



ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

**ASSESSMENT OF WATER RESOURCE AND
FORECASTING WATER DEMAND USING WEAP
MODEL IN BELES RIVER, ABAY RIVER BASIN,
ETHIOPIA**

By

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A Thesis Submitted as a Partial Fulfillment to the Requirements for the Award of the
Degree of Master of Science in Civil Engineering

(Hydraulic Engineering)

to

DEPARTMENT OF CIVIL ENGINEERING

COLLEGE OF ARCHITECTURE AND CIVIL ENGINEERING

APRIL 2021

Approval page

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Declaration

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Abstract

As water is vital for life, analysis of water supply and demand in the basin is necessary. This will enable to formulate water allocation strategies and allocation principles for present and future planning. In this paper assessment of water supply and demands was modeled using the Water Evaluation and Planning model. The parameter Estimation Tool was used to calibrate and validate the model. Future water demand was estimated using four different scenarios namely Scenario-I: high population growth, Scenario-II: Dangur hydropower, Scenario-III: Expansion of irrigation activities and Industries in Beles basin, and Scenario-IV: combination of scenario-I, scenario-II and scenario-III Simultaneously. According to the result obtained from the model, the total estimated mean annual surface runoff that leaves the basin is 5858.6 MCM, the estimated mean annual actual evapotranspiration is 10017.13 MCM, the estimated mean annual precipitation is 17525.33 MCM, mean annual interflow is 962.37 MCM, mean annual Base flow is 480.82 MCM, and mean annual flow to groundwater is 206.40 MCM. Total available annual streamflow including the Tana-Beles hydropower scheme is 10.03 BCM. Current water demand for Domestic, Industrial, Livestock, and Irrigation was 880.91MCM. The water demand result shows there is no shortage of water in the current situation. The first two scenarios, scenario-I and scenario-II have not much effect on future water demand. In the third scenario, scenario-III the shortage of water demand was happen in Upper and Lower Beles irrigation. Scenario-IV evaluates the water demand after Dangur hydropower is in operation. In this scenario the water resource of the basin satisfies all demand sites in the basin.

Key words: Beles Sub-Basin; Dangur; Upper Beles Irrigation, Water Demand, Allocation

Acknowledgments

First and for most, I would like to thank the Almighty ALLAH for his mercy and blessings in all my life. I would like to express my deepest gratitude and grateful acknowledgment to my Advisor Dr. Brook Abate for providing his guidance, fruitful comments and suggestions and the way how to conduct the research till the end of thesis work.

Again, I would like to express my deepest gratitude and grateful acknowledgment to Anne Hereford, Stockholm Environment Institute for providing free two years license for WEAP software to do my work. I am thankful to Ministry of Water, Irrigation and Energy Department of Hydrology, GIS and remote sensing, and Irrigation, Meteorological Agency, Central Statistical Agency, Mr. Thehaye Assefa Beles Basin Organization manager, who have been very helpful and cooperative especially with regard to various data acquiring during the work.

Finally, I am also very much grateful to all my family for their love and persistent encouragement on my life and my academic career.

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List of Abbreviations

ADSWE: Amhara Design and Supervision Work Enterprise

AMSL: Above Mean Sea Level

BCM: Billion Cubic Meter

BeSBO: Beles Sub-Basin organization

BGNRSBOA: Benishangul-Gumuz National Regional state Bureau of Agriculture

ETo: reference evapotranspiration

FAO: Food and Agriculture Organization

GUI: Graphical user Interface

Ha: Hectare

HPP: Hydropower plant

IWRM: Integrated water Resource Management

Kc: Crop coefficient

Km: Kilo meter

LPcd: Liter Per Capita per day

MCM: Million Cubic Meter

MW: Mega Watt

RIBASIM: River Bain Simulation

SEI: Stockholm Environment Institute

TLU: Total Livestock Unit

WBalMo: Water Balance Model

WEAP: Water Evaluation and Planning

WHO: World Health Organization

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1. INTRODUCTION

1.1 Background

Water is one of the principal physical resources that can play a major role in enhancing the pace of the overall development of a country. Sustainable development of water resources can significantly contribute to poverty alleviation and economic growth (BeSBO, 2016). Integrated water resource management (IWRM) is a way of analyzing the change in demand and operation of water institutions that evaluates a variety of supply-side and demand-side management measures to determine the optional way of providing water services. Demand-side management includes any measure or initiative that will result in a reduction in the expected water usage or water demand. Supply-side management includes any measure or initiative that will increase the capacity of water resources or water supply systems to supply water (Tibebe et al., 2016).

Water resource planning is part of complex multi-disciplinary processes overarching a wide range of stakeholders with different interests, technical expertise, and priorities. Successful planning requires effective integrated water resource planning models that can solve these complex problems (Hamlat et al., 2013). The concept of integrated water resource management was born of the realization that water policy and water management are often too fragmented to effectively address important questions such as How can society's needs for water meet suitably, how can the aspirations and priorities of different categories of users at local, national, and regional levels be addressed and how to strike a rational balance between beneficial utilization of the resource and resource protection? (Asmamaw, 2015). The complexity of the water allocation task and the increasing pressure on water (increasing demand and variability). Therefore, effective water allocation and management requires an understanding of water availability and reliability with considering the equity, efficiency, and sustainability as key principles in water allocation. The sustainable management of water resources requires a 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 (Mayol, 2015).

Ethiopia is commonly referred to as the water tower of East Africa, because of the huge amount of surface runoff from the Ethiopian highlands that make up over 86% of the flow of the Nile river. However, the country is constantly affected by the shortage of water for rain-fed agriculture mainly because of improper water resource utilization and management practice (Tefera, 2017). Ethiopia has embarked on an extensive water resource development plan for a few years back. Though the development activities encompass all major river basins of the country, the huge agricultural and hydroelectric power potential in the Abbay basin has attracted considerable attention (Adgolign et al., 2016). In Ethiopia, current planning is focused primarily on the Lake Tana and the Beles basin which have been identified by the government as an economic growth corridor. However, additional projects are planned in nearly all the sub-catchments as well as along the main river (Mc Cartney et al., 2013). The Tana-Beles HPP is a natural storage hydroelectric power plant in the country located near lake Tana. This power plant receives water from the lake to produce electricity and then the water is discharged into the Beles river. Irrigation schemes are under development in the upper and lower Beles, the water release from the Tana-Beles hydropower scheme and diverted to the Beles catchment through a tunnel to irrigate both parts of Beles basin.

The research employed a simple integrated water resources management model developed based on Water Evaluation and Planning (WEAP) to demonstrate how efficient the complexity of the water system can be managed by this methodology. The model illustrates the application of the suggested method to a specific river basin area. The model seeks to simulate the behaviors of demand and supply components, and at the same time optimizes the water allocation to the demand sites at every time step.

1.2 Statement of Problem

Most of Ethiopians cultivated lands are under rainfed agriculture due to the temporal and spatial variability of precipitation, these leads most of the farmers cannot produce more than one type of crops in the year. The increment of irrigation activities and socio-economic development causes the competition in fixed water resources and the result is water scarcity. There is a large-scale irrigation project like Tana Beles integrated sugar project. The development of such projects causes the increasing in water demand in the basin. Increased irrigation water demand in Beles river have resulted in increased surface water abstractions. Increase irrigation activities, growth in population, increase economic activities and improved standard of living have led to increasing demand.

In Beles basin there is a problem in the information available water resources potential, estimated future water demand, water requirement for different users, and supply and demand interaction in the sub-basin because the basin is one of the potential future development areas. These indicate there is a need to analyze the water supply and demand of the river basin and to formulate water allocation strategies and allocation principles for present and future planning. To implement the water allocation principles a consideration of information that shows the relationships between water usage and water resources is necessary.

1.3 Objectives

The main objective of this study is to assess water Resource and demand and allocation of water resources in the Beles river basin using the WEAP model

Specific objectives

- a. To assess water resource in Beles river
- b. To model the current water allocation for Beles river
- c. To predict future water demand based on different development scenarios
- d. To assess the effect of different developments on Beles river

1.4 Research Questions

To achieve the objectives of the research it should be necessary to answer the following research questions

What is the status of the water resource potential of the Beles river?

What is the status of the water allocation of the Beles river?

What future status of water demand?

What is the effect of different development on Beles River?

1.5 Significance of the study

The Beles basin is one of the most water-endowed regions and suitable for irrigation of the country, which the Beles river manifests it. There are many water demand and water sectors in the Beles basin, include irrigated agriculture, environmental requirement, and water supply. Effective planning and management of water resource development is essential to prevent conflict between competing water users and sectors. Conflict is reduced and benefit is maximized when the decision-makers allow water resources allocation between the users. The output of the study will be used as input for the Abbay Basin Authority for planning, development, and management of the sub-basin. Also, it helps the relevant stakeholders from the Beles river basin to use a water resource efficient and sustainable manner while giving consideration social, environmental, and economic benefits for Beles sub-basin region in particular and for country as general.

2. LITERATURE REVIEW

2.1 Introduction

Water is one of the most essential resources on earth and fundamentals for life to exist. It is also needed for agriculture and other economic sectors. This natural resource is affected by many factors such as climatic variability, population growth and economic development create scarcity. This leads to the implementation of effective water resources management which becomes particularly important towards determining how much water is available for human use and economic activities that water should be shared between users (Luitel, 1998). Water is a resource which appears in different forms such as surface streams, ground water or in lakes and reservoirs. The developments of this resources for a variety of purpose including water supply, irrigation, and hydropower are the basis for socio-economic of a society. The effective utilization of country's water resources heavily depends up on the estimation of quality and quantity of available water resources (Alkasim, 2016).

Water resource provide important benefits to humankind, both commodity benefits and environmental values. Because of the increasing scarcity of water for both its commodity and environmental benefits and scarcity of the resources required to develop water, economic consideration plays an increasingly important role in public decisions on water projects, reallocation proposals and other water policies. Allocation of water can be targeted via numerous forms of allocation ranging from complete control by government to a mixture of market and government allocation, to predominantly market allocation (Dinar et al., 2013). Optimizing water use for the benefit of people must take in to account a wide range of competing requirements including domestic needs, industry and agriculture as well as the requirements of communities dependent on natural resources and the needs of aquatic ecosystems. Good management of water resources should be based on an insight in to the evaluation of past water use, as well as an understanding of current demand and an awareness of possible future trends. Water allocation models estimate the quantity of water available to different users within a river basin at different times (Mccartney and Arranz, 2009). Integrated water resources management is becoming an absolute necessity for good governance of water resources allocation in

order to equitably satisfy the drinking water needs of population and economic sectors (Zerkaoui et al., 2018).

2.2 Water Resources in Ethiopia

Ethiopia constitutes 99.3% of land area and the remaining 0.7% is covered with water bodies. The country has 12 major basins, 12 large lakes, and differently sized water bodies. However, three of the major river basins are dry basins, which do not have any streamflow in these basins (Melesse et al., 2018). The total renewable freshwater (mean annual flow) of the country is estimated at 122 BCM and 2.6 BCM of groundwater could be developed for utilization (Tefera, 2017). According to Worku and Tripathi, (2015) Between 80% - 90% of the country's surface water resources are found within four major river basins, Abay (Blue Nile), Tekeze, Baro Akobo, and Omo Gibe.

Table 2.1: Major river basins of Ethiopia (Source: Worku and Tripathi, 2015)

River Basins	Catchment area (thousand km ²)	Runoff (BCM/year)	Rainfall (mm/year)
Abay (Blue Nile)	199.8	54.8	1400
Tekeze	82.3	8.2	950
Baro Akobo	75.9	23.6	1650
Omo Ghibe	79.0	16.6	1150
Wabishebele	202.7	3.16	950

As compared to surface water resources, Ethiopia has lower ground water potential. However, by many countries standard the total exploitable groundwater potential is high. The groundwater potential is estimated to be about 2.6 BCM annually (Awulachew et al., 2007). Always the occurrence of groundwater is mainly influenced by the geophysical and climatic conditions of the area. the difficulty in obtaining productive aquifers is a peculiar feature of Ethiopia., which is characterized by the wide heterogeneity of geology, topography, and Environmental conditions. Actually, the geology of the country provides usable groundwater and provides good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers (Melesse et al., 2013).

Abbay river basin has a catchment area of 199812 Km², covering parts of Amhara, Oromia, and Benishangul- Gumuz regional states. It has the major sub-basins of Anger, Beles, Dabus, Debre markos, Didessa, Dindir/Rahid, Fincha, Guder, Jemma, Lake Tana, Mota and Muger. The major river in the basin is the Blue Nile (Abbay) river. Which rises in lake Tana flowing about 1450 Km long, and merges with the White Nile to form the Nile proper (Awulachew et al., 2007). Abay river's annual discharge at the Sudanese border is 49 billion m³. It reaches 54.5 billion m³ annual discharge after crossing the Sudanese border when it is joined by Dinder, Gelego, and Rihad, its tributaries from the northwestern part of Ethiopia. Abay river basin accounts for half of the total annual discharge of the country and 62% of the total discharge that drains into Aswan dam in Egypt. 60% of the total land of the basin which is about 119,887 km² is suitable for agriculture, and 2.5 million hectares of these arable land can be developed through medium and large-scale irrigation schemes. The feasibility study has been completed for about 526,000 hectares out of the arable land. 28% and 23% of the total irrigable land in the basin can be developed by Beles Sub-basin and Tana sub-basin respectively (AbbayBasin Authority, 2016)

2.3 Water Resource Development in Beles Basin

The Beles river is one of the major tributaries of upper Blue Nile. The topographic height and high surface runoff of the area are favorable conditions and provide a high potential resource for hydropower and irrigation (Surur, 2010). Beles river has two main rivers to be named Beles river. These are Abat (main) and Gilgel Beles. The water transfer from Lake Tana for hydropower plant produces power at Qunzila and this water joins the Kasen river to the west direction and then joins main Beles from the left bank after 70 Km from the powerhouse. The main tributaries to the main Beles river are Kessen, Keteb, Muzan, Tikurwuha. Mamala, Crana, Burji, Aypapu, Genebaro, and Chankur, to Gilgele Beles river are Awissi, Gizan from Dangila high land, shar, Duksi, Gorshi, Kiwil, and Gulback. The Beles river is gaged at two points. Main Beles at bridge and Gilgel beles near to mandura which covers 30% of the total area while the rest of the catchment area of the basin is not gaged (BeSBO, 2016).

Halcrow-GIRD, (2010) report shows recently there is a considerable ongoing and planned water resource development for several irrigation schemes on Beles river. Irrigation development areas in upper Beles exceeding about 75,000 ha. The BCEOM, (1998) Abay Basin master plan study estimated that about 85,000 ha could be irrigated in the Lower Beles catchment. There is a planned Dam at Dangur on the main Beles river to increase the supply of more water to irrigate more irrigation areas (Halcrow-GIRD, 2010).

2.4 Water Resources Assessment

Water resources assessment is defined as the determination of the sources, extent, dependability, and quality of water resources for their utilization and control. Here, water resources are the water available, or capable of being made available, for use in sufficient quantity and quality at a location and over a period of time appropriate for an identifiable demand (Anandhi et al., 2014). Accurate information on the condition and trend of country's water resources surface water and ground water quantity and quality is required to support sustainable economic and social development whilst addressing maintenance of environmental quality. Uses of water resources information are many and varied. Water resource assessment relies on a full understanding of the water flows and storages in the river basin or catchment under consideration. The process of water resources assessment involves developing as complete as understanding as possible of these flows and stores with their relationship over time. Then it is possible to estimate what sustainable surplus flows may be made available for human or other uses as both sources and systems change in the future through climate change, natural evolution or human made interventions (Parwin, 2019). In order to properly state the available water resource potential of a certain river basin it is first essential to determine the amount of water available in that system. Accordingly, that requires understanding of the hydro-system and its interaction with the environment and to be able to properly describe the water flow "in and out" of the basin. Information and data regarding the basin such as runoff, evaporation and rainfall are some of the components that would be necessary in describing the water movement or circulation (Alkasim, 2016).

Water resources assessment of a catchment involves a detailed study of the surface and subsurface water. Water resource assessment follow three stages. The first water resources assessment stage involves collection, processing, and inventorying hydrological, hydro-meteorological, hydrogeological, physiographic and auxiliary data on the water cycle components and water use projects for the creation of water resources information system. Depending on the characteristics of the available water resources, current and future needs of the users, the requirements of data for water resources assessment are different for different regions and countries. The second stage is to interpret the collected data in the form of technical information for the water resources system. This stage involves assessing the state of water resources, forecasting of water related natural disasters (such as drought and floods), and using various techniques. The final stage is to interpret and evaluate the data and technical information and convert them in to knowledge, for making appropriate decisions (Anandhi et al., 2014).

2.5 Water Allocation

Water allocation within a basin or specific area needs to adhere to the principles of efficiency, equity, and sustainability and be in accordance with rules of market economy and resource allocation. Efficiency, as one of the more important concepts, generally refers to the satisfaction level of scarce resources for consumers. The efficient allocation of water can facilitate a balance between the supply and demand for water resources. Efficiency also forms a base for sharing among the different water demand sectors: domestic, industrial, agricultural, and ecological. Equity issues were extremely difficult to solve and defined the fairness components required for water use allocation between the environment and the needs of the residents and It was difficult to measure the sustainability of rivers or aquifers in water management, the fundamental objectives are to meet the water demand from the social-economic system through administrative control and management without affecting the ecological sustainability of each subarea (Hu et al., 2016). Due to the relative constancy of the water resources in the world water crises can occur because of population growth, increasing pollution of water resources, changing of the consumption patterns, changing of climate change, and also lack of water resource allocation. Moreover, shared water resources that are used by two or more

beneficiaries lead to intensifying complexity in an optimal allocation of water resources planning and management (Shahraki et al., 2018).

Water resource allocation problems are essentially concerned with how to distribute limited water resources among competing activities to achieve maximum social welfare. As a result, optimization is frequently utilized in terms of modeling techniques to find optimal water allocation schemes. Because water allocation is a problem involving multiple stakeholders, in which each stakeholder has different interests, conflicts usually arise in water allocation (Hussein, 2015). A hydrological model for making water allocation strategies needs to be considered both spatial and temporal variables including land use, surface water routing, groundwater movements, water extractions, irrigation, and their interactions. On the other hand, an increasing number of model parameters often leads to high computational complexity, which enhance the difficulty on the analysis of simulation results and future scenarios (Yu et al., 2017).

Table 2.2: Principle of water allocation

Objective	Principle	Outcome
Social objective	Equity	Provide for essential social needs <ul style="list-style-type: none"> * Clean drinking water * Water for sanitation * Food security
Economic objective	Efficiency	Maximize the economic value of production <ul style="list-style-type: none"> * Agricultural and industrial development * Power generation * Regional development * Local economics
Environmental objective	Sustainability	Maintain environmental quality <ul style="list-style-type: none"> * Maintain water quality * Support instream habitat and life

2.6 Water Resources Assessment and Management Models

Water resources management involves development, control, protection, and beneficial use of surface and groundwater resources. Models are the most essential tools for decision-making process of water resource management, they allow the users to evaluate the effects of different possible future trends and management before implementing them.

In the following sections, several models commonly used for analyzing the water resource of river basins and used as decision support tools in water resources planning and management are briefly discussed.

2.6.1 MODSIM

The modular simulator known as MODSIM is a generic river basin management DSS designed as a computer-aided tool for developing improved basin-wide planning. It was conceived in 1978 at Colorado state university, making it the longest continuously maintained river basin management software package currently available. MODSIM is designed for developing basin-wide strategies for short term operational planning, drought contingency planning, water rights analysis, and environmental concerns (Labadie, 2008).

The graphical user interface (GUI) connects MODSIM with the various database components and an efficient network flow optimization model. The objective function and constraints of the network flow optimization model are automatically constructed using parameters specified with the GUI without requiring any background in optimization or computer programming by the user. Optimization of the objective function essentially provides an efficient means of achieving system targets, demands, and guide curves according to desired priorities, while assuring that water is allocated according to physical, hydrological, and institutional/ administrative aspects of river basin management (Labadie, 2010). The MODSIM river basin management model has been extended to GEO-MODSIM for integration with GIS for spatial database management analysis and display. GEO-MODSIM is a custom ArcMap extension that provides the foundation for integrated river basin management. Numerous geo-database layers are loaded and processed including topography, hydro-geography, irrigated fields, soil maps, land use, field measurements, and satellite image (Triana and Labadie, 2007).

According to Berhe *et al.*(2013) MODSIM is used to analyze the water balance of the Awash Basin under different levels of irrigation development and also determine the water allocation in upper, middle, and lower valleys in the basin. Consumptive and non-consumptive uses were considered in allocation modeling. The model result shows that the 2005 irrigation level can be sustainable up to the year 2028 without having additional storage.

2.6.2 MIKE HYDRO

MIKE HYDRO is a versatile and highly flexible model framework for a large variety of applications concerning simulation, allocation, and management and planning aspects of water resources within a river basin. MIKE HYFRO offers a state of art, map-centric user interference for initiative model build, parameter definition, and results from presentation for water resources-related applications (Abebe, 2015). MIKE HYDRO is a comprehensive and physically-based modeling tool for simulation of water flow, water supply/demand, soil moisture, and crop growing. It has an integrated modular structure with basic computational modules for hydrology and hydrodynamics. MIKE HYDRO contains modules for climate, soil, crop irrigation, overland and channel flow, and exchange between aquifer and rivers (Yu et al., 2017).

2.6.3 Water Balance Model (WBalMo)

WBalMo was developed by WASY Ltd in Germany and it is an interactive simulation system for river basin management. It models the natural process of runoff and precipitation stochastically (Monte-Carlo simulation) and the respective time series are balanced with monthly water use requirements and reservoir storage changes. WBalMo has been used to identify management guidelines for river basins, design reservoir systems, and their operating policies, and perform environmental impact studies for development projects. Using an Arc view user interface, a representation of the river basin (system sketch) is constructed or derived from an existing digital stream network. Model data can substantially be modified in various scenarios. By the recording of relevant system characteristics during the simulation, probability estimates can be provided for water deficit, maintaining minimum runoff levels, or reservoir levels. Simulation can be performed both for stationary and transient.

2.6.4 WEAP21

WEAP is a microcomputer tool for integrated water resources planning. It provides a compressive, flexible, and user-friendly framework for policy analysis. A growing number of water professionals are finding WEAP to be a useful addition to their toolbox of models, databases, spreadsheets, and other software (Stockholm Environment Institute, 2016). WEAP is a straightforward and easy to use and attempts to assist rather than a substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flow, and storage, and pollution generation, treatment, and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems (Sieber and Purkey, 2015). Water Evaluation and Planning (WEAP) provides seamless integration of both the physical hydrology of the region and water management infrastructure that governs the allocation of available water resources to meet the different water needs. It is a priority-based optimization algorithm as an alternative to hierarchal rule-based logic that uses a concept of Equity Group to allocate water in time of inefficient supply (Mounir et al., 2011). WEAP operates on the basic principles of balance between water supply and demand at various system nodes. It calculates a water and pollution mass balance for every node and link in the system on a monthly time step. The development of water balance through WEAP requires climate and hydrological data as well as data on water supply and demand to map the existing water resources and users within the basin and to allocate the abstraction and discharge of water (Ayele, 2014).

