Mekelle University

Institute of Water and Environment

Assessment of Surface Water Resources and its Allocation: Case Study of Bahr el-Jebel River Sub-Basin, South Sudan

By

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A thesis

Submitted in Partial Fulfillment of the Requirements for the Master of Science Degree

In

Integrated River Basin Management (IRBM)

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Declaration

I, Malual Deng Mayol, hereby present for consideration by Institute of Water and Environment at Mekelle University, my dissertation in partial fulfillment of the requirement for the Degree of Master in **Integrated River Basin Management (IRBM), which entitled "an Assessment of Surface Water Resources and its Allocation: Case Study of Bahr el-Jebel River Sub-Basin South Sudan".** I sincerely declare that this thesis is the product of my own efforts. No other person has published a similar 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

South Sudan’s water resource is huge, but is underdeveloped. Only about 27 % of the people have access to improved water supply, and only 15 % have access to improved sanitation. Surface water is the primary source of water with only minimal reliance on utility water. The reliance on surface water in South Sudan is less than other East African countries on average. General understanding of the water resource base on both surface and groundwater, and their interaction is one of the gaps of water resources development in the country. Water resources have not developed in the Bahr el-Jebel sub-basin and there is no formal water allocation practice. In addition, lack of sufficient knowledge about available water resources and currently lack of clear water management in sub-basin is an issue. Knowing the potential, availability and use of surface water in Bahr el-Jebel would help to increase the productivity of agriculture, to improve ways and means of the traditional of water management system. There is therefore a need to understand the water availability and to formulate a tool for planning and decision making in prioritization of water development and allocation in the Bahr el-Jebel sub-basin. The objective of this study was to assess surface water resources potential, and water allocation system within the Bahr el-Jebel sub-basin. To achieve this, GIS technique was used to produce various thematic maps. This study described the use of the Water Evaluation and Planning (WEAP) model to evaluate scenarios of water resource development in the Bahr el-Jebel sub-basin. Water demand was simulated for three different sectors, domestic, livestock and agriculture.

Bahr el-Jebel sub-basin is rich with huge quantities of surface water resources an average annual flow estimated as 37.8 BCM. The current utilization of these resources is very limited at the moment is around 1.8 BCM, including domestic, keeping livestock and minor agricultural activities, mainly through rain-fed cultivation. Public Water Allocation as a mechanism that promotes the equitable water use, protects the poor, and sustains environmental needs proposed to apply in this sub-basin. The study, therefore, recommends that integrated and coordinated water resources development strategy is required in Bahr el-Jebel sub-basin.

Keywords: Surface water; Water availability; Water resources; Water evaluation and planning model; Water demand; Water allocation; Bahr el-Jebel;Sub-basin; South Sudan; Uganda.

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ACRONYMS

BCM	Billion Cubic Meter
BEJHP PF	Bahr El-Jebel Hydropower Project- Pre Feasibility
Bm^3y^{-1}	Billion Cubic meters per year
CAMP	Comprehensive Agriculture Master Plan
CWR	Crop Water Requirement
EFR	Environmental Flow Requirement
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GWh	Giga Watt hour
GWP	Global Water Partnership
GWP-TEC	Global Water Partnership- Technical Committee
Ha	Hectare
IDMP	Irrigation Development Master Plan

IWRM	Integrated Water Resources Management
Km	Kilometer
m/s	Meter per second
MAR	Mean Annual Runoff
MCM	Million Cubic Meter
MCP	Marginal Cost Pricing
MEDIWR	Ministry of Electricity, Dams, Irrigation and Water Resources
MODSIM- DSS	Model simulation based water allocation- Decision Support System
MW	Mega Watt
NBS	National Bureau of Statistics
NBI	Nile Basin Initiative
REALM	Resource Allocation Model
SCS-CN	Soil Conservation Service- Curve Number
SEI	Stockholm Environment Institute

SRTM	Shuttle Radar Topographic Mission
SS	South Sudan
SSNBS	South Sudan National Bureau of Standards
SSUWC	South Sudan Urban Water Cooperation
UN	United Nations
UNCSD	United Nations, Commission on Sustainable Development
UNEP	United Nations Environmental Programme
UNESCAP	United Nations, Economic and Social Commission for Asia and the Pacific
UNESCO	United Nations Education, Science, and Culture organization
UWC	Urban Water Cooperation
WASH	Water, Sanitation and Hygiene
WEAP	Water Evaluation and Planning System
WMO	World Meteorological Organization

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CHAPTER ONE: INTRODUCTION

1.1 Background

Water is necessary for all forms of human, animal and plant life. It is essential for overall human well-being and supports all aspects of human livelihoods. Furthermore, water plays an important role in supporting productive human activities such as agricultural, energy and industrial production, sanitation, transportation services, fishing and tourism (UNEP, 2009). The global water demand will primarily grow due to population and economic growth, rapid urbanization and the increasing demand for food and energy (GWP, 2009). Therefore, assessing water resource availability of relevant spatial and temporal scales is of importance (Yang and Zander, 2007) as well as an ability to assess the availability of freshwater resources has been an issue of importance in most countries for many decades (WMO, 2012).

Many researchers have done many studies on water resource availability at scales ranging from watershed to river basins worldwide. For example, Nata Tadesse (2006) assessed surface water potential at the watershed level in the Hantebet Basin, Northern Ethiopia. Montanez *et al.* (2013) carried out water availability in watershed scale in Migina Catchment, Rwanda. Based on basin scale the study conducted by Houghton-Carr, H. A., *et al.* (2011) on assessment of the surface water resources in Juba-Shabelle Basin, Somalia. Addition to that the San Diego River Basin sharing by California and Mexico is the one of the basin level, which the water resources have been, assessed (L. E. Flint *et al.*, 2012). This shows that Assessment of water resources at the watershed and basin, scales has been undertaken in many countries of the world for better water resources planning and management. The results of a water resources assessment are to be incorporated into wider of development planning.

The water resources availability assessment requires detailed insights into hydrological processes. However, studying the complexity of hydrological processes, needed for sustainable basin management, based on understanding rainfall characteristics and basin properties (Abushandi, 2011). Thus, water systems should be designed to meet present and future water demands, while maintaining a range of hydrologic variation necessary to preserve the ecological and environmental integrity of the basin (Loucks, 1997).

Due to high water demand from population growth, degradation of the rivers and pollution of surface and groundwater sources, and the loss of potential sources of freshwater supply since of old and unsustainable water, management practices (UNCSD, 1994; Wang, L. *et al.*, 2007*)*. The scientists and practitioners were forced to establish appropriate water allocation approaches and associated management institutions and policies in IWRM. Therefore, the water allocation approach becomes more important as a mechanism to prevent conflict originating in increasing scarcity and competition for basin water resources.

The complexity of the water allocation task and the increasing pressure on water (increasing demand and variability) has stimulated the revision of water allocation goals and means in many countries (Roa-García, M.C., 2014). Therefore, effective water allocation and management requires an understanding of water availability and reliability with considering the equity, efficiency and sustainability as the key principles in water allocation (UNESCAP, 2000). The sustainable management of water resources requires clear understanding of the water resources in the basin to meet the growing demand of the world's population for water and to achieve secure and sustainable water in the future.

South Sudan's water resource is huge, but is underdeveloped. Only about 27 percent of the people have access to improved water supply, and only 15 percent has access to improved sanitation (The Rapid Water Sector Needs Assessment, 2013). Surface water is the primary source of water with only minimal reliance on utility water. The reliance on surface water in South Sudan is less than other East African countries on average (Rupa R. and Cecilia M., 2011). Knowing the potential, availability and use of surface water would help to increase the productivity of agriculture, to improve ways and means of the traditional water management system, to increase drinking water supply and to increase the hydroelectric power generation of the country in the coming future.

Bahr el-Jebel sub-basin provides resources for livelihoods of the living population. The Bahr el-Jebel river is used as a source of food, drinking and agriculture water, wildlife, transport, grazing and water for livestock, and as a repository for human and agricultural. This makes the issue of water resource availability very crucial for effective water resources management and improves livelihoods.

Water allocation models are useful because, by simulating scenarios of situations encompassing complicated hydrological, environmental and socio-economic factors, they can provide insights into the likely impacts of different development options (McCartney, 2007). This study described the use of the Water Evaluation and Planning (WEAP) model to evaluate scenarios of water resource development in the Bahr el-Jebel sub-basin. The model was used to assess water availability and investigate the impacts of different water allocation scenarios (water demand management strategies) aimed to meet various sectorial water demands in the Bahr el-Jebel sub-basin, South Sudan.

1.2 Problem Statement of the Study

South Sudan has substantial water resources, but is unevenly distributed across the territory and varies substantially between years (The Rapid Water Sector Needs Assessment, 2013). At the same time water, demand for both domestic and productive uses is expected to grow rapidly in the near future. Currently utilization of water resources is very limited including domestic and minor agricultural activities, mainly through rain fed cultivation. However, knowledge and understanding of surface water and their interactions with spatial and temporal variability are essential for the present and future assessment of water resource availability.

General understanding of the water resource base on both surface and groundwater, and their interaction is one of the gaps of water resources development in the country (The Rapid Water Sector Needs Assessment, 2013). Water resources have not developed in the Bahr el-Jebel sub-basin and there is no formal water allocation practice in place. There is therefore a need to understand the water availability and to formulate a tool for planning and decision making in prioritization of water development and allocation in the sub-basin.

1.3 Objectives of the Research

1.3.1 General Objective

The overall aim of this study is to assess surface water resources potential, and water allocation system within Bahr el-Jebel sub-basin.

1.3.2 Specific objectives

- To assess the surface water resources potential of the sub-basin;
- To determine the utilizations and demands of water use within the sub-basin;
- To develop a water allocation system within the basin based on balancing the supply and demand;
- To make recommendation for water management strategies.

1.4 Research Questions

To reach the objective of the study, these questions need to be answered; what is a total surface water resource available, what kind of allocation system is available, and what water allocation mechanism can be suitable in the sub-basin?

The specific research question of the study formulated as follows:

- What is the total surface water resource potential in the sub-basin?
- What is the water utilization and demand within the sub-basin?
- What are the potential water uses within the sub-basin?
- What is the water allocation mechanism in the sub-basin?
- Is there enough surface water in the sub-basin to satisfy the future demand?

1.5 Significance of the Study

The Bahr el-Jebel sub-basin is facing the limitation in utilization of the water resources. However, given the abundance of rainfall and river flow received in the area, it would be expected that this water represent a valuable resource for the population. This study expected to contribute a lot endeavor and alleviating the different problems occurring in the area. As a contribution to the national efforts, this study of the surface water potential and allocation at sub-basin will have a paramount importance to understand the better picture of water resources.

1.6 Scope and limitations of the Study

This is research focused on whole Bahr el-Jebel river sub-basin located in the southern part of the South Sudan, where the overall available surface water in quantity manner and allocation are the objective. The allocation of the surface water over the most dominant users: irrigated land for agriculture, domestic water uses, livestock and the proposed hydropower and environment needed in the sub-basin. Only for Bahr el-Jebel sub-basin water allocation and utilization have been assessed. This research did not develop a full sustainable water resources management plan, but rather a water resources balance, which could be incorporated into such a plan.

In this thesis, based on a limited set of data in order to account for the hydrological process of the sub-basin and demands, allowing for reliable descriptions of the water system under different conditions. In addition to the assumption made, this study has been done within a framework of few information on water demand since was not available in detail.
The thesis does not involve the following:

- The ground water resources;
- Calibration of the WEAP model;

  Since no reliable flow data that can lead to reliable calibration and validation of catchment parameters in Nimule on border between Uganda and South Sudan.

The main problems include: (i) lack of sufficient studies in the area; (ii) lack of sufficient data Due to the civil war occurred in Sudan in 1983’s, almost all the stations (hydrological and hydro-meteorological) stopped its observation from that time and with many missing historical data sets;

1.7 Structure of the thesis

This thesis is present the results of study of the assessment of surface water resources and allocation of the Bahr el-Jebel sub-basin in South Sudan and divided into six chapters. The first chapter is an introductory chapter that explains the background, problem statement, objectives, and research questions, significance of the study, and scope and limitations of the study. The second chapter defines the main review of some literature on the water resources assessment, water allocation, integrated water resources management and water resources in South Sudan. The third chapter is methods and materials provide the description of the study area and discuss the topography, climate, soils, land use and land cover, water resource systems and the socio-economic condition. It also deals with research method and materials, which are, used for analysis the supply and demand in the sub-basin. Fourth chapter describes results and discussions of the study and provides general hydrological analyses and water demand in the Bahr el-Jebel river basin, then the discussion about hydrological components and demand in the study area and the interpretation of the main findings. Finally, conclusions and recommendations based on the main findings of the study are pointed out in Chapter 5.

CHAPTER TWO: LITERATURE REVIEW

2.1 Water Resources Assessment

Surface water is water that is open to the atmosphere and fed by runoff from the surface, such as in a stream, river, lake, or reservoir. Water discharged into a river is the runoff from the watershed drained by the river (Taffa, 2002; Durrans, 2003). Surface water is a valuable resource that can use for public, industrial, navigation and agricultural supply purposes, etc. Therefore, understanding surface water resources potential and use is a key aspect of water resource assessment, evaluation and development. The assessment of water availability at watershed level is realised by quantifying runoff generated in the watershed (Daniel *et al.,* 2011). Water resources assessment relies on a full understanding of all the water flows and storages in the river basin or catchment under consideration.

The literature has a good number of global and regional studies about water resources assessment in watershed and basin level. Consequently, the present research is focusing on sub-basins and watershed from different river basin aspects, to assess and monitor their water resources in detailed discussion. Therefore, assessment of water resources in the basin, regional or national scales has undertaken on many occasions in many countries of the world (WMO, 2012).

2.2 Water Resources Assessment Models

Several hydrologic models are widely used for the assessment of the water resource. Rainfall-runoff models have broadly used in hydrology over the last century for a number of applications, and play an important role in optimal planning and management of water resources in catchments (O'Loughlin *et al.,* 1999; Munyaneza, O., *et al.,* 2013). Oyebande (2001) reported that the main challenge associated with applying successfully rainfall-runoff model lies in the lack of monitoring data, mainly rainfall spatial distribution over the catchment area, since rainfall is the primary input in any hydrological model. Another potential problem is having no reliable flow data that can lead to reliable calibration and validation of catchment parameters.

Those models include SCS-CN (NEH, 1985), HEC-1, HEC-HMS (HEC 1990, 2001), SWAT (Arnold *et al.*, 1996), the MIKE BASIN (Supiah and Normala, 2002), WatBal (Water Balance Model) (Loucks, 2006; Mugatsia, 2010), WatBal is lumped conceptual model which consists of two major components. The first one calculates the potential evapotranspiration using Priestley-Taylor method and the other component calculates the water balance of the basin (Kaczmarek, 1993). The WEAP model simulates the natural hydrological processes (e.g., rainfall, evapotranspiration, runoff and infiltration) enable assessment of the availability of water within a catchment (basin) (Sieber *et al.,* 2005), etc.

The Soil Conservation Service Curve Number (SCS-CN) is use to predict runoff, which links rainfall response to soils, land use, and antecedent moisture condition (AMC), and it is widely applicable in predicting event-based runoff volume (SCS, 1972; NRCS, 2004; Teka, 2014). The SCS-CN is one of the most enduring methods for estimating the volume of direct surface runoff in ungauged catchment (watershed) and is developed from an empirical study of runoff in small catchments (Kousari, M.R., *et al,* 2010). In addition, the model has been widely used with success, providing consistently useful results (Soulis *at al., 2009*; D'Asaro and Grillone, 2010). The Soil and Water Assessment Tool (SWAT) model is a basin scale model where runoff is based on land use and soil type (Arnold *et al.*, 1998; Das *et al.*, 2004), has a comprehensive structure that models basically all hydrologic processes in the watershed over long periods of time (Neitsch *et al.*, 2002b). The model has also been applied in the many basins for example: Githui *et al.* (2009) used SWAT model to simulate stream flow in Western Kenya. Sang (2005) also applied the SWAT model in the Nyando Basin in Kenya and Magoma (2009) examined the applicability of SWAT in the Rugezi wetland catchment in Rwanda. The results showed important rainfall-runoff linear relationships that could extrapolate to estimate amounts of stream flow under various climates. Then the Water Evaluation and Planning (WEAP) model attempts to address the gap between water management and watershed hydrology and the requirements that an effective IWRM be useful, easy to-use, affordable, and readily available to the broad water resource community (Yates, 2005). In addition, the data structure and level of detail may easily customize to meet the requirements of a particular analysis and to reflect the limits imposed when data are limited (Yates *et al.*, 2005b).

2.2.1 Water Evaluation and Planning (WEAP) model

WEAP, which is an object-oriented computer-modeling package, having is an Integrated Water Resources Management (IWRM) tool designed for simulation of water resources systems and trade-off analysis. The model simulates water system operations within a river system with basic principles of water accounting on a user-defined time step, usually a month. Simulation allows the prediction and evaluation of "what if" scenarios and water policies such as water conservation programs, demand projections, hydrologic changes, new infrastructure and changes in allocations or operations priority (Raskin et al., 1992; Yates et al., 2005a, b; Purkey et al., 2007; SEI, 2008). WEAP model is developed by the Stockholm Environment Institute (SEI) in Boston and provides an integrated approach to simulating water systems associated with development (SEI, 2007). The model includes two separate systems (Yates et al., 2005):

- Simulation of natural hydrological processes (e.g., evapotranspiration, runoff and infiltration) to enable assessment of the availability of water within a watershed;
- Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e., consumptive and non-consumptive water demands) to enable evaluation of the impact of human water use.

It represents the system terms of its various supply sources (e.g. rivers, streams, groundwater, inter-basin transfer and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands (i.e., user-defined sectors but typically comprising hydropower, irrigation, domestic supply, etc.). The model essentially performs a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. Typically, the model applied by configuring the system to simulate a recent "baseline" year, for which the water availability and demands can be confidently determined. The model is then used to simulate alternative scenarios (i.e., possible futures based on "what if" propositions) to assess the impact of different development and management options. Thus, WEAP is considered as an integrated water management tool for evaluating water use and allocation with a greater focus on balancing supply and demand in a swift and transparent way.

2.3 Water Allocation

Water allocation is central to the management of water resources, it refers to the rules, and procedures through which access to water is decide for individual or collective use, and in relation to availability. The overall objective of water allocation is Therefore, to maximize the benefits of water to society (Wang L., 2005), which can be further classified as social, economic and environmental in nature. Due to geographically and temporally unevenly distributed precipitation (Al Radif, 1999; L. Z. Wang *et al.,2003*), rapidly increasing water demands driven by the world population and other stresses, and degradation of the water environment (L. Z. Wang *et al., 2003*), there are increasing scarcities of water resources in many countries. In order to achieve sustainable water management and a secured society, institutions and approaches for water allocation should reformed, especially for regions having water resources shortages.

Water allocation rules and procedures become more important as mechanisms to prevent conflict. Many studies have been carried out in this domain, but there are still many obstacles to reaching equitable, efficient and sustainable water allocations (Dinar *et al.*, 1997; UN-ESCAP, 2000). The simplest definition of water allocation is the sharing of water among users. A useful working definition would be that water allocation is the combination of actions that enable water users and water uses to take or to receive water for beneficial purposes according to a recognized system of rights and priorities (UN-ESCAP, 2000).

Many studies have been done about water allocation under the priority-based system with national development policies, objectives. These studies are viable for basins with multiple water demands and scarce water resource conditions to meet the existing demands, like in the Upper Ewaso Ng'iro North Basin, Kenya (J.K. Mutiga *et al.*, 2010), the Walawe River Basin, Sri Lanka (D. K. Neelanga, 2010) , etc.

2.3.1 Criteria for Allocation

Appropriate means of resource allocation are necessary to achieve optimal allocation of the resource. Several criteria are used to compare forms of water allocation (Howe *et al.,* 1986; Weragala, D. K., 2010) such as:

- Flexibility in the allocation of supplies;
- Security of tenure for established users;
- Real opportunity cost of providing the resource is paid by the users;
- Predictability of the outcome of the allocation process;
- Equity of the allocation process;
- Political and public acceptability;

An additional set of criteria should include (Winpenny, 1994, Carraro *et al.*, 2005):

- Efficacy, so that the form of allocation changes existing undesirable situation such as depletion of ground water, and water pollution, and drives towards achieving desired policy goals.
- Administrative feasibility and sustainability, is to be able to implement the allocation mechanism, and to allow a continuing and growing effect of the policy.

2.3.2 Water Allocation Mechanisms

Dinar *et al.* (1997) and Wang L. (2005) discuss the concepts of four basic mechanisms for water allocation: user-based allocation, marginal cost pricing, public allocation and water markets allocation.

User-Based Allocation: many studies have shown a wide variation of rules for allocation within such systems; by timed rotation, the depth of water, an area of land, or shares of the flow (Yoder, 1994). User-based allocation requires collective action institutions with authority to make decisions on water rights (Dinar *et al.*, 1997). The effectiveness of user-based allocation depends on local norms and the strength of local institutions, but such institutions are not always in place or strong enough to allocate water efficiently.

In the developing world have shown that, user based allocation performs better when compared to public allocation (Merry.D., 1996; Weragala D. K., 2010). Study by Van Koppen *et al* (2007) showed that user based/managed water allocation has been promoted in the developing world to address some of the shortcomings in public allocation. The advantage of the user-based allocation includes, in summary, administrative feasibility and sustainability, and political acceptability.

