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JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY
SCHOOL OF POST GRADUATE STUDIES
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
DEPARTEMENT OF HYDRAULIC AND WATER RESOURCE ENGINEERING
MASTER PROGRAM IN HYDRAULIC ENGINEERING

MODELING SURFACE WATER SUPPLY AND DEMAND BALANCES USING WATER EVALUATION AND PLANNING MODEL: THE CASE OF KATAR WATERSHED, OROMIYA, ETHIOPIA

By: Demissie Sime Alemu

A Thesis Submitted to Jimma Institute of Technology, Hydrology and Hydraulic Engineering Chair in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering

January, 2020
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Main Advisor: Dr-Ing. Fekadu Fufa (PhD)

Co-advisor: Mr. Chala Hailu (MSc.)

January, 2020
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DECLARATION

I under signed, declare that this thesis entitled “Modelling Surface Water Supply- Demand Balances Using Water Evaluation and Planning Model: The case of Katar watershed, Oromiya, Ethiopia” is my original work, and has not been presented by any others person for an award of a degree in Jimma University or other University.

Demissie Sime		01/01/2020
Student Name	Signature	Date

APPROVAL SHEET

We certify that the Thesis entitled "Modelling Surface Water Supply and Demand Balances Using Water Evaluation and Planning Model: The case of Katar watershed, Oromiya, Ethiopia" is the work of Demissie Sime and we here by recommend for the examination by Jimma Institute of Technology in partial fulfillment of the requirements for degree of Masters of Science in Hydraulic Engineering.

Dr-Ing. Fekadu Fufa (PhD) ____________________ __________________

(Main-advisor) Signature Date

Mr. Chala Hailu (MSc.) ____________________ __________________

(Co-Advisor) Signature Date

As a member of Board of Examiners of the MSc. Thesis open Defense Examination, We certify that we have read, evaluated the Thesis prepared by Demissie Sime and examined the candidate. We recommended that the Thesis could be accepted as fulfilling the Thesis requirements for the Degree of Masters of Science in Hydraulic Engineering.

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Mr. Walabuma Oli (MSc.) ________________________ __________________

(Chair Person) Signature Date

ABSTRACT

Katar watershed which is located in the Central Rift Valley basin of Ethiopia is gifted with plentiful amounts of water resources. However, there is no clear current figure of water resources potential between water utilized sectors in the watershed. This leads to conflict and allocation struggle near the future. Therefore, modeling the surface water resources of the watershed which satisfy the projected water demands and, give clue for future plan which is used to generate wise decisions for surface water resource based questions was very important. To achieve this, the Water Evaluation and Planning (WEAP21) model was applied as a Decision Support System (DSS). Checking consistency and homogeneity of rain fall station were done by double mass curve and non-dimensional pi value respectively. The analysis shows that the stations were consistent and homogenous. About 26.90% of the katar river flow was allocated for the environment needs to maintain the ecological services as well as the natural channel habitat associated to the historic flow regimes of the river. For simulation process, the population data were projected and hydro-metrological data were cycled for scenario analysis. The model was structured according to four scenarios of the periods from (2019-2050) with a current account year 2018. The four scenarios were: reference scenario, high population growth scenario, increasing irrigation activity scenario and improved irrigation efficiency scenario. In year 2018 most amount of water was consumed by irrigation (37.18%), livestock (28.16%) and rural (34.50%) relative to urban water demand which consumed about, 0.165% of total water demand in the watershed. Between 2019 and 2050 in all scenarios the maximum water demand is consumed for irrigation activity scenario. Under high population growth scenario, the water demand will be increased by double on 2050 when compare to the year 2018 water demand situation. On the other hand, if compare high population growth scenario with respect to the reference scenario there is an increment of water demand by 20% on the year 2050. The average annual unmet demands of four scenarios were 5.87 Mm^3 (1.70% of the total annual demand), 6.403 Mm^3 (1.86% of the total annual demand), 10.84 Mm^3 (3.14% of the total annual demand) and 0.24 Mm^3(0.069% of the total annual demand) for reference scenarios, high population growth scenario, increasing irrigation activity scenario and improved irrigation efficiency scenario respectively. The average annual demand coverage over the year (2019-2050) of the study periods would reached 92% which shows good demand coverage condition. Generally, the model results over all scenarios except for improving irrigation efficiency scenario shows that the water demand coverage problem was experienced during dry season of the year. Calibration of the WEAP model was based on the stream flow data observed at Abura gauging station with relative to the simulated runoff from the entire watershed for the period 1987-2017. The statistical parameters seen between the simulated and observed stream flow values indicates that the WEAP model can be efficiently applicable for water resource management system and best strategic plan for enhancing economic improvement, if the situation examined in this study would have been perfectly put into practice for the future development in Katar watershed. Generally, this study output can be used for the different stakeholders in the watershed specially to encourage well fitted irrigation activities and water supply division on equal basis, so that food security can be achieved in the watershed as well as in the region.