2.6.5 RIBASIM

RIBASIM is a generic model package to simulate the hydrological behavior of river basins for varying current and future hydrological, climate, and anthropogenic conditions. The model is a compressive and flexible tool to link the hydrologic water inputs at various locations in a basin to the diverse water using activities taking place at the same analytical scale. By processing this combination of inputs, RIBASIM can evaluate a large set of system modeling options and outputs. RIBASIM has been developed and fine-tuned at Deltares Delft Hydraulics in the early 1980's. The current documentation

describes RIBASIM in the framework of the so-called Delft tools. RIBASIM can be used for several types of assessments like Evaluation of the limits on resources and/or the potential for development in a region or basin, Evaluation of measures to improve the water supply or water quality situation, and Evaluation of the origin of water for every location in the river basin as a first step towards an actual water quality analysis (Krogt and Boccalon, 2013).

According to Kamel, Amin and Eldin (2019) River Basin Simulation Model is one of the most used models in the Nile river management. It was used to quantify the trade-off between hydropower generation from Tekeze dam, downstream environmental flow, and new irrigation development in the western parts of Ethiopia. It was used also to simulate the existing system and management conditions of the Eastern Nile Basin.

2.7 Rainfall-Runoff simulation

Hydrological models are widely used for water resources assessment, to estimate water availability and describe streamflow characteristics important for many applications, and to predict how these may change in the future. Runoff from land surface is the flow of water that comes from excess water, from rain, meltwater or other sources that flow over the earth's surface. It is the major component in regional and global hydrological cycle. It is crucial to understand complex relationships between rainfall and runoff processes and then to accurately estimate surface runoff for efficient design, planning, and management of catchments. Runoff component analysis are important in hydrological studies. However, very limited attention has been paid to proper simulation of runoff component when using hydrological models (Li et al., 2015).

Rainfall-runoff simulation is very significant in catchment management. Simulation of the catchment hydrology indicates resource capacity. For water resource assessment, it is necessary to have an understanding of flow conditions unaffected by human-induced land cover and water use changes naturalized flow. Flow naturalization adjustments consist primely of removing the effects of historical reservoir storage and evaporation, water supply diversions, and return flows from the surface and groundwater supplies and in some cases other considerations. Apart from rainfall characteristics rainfall intensity, amount duration, distribution over the drainage basin, and other meteorological and

climate conditions that affect evapotranspiration, such as temperature, wind speed, relative humidity, and season (Mugatsia, 2010). Runoff is very important in various activities of water resources development and management, such as flood control and its management, irrigation scheduling, design of irrigation and design works, design of hydraulic structures, hydropower generation, and so on. The method of transformation of rainfall to runoff is highly complex, dynamic, nonlinear, and exhibits temporal and spatial variability. It is further affected by many parameters and often inter related physical factors. It is a common experience that for a given amount of rainfall on a watershed, the event produces high or low runoff depend on the parameters. The small or large time interval or duration with infiltration and evaporation losses depending significantly on how long the water remains in the watershed (Meher, 2014).

2.8 Water Demand

Water demand is defined as the volume of water requested by users to satisfy their needs. Water demand forecasting is a process achieved through several techniques and is typically used to predict future water requirements for different uses including hydropower, domestic, and agriculture water demands. The type of technique used depends on the availability of the data needed, the general scope of the region for which the forecast is being conducted, and the resources available to the organization for which the forecast is being conducted. The accelerating growth of human population, the rapid advances made in industry and agriculture have resulted in a rapidly increasing use of water by a human, to the extent that the availability of water, as well as the control of excessive water, become a critical factor in the development of every region of the world (Getu, 2015).

2.8.1 Domestic Water demand

Domestic water demand includes water used for basic needs such as drinking, cooking, ablution, washing clothes, and cleaning houses. The average amount of water used per person per capita varies from country to country and as well as from place to place within a country. The major important factors for these variations are the level of water supply service to be provided, location and climatic conditions, level of socio-economic development, water quality standard, etc. For instance, in India there is a large variability

of the quantity supplied in urban areas from 10 to 500 Lpcd and in rural areas from 5 to 70 Lpcd. In Iran the planned demand for food is based on a diet of 2700 Cal per person per day, which is in accordance with the FAO,1996 estimate. Accordingly, some 1600 m³ per person per year of water is required to allow sufficient food production (Getu, 2015).

2.8.2 Irrigation Water Demand

The majority population of Ethiopia is dependent on rainfed agricultural production for its livelihood. However, estimated crop production is not close to fulfill the food requirements of the country. One of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales through river diversion, constructing micro dams water harvesting structures, etc., (Lambisso, 2015). Irrigation is one means by which agricultural production can be increased to meet the growing demands in Ethiopia. Ethiopia has a significant irrigation potential identified from both available land and water resources. The country has developed irrigation schemes in many parts of the country at different scales (Awulachew et al., 2007). According to Worqlul *et al.* (2015) irrigation command areas can be classified into three groups. The first group is small scale irrigation areas of less than 200 ha, the medium scale between 200 and 3000 ha, and large scale above 3000 ha.

Irrigated agriculture plays an important role because it is generally two times productive than rainfed agriculture. Irrigation is largely used for high-value crops such as fruits and vegetables, sugarcane, sorghum, and maize. Currently, the government is giving more emphasis to the sub-sector by a way of enhancing the food security situation in the country. Efforts are being made to involve farmers progressively in various aspects of management of small-scale irrigation systems starting from planning, implementation, and management aspects, particularly, in water distribution and operation and maintenance to improve the performance of irrigated agriculture. Irrigation water demand is a function of crop type, growing cycles (and their corresponding crop coefficients), reference evapotranspiration, and effective precipitation within the irrigated area (Engdaw, 2016). Irrigation water demand is calculated using CROPWAT8.0 which is developed by FAO to estimate Irrigation water demand for the proposed irrigation

scheme by multiplying the crop water requirement by the total area covered by crop pattern. Crop water requirement differs from crop to crop.

2.8.3 Hydropower Water Demand

Two methods were used to define demand for Hydropower. The first method, the water year index method, is based on energy demand and used to simulate historical reservoir releases to hydropower plants. The water year index method uses historical observations to approximate operating rules. The second method called the spill demand method is based on water demand rather than energy demand. It is used to simulate the operating goal of operators to minimize spill, which usually represents lost revenue. Energy demand is modeled explicitly water year index method only for powerhouses that receive water directly from a large reservoir (Engdaw, 2016).

To prevent hydropower demand at less than capacity when a reservoir is spilling, another hydropower operating rule is introduced, called the spill demand method. The spill demand method simply requires that any inflow over existing demands to be diverted to generate hydropower. This ensures that hydropower plant uses as much as possible, water that cannot be stored and that otherwise spill. Hydropower will only be generated for flows up to maximum turbine flow. Tailwater elevation defines the working water head on the turbine. The power generated in a given month depends on the head available, which is computed as the drop from the reservoir elevation to the tailwater elevation. The plant factor specifies the percentage of each month that the plant is running. The plant generating efficiency defines the generator's overall operation effectiveness in converting the energy of the falling water into electricity.

2.8.4 Environmental water Demand

The environment is increasingly being considered a legitimate water user in many world countries. As a consequence, the water requirement of the environment needs to be estimated. The environmental or instream 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 (Engdaw, 2016). The assessment of environmental water requirements is done by a range of methods based on simple statistical hydrological indices, one such method is flow duration curve, the flow duration

relationship shows the frequency or percentage of time that stream discharge falls within various ranges. Naturalized flows or present-day historical flow data over specific durations are usually used in the flow duration analysis. In some cases, the 90% flow (Q_{90}) may be set as the minimum environmental flow, the 90% flow is the flow that is equaled or exceeded 90 percent of the time (Hassan, 2015).

According to Arranz and McCartney ,(2007) a study conducted to determine environmental flow requirements selected 18 so-called instream flow requirement (IFR) points. For each, the quantity and quality of the water needed to achieve the recommended ecological class were determined. Flow variability is recognized as being a key component of environmental flows and both drought and the so-called maintenance flow requirements were determined. According to Peden et al., (2013) no comprehensive assessment of environmental flow requirements for the Nile has been conducted, but the various transboundary agreements have to, some extent acted to secure environmental flows. McCartney et al., (2010) conducted a study to estimate the environmental flow requirement downstream of Chara-Chara weir on Lake Tana. They estimate an average annual allocation of 22% of the mean annual flow for environmental flow requirements.

2.9 Previous Studies and Gaps in Beles Sub-Basin

Different studies were conducted in Beles sub basin, among them the following are described and their achievements and gaps to be filled are also described below. Yimer et al., (2009) stated the Hydrological response of a catchment to climate change in the upper Beles river basin. The result of the study indicated an increasing trend in both minimum and maximum temperature in the future and also the result of downscaling precipitation indicated a reduction in precipitation in the main rainy season which accounts the major share of the annual runoff of the area. Surur, (2010) evaluate the impact of land use dynamics on hydrology during a 20-year period in the basin. The result has clearly revealed the significant change in land use/cover has been occurred in the area. the forest cover has shown significant change in twenty-year time. This indicates that the shrinking of the forest cover was mainly caused by deforestation for farming land.

Abshiro, (2016) studied the Evaluation of sprinkler Irrigation system at Beles sugar development project. According to the study the average actual application efficiency of

the overlapping sprinklers had 62%. This shows that the system is working below the design application efficiency of 70%. The determined irrigation interval and set hour of is vary with respect of growing month and stage of growth. Ahmad and Dar, (2019) studied ground water development in the basin. The result show that the basin was classified in to four categories depend on the ground water potential. Around 19% of the basin is falling in high ground water potential.

Even though the above studies were conducted in the basin, still there is a gap on the water resource availability and water demand forecasting analysis for Irrigation, domestic, Industrial and livestock in the basin. For planning and development, it is necessary to know the water resource potential of the basin. After knowing the potential of the basin, it is possible to allocate the water resource for demand users equitably, efficiently and sustainably.

3.MATERIALS AND METHODS

3.1 Description of the Study Area

Beles basin is one of the major tributaries of the upper Nile and it is situated on the plateau of north-western highlands. It is located in both Benishangul Gumuz and Amhara National Regional states at the south west of Lake Tana. Beles river is the last tributary of Abbay River in Ethiopia, its length is 296 km. The main Beles River is starting from Alefa woreda mountain and Gilgel Beles River is starting from Dangla woreda mountain. It is one of among 16 sub-basins of Abbay Basin. The Beles river originates on the face of the escarpment across the divide to the west of the southwestern portion of Lake Tana. Geographically it extends from 10°56'00'' to 12°00'00'' N latitude and 35°15'00'' to 37°00'00'' E longitude and the total area of the basin is 13581 km². The topography of the area is mostly flat (44.76%) with altitudes between 473 m and 2752 m above mean sea level.

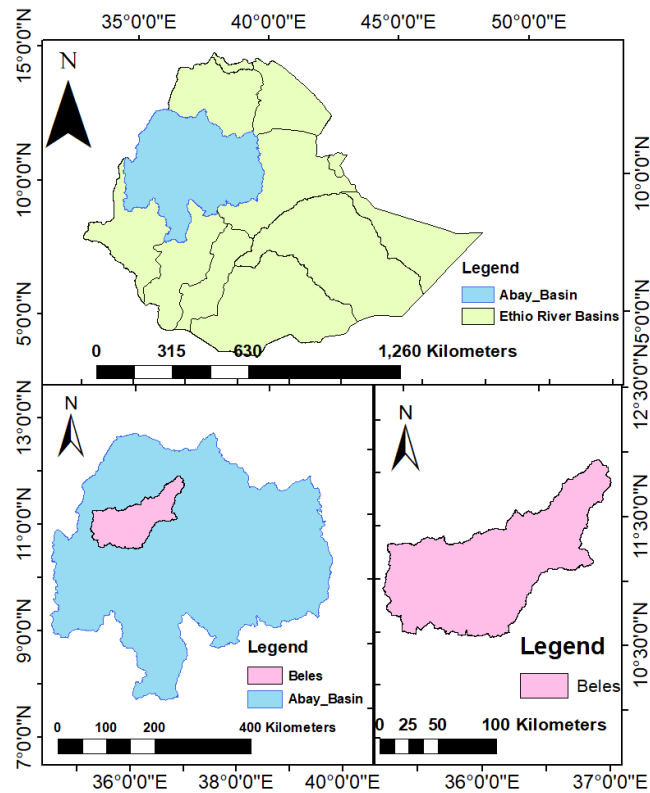


Figure 3.1: Location of Beles Basin

3.1.1 Topography

Beles basin topographically categorized into three major landforms depending on their elevation. The flat low-lying areas elevation 473-1033 m AMSL, mid-altitude elevation ranges 1034-1605 m AMSL and the mountainous areas with an elevation 1606-2752 m AMSL located in the highland areas of the basin. Around 39.63% of the basin area considered being lowland, 44.76% of the area as mid-altitude and 15.62% of the area considered as highland. The Beles basin is bounded on the east and southeast by steep escarpment and on the north and west by rolling to hilly terrain which separates it from Dinder Sub-basin. The highest point in the basin is 2752 m AMSL at the water divide between the Tana and Beles basins. The central part of this sub-basin encloses the wide, gently undulating to flat plains of the pawe area.

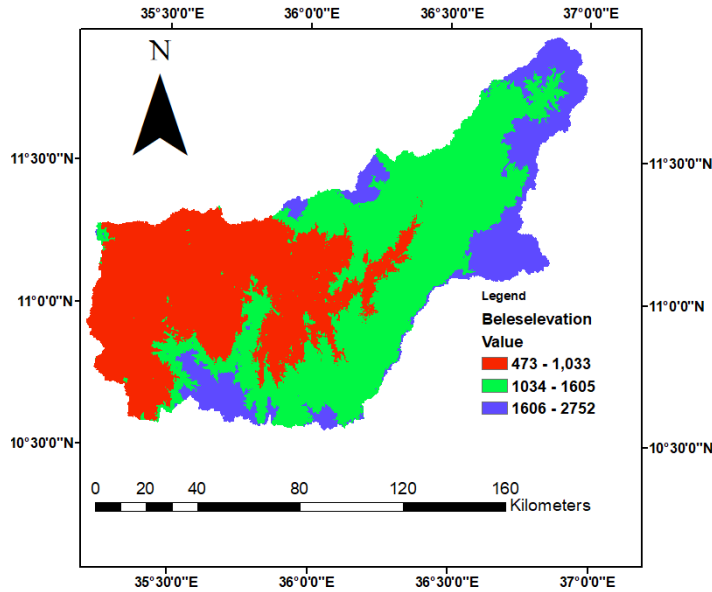


Figure 3.2: Beles Basin Elevation

3.1.2 Climate

Ethiopia is suited in the tropics and its climate is the reflection of its diversified topography. The climate season of Ethiopia is controlled by the annual migration of the Inter-Tropical Convergence Zone and associated atmospheric circulation which are modulated by the complex topography on the region. The climate of Beles basin classified as a tropical climate with hot and moist climate conditions distinguished by a highly seasonal rainfall pattern due to a winter/summer. The rainy seasons of the basin are from May to October when the temperature lower and the maximum temperature records from February to April.

3.1.2.1 Rainfall

Rainfall is the most important parameter to characterize the climate region. The distribution of mean annual rainfall over the basin shows a distinct east to west gradient. The highest rainfalls of more than 1,514 mm/year occur in the south and middle areas of the basin and the lowest, less than 1,162 mm/year, in the lower area of the basin near Beles river joins Abbay river. The wet season extends from the month of May-October, whereas the dry season is from November to April. About 55% of the basin gets the rainfall above average. For this study, the rainfall data is available from 1995 to 2018 from Pawe, Shahura, Gulback, Mankush, and Bullen stations.

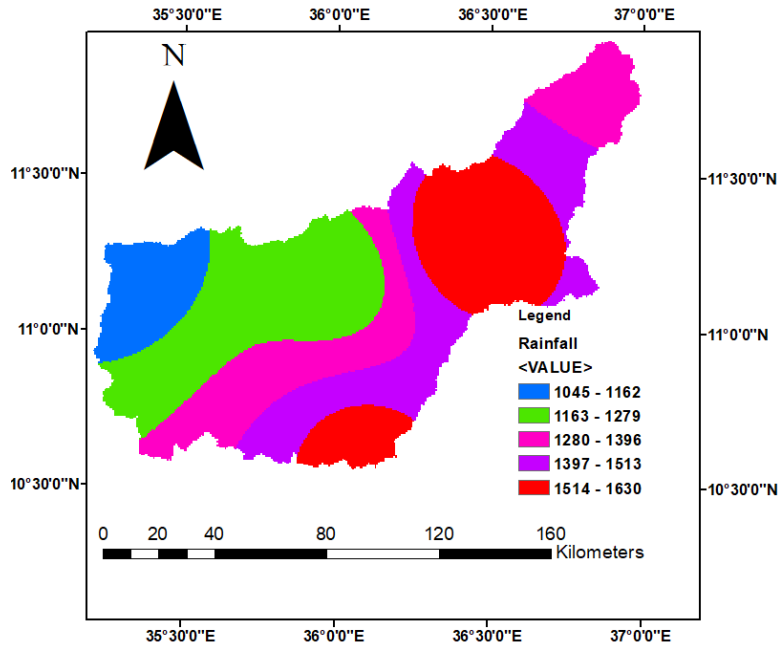


Figure 3.3: Beles basin rainfall distribution (mm/year)

3.1.2.2 Temperature

The mean annual temperature of Beles basin is 23°C. From March to April the average maximum and minimum temperature of the basin is high and in July low, due to the cloud is persist through the wet season. About 63% of the basin gets temperature above the calculated mean temperature.

3.1.3 Soil Types

Soil data is an important parameter to model catchment hydrology. The property of water holding capacity of soil affects the generation of surface runoff from the meteorological data like rainfall. The soil data is obtained from the GIS department of the Ministry of Water, Irrigation, and Energy of Ethiopia. There are eleven dominant soil groups in the Beles Sub-basin. Chromic Luvisols, Eutric Cambisols, Eutric Fluvisols, Eutric Leptosols, Eutric Regosols, Eutric Vertisols, Haplic Aerisols, Haplic Alisols, Haplic Luvisols, Haplic Nitisols, and Rhodic Nitisols.

Nitisols: soils are accommodated deep, well-drained, red, and tropical soils. They are characterized by the strong development of structure frequently with shiny aggregate faces. They originate from basic and intermate rocks or sediments derived under

relatively intense weathering conditions in the tropical and sub-tropical climate. Cambisols: the reference soil group of cambisols holds soils with incipient soil formation. The beginning transformation of soil material is evident from weak, mostly brownish discoloration and structure formation below the surface horizon. Cambisols are found in a wide range of climates in all vegetation types and levels to steep reliefs. The typical parent material is medium and fine-textured, derived from a wide range of rocks. Fluvisols: the reference soil group the fluvisols accommodates generally young, azonal soils in alluvial deposits. Luvisols: these soils are derived from various volcanic and undifferentiated lower complex rocks. They are identified in color as brown/reddish brown with clay to silty clay texture. These soils are friable to firm, sticky and slightly plastic. Leptosols: these soils are developed in a relatively younger surface and were probably only moderately deep too deep by origin. The dominant soil groups in Beles basin are portrayed in the Table 3.1 with their coverage percentage.

Table 3.1: Beles catchment soil types

Soil Type	% age	Hydrologic soil group
Chromic Luvisols	4.0	B
Eutric Cambisols	15.6	B
Eutric Fluvisols	9.8	B
Eutric Leptosols	7.1	D
Eutric Regosols	0.1	A
Eutric Vertisols	0.6	D
Haplic Acrisols	7.5	B
Haplic Alisols	2.0	B

Haplic Luvisols	5.4	B
Haplic Nitisols	44.7	B
Rhodic Nitisols	3.2	B

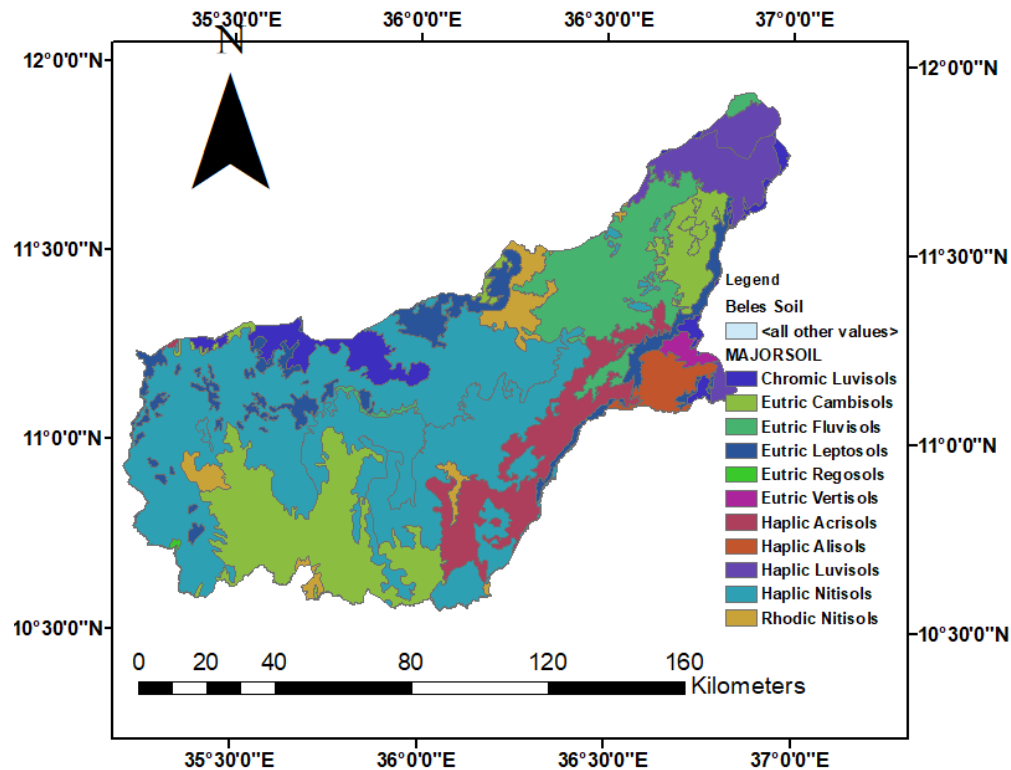


Figure 3.4: Beles Soil

3.1.4 Land Cover

The land cover map of Beles basin is obtained from European Space Agency's climate change initiative Land cover database (ESA-CCI-LC, version 2.1.1). The land cover is the main factor to evaluate the water resource potential of the basin. The study area is dominantly covered by cultivated land and Forest land. The upper Beles is covered by small trees and cultivated areas where as the lower Beles is dominantly covered by Forest land.

