31	5.58
2036	298,856.6	628,463.7	5.45	5.73
2037	306,925.8	645,432.2	5.60	5.89
2038	315,212.8	662,858.8	5.75	6.05
2039	323,723.5	680,756.0	5.91	6.21
2040	332,464.0	699,136.4	6.07	6.38

APPENDIX A.c, Scenario I: Current trend up to 2040 for population Lower Shabelle Regional

Year	population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	318,722.0	883,497.0	5.82	5.82
2015	327,327.5	907,351.4	5.97	5.97
2016	336,165.3	931,849.9	6.14	6.14
2017	345,241.8	957,009.9	6.30	6.30
2018	354,563.3	982,849.1	6.47	6.47
2019	364,136.5	1,009,386.0	6.65	6.65
2020	373,968.2	1,036,639.5	6.82	6.82
2021	384,065.4	1,064,628.7	7.01	7.01
2022	394,435.1	1,093,373.7	7.20	7.20
2023	405,084.9	1,122,894.8	7.39	7.39
2024	416,022.2	1,153,213.0	7.59	7.59
2025	427,254.8	1,184,349.7	7.80	7.80
2026	438,790.7	1,216,327.2	8.01	8.01
2027	450,638.0	1,249,168.0	8.22	8.22
2028	462,805.2	1,282,895.5	8.45	8.45
2029	475,301.0	1,317,533.7	8.67	8.67
2030	488,134.1	1,353,107.1	8.91	8.91
2031	501,313.7	1,389,641.0	9.15	9.15
2032	514,849.2	1,427,161.3	9.40	9.40
2033	528,750.1	1,465,694.7	9.65	9.65
2034	543,026.4	1,505,268.4	9.91	9.91
2035	557,688.1	1,545,910.7	10.18	10.18
2036	572,745.7	1,587,650.3	10.45	10.45
2037	588,209.8	1,630,516.8	10.73	10.73
2038	604,091.4	1,674,540.8	11.02	11.02
2039	620,401.9	1,719,753.4	11.32	11.32
2040	637,152.8	1,766,186.7	11.63	11.63

APPENDIX A.d, Scenario I: Current trend up to 2040 for Livestock Hiiran Regional

Year	Livestock population			Water demand (Mm³)		
	Cattle	Sheep/Goat	camel	Cattle	Sheep/Goat	Camel
2014	200,750.0	1,865,740.0	530,960.0	2.93	4.76	1.79
2015	200,750.0	1,865,740.0	530,960.0	2.93	4.76	1.79
2016	204,765.0	1,903,054.8	541,579.2	2.99	4.85	1.83
2017	208,860.3	1,941,115.9	552,410.8	3.05	4.95	1.87
2018	213,037.5	1,979,938.2	563,459.0	3.11	5.05	1.90
2019	217,298.3	2,019,537.0	574,728.2	3.17	5.15	1.94
2020	221,644.2	2,059,927.7	586,222.7	3.24	5.25	1.98
2021	226,077.1	2,101,126.3	597,947.2	3.30	5.36	2.02
2022	230,598.6	2,143,148.8	609,906.1	3.37	5.47	2.06
2023	235,210.6	2,186,011.8	622,104.3	3.43	5.57	2.10
2024	239,914.8	2,229,732.0	634,546.4	3.50	5.69	2.14
2025	244,713.1	2,274,326.6	647,237.3	3.57	5.80	2.19
2026	249,607.4	2,319,813.2	660,182.0	3.64	5.92	2.23
2027	254,599.5	2,366,209.4	673,385.7	3.72	6.03	2.28
2028	259,691.5	2,413,533.6	686,853.4	3.79	6.15	2.32
2029	264,885.4	2,461,804.3	700,590.4	3.87	6.28	2.37
2030	270,183.1	2,511,040.4	714,602.3	3.94	6.40	2.42
2031	275,586.7	2,561,261.2	728,894.3	4.02	6.53	2.46
2032	281,098.5	2,612,486.4	743,472.2	4.10	6.66	2.51
2033	286,720.4	2,664,736.2	758,341.6	4.19	6.80	2.56
2034	292,454.8	2,718,030.9	773,508.5	4.27	6.93	2.61
2035	298,303.9	2,772,391.5	788,978.6	4.36	7.07	2.67
2036	304,270.0	2,827,839.3	804,758.2	4.44	7.21	2.72
2037	310,355.4	2,884,396.1	820,853.4	4.53	7.36	2.77
2038	316,562.5	2,942,084.0	837,270.4	4.62	7.50	2.83
2039	322,893.8	3,000,925.7	854,015.8	4.71	7.65	2.89
2040	329,351.7	3,060,944.2	871,096.2	4.81	7.81	2.94

APPENDIX A.e, Scenario I: Current trend up to 2040 for Livestock Middle Shabelle Regional

Year	Livestock population			Water demand (Mm^3)		
	Cattle	Sheep/Goat	camel	Cattle	Sheep/goat	Camel
2014	44,320.0	1,848,380.0	235,140.0	0.65	4.71	1.03
2015	44,320.0	1,848,380.0	235,140.0	0.65	4.71	1.03
2016	45,206.4	1,885,347.6	239,842.8	0.66	4.81	1.05
2017	46,110.5	1,923,054.6	244,639.7	0.67	4.90	1.07
2018	47,032.7	1,961,515.6	249,532.4	0.69	5.00	1.09
2019	47,973.4	2,000,746.0	254,523.1	0.70	5.10	1.11
2020	48,932.9	2,040,760.9	259,613.6	0.71	5.20	1.14
2021	49,911.5	2,081,576.1	264,805.8	0.73	5.31	1.16
2022	50,909.7	2,123,207.6	270,101.9	0.74	5.41	1.18
2023	51,927.9	2,165,671.8	275,504.0	0.76	5.52	1.21
2024	52,966.5	2,208,985.2	281,014.1	0.77	5.63	1.23
2025	54,025.8	2,253,164.9	286,634.3	0.79	5.75	1.26
2026	55,106.3	2,298,228.2	292,367.0	0.80	5.86	1.28
2027	56,208.5	2,344,192.8	298,214.4	0.82	5.98	1.31
2028	57,332.6	2,391,076.6	304,178.7	0.84	6.10	1.33
2029	58,479.3	2,438,898.2	310,262.2	0.85	6.22	1.36
2030	59,648.9	2,487,676.1	316,467.5	0.87	6.34	1.39
2031	60,841.9	2,537,429.6	322,796.8	0.89	6.47	1.41
2032	62,058.7	2,588,178.2	329,252.8	0.91	6.60	1.44
2033	63,299.9	2,639,941.8	335,837.8	0.92	6.73	1.47
2034	64,565.9	2,692,740.6	342,554.6	0.94	6.87	1.50
2035	65,857.2	2,746,595.4	349,405.7	0.96	7.00	1.53
2036	67,174.3	2,801,527.4	356,393.8	0.98	7.14	1.56
2037	68,517.8	2,857,557.9	363,521.7	1.00	7.29	1.59
2038	69,888.2	2,914,709.1	370,792.1	1.02	7.43	1.62
2039	71,285.9	2,973,003.2	378,207.9	1.04	7.58	1.66
2040	72,711.7	3,032,463.3	385,772.1	1.06	7.73	1.69