Marginal cost pricing (MCP): a marginal cost pricing (MCP) mechanism, in principle, targets a price for water to equal the marginal cost of supplying the last unit of that water. A price defined as an observed price (marginal value) of water on a demand curve, which corresponds to an observed quantity (i.e. Reference quantity). An allocation that equates the water's unit price (the marginal value of water) with the marginal cost is considered an economically efficient, or socially optimal, allocation of water resources. The limitation of MCP, however is, it is hard to implement at a river basin level because, it is difficult to collect sufficient information to estimate the correct volume of water.

Public (Administrative) Water Allocation: Public allocation promotes the equitable water use, can protect the poor, and can sustain environmental needs. But often leads to inefficient use of water and failure to create incentives for water users to conserve water, improve use efficiency and allow tradable water transfers to achieve maximum benefits in a whole river basin and also public allocation mechanisms often lead to waste and miss-allocation of water, as well as fragmented investment and management of the existing resource.

The quantity based administrative allocation is the most common water allocation mode in the developing world today (Meinzen- Dick and Mendoza, 1996; Molle, 2004). In general, state managed administrative allocation (public allocation) has multiple objectives and is more concerned with equity, sovereignty and satisfying greater public good (Dinar *et al.*, 1997). Some studies have shown that the practice of public water allocation in the developing world has run into a number of difficulties. Lack of a comprehensive legal framework, unclear institutional responsibilities, inadequate staffing of allocation agencies, lack of proper systems of water rights and inadequate monitoring are some of the common reasons (UN, 2000).

Water Markets: water markets allocate water by means of tradable water use rights and promote efficient water usage through allowing users to sell and buy their water rights freely. Furthermore, it argues that water markets are rare in reality and are not true free markets. Due to the transaction costs, technological constraints, political constraints and many other reasons the real-world water markets do not attain first-best allocations. The absence of properly defined water rights is also seeing as a major obstacle in formulating water markets in the developing world (Rosegrant and Gazmuri, 1994). Dellapenna (2000) maintains that water markets are rare in reality and are not true free markets.

The argument said the performance of such allocation method could evaluate by simulating the allocation process and estimating the social, economic and environmental effects of the resulting allocation schedules (Jain and Singh, 2003). Based upon the idea that the achievement of equitable and efficient water allocation requires all stakeholders' cooperation in sharing water resources, a modelling framework was proposed by Wang *et al.* (2003) for obtaining equitable, efficient and sustainable short-term water allocations among competing water uses and stakeholders in a river basin. In this methodology, water allocation carried out in two steps based on a network representation of a river basin:
(1) Initial allocation of water rights to water stakeholders and users founded on legal water rights systems or agreements; and (2) reallocation of water to achieve efficient use of water and equitable redistribution of net benefits to promote cooperation of all stakeholders in a river basin by utilizing cooperative game theoretic approaches.

2.3.3 Water allocation Models

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). Effective IWRM models must deal with the biophysical system, which create runoff generation and its movement, and the socio-economic management system, which create water storage, allocation, and delivery (Yates *et al.*, 2005).

Allocation models are typically divided into two categories, simulation and optimization models. Linear and nonlinear programming models for integrated hydro-economic modelling have been used in many river basins like Mekong, Murray, Yellow river, etc. (Ringler & Huy, 2004, Rodgers *et al.*, 2002). The optimization models will provide the optimum solution for a particular problem. Simulation models are widely used by managers for planning and management of complex systems. Simulation based water allocation models use mass balance principles to allocate resources in a river system, as in MODSIM-DSS (Fredericks *et al.*, 1998), Mike Basin (DHI, 2001), WEAP (Yates *et al.*, 2005), REALM (Perera *et al.*, 2005), etc.

The literature findings are river basin flow simulation models have successfully applied to manage water resources systems and optimization models to optimize and select allocations and infrastructure operations based on objectives and constraints. However, the assessment of system performance could address better with simulation models; optimization models are more useful if improvement of the system performance is the main goal (McKinney *et al.*, 1999). Form reviewed literatures Mike Basin and Water Evaluation and Planning are common use in water allocation.

2.4 Integrated Water Resources Management

Integrated Water Resources Management (IWRM) promotes the coordinated management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000).

For the improvement of water infrastructure in the developing world, subsidies are crucial. In most river basins, mechanisms and institutions to manage water resource disputes are either absent or unsatisfactory (UNESCO and Green Cross International, 2003). Literature review in this aspect shows that a practical challenge to the concept of IWRM is found at two levels. First, water related to development and societies in countless ways. Its priorities and relative importance vary enormously from one place to another. Second, water must see as one factor in a broader context (Varis, 2005). Therefore, the different concepts and related policies are not integrated. Further, there should be an emphasis on the relations between land use and water resources and to the integration of natural limitations, social and economic demands and legal, political and administrative processes (Mostert, 1999a, and 1999b). There is a consensus about integrated water management at the basin level as the approach is to use it for sustainable water resources management (GWP-TEC, 2009). To provide policies, strategies, legal and institutional arrangements, financial and economic instruments and relevant human and institutional capacities at the right time and in the right place and coordinated at the (inter) national, regional and river basin level is a task that can only be covered by the aggregated international community (cf. van Hofwegen & Jaspers, 1999).

2.5 Water Resources in South Sudan

South Sudan is rich with its surface water resources, but water availability is uneven distributed across the country and varies considerably from year to year. Besides, drivers such as demographic and climatic changes further increase the stress on water resources, and therefore the traditional fragmented approach is no longer viable and a more holistic approach to water management is essential. The country has four (4) major river basins, which are Bahr el-Ghazal basin, Bahr el Jebel basin, the River Sobat basin and the White Nile basin contributing to the flow of the White Nile. There is also Sudd wetland with a total area of coverage, which is more than 30,000 km2, is one of the most prominent features of South Sudan’s water resource system, which is one of the vast wetlands of the region.

Water resources development is low compared to neighbouring countries in the region. The reliance on surface water in South Sudan is less than other East African countries on average

(Rupa Ranganathan and Cecilia M., 2011). Irrigated farming at present are practiced on a small scale by individual farmers in isolated locations, with simple water-lifting techniques from rivers and river flooding. Currently, South Sudan utilizes very little of the water resources where it is a similar case in Bahr el-Jebel basin because the water resources is underdeveloped. Agriculture, which is the main occupation of the inhabitants in the basin, is primarily rain fed with almost no irrigation. South Sudan plans to increase development of the Bahr el-Jebel water resources significantly in the near future.

Many of the findings of rapid assessment of water resources use, management, and development in South Sudan (The Rapid Water Sector Needs Assessment, 2013) indicates seven priority programs, as described below:

- Implementing the Water, Sanitation and Hygiene (WASH) strategic framework
- Creating irrigation policy and strategy framework
- Developing major hydropower
- Monitoring the social and environmental impacts of water resources management
- Generating and adapting complementary knowledge
- Assessing the water resources integrated catchment planning and water allocation
- Integrating catchment planning and water allocation

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Bahr el-Jebel River sub-basin is located in the southern part of South Sudan and is a trans-boundary basin shared between South Sudan, and Uganda. It has a drainage area of 74,536 km^2, extending from Lake Albert in Uganda to Mangalla in South Sudan. The area within South Sudan is about 24,527 km^2. Geographically the basin is located between latitudes 2º 1' 44.47" N to 5º 12' 6" N and longitude 30º 43' 49.45" E to 34º 16' 48.81" E (Fig. 3.1). The most important rivers within the basin are Bahr el-Jebel, Aswa and Kaia within South Sudan. The main river flows from Lake Albert in Uganda then continue north to Nimule where it enters South Sudan and is commonly known as Bahr el Jebel, is a very important part of the White Nile system.

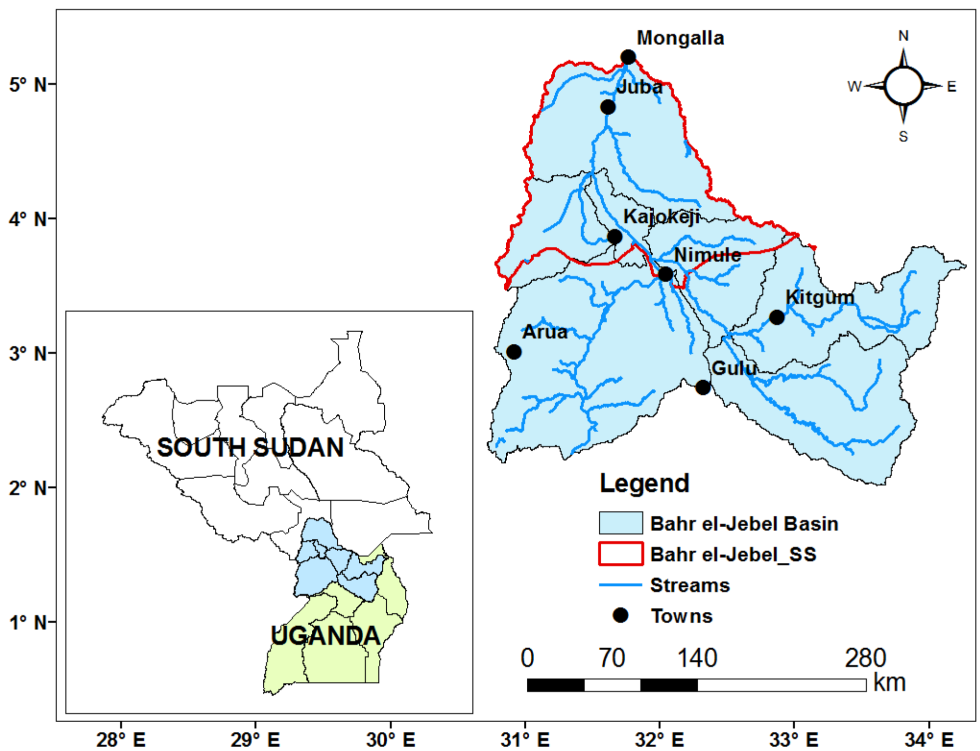

Figure 3.1 Location of the study area

3.1.2 Physical Characteristics

Topography

The topography of the basin is enclose by the highlands on the southeast and southwest closed with Uganda. Altitude ranges between 425 m above mean sea level (a.m.s.l) at northern to 3172 m (a.m.s.l) at the southeast of the sub-basin (Fig. 3.2a). The slope in sub-basin ranges from 1 to 10% (Fig. 3.2b). At Nimule the river crosses the South Sudan border, turn suddenly to the northwest and flows in a steeper channel, with several rapids, towards Juba and Mongalla (Sutcliffe, J.V. and Parks, Y.P., 1999).

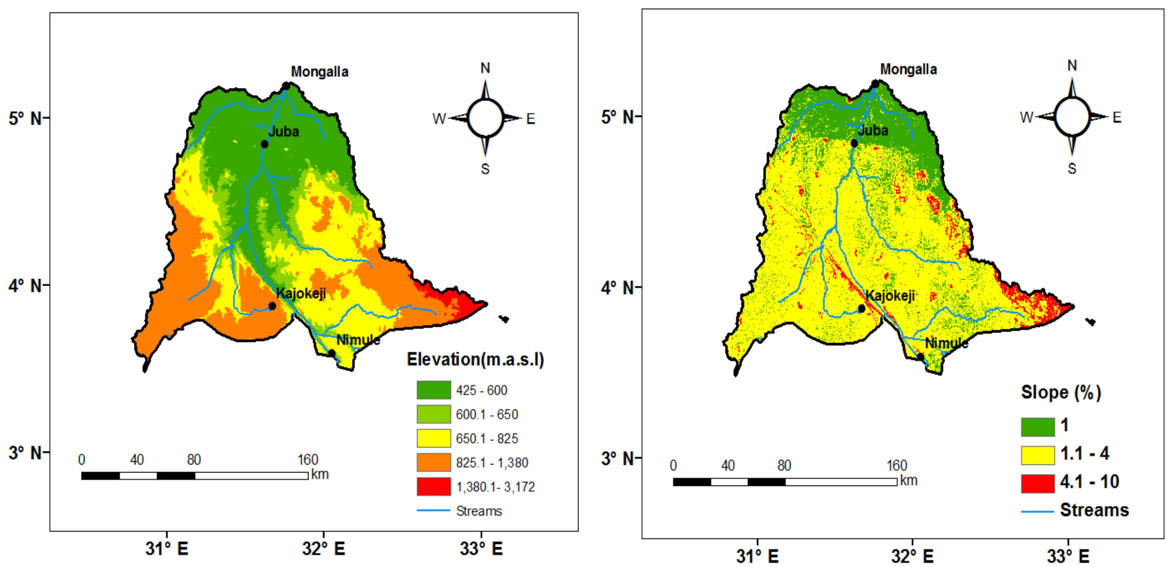

Figure 3.2 Topography of Bahr el-Jebel Sub-basin (a) and slope of Bahr el-Jebel Sub-basin (b)

Climate

The sub-basin has a humid climate, where the northern part of the sub-basin is semi humid and the southern part is humid. Annual rainfall in the sub-basin ranges between 900 to 1600 mm from northern to southern part of the sub-basin (Fig. 3. 4). The annual average humidity of sub-basin is 65% and average temperature ranges from 19^0 C to 37^0 C (Fig. 3.3).

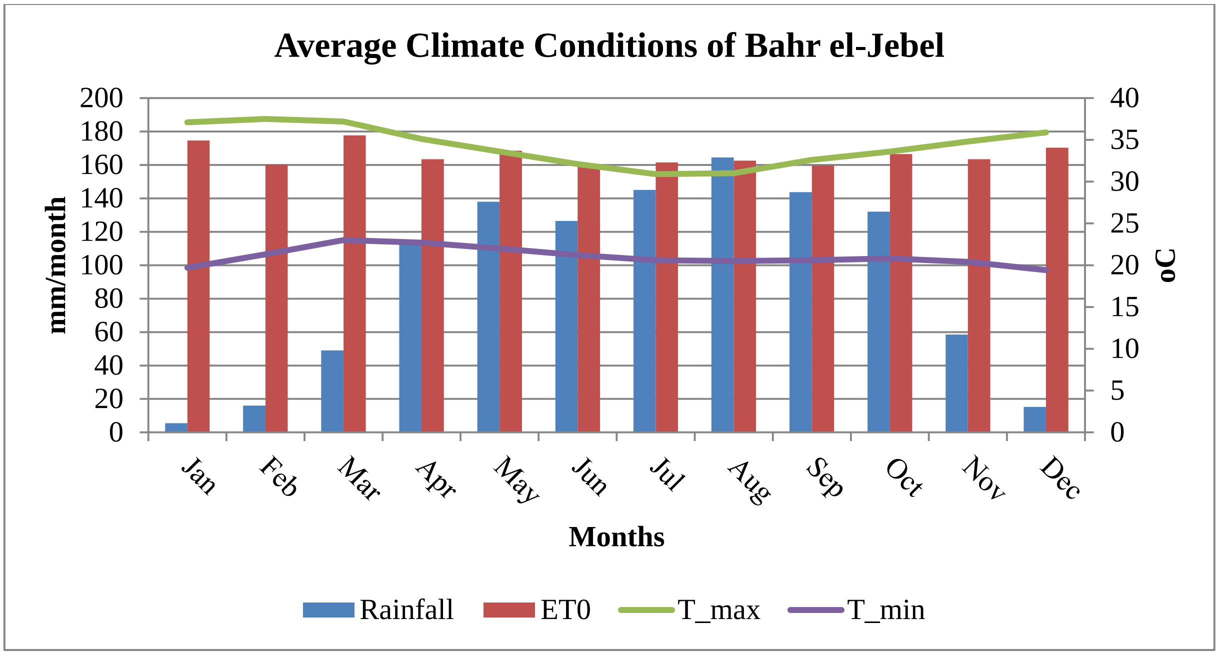

Figure 3.3 Average Monthly, Rainfall, ETo, T-max and T-min in Bahr el-Jebel sub-basin

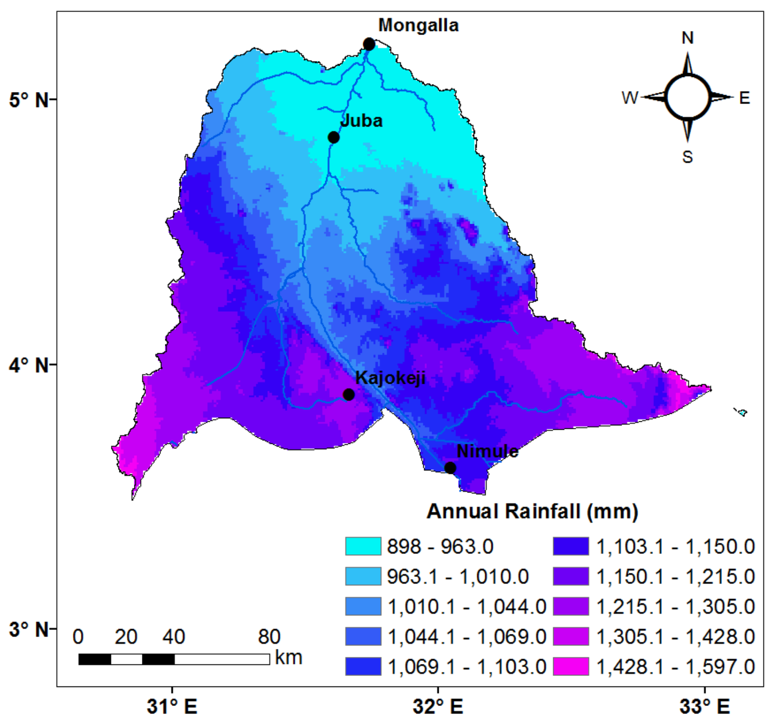

Figure 3.4 Distribution of Average Annual Rainfall in Bahr el-Jebel Sub-basin (WorldClim, 2015)

Soils

The soils classified in the sub-basin as Lithic and Eutric-Leptosols, Ferralic and Eutric-Cambisols, Haplic-Nitosols, Ferric-Lixisols, Luvic-Phaeozems and Eutric-Fluvisols (Fig. 3. 5). Generally, soil in the sub-basin is consisted with very shallow soil over hard rock, that soil is gravelly and/or stony by 35.43 percent, neutrality or acidity soil that makes good agricultural land by 23 percent and alluvial soil along the streams. The soil texture is dominating with clay loam.

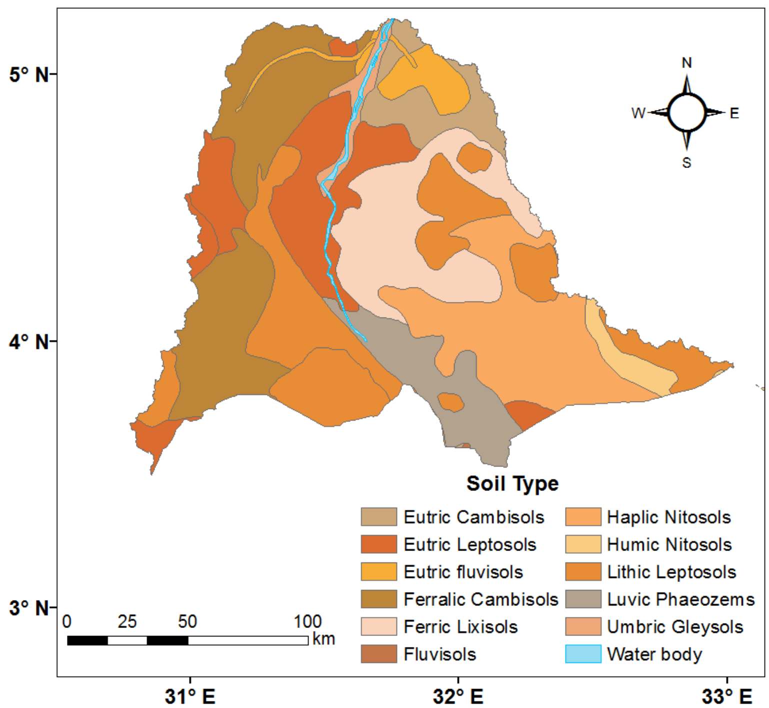

Figure 3.5 Soil of Bahr el-Jebel Sub-basin (The National Bureau of Statistics, 2009)

Land Cover/Land use

The sub-basin consists of good and widely vegetated species. The main forms of land cover/ use in the sub-basin are shrubs, open tree with shrubs and herbaceous (Fig. 3.6). Maize cultivation is also predominant in the sub-basin as small-scale farms; the northern part of the sub-basin is dominant by grazing lands mainly for communal grazing.

Table 3.1 Land cover /use type of Bahr el-Jebel

Land cover	Percentage
shrubs	67.27
Open tree with shrubs	17.56
herbaceous	10.00
Rain-fed Crops	4.50
Water bodies	0.32
Urban area	0.30

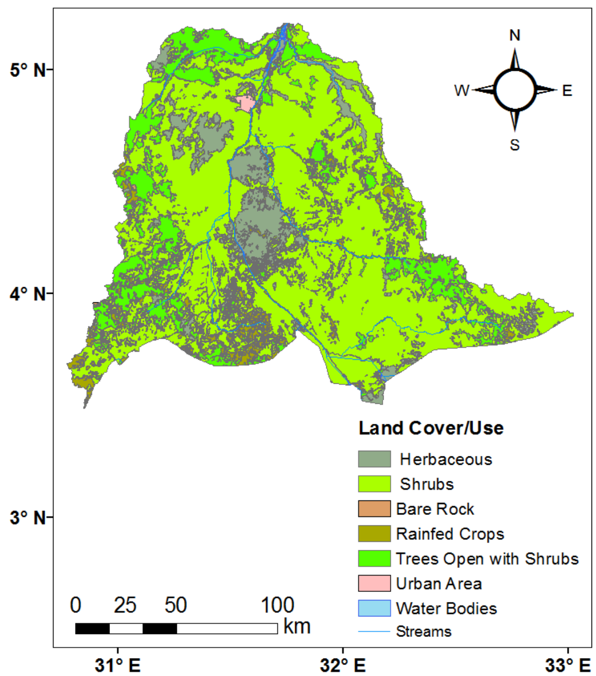

Figure 3.6 Land cover/use map of Bahr el-Jebel (SS Land Cover, FAO, 2011)

Water Resource Systems

The main source of water is the outflow from Lake Albert, between Nimule and Mangalla Bahr el-Jebel receives inflow from seasonal streams that superimpose their short period runoff peaks on the relatively constant outflow from Lake Albert. Furthermore, the Aswa River is contributing to sub-basin and it is share by South Sudan, Uganda, and Kaia River in South Sudan. The ground water potential of the sub-basin is unknown.