Table 3.2: Beles Land Cover (Source: <http://2016africalandcover20m.esrin.esa.int>)

Land Cover	% age
------------	-------

Cultivated Land	20.892
Forest Land	57.093
Shrub Land	6.207
Grass land	14.632
Bare Land	0.001
Urban	1.132
Water Body	0.044

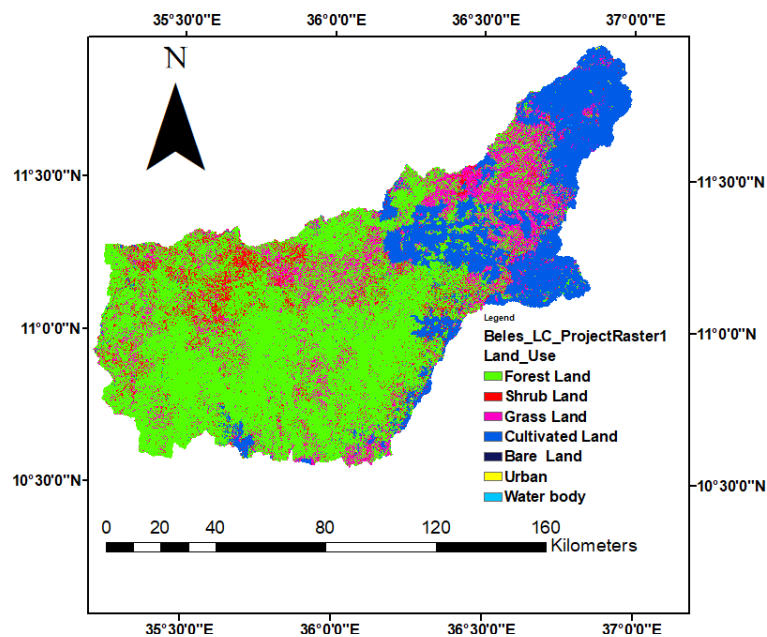


Figure 3.5: Beles Basin Land cover

3.2 Data Collection

3.2.1 Hydrological Data

There are two gaging stations in Beles basin. The gaged part of the basin is about 30% of the total basin area which is 13581 km². Flow data for main Beles at bridge and Gilgel-Beles near mandura was collected from Ministry of Water, Irrigation and Energy of Ethiopia.

Table 3.3: Flow data

Station Name	Catchment	Area	Mean annual flow(M ³ /s)	Data used
--------------	-----------	------	-------------------------------------	-----------

	(Km ²)		
Gilgel Beles	675	16.04	1995-2011
Main Beles	3431	61.85	1995-2011

3.2.2. Population Data

The human population census data is obtained from the Ethiopian Central Statistical Agency. For this study, the 2019 population data is used. Livestock population data is obtained from the Benishangul-Gumuz Regional state Bureau of Agriculture.

3.2.3 Meteorological Data

Hydrological modeling depends on meteorological data like precipitation, relative humidity, temperature, sunshine hours, and wind speed. The reliability of collected meteorological data affects the accuracy of the model input data and the model simulation result. The meteorological data is obtained from the National Meteorological Agency for 24 consecutive years for this study.

Table 3.4: Meteorological stations

Stations	Latitude	Longitude	Altitude (MASL)	Year of data used	% of missed data
Shahura	11.929	36.874	2205	1995-2018	8.67
Pawe	11.312	36.410	1119	1995-2018	5.35
Gulback	11.179	36.001	890	1995-2018	27.46
Mankush	11.250	35.300	824	1995-2018	37.52
Bullen	10.596	36.082	1659	1995-2018	13.68

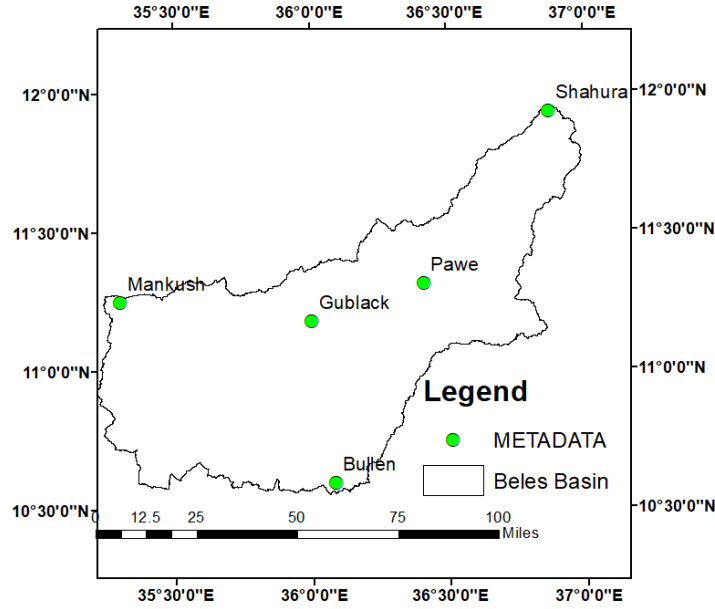


Figure 3.6: Location map of Metrological stations

3.3 Filling Missing Rainfall Data

Failure of rain gage or absence of observer from a station causes a short break in the record of rainfall at the stations. These gaps must be filled before using the data for analysis. The surrounding stations located within the basin help to fill the gap on the assumption of hydro-meteorological similarity of the group of stations.

Methods which is proposed to estimate missing rainfall data are station Average method, Normal ratio method, and regression method. For this research regression method is selected due to the shortage of data of total annual rainfall and normal rainfall. Assume two stations gages X and Y have long records of annual precipitation, and the missing precipitation Y_m the missing data will be filled based on the simple linear regression equation

$$Y_m = a + bX_n \dots\dots\dots (3.1)$$

The parameters a and b will be estimated by

$$\hat{a} = \bar{Y} - \hat{b}\bar{X} \dots\dots\dots (3.2)$$

$$\hat{b} = r_{xy} \frac{s_y}{s_x} \dots\dots\dots (3.3)$$

Where \bar{Y} and \bar{X} are the sample means and S_y and S_x the sample unbiased standard deviations of Y and X , respectively and r_{xy} is the cross-correlation coefficient between X and Y .

$$r_{xy} = \frac{\frac{1}{N} \sum_{i=1}^N [(X_i - \bar{X})(Y_i - \bar{Y})]}{S_x S_y} \dots\dots\dots (3.4)$$

3.4 Data Quality Analysis

3.4.1 Homogeneity Test

Homogeneity is used to detect the variability of data. When the data is homogeneous, it means that the measurement of the data taken at the time with the same instruments and environments. The method to check homogeneity of the stations in the catchment is nondimensional rainfall records and plotted to compare the stations to each other. Nondimensional values of the monthly precipitation of each station can be computed by

$$P_i = \frac{P_{iav}}{P_{av}} * 100 \dots\dots\dots (3.5)$$

Where

P_i is a non-dimensional value of precipitation for the month in station i .

P_{iav} is over years averaged monthly precipitation for the station i

P_{av} is over years averaged yearly precipitation of the station

When the rainfall patterns are spatially identical or vary with range they considered as homogenous.

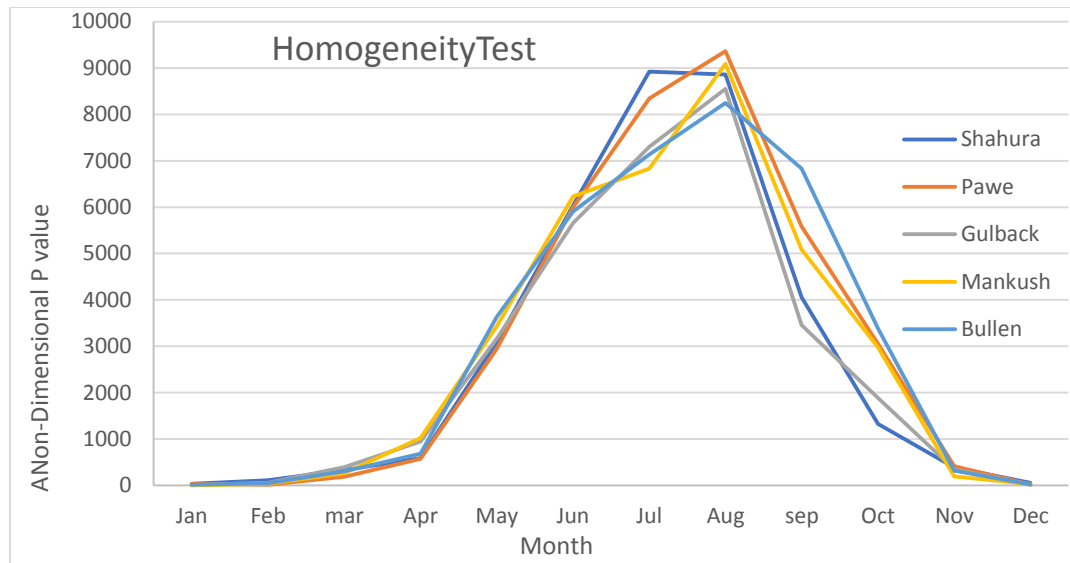


Figure 3.7: Homogeneity test

3.4.2 Consistency Test

If the conditions relevant to the recording of rain gage stations have undergone a significant change during the period of record, inconsistency would occurred from the time of significant change took place Double mass curve is a simple, visual and practical method, and it is widely used in the study of the consistency and long- term trend test of hydro-meteorological data. The accumulated total of the individual rain gage is compared with the corresponding totals for a representative group of nearby rain gage.

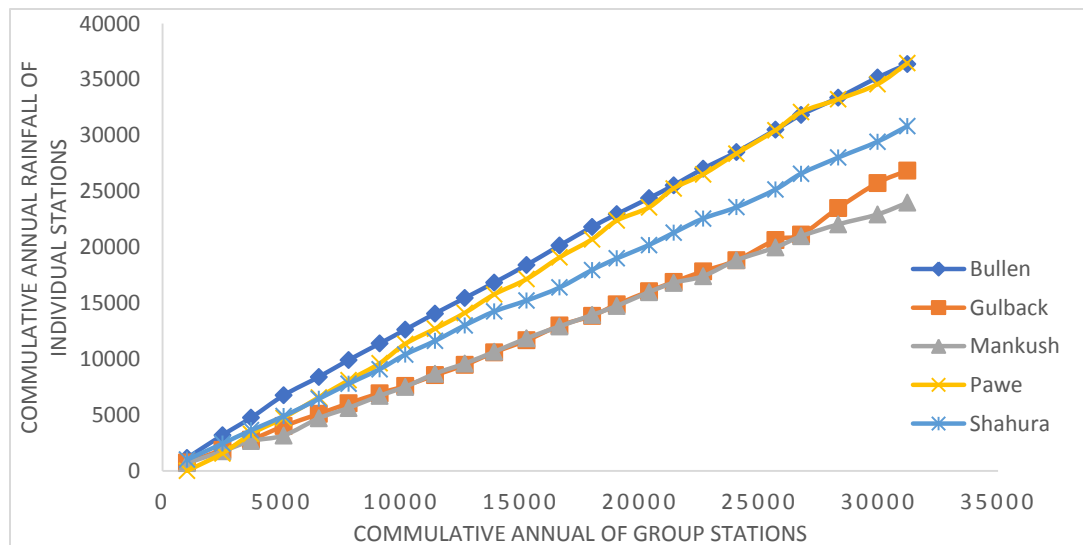


Figure 3.8: Consistency test

3.4.3 Outlier Test

Outliers are data points that depart significantly from the trend of the remaining data, which may be due to errors in data collection, or recording or due to natural causes. All procedures for treating outliers ultimately requires judgment involving both mathematical and hydrologic considerations. According to the water resource council (1981), if the station skew is greater than +0.4, tests for high outlier are considered first, if the station skew is less than -0.4, tests for a low outlier is considered first. Where the station skew is between ± 0.4 , tests for both high and low outliers should be applied before eliminating any outliers from the data set (Chow et al., 1988).

The following frequency equations can be used to detect high outliers.

$$y_H = \bar{y} + K_N S_y \dots \dots \dots (3.6)$$

Where

y_H = logarithmic high outlier test threshold

S_y = standard deviation

K_N = 10 percent significance level (Appendix-3)

If the logarithm value in sample is greater than y_H , then they are considered as higher outlier.

A similar equation can be used to detect for low outliers

$$y_L = \bar{y} - K_N S_y \dots \dots \dots (3.7)$$

where

y_L = logarithmic low outlier test threshold

the largest average annual value become $P_{max} = 10^{y_H}$ and the smallest average annual value $P_{min} = 10^{y_L}$

The outlier test result in Appendix-3 shows that the largest record station value does not exceed the higher outlier test threshold and also the smallest recorded value is not lower

than the lower outlier threshold. So, all data are between Lower outlier threshold and higher outlier threshold.

3.5 Model Selection and Setup

The following set of criteria should be considered when selecting software package to support a water resource management effort. Each application is different in issue complexity, user needs, data availability, and this specific criterion will have to be further refined and the degree of importance considered for each application.

- i. Simulation and optimization: water resource simulation algorithms tend to support either simulation or optimization. Simulation algorithms are more appropriate for running “what if” scenarios, whereas optimization algorithms are best for designing systems for optimizing system performance.
- ii. Complexity: water resource simulation ranges from simple to complex representation of the hydrologic, hydraulic, and hydrological systems. In general, the more complex representation, the more data and computational capacity required. Aspects that define complexity include spatial-temporal scale, modeling domain extent, data requirements, and computational complexity.
- iii. Licensing cost and maintenance fee: proprietary and commercial water resource simulation package require the purchase of a license. Licensed versions are generally available for either single-seat or network licenses, with prices per seat decreasing as more seats are purchased. Prices can differ based on the institution purchasing the software (for example, discounted rates for government or academic institutions).

Based on the selection criterion stated above and a one-year free license for developing countries WEAP model was selected for this study.

The WEAP model was developed by SEI to enable evaluation of planning and management issues associated with water resources development. The WEAP model can be applied to both municipal and agricultural systems and can address a wide range of issues including sectoral demand analysis, water conservation, water rights and allocation priorities, streamflow simulation, reservoir operation, ecosystem requirements, and

project cost-benefit analyses. WEAP model has two primary functions (Arranz and McCartney, 2007).

- i. simulation of natural hydrological processes (e.g., evapotranspiration, runoff, and infiltration) to enable assessment of the availability water within the catchment.
- ii. 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.

The modeling of a watershed using the WEAP consists of the following (Mayol, 2015).

- i. Define 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, 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 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 is scenarios”, like what if there is a population increase, what if irrigation activities 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 process.

3.6 Model Calibration and Validation

Calibration is an iterative exercise to establish the most suitable parameter in modeling studies. It is very important because reliable values for some parameters can only be found by calibration. It involves the identification of the most important model parameters and changing the parameter set. Model parameters changed during calibration

were classified into physical and process parameters. Physical parameters represent physically measurable properties of the watershed, while the process parameters are those not directly measurable (Tadesse, 2016).

WEAP includes linkage to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy (Sieber and Purkey, 2015). The WEAP model is calibrated for the Beles basin using streamflow gaging stations from Main Beles and Gilgel Beles.

3.7 Model Performance Evaluation

The quantitative statistics used for the evaluation of model performance are Nash-Sutcliffe efficiency (NSE) and the coefficient of determination (R^2).

3.7.1 Nash-Sutcliffe Efficiency (NSE)

Nash-Sutcliffe efficiency (NSE) is normalized statistics that determine the relative magnitude of the residual variance compared to the measured data variance. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE ranges between $-\infty$ and 1, with NSE equal to one being optimal value. Values between 0 and 1 are generally viewed as acceptable levels of performance, whereas values less than 0 indicate that the mean observed value is a better predictor than the simulated value which indicates unacceptable performance (Leong and Lai, 2017). NSE is computed as shown below

$$NSE = 1 - \left[\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^n (Y_i^{obs} - \bar{Y}^{obs})^2} \right] \dots \dots \dots (3.8)$$

Where Y_i^{obs} : the i^{th} observed streamflow

Y_i^{sim} : the i^{th} simulated streamflow

\bar{Y}^{obs} the mean of observed streamflow

3.7.2 Coefficient of Determination (R^2)

The coefficient of determination (R^2) outlines the degree of collinearity between simulated and measured data. R^2 describes the proportion of variance in measured data

explained by the model. R^2 ranges from 0 to 1, given higher values indicating less error variance. Values which is greater than 0.5 are considered acceptable (Leong and Lai, 2017). The computation of R^2 is shown as below

$$R^2 = \left[\frac{\sum_{i=1}^n ((Y_i^{sim} - \bar{Y}^{sim})(Y_i^{obs} - \bar{Y}^{obs}))}{\sqrt{\sum_{i=1}^n (Y_i^{sim} - \bar{Y}^{sim})^2 * \sum_{i=1}^n (Y_i^{obs} - \bar{Y}^{obs})^2}} \right] \dots\dots\dots (3.9)$$

Where Y_i^{sim} the i^{th} simulated stream flow

Y_i^{obs} : the i^{th} observed stream flow

\bar{Y}^{obs} the mean of observed stream flow

\bar{Y}^{sim} the mean of simulated stream flow

3.8 Water Resources Assessment

3.8.1 Surface Water Assessment

The surface water potential of Beles basin is assessed by using WEAP model. To determine surface water resource in the basin the model follows long term average climate data like (rainfall, mean of high and low temperature, humidity and wind speed), monthly mean values of streamflow, land use land cover of the catchment and average Kc value. The Kc value is obtained from FAO paper 56. Average Kc value of Beles basin was portrayed in Apendix-5.

Tana-Beles hydropower plant is currently in operation to supply electricity to the national grid. Its installed capacity of 460 MW and 2051 GWh average annual energy production. The release from the Tana-Beles hydropower scheme is entering into Main Beles, significantly it changes the hydrological and morphological regime of the Beles basin by increasing river flow from the power plant scheme. When the power plant is at the maximum operating level it releases 160 m³/s flow to the Beles basin. The data obtained From Ethiopian Electric Power, based on the energy production of Tana-Beles hydropower the power plant generates power with an average discharge of 86.6 m³/s. so this data is used as a head flow of Beles river.

Table 3.5: Tana-Beles Hydropower (Source: Tesfaw, 2016)

Power plant	Installed capacity (MW)	Gross head(m)	Maximum Discharge(m ³ /s)	Average Discharge(m ³ /s)	Starting year
Tana-Beles	460	325.5	160	86.6	2010

3.8.2 Groundwater Assessment

Always the occurrence of groundwater is mainly influenced by the geophysical and climatic conditions of the area. the difficulty in obtaining productive aquifers is a peculiar feature of Ethiopia., which is characterized by the wide heterogeneity of geology, topography, and Environmental conditions. Actually, the geology of the country provides usable groundwater and provides good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers (Melesse et al., 2013).

Groundwater is the main source of water to meet the demands of the public in northern Ethiopia as the rainfall is scarce and unevenly distributed (Ahmad and Dar, 2019). Many boreholes, Deep and shallow wells and springs are found in the study area for public and livestock consumption. The abstractions of Hand dug wells (HDW) are carried out by hand. Deep wells (DW) and Shallow wells (SW) were drilled by governmental, non-governmental and private companies. According to Ahmad and Dar, (2019) the groundwater potential areas in Beles basin were very low, low, moderate and high. 19.34% of total area was found to have high ground water potential. While as 41.82%, 32.06%, and 6.79% of the total area are represent moderate, low, and very low ground water potentials.

Based on the data collected from basin woreda water and Energy offices the main groundwater sources in the sub basin are springs, boreholes and wells. In the basin existing main groundwater sources are identified as springs, boreholes and wells which discharges from 0.5l/s to 56l/s. Ali spring 56l/s, Guragur spring 30l/s, and cher Anguch springs cumulative 40l/s around pawi and jawi area and boreholes discharges as potential

yield ranging from 0.5l/s -14l/s like Alefa 1.5l/s, Dangur 4l/s, Bullen 5l/s, Dibatie 9l/s and WorkMeda 14l/s. Groundwater sources and their discharges are listed in Appendix-4.

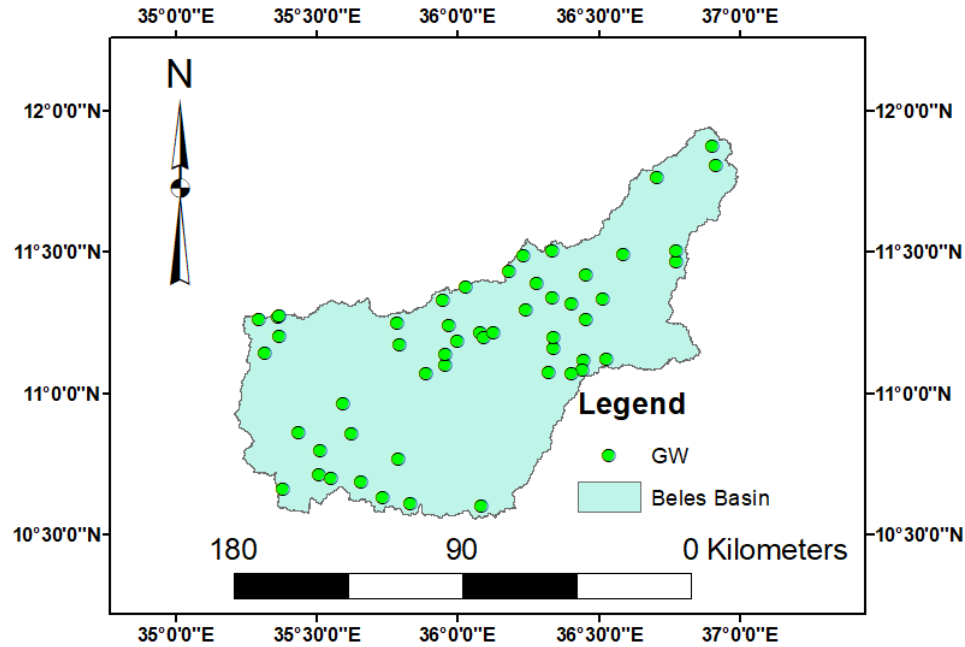


Figure 3.9: Location of Groundwater sources

3.8.3 Catchment Simulation

There is a choice among five methods to simulate processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall-Runoff and (2) Irrigation Demands Only Versions of the Simplified Coefficient Approach, (3) the Soil Moisture Method, (4) the MABIA Method and (5) the Plant Growth Model or PGM. The choice of method should depend on the complexity desired for representing the catchment process and data availability (Sieber and Purkey, 2015).

To simulate Beles basin the Soil moisture method is selected due to its more complexity, representing the catchment with two soil layers. In the upper soil layer, it simulates evapotranspiration considering rainfall and irrigation on agricultural and nonagricultural land, runoff and shallow interflow, and soil moisture. This method allows for the characterization of land use and soil type impacts to this process. The parameters of this model include the water holding capacity of the layer as well as the water movement between them. A watershed unit can be divided into N fractional areas representing

different land uses/soil types, and a water balance is computed for each fractional area, j of N . climate is assumed uniform over each sub-catchment, and the water balance is given as,

$$Rd_j \frac{dz_{1,j}}{dt} = P_e t - PET(t)K_{c,j}(t) \left(\frac{5Z_{1,j} - 2Z_{1,j}^2}{3} \right) - P_e(t)Z_{1,j}^{RRF_j} - f_j K_{s,j} Z_{1,j}^2 - (1 - f_j) K_{s,j} Z_{1,j}^2 \dots \dots \dots (3.10)$$

Where $Z_{1,j} = [1,0]$ is the relative storage given as a function of total effective storage of the root zone (mm) for land cover fraction, j . the effective precipitation, P_e . includes snowmelt from accumulated snowpack in the sub-catchment. PET is potential evapotranspiration, $K_{c,j}$ is the crop/plant coefficient for each fractional land cover. The third term represents surface runoff, where RRF_j is the runoff resistance factor of the land cover. Higher values of RRF_j lead less surface runoff. The fourth and fifth terms are the interflow and deep percolation terms respectively. Where the parameter $K_{s,j}$ is an estimate of the root zone saturated conductivity (mm/time) and f_j as a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically.