APPENDIX A.f, Scenario I: Current trend up to 2040 Livestock Lower Shabelle Regional

Year	**Livestock Population**			**Water Demand (Mm^3)**		
	Cattle	Sheep/Goat	Camel	Cattle	Sheep/Goat	Camel
2014	43,940.0	3,748,210.0	336,070.0	0.6	9.6	1.5
2015	43,940.0	3,748,210.0	336,070.0	0.6	9.6	1.5
2016	44,818.8	3,823,174.2	342,791.4	0.7	9.7	1.5
2017	45,715.2	3,899,637.7	349,647.2	0.7	9.9	1.5
2018	46,629.5	3,977,630.4	356,640.2	0.7	10.1	1.6
2019	47,562.1	4,057,183.0	363,773.0	0.7	10.3	1.6
2020	48,513.3	4,138,326.7	371,048.4	0.7	10.6	1.6
2021	49,483.6	4,221,093.2	378,469.4	0.7	10.8	1.7
2022	50,473.2	4,305,515.1	386,038.8	0.7	11.0	1.7
2023	51,482.7	4,391,625.4	393,759.6	0.8	11.2	1.7
2024	52,512.4	4,479,457.9	401,634.8	0.8	11.4	1.8
2025	53,562.6	4,569,047.1	409,667.5	0.8	11.7	1.8
2026	54,633.9	4,660,428.0	417,860.8	0.8	11.9	1.8
2027	55,726.5	4,753,636.6	426,218.0	0.8	12.1	1.9
2028	56,841.1	4,848,709.3	434,742.4	0.8	12.4	1.9
2029	57,977.9	4,945,683.5	443,437.2	0.8	12.6	1.9
2030	59,137.5	5,044,597.2	452,306.0	0.9	12.9	2.0
2031	60,320.2	5,145,489.1	461,352.1	0.9	13.1	2.0
2032	61,526.6	5,248,398.9	470,579.1	0.9	13.4	2.1
2033	62,757.1	5,353,366.9	479,990.7	0.9	13.7	2.1
2034	64,012.3	5,460,434.2	489,590.5	0.9	13.9	2.1
2035	65,292.5	5,569,642.9	499,382.3	1.0	14.2	2.2
2036	66,598.4	5,681,035.7	509,370.0	1.0	14.5	2.2
2037	67,930.3	5,794,656.5	519,557.4	1.0	14.8	2.3
2038	69,289.0	5,910,549.6	529,948.5	1.0	15.1	2.3
2039	70,674.7	6,028,760.6	540,547.5	1.0	15.4	2.4
2040	72,088.2	6,149,335.8	551,358.5	1.1	15.7	2.4

APPENDIX B.a, Scenario II: Medium growth up to 2040 for Population Hiiraan Regional

Year	Hiiraan Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**rural**
2014	132,379.0	388,146.0	3.62	7.08
2105	136,218.0	399,402.2	3.73	7.29
2016	140,168.3	410,984.9	3.84	7.50
2017	144,233.2	422,903.5	3.95	7.72
2018	148,416.0	435,167.7	4.06	7.94
2019	152,720.0	447,787.5	4.18	8.17
2020	157,148.9	460,773.4	4.30	8.41
2021	161,706.2	474,135.8	4.43	8.65
2022	166,395.7	487,885.7	4.56	8.90
2023	171,221.2	502,034.4	4.69	9.16
2024	176,186.6	516,593.4	4.82	9.43
2025	181,296.0	531,574.6	4.96	9.70
2026	186,553.6	546,990.3	5.11	9.98
2027	191,963.6	562,853.0	5.26	10.27
2028	197,530.6	579,175.7	5.41	10.57
2029	203,259.0	595,971.8	5.57	10.88
2030	209,153.5	613,255.0	5.73	11.19
2031	215,218.9	631,039.4	5.89	11.52
2032	221,460.3	649,339.6	6.06	11.85
2033	227,882.6	668,170.4	6.24	12.19
2034	234,491.2	687,547.3	6.42	12.55
2035	241,291.5	707,486.2	6.61	12.91
2036	248,288.9	728,003.3	6.80	13.29
2037	255,489.3	749,115.4	7.00	13.67
2038	262,898.5	770,839.8	7.20	14.07
2039	270,522.5	793,194.1	7.41	14.48
2040	278,367.7	816,196.7	7.62	14.90

APPENDIX B.b, Scenario II: Medium growth up to 2040 for population Middle Shabelle Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	166,308.0	349,728.0	4.55	6.38
2105	171,130.9	359,870.1	4.69	6.57
2016	176,093.7	370,306.3	4.82	6.76
2017	181,200.4	381,045.2	4.96	6.95
2018	186,455.3	392,095.5	5.11	7.16
2019	191,862.5	403,466.3	5.25	7.36
2020	197,426.5	415,166.8	5.41	7.58
2021	203,151.8	427,206.7	5.56	7.80
2022	209,043.2	439,595.7	5.72	8.02
2023	215,105.5	452,343.9	5.89	8.26
2024	221,343.6	465,461.9	6.06	8.49
2025	227,762.5	478,960.3	6.24	8.74
2026	234,367.6	492,850.2	6.42	8.99
2027	241,164.3	507,142.8	6.60	9.26
2028	248,158.1	521,850.0	6.79	9.52
2029	255,354.6	536,983.6	6.99	9.80
2030	262,759.9	552,556.1	7.19	10.08
2031	270,380.0	568,580.3	7.40	10.38
2032	278,221.0	585,069.1	7.62	10.68
2033	286,289.4	602,036.1	7.84	10.99
2034	294,591.8	619,495.1	8.07	11.31
2035	303,134.9	637,460.5	8.30	11.63
2036	311,925.9	655,946.8	8.54	11.97
2037	320,971.7	674,969.3	8.79	12.32
2038	330,279.9	694,543.4	9.04	12.68
2039	339,858.0	714,685.2	9.31	13.04
2040	349,713.9	735,411.0	9.58	13.42