3.1.3 Socio-economic Condition

Major Economic Activities

Agriculture, mainly through rain fed cultivation and keeping livestock are the major activities in the study area. Small-scale horticulture farms are also located along the Bahr el-Jebel River. Pastoralists, who occupy the lower parts of the sub-basin, are using the river water for their domestic use and for watering their animals. Although more than 80% of the populations (Uganda National Water, 2005) in Uganda side are involved in agriculture, most of it is rain-fed small-scale subsistence farming.

Demography

The total population within the basin is around 5,573,775 people and within South Sudan, it is 1,637,374 (NBS, 2011), generally the majority of the population of the South Sudan is living in rural areas where it is estimated to be around 84.4 percent. On the Uganda side, however the population is 3,936,401 (Uganda Census, 2014), 87 percent is living in rural and the remaining 13 percent is living in urban. The highest concentration of population is in Juba, Kajo Kaji, Nimule and Mongalla towns in the South Sudan side. However, the main towns in Uganda are Kitgum, Laropi, Moyo, Arua, Gulu, Pakwach and Maracha.

3.2 Research Methods

3.2.1 Data Collection

General work was carried out by collecting secondary data and validated by comparing the data collected from different data sources.

Biophysical Data

Land use/land cover, topography, soils collected from the Ministry of Electricity, Dams, Irrigation and Water Resources (MEDIWR) were required to characterize the sub-basin. These data were prepared for conducting irrigation development master plan study of the country wide 2012, and the pre-feasibility studies for each of the planned schemes are ongoing.

Hydro-meteorological Data

In order to determine the basic hydrologic parameters, meteorological and hydrological data were collected. The daily rainfall and temperature were collected from the meteorological office of the Juba Airport station. The data were processed into monthly time step. The Juba station is the only station having data in the sub-basin for the last 24 years of record (1990 to 2014). The Global Climate Data (WorldClim - Global Climate Data) have been also used. Finally, river flow data was also collected from MEDIWR.

Table 3.2 Correlation between Ground Data and Global Data of Rainfall

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ground Data(mm)	8.0	10.6	41.8	132.8	130.7	121.9	153.6	128.2	113.3	140.0	55.9	9.5
Global Data(mm)	4	7	37	89	130	113	127	144	117	107	39	6
correlation(r)			0.95									

Note ground data are average of 24 years.

Socio-economic Data

Important socio-economic information such as Agriculture, Domestic water supply, Demographic surveys (population and population density) and Water-use were collected from different governmental offices. Agriculture information was collected from MEDIWR, the demographic data from the National Bureau of Statistics and Comprehensive Agriculture Master Plan (CAMP), and the water use data were collected from MEDIWR, South Sudan Urban Water Cooperation (SSUWC), Juba municipal (Payam), Kator municipal (Payam), South Sudan National Bureau of Standards (SSNBS), etc. Data from Uganda side was collected through reviewing literature.

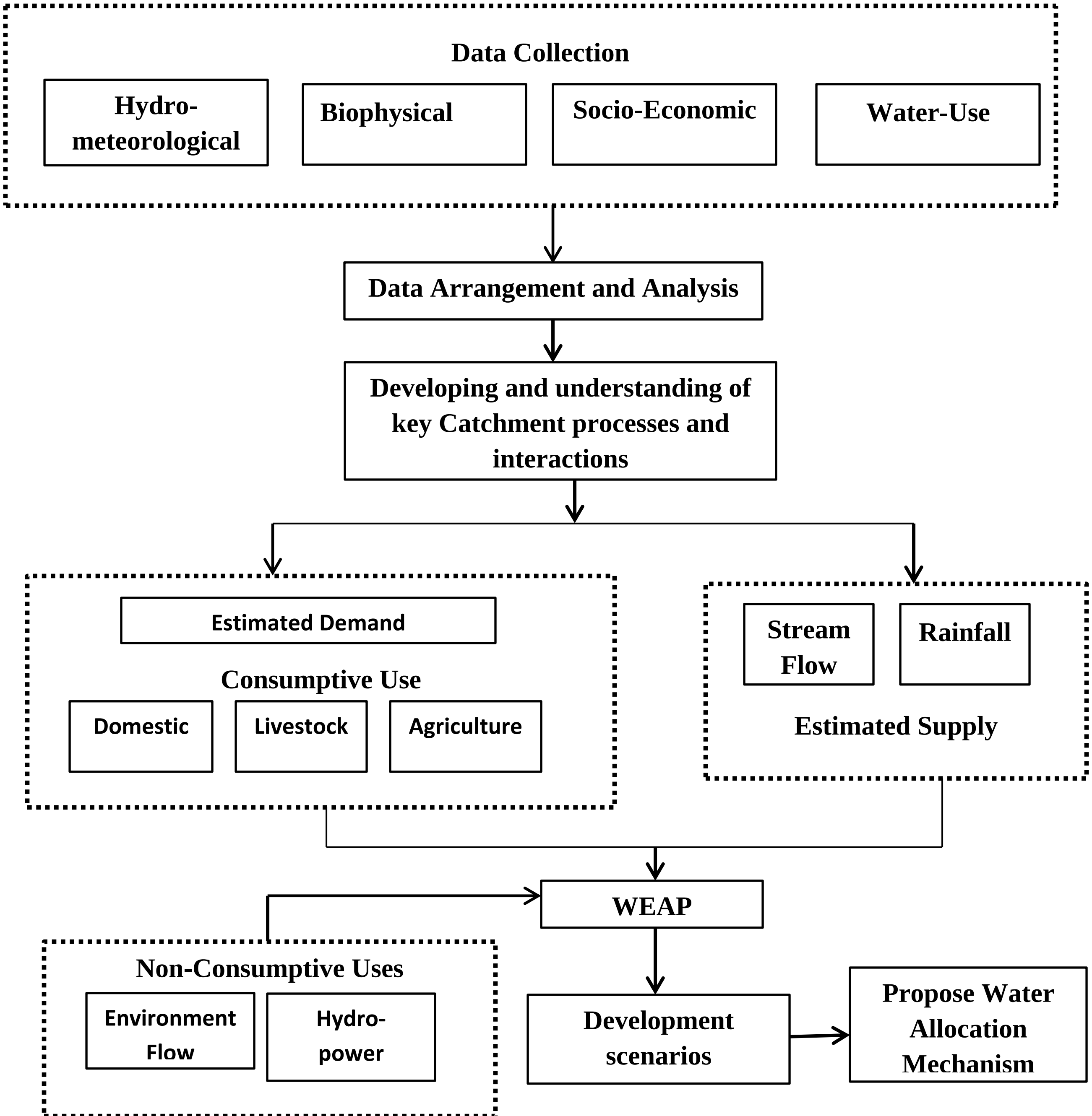

Figure 3.7 Research Design

3.2.2 Data Processing

WEAP Application

WEAP model applied by simulating recent base year account, for the water availability and demand was determined. This information obtained from different institutions in the sub-basin. The model used to simulate alternative scenarios of different development and management options in the future. The application defined by time frame, spatial boundaries and system components.

The modeling of a watershed using the WEAP consists of the following steps (Levite *et al.*, 2003):

i. Define of the study area and time frame. The setting up of the time frame includes the last year of scenario creation (last year of the analysis) and the initial year of application.
ii. Create the current account, which is more or less the existing water resources situation of the study area. Under the current account, available water resources and various existing demand nodes are specified.
iii. Create the scenarios based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated from running the model. The scenarios are used to address a lot of "what if situations", like what if reservoirs operating rules are altered, what if groundwater supplies are fully exploited, what if there is a population increase. Scenario creation can take into consideration factors that change with time.
iv. Evaluate the scenarios about the availability of the water resources for the study area. Results generated from the creation of scenarios can help the water resources planner in decision making, which is the core of this study.

WEAP acts based on fundamental equations of the water budget and it can used in urban and agricultural systems, complex river systems or independent basins.

The study has adopted a baseline scenario using the demand data of 2014, and simulated stream data (supply) 2008-2011 assuming that similar trends of stream situation will exist in future without considering the climate and land use change. The modeling framework for this study consisted of: (1) The estimated monthly discharges converted into the volume of flow and; (2) an estimation of water demand and allocation modeling to allocate water for different sectors.

WEAP model is chosen because it operates in a simple manner. One of WEAP’s advantages is that it places the demand side of the water balance equation on a par with the supply side, and addresses some of the evaluations of water Decision Support Systems (Loucks, 1995). Since no comprehensive work previously has done on IWRM in the study area, adopting a user-friendly interface, such as WEAP could enhance building a shared understanding of the water supply and demand system, problems and their causes; exploring and expanding solution options; and developing and evaluating alternatives for the Bahr el-Jebel sub-basin.

Surface Water Supply

I. Stream Flow

Continuous stream flow records are necessary to make accurate water resources assessment. Stream flow records representing historical, natural hydrology unaffected by humans are fundamental to modeling basin hydrology (WMO, 2012). In this, study the daily stream flows of each month added up to obtain the monthly total discharge. The estimated monthly discharges converted into the volume of flow within Bahr el-Jebel River Basin at Mongalla.

The Bahr el-Jebel sub-basin is connected with several sub-basins in upstream Uganda side like Lake Victoria, Lake Kyoga, Victoria Nile, Lake Edward, Lake Albert, Albert Nile and Aswa. As a result, it was difficult to analyses the runoff of the basin by computer models or scale models. Therefore, in this study, the volume of runoff was determined by using direct observed flow data at outlet Mongalla, South Sudan.

Table 3.3 Variation annual Discharge on basin system for different period

Location	Average annual flow in km^3		
	1961-1970	1948-1970	1912-1982
Lake Victoria exit	41.6	29.4	27.2
Lake Kyoga exit	44.1	30.1	26.4
Lake Albert exit	48.8	33.7	31.4
Mongalla(Bahr el-Jebel)	52.6	36.8	33.1

Source: Water Sharing in the Nile River Valley (UNEP, 2000); (Willems *et al.*, 2009)

The data used in this analysis were obtained from MEDIWR. The observed stream flow data at outlet Mongalla of the sub-basin (2008-2011) used to estimate the surface runoff in Bahr el-Jebel sub-basin. The rating curve was developed which is discharges were plotted against their corresponding gauge (water level) to estimate the flow of the year 2011 by using available gauging water level (Fig. 3.8).

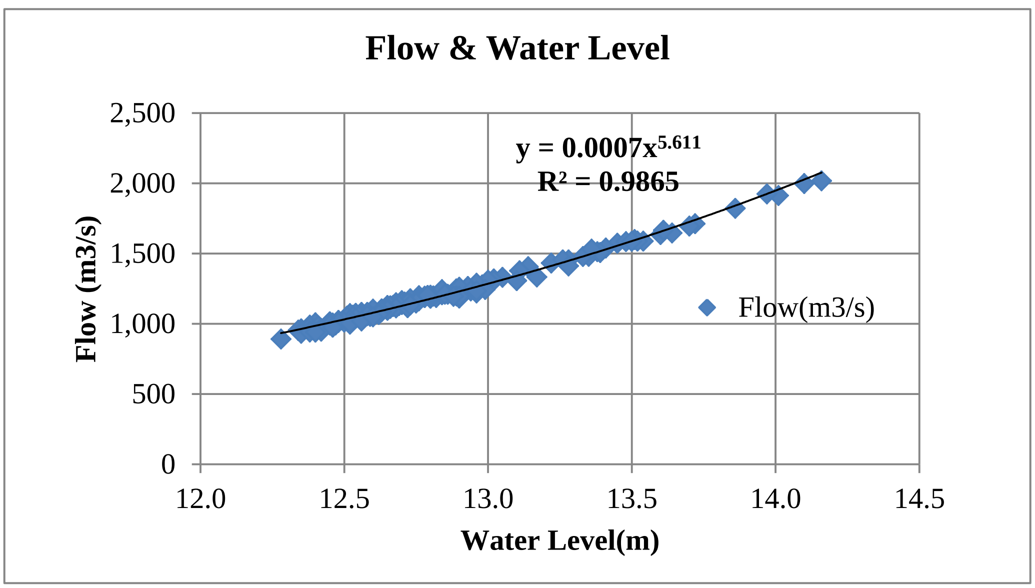

Figure 3.8 Mongalla Rating Curve (2008-2010)

By using WEAP model, those data are used as Riverhead flow represents the flow of the river in the outlet of Mongalla, and it does not emphasize the upstream flow of the sub-basin.

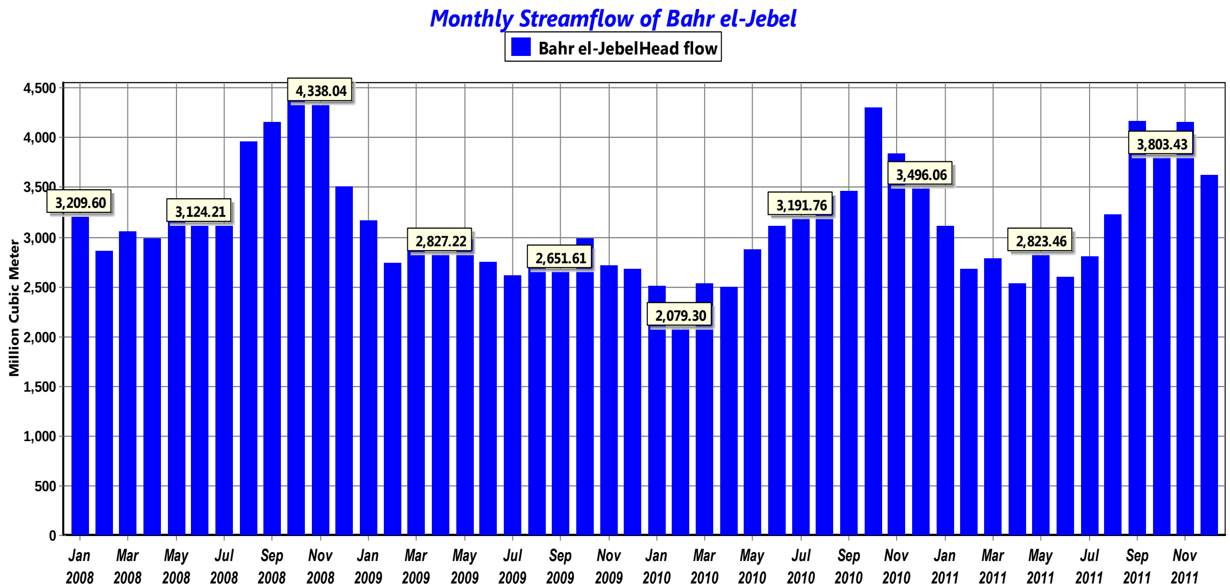

Figure 3.9 Average Monthly Stream flow of Bahr el-Jebel at Mongalla

II. Rainfall Runoff Simulation by WEAP

Rainfall-runoff simulation is very significant in basin management. Simulation of the basin hydrology gives an indication of resource capacity. For the purpose of water resource assessment, it is necessary to have an understanding of flow conditions unaffected by human interference. The rainfall Runoff correlation method has been used to determine the surface runoff in Bahr el-Jebel Sub-basin to understand runoff generated within the South Sudan part. In order to estimate surface runoff the rainfall runoff method in WEAP chosen to simulate surface runoff in the study area; this was constrained by the type of data available (Rainfall, Evapotranspiration and Land use). The following type of data is required to perform rainfall-runoff simulation using this method:

I. Land use (Area and Kc)

II. Climate (Precipitation, Effective precipitation and ETo)

Where Kc- crop coefficients and ETo is the reference crop evapotranspiration.

The Rainfall Runoff method also determines evapotranspiration for irrigated and rain fed crops using crop coefficients, and it uses crop coefficients to calculate the potential evapotranspiration in the catchment. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via catchment links.

The sub-basin is divided into three watersheds (Fig. 3. 10) for the study area based on major tributaries, to simulate surface runoff within Bahr el-Jebel sub-basin and Kc was adopted based on FAO-56 (FAO, 1998a, Allen *et al.*, 2006). This surface runoff represents the runoff generated in the Bahr el-Jebel sub-basin. Groundwater analysis did not consider in this study; this is because the available information was not sufficient to estimate the aquifer storage capacity and the recharge rates to the various aquifers. The rainfall from WorldClim data were used to estimate the surface runoff, the data checked by correlation analysis with observed data from Juba station.

Rainfall

Rainfall based on WorldClim data monthly time step, the data were analyzed calculating the spatial distribution and extent of rainfall events for the area of interest. ArcGIS 9.3 tool was built for a cell-by-cell extraction of monthly average rainfall values within sub-basin.

Evapotranspiration (ETo)

The Blaney Criddle method used to estimate monthly ETo of mean monthly temperature, percent of annual daylight hours (Singh, 1989; ASCE, 1990; Morton, 1994; C. -Y. XU and V. P. Singh, 2001). This method only considers temperature changes at a particular region for measuring reference ET. The Blaney-Criddle formula for estimating ET is as follows:

Equation 1: $ETo = P\,(0.46\,T_{mean} + 8)$

Where, ETo is evapotranspiration from the reference crop in (mm), p is the mean daily percentage of annual daytime hours due to the latitude of the region; and T mean is mean temperature (°C).

Effective precipitation:

The effective precipitation has been calculated using FAO formula

Equation 2: P eff. =0. 6*P-10/3 P <=70/3 mm

Equation 3: P eff. =0. 8*P-24/3 P >70/3 mm

Where P eff. is effective precipitation (mm) and p is precipitation (mm).

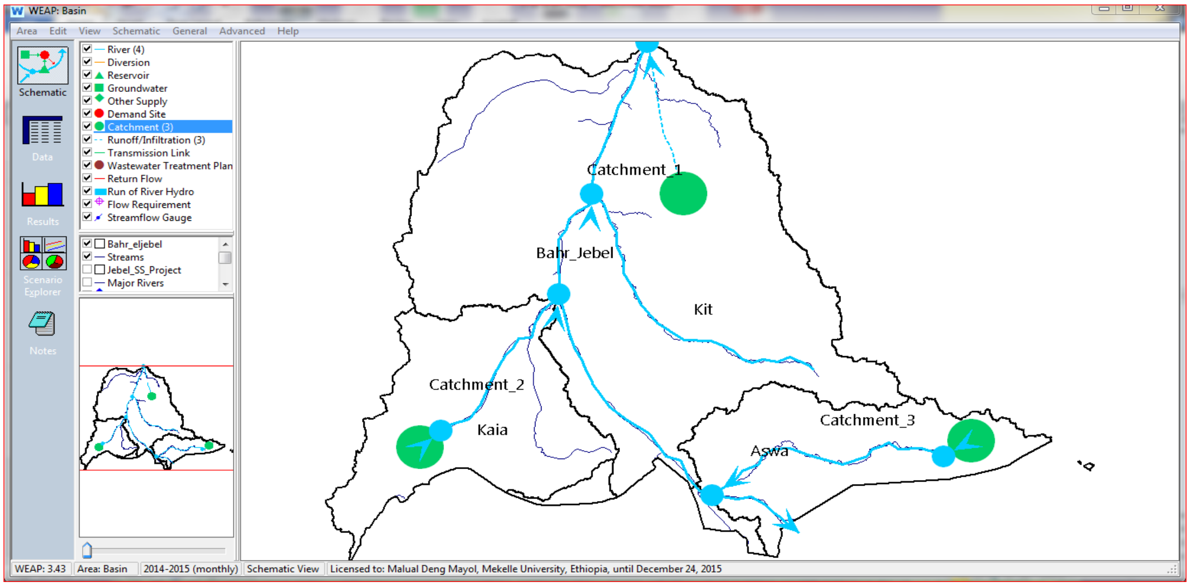

Figure 3.10 Schematic diagrams showing the configuration of the WEAP model for Sub-Catchment of Bahr el-Jebel Sub-basin in South Sudan.

Rainfall-Runoff Simulation Using WEAP was applied for Qarasoo Basin, Iran (Behrooz Y., et al., 2014) data were input manually using land use and climate data as 20 years' time-series input using. Results obtained using that the combinations of several physical and climatic factors of the basin are precipitation, effective precipitation, surface area, moisture, vegetation cover. The study was considered evaluating of each factor in each sub-basin their effect on the output discharge of the watershed and the result of the model is accepted. The other study on Perkerra Catchment, Kenya (Erick A. M., 2010) the data input was Land use (Area and Kc), Climate (precipitation, Effective precipitation and ETo) 10 year. The subdivisions were done along the Thiessen polygons over the catchment for estimating rainfall in each polygon. The results of the modeling were good and the model was able to simulate the runoff in the sub-basin. The rainfall-runoff simulation of WEAP model depends on the data available and can perform much better with the availability of more data.

Water requirements and demands

The water use/requirements assessed for various needs in the sub-basin. Hydropower and environmental requirements (non-consumptive) together with three consumptive uses; domestic, livestock and agriculture were identified in the sub-basin.