The total surface and interflow runoff, RT from each sub-catchment at time t is

$$RT(t) = \sum_{j=1}^N A_j \left(P_e(t)Z_{1,j}^{RRF_j} + f_j K_{s,j} Z_{1,j}^2 \right) \dots \dots \dots (3.11)$$

Where no return flow link is created from a catchment to a groundwater node baseflow emanating from the second bucket will be computed as

$$S_{max} \frac{dz_2}{dt} = \left(\sum_j (1 - f_j) K_{s,j} Z_{1,j}^2 \right) - K_{s,2} Z_2^2 \dots \dots \dots (3.12)$$

Where the inflow to this storage, S_{max} is the deep percolation from the upper storage and $K_{s,2}$ is the saturated conductivity of the lower storage (mm/time).

Beles basin is divided into five sub-catchments to simulate the surface runoff. The sum of the five-catchment surface runoff represents the runoff of the Beles basin.

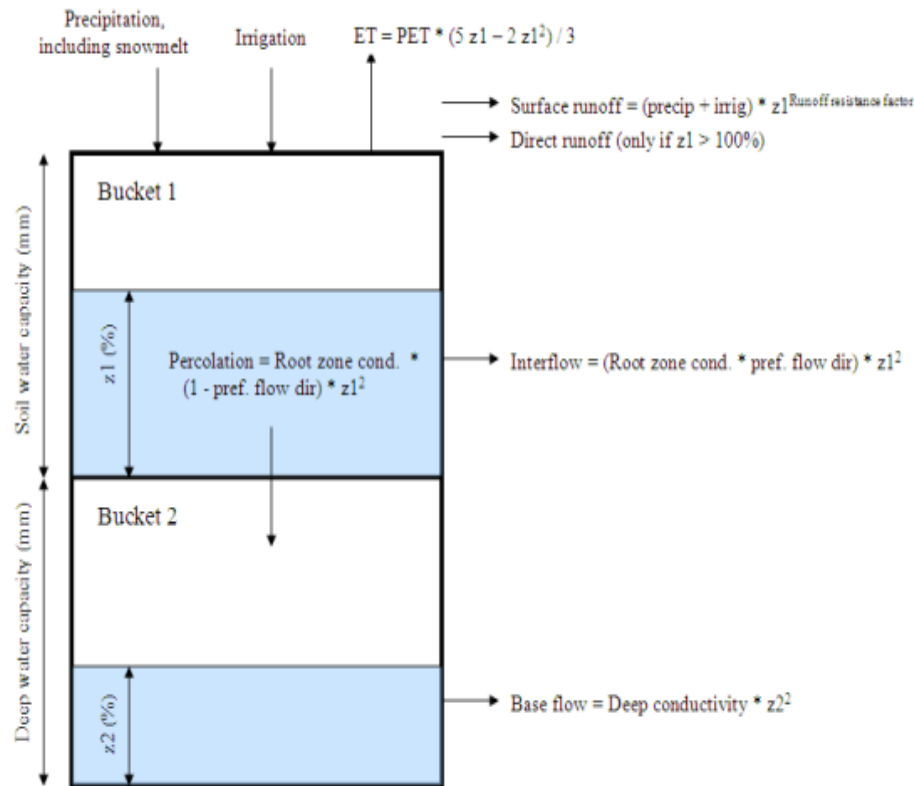


Figure 3.10: Conceptual diagram and equations incorporated in the soil moisture method (WEAP- User Guide)

3.9 Water Demand Assessment

Demand is defined as a set of water users that share a physical distribution system that is all within a defined region or that share an important withdrawal supply point. With the increasing population including urbanization, economic growth, industrial production, agricultural and livestock production, water demand increased rapidly over the years.

Water is a resource, which appears in different forms of surface stream, groundwater, lakes, and reservoirs. The developments of these resources for various purposes like water supply, irrigation, and hydropower are the basis for the socio-economic development of society. The effective utilization of countries water resources heavily depends on the estimation of the quality and quantity of the available water resource. In a very general way, water demand can broadly classify into off-stream and in-stream use.

In stream use refers to the water that is used but not withdrawn from groundwater or surface water for purposes such as hydroelectricity and navigation while off-stream refers to water that is withdrawn and diverted from a source

Forecasting water demand is an essential input for decision making in water resources planning and management. The most influential factors affecting water demand and use are related to the population level of services, tariffs, demand management measures as well as climatic conditions Demand site is classified into domestic, irrigation, and livestock. Each demand site has a transmission link to its source and where applicable a return link directly to a river.

3.9.1 Domestic Water Demand

Domestic water demand includes water used for basic needs such as drinking, cooking, washing clothes, and cleaning houses. The average amount of water used per person per capita varies from country to country and as well as from place to place within a country. The major important factors for these variations are the level of water supply service to be provided, location and climatic conditions, level of socio-economic development, water quality standard, etc.

The amount of water used per person per day is known as per capita water demand and it uses as a basis for estimating the domestic water demand for the community. The per capita water demand is varies depending on the size of a town, the level of development, the type of water supply schemes, the cost of the water system of sanitation, and the climatic condition of the area. According to WHO, (2003) the per capita per person per day is about 100 liters. But according to Ethiopian transformation plan-1 rural and urban water supply targets were 15 and 20 liters per capita per day respectively the country develops a new standard of quantity supplied 25 liters per capita per day for rural and 40-100 liters per capita per day for urban(GTP-2, 2015).

The design of the water supply project is done based on the projected population at the end of the design period. Otherwise, a present scheme will be inadequate in the near future. The following are the standard method by which the forecasting of population done; Arithmetical increase method, geometrical increase method, simple graphical method and the logistic curve method. The geometrical increase method is mostly

applicable for growing town and rural areas having a possibility of growth. This method is based on the assumption of the percentage increase in population from decade to decade remains constant. If the present population is P and the average percentage growth is K, the population at the end of n decade will be

$$P_n = P_0(1 + k)^n \dots\dots\dots (3.13)$$

Where P_0 = initial population, P_n = population at n decades, n = decades and k = percentage(geometric) increase. The total water consumptive for Beles sub-basin is forecasted for the year 2019 from the 2007 census data

Table 3.6: 2019 Population of Beles basin (Source: Ethiopian Central Statistics)

Sub-Catchment	Urban Population	Rural Population
Bullen	13931	96405
Pawe	38637	286891
Alefa	11076	177000
Dangur	8101	68478
Guba	5983	89758

Table 3.7: Domestic annual water consumption

Demand	Population	Average daily demand (l/c/d)	Annual water use rate(m ³ /person)
Urban	77727	70	25.55
Rural	718532	25	9.125

3.9.2 Industrial Water Demand

Industries require water for different purposes such as production and cooling processes. Now Tana Beles sugar factory is expected to start sugar production. In coming years different Agro-processing, mining and tannery industries are expected to be established and functional. At this stage only Tana Beles sugar factory is considered as current

Industrial water user. However, for the purpose of water allocation the annual water use for industries were determined from different literatures as 12.9 MCM per year (BeSBO, 2016).

3.9.3 Livestock water Demand

Livestock is major components of the livelihood of both pastoralists in the arid and semi-arid lowlands of the Ethiopia and the crop-livestock farmers in the highlands. The water resource is pertinent and vital for the existence and development of the livestock sector. Water requirement by livestock appears to be very individual and specific characteristics. Water for livestock is an essential basis of subsistence and development of population and used as income. Ethiopia is home to about 35 million tropical livestock units (TLU), and on average one TLU requires about 25 liters of water per day (Sileshi et al., 2008). Livestock population type is expressed in Tropical Livestock Unit (TLU).

The total water requirement for basin livestock was calculated based on the population of Livestock multiplied by TLU and unit water requirement of each livestock.

According to the 2019 livestock census data from the Benishangul regional state the number of livestock in the basin is listed below.

Table 3.8: Livestock Population in Beles basin. (Source: BGNRSBOA)

Catchment	Cattle	Sheep	goat	Equine
Bullen	340039	38819	127736	21299
Pawe	133266	18923	46058	5742
Dangur	54516	14174	41937	6694
Guba	156668	107046	100119	25883

Table 3.9: Livestock consumption rate (Source: BeSBO, 2016)

Livestock	Consumption rate (L/TLU/d)	Annual water requirement (M ³ /TLU/yr.)
Cattle	50	18.25
Sheep	7	2.6
Goat	7	2.6

Equine	40	14.6
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3.9.4 Irrigation Water Demand

One of the best alternatives to consider for reliable and sustainable food security development is expanding irrigation development on various scales through river diversion, constructing micro dams water harvesting structures etc.,(Lambisso, 2015). Irrigation is one means by which agricultural production can be increased to meet the growing demands in Ethiopia. Ethiopia has a significant irrigation potential identified from both available land and water resources. The country has developed irrigation schemes in many parts of the country at different scales (Awulachew et al., 2007).

Irrigation water demand is one of the most key assumptions in scenario development. Irrigation demand is varying considerably from month to month depending on the variation of crop type. Irrigation water demand is calculated using CROPWAT8.0 which is developed by FAO to estimate Irrigation water demand for the proposed irrigation scheme by multiplying the crop water requirement by the total area covered by crop pattern. Crop water requirement is calculated using Reference crop evapotranspiration (ET_o), crop coefficient (K_c), and effective precipitation (P_{eff}).

$$ET_c = ET_o * K_c \dots\dots\dots (3.14)$$

$$IWR = ET_c - P_{eff} \dots\dots\dots (3.15)$$

Where ET_c = crop evapotranspiration(mm/period)

IWR = irrigation water requirement in (mm/period)

Table 3.10: Annual crop water requirement

Irrigation	Area(ha)	Annual CWR (M ³ /ha)
Upper Beles LSI	54000	15538.18
Dangur MSI	200	6737.76
Dura SSI	50	4732.13
Kuwil SSI	91	5343.84
Wila SSI	100	5754.52
Tikur wuha SSI	45	5247.36

Kuilla MSI	422	6487.47
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3.9.4 Environmental Flow Requirement

The Environmental (instream) flow refers to the flow regime in a river that ensures conservation of a river ecosystem. It is the minimum monthly flow required along a river to meet water quality, fish and wild life, navigation, recreation, downstream, and other requirements. Depend on its demand priority an Environmental Flow requirement will be satisfied before, after, or at the same time as other demands on the river (Ayele, 2014). According to Peden et al., (2013) no comprehensive assessment of environmental flow requirements for the Nile has been conducted, but the various transboundary agreements have to some extent acted to secure environmental flows. McCartney *et al.*(2010) conducted a study to estimate the environmental flow requirement downstream of CharaChara weir on Lake Tana. They estimate an average annual allocation of 22% of the mean annual flow for environmental flow requirements. For Beles Basin 20% of mean annual runoff is kept for the river ecosystem and downstream water users.

3.10 Scenario Development

A scenario can be defined as a plausible description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and deriving forces (Arranz and McCartney, 2007). Scenarios are self-consistent story lines of how a future system might evolve in a particular socio-economic setting and under a particular set of policy and technology conditions. Using WEAP, scenarios be built and then compared to assess their water requirements. The scenarios can address a broad range of “what if” questions (Sieber and Purkey, 2015).

3.10.1 Scenario-I: High population Growth

Based on the reference scenario alternative assumptions made for future development. This scenario address what-if questions for population growth pattern change for both Humans and Livestock. Population growth is one of the dominant factors for water supply-demand decisions and future development in the water resources sector. The population growth rate varies from time to time; hence it is necessary to assess future water demand depending on the population growth rate. According to Bekele and Lakew, (2014) previous national census conducted in 1984, 1994,2007 with a growth rate of

3%,2.9%, and 2.6% respectively for human population. According to BeSBO, (2016) the sub-basin is highly suitable for livestock production. Now depend on these previous growth rate 3% and 2.5% high population growth rate for Human and Livestock respectively used for this study. When the population is increased also the development and urbanization will be increased. In line with this increment the per capita water consumption also increase.

According to GTP-2, (2015) rural settlement in Ethiopia will enjoy 25 liters of per capita domestic water consumption by 2020. The per capita water demand is steadily increase and reach 50 liters in 2045 which is recommended by WHO. The per capita water demand in 2025 and 2035 are projected to be 30 liters and 40 liters respectively. The per capita domestic water in urban areas will vary from 40-100 liters by 2020 depending on population size. Using this as a base the per capita domestic water demands are projected to be 80 liters in 2025, 90 liters in 2035 and 100 liters in 2045 (GIRDC, 2020). Depending on the above projected demand for this study it is forecasted up to 2060.

Table 3.11: Water demand (l/c/d) (Source: GIRDC, 2020).

Year	2020	2030	2040	2050	2060
Urban	70	85	95	105	115
Rural	25	35	45	55	65

3.10.2 Scenario-II: Dangur Hydropower

Currently, there is one hydropower plant that exist at the Beles basin which is Tana-Beles Multipurpose hydropower scheme. The power plant takes water from lake Tana and used to generate 460 MW power and irrigate the irrigation command area in Upper Beles. Halcrow-GIRD, (2010) report recommend Dam construction option at Dangur to maximize energy potential and to irrigate Lower Beles irrigation area. The physical data for the dam and man-made reservoir for the pre-feasibility power plant were portrayed in the Table 3.12.

Table 3.12: Dangur Hydropower plant Physical data (Source: Halcrow-GIRD, 2010)

Power plant	Installed capacity (MW)	Gross head(m)	Maximum Discharge(m ³ /s)	Energy KWh/m ³	Reservoir Live storage (MCM)
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Dangur	98	120	92	0.294	4640
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3.10.3 Scenario-III: Expansion of Irrigation Activities and Industries

To estimate future water demand in the basin the possible future irrigation development and Industries should be considered. In Beles basin there is considerable potential for irrigation expansion about 200,000 ha. Halcrow-GIRD, (2010) state that Upper Beles has a potential of 84,000 ha, from this 54,000 ha is currently irrigated by Tana-Beles integrated sugar development project. According to Abbay river basin integrated master plan project BCEOM, (1998) in lower Beles there will be 85,000 ha irrigable land.

In case of Industries Some mining (gold and marble) and, agro-processing (sugarcane and oil) industries will be expected in the future. The government promotes agro-processing industries, on the basis that rural production can support and be supported by such industries as tanneries, fish processing and other value-added enterprises. During the scenario period the industries will be increased from one industry at the starting of scenario to twelve industries at the end of scenario in the sub basin. These scenarios consider to irrigate the lower and upper Beles irrigation area under full potential and possible future expansion of Industries in the basin.

The irrigation efficiency reflects the potential of the water user's capacity in securing adequate water supply for optimum growth of the targeted crops. For this study took experience of two countries, Egypt from Africa region and China from Asian countries as bench marking for Irrigation efficiency improvement rate. Egypt planned to change the overall country irrigation efficiency from 50-55 % to 80% in 2030. Similarly, th 13th five-year china's plan (2016-2020) stated to increase average irrigation water use efficiency which is about 45% at present to 55% and 60% by 2020 and 2030 respectively. According to GIRDC, (2020) overall change of irrigation efficiency of for the next three consecutive decades to be incremental as 49.3%, 57.3%, and 67.3% for 2025, 2035, and 2040 years respectively by increasing 5% to 10% of efficiency per decade. For this study depending on this increment the Irrigation efficiency is extending up to the year 2060.

Table 3.13: Lower and Upper Beles Irrigation

Irrigation	2020	2030	2040	2050	2060
Lower Beles (ha)	0	30000	50000	75000	85000
Upper Beles (ha)	54000	65000	75000	84000	84000
Efficiency (%)	44	50	55	65	75
Annual CWR (M ³ /ha)	15538.18	13871.52	12604.03	10663.49	9281.09

3.10.4 Scenario-IV: Combination of Scenario-I, Scenario-II, and Scenario-III

In this scenario, the combination of High population growth, Dangur Hydropower, and Expansion of Irrigation activities with increased irrigation efficiency and Industries simultaneously are analyzed. So, this scenario answer what will be future water demand in Beles basin if the human and livestock population growth as well as all possible developments like Irrigation and Industries were applied in the water resources of Beles basin at the same time.

4 RESULTS AND DISCUSSIONS

4.1 WEAP Model Performance Evaluation

4.1.1 Model Parameters

The calibration of WEAP model is important to know the parameters which significantly change the model performance. WEAP has parameter Estimation Tool to adjust the parameters by comparing the observed flow data to simulate the model. Parameters with high sensitivity alter the model result significantly. The range of parameters used in soil moisture method to overlap the model result with observed streamflow is listed below.

Table 4.1: Range of sensitive parameters

Parameter	Range	Unit
Soil water capacity	≥ 0	mm
Deepwater capacity	≥ 0	mm
Runoff resistance factor	0-1000	
Deep conductivity	≥ 0.1	mm/month
Preferred flow direction	0-1	

4.1.2 WEAP Model Calibration Result

Calibration is a process of adjusting some parameters of the basin to decide the model result is real. In Beles sub-basin there are two gaging stations Main Beles and Gilgel Beles. The mean monthly streamflow is calibrated by Parameter Estimation Tool in WEAP for ten years from 1995 to 2005 monthly time step for Main Beles and Gilgel Beles stream flow depend on the full record of gage data. The calibration is done by comparing the simulated result of the model and observed streamflow of the basin.

The performance parameters used are R^2 and NSE. Coefficient of determination is considered as best if $R^2 > 0.6$ and the Nash and Sutcliffe coefficient of efficiency is considered as best if $NSE > 0.5$. The relationship between observed and simulated streamflow indicates a high correlation with the coefficient of determination R^2 0.93 and 0.89 for Main Beles and Gilgel Beles respectively and coefficient of efficiency NSE 0.76

and 0.78 for Main Beles and Gilgel Beles respectively. These results show a very good model performance between observed and simulated flow data.

Table 4.2: Calibration result

Parameter	Main Beles	Gilgel Beles
R^2	0.93	0.89
NSE	0.76	0.78

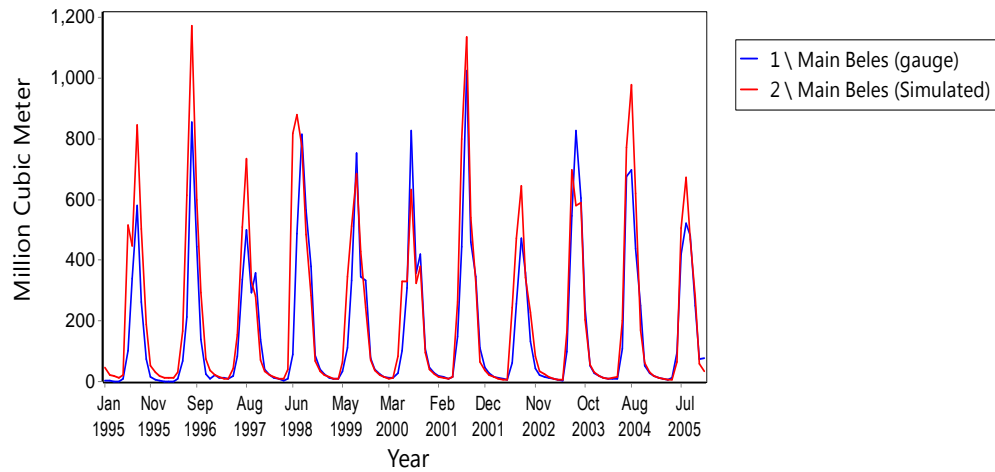


Figure 4.1: Main Beles Calibration

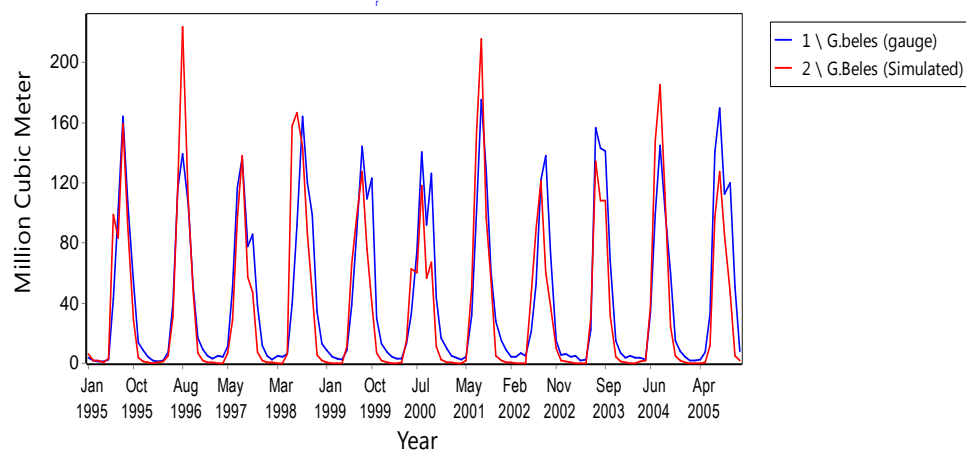


Figure 4.2: Gilgel Beles calibration

4.1.3 WEAP Model Validation Result

The calibrated model is validated when the model is run out of the calibrated time. The parameters used in the calibration process are used to validate the model for the selected validation time range of the data. The range of the validation data for Main Beles and Gilgel Beles is from the period 2006 to 2011 with a monthly time step. Coefficient of determination is considered best if $R^2 > 0.6$ and the Nash and Sutcliffe coefficient of efficiency is considered best if $NSE > 0.5$. The relationship between observed and simulated streamflow indicates a high correlation with the coefficient of determination R^2 0.95 and 0.94 for Main Beles and Gilgel Beles respectively and coefficient of efficiency NSE 0.86 and 0.72 for Main Beles and Gilgel Beles respectively. These results show a very good model performance between observed and simulated flow data.