APPENDIX B.c, Scenario II: Medium growth up to 2040 for population Lower Shabelle Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	318,722.0	883,497.0	8.73	16.12
2015	327,964.9	909,118.4	8.98	16.59
2016	337,475.9	935,482.8	9.24	17.07
2017	347,262.7	962,611.8	9.51	17.57
2018	357,333.3	990,527.6	9.78	18.08
2019	367,696.0	1,019,252.9	10.07	18.60
2020	378,359.2	1,048,811.2	10.36	19.14
2021	389,331.6	1,079,226.8	10.66	19.70
2022	400,622.2	1,110,524.3	10.97	20.27
2023	412,240.3	1,142,729.5	11.29	20.85
2024	424,195.2	1,175,868.7	11.61	21.46
2025	436,496.9	1,209,968.9	11.95	22.08
2026	449,155.3	1,245,058.0	12.30	22.72
2027	462,180.8	1,281,164.7	12.65	23.38
2028	475,584.1	1,318,318.4	13.02	24.06
2029	489,376.0	1,356,549.7	13.40	24.76
2030	503,567.9	1,395,889.6	13.79	25.47
2031	518,171.4	1,436,370.4	14.19	26.21
2032	533,198.3	1,478,025.2	14.60	26.97
2033	548,661.1	1,520,887.9	15.02	27.76
2034	564,572.3	1,564,993.6	15.46	28.56
2035	580,944.9	1,610,378.4	15.91	29.39
2036	597,792.3	1,657,079.4	16.37	30.24
2037	615,128.2	1,705,134.7	16.84	31.12
2038	632,967.0	1,754,583.6	17.33	32.02
2039	651,323.0	1,805,466.6	17.83	32.95
2040	670,211.4	1,857,825.1	18.35	33.91

APPENDIX B.d, Scenario II: Medium growth up to 2040 for livestock Hiiran Regional

Year	Livestock population			Water demand (Mm^3)		
	Cattle	**Sheep/Goat**	**Camel**	**Cattle**	**Sheep/Goat**	**Camel**
2014	200,750.0	1,865,740.0	530,960.0	2.9	4.8	1.8
2015	200,750.0	1,865,740.0	530,960.0	2.9	4.8	1.8
2016	205,166.5	1,906,786.3	542,641.1	3.0	4.9	1.8
2017	209,680.2	1,948,735.6	554,579.2	3.1	5.0	1.9
2018	214,293.1	1,991,607.8	566,780.0	3.1	5.1	1.9
2019	219,007.6	2,035,423.1	579,249.1	3.2	5.2	2.0
2020	223,825.7	2,080,202.4	591,992.6	3.3	5.3	2.0
2021	228,749.9	2,125,966.9	605,016.4	3.3	5.4	2.0
2022	233,782.4	2,172,738.2	618,326.8	3.4	5.5	2.1
2023	238,925.6	2,220,538.4	631,930.0	3.5	5.7	2.1
2024	244,182.0	2,269,390.3	645,832.5	3.6	5.8	2.2
2025	249,554.0	2,319,316.8	660,040.8	3.6	5.9	2.2
2026	255,044.2	2,370,341.8	674,561.7	3.7	6.0	2.3
2027	260,655.1	2,422,489.3	689,402.0	3.8	6.2	2.3
2028	266,389.6	2,475,784.1	704,568.9	3.9	6.3	2.4
2029	272,250.1	2,530,251.3	720,069.4	4.0	6.5	2.4
2030	278,239.6	2,585,916.9	735,910.9	4.1	6.6	2.5
2031	284,360.9	2,642,807.0	752,101.0	4.2	6.7	2.5
2032	290,616.8	2,700,948.8	768,647.2	4.2	6.9	2.6
2033	297,010.4	2,760,369.7	785,557.4	4.3	7.0	2.7
2034	303,544.6	2,821,097.8	802,839.7	4.4	7.2	2.7
2035	310,222.6	2,883,162.0	820,502.1	4.5	7.4	2.8
2036	317,047.5	2,946,591.5	838,553.2	4.6	7.5	2.8
2037	324,022.6	3,011,416.5	857,001.4	4.7	7.7	2.9
2038	331,151.1	3,077,667.7	875,855.4	4.8	7.8	3.0
2039	338,436.4	3,145,376.4	895,124.2	4.9	8.0	3.0
2040	345,882.0	3,214,574.7	914,816.9	5.0	8.2	3.1

APPENDIX B.e, Scenario II: Medium growth up to 2040 for livestock Middle Shabelle Regional

Year	Livestock Population			Water demand (Mm^3)		
	Cattle	**Sheep/Goat**	**Camel**	**Cattle**	**Sheep/Goat**	**Camel**
2014	44,320.0	1,848,380.0	235,140.0	4.7	0.6	1.0
2015	44,320.0	1,848,380.0	235,140.0	4.7	0.6	1.0
2016	45,295.0	1,889,044.4	240,313.1	4.8	0.7	1.1
2017	46,291.5	1,930,603.3	245,600.0	4.9	0.7	1.1
2018	47,309.9	1,973,076.6	251,003.2	5.0	0.7	1.1
2019	48,350.8	2,016,484.3	256,525.2	5.1	0.7	1.1
2020	49,414.5	2,060,846.9	262,168.8	5.3	0.7	1.1
2021	50,501.6	2,106,185.6	267,936.5	5.4	0.8	1.2
2022	51,612.6	2,152,521.7	273,831.1	5.5	0.8	1.2
2023	52,748.1	2,199,877.1	279,855.4	5.6	0.8	1.2
2024	53,908.6	2,248,274.4	286,012.2	5.7	0.8	1.3
2025	55,094.6	2,297,736.5	292,304.5	5.9	0.8	1.3
2026	56,306.6	2,348,286.7	298,735.2	6.0	0.8	1.3
2027	57,545.4	2,399,949.0	305,307.4	6.1	0.9	1.3
2028	58,811.4	2,452,747.9	312,024.1	6.3	0.9	1.4
2029	60,105.2	2,506,708.3	318,888.6	6.4	0.9	1.4
2030	61,427.5	2,561,855.9	325,904.2	6.5	0.9	1.4
2031	62,779.0	2,618,216.7	333,074.1	6.7	0.9	1.5
2032	64,160.1	2,675,817.5	340,401.7	6.8	1.0	1.5
2033	65,571.6	2,734,685.5	347,890.6	7.0	1.0	1.5
2034	67,014.2	2,794,848.6	355,544.1	7.1	1.0	1.6
2035	68,488.5	2,856,335.2	363,366.1	7.3	1.0	1.6
2036	69,995.2	2,919,174.6	371,360.2	7.4	1.0	1.6
2037	71,535.1	2,983,396.4	379,530.1	7.6	1.1	1.7
2038	73,108.9	3,049,031.2	387,879.8	7.8	1.1	1.7
2039	74,717.3	3,116,109.9	396,413.1	7.9	1.1	1.7
2040	76,361.1	3,184,664.3	405,134.2	8.1	1.1	1.8

APPENDIX B.f, Scenario II: Medium growth up to 2040 for livestock Lower Shabelle Regional