Water Demand in WEAP

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 Agriculture entities were based on a disaggregated accounting for various measures of social and economic activity such as population served, livestock population. In this study, other Water Requirement such as mining, heavy industry was not included as demand sites since there is no any available information currently.

Standard Water Use Method was selected in the simplest case, the user determines an appropriate activity level (e.g. Persons, heads, hectares of land) for each disaggregated level and multiplies these by the appropriate annual water use rate for each activity. In this study, it is assumed that, there is no monthly variation in estimated water requirement of domestic and livestock uses.

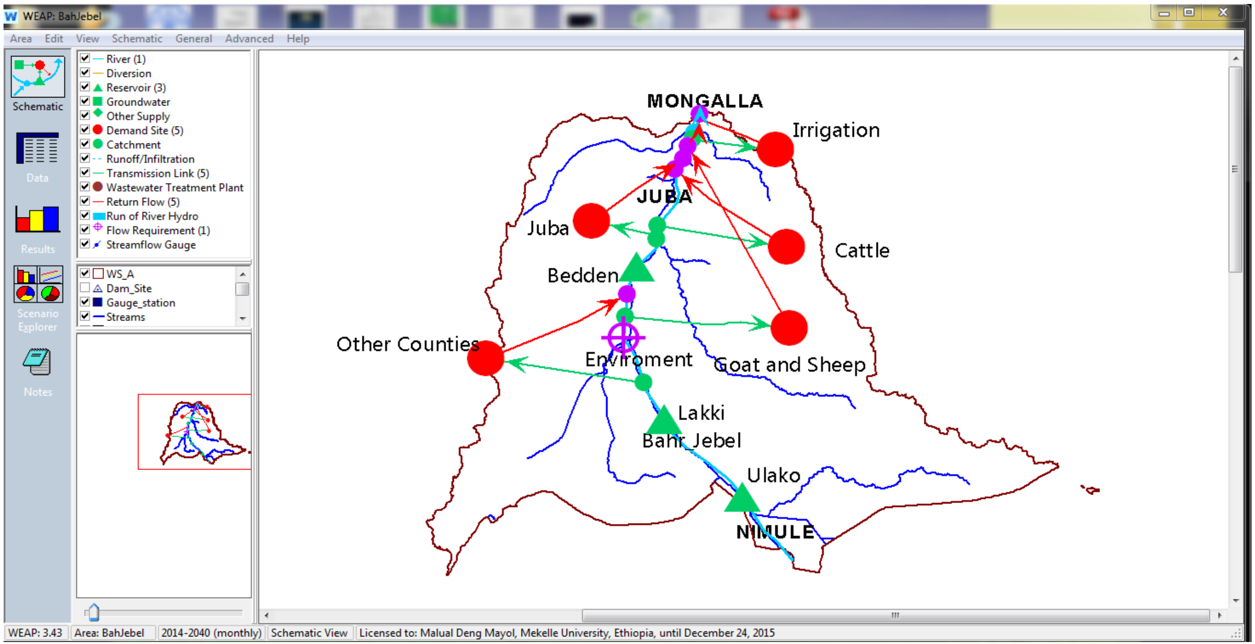

Figure 3.11 Schematic diagrams showing the configuration of the WEAP model for demand sides of Bahr el-Jebel Sub-basin in South Sudan.

I. Domestic Water Demand

The domestic water supply requirement within the sub-basin is primarily concentrated in the urban (Juba county) and rural (other counties). However, Juba and other counties are generally concentrated close to major water sources such as permanent rivers (Bahr el-Jebel), ephemeral streams (seasonal). The total consumptive water requirement was based on the population census of 2008. Due to lack of accurate data, each of TereKeka, Lainya, Morobo, Torit and Ikotos counties the population estimated based on population density of county and area of the county located in the study area.

Table 3.4 Population based on the area of the county within the study area

County	Area in Bahr el-Jebel(km^2)	Population Density	Population
Terekeka	36.127	13.7	495
Lainya	925.391	25.9	23,968
Morobo	762.143	76.9	58,609
Torit	1439.605	17.2	24,762
Ikotos	198.382	24.0	4,762

Source: (NBS)

Table 3.5 Population Projections Based on Census Conducted in April 2008.

County	Year	2008	2009	2010	2011	2012	2013	2014	2015
	Growth Rate		5.52	5.31	5.12	4.94	4.77	4.62	4.47
Terekeka		495	522	550	578	607	636	665	695
Kajo-Keji		196387	207228	218231	229405	240737	252221	263873	275668
Magwi		169826	179200	188716	198378	208178	218108	228185	238385
Lainya		23968	25291	26634	27998	29381	30782	32204	33644
Morobo		58609	61844	65128	68463	71845	75272	78749	82269
Torit		24762	26129	27516	28925	30354	31802	33271	34758
Ikotos		4762	5025	5292	5563	5837	6116	6398	6684
								643,346	

Source: (NBS)

The population data is based on county level. However, some of the counties are not fully located in study area accordingly the assumption was made based on the area of the county, which located in Bahr el-Jebel Sub-basin with a population density of that county (Fig. 3. 12) as is summarized in table 3.5.

Table 3.6 Urbanization Growth of Juba Town

Item	Year 2008	2010	2011	2012	2013	2014	2015
Juba Town	Growth Rate	13%	13%	13%	13%	13%	7%
Population	368,436	470,456	531,615	600,725	678,819	**767,066**	866785

Source: Juba Supply Master Plan, 2009

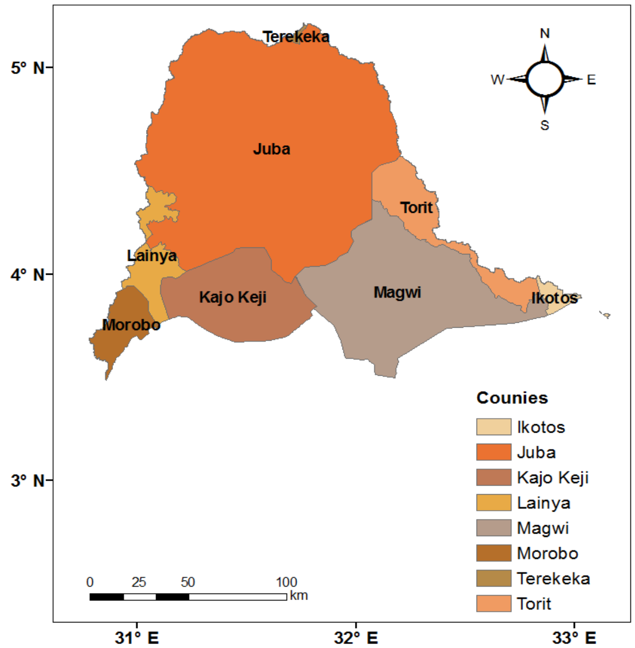

Figure 3.12 Administration boundary of Bahr el-Jebel Sub-basin

Domestic daily demands of Juba county (urban) and other counties (rural); are estimated to be 60 and 20 lit/cap per day for urban and rural respectively. This estimation is according to Juba water supply Master Plan (2009) and World Bank (Rupa R and Cecilia M., 2011) respectively. The industrial sector in the sub-basin is small-scale industries (mineral water) with a low water consumption rate, which considered under domestic demands.

Table 3.7 Estimated Water Demands of the Domestic

Demand	Population	Actual Average(l/c/d)	Annual Water Use (Mm3/yr.)
Juba	767,066	60	16.88
Other counties	643,346	20	4.70

Uganda's current utilization of domestic demand in basin (Albert Nile and Aswa Sub-basin)

Table 3.8 District Population based on Census 2014

Population		
District /(Albert Nile Sub-basin)	Urban	Rural
Adjumani	43022	189791
Amuru	9846	180670
Apac(Albert)	11071	173322
Arua	62657	722532
Koboko	37825	170338
Maracha	8901	177275
Moyo	10507	126982
Nebbi	57335	327885
Yumbe	35606	449976
District/ (Aswa Sub-basin)		
Amuria (Aswa)	3533	131767.5
Gulu	152276	291457
Kaabong (Aswa)	5772	78865.5
Kitgum (60)	44604	159408
Kotido (Aswa)	6995	82459.5
Pader	14080	169643
Total	504,030	3,432,372

Source; Uganda Census, 2014

Table 3.9 Estimated Actual Water Consumption Rate in Uganda side

Demand	Population	Actual Average(l/c/d)
Urban	504,030	70
Rural	3,432,372	20

Source: Uganda National Water Development, 2005

Note: Growth rate of 3.03 percent is considered

II. Livestock Water Demand

Livestock water demand is estimated based on Comprehensive Agriculture Master Plan (CAMP) data. The livestock population growth annual rate is about 3 % (The Rapid Water Sector Needs Assessment, 2013).

Table 3.10-Estimated Livestock Population

County	Cattle	Goat	Sheep
Terekeaka	2,000,000	1,800,000	1,200,000
Magwi	20,000	110,000	80,000
Torit	250,000	350,000	175,000
Ikotos	120,000	320,000	145,000
Total	2,390,000	2,580,000	1,600,000

Source: CAMP Draft, 2013

Note: Livestock population data in other counties is not available. Source; Central Equatoria State Ministry of Animal Resources and Fisheries (MARF).

Considering all livestock, populations of the counties sharing within the sub-basin are beneficiary form sub-basin due to lack of detailed information about the livestock settlement in the study area. There are no recent counts of livestock population density, but many pastoralists are moving with their large heads of cattle and other livestock in response to the annual regime of the Bahr el Jebel River. The communities are using the sub-basin extensively for livestock grazing. Livestock's water requirement rate given as the unit 40 and 10 lit/head per day for cattle and goat/sheep respectively. However, the water requirement of the livestock is according to FAO assessment in Jonglei State, South Sudan (2012) and water consumption of livestock according to NRC (1981), USGS (2000).

Uganda side within the basin

Table 3.11-Estimated Livestock Population

District (Albert Nile Sub-basin)				
	Cattle	Goat	Sheep	Pig
Adjumani	105230	131282	26030	7450
Amuru	33060	67092	9770	19180
Apac(Albert)	225090	279649	45980	28440
Arua	117160	273012	45920	22930
Koboko	54200	101602	33250	270
Moyo	103870	190341	37740	9030
Nebbi	101950	302576	46080	19890
Yumbe	223650	409793	151360	17510
District /(Aswa Sub-basin)				
Amuria (Aswa)	171380	113110	35940	41320
Gulu	40130	65301	4290	26570
Kaabong	518470	525389	424730	33830
Kitgum	38460	54815	11510	38440
Kotido	694250	535138	555690	1320
Pader	57090	57807	6300	39430
Total	2,483,990	3,106,907	1,434,590	305,610

Source; Uganda national livestock census, 2008

Table 3.12 Estimated Livestock Population 2014, at growth Rate of 3.5

Sub-basin	Cattle	Goat	Sheep	Pig
Albert Nile	1,185,260	2,157,770	486,945	153,288
Aswa	1,868,198	1,661,412	1,276,532	222,385
Total	3,053,458	3,819,182	1,763,477	375,673

Table 3.13 Estimated Water Demands of the Tropical Livestock Units [a]

Animal	Consumption rate (L/d)
Cattle	27
Sheep	5
Goat	5
Pig	5

Source: FAO (Pallas P. 1986); Kijne *et al. 2002*.

a. Cattle, sheep, and goat tropical livestock unit = (180, 25 and 25) kg of live animal weight.

III. Water Demand for Agriculture

The agriculture demand is estimated based on land use and water requirement for rain-fed crops by using Area, Crop coefficients (Kc), and the Reference Crop Evapotranspiration (ETo). Maize is the dominant crop in the sub-basin and is considered as the main crop. Another assumption is maize will have a season average Kc of 0.82, total growing period of 125 days (Richard G. Allen *et al.*, 2006) and the average ETo is 5.45 mm per day and evapotranspiration in South Sudan is range from 1750-2000 mm/year(Seleshi B. Awulachew .*et al.*, 2012). In addition, the area under rain-fed crops is around 109,780 hectares of the area.

CROPWAT, which developed by FAO, is used to estimate water requirements for the proposed irrigation schemes. According to Irrigation Development Master Plan (IDMP) studies in the study area, the main crops are Maize, Cassava, Sorghum, Sugarcane, Rice and Vegetables. As a result, these crops were chosen to estimate the crop water requirement for proposed irrigation. The Blaney-Criddle formula was used to determine the reference crop evapotranspiration (ETo) and the FAO formula for effective rainfall.

Table 3.14 Proposed Irrigation projects in the Sub-basin

S/N	Project Name	Main Crop	Area(ha)	Term	Period
1	Jabel Lado Irrigation	Maize/cassava	2000	Short-term	2015-2021
2	Rajaf Irrigation	Vegetables	1000	Short-term	2015-2021
3	Luri Scheme	Sorghum	1000	Short-term	2015-2021
4	Mongalla (Small scale)	rice	1000	Mid-term	2022-2027
5	Mangalla Irrigation	Sugarcane	1000	Long-term	2028-2040

Source: IDMP Draft , 2015

Table 3.15 Crop Water Requirement for Proposal Schemes

Crop	Season	Area(ha)	CWR(m3/ha)
Maize	Two	2000	12162
Vegetables	Two	1000	10082
Sorghum	Two	1000	10970
rice	one	1000	9083
Sugarcane		1000	16953

Table 3.16 Estimated Water Requirement of Existing Irrigation within the Basin in Uganda side

sub-basin	Area(ha)	Crop	Average CWR(m^3/ha)	Crop Water Demand (10^6 m^3/year)
Albert Nile	6,144	Maize, Vegetable, Fruit,	7,500	46.08
Aswa	1,871	Cassava and millet	7,500	14.03
Total	8,015			60.11

Source: Irrigation Master Plan, Uganda, 2011

The area under rain-fed agriculture in the basin is around 191042 ha in both Albert Nile and Aswa sub-basin in Uganda side, which estimated according to Africa land use map (FAO, 2014) created in 2004. The crop water requirement is also estimated to be 5000 m^3/ha of rain-fed agriculture (Uganda National Water Development, 2005), because a large part of the crop, water requirement is met from rainfall. In addition, increase the effective rainfall can reduce water requirements needed for crops. Subsequent crop water requirement frequently restores the soil, water content to field capacity, and depend on the rainfall pattern. In addition, Uganda has a tropical climate characterized by strong seasonality in rainfall (UN-Water, 2006) it makes less demand.

Table 3.17 Irrigation Potential (ha) in Basin in Uganda Side, Type A

Sub-basin	Area(ha)	Average CWR (m^3/ha)
Albert Nile	43,539	12,000
Aswa	20,398	12,000
Total	63,937- By the end of the Long Term 2035	

Source: Irrigation Master Plan, Uganda, 2011

Note: the crop water requirement estimated according to the Uganda National Water Development, 2005. Furthermore, type 'A' land lies close to surface water resources on which agricultural water can be managed without the need for a storage facility.

Detailed information on water demand was not available for this period and water demand had been assumed from data taken from the institutions by interviewing experts.

Future water demands in the Bahr el-Jebel Sub-basin

Scenario projections for this study established in WEAP based on Irrigation Development Master Plan stage for the implementation plan. These all scenarios will adopt some change in domestic and agricultural water consumption rate, but consumption rate of livestock will remain constant, and the trend would follow the same pattern as the water demand is increasing. Which means the livestock will increase in population, but the water consumption rate will be constant.

I. Reference Scenario

The Reference scenario is the scenario in which the current situation, the current account year as 2014 and is extended to the 'future' (2015-2040). No major changes are imposed in this scenario, simply linear population increase.

II. Scenarios Full Development (2015-2040)

If the irrigation potential in the basin is developed and water consumption per capita is increased to 120 l/c/d, 35 l/c/d for urban and rural demand respectively. Moreover, the annual crop water requirement rate is 12, 000 m^3 per ha.

Water Requirement for Non-consumptive uses

I. Environment Requirement

The environmental water demand or environmental flow requirement (EFR) of river basins has been attracting increasing attention (e.g., Naiman *et al.*, 2002; Sharma *et al.* 2004). The most straightforward practices of environmental water allocation focus on keeping some minimum flow in a river downstream of the major abstractions. The environment or in-stream flow requirement is often defined as how much of the original flow regime of a river should continue to flow down it in order to maintain the riverine ecosystem in a prescribed state. In addition to the ecology of a watercourse, there may be a need to recommend in-stream flow requirements for the following reasons:

- Protection of the rights of other abstractors in downstream;
- Navigation;
- Dilution of effluent;
- Maintenance of the flood carrying capacity of the channel;
- Cultural and social reasons;
- Prevention of invasive plant species;
- Wildlife and game reserve;

- Maintenance of the channel diversity;

According to Tennant, 1976 suggested that, 10 percent of MAR is the lowest feasible limit for EFR. The "moderately modified" (Smakhtin *et al.*, 2004), EFR estimates obtained in the global scenario vary from 20 to 50 percent of MAR. However, a global distribution of estimated total EFR expressed as a percentage of long-term mean annual river runoff in Nile Basin is 20-25% of MAR (Smakhtin *et al.*, 2004). Hydrological methods use flow data for estimating EFR are recommended where flow data is available, data for estimating EFR (Hughes and Hannart, 2003; Smakhtin and Weragala, 2005; Smakhtin *et al.*, 2006).

Environmental flow is one of the important components in water resources planning, management and allocation, and sustainable environmental flow benefits the health and maintenance of the aquatic ecosystem. The environmental flow in this study is assigned to be 25 percent of mean annual runoff in-stream flow required at a point on a river to meet water quality, fish & wildlife, navigation, recreation, and downstream or other requirements.

Navigation; at present, river navigation within the sub-basin exists only between Mangalla and Juba. However, the route needs to be maintained, particularly from Hyacinth growth and keeping depth required for navigation in order to intensify transport of passengers and goods.

Wildlife; Nimule National Park is the one of the national parks in South Sudan and is located in this sub-basin. Wildlife in the park is especially the elephant, hippopotamus and Uganda Kob, although other species were covered (Malik D.M.*et al*., 2004). The wildlife is of fundamental importance to the development of tourism in the country.

II. Water Requirement for Hydropower

There is no hydropower generation existing at present in the sub-basin. However, South Sudan has considerable hydropower potential, with the greatest lying on the White Nile River between Nimule and Juba is located in the sub-basin. The pre-feasibility study done on hydropower dams in the sub-basin in 2009 proposed the developing the power generation. The study analyzed a number of dam development options to maximize the energy potential of Bahr El-Jebel Hydropower. The study identified and studied the three options are:

- Option A - 4 Dams (Fula, Shukoli, Lakki and Bedden)
- Option B - 3 Dams (Ulako, Lakki and Bedden)
- Option C - 2 Dams (Shukoli and Bedden)

The study was preferred option B, with the development of dams at Bedden, Lakki and Ulako (downstream of Fula). The key criteria in favour of this option are environment and social impacts and economics.

Table 3.18 List the Major Parameters of the Three Proposed Dams

		Ulako	Lakki	Bedden
Installed Capacity	MW	640	522	522
Full Supply Level	masl	600	550	510
Maximum Flood Level	masl	602.4	553.1	513.2
Minimum Operating Level	masl	595	545	505
Live Storage	Mm^3	107.2	259.4	604.7
Dead Storage	Mm^3	244.1	595.3	1225.4
Total Storage	Mm^3	351.3	854.7	1830.1

Source: BEJHP PF Study, 2009

Three hydro-powers are mainly for power productions, which rely on storage of water in the dam during rainy seasons and then a relatively constant release of water through the turbines. This regulation by those dams also ensures a relatively even flow to the downstream. However, the value of power generation in terms of its impact on national economic benefit would contribute in water resources management development in sub-basin and in the country in general.

3.2.3 Linking the Demand with Supply

Configuration of the entire demand and supply system, including the links between supplies and demands is important. In order to inform WEAP how the demand is satisfied, the user needs to connect to the supply system that has been identified previously to each demand site. To understand how supply, fit the demand in different scenarios.

3.3 Materials

3.3.1 GIS for Watershed delineation

Determination of the basin boundary was done using the spatial analyst tool in ArcGIS version 9.3 and the SRTM. Using ArcGIS 9.3, various thematic maps such as topography, drainage, land cover/use, and soils produced.

3.3.2 CROPWAT

The CROPWAT 8.0 software was used in calculating crop water requirements. This software uses monthly averages of the climatic parameters. The ETo is calculated using the Blaney Criddle method and effective rainfall is estimated by FAO formula. The software provides data on crop such as Kc, growing stage, rooting depth, soil moisture as defaults.

3.3.3 Water Evaluation and Planning

The Water Evaluation and Planning software selected for the purpose of this study. The WEAP model essentially calculates a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. The elements that comprise the water demand–supply system and their spatial relationship are characterized within the model.

The purpose was not to describe accurately the hydrological process of the sub-basin, but to be able to simulate the surface water resources of the study area with limited data and using a small number of parameters. Several assumptions in demand side also have been made in the data estimation because of the lack of consistent data in Bahr el-Jebel sub-basin. The study area was so large that determination of the data from a field study was not possible.

Microsoft Excel is also used for data processing, for CROPWAT and WEAP model.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Surface Water Availability

4.1.1 Stream Flow

Due to shortcomings in the available data for Bahr el-Jebel, four-year data were taken to estimate the river flow at Mongalla, which is the outlet of the sub-basin. The total annual river flow of Bahr el-Jebel at Mongalla has been estimated to be 37.8 BCM. The higher flows of 2008, 2010 and 2011 (Fig. 4.1) due to the expected higher rainfall occurred in those years (Fig. 4.2). The peak flow in Bahr el-Jebel is occurring on August to November (Fig. 4.3). Furthermore, the highest monthly average flow occurs in October and the lowest occurring in February with values 3880.82 and 2588.61 M m^3 respectively (Fig. 4. 3).