Table 4.3: Validation result

Parameter	Main Beles	Gilgel Beles
R^2	0.95	0.94
NSE	0.86	0.72

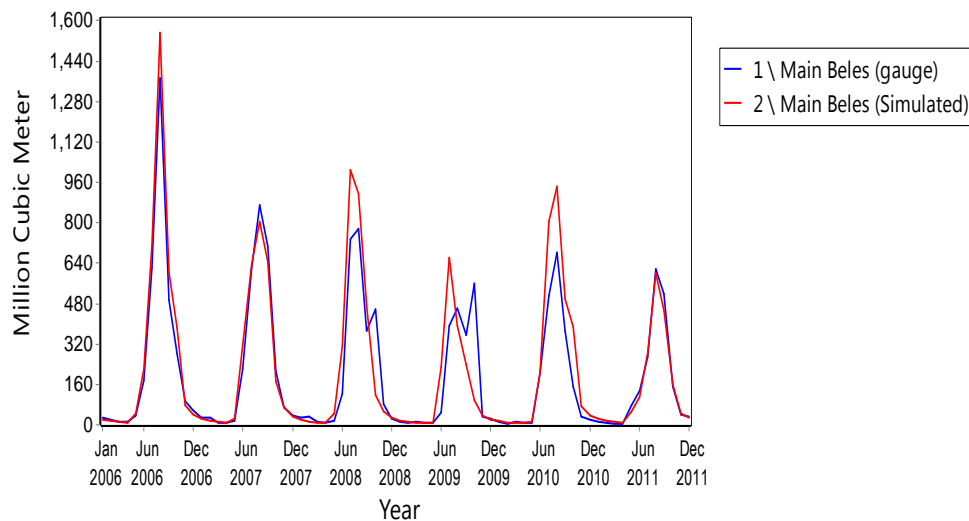


Figure 4.3: Main Beles Validation

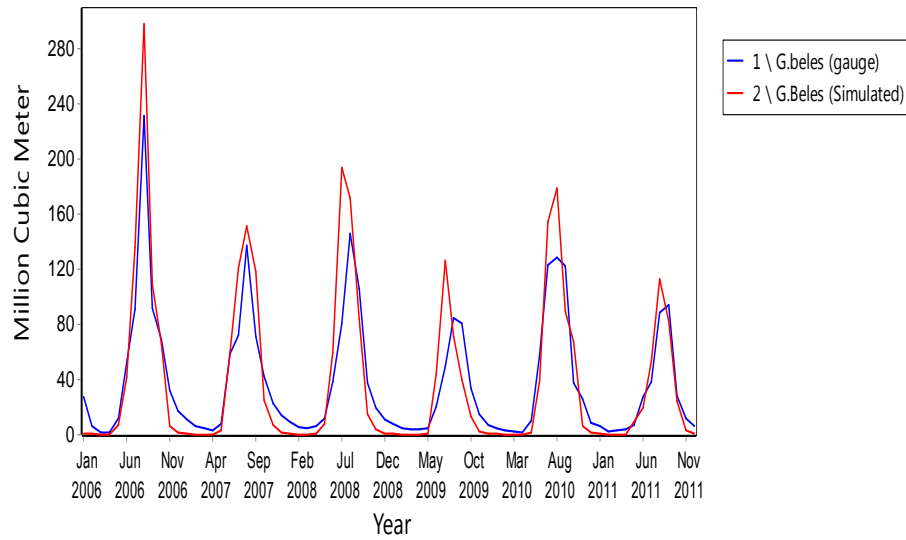


Figure 4.4: Gilgel Beles Validation

4.2 Catchment Simulation

After calibrating and validating gauged streamflow for Gilgel Beles and Main Beles, and checking the performance evaluation parameters like the coefficient of determination R^2 and Nash and Sutcliffe coefficient of efficiency (NSE) the following result is obtained. The catchment simulation of WEAP model shows that the surface runoff generated from the whole catchment in Beles basin is 5858.60 MCM. the estimated mean annual actual evapotranspiration is 10017.13 MCM, the estimated mean annual precipitation is 17525.33 MCM, mean annual interflow is 962.37 MCM, mean annual Base flow is 480.82 MCM, and mean annual flow to groundwater is 206.40 MCM. The maximum and minimum surface runoff was occurred in August and January respectively. From the total estimated precipitation 33.35% was converted to surface runoff.

The surface runoff result shows that slightly increment (2.9%) from the previous study. According to The World Bank, (2008) the surface runoff generated from the Beles catchment estimated to be 5690 MCM per year. The reason is due to the variation of rainfall. For the years 2013 and 2017, there is an increased rainfall trend in upper Beles catchment. The other reason behind the variation in land-use change from time to time and method of estimation.

Table 4.4: Surface runoff, interflow and baseflow from Beles Basin

Month	Surface runoff (MCM)	Interflow (MCM)	Base flow (MCM)
Jan	0.50	14.11	37.50
Feb	0.54	5.91	27.65
Mar	4.34	3.48	20.96
Apr	17.71	5.61	16.62
May	117.36	27.72	14.82
Jun	493.39	90.52	18.58
Jul	1331.26	161.18	32.39
Aug	1971.30	195.48	52.78
Sep	1215.22	187.68	68.75
Oct	618.66	149.81	73.28
Nov	87.02	85.32	66.37
Dec	1.30	35.55	51.13

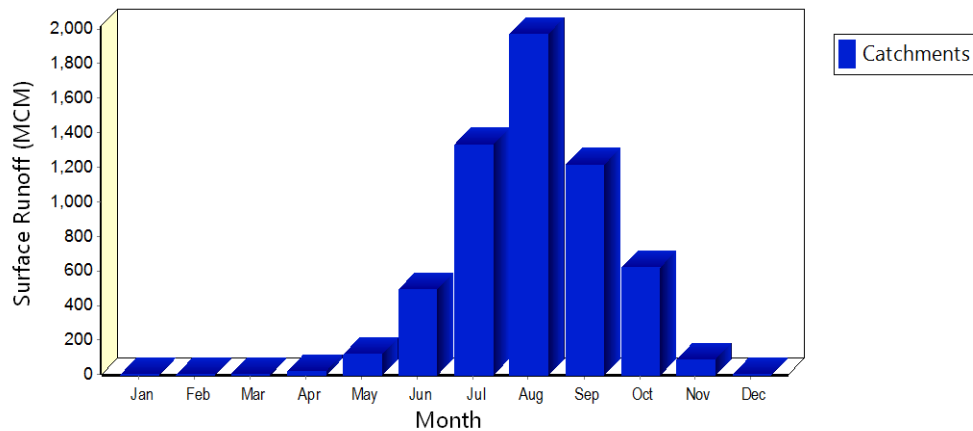


Figure 4.5: Monthly Beles basin surface runoff

4.3 Water Resources Availability

Planning and allocation of water resources to different users in the basin is one of the basic activities to fill the gaps in water use. The water use and allocation are based on the procedures to determine water requirements and allocation for Domestic, Livestock, Industries and irrigation. To estimate river flow at Beles basin 24 years of meteorological

data and groundwater recharges based on a monthly basis were used. The flow release from the Tana-Beles hydropower scheme is used as a head flow for Beles river. The simulation result of mean annual river flow from Beles basin at outlet point including the Tana-Beles hydropower diversion scheme is **10.03 BCM**. This result accounts for about 18.30% of the total estimated mean annual flow from Abbay basin which is 54.8 BMC (Awulachew et al., 2007). The basin has maximum and minimum flow volume of 2.43 BCM in August and 0.26 BCM in February.

Table 4.5: Average monthly flow at Beles-Abay confluence (BCM)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
River flow	0.31	0.26	0.28	0.28	0.40	0.81	1.73	2.43	1.67	1.06	0.47	0.34

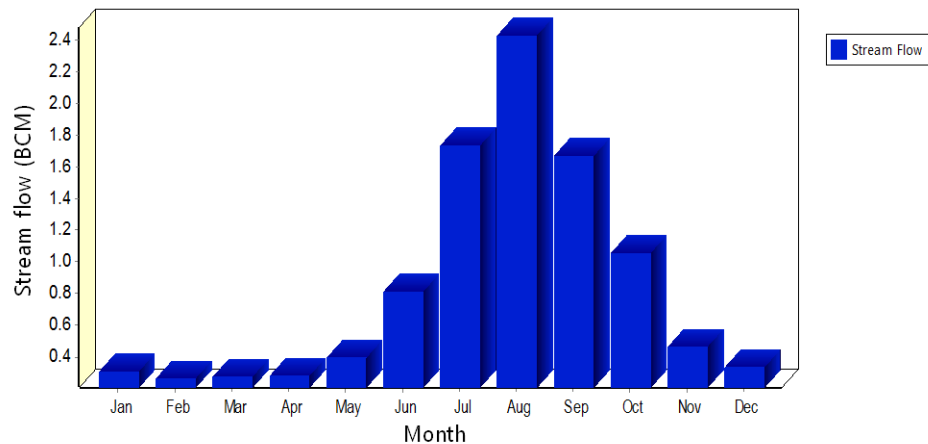


Figure 4.6: Monthly Beles river streamflow

Table 4.6: Annual streamflow from important reaches

S.No	Reach	Streamflow (BCM)
1	Bullen	1.71
2	Dangur	1.27
3	Gilgel Beles	0.53
4	Guba	0.88
5	Johana	0.52

6	Main Beles	2.67
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4.4 Water Demand Assessment

WEAP model uses annual activity levels and annual water use rates to model the water demand in the basin. The water demand in the basin receives water from the simulated streamflow from Beles basin. For this study there are four demand consumptives' users, Domestic water demand, Industrial water demand, Livestock water demand, and Irrigation water demand in the basin were modeled. WEAP model was set up for demand assessment in Beles basin to simulate the Base year (current account year) 2019. Base year account comprises current hydrological, environmental, and socio-economic conditions against which future developments can be compared in the Basin. This has been agreed based on the hydrological situation of (1995-2018), and the environmental and socio-economic situation of the year 2019. Four subsequent scenarios, the high population growth, Dangur Hydropower, the Expansion of Irrigation activities and Industries, and combination of the three scenarios are analyzed. Under each scenario, the projected water demand was computed and the demand coverage and unmet demands were analyzed. The required demands are allocated in their priority order. Priority order for the specified demand sites is portrayed in the table below.

Table 4.7: Demand priorities for different water use sectors

Demand	Priority
Domestic	1
Livestock	2
Environmental flow requirement	3
Industrial	4
Irrigation	5

4.4.1 Base Year Water Demand

The Base year account represents a description of the water system currently exist. The base year used to start a scenario by feeding the currently available data and it as a base for determining future water demand by developing scenarios.

4.4.1.1 Domestic water demand

Domestic water demand is a demand used for household purposes at home for every person which includes drinking, washing clothes, preparing food, flushing toilets, etc. Supply delivered to the domestic demand site depends on the available water resource in the basin and the demand required to meet each demand site. When the available water resource is sufficient to cover all demand sites there is no unmet demand. Based on water allocation and demand priority the demand coverage of domestic water demand showed 100% and there is no unmet demand for all domestic water demand sites. The total domestic water demand for the projected total population in the study period in Beles basin was 8.77 MCM per year. Monthly Domestic water demand in the basin was portrayed in the Table below.

Table 4.8: Monthly domestic water demand, demand coverage, and unmet demand

Month	Demand (MCM)	Demand coverage (%)	Unmet Demand (CM)
Jan	0.74	100	0
Feb	0.67	100	0
Mar	0.74	100	0
Apr	0.72	100	0
May	0.74	100	0
Jun	0.72	100	0
Jul	0.74	100	0
Aug	0.74	100	0
Sep	0.72	100	0
Oct	0.74	100	0
Nov	0.72	100	0
Dec	0.74	100	0
Total	8.77		0

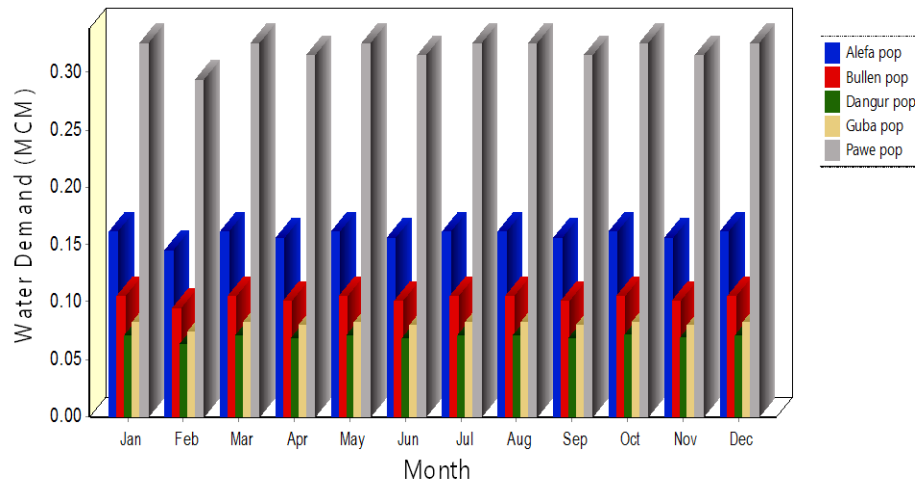


Figure 4.7: Monthly Domestic water demand

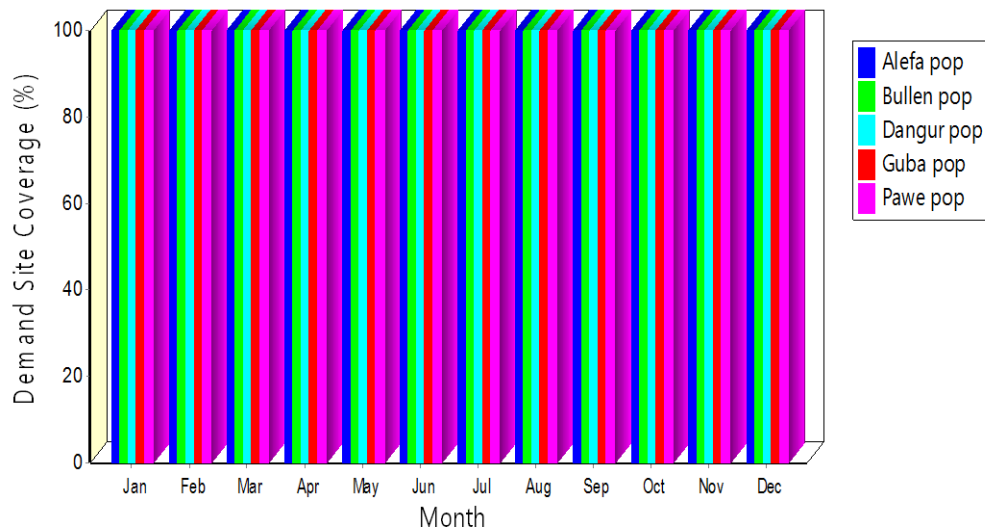


Figure 4.8: Monthly demand coverage

4.4.1.2 Industrial Water Demand

The Tana-Beles growth corridor is selected as first growth corridor by Ethiopian government. Thus, in Beles sub basin different projects are undertaking and will be take place. The presence of this projects leads to the establishment of different industries in the sub basin. The current industrial water demand in the basin is 12.9 MCM per year.

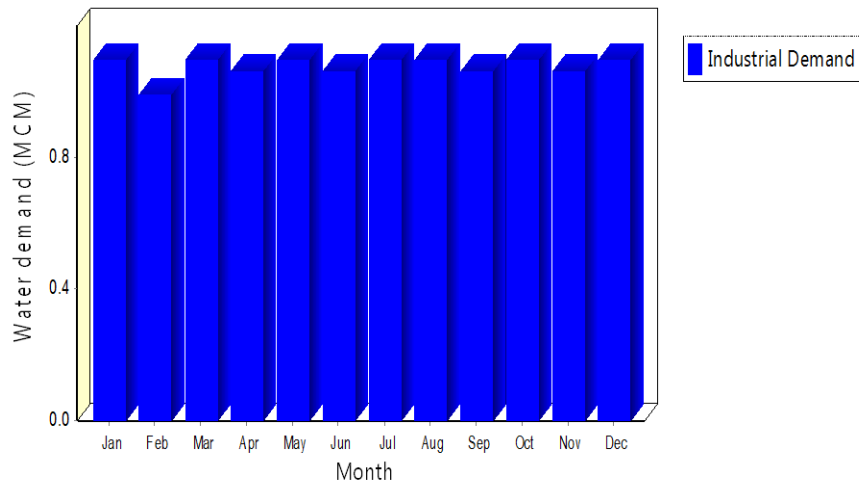


Figure 4.9: Monthly Industrial water demand

4.4.1.3 Livestock water demand

In Beles basin the Livestock developmet is traditional, it needs modern development. The rainfed agriculture in the basin is complement with the livestock sector by drought power, organic agriculture (manure) and also, the farmers supplement their food security gap with additional foods from the livestock sector. Farmers also use livestock to generate additional income for their livelihood. water requirement by livestock is different based on types of animals. Depend on their daily consumption rate the current total annual livestock water demand is 14.65 MCM.

Table 4.9: Annual Livestock water demand

Livestock	Demand (MCM)
Cattle	12.49
Equine	0.87
Goat	0.82
Sheep	0.47
Total	14.65

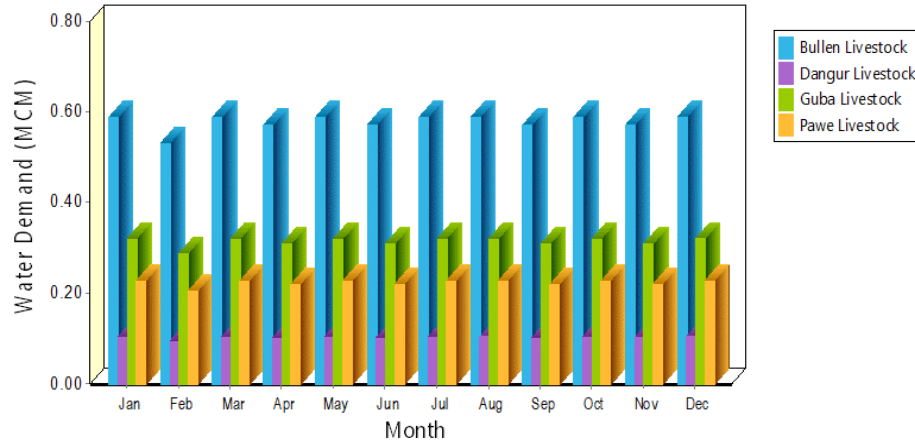


Figure 4.10: Monthly Livestock water demand

4.4.1.4 Irrigation Water Demand

The rural population in Ethiopia accounts for 85% of the total population which depends on agriculture production. To maximize agricultural production for domestic use and to supplement industry lead economy, irrigation is the best option. It assists in rainfed agriculture and alleviates poverty and drought. Beles Basin has huge irrigation potential for vast and mechanized agriculture which contributes to the economic development of the basin in particular and the country as large. Beles basin has a potential of about 160,000 ha land that could be cultivated through large scale irrigation agriculture. This amount does not include the small scale in pocket areas and other medium level irrigation on tributaries of Beles river.

According to the Ministry of Water, Irrigation and Energy of Ethiopia irrigation command area are classified into small-scale, Medium-scale, and Large-scale irrigation, in line with this classification currently in Beles basin, there are four small scales, two Medium-scale, and one large scale irrigation projects. Currently the total irrigable area in the basin is 55000 ha. The total amount of water to meet total annual irrigation water demand for all irrigation site is 844.59 MCM, the result show that 8.44% of the available river flow is used for irrigation. The amount of water supply delivered to each irrigation command area and the water required to meet irrigation are equal. This shows there is no unmet demand and the river flow satisfy all demands. The annual irrigation water demand is portrayed in the table below.

Table 4.10: Annual Irrigation water demand (MCM)

Month	Upper Beles LSI	Dangur MSI	Kuilla MSI	Dura SSI	Kuwil SSI	Tikur wuha SSI	Wila SSI
Jan	142.81	0.13	0.44	0.05	0.11	0.05	0.13
Feb	150.19	0.24	0.61	0.06	0.13	0.06	0.15
Mar	169.24	0.43	0.81	0.06	0.13	0.06	0.15
Apr	142.81	0.35	0.46	0.02	0.04	0.02	0.05
May	28.53	0.08	0.10	0.01	0.00	0.01	0.02
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oct	62.17	0.00	0.01	0.00	0.00	0.00	0.00
Nov	60.16	0.03	0.07	0.00	0.01	0.00	0.01
Dec	83.07	0.09	0.25	0.03	0.06	0.03	0.07
Sum	838.98	1.35	2.74	0.24	0.48	0.24	0.58

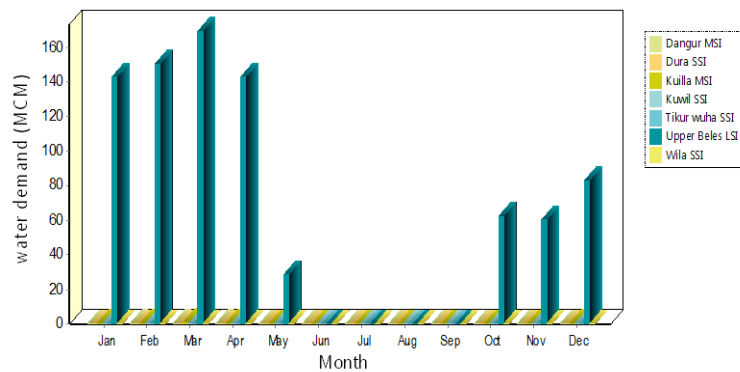


Figure 4.11: Monthly irrigation water demand

Current water demand in the basin such as Domestic water demand, Industrial water demand. Livestock water demand, and Irrigation water demand which comprises current hydrological, environmental, and socio-economic conditions in the Basin are summarized in the table below.

Table 4.11: Current water demand

Water user	Demand (MCM)
Domestic	8.77
Industrial	12.90
Livestock	14.65
Irrigation	844.59
Total	880.91

The current total water demand for the above four water users, Domestic, Industrial, Livestock, and irrigation are 880.91 MCM. The result indicates irrigation consume a high amount of water compare to Domestic, Industrial and Livestock in the basin. For the current (base) year there is no unmet demand for all water users. The basin water resource fully satisfies the demand requirements. The total current withdrawal of water by the four water users is around 8.78% of the available water resource in the basin.

Table 4.12: Base year total water demand, unmet demand and demand coverage

Month	Demand (MCM)	Unmet Demand (CM)	Demand Coverage (%)
Jan	146.80	0.00	100
Feb	154.23	0.00	100
Mar	173.97	0.00	100
Apr	146.74	0.00	100
May	31.83	0.00	100
Jun	2.99	0.00	100
Jul	3.08	0.00	100
Aug	3.08	0.00	100
Sep	2.99	0.00	100
Oct	65.27	0.00	100
Nov	63.27	0.00	100
Dec	86.66	0.00	100
Sum	880.91	0.00	

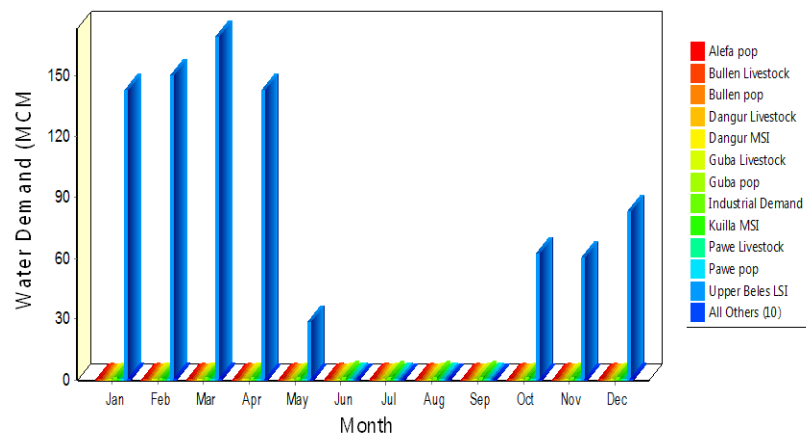


Figure 4.12: Base year monthly water demand

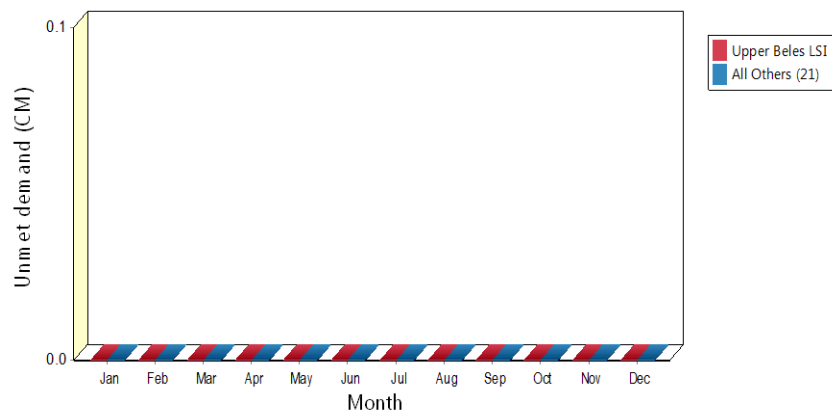


Figure 4.13: Base year unmet demand

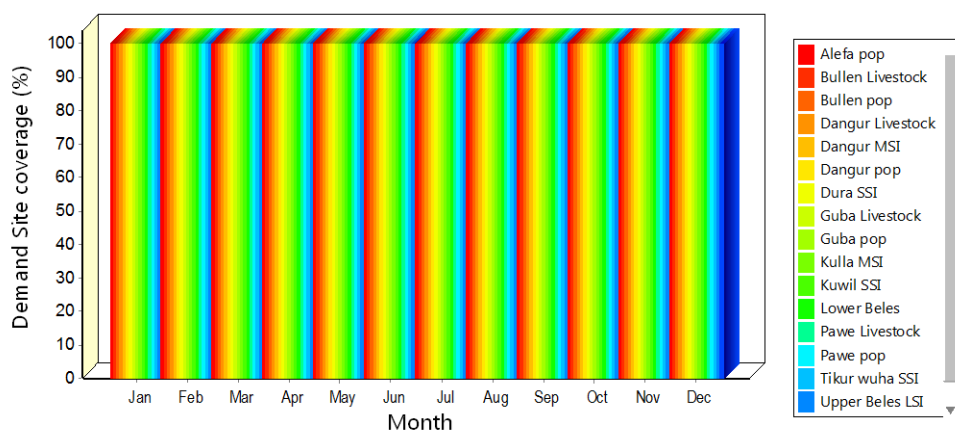


Figure 4.14: Base year demand coverage

4.4.2 Environmental Water Demand

Environmental Flow Requirement is used to keep the natural ecosystem and for downstream water users in the basin. Environmental Flow Requirement is one of the different types of water demand that need to allocate to reserve water for basic human need and ecosystem sustainability. Its allocation is the first priority before other water demands are allocated and satisfied in the basin. In Beles Basin 20% of mean annual river flow is taken for Environmental Flow Requirement. The 20% mean annual river flow of Environmental Flow Requirement is used for navigation, wildlife, and in the downstream there is Grand Ethiopian Renaissance dam. At the outlet point of Beles river, 2.01 BCM of water is needed for the Environmental flow requirement.