Year	Livestock Population			Water demand (Mm^3)		
	Cattle	**Sheep/Goat**	**Camel**	**Cattel**	**Sheep/Goat**	**Camel**
2014	43,940.0	3,748,210.0	336,070.0	0.6	9.6	1.5
2015	43,940.0	3,748,210.0	336,070.0	0.6	9.6	1.5
2016	44,906.7	3,830,670.6	343,463.5	0.7	9.8	1.5
2017	45,894.6	3,914,945.4	351,019.7	0.7	10.0	1.5
2018	46,904.3	4,001,074.2	358,742.2	0.7	10.2	1.6
2019	47,936.2	4,089,097.8	366,634.5	0.7	10.4	1.6
2020	48,990.8	4,179,058.0	374,700.5	0.7	10.7	1.6
2021	50,068.6	4,270,997.2	382,943.9	0.7	10.9	1.7
2022	51,170.1	4,364,959.2	391,368.6	0.7	11.1	1.7
2023	52,295.8	4,460,988.3	399,978.7	0.8	11.4	1.8
2024	53,446.4	4,559,130.0	408,778.3	0.8	11.6	1.8
2025	54,622.2	4,659,430.9	417,771.4	0.8	11.9	1.8
2026	55,823.9	4,761,938.4	426,962.4	0.8	12.1	1.9
2027	57,052.0	4,866,701.0	436,355.5	0.8	12.4	1.9
2028	58,307.1	4,973,768.4	445,955.4	0.9	12.7	2.0
2029	59,589.9	5,083,191.3	455,766.4	0.9	13.0	2.0
2030	60,900.9	5,195,021.5	465,793.2	0.9	13.2	2.0
2031	62,240.7	5,309,312.0	476,040.7	0.9	13.5	2.1
2032	63,610.0	5,426,116.9	486,513.6	0.9	13.8	2.1
2033	65,009.4	5,545,491.4	497,216.9	0.9	14.1	2.2
2034	66,439.6	5,667,492.3	508,155.7	1.0	14.5	2.2
2035	67,901.3	5,792,177.1	519,335.1	1.0	14.8	2.3
2036	69,395.1	5,919,605.0	530,760.5	1.0	15.1	2.3
2037	70,921.8	6,049,836.3	542,437.2	1.0	15.4	2.4
2038	72,482.1	6,182,932.7	554,370.8	1.1	15.8	2.4
2039	74,076.7	6,318,957.2	566,567.0	1.1	16.1	2.5
2040	75,706.4	6,457,974.3	579,031.4	1.1	16.5	2.5

APPENDIX C.a, Scenario III: High growth up to 2040 for Population Hiiraan Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	132,379.0	388,146.0	4.83	10.63
2015	136,615.1	400,566.7	4.99	10.97
2016	140,986.8	413,384.8	5.15	11.32
2017	145,498.4	426,613.1	5.31	11.68
2018	150,154.3	440,264.7	5.48	12.05
2019	154,959.3	454,353.2	5.66	12.44
2020	159,918.0	468,892.5	5.84	12.84
2021	165,035.3	483,897.1	6.02	13.25
2022	170,316.5	499,381.8	6.22	13.67
2023	175,766.6	515,362.0	6.42	14.11
2024	181,391.1	531,853.6	6.62	14.56
2025	187,195.7	548,872.9	6.83	15.03
2026	193,185.9	566,436.8	7.05	15.51
2027	199,367.9	584,562.8	7.28	16.00
2028	205,747.6	603,268.8	7.51	16.51
2029	212,331.6	622,573.4	7.75	17.04
2030	219,126.2	642,495.8	8.00	17.59
2031	226,138.2	663,055.6	8.25	18.15
2032	233,374.6	684,273.4	8.52	18.73
2033	240,842.6	706,170.2	8.79	19.33
2034	248,549.6	728,767.6	9.07	19.95
2035	256,503.2	752,088.2	9.36	20.59
2036	264,711.3	776,155.0	9.66	21.25
2037	273,182.0	800,992.0	9.97	21.93
2038	281,923.9	826,623.7	10.29	22.63
2039	290,945.4	853,075.7	10.62	23.35
2040	300,255.7	880,374.1	10.96	24.10

APPENDIX C.b, Scenario III: High growth up to 2040 for Population Middle Shabelle Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	166,308.0	349,728.0	6.07	9.57
2015	171,629.9	360,919.3	6.26	9.88
2016	177,122.0	372,468.7	6.46	10.20
2017	182,789.9	384,387.7	6.67	10.52
2018	188,639.2	396,688.1	6.89	10.86
2019	194,675.6	409,382.1	7.11	11.21
2020	200,905.3	422,482.4	7.33	11.57
2021	207,334.2	436,001.8	7.57	11.94
2022	213,968.9	449,953.9	7.81	12.32
2023	220,815.9	464,352.4	8.06	12.71
2024	227,882.0	479,211.7	8.32	13.12
2025	235,174.3	494,546.4	8.58	13.54
2026	242,699.9	510,371.9	8.86	13.97
2027	250,466.2	526,703.8	9.14	14.42
2028	258,481.2	543,558.3	9.43	14.88
2029	266,752.6	560,952.2	9.74	15.36
2030	275,288.6	578,902.7	10.05	15.85
2031	284,097.9	597,427.6	10.37	16.35
2032	293,189.0	616,545.2	10.70	16.88
2033	302,571.1	636,274.7	11.04	17.42
2034	312,253.3	656,635.5	11.40	17.98
2035	322,245.4	677,647.8	11.76	18.55
2036	332,557.3	699,332.6	12.14	19.14
2037	343,199.1	721,711.2	12.53	19.76
2038	354,181.5	744,806.0	12.93	20.39
2039	365,515.3	768,639.7	13.34	21.04
2040	377,211.8	793,236.2	13.77	21.71

APPENDIX C.c, Scenario III: High growth up to 2040 for Population Lower Shabelle Regional

Year	Population		Water demand (Mm^3)	
	Urban	**Rural**	**Urban**	**Rural**
2014	318,722.0	883,497.0	11.63	24.19
2015	328,921.1	911,768.9	12.01	24.96
2016	339,446.6	940,945.5	12.39	25.76
2017	350,308.9	971,055.8	12.79	26.58
2018	361,518.8	1,002,129.5	13.20	27.43
2019	373,087.4	1,034,197.7	13.62	28.31
2020	385,026.1	1,067,292.0	14.05	29.22
2021	397,347.0	1,101,445.4	14.50	30.15
2022	410,062.1	1,136,691.6	14.97	31.12
2023	423,184.1	1,173,065.7	15.45	32.11
2024	436,726.0	1,210,603.9	15.94	33.14
2025	450,701.2	1,249,343.2	16.45	34.20
2026	465,123.6	1,289,322.2	16.98	35.30
2027	480,007.6	1,330,580.5	17.52	36.42
2028	495,367.8	1,373,159.0	18.08	37.59
2029	511,219.6	1,417,100.1	18.66	38.79
2030	527,578.6	1,462,447.3	19.26	40.03
2031	544,461.1	1,509,245.7	19.87	41.32
2032	561,883.9	1,557,541.5	20.51	42.64
2033	579,864.2	1,607,382.8	21.17	44.00
2034	598,419.8	1,658,819.1	21.84	45.41
2035	617,569.3	1,711,901.3	22.54	46.86
2036	637,331.5	1,766,682.1	23.26	48.36
2037	657,726.1	1,823,216.0	24.01	49.91
2038	678,773.3	1,881,558.9	24.78	51.51
2039	700,494.1	1,941,768.8	25.57	53.16
2040	722,909.9	2,003,905.4	26.39	54.86