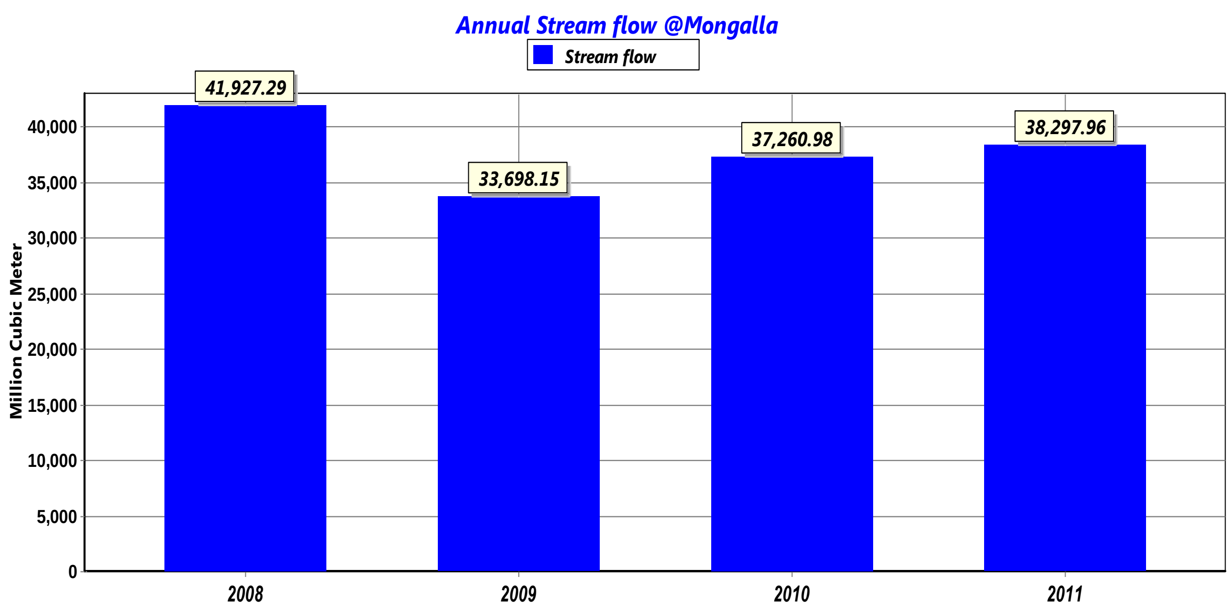

Figure 4.1 Annual Stream flow data at Mongalla(2008-2011)

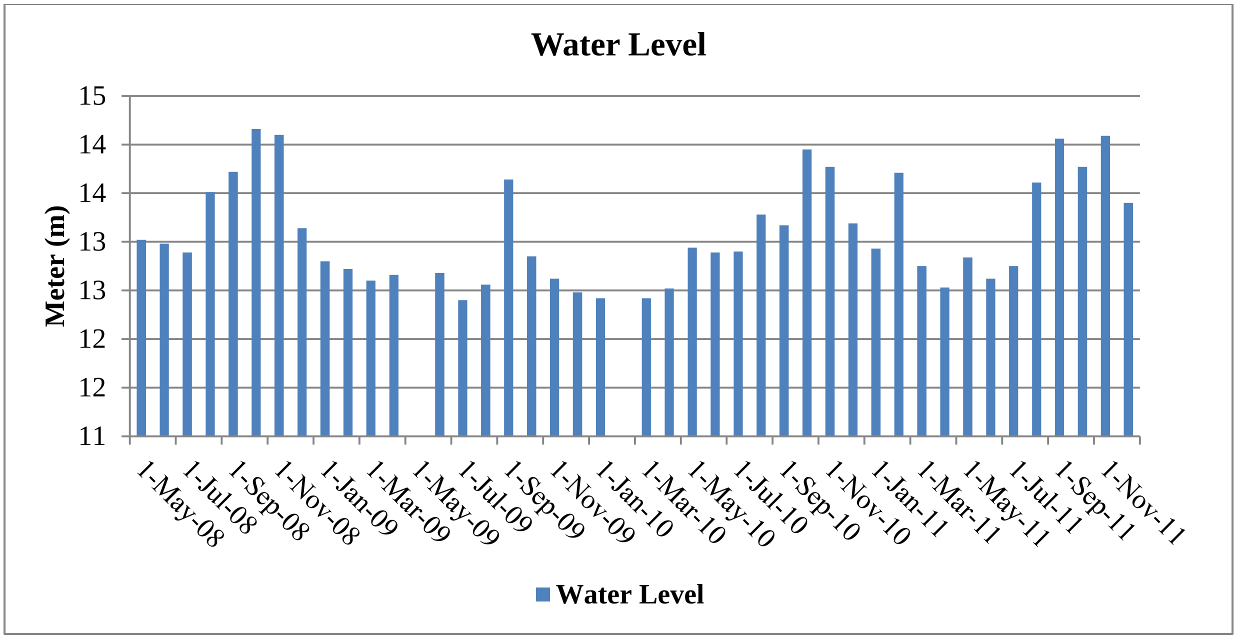

Figure 4.2 Water levels at Mongalla

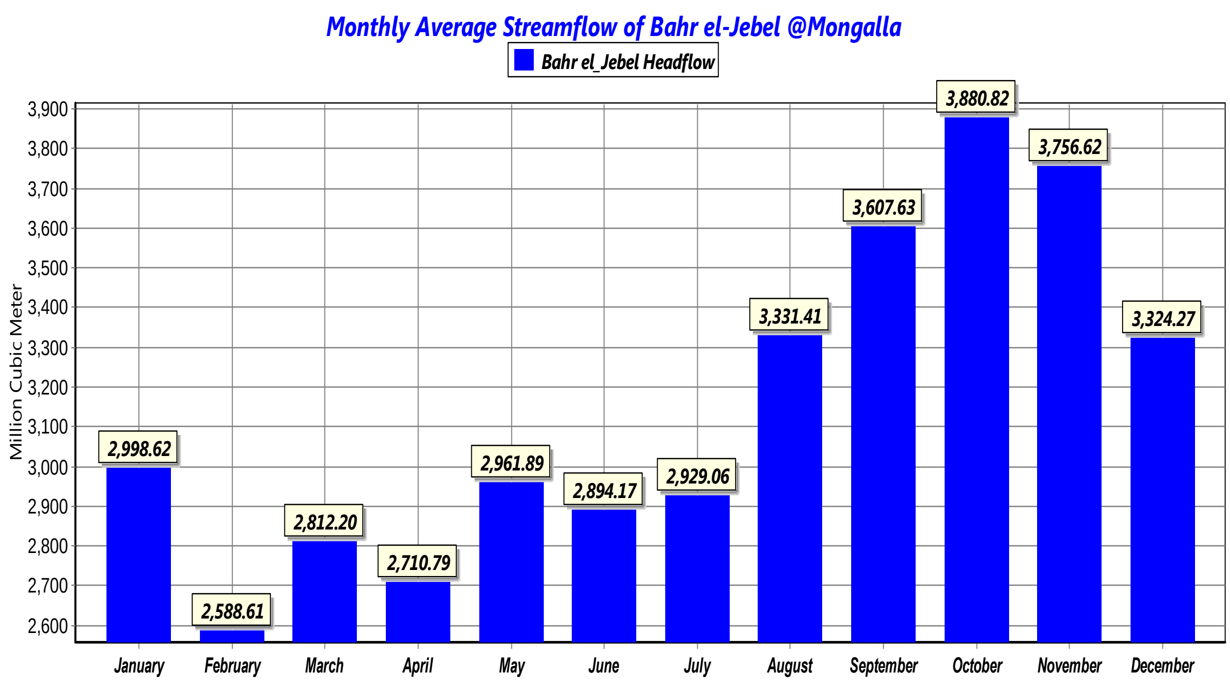

Figure 4.3 Monthly Average Stream Flow of Bahr el-Jebel in 2008-2011

Table 4.1 Annual Bahr el-Jebel Stream Flow (MCM) at Mongalla

Jan	Feb	Marc	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
2998.62	2588.61	2812.20	2710.79	2961.89	2894.17	2929.06	3331.42	3607.63	3880.82	3756.62	3324.28	37796.10

The total surface water available in Bahr el-Jebel sub-basin is 37,796.10 MCM. Accordingly, there are previous studies shown that the flow at Mongalla was 36.8 km^3 (1948-1970) and 33.1km^3 (1912-1982) (Karyabwite, D.R., 2000; UNEP, 2000; Willems, *et al.*, 2009). However, outflows from the Lake Albert basin at Laropi (Uganda) near the border of South Sudan for the period Jan 2000 to Oct 2010 with some gaps. The average monthly flow calculated and the total annual flow volume was 37.60 BCM/yr (NBI, 2014, 01).

Table 4.2 Average Monthly flow on basin system at Mongalla and Laropi (BCM)

	Jan	Feb	Marc	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Total
D/S at Mangalla	3.00	2.59	2.81	2.71	2.96	2.89	2.93	3.33	3.61	3.88	3.76	3.32	37.80
U/S at Laropi	2.98	2.58	2.80	2.70	2.95	2.88	2.91	3.31	3.59	3.86	3.74	3.31	37.60

Note: the monthly average in upstream calculated by normal correlation of total annual flow.

There is such variation in flow was observed in those years 2008 to 2011 due to higher rainfall in upstream basin over Lake Victoria. According to study was conducted by J.L. Awange, *et al.*, (2013) showed that there is an increase of 4.5 mm/yr. in flow over 2007-2013, likely due to two massive rainfalls in 2006-2007 and 2010-2011. The same study indicated that there is increased in rainfall trends over the Lake Victoria Basin from 2003-2013. Generally, there is increasing natural river flow in sub-basin due increased rainfall in the upstream sub-basins. Overall, this study confirms that increase of the rainfall in upstream has significant increasing on river flow over the Bahr el-Jebel Sub-basin during the last decade.

During the civil war in Sudan, measurements were not taken in Mongalla between 1983 to 2007. Measurements have resumed since 2008. Accordingly, Mongalla station indicates the outflow White Nile from the Equatorial Lakes where the White Nile enters to Sudd area (swamps). Furthermore, all rivers sub-basins in South Sudan ultimately reach the Nile through various interconnections. Thus an understanding of the Nile flow, gives an insight into the flow regime of major rivers in South Sudan.

4.1.2 Rainfall Runoff Modeling

The runoff generated from the rainfall of the study area has been estimated using water balance, rainfall runoff method in WEAP model. As a result of the calculations, based on the Rainfall Runoff method in WEAP, it was found that the total annual surface runoff from a given precipitation in Bahr el-Jebel is 4,735.72 MCM (Table 4.3) which is 13 % of total surface water in Bahr el-Jebel sub-basin. Sutcliffe and Parks (1999), reported that the flow of Bahr el-Jebel between Nimule (enter to South Sudan border) and Mongalla was 4,691 Mm^3/yr. and flow at Mongalla was 36,047 Mm^3/yr. which is a 13 % contribution within South Sudan.

The results of the model indicate that the runoff generates within South Sudan is estimated around 13% of the total annual flow in Bahr el-Jebel sub-basin.

Table 4.3 Runoff Monthly Average (MCM) in Bahr el-Jebel Sub-basin

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Catch-ment													
C1	8	22	84	203	273	239	279	314	255	235	94	18	2027
C2	4	18	55	144	162	162	157	357	256	172	62	16	1565
C3	5	19	51	115	138	124	148	174	149	136	67	18	1144
Total	18	59	189	461	574	526	585	845	661	542	224	52	4,736

Note; C1, C2, C3 is catchment 1, catchment 2 and catchment 3.

Precipitation within Bahr el-Jebel sub-basin

The results show that Bahr el-Jebel sub-basin receives a huge amount of rainfall estimated around 25.8 BCM annually (Table 4.3) which can to enhance rainwater harvesting in the study area. The higher month's rainfall is occurring from May to October and lowers from December to February. Moreover, the highest monthly average rainfall over area occurs in August and the lowest occurring in January with values 3868 and 102 M m^3 respectively. There are also substantial variations of rainfall regime from one month to another, and from area to another. The three catchments showed significant spatial and temporal variations.

Table 4.4 Observed Precipitation Monthly Average (MCM) in Bahr el-Jebel Sub-basin

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Catch- -ment													
C1	54	147	563	1354	1823	1595	1863	2024	1702	1568	630	121	13442
C2	22	89	273	718	812	812	784	1029	918	857	312	78	6703
C3	26	95	253	574	689	621	742	816	747	679	337	89	5667
Total	102	331	1088	2645	3324	3028	3389	3868	3367	3103	1278	288	25,812

The water balance of simulations shows that on average, of 20% rainfall is contributing to surface and subsurface flow and 80% is evapotranspiration; the total water balance is shown in (Fig. 4.4). That means more water is consumed by vegetation (evapotranspiration) is 21,076 million m^3/year is around 80% of rainfall from Bahr el-Jebel sub-basin. According to NBI (2014, 01) Bahr el-Jebel and Lake Albert basins seem to have the highest evapotranspiration 73% to 87%. The evapotranspiration considers consumptions of human, plant and the soil as these consumptions is either directly or indirectly evaporated or transpirated.

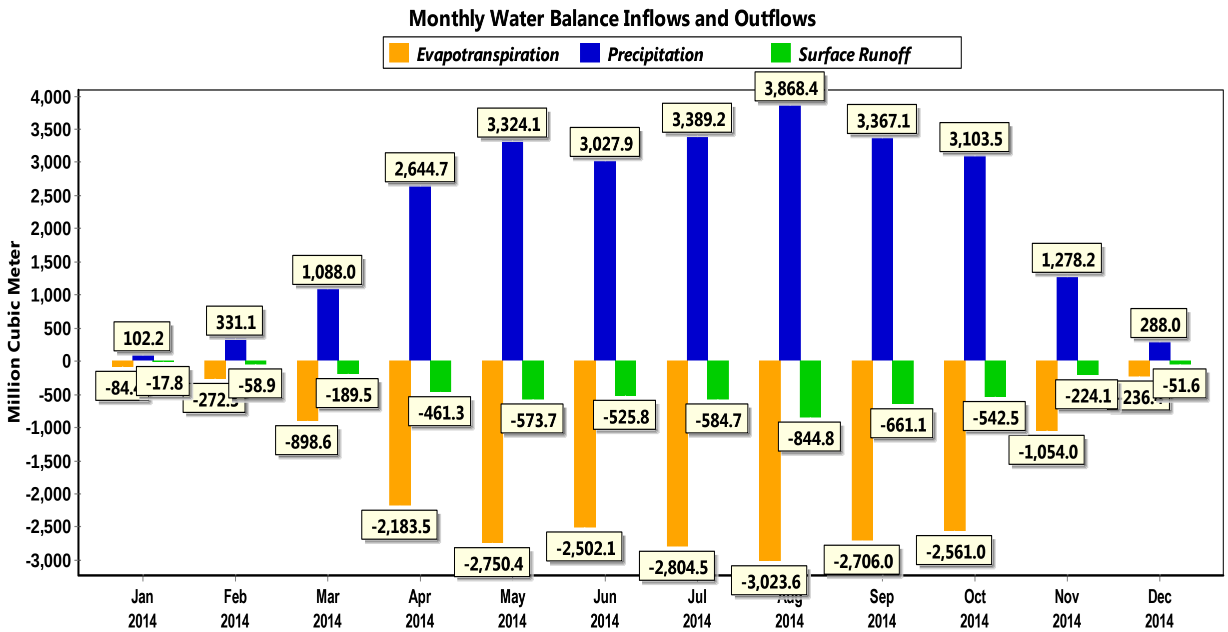

Figure 4.4 Water Balance in Bahr el-Jebel Sub-basin (MCM)

4.2 Modeling of Water Demand

The current account of the model was developed using the demand data of 2014 and simulated stream flow data (Supply) at outlet Mongalla is 37.8 Bm^3. The basin has at least three consumptives demand domestic, agriculture and livestock. Table 4.4 summarizes the results of the model for the current account (water consumption). These results indicate that, the utilization is low compare with a population within the basin.

Table 4.5 Annual Water Consumption

Demand	South Sudan (MCM)	Uganda (MCM)	Total MCM
Domestic	21.57	37.93	59.50
Livestock	50.15	40.97	91.12
Agriculture	613.23	1015.32	1628.55
Total Consumption	684.95	1094.22	1,779.17

The current total water consumption for the above three consumers (domestic, livestock and agriculture) within the basin is estimated to be 1,779.17 MCM per year. Therefore, the water withdrawal in Bahr el-Jebel is around 4.7 % of the total water available in the basin, which is 37.8 billion meters cubic per year. Comparing the water requirements with the available surface water, Bahr Jebel had a capacity to utilize only 4.7% of the current water available in the basin for consumptive uses. Nevertheless, the water utilization in Bahr el-Jebel basin is 38.5% within South Sudan and 61.5% in Uganda side. Table 4.5 describes and presents the net demand for each sector incorporated within the WEAP model simulation.

Currently water utilization in Uganda greatly exceeds than in South Sudan. Although there is, variation, reflecting differences in total Agriculture demand in Uganda, currently estimated to be 1.02 Bm^3y^{-1} on average. This is not comparable to an average of just 0.61 Bm^3y^{-1} in South Sudan side. The water demand for livestock, however, is higher in South Sudan side than Uganda since the water consumption rate in Uganda is less due to tropical livestock units' type.

Table 4.6 Average monthly Water Demands for Domestic, Agriculture and Livestock (MCM) (not including loss)

Demand	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Domestic	5.1	4.6	5.1	4.9	5.1	4.9	5.1	5.1	4.9	5.1	4.9	5.1	59.5
Livestock	7.7	7.0	7.7	7.5	7.7	7.5	7.7	7.7	7.5	7.7	7.5	7.7	91.1
Agriculture	86.2	77.9	116.9	206.1	178.2	132.5	129.2	116.9	206.1	166.0	126.4	86.2	1628.6
Total	99.0	89.4	129.7	218.5	191.0	144.9	142.0	129.7	218.5	178.7	138.8	99.0	1,779.2

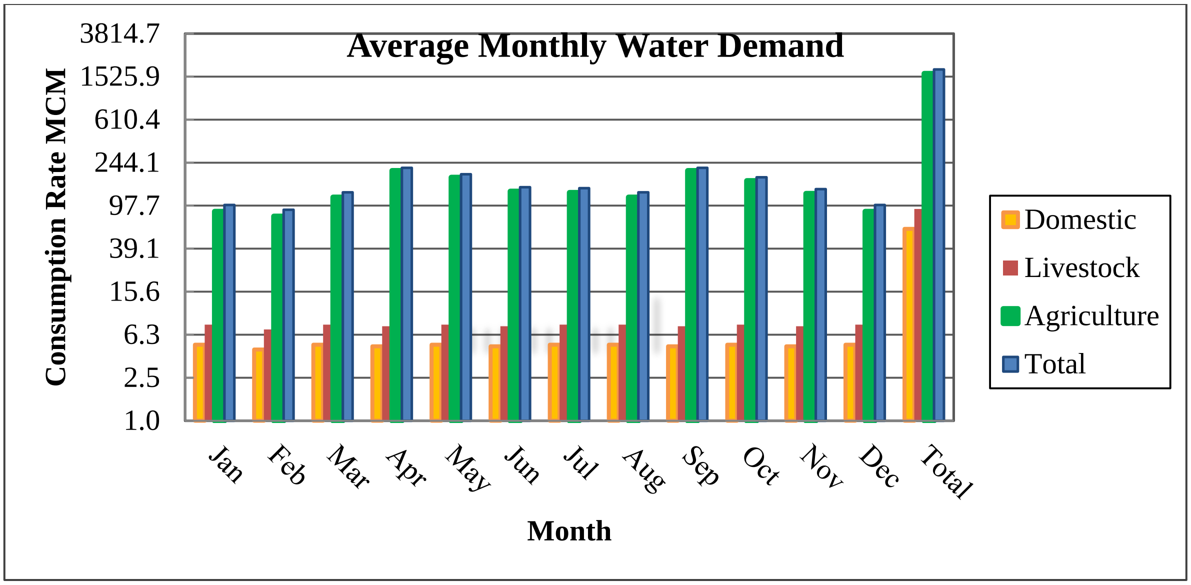

Figure 4.5 Water Demand for Difference Sectors

4.3 Scenario Analysis and Water allocation

Scenarios are defined as alternatives or a set of assumptions, increasing population and future development or policies. Changes in these assumptions could grow demand. However, Scenarios in WEAP encompass any factor that can change over time, including those factors that may change because of particular policy interventions, and those that reflect different socio-economic assumptions.

Water allocation models must accurately represent the significant features of water resource systems within any basin. Ideally, they should simulate the water availability and demand (Etchells and Malano, 2005). The demand priority in this case, represented the level of priority for allocation of the available water resource (SEI, 2008; Al-Omari *et al.*, 2009). This means, for example, the demand that all sites with the highest priority would be supplied first before moving to lower priority sites until all the demands are met or all the available resources are used, whichever comes first. Priorities for different demand sites in the basin were set on the base on assumption of water availability in the basin and demand needs between different sectors as well as the possible consideration of environment requirement and downstream allocation (Table 4.6).