Keywords: Katar, Surface water, WEAP, Watershed, Water demand

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ABBREVIATIONS & ACRONYMS

AZLFDO	Arsi Zone Livestock and Fishery Development Office
CROPWAT	Crop Water Requirement software developed by FAO
CRV	Central Rift Valley
CSA	Central Statistical Agency
CSV	Common Separated Value
CWR	Crop Water Requirement
d	Day
DEM	Digital Elevation Model
DSS	Decision Support System
EDRI	Ethiopia Development Research Institute
EFR	Environmental Flow Requirement
ETB	Ethiopian Birr
ETo	Reference Crop Evapotranspiration
FAO	United Nations Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
GIS	Geographical Information System
HPGS	High Population Growth Scenario
IIAS	Increasing Irrigation Activity Scenario
IIES	Increasing Irrigation Efficiency Scenario
ITCZ	Inter Tropical Convergence Zone
IWR	Irrigation Water Requirement
IWRM	Integrated Water Resource Management
Kc	Hydraulic Conductivity
MILP	Mixed Integer Linear Programming
MODSIM	Modular Simulator
MoWR	Ministry of Water Resources
NIWR	Net Irrigation Water Requirement
NSE	Nash-Sutcliffe Efficiency
OSF	Observed Stream Flow
PEST	Parameter Estimation Tool

PET	Potential Evapotranspiration
REALM	Resource Allocation Model
RH	Relative Humidity
RIBASIM	River Basin Simulation Model
RS	Reference Scenario
SEI	Stockholm Environmental Institute
SNNPR	Southern Nation Nationalities and People Region
SSF	Simulated Stream Flow
SWAT	Soil and water assessment tools
TAM	Total Available Moisture
UWD	Unmet Water Demand
WD	Water Demand
WEAP	Water Evaluation and Planning
WGS84	World Geodetic System
Yr	Year

1. INTRODUCTION

1.1 Background

Water is one of the most important natural resources on Earth and the most essential for life to exist. It also plays a vital role in supporting productive social activities such as agricultural, energy and industrial production, sanitation, transportation services, fishing, and tourism (Behailu *et al.*, 2018). This natural resource is affected by many factors such as climatic variability, population growth and economic development and create scarcity. Thus, this leads to 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 among users. Water resource management is a multifaceted issue that becomes more complex when considering multiple nations' interdependence upon a single shared transboundary river basin (Teasley & Kenney, 2013).

Sustainably providing healthy, Wealth and meaningful livelihoods for all of humanity is the major challenge in the World. Meeting this challenge is going to require changes in the way that the people use water for food production in case of modern irrigation, energy generation, and other sectors consuming water resource (Cosgrove *et al.*, 2015).

Ethiopia has abundant surface water resources, which could be appropriately utilized to enhance socioeconomic development of the country, but only small fraction of these potentials are utilized to accomplish the national economic and social development goals of the country. Nowadays, the government of Ethiopia has committed to increase the utilization of surface water resources. However, sustainable development can be achieved by careful utilization of its existing water resources supported by research works which may take into account the emerging challenges like population growth and climate change (MoWR, 2002).

Especially, there is a rapid population growth in Ethiopia; the country is also in a range of highly growing population countries. The government has a plan to emerge middle income country within short period of time. Due to this reason the water demand pattern of the country will be changed near the future. Therefore, it is necessary to analyze and study the relationship between supply and demand of water resources in Ethiopia, particularly in the study area. Shuning (2016) suggests that, through the analysis of supply and demand of water resources, the conflict between the supply and the demand can be exposed; thus, the measures to solve the problems can be put forward. The WEAP model integrates water demands with water supply. This integration of watershed hydrology with the water planning process makes WEAP particularly suitable to evaluate the potential impacts of population growth, economic growth, irrigation expansion and climate change on the water balance. Understanding the water balance of a watershed is essential to determine how much water is available in the watershed for consumptive requirements over a specific period of time and how that water should be shared between users in the process of planning (Suryadi *et al.*, 2018).

In this study, the WEAP21 model was used to simulate water resources in the Katar watershed and to evaluate the water balance under increased service levels due to increase in population, increase in irrigation development and expansion industrialization, and to determine water allocation among users.

1.2 Statement of The Problem

Ethiopia is endowed with plentiful amounts of water resources potential. However, the backbone of Ethiopian economy, agriculture, is highly rainfall dependent. This is because of no clear current figure of water resources potential between water utilized sectors and future water resources allocation fruitful deep study (Ayalew, 2018). Currently utilization of water resources is very limited including domestic and minor agricultural activities, mainly through rain fed cultivation. However, knowledge and understanding of surface water and their interactions with spatial and temporal variability are essential for the present and future modeling of water resource availability (Mourad *et al*., 2018). The rising demands for surface water resources will make its allocation a struggle near the future. The main problem may not be scarcity of water in terms of average per capita but the high cost of making water available at the right place, at the right time, with the required quality and quantity (Kumar *et al*., 2017).