APPENDIX C.d, Scenario III: High growth up to 2040 for livestock Hiiraan Regional

Year	Livestock Population			Water demand (Mm^3)		
	Cattle	**Sheep/Goat**	**Camel**	**Cattle**	**Sheep/Goat**	**Camel**
2014	200,750.0	1,865,740.0	530,960.0	2.9	4.8	1.8
2015	200,750.0	1,865,740.0	530,960.0	2.9	4.8	1.8
2016	205,768.8	1,912,383.5	544,234.0	3.0	4.9	1.8
2017	210,913.0	1,960,193.1	557,839.8	3.1	5.0	1.9
2018	216,185.8	2,009,197.9	571,785.8	3.2	5.1	1.9
2019	221,590.4	2,059,427.9	586,080.5	3.2	5.3	2.0
2020	227,130.2	2,110,913.6	600,732.5	3.3	5.4	2.0
2021	232,808.5	2,163,686.4	615,750.8	3.4	5.5	2.1
2022	238,628.7	2,217,778.6	631,144.6	3.5	5.7	2.1
2023	244,594.4	2,273,223.0	646,923.2	3.6	5.8	2.2
2024	250,709.2	2,330,053.6	663,096.3	3.7	5.9	2.2
2025	256,977.0	2,388,304.9	679,673.7	3.8	6.1	2.3
2026	263,401.4	2,448,012.6	696,665.5	3.8	6.2	2.4
2027	269,986.4	2,509,212.9	714,082.2	3.9	6.4	2.4
2028	276,736.1	2,571,943.2	731,934.2	4.0	6.6	2.5
2029	283,654.5	2,636,241.8	750,232.6	4.1	6.7	2.5
2030	290,745.9	2,702,147.8	768,988.4	4.2	6.9	2.6
2031	298,014.5	2,769,701.5	788,213.1	4.4	7.1	2.7
2032	305,464.9	2,838,944.1	807,918.4	4.5	7.2	2.7
2033	313,101.5	2,909,917.7	828,116.4	4.6	7.4	2.8
2034	320,929.0	2,982,665.6	848,819.3	4.7	7.6	2.9
2035	328,952.3	3,057,232.2	870,039.8	4.8	7.8	2.9
2036	337,176.1	3,133,663.0	891,790.8	4.9	8.0	3.0
2037	345,605.5	3,212,004.6	914,085.5	5.0	8.2	3.1
2038	354,245.6	3,292,304.7	936,937.7	5.2	8.4	3.2
2039	363,101.7	3,374,612.4	960,361.1	5.3	8.6	3.2
2040	372,179.3	3,458,977.7	984,370.2	5.4	8.8	3.3

APPENDIX C.e, Scenario III: High growth up to 2040 for livestock Middle Shabelle Regional

Year	Livestock Population			Water demand (Mm^3)		
	Cattle	**Sheep/Goat**	**Camel**	**Cattle**	**Sheep/Goat**	**Camel**
2014	44,320.0	1,848,380.0	235,140.0	0.6	4.7	1.0
2015	44,320.0	1,848,380.0	235,140.0	0.6	4.7	1.0
2016	45,428.0	1,894,589.5	241,018.5	0.7	4.8	1.1
2017	46,563.7	1,941,954.2	247,044.0	0.7	5.0	1.1
2018	47,727.8	1,990,503.1	253,220.1	0.7	5.1	1.1
2019	48,921.0	2,040,265.7	259,550.6	0.7	5.2	1.1
2020	50,144.0	2,091,272.3	266,039.3	0.7	5.3	1.2
2021	51,397.6	2,143,554.1	272,690.3	0.8	5.5	1.2
2022	52,682.6	2,197,143.0	279,507.6	0.8	5.6	1.2
2023	53,999.6	2,252,071.5	286,495.3	0.8	5.7	1.3
2024	55,349.6	2,308,373.3	293,657.6	0.8	5.9	1.3
2025	56,733.3	2,366,082.7	300,999.1	0.8	6.0	1.3
2026	58,151.7	2,425,234.7	308,524.1	0.8	6.2	1.4
2027	59,605.5	2,485,865.6	316,237.2	0.9	6.3	1.4
2028	61,095.6	2,548,012.2	324,143.1	0.9	6.5	1.4
2029	62,623.0	2,611,712.6	332,246.7	0.9	6.7	1.5
2030	64,188.6	2,677,005.4	340,552.8	0.9	6.8	1.5
2031	65,793.3	2,743,930.5	349,066.7	1.0	7.0	1.5
2032	67,438.1	2,812,528.8	357,793.3	1.0	7.2	1.6
2033	69,124.1	2,882,842.0	366,738.2	1.0	7.4	1.6
2034	70,852.2	2,954,913.0	375,906.6	1.0	7.5	1.6
2035	72,623.5	3,028,785.9	385,304.3	1.1	7.7	1.7
2036	74,439.1	3,104,505.5	394,936.9	1.1	7.9	1.7
2037	76,300.0	3,182,118.1	404,810.3	1.1	8.1	1.8
2038	78,207.5	3,261,671.1	414,930.6	1.1	8.3	1.8
2039	80,162.7	3,343,212.9	425,303.8	1.2	8.5	1.9
2040	82,166.8	3,426,793.2	435,936.4	1.2	8.7	1.9

APPENDIX C.f, Scenario III: High growth up to 2040 for livestock Lower Shabelle Regional

Year	Livestock Population			Water demand (Mm^3)		
	Cattle	**Sheep/Goat**	**Camel**	**Cattle**	**Sheep/Goat**	**Camel**
2014	43,940.0	3,748,210.0	336,070.0	0.6	9.6	1.5
2015	43,940.0	3,748,210.0	336,070.0	0.6	9.6	1.5
2016	45,038.5	3,841,915.3	344,471.8	0.7	9.8	1.5
2017	46,164.5	3,937,963.1	353,083.5	0.7	10.0	1.5
2018	47,318.6	4,036,412.2	361,910.6	0.7	10.3	1.6
2019	48,501.5	4,137,322.5	370,958.4	0.7	10.6	1.6
2020	49,714.1	4,240,755.6	380,232.4	0.7	10.8	1.7
2021	50,956.9	4,346,774.5	389,738.2	0.7	11.1	1.7
2022	52,230.9	4,455,443.8	399,481.6	0.8	11.4	1.7
2023	53,536.6	4,566,829.9	409,468.7	0.8	11.6	1.8
2024	54,875.0	4,681,000.7	419,705.4	0.8	11.9	1.8
2025	56,246.9	4,798,025.7	430,198.0	0.8	12.2	1.9
2026	57,653.1	4,917,976.3	440,953.0	0.8	12.5	1.9
2027	59,094.4	5,040,925.7	451,976.8	0.9	12.9	2.0
2028	60,571.8	5,166,948.9	463,276.2	0.9	13.2	2.0
2029	62,086.1	5,296,122.6	474,858.1	0.9	13.5	2.1
2030	63,638.2	5,428,525.7	486,729.6	0.9	13.8	2.1
2031	65,229.2	5,564,238.8	498,897.8	1.0	14.2	2.2
2032	66,859.9	5,703,344.8	511,370.2	1.0	14.5	2.2
2033	68,531.4	5,845,928.4	524,154.5	1.0	14.9	2.3
2034	70,244.7	5,992,076.6	537,258.4	1.0	15.3	2.4
2035	72,000.8	6,141,878.5	550,689.8	1.1	15.7	2.4
2036	73,800.8	6,295,425.5	564,457.1	1.1	16.1	2.5
2037	75,645.8	6,452,811.1	578,568.5	1.1	16.5	2.5
2038	77,537.0	6,614,131.4	593,032.7	1.1	16.9	2.6
2039	79,475.4	6,779,484.7	607,858.5	1.2	17.3	2.7
2040	81,462.3	6,948,971.8	623,055.0	1.2	17.7	2.8