Table 4.13: Environmental flow Requirement at selected reach

Reach	Demand (BCM)
@Tana-Beles Transfer	0.64
@Main Beles	0.53
@Gilgel Beles	0.09
@Dangur	1.53
@Beles outlet	2.01

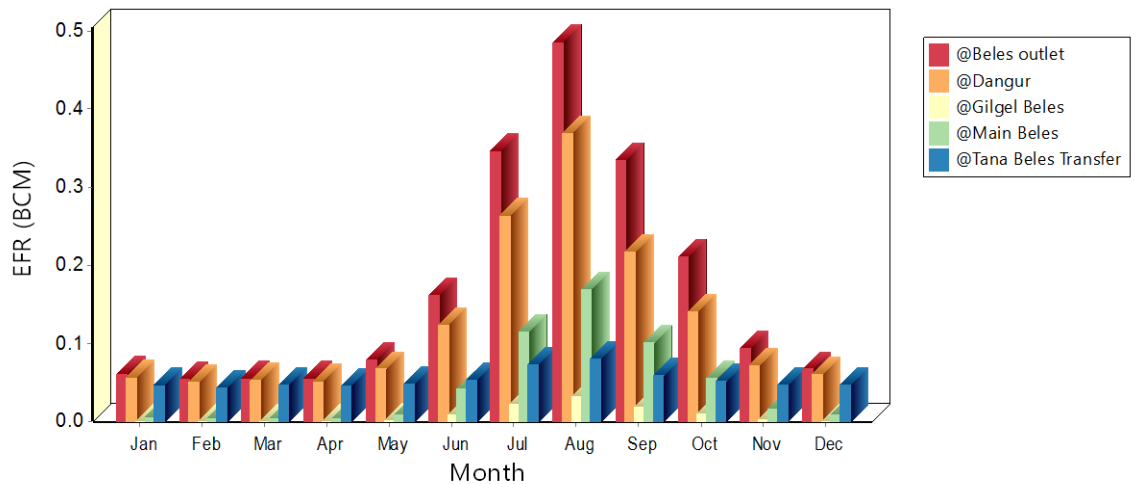


Figure 4.15: Environmental Flow Requirement

4.4.3 Future Water Demand

Future water demand is determined based on four basic scenarios. The first scenario is high population growth in both human and Livestock. The second scenario determines the power generated at Dangur by constructing a dam. The third scenario explains what will be the future water demand when the Expansion of Irrigation activities and Industries will be applied in the basin. The fourth scenario discuss the combination of the High population, Dangur Hydropower and the Expansion of Irrigation activities in Lower and Upper Beles and Industries in Beles basin. The above scenarios are discussed individually one by one as below.

4.4.3.1 Scenario-I: High population Growth

Scenarios are self-consistent story lines of how a future system might evolve in a particular socio-economic setting and under a particular set of policy and technology conditions (Sieber and Purkey, 2015). However, in this scenario there is no policy or technology change is applied. Annual population growth rate of 3% for humans and 2.5% for Livestock and increasing daily per capita per person is added. Irrigation and Industrial water demands are constant under this scenario. The total water demand under this scenario for the year 2060 is 967.30 MCM.

Water resource in the basin implies that the number of human population and livestock population is increasing, the volume of water required for humans and livestock is increasing. From the reference scenario, the total water demand by Domestic, Industrial, livestock, and irrigation for the year 2019 is 880.91 MCM. comparing this result with a high population growth scenario for the year 2060 the demand increases by 86.39 MCM. considering the water resource of the Beles basin there is no unmet demand for high population growth scenario and the demand coverage is 100% for all demand sites.

Table 4.14: Total annual water demand under scenario-I

Year	2020	2030	2040	2050	2060
Demand (MCM)	881.54	893.13	909.64	933.35	967.30
Unmet Demand (MCM)	0.00	0.00	0.00	0.00	0.00

Table 4.15: Demand covergae under scenario-I

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand Coverage (%)	100	100	100	100	100	100	100	100	100	100	100	100

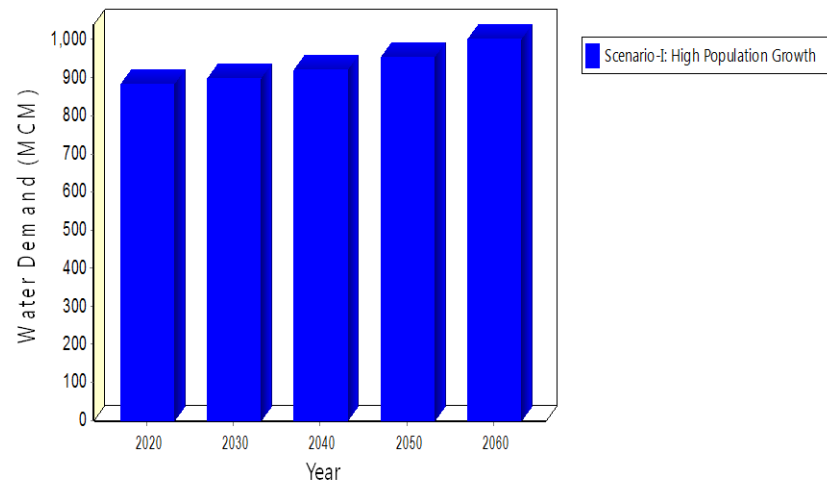


Figure 4.16: Total water demand under Scenario-I

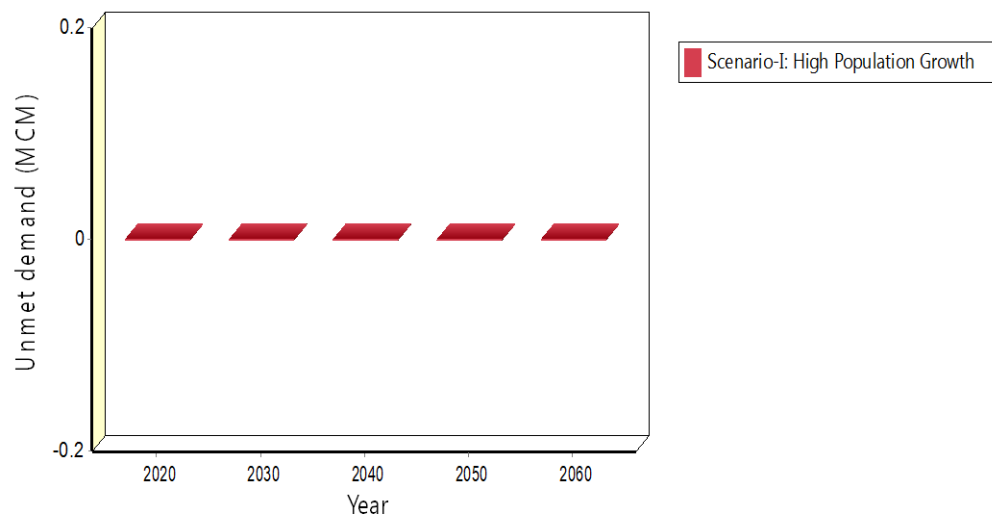


Figure 4.17: Unmet water demand under Scenario-I

4.4.3.2 Scenario-II: Dangur Hydropower

Construction of Dam at Dangur is used to store water in the rainy season to use in dry season for hydropower. In this scenario, the reservoir water is used only for hydropower. Dangur hydropower has a total installed capacity of 98 MW power. To generate such amount of power a total capacity of 4640 MCM reservoir is needed. The total annual water demand under this scenario to generate 98 MW power is 1762 MCM. There is no unmet demand and the demand coverage is 100%.

Table 4.16: Dangur Hydropower Water Demand and Unmet Demand

Year	2020	2030	2040	2050	2060
Demand (BCM)	0.00	1.76	1.76	1.76	1.76
Unmet Demand (BCM)	0.00	0.00	0.00	0.00	0.00

Table 4.17: Dangur Hydropower demand coverage

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand coverage	100	100	100	100	100	100	100	100	100	100	100	100

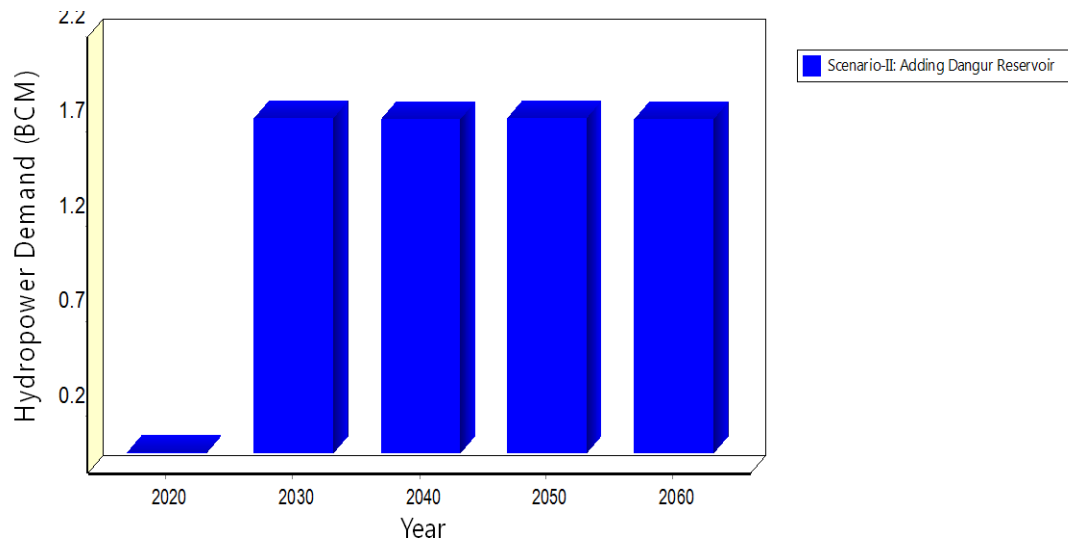


Figure 4.18: Dangur Hydropower Demand

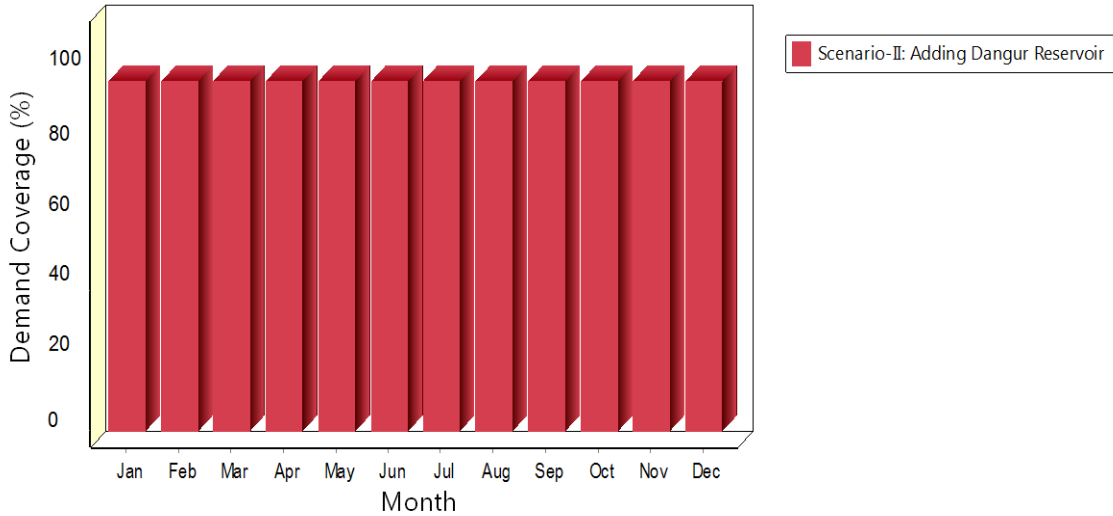


Figure 4.19: Dangur Hydropower Demand coverage

4.4.3.3 Scenario-III: Expansion of irrigation Activities and Industries

Beles Basin is one of the highly considerable potentials for irrigation and industries. Currently, only upper Beles is developed by irrigation around 54,000 ha, but the Lower Beles is still not potentially irrigated. BCEOM, (1998) identified 85,000 ha irrigable land in Lower Beles in its full potential. (Halcrow-GIRD, 2010) state Irrigation and drainage feasibility report for Tana Beles integrated sugar development project with a maximum command area of 84000 ha in upper Beles for sugar factory.

This scenario considers full irrigation development by maximizing irrigation efficiency and industries in Beles basin up to 2060. The total water demand in the Expansion of irrigation activities and Industries scenario for the year 2060 is 1.75 BCM. The supply delivered to the demand sites is less than the supply requirement of all demands, there is a water deficit to perform future irrigation development under full potential. The unmet demand occurs in Lower Beles and Upper Beles, irrigation because both of them have equal priority order. Domestic, industries and Environmental demands have higher priority than Irrigation water demand. Irrigation water demand has the priority of two as mentioned above. The unmet demand is increased substantially from 2030 up to 2050 then it decreased to the last scenario year of 2060. This is due to increased irrigation efficiency the water demand will be decreased. Unmet demand occurs from January up to April for Lower and Upper Beles Irrigation.

Table 4.18: Total water demand and unmet demand under scenario-III

Year	2020	2030	2040	2050	2060
Demand (BCM)	0.90	1.40	1.68	1.83	1.75
Unmet Demand (BCM)	0.00	0.09	0.26	0.37	0.28

Table 4.19: Demand coverage for scenario-III

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Domestic	100	100	100	100	100	100	100	100	100	100	100	100
Livestock	100	100	100	100	100	100	100	100	100	100	100	100
Industrial	100	100	100	100	100	100	100	100	100	100	100	100
Lower Beles	90.98	79.78	74.89	85.67	100	100	100	100	100	100	100	100
Upper Beles	90.98	79.78	74.89	85.67	100	100	100	100	100	100	100	100
Other Irrig	100	100	100	100	100	100	100	100	100	100	100	100

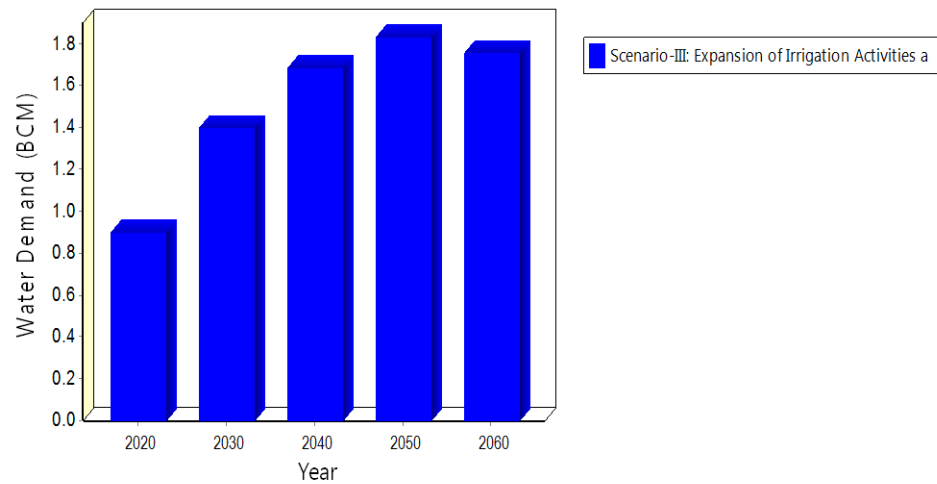


Figure 4.20: Water demand under scenario-III

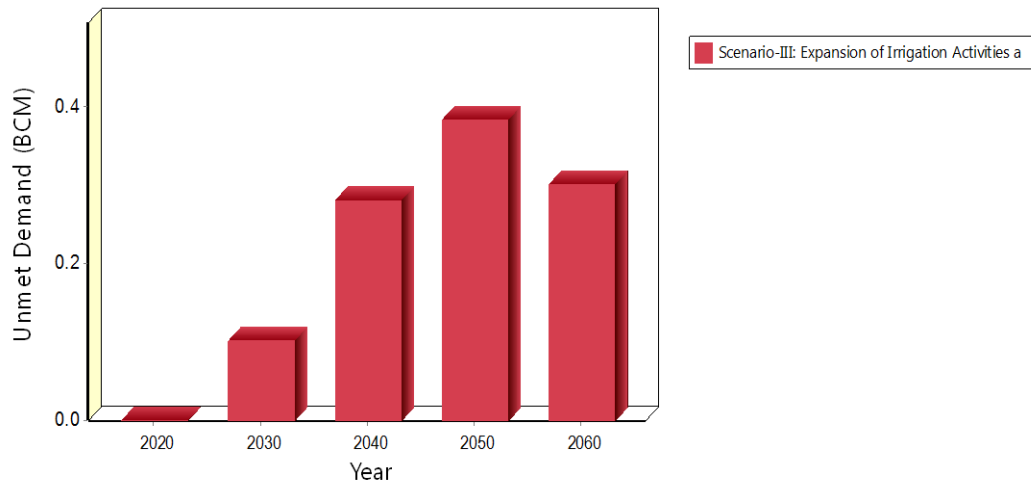


Figure 4.21: Unmet water demand under Scenario-III

4.4.3.4 Scenario-IV: Combination of All Scenarios

This scenario analyses what will be future water demand looks like when a high population growth rate, Dangur Hydropower and Expansion of irrigation Activities and Industries were applied at the same time in the water resource of Beles basin. In scenario-I, the water demand is fully satisfied. Scenario-II is applied only to generate hydropower at Dangur. Hydropower is non-consumptive demand user, after generating power it releases water to downstream. but in Scenario-III the water demand is not fully satisfied with the required demand. Due to the combination of the three scenarios future water demand in 2060 become 1.84 BCM and there is no unmet demand. This shows that the high population has not much effect on the water resource of Beles basin, while in the Expansion of Irrigation activities and Industries supply delivered to demand site and supply requirement for demand sites are not equal, especially Lower Beles Irrigation and Upper Beles Irrigation demand sites. After constructing a dam at Dangur and generating power, Lower Beles and Upper Belers will be fully irrigated with a command area of 85000 ha and 84000 ha respectively in 2060. For the combination of all scenarios the water resource of beles is fully satisfy all demand sites in the basin. But Upper Beles irrigation depends on the operation rule of the Tana-Beles hydropower plant because it gains water from the Tana-Beles hydropower release.

Table 4.20: Total water demand for scenario-IV

Year	2020	2030	2040	2050	2060
Demand (BCM)	0.90	1.41	1.71	1.88	1.84
Unmet Demand (BCM)	0.00	0.00	0.00	0.00	0.00

Table 4.21: Demand coverage for scenario-IV

Demand site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Domestic	100	100	100	100	100	100	100	100	100	100	100	100
Livestock	100	100	100	100	100	100	100	100	100	100	100	100
Industrial	100	100	100	100	100	100	100	100	100	100	100	100
Lower Beles Irrig	100	100	100	100	100	100	100	100	100	100	100	100
Upper Beles Irrig	100	100	100	100	100	100	100	100	100	100	100	100
Other Irrig	100	100	100	100	100	100	100	100	100	100	100	100

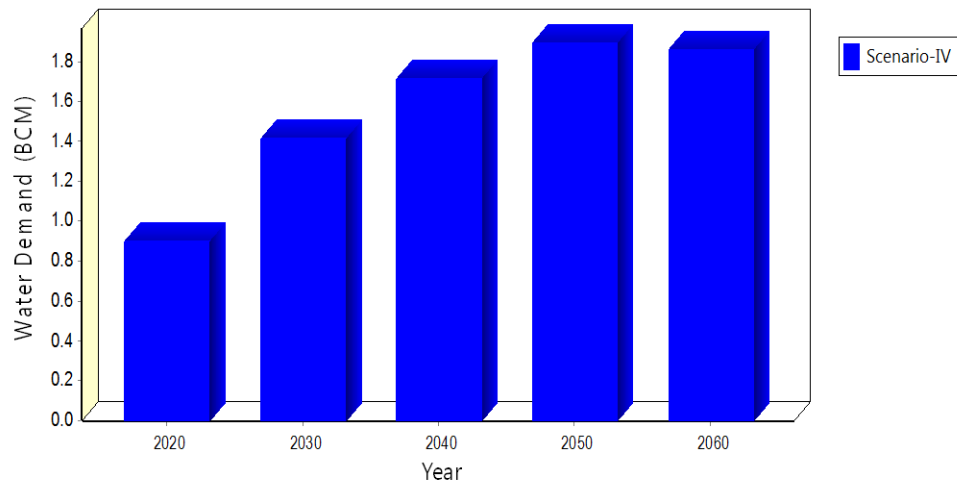


Figure 4.22: Total water demand under scenario-IV

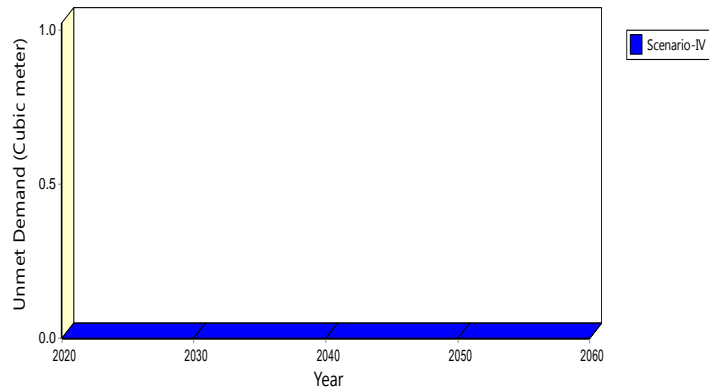


Figure 4.23: Unmet water demand under scenario-IV

To summarize the above four scenarios, the water demand and unmet demand was portrayed in the below.