Table 4.7 Priorities for Different Demands in The All scenarios

Demand	Priority
Domestic	1
Environmental flow	1
Agriculture	2
Livestock	2
Hydropower	3

4.3.1 Reference Scenario

Reference Scenario (2015-2040) represents the changes that are likely to occur in the future without intervention new policy measures; it only increases in population growth. The population growth rate is 7, 4.47 and 3.05 % annually for Juba, other counties and Uganda side respectively, and for livestock is 3 and 3.5 % annually in South Sudan and Uganda respectively. While assuming that similar trends of the stream flow situation will exist in future. Agricultural demand and hydrological condition is assumed unchanged into the future in this scenario. Climate change scenarios and their impact on water resources in this study are hardly to be taken into account due to limitation of climate data. Therefore, the further studies should be collaborated with climate change model.

Table 4.8 Water Consumption (MCM) of the Reference Scenarios 2015_2040

Year Sector	2015	2020	2025	2030	2035	2040
Domestic	62.05	76.86	95.91	120.62	152.93	195.49
Livestock	94.06	110.24	129.23	151.52	177.66	208.36
Agriculture	1628.55	1628.55	1628.55	1628.55	1628.55	1628.55
Total	1784.66	1815.65	1853.69	1900.69	1959.15	2032.40

Table 4.9 Water Demand Distribution for Different Sectors in the Reference Scenario

Sector	Current Demand (MCM)		Future Demand 2040 (MCM)	
	South Sudan	Uganda	South Sudan	Uganda
Domestic	21.57	37.93	112.64	82.85
Livestock	50.15	40.97	108.16	100.20
Agriculture	613.23	1015.32	613.23	1015.32
Total	684.95	1094.22	834.03	1198.37

The analysis of the result shows that there is not a significant change in the demand within the basin (Table 4.9) comparing with scenario of current account and is around 5.4 % of total supply. Therefore, there is a significant increase in domestic demand in the South Sudan side due to the high rate of population growth in Juba town the Capital of South Sudan.

4.3.2 Water Requirement for Non-consumptive

Environmental Flow Requirement

In estimating the availability of water resources, consideration must be given to requirements for environmental flows to maintain the ecosystems of the river, to consider the obligations, and to maintain flow levels of downstream users.

The environmental flow in Bahr el-Jebel sub-basin in this study adopted 25% of the river flow to be allocated to the environment needs in order to fulfill fish and wildlife, navigation in sub-basin and downstream requirement. The 25% of the average annual flow was adopted since no comprehensive assessment of environmental flow requirements has been conducted in the Nile Basin (Seleshi B. Awulachew *.et al.*, 2012). Water allocated for EFR equivalent to 25% of the MAR of the sub-basin for wildlife and navigation in sub-basin and assigning a considerable demand on the national and trans-boundary water resource like the river Nile riparian's. The results of this study suggested EFR that can be included in sub-basin water resources planning is 9.45 BCM annually.

According to a study conducted by McCartney *et al*. (2010) to determine environmental flow requirements (both high and low flows) for the Blue Nile downstream of CharaChara weir on Lake Tana. It estimated that an average annual allocation of 22 % of the mean annual flow.

Furthermore, in South Africa, Olifants River the environmental flow requirements vary from year to year, depending on rainfall, but overall the flows recommended for the long-term ecological maintenance of the Olifants River constitute between 15.7 and 33.5 percent of the mean annual flow (McCartney, M. P. *et al*., 2007).

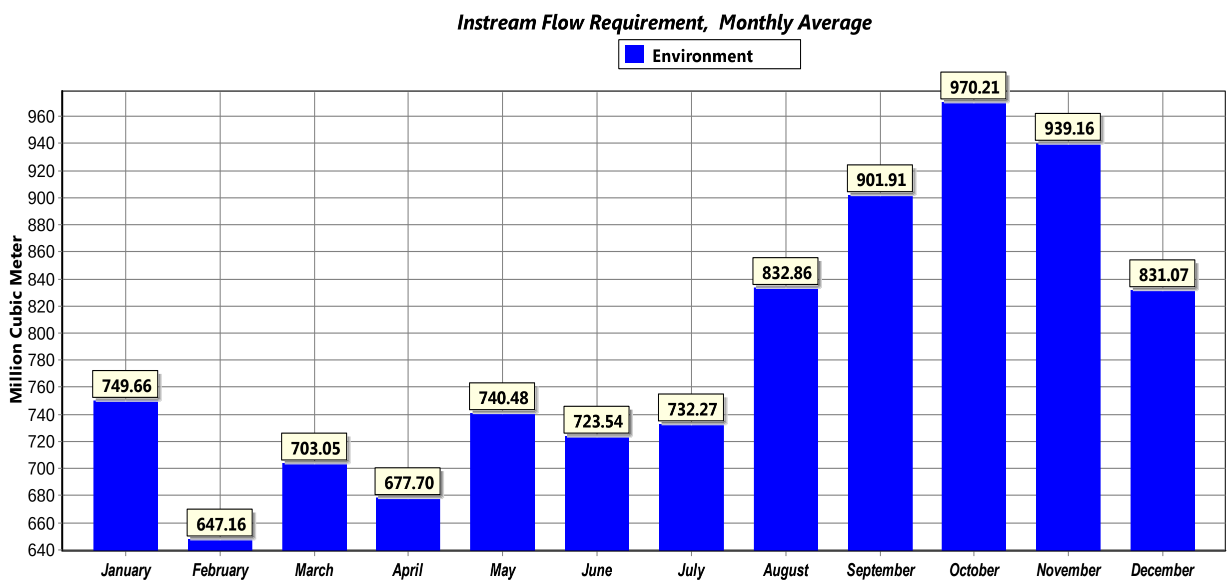

Figure 4.6 Monthly Average of Environment Flow

This study suggested that the 25% MAR both high and low flows to release to maintain swamp area(Sudd), the ecosystems and downstream needs since the permanent swamps are an important dry-season for wildlife evacuation, including large populations of different animals. South Sudan has recently declared the Sudd swamp a national reserve, with plans to develop eco-tourism in the area (Seleshi Bekele Awulachew .*et al*., 2012).

Water Requirement for Hydropower

Currently, there is no existing Hydropower generation in particular within the sub-basin and even within the country. With the construction of the three proposed dams, it is estimated to be approximately (1684 WM) 6,094 GWHy^{-1}.

Table 4.10 Proposed Hydropower Capacities

		Ulako	Lakki	Bedden
Installed Capacity	MW	640	522	522
Total Storage	Mm^3	351.3	854.7	1830.1
Design Discharge	m^3/s	1276.6	1211.4	1210.6
Max. Turbine flow	m^3/s	858.6	800	810.6
Energy Demand	GWH	1909	2323.4	1862

Source (BEJHP PF Study, 2009)

Due to the construction of dams, the flow towards the downstream regulated. The dams may be required to release water for downstream users since is for power generation purpose. The evaporation losses from the dam are not calculated due to lack of data.

The hydropower demand, which is a non-consumptive use, was taken as unimportant in affecting the water availability in the sub-basin. The water management practices could be associated with hydropower releases.

4.3.3 Scenarios Future water demands (Full Development)

This scenario defined a set of assumptions that, all irrigation schemes in the basin are implemented and access to water for domestic is improved. In addition, the environment flow requirement would be remaining 25% of MAR. Therefore, the water demand could be 3.78 B m^3 10 % (Table 4.10) of total supply in Bahr el-Jebel sub-basin. By 2040 it was estimated the total annual consumptive demand would be like 1719.59 MCM (4.5 % of the natural flow of South Sudan side), of this 2062.81 MCM (5.5 %) will be consumed in Uganda. Moreover, the environmental flow requirement would be 9.45 BCM annual releases to environmental needs and downstream requirement. However, of the scenarios full development there would be reduced about 2.06 Bm^3 (5.5%) of stream flow from upstream (Uganda side) due to water abstraction.

Table 4.11 Water Demand MCM) for Scenarios 2015_2040 Full Development

Year Sector	2015	2020	2025	2030	2035	2040
Domestic	112.79	140.47	176.31	223.09	284.60	366.05
Livestock	94.06	110.24	129.23	151.51	177.66	208.36
Agriculture	1691.22	2026.50	2394.71	2787.72	3207.99	3207.99
Total	1898.07	2277.21	2700.25	3162.32	3670.25	3782.40

Table 4.12 Water Demand in South Sudan and Uganda for Difference Sector

	Demand 2035(MCM)		Demand 2040 (MCM)	
Demand	South Sudan	Uganda	South Sudan	Uganda
Domestic	160.70	123.90	222.08	143.98
livestock	93.30	84.37	108.16	100.20
Agriculture	1389.36	1818.63	1389.36	1818.63
Total	1643.35	2026.90	1719.59	2062.81

According to the Irrigation Master Plan of Uganda (2011), full development of Uganda's irrigation potential, which estimated that the flows would reduce around 2.13 billion m^3 per year of water, crosses the border into the South Sudan. Also other study showed that if irrigation potential fully developed in Uganda the water demand of 2.7 billion m^3 per year would be reduce from the water flow to downstream the River Nile countries (Nsubuga, F.N.W. *et al.*, 2014). While the result of water demand projection in 2035 (Table 4.11) in the Uganda side with the full development scenario is closed with reduction estimated by the irrigation master plan study in Uganda. Generally, the flow coming from upstream Uganda would be reduced by an average 2.42 billion m^3 annually where irrigation potential is fully developed by 2035 due to development activities. The estimated water that can supplied at different levels of assurance to each sector in each scenario (Table 4.12), the result indicates that surplus occurs every year, even in the full development scenario. However, with abundant water surface potential, clearly, careful consideration of policy, regulatory, institutional, economic and social issues is required as well as an integrated river basin approach for future sustainability.

Table 4.13 Water Demand Distribution for Different Sectors in the All Scenario (MCM)

Sector	R-Scenario 2015-2040	%	Scenario Full-Dev.	%	Full-Dev. SS	%	Full-Dev. Uganda	%
Domestic	195.49	9.6	366.05	9.7	222.08	12.9	143.98	7.0
Livestock	208.36	10.3	208.36	5.5	108.16	6.3	100.20	4.9
Agriculture	1628.55	80.1	3207.99	84.8	1389.36	80.8	1818.63	88.1
Total	2032.40	100	3782.40	100	1719.59	100	2062.81	100
Percent from Supply (37,796.10)	5.4%		10 %		4.5%		5.5%	

Dev. = Development

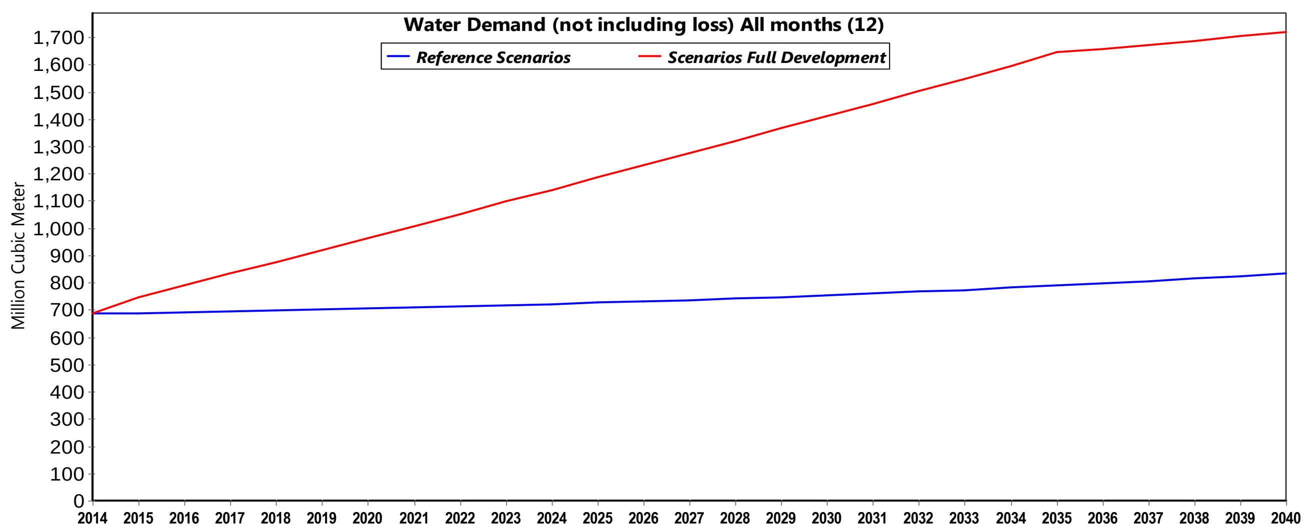

Figure 4.7 Water Demand of Reference and Full Development Scenarios in Bahr el-Jebel in South Sudan Side

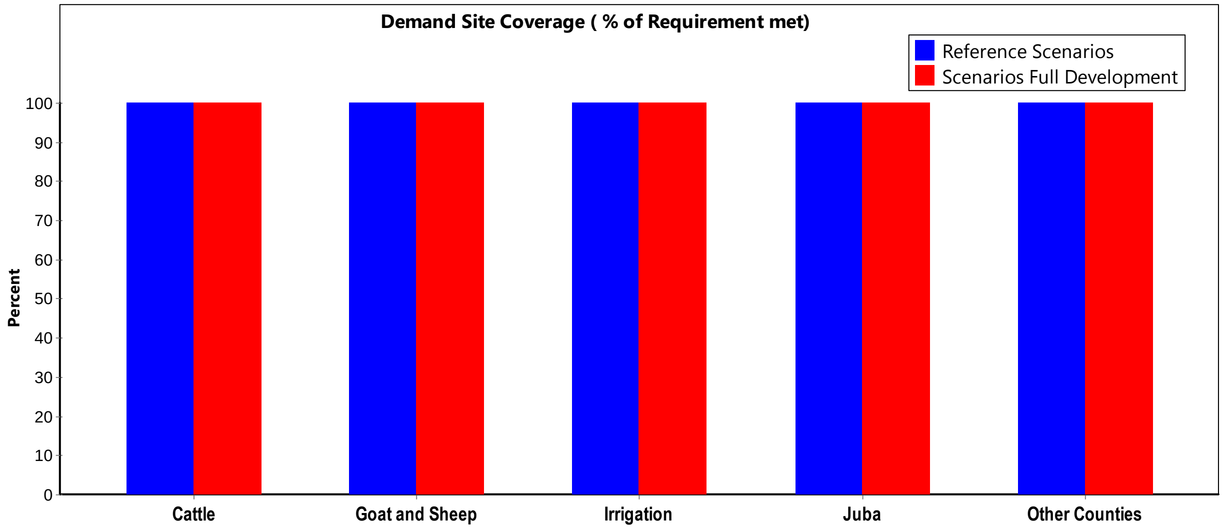

Figure 4.8 Demand Coverage of the Difference Sectors

The figure 4.8 indicates all the demands met full requirement, which means a demand site's demand was fully satisfied in all scenarios. If full development is implemented it would greatly improve the economic status of the population in this sub-basin. In addition, hydropower productions at its potential 1684 MW would also increase the total national yield.

According to the study conducted by Tate *et al.*, (2004) there are possibilities impacts of climate change on the Lake Victoria basin, which is estimated that by 2050 mean annual runoff in outflow shown a reduction of 2.6-4.2%. It is also probable that climate change will affect the temporal distribution of runoff and this could affect both water availability and water demand. However, this means the changing in outflow in upstream should be considered in water resources planning in Bahr el-Jebel sub-basin.

The results of this study indicated clearly, that there is a surplus in supply side in sub-basin in full development, which mean an integrated approach for the development of water resources in the sub-basin is necessary in order to meet the water requirements of all sectors to avoid competition and conflicts in water use during the dry season. The water resources in sub-basin required assigning a considerable demand on the trans-boundary water resource like the river Nile, in order to manage water fairly. Adding to that, surplus needs safeguarding to meet future demand.

One of the main objectives of the study is to develop a water allocation system within Bahr el-Jebel sub-basin. The output in this study is to improve and strengthen better the management of the existing system and developing a new allocation system that clear the ownership of water, water use, primary use, equity, efficiency, and the precise rights and obligations conferred with a water permit. This study is coming out with Public (Administrative) Water Allocation as a mechanism of allocation since local norms and the strength of local institutions is still weak in the South Sudan. However, a comprehensive legal framework, clear institutional responsibilities, adequate staffing of allocation authorities, proper systems of water rights, permits and adequate monitoring need be strengthened. In addition, allocation principles should include clear provisions for (extreme) drought situations and depletion of ground water, and pollution of water systems.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The analysis and simulation of surface water and allocation in the Bahr el-Jebel sub-basin was conducted under limited data availability, through the basic functions of WEAP, without using linkage to a groundwater analysis and climate change. Also, lack of flow data, particularly on crossing border of South Sudan, Nimule, make it very difficult to calibrate and validate the model for the current situation. However, all possible measures were taken to ensure the assumptions made herein are consistent with the realities observed in the sub-basin.

The Bahr el-Jebel sub-basin is rich with huge quantities of surface water resources' including over 25.8 billion cubic meters of rainfall, an average annual flow was estimated as 37.8 billion cubic meters in Bahr el-Jebel at Mongalla, South Sudan. The current utilization of these resources is very limited at the moment and it is about 1,779.17 MCM (4.7%) in the basin only around 684.95 million cubic meters within South Sudan, including domestic, livestock and minor agricultural activities, mainly through rain-fed cultivation. Furthermore, the scenarios based on the full development in the basin by 2040 it is estimated that total annual consumptive use the demand is around 3.78 billion cubic meters (10 % of the natural flow at Mongalla), of this 1.72 billion cubic meters will be consumed in South Sudan and 2.06 billion cubic meters in Uganda side. The results indicate clearly that there is a surplus in supply in whole the year to meet the demand sites.

This study determines environmental flow requirements for the Bahr el-Jebel, which is estimated an average annual allocation of 25 % of the mean annual flow (9.45 BCM) to maintain the basic ecological functioning in the basin and regulate the inflows to the Sudd permanent swamp, and maintain flow for downstream uses.

There are also potentials for enhancing supplementary irrigation using water harvesting possibilities and other resources. Thus, building dams on those three sites Ulako, Lakki and Bedden could contribute in water resources management and development as well as economic growth of the population within sub-basin and in South Sudan as general.

The study has adopted Public Water Allocation as a mechanism that promotes the equitable water use, protect the poor, and sustain environmental needs. This mechanism can improve the traditional water resource management in sub-basin for socio-economic benefits. The water allocation system, for instance, certain legal and institutional arrangements may enhance people's willingness to invest in water infrastructure, or induce them pricing of water services, to waste less water, or pollute less. This will eventually lead to increased sharing water use among sectors as well as increased economic benefit.

In general, there are huge resources and possibilities, but they are constrained with the poor monitoring networks, and reliable information system and management.

5.2 Recommendations

- The hydrology of the sub-basin using improved climatic and hydrologic data monitoring should be conducted in the study area to enhance the estimation of current and future water resources availability.
- The rainwater harvesting should be promoted in the sub-basin in order to improve water availability for productive use.
- Irrigation should be promoted in Bahr el-Jebel for economic development and for attaining food security.
- The allocation principles must be promoted for social and economic benefit.
- Groundwater potential need to be investigated and explored to enable more understanding of water resources potential in this study area.
- Integrated and coordinated water resources development strategy is required; integrated all aspects, social, economic, political, and environment and coordinated all stakeholders in sub-basin and basin wide as well.
- The environmental flow requirement is required more detailed studies of water allocation patterns within the basin.
- Establish a reliable Water Information System for water resources in sub-basin.

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Appendix

A. Existing Water Supply Conditions in Juba Town

The residents utilize following types of water supply services.

I. Treatment Plant with capacity 7200 m^3/day
   - Water supply by house connection (UWC)
   - Water supply by public tap (UWC: water source is piped water)
   - Private water conveyances
     - Water tanker truck
     - Jerry can vendor by bicycle

II. Public well equipped with hand pumps;

III. Private well

IV. Supply water from Bahr el-Jebel River direct

Table A1 Water tanker within Juba Town

Tanker truck	No.	Capacity (Barrel/day)	Time
Dry season	400	40 (40*250 liter)	2-5 daily
Rainy season	300	40 (40*250 liter)	2-5 daily
Average	350	40 (40*250 liter)	3.5 times/ day

V. Mineral Water Factories

There are thirty-two Factories working in Juba Town producing mineral water and three among them producing Beer, juices and soft drink.