APPENDIX D.a, Agriculture water demand in Medium growth up to 2040

Year	Irrigated area (Ha)	Agricultural water demand (Mm^3)
2014	50,000.0	671.7
2015	53,269.2	715.7
2016	56,538.5	759.6
2017	59,807.7	803.5
2018	63,076.9	847.4
2019	66,346.2	891.4
2020	69,615.4	935.3
2021	72,884.6	979.2
2022	76,153.8	1,023.1
2023	79,423.1	1,067.0
2024	82,692.3	1,111.0
2025	85,961.5	1,154.9
2026	89,230.8	1,198.8
2027	92,500.0	1,242.7
2028	95,769.2	1,286.7
2029	99,038.5	1,330.6
2030	102,307.7	1,374.5
2031	105,576.9	1,418.4
2032	108,846.2	1,462.3
2033	112,115.4	1,506.3
2034	115,384.6	1,550.2
2035	118,653.8	1,594.1
2036	121,923.1	1,638.0
2037	125,192.3	1,682.0
2038	128,461.5	1,725.9
2039	131,730.8	1,769.8
2040	135,000.0	1,813.7

APPENDIX D. b, Agricultural water demand in High growth up to 2040

Year	Irrigated area (Ha)	Agricultural water demand (Mm^3)
2014	50,000.0	671.7
2015	55,586.2	746.8
2016	61,172.5	821.9
2017	66,758.7	896.9
2018	72,344.9	972.0
2019	77,931.2	1,047.0
2020	83,517.4	1,122.1
2021	89,103.6	1,197.1
2022	94,689.8	1,272.2
2023	100,276.1	1,347.2
2024	105,862.3	1,422.3
2025	111,448.5	1,497.3
2026	117,034.8	1,572.4
2027	122,621.0	1,647.4
2028	128,207.2	1,722.5
2029	133,793.5	1,797.5
2030	139,379.7	1,872.6
2031	144,965.9	1,947.6
2032	150,552.2	2,022.7
2033	156,138.4	2,097.7
2034	161,724.6	2,172.8
2035	167,310.8	2,247.8
2036	172,897.1	2,322.9
2037	178,483.3	2,397.9
2038	184,069.5	2,473.0
2039	189,655.8	2,548.0
2040	195,242.0	2,623.1

APPENDIX D. c, Scenario IV: Improved irrigation efficiency

Year	Improving irrigation efficient (Mm^3)	
	Medium trend up	High trend up
2014	335.9	335.9
2015	357.8	373.4
2016	379.8	410.9
2017	401.8	448.5
2018	423.7	486.0
2019	445.7	523.5
2020	467.6	561.0
2021	489.6	598.6
2022	511.6	636.1
2023	533.5	673.6
2024	555.5	711.1
2025	577.4	748.7
2026	599.4	786.2
2027	621.4	823.7
2028	643.3	861.2
2029	665.3	898.8
2030	687.3	936.3
2031	709.2	973.8
2032	731.2	1,011.3
2033	753.1	1,048.9
2034	775.1	1,086.4
2035	797.1	1,123.9
2036	819.0	1,161.4
2037	841.0	1,199.0
2038	862.9	1,236.5
2039	884.9	1,274.0
2040	906.9	1,311.5

APPENDIX D. e, Monthly crop water demands at Afgoi (m^3/ha)

Date	ETo mm/Day	Effective Rainfall (mm)	Net Irrigation (mm)	Irrigated demand m^3/ha
Jan	5.65	0.2	49.4	272.5
Feb	5.84	0.1	61.8	3042.5
March	6.03	0.3	0.0	0
April	5.06	47.5	2.3	115
May	4.25	51.6	6.7	322.5
June	3.85	28.2	3.3	160
July	4.4	25	3.4	412.5
Aug	4.68	5	15.8	1297.5
Sep	5.16	0.4	33.5	1777.5
Oct	4.89	26.8	27.8	1377.5
Nov	4.5	73	21.7	1065
Dec	4.97	18.8	29	1152.5
Total	**59.28**	**149**	**254.7**	**13,435**