Table 4.22: Water demand and unmet demand for all scenarios (BCM)

Year	Scenario-I		Scenario-II		Scenario-III		Scenario-IV	
	Demand	Unmet Demand	Demand	Unmet Demand	Demand	Unmet Demand	Demand	Unmet Demand
2020	0.88	0.00	0.00	0.00	0.90	0.00	0.9	0.00
2030	0.89	0.00	1.76	0.00	1.40	0.09	1.41	0.00
2040	0.91	0.00	1.76	0.00	1.68	0.26	1.71	0.00
2050	0.93	0.00	1.76	0.00	1.83	0.37	1.88	0.00
2060	0.97	0.00	1.76	0.00	1.75	0.28	1.84	0.00

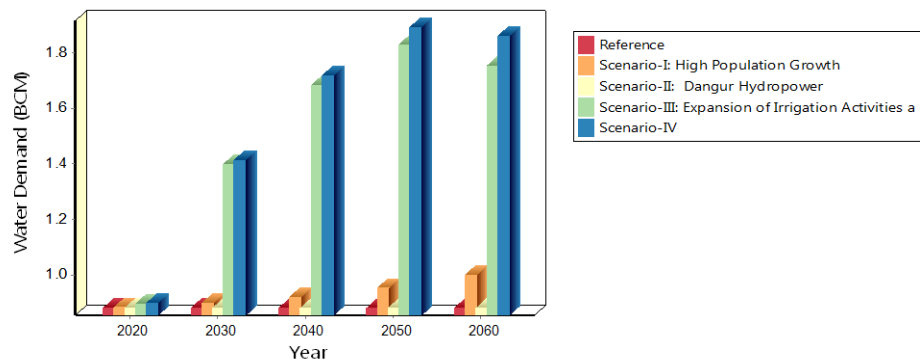


Figure 4.24: Water demand for all scenarios

The result show that the water demand is increased from scenario-I to Scenario-IV. The water demand in Scenario-I and scenario-II is minimum compared to Scenario-III and Scenario-IV, because Expansion of Irrigation and Industries are considered in Scenario-III and Scenario-IV. In Scenario-I, Scenario-II and Scenario-IV there is no unmet demand, but for Scenario-III the water demand is not fully satisfied due to that unmet demand is occurred. Finally, to use the water resource of Beles sub basin efficiently, equitably and sustainably scenario-IV is the best scenario from the other scenarios.

4.5 Effect of Different Developments on Beles River

Beles basin has the highest potential for the development of hydropower and irrigation. The Development of the Tana-Beles multipurpose hydropower project changes the hydrological and morphological regime of Beles river. The Tana-Beles hydropower is possible to divert about 3,500 MCM per year to Beles river. Adding such amount of water in the basin the Beles river flow is increased 2.2 times the previous flow in lower Beles and 2.6 times the previous flow in upper Beles. When the power plant operates at its capacity level it releases 160 m³/s to Beles river, this maximum release affects the river by flooding, sedimentation, and erosion. After meeting the diverted flow and Main Beles flow maximum flow is occurring in August. This flow significantly affects the river by changing the hydraulic property of the river, ecology, and soil types.

When Irrigation developments are fully implemented in Upper and Lower Beles, the available river flow is decreased and the river changes from perennial river to seasonal river from January to April. Constricting Dam at Dangur changes the biodiversity around the reservoir and the river downstream of the dam. Generally, the developments have a negative and positive effects. The negative effects should be handling by mitigation measures to minimize the effect.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study, the Water Evaluation and Planning (WEAP) model was applied to assess water supply and the current and future water demand. Assessment of Future water demand was made based on four scenarios namely Scenario-I: high population growth, Scenario-II: Dangur hydropower, Scenario-III: Expansion of irrigation activities and Industries in Beles basin, and Scenario-IV: combination of scenario-I, scenario-II and scenario-III Simultaneously. The catchment simulation was simulated using the Soil moisture method that requires land use and climate data. WEAP was calibrated and validated based on observed and simulated streamflow data of Main Beles and Gilgel Beles stations. The performance evaluation coefficients result shows a very good model performance between observed and simulated flow that used to simulate the catchment. After simulating the model, the total annual streamflow of Beles basin at the confluence of the Abbay river was 10.03 BCM.

The water demand analysis result shows that the current water demand for Domestic, Livestock, Industries and Irrigation was 880.91 MCM. This shows that the current utilization of the water resources was very limited around 8.78% of the total available river flow. To predict future water demand under existing and planned water resources development fully implemented for the year 2060 four scenarios were conducted. Comparing Scenario-I and Scenario-II with Base year water demand it has not much effect on the water demand. Under Scenario-III, Expansion of Irrigation activities and Industries are applied, the water shortage will happen for both Lower Beles and Upper Beles irrigation. In Scenario-IV, all demand sites are fully satisfied and the demand coverage is 100%. Upper Beles irrigation is depend on the operation of the Tana-Beles Multipurpose hydropower plant scheme.

After applying all scenarios, the total water demand in the basin becomes 1.84 BCM for the year 2060, this shows 18.35% of the total available river flow. Finally, the surplus water can be delivered to the Grand Ethiopian Renaissance Dam after meeting all developments in Beles basin.

5.2 Recommendations

From the results obtained the following recommendations are derived.

- ❖ The accuracy of the model is highly dependent on the quality of input data. Hence, more detailed measurement data and more principal meteorological stations should be established in Beles basin for future catchment simulation.
- ❖ The Beles river is gaged only at two points. Main Beles at bridge and Gilgel beles near to mandura which covers 30% of the total area while the rest of the catchment area of the basin is not gaged. Additional flow gaging stations are required to correctly measure the river flow especially at the outlet of Beles river.
- ❖ Irrigation system in this area is furrow/surface irrigation which demands high amount of water. So, I suggest to high efficiency of irrigation systems like drip, sprinkler irrigation system which leads to increase irrigation area coverage and reduce the probability of water loss through evaporation.
- ❖ Even if all scenarios are implemented the total water demand in the basin is small relative to the available river flow. This shows the basin can be possible to bring different development activities like industries, irrigation, and livestock production for the future.

References

- AbbayBasin Authority. 2016. *The Federal Democratic Republic of Ethiopia Abbay Basin Authority*.
- Abebe, Tesfaye. 2015. "Eastern Nile River Basin Simulation with Grand Ethiopian Renaissance Dam / GERD."
- Abshiro, Fikadu Kinfu. 2016. "EVALUATION OF SPRINKLER IRRIGATION SYSTEM AT BELES."
- Adgolign, Tena Bekele, G V R Srinivasa Rao, and Yerramsetty Abbulu. 2016. "WEAP Modeling of Surface Water Resources Allocation in Didessa." *Sustainable Water Resources Management* 2(1): 55–70.
- Ahmad, Imran, and Mithas Ahmad Dar. 2019. "Groundwater Development Using Geographic Information System." 2.
- Alkasim, Muhammed. 2016. "Assessment and Evaluation of Surface Water Potential and Demands in Baro-Akobo River Basin , Ethiopia ."
- Anandhi, Aavudai, V Srinivas, and D Kumar. 2014. "Water Resources Assessment in a River Basin Using AVSWAT Model." *Handbook of Engineering Hydrology* (July): 501–18.
- Arranz, Roberto, and Matthew McCartney. 2007. International Water Management Institute *Application of the Water Evaluation And Planning (WEAP) Model to Assess Future Water Demands and Resources in the Olifants Catchment, South Africa*.
- Asmamaw, Desale Kidane. 2015. "A Critical Review of Integrated River Basin Management in the Upper Blue Nile River Basin: The Case of Ethiopia." 5124(September).
- Awulachew, Seleshi Bekele et al. 2007. *Assessment of Design Practices and Performance of Small Scale Irrigation Structures in South Region*.

- Ayele, Abebe Seyoum. 2014. “Application of Water Evaluation and Allocation Planning (WEAP) Model to Assess Future Water Demands and Water Balance of the Caledon River Basin.”
- BCEOM. 1998. *ABBAY RIVER BASIN INTEGRATED DEVELOPMENT MASTER PLAN PROJECT*.
- Bekele, Alemayhu, and Yihunie Lakew. 2014. *Projecting Ethiopian Demographics from 2012–2050 Using the Spectrum Suite of Models*.
- Berhe, F. T., A. M. Melesse, D. Hailu, and Y. Sileshi. 2013. “MODSIM-Based Water Allocation Modeling of Awash River Basin, Ethiopia.” *Catena* 109: 118–28. <http://dx.doi.org/10.1016/j.catena.2013.04.007>.
- BeSBO. 2016. *Abbay River Basin Authority Beles Sub-Basin Integrated Water Resource Development and Management Plan*.
- Chow, Ven Te, David R. Maidment, Larry W. Mays, and G. Larson. 1988. *APPLIED HYDROLOGY*.
- Dinar, Ariel, Mark W. Rosegrant, and Ruth Meinzen-Dick. 2013. “Water Allocation Mechanisms: Principles and Examples.” *Policy Research Working Papers* (July).
- Engdaw, Kindie. 2016. “Surface Water Potential and Demands of Wabishebele Basin in Ethiopia.”
- Getu, Setegn Abate. 2015. “Assessment of Surface Water Potential and Demands in Tekeze River Basin, Northern Ethiopia.”
- GIRDC. 2020. “ASSESSMENT OF NATIONAL WATER USE AND DEMAND FORECAST.”
- GTP-2. 2015. *Growth and Transformation Plan-2 for Water Sector, Addis Ababa, Ethiopia*.
- Halcrow-GIRD. 2010. *Water Balance Modelling of Lake Tana and Operational Rules and Irrigation Development in the Upper Beles Catchment 2010*.
- Hamlat, Abdelkader, Mohamed Errih, and Azeddine Guidoum. 2013. “Simulation of

- Water Resources Management Scenarios in Western Algeria Watersheds Using WEAP Model.” *Arabian Journal of Geosciences* 6(7): 2225–36.
- Hassan, Ahmed Mohamed. 2015. ““Surface Water Availability and Demand Analysis: Implication for Enhancing Water Resource Planning at Shabelle Basin in Southern Somalia.”
- Hu, Zhineng et al. 2016. “Resources , Conservation and Recycling Optimal Allocation of Regional Water Resources : From a Perspective of Equity – Efficiency Tradeoff.” *“Resources, Conservation & Recycling”* 109: 102–13. <http://dx.doi.org/10.1016/j.resconrec.2016.02.001>.
- Hussein, Abdullahi H. 2015. “Incorporating Water Demand Management into a Cooperative Water Allocation Framework.”
- Kamel, Asmaa M, Doaa Amin, and Mohamed M Nour Eldin. 2019. “Updating and Assessment of the Eastern Nile Model in RiverWare for Reservoir Management.” 14(8): 1772–81.
- Krogt, W.N.M. van der, and A. Boccalon. 2013. “River Basin Simulation Model RIBASIM Version 7.00.” : 223.
- Labadie, John W. 2008. “MODSIM : Decision Support System for Integrated River Basin Management.”
- Labadie, John W. 2010. “MODSIM 8 . 1 : River Basin Management Decision Support System.”
- Lambisso, Robel. 2015. “Assessment of Design Practice and Performance of Small Irrigation Structures in South Region, Ethiopia.” : 47–57.
- Leong, W. K., and S. H. Lai. 2017. “Application of Water Evaluation and Planning Model for Integrated Water Resources Management: Case Study of Langat River Basin, Malaysia.” *IOP Conference Series: Materials Science and Engineering* 210(1).
- Li, Hongxia, Yongqiang Zhang, and Xinyao Zhou. 2015. “Predicting Surface Runoff

- from Catchment to Large Region.” *Advances in Meteorology*.
- Luitel, Achyut. 1998. “Water Resources Management for Drinking Water.” *Sanitation and Water for All: Proceedings of the 24th WEDC Conference*: 303–5.
- Mayol, Malual Deng. 2015. “Assessment of Surface Water Resources and Its Allocation: Case Study of Bahr El-Jebel River Sub-Basin, South Sudan.”
- Mc Cartney, Matthew P., Tadesse Alemayehu, Zachary M. Easton, and Seleshi B. Awulachew. 2013. “Simulating Current and Future Water Resources Development in the Blue Nile River Basin.” *The Nile River Basin: Water, Agriculture, Governance and Livelihoods* 9780203128(i): 269–91.
- McCartney, Matthew, Tadesse Alemayehu, Abeyu Shiferaw, and Seleshi Bekele Awulachew. 2010. 2010 IWMI Research Report *Evaluation of Current and Future Water Resources Development in the Lake Tana Basin, Ethiopia*.
- Mccartney, Matthew, and Roberto Arranz. 2009. 7 International Journal of River Basin Management *Evaluation of Water Demand Scenarios for the Olifants River Catchment, South Africa*.
- Meher, Janhabi. 2014. “RAINFALL AND RUNOFF ESTIMATION USING ROURKELA-769008 , INDIA National Institute of Technology Rourkela.”
- Melesse, Assefa M., Yilma Selesh, and Belete Berhanu Kidanewold. 2013. “Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics.” *Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics* (June 2018): 1–718.
- Mounir, Zakari Mahamadou, Chuan Ming Ma, and Issoufou Amadou. 2011. “Application of Water Evaluation and Planning (WEAP): A Model to Assess Future Water Demands in the Niger River (in Niger Republic).” *Modern Applied Science* 5(1): 38–49.
- Mugatsia, Erick Akivaga. 2010. “Simulation and Scenario Analysis of Water Resources Mngement in Perkerra Catchmnet Using WEAP Model.”

- Parwin, Rijwana. 2019. "Water Resource Assessment and Management-A Review." 2(11): 9–12.
- Peden, Don, Vladimir Smakhtin, and David Molden. 2013. 9780203128 The Nile River Basin: Water, Agriculture, Governance and Livelihoods *The Nile River Basin: Water, Agriculture, Governance and Livelihoods*.
- Shahraki, Sardar A, J Shahraki, and Monfared S.A Hashemi. 2018. "An Integrated Fuzzy Multi-Criteria Decision-Making Method Combined with the WEAP Model for Prioritizing Agricultural Development , Case Study : Hirmand Catchment." 6(4): 205–14.
- Sieber, Jack, and David Purkey. 2015. "Water Evaluation and Planing System (WEAP) User Guide,." *Stockholm Environment Instiute (SEI), U.S.Center*.
- Sileshi, Zinash, Azage Tegegne, and Getnet Tekle Tsadik. 2008. "Water Resources for Livestock in Ethiopia : Implications for Research and Development." : 66–79.
- Stockholm Environment Institute. 2016. "WEAP- TUTORIAL Water Evaluation And Planning System." *Weap* (August): 286.
- Surur, Anwar Negash. 2010. "Simulated Impact of Land Use Dynamicson Hydrology During A20 Year-Period of Beles Basin In Ethiopia."
- Tadesse, Fufa. 2016. "Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios (Case Study Downstream of Koka Dam to Metahara)." : 118. [https://www.bertelsmann-stiftung.de/fileadmin/files/BSt/Publikationen/GrauePublikationen/MT_Globalization_Report_2018.pdf%0Ahttp://eprints.lse.ac.uk/43447/1/India_globalisation%2C society and inequalities%28lsero%29.pdf%0Ahttps://www.quora.com/What-is-the](https://www.bertelsmann-stiftung.de/fileadmin/files/BSt/Publikationen/GrauePublikationen/MT_Globalization_Report_2018.pdf%0Ahttp://eprints.lse.ac.uk/43447/1/India_globalisation%2C_society_and_inequalities%28lsero%29.pdf%0Ahttps://www.quora.com/What-is-the).
- Tefera, Ashebir Haile. 2017. "Application of Water Balance Model Simulation for Water Resource Assessment in Upper Blue Nile of North Ethiopia Using Hec-Hms by Gis and Remote Sensing : Case of Beles River Basin." 1(7): 222–27.
- Tesfaw, Bewuketu Abebe. 2016. "The Optimize Operation and Future Development of Multipurpose Tana-Beles Hydropower Project , Ethiopia."

- The World Bank. 2008. *Document of The World Bank for Tana & Beles Integrated Water Resources Development Project*.
- Tibebe, Mahtsente, M Assefa, and Birhanu Zemadim. 2016. “Runoff Estimation and Water Demand Analysis for Holetta River , Awash Subbasin , Ethiopia Using SWAT and CropWat Models.” In , 113–40.
- Triana, Enrique, and John W Labadie. 2007. “GEO-MODSIM : Spacial-Decison Support System for River Basin Management.” 9.
- WHO. 2003. *The Right to Water*.
- Worku, Tesfa, and Sangharsh Kumar Tripathi. 2015. “Watershed Management in Highlands of Ethiopia : A Review.” : 1–11.
- Worqlul, Abeyou W et al. 2015. “Catena Assessment of Surface Water Irrigation Potential in the Ethiopian Highlands : The Lake Tana Basin.” *Catena* 129: 76–85. <http://dx.doi.org/10.1016/j.catena.2015.02.020>.
- Yimer, Girma, Andreja Jonoski, and Ann Van Griensven. 2009. “Hydrological Response of a Catchment to Climate Change in the Upper Beles River Basin, Upper Blue Nile, Ethiopia.” 2: 49–59.
- Yu, Yang et al. 2017. “Agricultural Water Allocation Strategies along the Oasis of Tarim River in Northwest China.” *Agricultural Water Management* 187: 24–36. <http://dx.doi.org/10.1016/j.agwat.2017.03.021>.
- Zerkaoui, Laidia, Mohamed Benslimane, and Abderrahmane Hamimed. 2018. “Mebtouh River.” : 771–74.

Appendices

Appendix-1: Hydrological data

A. Main Beles monthly Stream flow (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	1.3	0.7	0.5	0.3	2.9	39.9	127.1	216.6	101.4	27.4	5.5	2.5
1996	1.2	0.6	0.5	0.3	3.3	26.3	79.8	319.7	171.1	51.5	9.4	3.9
1997	7.8	5.6	4.2	3.2	7.1	32.2	126.0	187.1	113.5	133.3	53.7	14.7
1998	7.6	4.7	3.2	1.6	3.6	34.4	182.6	304.6	218.1	141.8	33.4	14.7
1999	8.8	5.3	4.0	3.3	12.7	42.9	124.9	281.6	132.8	124.1	29.8	14.6
2000	9.1	6.1	4.2	4.6	10.8	39.5	115.1	309.0	137.8	156.9	41.6	17.0
2001	10.8	7.8	6.1	3.2	6.2	57.7	166.0	382.1	177.3	129.3	43.3	16.8
2002	10.6	7.0	5.1	3.5	2.4	24.3	95.6	176.5	138.1	49.5	16.7	8.4
2003	5.7	4.5	3.3	1.8	0.8	38.1	203.7	308.6	233.0	90.2	20.0	10.5
2004	6.8	5.2	3.7	3.5	3.9	41.8	252.1	260.0	169.2	93.9	20.0	10.5
2005	6.5	4.5	3.8	2.5	4.3	37.3	156.3	195.1	185.5	93.9	28.5	28.5
2006	11.3	4.5	4.3	2.9	9.1	68.2	123.4	160.5	152.5	73.7	35.8	21.4
2007	11.3	3.1	2.7	3.6	5.4	46.9	124.9	178.5	136.5	80.0	20.8	8.5
2008	4.4	3.0	4.3	3.6	6.0	46.9	124.9	178.5	144.0	170.3	30.9	8.5
2009	5.1	3.3	4.4	3.6	3.0	19.3	146.4	171.7	137.4	209.0	12.7	8.5
2010	5.1	2.5	4.4	3.6	3.0	79.4	157.0	169.8	143.9	57.1	12.7	8.4
2011	5.1	3.1	2.0	1.7	40.6	80.2	157.0	169.8	143.9	57.1	12.7	8.4

B. Gilgel Beles monthly Stream flow (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	1.5	0.9	0.5	0.4	0.9	16.4	38.1	61.4	41.1	20.3	5.3	3.2
1996	1.7	0.6	0.4	0.7	2.8	15.5	43.5	52.0	40.8	19.3	6.6	3.4
1997	1.9	1.3	1.8	1.6	4.3	19.4	43.7	51.0	30.0	32.1	14.8	4.5
1998	1.8	1.2	1.8	1.8	2.3	15.1	34.1	61.3	46.2	36.9	13.2	4.8
1999	3.3	1.8	1.2	0.9	3.3	14.8	31.7	53.9	42.3	45.9	11.4	4.8
2000	2.9	1.8	1.1	1.2	4.8	12.7	28.0	86.2	51.6	47.2	16.7	6.2
2001	3.7	2.1	1.4	1.0	1.6	12.2	37.7	48.5	49.6	22.7	10.8	5.6
2002	3.3	1.9	1.7	2.6	1.8	8.2	19.9	45.5	53.4	27.2	5.7	2.2
2003	2.3	1.9	1.8	0.7	0.9	8.5	72.1	53.5	54.4	25.6	5.7	2.6
2004	1.5	1.9	1.3	1.4	0.9	12.9	37.1	54.1	39.6	22.3	5.8	3.1
2005	1.6	0.8	0.7	1.1	2.7	12.7	52.4	63.4	105.0	44.9	19.7	3.1
2006	10.3	2.5	0.7	0.6	4.5	20.3	33.9	45.8	35.3	25.7	12.5	6.6
2007	4.0	2.5	1.7	1.2	2.9	22.5	27.0	33.1	27.5	15.9	8.9	5.2
2008	3.4	2.3	1.7	2.4	4.3	14.7	30.1	43.6	40.7	13.9	7.6	4.0
2009	2.9	2.1	1.5	1.5	1.8	7.8	18.5	31.7	31.2	12.6	5.7	2.8
2010	1.7	1.3	0.8	0.6	3.9	22.3	46.0	48.0	47.1	14.2	9.9	3.3
2011	2.2	0.9	1.1	1.4	2.8	10.7	14.3	33.1	36.2	10.6	4.6	2.4

Appendix-2: Metrological Data

A. Pawe monthly total rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	0.0	0.0	35.3	14.8	92.7	412.9	233.3	433.6	248.1	91.6	0.0	1.4
1996	0.2	0.0	42.5	57.1	98.8	206.9	370.5	532.7	272.2	144.7	12.3	0.0
1997	0.0	0.0	2.1	31.2	147.4	180.4	330.8	383.3	175.7	170.0	16.9	1.4
1998	0.0	0.0	9.8	9.6	153.6	511.3	384.8	366.6	243.0	146.7	5.6	0.0
1999	2.2	0.0	0.0	35.5	180.7	280.9	285.7	359.2	223.6	134.6	19.2	4.3
2000	0.0	0.0	2.1	61.2	188.7	264.8	200.9	365.3	176.7	223.8	30.0	2.0
2001	0.0	0.7	0.0	0.0	100.3	290.3	417.4	503.5	247.6	167.5	0.0	6.4
2002	0.0	0.0	0.0	0.0	0.0	344.8	283.3	355.8	190.0	139.7	39.5	0.0
2003	15.5	0.0	0.0	0.0	3.0	287.2	402.3	304.3	310.3	97.3	5.9	0.0
2004	0.0	0.6	0.1	83.0	45.0	264.4	423.1	455.3	293.2	69.7	15.1	4.0
2005	0.0	0.0	18.1	3.0	43.8	166.0	369.2	361.5	250.7	153.9	3.2	0.0
2006	9.2	11.2	0.0	18.0	152.7	226.6	401.9	660.2	263.4	192.3	6.2	0.0
2007	0.0	0.0	1.9	36.5	99.8	317.7	348.7	400.7	314.4	69.9	27.3	0.0
2008	2.2	1.0	0.0	55.1	141.5	280.3	489.5	412.0	232.2	42.6	13.0	0.0
2009	0.0	0.0	3.2	22.9	42.1	305.1	370.3	218.3	155.1	58.9	6.2	0.0
2010	5.2	0.0	0.0	24.1	71.0	270.3	435.1	438.1	242.4	203.9	6.4	0.0
2011	0.0	0.0	7.5	4.7	181.6	132.3	237.2	362.0	247.6	80.5	0.0	0.0
2012	0.0	0.0	0.0	0.2	77.4	216.2	511.5	597.0	286.4	140.5	27.0	4.6
2013	0.0	0.0	0.0	0.0	184.8	214.9	606.3	632.8	308.1	91.6	48.6	0.0
2014	0.0	0.0	26.3	74.5	192.3	234.7	279.3	303.0	284.7	226.4	0.0	0.0
2015	0.0	0.0	0.0	0.0	190.6	155.1	176.1	247.8	232.1	94.6	50.1	0.0
2016	0.0	0.0	40.6	0.0	240.1	189.5	337.6	262.4	163.8	109.2	5.8	0.0
2017	0.0	1.5	0.0	60.9	258.9	165.4	442.6	443.5	311.7	165.3	25.0	0.0
2018	0.0	0.0	4.7	2.4	170.7	315.7	338.5	340.9	131.0	159.9	69.2	0.0