Table A2 List of Mineral Water Factories and Their Location in Juba

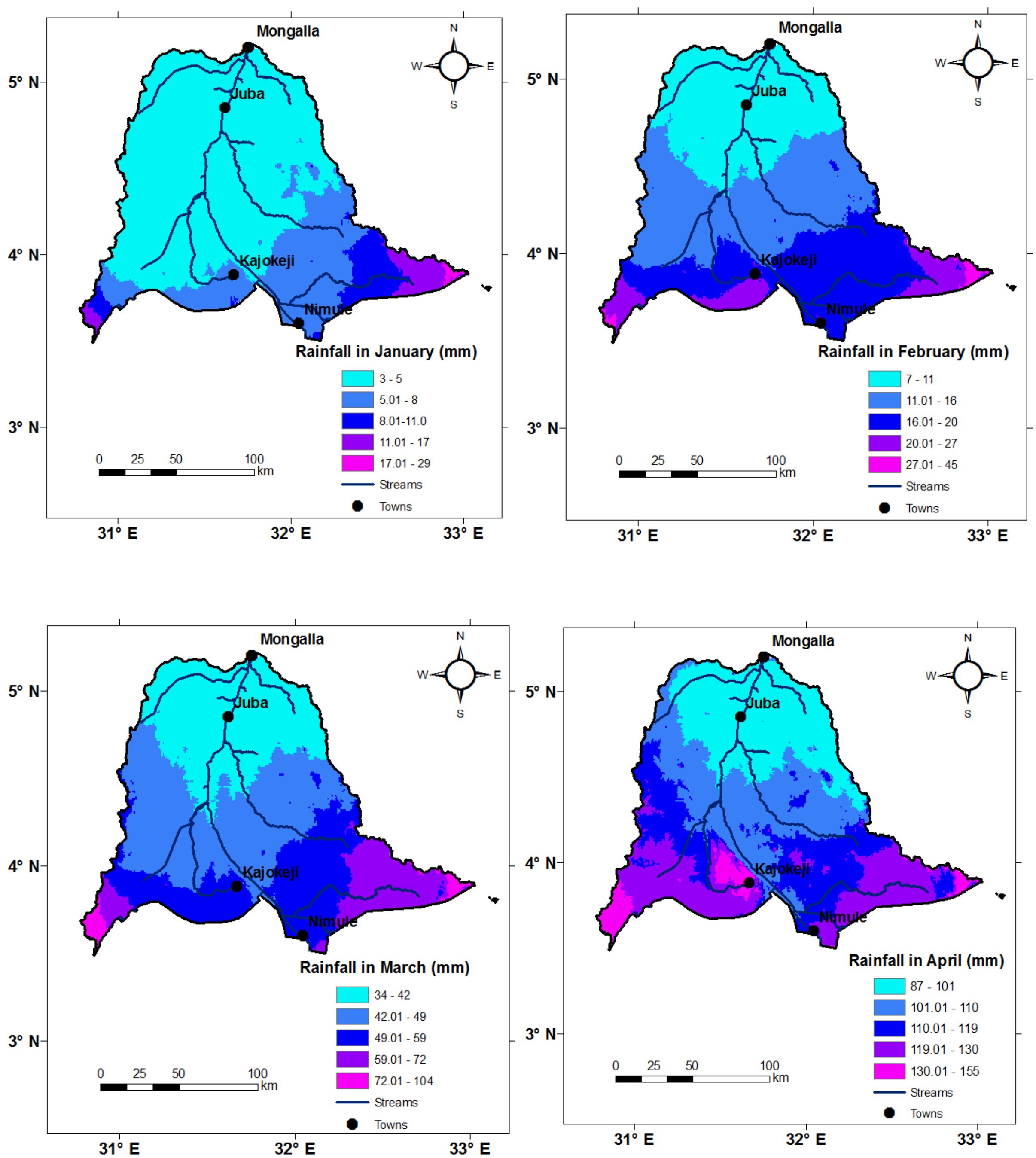
S/N	Name	Product	location
1	True Company	Juice	Kapuri
2	Star Land Water Factor	Water	Kasaba
3	Lehem Enterprises	Juice	Jandaru
4	Happy Foam	Foam	Lologo
5	Delta Water Factory	Water	Gabat
6	Al Equa Ice factory	Ice Water	Thongping
7	Nice beverages Company Ltd	Water and Juice	Kator
8	Africana Water Factory	Water	Kator
9	Al-Hasanan Ice Factory	Ice Water	Thongping
10	Life Water Factory	Water	Lologo
11	Aquana Water Factory	Water	Hai Malakal
12	Canaan Water Factory	Water	Thongping
13	Gumbo Spring	Water	Gumbo
14	Al-Wazni Ice Factory	Ice Water	Kator
15	Aqua-quality Water Factory	Water	Hai Malakal
16	Aqunna International Ltd.	Water	Thongping
17	Best Water factory	Water	Cumbo
18	Jit Water Factory	Water	Gabat
19	South Sudan Beverages Ltd.	Bear and Soda	Khor Romla
20	Yanyyom Water Factory	Water	Konyokonyo

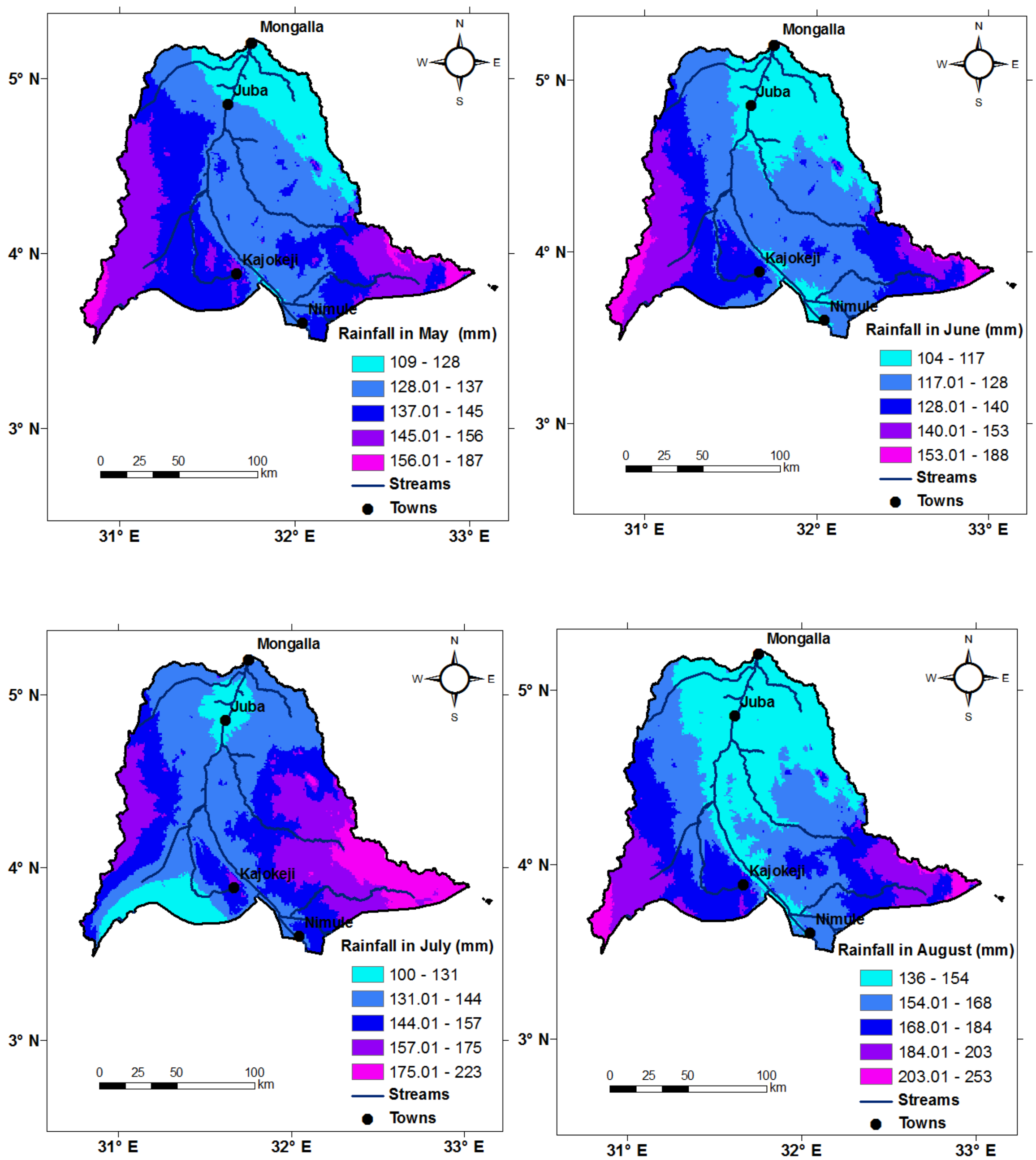
21	Fula Water Factory	Water	Konyokonyo
22	Cool Water Factory	Water	River Site
23	Spa Nile Water factory	Water	Gumbo
24	Holy Water Factory	Water	Kator
25	Aqua-Prima Water Factory	Water	Gumbo
26	Top Juice beverage	Juice	Nyakuroon West
27	Pearl Pure Water	Water	Rock City
28	Bella Aqua Water Factory	Water	
29	Muscot Water Factory	Water	Luri Boma
30	Blue Wave Water factory	Water	Hai Malakal
31	Al-Butrus Ice Factory	Ice Water	Thongping
32	Spring Co. Ltd	Water	Jebel Kujor
33	Falcon Industries Ltd Company	Water	Jabel Kujor,
34	S.D.I General Trading Company limited	Water	Juba, Munuki area
35	Ayed Real E. Co. Ltd	Water	Juba, Next to Juba bridge
36	Nile River Development Co. LTD	Water	Kololo West, Juba
37	Invest South Co.Ltd	Water	Juba, near International Airport

Source: SSNBS

B. Monthly Rainfall in Bahr el-Jebel Sub-basin

Figure B.1 Monthly rainfall in Bahr el-Jebel Sub-basin





Mongalla
Juba
Kajokeji
Nimule
N
S
W
E
5° N
4° N
3° N
31° E
32° E
33° E
0 25 50 100 km
Rainfall in May (mm)
109 - 128
128.01 - 137
137.01 - 145
145.01 - 156
156.01 - 187
Streams
Towns
Rainfall in June (mm)
104 - 117
117.01 - 128
128.01 - 140
140.01 - 153
153.01 - 188
Streams
Towns
Rainfall in July (mm)
100 - 131
131.01 - 144
144.01 - 157
157.01 - 175
175.01 - 223
Streams
Towns
Rainfall in August (mm)
136 - 154
154.01 - 168
168.01 - 184
184.01 - 203
203.01 - 253
Streams
Towns

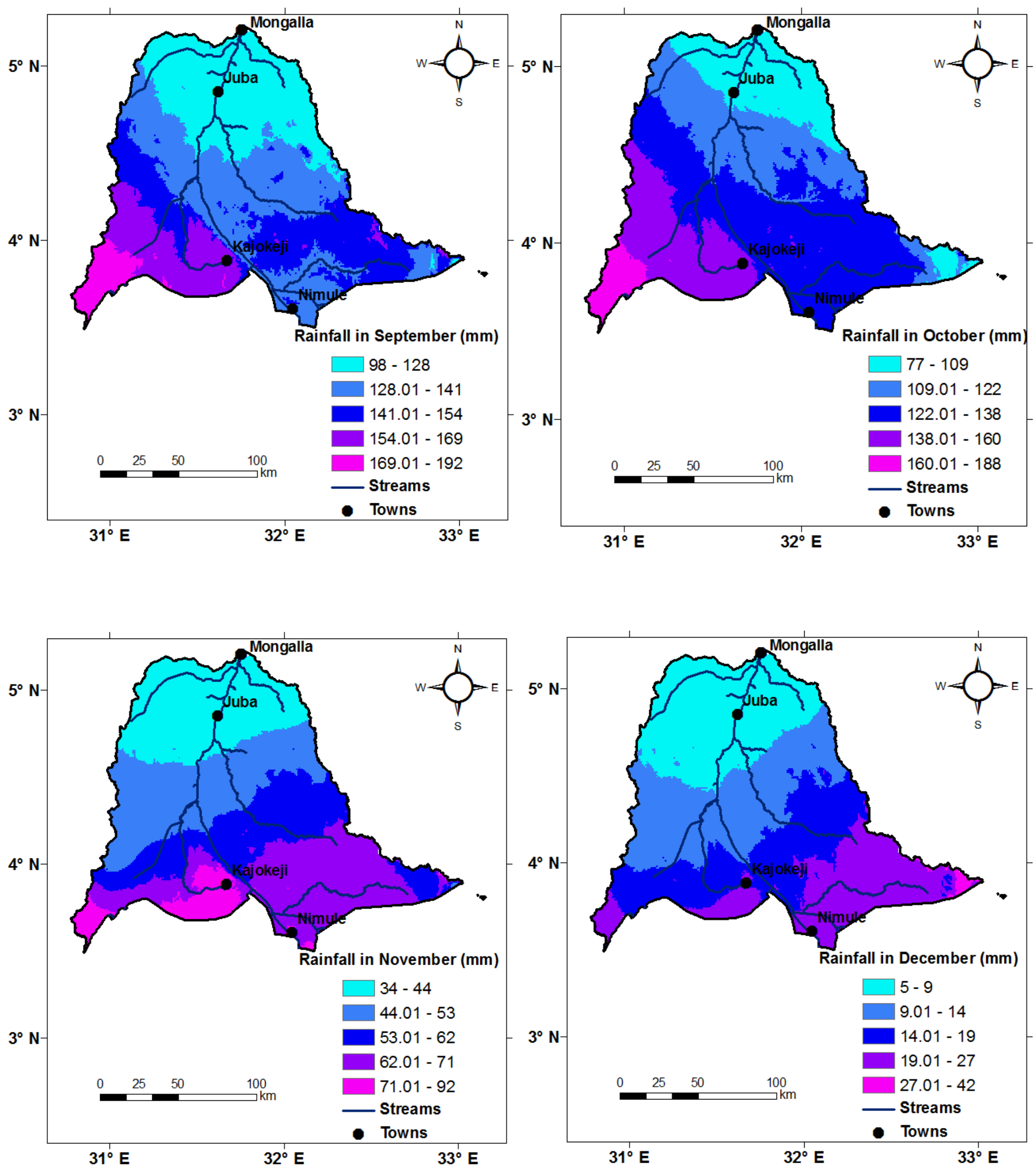


Figure B.1 Monthly Rainfall Distribuation in Bahr el-Jebel Sub-basin

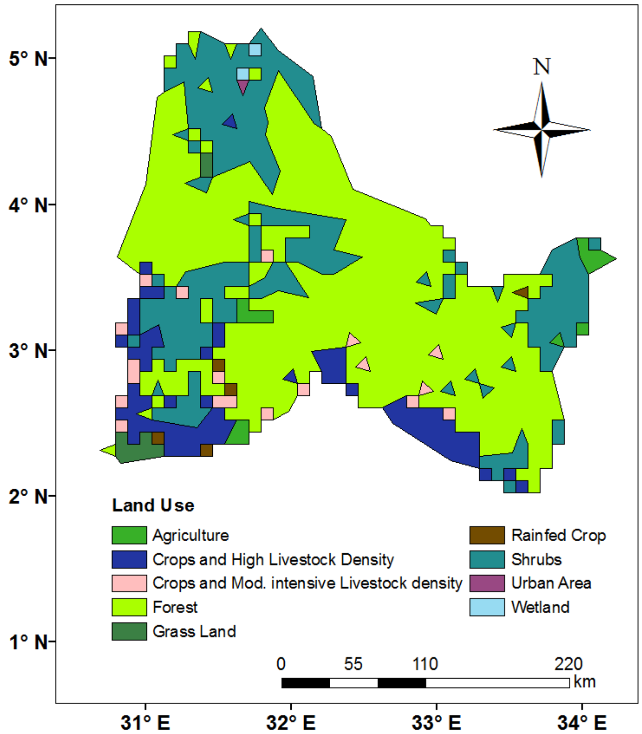


Figure B.2 Land Use of Bahr el-Jebel Basin, Source: Create 2004 FAO, 2014

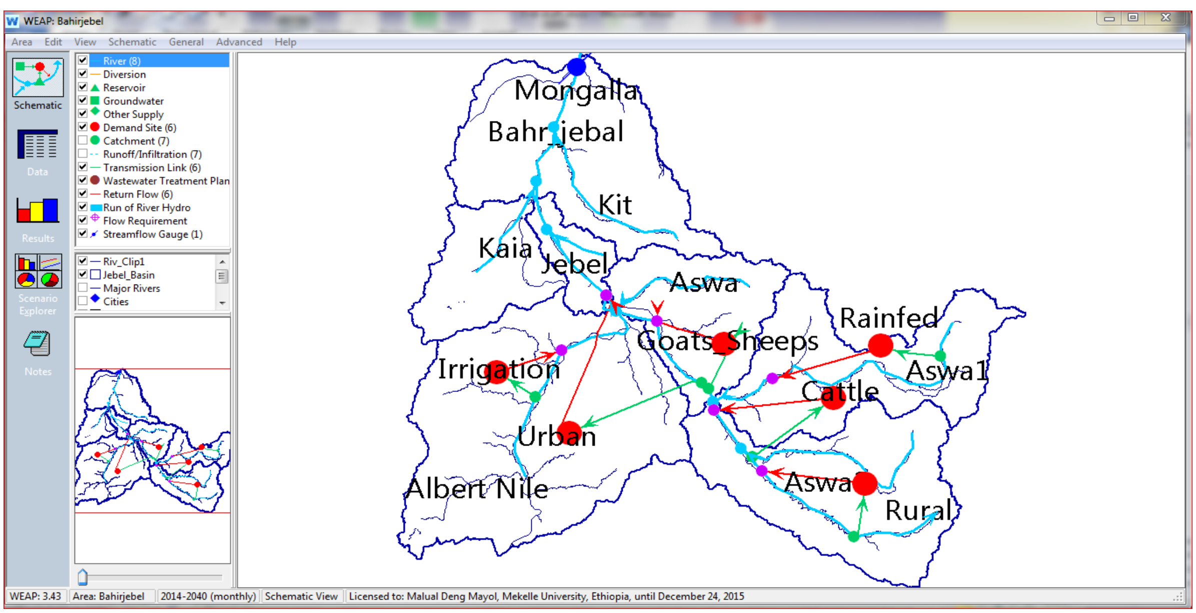


Figure B.3 Schematic diagrams showing the configuration of the WEAP model for Demand of the Bahr el-Jebel Basin in Uganda Side.

C. Flow Data

Year 2008	Gauge(m)	Flow (m3/s)	15-Jul-08	12.71	1,141.00
5-Jan-08	12.86	1,210.00	25-Jul-08	12.80	1,182.00
18-Jan-08	12.82	1,188.00	29-Jul-08	12.89	1,249.00
28-Jan-08	12.80	1,197.00	1-Aug-08	13.05	1,331.00
4-Feb-08	12.76	1,200.00	5-Aug-08	13.02	1,308.00
25-Feb-08	12.70	1,165.00	12-Aug-08	13.35	1,480.00
4-Mar-08	12.68	1,150.00	15-Aug-08	13.51	1,600.00
7-Mar-08	12.69	1,129.00	19-Aug-08	13.45	1,574.00
11-Mar-08	12.65	1,131.00	22-Aug-08	13.28	1,455.00
14-Mar-08	12.68	1,134.00	29-Aug-08	13.48	1,585.00
18-Mar-08	12.67	1,124.00	5-Sep-08	13.22	1,432.00
25-Mar-08	12.68	1,135.00	16-Sep-08	13.60	1,635.00
28-Mar-08	12.73	1,179.00	19-Sep-08	13.72	1,713.00
1-Apr-08	12.71	1,155.00	23-Sep-09	13.64	1,647.00
4-Apr-08	12.68	1,149.00	26-Sep-08	13.54	1,588.00
8-Apr-08	12.68	1,128.00	7-Oct-08	13.41	1,540.00
11-Apr-08	12.68	1,131.00	10-Oct-08	13.33	1,479.00
15-Apr-08	12.71	1,152.00	14-Oct-08	13.38	1,513.00
18-Apr-08	12.76	1,181.00	17-Oct-08	13.39	1,508.00
25-Apr-08	12.80	1,184.00	21-Oct-08	13.52	1,589.00
29-Apr-08	12.70	1,137.00	24-Oct-08	13.70	1,696.00
2-May-08	12.70	1,159.00	28-Oct-08	14.01	1,913.00
6-May-08	13.02	1,320.00	31-Oct-08	14.16	2,018.00
9-May-08	12.72	1,150.00	2-Nov-08	13.14	1,406.00
13-May-08	12.70	1,149.00	4-Nov-08	13.86	1,822.00
20-May-08	12.84	1,210.00	7-Nov-08	13.97	1,924.00
23-May-08	12.72	1,151.00	11-Nov-08	14.10	1,998.00
27-May-08	12.69	1,129.00	18-Nov-08	13.61	1,666.00
30-May-08	12.89	1,244.00	21-Nov-08	13.50	1,587.00
6-Jun-08	12.78	1,187.00	25-Nov-08	13.36	1,531.00
10-Jun-08	12.81	1,197.00	28-Nov-08	13.26	1,455.00
13-Jun-08	12.98	1,278.00	2-Dec-08	13.14	1,406.00
17-Jun-08	12.84	1,207.00	5-Dec-08	13.11	1,378.00
24-Jun-08	12.81	1,199.00	12-Dec-08	13.00	1,311.00
27-Jun-08	12.76	1,164.00	16-Dec-08	12.96	1,289.00
1-Jul-08	12.70	1,148.00	19-Dec-08	12.93	1,266.00
4-Jul-08	12.72	1,142.00	23-Dec-08	12.90	1,261.00
8-Jul-08	12.67	1,128.00	30-Dec-08	12.84	1,243.00