APPENDIX E.a, Long time river flow

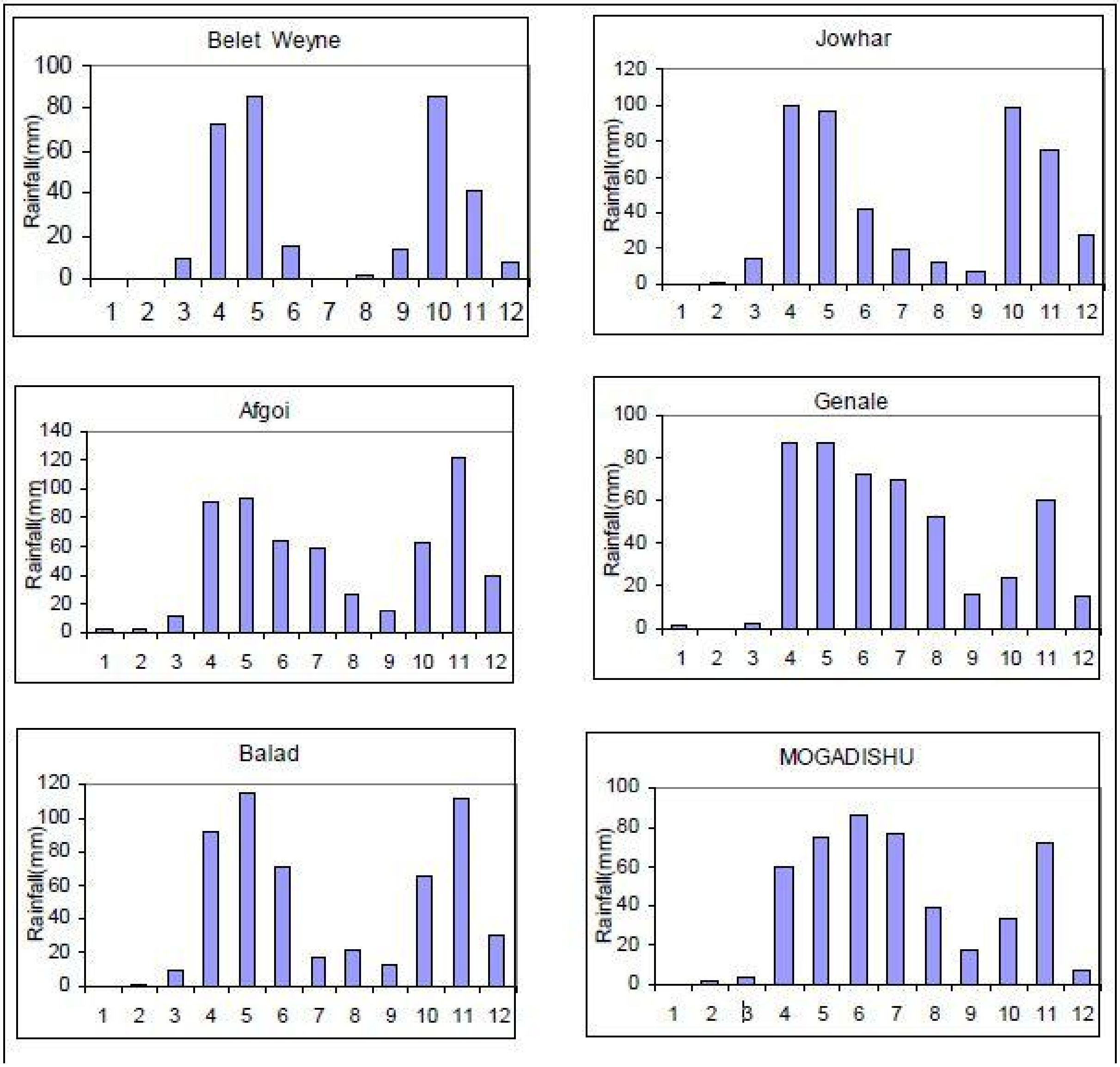
Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Belet Weyne (193,224 km^2)	Mean:	13.5	13.8	30.0	79.8	151.2	82.7	57.0	110.0	151.8	129.6	77.5	36.9	75.0
	Std. Dv.	11.1	13.3	35.0	68.2	88.2	65.6	22.5	32.3	57.3	60.2	62.9	39.8	22.6
	C.V.	82%	96%	117%	85%	58%	79%	40%	29%	38%	46%	81%	108%	30%
Bulu Burti (207,488 km^2)	Mean:	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
	Std. Dv.	15.0	12.8	18.1	24.7	19.7	22.4	19.7	19.3	10.3	9.5	20.1	25.5	10.7
	C.V.	105%	130%	125%	78%	30%	40%	48%	29%	14%	13%	35%	81%	24%
M. Weyne (209,865 km^2)	Mean:	17.2	13.1	21.1	53.6	104.5	74.8	52.0	98.3	122.8	111.4	74.6	37.5	65.1
	Std. Dv.	12.9	12.0	25.4	38.1	39.0	40.7	25.5	27.9	26.9	27.8	37.4	33.7	15.3
	C.V.	75%	92%	121%	71%	37%	54%	49%	28%	22%	25%	50%	90%	23%
Balcad (214,516 km^2)	Mean:	17.2	13.1	21.1	53.6	104.5	74.8	52.0	98.3	122.8	111.4	74.6	37.5	65.1
	Std. Dv.	12.9	12.0	25.4	38.1	39.0	40.7	25.5	27.9	26.9	27.8	37.4	33.7	15.3
	C.V.	75%	92%	121%	71%	37%	54%	49%	28%	22%	25%	50%	90%	23%
Afgoi (244,672 km^2)	Mean:	14.2	9.6	14.7	34.7	70.9	57.4	40.0	72.8	84.8	79.2	60.4	32.4	47.6
	Std. Dv.	13.9	11.7	19.6	27.1	22.9	25.8	20.0	22.3	15.7	14.6	24.6	27.1	12.1
	C.V.	98%	122%	133%	78%	32%	45%	50%	31%	18%	18%	41%	84%	26%
Awdhegle (245,069 km^2)	Mean:	14.3	9.8	14.5	31.9	65.6	56.1	40.8	67.3	74.8	71.9	57.2	31.7	44.7
	Std. Dv.	15.0	12.8	18.1	24.7	19.7	22.4	19.7	19.3	10.3	9.5	20.1	25.5	10.7
	C.V.	105%	130%	125%	78%	30%	40%	48%	29%	14%	13%	35%	81%	24%

Source: SWALIM, 2009

APPENDIX E.b, Environmental Flow Requirement (Mm^3)