B. Shahura monthly total rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	0.0	0.1	5.7	3.0	99.1	70.4	303.8	358.8	140.1	9.5	8.3	0.0
1996	0.0	0.0	138.6	17.3	159.6	265.6	360.8	316.1	152.6	23.3	4.2	0.0
1997	0.0	0.0	0.0	15.8	126.9	196.3	256.8	275.9	145.8	148.4	28.2	2.0
1998	0.0	0.0	0.0	0.0	168.3	270.7	299.5	333.7	145.3	39.3	0.2	0.0
1999	3.2	0.0	0.0	0.0	168.3	323.9	359.9	332.8	172.8	176.1	5.9	2.2
2000	1.8	1.4	0.0	0.0	168.3	339.3	351.2	335.7	145.3	1.7	0.0	0.0
2001	0.0	0.0	0.0	25.7	168.3	270.7	299.5	333.7	145.3	51.5	0.0	11.2
2002	0.0	0.0	0.0	25.7	168.3	270.7	299.5	333.7	145.3	51.5	0.0	11.2
2003	0.0	0.0	0.5	4.0	44.8	224.3	362.0	340.4	186.0	53.1	0.5	5.7
2004	0.0	24.8	2.6	0.0	6.0	268.2	408.3	423.8	225.9	0.9	34.3	2.5
2005	1.6	0.0	0.0	42.6	10.6	328.3	322.7	264.2	185.4	66.5	17.6	0.0
2006	0.0	0.0	0.0	10.9	17.1	307.3	156.8	241.1	187.4	53.5	7.7	0.0
2007	0.0	0.0	1.9	34.6	76.5	253.9	278.5	334.6	103.3	42.2	33.2	0.0
2008	2.2	0.0	0.9	69.7	162.3	345.6	352.4	464.5	157.9	9.0	4.0	0.0
2009	0.0	0.0	16.7	16.2	12.5	107.9	410.3	303.9	107.5	36.9	20.5	2.0
2010	8.8	0.0	7.0	53.2	104.7	204.2	410.3	303.9	107.5	0.0	0.0	0.0
2011	14.6	0.0	0.0	3.2	138.8	167.8	373.3	291.1	103.9	2.9	0.8	0.0
2012	0.0	0.0	0.0	0.0	55.5	179.6	388.8	408.8	163.6	17.0	51.3	6.5
2013	0.0	0.0	0.0	0.0	92.8	139.9	273.6	313.0	143.5	48.8	0.0	0.0
2014	0.0	30.3	96.6	116.0	245.2	118.2	330.7	347.1	212.0	88.6	0.0	9.6
2015	0.0	0.0	9.4	0.0	144.5	186.9	394.0	408.3	151.9	70.2	39.0	0.0
2016	0.0	0.0	16.4	14.9	179.6	241.1	444.0	376.7	135.9	36.1	0.0	0.0
2017	0.0	10.5	2.7	63.7	173.4	217.2	354.5	337.3	141.1	114.4	3.9	0.0
2018	0.0	35.4	5.9	17.7	121.1	208.2	343.6	302.5	196.3	69.3	90.8	0.0

C. Gulback monthly total rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	0.0	0.0	1.2	4.9	83.2	60.5	190.3	301.3	95.8	8.1	0.4	0.5
1996	0.0	0.0	57.7	3.4	122.9	192.4	242.5	331.5	154.4	24.7	0.1	0.0
1997	0.0	0.0	4.4	41.5	165.0	152.4	238.3	182.6	36.8	68.1	6.1	0.0
1998	0.0	0.0	16.6	7.6	143.1	187.2	308.8	349.4	145.7	71.7	0.0	0.0
1999	0.2	0.0	0.0	5.2	88.8	179.5	228.1	292.2	154.2	140.0	0.0	0.0
2000	0.0	0.0	0.0	47.1	57.5	101.6	288.3	302.0	74.5	73.1	4.6	0.0
2001	0.0	0.1	0.0	1.8	52.2	183.8	287.2	309.8	62.0	7.5	0.4	0.0
2002	0.0	0.0	0.0	0.0	2.6	157.3	165.4	244.5	57.9	16.2	0.0	0.0
2003	0.0	0.1	0.1	0.0	1.3	137.1	375.1	287.2	149.0	12.9	0.0	0.0
2004	0.0	0.0	0.0	6.5	10.7	129.9	375.8	309.4	68.2	14.0	3.1	0.1
2005	0.0	0.0	0.5	0.1	35.8	184.9	408.3	383.1	104.2	8.3	0.0	0.0
2006	0.0	0.0	0.0	0.4	78.3	84.1	327.0	373.4	162.6	52.4	0.0	0.0
2007	0.0	0.0	0.1	1.0	31.3	237.4	356.8	492.2	170.9	25.9	1.9	0.0
2008	0.0	0.0	0.0	78.8	347.7	285.3	123.2	8.6	0.0	0.0	26.9	1.5
2009	3.0	10.0	10.7	2.1	1.1	13.3	235.5	236.9	342.3	149.2	13.4	3.7
2010	0.0	0.0	0.3	8.0	11.6	194.8	198.6	253.4	256.7	178.0	65.4	5.4
2011	0.0	0.0	0.0	208.9	260.3	193.4	97.5	77.5	0.2	1.8	0.0	0.0
2012	1.3	42.0	152.9	202.0	179.3	175.6	156.6	28.3	0.0	0.0	8.4	1.2
2013	2.0	0.0	0.0	1.1	87.2	147.1	207.8	179.3	175.6	156.6	28.3	0.0
2014	0.0	1.7	82.2	142.7	107.0	227.5	444.0	778.5	0.0	0.0	41.6	0.0
2015	0.0	0.0	0.0	36.0	102.0	70.7	89.7	55.4	89.3	16.2	0.0	0.0
2016	0.0	0.0	0.0	0.0	33.0	228.0	514.5	575.8	458.3	468.4	117.0	0.0
2017	0.0	0.0	14.9	31.0	345.4	410.0	523.0	496.5	263.0	153.6	0.0	0.0
2018	0.0	0.0	14.9	36.0	102.0	171.0	277.5	297.6	132.0	71.3	0.0	0.0

D. Mankush monthly total rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	0.0	0.0	1.1	4.5	77.3	56.3	177.0	280.2	89.0	7.5	0.4	0.7
1996	0.0	0.0	53.7	3.2	114.3	178.9	225.6	308.3	143.6	22.9	0.1	0.0
1997	0.0	0.0	0.0	43.8	51.8	15.4	1.8	102.0	335.3	349.4	25.0	0.0
1998	0.5	0.0	16.9	0.0	82.0	180.6	101.8	36.8	56.2	6.1	15.0	0.0
1999	0.0	0.0	0.0	0.0	168.3	323.9	359.9	332.8	172.8	176.1	5.9	0.0
2000	0.0	0.0	0.0	43.8	53.5	13.8	1.8	110.2	365.7	322.5	14.0	0.1
2001	0.0	0.0	12.5	24.2	2.3	31.4	229.0	354.3	347.7	73.9	7.6	1.6
2002	0.0	0.0	0.0	193.5	171.0	0.0	93.0	6.1	7.4	319.4	10.0	0.0
2003	0.0	9.0	0.0	17.9	71.1	178.2	320.3	264.6	273.3	38.0	1.0	0.0
2004	0.0	0.2	0.0	6.5	42.9	67.5	265.0	258.9	245.0	25.4	0.0	0.0
2005	0.0	0.0	0.4	33.3	171.9	376.4	353.3	103.3	7.7	0.0	0.0	0.0
2006	0.0	2.8	0.0	0.0	270.3	163.8	189.4	233.8	225.2	113.3	0.4	5.9
2007	0.0	7.0	7.7	19.3	33.1	257.6	320.6	219.3	125.2	75.8	1.8	0.0
2008	0.0	0.0	0.0	132.7	43.2	135.1	289.4	205.5	112.3	100.4	1.3	0.0
2009	0.0	0.6	0.0	27.6	21.2	119.8	87.2	176.9	230.0	139.5	0.0	3.5
2010	0.0	0.0	31.4	75.2	101.0	271.8	156.9	402.7	162.5	13.4	24.6	2.6
2011	0.4	0.0	0.0	191.8	167.5	5.1	81.1	200.0	131.0	52.5	0.0	1.1
2012	0.0	0.0	0.0	0.0	165.9	5.1	81.1	200.0	2.8	87.4	42.0	5.0
2013	0.0	0.0	0.0	66.5	89.7	18.0	7.4	308.2	508.7	428.3	0.0	0.0
2014	0.0	12.3	63.9	45.8	125.1	124.2	252.3	247.8	170.7	110.2	0.0	0.0
2015	0.0	0.0	0.8	0.0	65.5	148.9	136.8	239.4	354.6	42.7	1.8	0.0
2016	0.0	0.0	8.6	0.0	148.8	209.6	257.7	187.5	176.3	49.5	27.4	0.0
2017	0.0	0.0	0.0	15.9	90.0	93.7	182.5	187.0	246.5	70.3	0.7	0.0
2018	0.0	1.2	47.0	0.0	90.0	204.8	183.0	182.7	209.8	125.0	0.2	2.9

E. Bullen monthly total rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1995	0.0	0.0	1.9	7.5	127.9	93.1	292.7	463.5	147.3	12.4	0.7	0.7
1996	0.0	0.0	2.0	5.1	141.6	222.6	379.7	463.2	432.0	392.0	7.8	0.0
1997	0.0	0.0	19.1	38.4	275.4	201.5	298.9	268.1	281.0	175.8	4.0	0.0
1998	0.0	0.0	1.9	5.0	141.6	218.7	379.7	462.0	432.0	352.0	7.7	0.0
1999	2.8	0.0	0.0	24.4	264.1	363.9	209.6	278.9	269.7	212.0	13.3	0.0
2000	0.0	0.0	0.0	44.9	141.1	299.2	372.4	308.2	153.1	183.0	13.8	0.1
2001	0.0	0.0	0.0	40.0	138.4	227.9	391.4	370.0	164.8	132.2	5.1	1.6
2002	3.5	0.0	2.2	16.9	46.5	259.7	250.2	304.1	225.5	105.1	18.2	0.0
2003	0.0	9.0	6.5	7.7	64.4	308.1	333.1	377.8	296.6	40.6	5.1	0.0
2004	0.2	0.2	9.6	51.9	75.8	267.2	221.9	409.0	238.2	76.8	37.0	0.0
2005	0.0	0.0	70.9	9.8	63.6	334.3	240.1	203.6	288.4	130.9	40.1	0.0
2006	0.0	2.8	0.0	5.3	138.0	225.9	318.2	274.3	359.6	226.0	18.3	5.9
2007	1.3	7.0	4.5	83.2	141.3	268.9	320.0	454.9	359.6	93.0	8.8	0.0
2008	5.8	0.0	0.0	101.7	125.7	343.2	312.4	414.7	315.8	42.5	1.8	0.0
2009	0.0	0.6	4.8	25.3	56.8	234.6	191.0	359.4	187.5	74.2	0.0	3.5
2010	3.4	0.0	0.0	6.3	137.5	256.6	296.9	335.9	351.3	30.3	7.5	2.6
2011	0.0	0.0	0.0	11.0	104.3	201.3	197.4	244.8	281.3	114.5	1.4	1.1
2012	0.0	0.0	1.4	11.0	84.4	241.5	328.5	471.9	241.7	65.4	27.3	5.0
2013	0.0	0.0	0.0	0.2	137.6	226.2	303.1	312.7	269.5	190.6	58.4	0.0
2014	0.0	12.3	118.5	126.3	192.8	263.8	302.5	240.1	453.7	271.8	0.0	0.0
2015	0.0	0.0	5.8	2.3	257.2	106.3	166.9	316.2	328.0	146.6	0.7	0.0
2016	0.0	0.0	11.6	0.0	261.5	289.5	414.3	310.9	209.7	52.0	0.0	0.0
2017	0.0	15.9	2.0	53.5	327.2	269.3	309.4	284.2	323.9	203.5	2.7	0.0
2018	0.0	0.0	39.7	0.0	170.0	159.3	270.7	283.3	191.3	47.1	37.7	2.9

Appendix-3: Outlier test

A. Outlier test K_N values

Sample size	K_N value	Sample size	K_N value	Sample size	K_N value	Sample size	K_N value
10	2.036	45	2.727	80	2.940	115	3.064
11	2.088	46	2.736	81	2.945	116	3.067
12	2.134	47	2.744	82	2.949	117	3.070
13	2.175	48	2.753	83	2.953	118	3.073
14	2.213	49	2.760	84	2.957	119	3.075
15	2.247	50	2.768	85	2.961	120	3.078
16	2.279	51	2.775	86	2.966	121	3.081
17	2.309	52	2.783	87	2.970	122	3.083
18	2.335	53	2.790	88	2.973	123	3.086
19	2.361	54	2.798	89	2.977	124	3.089
20	2.385	55	2.804	90	2.981	125	3.092
21	2.408	56	2.811	91	2.984	126	3.095
22	2.429	57	2.818	92	2.989	127	3.097
23	2.448	58	2.824	93	2.993	128	3.100
24	2.467	59	2.831	94	2.996	129	3.102
25	2.486	60	2.837	95	3.000	130	3.104
26	2.502	61	2.842	96	3.003	131	3.107
27	2.519	62	2.849	97	3.006	132	3.109
28	2.534	63	2.854	98	3.011	133	3.112
29	2.549	64	2.860	99	3.014	134	3.114
30	2.563	65	2.866	100	3.017	135	3.116
31	2.577	66	2.871	101	3.021	136	3.119
32	2.591	67	2.877	102	3.024	137	3.122
33	2.604	68	2.883	103	3.027	138	3.124
34	2.616	69	2.888	104	3.030	139	3.126
35	2.628	70	2.893	105	3.033	140	3.129
36	2.639	71	2.897	106	3.037	141	3.131
37	2.650	72	2.903	107	3.040	142	3.133
38	2.661	73	2.908	108	3.043	143	3.135
39	2.671	74	2.912	109	3.046	144	3.138
40	2.682	75	2.917	110	3.049	145	3.140
41	2.692	76	2.922	111	3.052	146	3.142
42	2.700	77	2.927	112	3.055	147	3.144
43	2.710	78	2.931	113	3.058	148	3.146
44	2.719	79	2.935	114	3.061	149	3.148

Source (Chow et al., 1988)

B. Outlier test result

Station	Bullen		Gulback		Mankush		Pawe		Shahura	
Year	P_{av}	Log P_{av}	P_{av}	Log P_{av}	P_{av}	Log P_{av}	P_{av}	Log P_{av}	P_{av}	Log P_{av}
1995	95.65	1.98	62.17	1.79	57.84	1.76	130.31	2.11	83.23	1.92
1996	170.50	2.23	94.14	1.97	87.55	1.94	144.83	2.16	119.84	2.08
1997	130.19	2.11	74.60	1.87	77.05	1.89	119.93	2.08	99.68	2.00
1998	166.72	2.22	102.51	2.01	41.33	1.62	152.58	2.18	104.75	2.02

1999	136.56	2.14	90.68	1.96	128.31	2.11	127.16	2.10	128.76	2.11
2000	126.32	2.10	79.05	1.90	77.12	1.89	126.30	2.10	112.05	2.05
2001	122.61	2.09	75.41	1.88	90.37	1.96	144.48	2.16	108.83	2.04
2002	102.66	2.01	53.66	1.73	66.70	1.82	112.76	2.05	108.83	2.04
2003	120.74	2.08	80.24	1.90	97.78	1.99	118.82	2.07	101.78	2.01
2004	115.65	2.06	76.48	1.88	75.95	1.88	137.79	2.14	116.44	2.07
2005	115.14	2.06	93.75	1.97	87.18	1.94	114.12	2.06	103.29	2.01
2006	131.19	2.12	89.84	1.95	100.41	2.00	161.81	2.21	81.82	1.91
2007	145.21	2.16	109.79	2.04	88.95	1.95	134.74	2.13	96.56	1.98
2008	138.63	2.14	72.67	1.86	84.99	1.93	139.12	2.14	130.71	2.12
2009	94.81	1.98	85.10	1.93	67.19	1.83	98.51	1.99	86.20	1.94
2010	119.03	2.08	97.70	1.99	103.51	2.01	141.38	2.15	99.97	2.00
2011	96.43	1.98	69.98	1.84	69.21	1.84	104.45	2.02	91.37	1.96
2012	123.17	2.09	78.97	1.90	49.11	1.69	155.07	2.19	105.93	2.02
2013	124.86	2.10	82.09	1.91	118.90	2.08	173.93	2.24	84.30	1.93
2014	165.15	2.22	152.10	2.18	96.02	1.98	135.10	2.13	132.86	2.12
2015	110.83	2.04	38.27	1.58	82.54	1.92	95.53	1.98	117.02	2.07
2016	129.13	2.11	199.58	2.30	88.78	1.95	112.42	2.05	120.39	2.08
2017	149.30	2.17	186.45	2.27	73.88	1.87	156.23	2.19	118.23	2.07
2018	100.17	2.00	91.85	1.96	87.22	1.94	127.75	2.11	115.90	2.06
P _{mean}		2.10		1.94		1.91		2.12		2.03
SDV		0.07		0.15		0.11		0.07		0.06
KN		2.47		2.47		2.47		2.47		2.47
Y _H		2.28		2.32		2.18		2.28		2.18
Y _L		1.91		1.56		1.63		1.95		1.87
P _{max}	190.54		209.52		152.06		190.54		151.35	
P _{min}	81.28		36.51		42.95		89		74.13	

Appendix-4: Ground water Source

Code	Source Type	LONGITUDE	LATITUDE	Discharge (l/s)	Source Photo
BGWB1	Borehole	35.626	10.858	3.5	edacae4
BGWB2	Borehole	35.511	10.713	5.0	2fdb0c73
BGWB3	Borehole	36.085	10.601	4.0	edacae4c
BGWB4	Borehole	35.835	10.612	2.0	6fa9294a
BGWB5	Borehole	35.792	10.770	3.0	612942db
BGWC1	Spring	35.596	10.964	12.0	ad615a72
BGWC2	Spring	35.514	10.796	7.0	711a47bc
BGWC3	Spring	35.380	10.661	6.0	924d4cc4
BGWC4	Spring	35.550	10.701	9.0	917fa046-658c
BGWC5	Spring	35.735	10.634	6.0	776a9a34
BGWC6	Spring	35.659	10.687	4.0	f2bf7656
BGWS1	SW	35.436	10.864	14.0	f0390d6e
DGWB1	Borehole	36.078	11.217	1.5	afa83fa0
DGWB2	Borehole	35.785	11.250	2.0	a497f955
DGWB3	Borehole	35.957	11.102	3.0	0ba5c218
DGWB4	Borehole	35.955	11.139	2.0	d5cfb1ca
DGWB5	Borehole	35.999	11.188	1.5	bd96e6a3
DGWB6	Borehole	36.128	11.215	4.0	37e64229
DGWB7	Borehole	36.029	11.379	3.5	40d6c976
DGWC	Spring	36.092	11.197	1.5	a9a95073
DGWD	DW	35.889	11.069	2.0	f21091bb
DGWS1	SW	35.796	11.173	11.0	bc24cdd4
DGWS2	SW	35.969	11.243	9.0	bd9cf6b1
DGWS3	SW	35.949	11.331	7.0	faa52ab7
GGWB1	Borehole	35.298	11.265	0.8	937ff936

GGWB2	Borehole	35.366	11.273	1.0	a286a0ec
GGWC1	Spring	35.370	11.275	8.0	49cd7ee7
GGWC2	Spring	35.318	11.145	17.0	d97c32c1
GGWS	SW	35.369	11.204	13.0	af46dd6c
PGWB1	Borehole	36.324	11.074	7.0	9582db1b
PGWB2	Borehole	36.530	11.123	5.5	e3fc54c6
PGWB3	Borehole	36.457	11.263	6.0	5c0ee3d5
PGWB4	Borehole	36.405	11.319	6.0	458ec38e
PGWB5	Borehole	36.242	11.295	3.5	6fa9294a
PGWB6	Borehole	36.281	11.391	4.0	047fad9b
PGWC1	Spring	36.446	11.116	20.0	49cd7ee7
PGWC2	Spring	36.444	11.083	56.0	2f275770
PGWC3	Spring	36.403	11.071	9.0	917fa046-658c
PGWC4	Spring	36.342	11.162	23.0	d97c32c1-1901
PGWC5	Spring	36.234	11.490	7.0	37535c3a
PGWC6	Spring	36.335	11.338	6.0	65064ccf
PGWD	DW	36.341	11.201	13.0	87350d23-2dd6
PGWS1	SW	36.514	11.335	18.0	af46dd6c-0579
PGWS2	SW	36.181	11.433	6.0	f21091bb
SGWB1	Borehole	36.773	11.469	2.0	51287bb5
SGWB2	Borehole	36.586	11.495	0.5	05ca0644
SGWB3	Borehole	36.773	11.507	8.0	d9112e0c
SGWC1	Spring	36.336	11.506	2.5	941e8def
SGWC2	Spring	36.905	11.878	3.0	e9ad5cb4
SGWC3	Spring	36.707	11.765	6.0	46849b8b
SGWS1	SW	36.455	11.422	0.8	0ba5c218
SGWS2	SW	36.914	11.809	2.5	7d7f529d

Appendix-5: Average Kc value of Beles basin

Land Use	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	oct	Nov	Dec
Cultivated land	1.2	1.2	1.1	1	0.8	0.4	0.6	1	1	0.7	1.2	1.2
Forest Land	0.8	0.8	0.8	0.8	0.8	1.15	1.15	1.15	0.85	0.85	0.85	0.85
Shrub Land	0.66	0.7	0.76	0.76	0.78	0.78	0.78	0.78	0.78	0.78	0.77	0.7
Grass Land	0.87	0.87	0.87	0.87	0.87	0.86	0.85	0.85	0.85	0.85	0.85	0.87
Bare Land	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Urban	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Appendix-6: WEAP schematic diagram of Beles Basin