Year 2009	Gauge(m)	Flow(m3/s)	Year 2009	Gauge(m)	Flow(m3/s)
6-Jan-09	12.80	1203.00	28-Jul-09	12.38	983.00
13-Jan-09	12.76	1181.00	31-Jul-09	12.34	952.00
16-Jan-09	12.76	1178.00	4-Aug-09	12.51	1027.00
20-Jan-09	12.75	1159.00	7-Aug-09	12.38	978.00
23-Jan-09	12.73	1147.00	14-Aug-09	12.48	1018.00
27-Jan-09	12.78	1197.00	18-Aug-09	12.53	1055.00
30-Jan-09	12.79	1202.00	28-Aug-09	12.56	1060.00
13-Feb-09	12.72	1149.00	1-Sep-09	12.45	1014.00
17-Feb-09	12.69	1132.00	8-Sep-09	12.41	986.00
20-Feb-09	12.67	1132.00	11-Sep-09	12.45	1013.00
24-Feb-09	12.66	1128.00	15-Sep-09	12.48	1017.00
27-Feb-09	12.63	1107.00	18-Sep-09	12.51	1050.00
6-Mar-09	12.60	1104.00	25-Sep-09	12.55	1058.00
17-Mar-09	12.56	1082.00	2-Oct-09	12.65	1110.00
24-Mar-09	12.54	1075.00	6-Oct-09	12.75	1148.00
27-Mar-09	12.53	1061.00	9-Oct-09	12.85	1210.00
31-Mar-09	12.51	1055.00	16-Oct-09	12.72	1115.00
3-Apr-09	12.52	1056.00	20-Oct-09	12.65	1097.00
14-Apr-09	12.52	1072.00	23-Oct-09	12.63	1086.00
17-Apr-09	12.66	1110.00	27-Oct-09	12.59	1053.00
21-Apr-09	12.66	1125.00	30-Oct-09	12.62	1080.00
2-Jun-09	12.65	1096.00	3-Nov-09	12.62	1070.00
5-Jun-09	12.68	1113.00	6-Nov-09	12.58	1058.00
19-Jun-09	12.48	1021.00	10-Nov-90	12.62	1067.00
23-Jun-09	12.48	1025.00	13-Nov-09	12.54	1039.00
26-Jun-09	12.45	1010.00	17-Nov-09	12.52	1029.00
30-Jun-09	12.58	1082.00	24-Nov-09	12.5	1012.00
8-Jul-09	12.40	1008.00	4-Dec-09	12.46	1005.00
14-Jul-09	12.38	991.00	11-Dec-09	12.47	992.00
17-Jun-09	12.35	956.00	8-Dec-09	12.45	1001.00
21-Jul-09	12.34	955.00	18-Dec-09	12.48	1010.00
24-Jul-09	12.35	964.00	22-Dec-09	12.45	992.00

Year 2010	Gauge (m)	Flow (m3/s)	year 2010	Gauge (m)	Flow (m3/s)
15-Jan-10	12.42	968.00	2-Nov-10	13.74	1,699.58
22-Jan-10	12.38	948.00	3-Nov-10	13.70	1,672.00
16-Jan-10	12.28	892.00	4-Nov-10	13.65	1,638.05
26-Jan-10	12.35	944.00	5-Nov-10	13.59	1,598.06
29-Jan-10	12.35	932.00	6-Nov-10	13.54	1,565.35
9-Mar-10	12.42	947.00	7-Nov-10	13.51	1,545.98
12-Mar-10	12.38	942.00	8-Nov-10	13.47	1,520.48
23-Apr-10	12.42	952.00	9-Nov-10	13.44	1,501.57
27-Apr-10	12.40	941.00	10-Nov-10	13.42	1,489.08
30-Apr-10	12.52	997.00	11-Nov-10	13.42	1,489.08
4-May-10	12.46	976.00	12-Nov-10	13.40	1,476.67
7-May-10	12.52	1003.00	13-Nov-10	13.39	1,470.50
11-May-10	12.56	1020.00	14-Nov-10	13.39	1,470.50
14-May-10	12.60	1050.00	15-Nov-10	13.38	1,464.34
18-May-10	12.73	1134.00	16-Nov-10	13.37	1,458.21
25-May-10	12.94	1234.00	17-Nov-10	13.37	1,458.21
29-Jun-10	12.89	1199.00	18-Nov-10	13.34	1,439.95
6-Jul-10	12.90	1196.00	19-Nov-10	13.32	1,427.88
17-Jul-10	12.90	1183.00	20-Nov-10	13.30	1,415.89
23-Jul-10	12.90	1196.00	21-Nov-10	13.28	1,403.98
3-Aug-10	13.10	1307.00	22-Nov-10	13.25	1,386.28
6-Aug-10	12.96	1220.00	23-Nov-10	13.27	1,398.06
10-Aug-10	12.88	1196.00	24-Nov-10	13.26	1,392.16
13-Aug-10	13.28	1412.00	25-Nov-10	13.25	1,386.28
27-Aug-10	12.99	1245.00	26-Nov-10	13.24	1,380.42
31-Aug-10	12.96	1234.00	27-Nov-10	13.23	1,374.58
2-Sep-10	13.17	1333.00	28-Nov-10	13.21	1,362.96
1-Oct-10	13.31	1421.87	29-Nov-10	13.20	1,357.18
2-Oct-10	13.29	1409.93	30-Nov-10	13.20	1,357.18
3-Oct-10	13.27	1398.06	1-Dec-10	13.19	1,351.42
4-Oct-10	13.24	1380.42	2-Dec-10	12.19	868.29
5-Oct-10	13.23	1374.58	3-Dec-10	13.19	1,351.42
6-Oct-10	13.32	1427.88	4-Dec-10	13.18	1,345.68
7-Oct-10	13.37	1458.21	5-Dec-10	13.17	1,339.97
8-Oct-10	13.35	1446.02	6-Dec-10	13.15	1,328.59
9-Oct-10	13.33	1433.90	7-Dec-10	13.15	1,328.59
10-Oct-10	13.41	1482.86	8-Dec-10	13.14	1,322.93
11-Oct-10	13.49	1533.19	9-Dec-10	13.12	1,311.67
12-Oct-10	13.53	1558.87	10-Dec-10	13.12	1,311.67
13-Oct-10	13.55	1571.84	11-Dec-10	13.10	1,300.49

14-Oct-10	13.57	1584.91	12-Dec-10	13.09	1,294.93
15-Oct-10	13.50	1539.57	13-Dec-10	13.09	1,294.93
16-Oct-10	13.53	1,558.87	14-Dec-10	13.07	1,283.87
17-Oct-10	13.52	1,552.42	15-Dec-10	13.06	1,278.37
18-Oct-10	13.59	1,598.06	16-Dec-10	13.04	1,267.42
19-Oct-10	13.66	1,644.80	17-Dec-10	13.03	1,261.98
20-Oct-10	13.73	1,692.65	18-Dec-10	13.02	1,256.55
21-Oct-10	13.84	1,770.16	19-Dec-10	13.01	1,251.15
22-Oct-10	13.92	1,828.34	20-Dec-10	13.01	1,251.15
23-Oct-10	13.91	1,820.99	21-Dec-10	13.00	1,245.76
24-Oct-10	13.84	1,770.16	22-Dec-10	12.99	1,240.39
25-Oct-10	13.88	1,799.06	23-Dec-10	12.99	1,240.39
26-Oct-10	13.95	1,850.56	24-Dec-10	12.98	1,235.04
27-Oct-10	13.91	1,820.99	25-Dec-10	12.97	1,229.71
28-Oct-10	13.85	1,777.35	26-Dec-10	12.97	1,229.71
29-Oct-10	13.81	1,748.74	27-Dec-10	12.96	1,224.40
30-Oct-10	13.87	1,791.80	28-Dec-10	12.95	1,219.11
31-Oct-10	13.81	1,748.74	29-Dec-10	12.96	1,224.40
1-Nov-10	13.77	1,720.51	30-Dec-10	12.95	1,219.11
			31-Dec-10	12.93	1,208.59

year 2011	**Gauge (m)**	**Flow (m3/s)**	**year 2011**	**Gauge (m)**	**Flow (m3/s)**
1-Jan-11	12.93	1208.58	3-Jul-11	12.49	995.20
2-Jan-11	12.93	1208.58	4-Jul-11	12.48	990.74
3-Jan-11	12.92	1203.35	5-Jul-11	12.51	1004.17
4-Jan-11	12.91	1198.13	6-Jul-11	12.50	999.68
5-Jan-11	12.91	1198.13	7-Jul-11	12.48	990.74
6-Jan-11	12.91	1198.13	8-Jul-11	12.53	1013.22
7-Jan-11	12.89	1187.76	9-Jul-11	12.56	1026.90
8-Jan-11	12.89	1187.76	10-Jul-11	12.59	1040.74
9-Jan-11	12.88	1182.60	11-Jul-11	12.57	1031.50
10-Jan-11	12.87	1177.45	12-Jul-11	12.56	1026.90
11-Jan-11	12.87	1177.45	13-Jul-11	12.63	1059.43
12-Jan-11	12.86	1172.33	14-Jul-11	12.70	1092.80
13-Jan-11	12.86	1172.33	15-Jul-11	12.56	1026.90
14-Jan-11	12.86	1172.33	16-Jul-11	12.54	1017.76
15-Jan-11	12.85	1167.22	17-Jul-11	12.65	1068.88
16-Jan-11	12.85	1167.22	18-Jul-11	12.58	1036.11
17-Jan-11	12.85	1167.22	19-Jul-11	12.59	1040.74
18-Jan-11	12.83	1157.06	20-Jul-11	12.58	1036.11
19-Jan-11	12.83	1157.06	21-Jul-11	12.53	1013.22

20-Jan-11	12.82	1152.01	22-Jul-11	12.51	1004.17
21-Jan-11	12.80	1141.97	23-Jul-11	12.66	1073.63
22-Jan-11	12.80	1141.97	24-Jul-11	12.70	1092.80
23-Jan-11	12.79	1136.97	25-Jul-11	12.65	1068.88
24-Jan-11	12.78	1131.99	26-Jul-11	12.62	1054.73
25-Jan-11	12.78	1131.99	27-Jul-11	12.61	1050.05
26-Jan-11	12.77	1127.03	28-Jul-11	12.64	1064.15
27-Jan-11	12.77	1127.03	29-Jul-11	12.68	1083.18
28-Jan-11	12.76	1122.08	30-Jul-11	12.71	1097.64
29-Jan-11	12.75	1117.16	31-Jul-11	12.75	1117.16
30-Jan-11	12.75	1117.16	1-Aug-11	12.85	1167.22
31-Jan-11	12.75	1117.16	2-Aug-11	12.88	1182.60
1-Feb-11	12.74	1112.25	3-Aug-11	12.74	1112.25
2-Feb-11	12.74	1112.25	4-Aug-11	12.71	1097.64
3-Feb-11	12.74	1112.25	5-Aug-11	12.73	1107.36
4-Feb-11	12.73	1107.36	6-Aug-11	12.72	1102.49
5-Feb-11	12.73	1107.36	7-Aug-11	12.76	1122.09
6-Feb-11	12.73	1107.36	8-Aug-11	12.80	1141.97
7-Feb-11	12.72	1102.49	9-Aug-11	12.77	1127.03
8-Feb-11	12.72	1102.49	10-Aug-11	12.74	1112.25
9-Feb-11	12.72	1102.49	11-Aug-11	12.71	1097.64
10-Feb-11	12.72	1102.49	12-Aug-11	12.77	1127.03
11-Feb-11	13.71	1678.86	13-Aug-11	12.80	1141.97
12-Feb-11	12.71	1097.64	14-Aug-11	12.78	1131.99
13-Feb-11	12.71	1097.64	15-Aug-11	12.77	1127.03
14-Feb-11	12.70	1092.80	16-Aug-11	12.98	1235.04
15-Feb-11	12.69	1087.98	17-Aug-11	12.87	1177.45
16-Feb-11	12.68	1083.18	18-Aug-11	13.00	1245.76
17-Feb-11	12.68	1083.18	19-Aug-11	12.98	1235.04
18-Feb-11	12.67	1078.39	20-Aug-11	12.95	1219.11
19-Feb-11	12.66	1073.63	21-Aug-11	12.93	1208.58
20-Feb-11	12.65	1068.88	22-Aug-11	12.85	1167.22
21-Feb-11	12.65	1068.88	23-Aug-11	12.96	1224.40
22-Feb-11	12.64	1064.15	24-Aug-11	12.94	1213.84
23-Feb-11	12.65	1068.88	25-Aug-11	12.58	1036.11
24-Feb-11	12.66	1073.63	26-Aug-11	13.03	1261.98
25-Feb-11	12.65	1068.88	27-Aug-11	13.08	1289.39
26-Feb-11	12.64	1064.15	28-Aug-11	13.03	1261.98
27-Feb-11	12.63	1059.43	29-Aug-11	13.05	1272.88
28-Feb-11	12.63	1059.43	30-Aug-11	13.61	1611.30
2-Mar-11	12.62	1054.73	31-Aug-11	13.32	1427.88

3-Mar-11	12.62	1054.73	1-Sep-11	13.37	1458.21
4-Mar-11	12.61	1050.05	2-Sep-11	13.44	1501.57
5-Mar-11	12.60	1045.39	3-Sep-11	13.73	1692.65
6-Mar-11	12.61	1050.05	4-Sep-11	13.79	1734.58
7-Mar-11	12.60	1045.39	5-Sep-11	13.68	1658.35
8-Mar-11	12.60	1045.39	6-Sep-11	13.55	1571.84
9-Mar-11	12.59	1040.74	7-Sep-11	13.70	1672.00
10-Mar-11	12.58	1036.11	8-Sep-11	13.68	1658.35
11-Mar-11	12.58	1036.11	9-Sep-11	13.80	1741.65
12-Mar-11	12.57	1031.50	10-Sep-11	14.06	1933.94
13-Mar-11	12.56	1026.90	11-Sep-11	14.00	1888.09
14-Mar-11	12.55	1022.32	12-Sep-11	13.95	1850.56
15-Mar-11	12.53	1013.22	13-Sep-11	13.79	1734.58
16-Mar-11	12.54	1017.76	14-Sep-11	13.73	1692.65
17-Mar-11	12.56	1026.90	15-Sep-11	13.67	1651.56
18-Mar-11	12.58	1036.11	16-Sep-11	13.53	1558.87
19-Mar-11	12.59	1040.74	17-Sep-11	13.50	1539.58
20-Mar-11	12.60	1045.38	18-Sep-11	13.48	1526.82
21-Mar-11	12.75	1117.16	19-Sep-11	13.44	1501.57
22-Mar-11	12.69	1087.98	20-Sep-11	13.50	1539.58
23-Mar-11	12.66	1073.63	21-Sep-11	13.54	1565.35
24-Mar-11	12.64	1064.15	22-Sep-11	13.64	1631.33
25-Mar-11	12.62	1054.73	23-Sep-11	13.48	1526.82
26-Mar-11	12.62	1054.73	24-Sep-11	13.41	1482.86
27-Mar-11	12.57	1031.50	25-Sep-11	13.40	1476.67
28-Mar-11	12.53	1013.22	26-Sep-11	13.37	1458.21
29-Mar-11	12.52	1008.69	27-Sep-11	13.44	1501.57
30-Mar-11	12.51	1004.17	28-Sep-11	13.44	1501.57
31-Mar-11	12.51	1004.17	29-Sep-11	13.51	1545.99
1-Apr-11	12.49	995.20	30-Sep-11	13.42	1489.08
2-Apr-11	12.48	990.74	1-Oct-11	13.31	1421.87
3-Apr-11	12.47	986.29	2-Oct-11	13.30	1415.89
4-Apr-11	12.47	986.29	3-Oct-11	13.37	1458.21
5-Apr-11	12.46	981.86	4-Oct-11	13.38	1464.35
6-Apr-11	12.45	977.44	5-Oct-11	13.33	1433.90
7-Apr-11	12.44	973.05	6-Oct-11	13.27	1398.06
8-Apr-11	12.43	968.67	7-Oct-11	13.31	1421.87
9-Apr-11	12.41	959.96	8-Oct-11	13.28	1403.98
10-Apr-11	12.41	959.96	9-Oct-11	13.30	1415.89
11-Apr-11	12.40	955.62	10-Oct-11	13.26	1392.16
12-Apr-11	12.39	951.31	11-Oct-11	13.25	1386.28

13-Apr-11	12.40	955.62	12-Oct-11	13.19	1351.42
14-Apr-11	12.42	964.30	13-Oct-11	13.16	1334.27
15-Apr-11	12.41	959.96	14-Oct-11	13.13	1317.29
16-Apr-11	12.43	968.67	15-Oct-11	13.12	1311.67
17-Apr-11	12.42	964.30	16-Oct-11	13.09	1294.93
18-Apr-11	12.43	968.67	17-Oct-11	13.08	1289.39
19-Apr-11	12.44	973.05	18-Oct-11	13.10	1300.49
20-Apr-11	12.45	977.45	19-Oct-11	13.14	1322.93
21-Apr-11	12.46	981.86	20-Oct-11	13.09	1294.93
22-Apr-11	12.44	973.05	21-Oct-11	13.20	1357.18
23-Apr-11	12.44	973.05	22-Oct-11	13.10	1300.49
24-Apr-11	12.46	981.86	23-Oct-11	13.18	1345.68
25-Apr-11	12.47	986.29	24-Oct-11	13.18	1345.68
26-Apr-11	12.48	990.74	25-Oct-11	13.20	1357.18
27-Apr-11	12.48	990.74	26-Oct-11	13.69	1665.17
28-Apr-11	12.48	990.74	27-Oct-11	13.54	1565.35
29-Apr-11	12.53	1013.22	28-Oct-11	13.50	1539.58
30-Apr-11	12.53	1013.22	29-Oct-11	13.77	1720.51
1-May-11	12.49	995.20	30-Oct-11	13.72	1685.75
2-May-11	12.50	999.68	31-Oct-11	13.56	1578.36
3-May-11	12.48	990.74	1-Nov-11	13.52	1552.42
4-May-11	12.51	1004.17	2-Nov-11	13.52	1552.42
5-May-11	12.50	999.68	3-Nov-11	13.49	1533.19
6-May-11	12.49	995.20	4-Nov-11	13.49	1533.19
7-May-11	12.47	986.29	5-Nov-11	13.47	1520.48
8-May-11	12.46	981.86	6-Nov-11	13.44	1501.57
9-May-11	12.48	990.74	7-Nov-11	13.52	1552.42
10-May-11	12.48	990.74	8-Nov-11	13.58	1591.47
11-May-11	12.52	1008.69	9-Nov-11	13.59	1598.06
12-May-11	12.55	1022.32	10-Nov-11	13.57	1584.91
13-May-11	12.59	1040.74	11-Nov-11	13.53	1558.87
14-May-11	12.55	1022.32	12-Nov-11	13.51	1545.98
15-May-11	12.51	1004.17	13-Nov-11	13.95	1850.56
16-May-11	12.53	1013.22	14-Nov-11	14.09	1957.21
17-May-11	12.70	1092.80	15-Nov-11	14.03	1910.90
18-May-11	12.58	1036.11	16-Nov-11	13.93	1835.73
19-May-11	12.58	1036.11	17-Nov-11	13.78	1727.53
20-May-11	12.66	1073.63	18-Nov-11	13.69	1665.17
21-May-11	12.73	1107.36	19-Nov-11	13.61	1611.30
22-May-11	12.81	1146.98	20-Nov-11	13.57	1584.91
23-May-11	12.78	1131.99	21-Nov-11	13.55	1571.84

24-May-11	12.74	1112.25	22-Nov-11	13.6	1604.67
25-May-11	12.71	1097.64	23-Nov-11	13.58	1591.47
26-May-11	12.70	1092.80	24-Nov-11	13.56	1578.36
27-May-11	12.79	1136.97	25-Nov-11	13.55	1571.84
28-May-11	12.84	1162.13	26-Nov-11	13.53	1558.87
29-May-11	12.80	1141.97	27-Nov-11	13.51	1545.98
30-May-11	12.74	1112.25	28-Nov-11	13.1	1300.49
31-May-11	12.70	1092.80	29-Nov-11	13.44	1501.57
1-Jun-11	12.62	1054.73	30-Nov-11	13.43	1495.32
2-Jun-11	12.55	1022.32	1-Dec-11	13.4	1476.67
3-Jun-11	12.52	1008.69	2-Dec-11	13.36	1452.10
4-Jun-11	12.52	1008.69	3-Dec-11	13.33	1433.90
5-Jun-11	12.50	999.69	4-Dec-11	13.32	1427.88
6-Jun-11	12.51	1004.17	5-Dec-11	13.31	1421.87
7-Jun-11	12.49	995.20	6-Dec-11	13.29	1409.93
8-Jun-11	12.47	986.29	7-Dec-11	13.28	1403.98
9-Jun-11	12.46	981.86	8-Dec-11	13.28	1403.98
10-Jun-11	12.50	999.68	9-Dec-11	13.27	1398.06
11-Jun-11	12.57	1031.50	10-Dec-11	13.26	1392.16
12-Jun-11	12.55	1022.32	11-Dec-11	13.26	1392.16
13-Jun-11	12.53	1013.22	12-Dec-11	13.21	1362.96
14-Jun-11	12.51	1004.17	13-Dec-11	13.21	1362.96
15-Jun-11	12.50	999.68	14-Dec-11	13.21	1362.96
16-Jun-11	12.49	995.20	15-Dec-11	13.20	1357.18
17-Jun-11	12.50	999.68	16-Dec-11	13.20	1357.18
18-Jun-11	12.48	990.74	17-Dec-11	13.18	1345.68
19-Jun-11	12.47	986.29	18-Dec-11	13.15	1328.59
20-Jun-11	12.58	1036.11	19-Dec-11	13.15	1328.59
21-Jun-11	12.53	1013.22	20-Dec-11	13.14	1322.93
22-Jun-11	12.47	986.29	21-Dec-11	13.13	1317.29
23-Jun-11	12.47	986.29	22-Dec-11	13.12	1311.67
24-Jun-11	12.48	990.74	23-Dec-11	13.12	1311.67
25-Jun-11	12.50	999.68	24-Dec-11	13.11	1306.07
26-Jun-11	12.49	995.20	25-Dec-11	13.11	1306.07
27-Jun-11	12.47	986.29	26-Dec-11	13.10	1300.49
28-Jun-11	12.46	981.86	27-Dec-11	13.10	1300.49
29-Jun-11	12.52	1008.69	28-Dec-11	13.10	1300.49
30-Jun-11	12.56	1026.90	29-Dec-11	13.09	1294.93
1-Jul-11	12.64	1064.15	30-Dec-11	13.09	1294.93
2-Jul-11	12.52	1008.69	31-Dec-11	13.09	1294.93