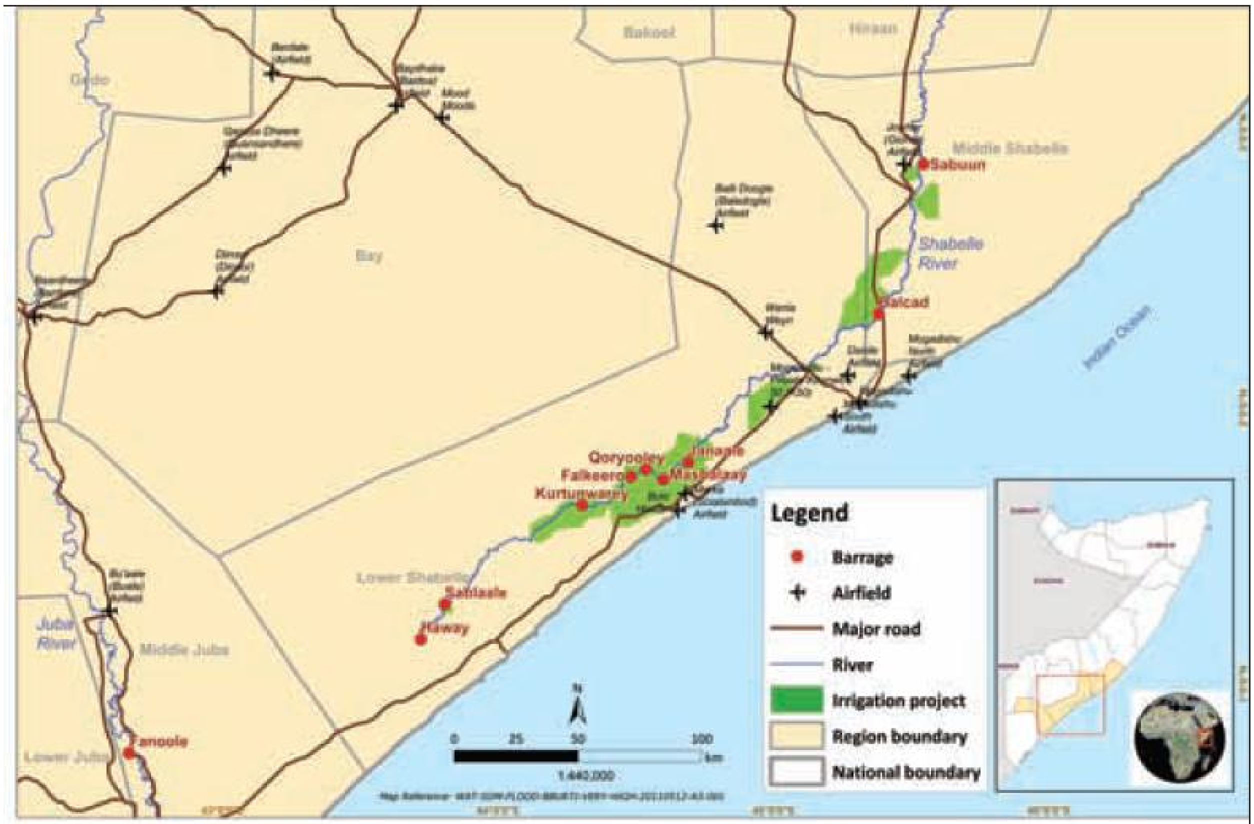
Yearly	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2003	16.36	13.54	13.32	19.94	17.81	9.8	5.65	10.84	14.97	32.27	27.27	6.52
2004	5.56	3.56	2.03	24.6	32.1	7.12	4.52	20.52	19.62	27.2	26.42	12.21
2005	4.04	2.58	4.79	16.2	87.49	58.7	22.5	37.65	39.9	40.72	14.33	12.4
2006	6	5.4	10.43	31.64	52.81	20.35	20.71	42.92	55.91	60.76	84.82	37.85
2007	9.29	11.37	9.37	25.03	46.97	28.86	22.69	33.39	58.54	63.65	23.13	13.85
2008	9.29	7.75	7.37	7.53	24.17	23.02	19.09	27.54	35.01	28.77	52.2	29.34
2009	16.36	13.54	13.32	19.94	17.81	9.8	5.65	10.84	14.97	32.27	27.27	6.52
2010	10.06	18.56	18.56	27.64	41.25	37.87	20.67	42.25	65.56	61.63	28.04	23.61
2011	21.46	15.56	20.53	24.47	41.62	20.54	16.5	38.59	41.24	33.98	25.21	15.42
2012	10.67	5.92	5.97	10.49	33.64	13.55	6.42	12.31	18.56	67.4	32.35	19.69
2013	16.89	14.75	19.42	38.32	44.16	23.12	10.94	20.8	40.36	30.61	38.11	20.25
2014	7.07	5.95	8.83	27.63	52.02	35.41	16.54	21.32	33.49	36.86	37.7	21.31

APPENDIX F, Rainfall map at the different location in the basin



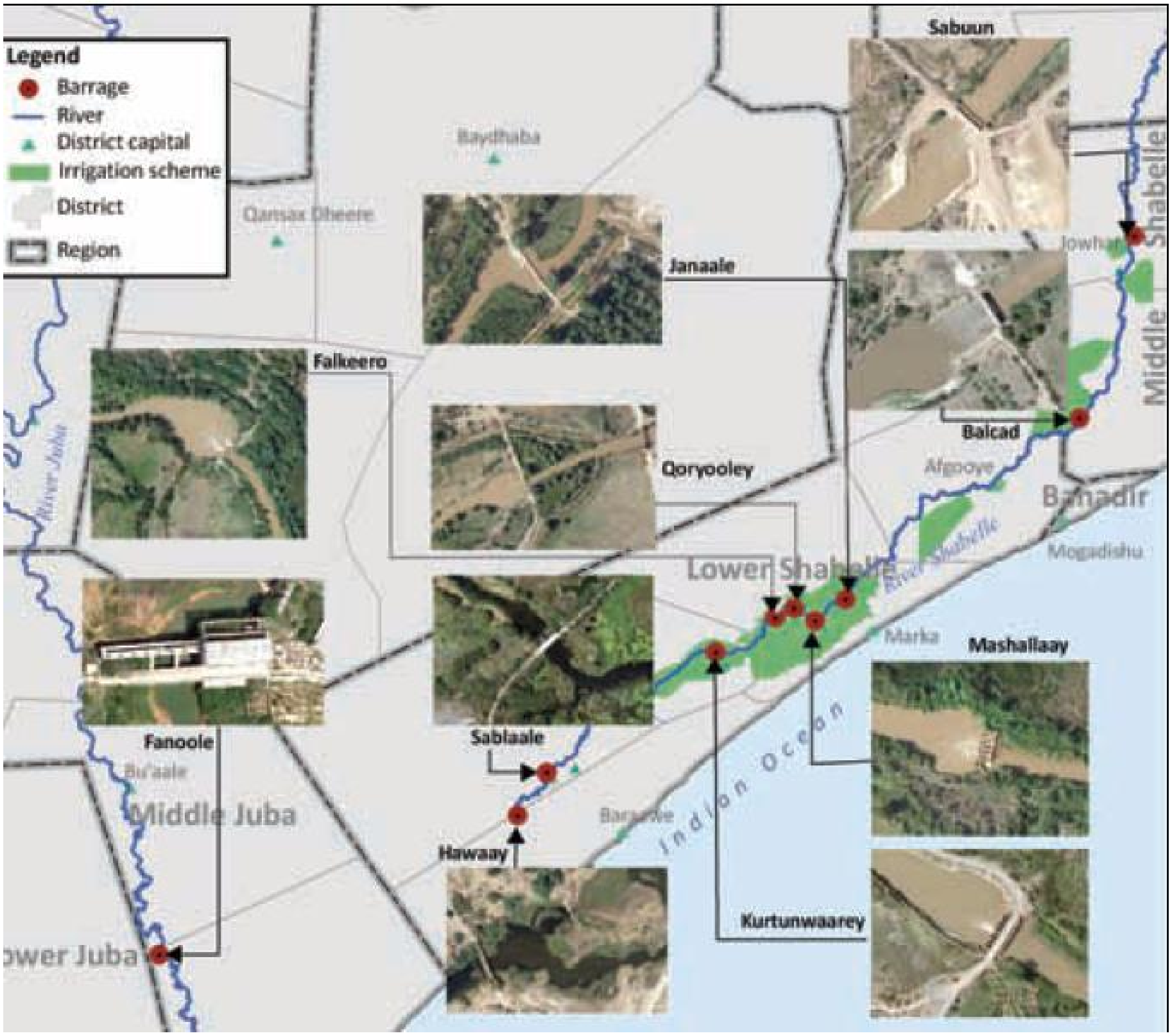
Source: SWALIM, 2007

APPENDIX G. a, Map of southern Somalia showing location of barrage infrastructure and pre-war irrigation schemes



Source: SWALIM, 2011

APPENDIX G. b, Map of geographical location of barrages and irrigation schemes



Source: SWALIM, 2011