Water consumption has increased about sevenfold since the beginning of the twenty-one century. This is especially true for developing countries, particularly in Ethiopia, where the need to enhance agricultural productivity to secure the food requirement of the country which is based on rain-fed irrigation system. Research showed that 54% of the world is suitable for rain-fed agriculture whereas 80% of agricultural production is from rain-fed areas (Shumet & Mengistu, 2016).

In order to guarantee the sustainable development in the environment and economic development in the central rift valley (CRV), Katar watershed a proper modeling of the existing and future water demand by using scenario analysis and proposing proper management for such water resources becomes very essential. On the other hand, Katar watershed water resources is under pressure by increasing population, new infrastructure and new large scale irrigation projects development. Therefore, determination of the surface water potential and water demands of the watershed are fundamental to sustainable water allocation and conflict management.

In addition to large scale irrigation projects there is also different small scale and medium scale projects development in the area that needs the value of water in quantity and quality due to this the surface water quantification and modeling demand in a given river watershed will be of great importance. The randomness nature, temporal and spatial variability of precipitation all over the Katar watershed shows the gaps on water resources and demand assessment timely and efficiently to implement Integrated Water Resource and Management (IWRM) strategic plan. This water demands modeling and water allocation issue will be achieved through Scenarios Analysis approach by WEAP model.

1.3 Objective

1.3.1 General Objective

The aim of this study was to apply the WEAP21 model as a decision support system tool for Modeling Surface Water Supply and Demand Balances in Katar watershed.

1.3.2 Specific Objectives of the study were:

1. to estimate water allocation for environmental flow requirement in Katar watershed.
2. to determine the present water allocation for domestic, agriculture and livestock;
3. to predict future water demands, water allocations and water demand coverage for the period 2019 to 2050 based on different developmental scenarios.

1.4 Research questions

1. How much percentage of available water is allocated for environmental flow requirement in Katar watershed?
2. What are the present consumption of surface water for domestic, agriculture and livestock in Katar watershed?
3. What are the future water demands, water allocation and demand coverage for the period 2019 to 2050 in Katar watershed?

1.5 Significance of The Study

The study can support Governmental and non-governmental organization working on the area of water resource related project as an input for future water based expansion to satisfy communities water demand complain. Different researchers’ studies on the area of water demand concern in the Katar watershed and in the region can use this study as an input for further research investigations. The study also provides clear awareness on surface water potential and water demand pattern in the watershed. Agricultural institution and organization can have clear understanding & awareness on surface water resource for expansion of accurate irrigation sectors based on well-adjusted surface water availability and allocation demand. All surface water users including: domestic, livestock, irrigation project site, industries, future planned project and non-consumptive water users in the study area can obtained fairly surface water distributions, based on their water demand capacity and water demand priorities.

1.6 Scope of The Study

This study was carried out in Katar watershed, central rift valley of Ethiopia and covers the modeling of surface water demands for water user sectors including: the domestic (rural & urban), livestock and agriculture water demands to build future scenarios which enables the possible water supply and demand balances in the watershed.

1.7 Limitation of The Study

The un availability of sufficient data on reviews of material to compare the finding of this study with another finding especially, during the analysis of scenario periods. The problem of obtaining full water demand data which was used for deep modeling of water demand patterns in the watershed such as; design guide line for water supply sectors, resent population data, future strategic plan related with water resource development, ground water resource concerned data and the exact location of surface water abstraction are the factors that limit scientific quality of the finding to some extent.

2. LITERATURE REVIEW

2.1 General Overview

Surface water is any natural water that has not penetrated under the surface of the ground underneath. It is unlike ground-water, which is underground or has seeped under the surface of the earth. Rivers, lakes, oceans and wetlands are commonly known bodies of surface water.

Ethiopia has abundant surface water resources, which could be properly exploited to improve socioeconomic development of the country, but only small fraction of these potentials are utilized to achieve the national economic and social development goals of the country. Nowadays, the government of Ethiopia has devoted to increase the utilization of surface water resources through application of IWRM, which is mainly target to the maximization of socio economic welfare related to water resources, through coordination of multiple activities and resolution of conflicts arising between different users about the limited resource base (Shumet & Mengistu, 2016).

Surface water is lost through evaporation and regained through precipitation (rain) or recruited from ground-water sources. Sustainable water resources management in the catchment needs to address the current and future gap between water supply and demand, while meeting conflicting goals (Psomas *et al.*, 2017). Globally, it is estimated that nearly two-thirds of all nations will experience water stress by the year 2025 (Amin *et al.,* 2018).

2.2 Hydrological Processes

Hydrological process in Surface-water hydrology is a field that encompasses all surface waters of the globe (overland flows, rivers, lakes, wetlands, oceans), the subset of the hydrologic cycle that does not include atmospheric and ground waters. Surface-water hydrology relates the dynamics of flow in surface-water systems (rivers, canals, streams, lakes, ponds, wetlands, marshes, oceans). This includes the field measurement of flow (discharge); the statistical variability at each setting; floods; drought susceptibility and the development of the levels of risk; and the fluid mechanics of surface waters (Wang *et al.,* 2018).

River basin modeling requires a clear understanding on the hydrologic cycle at sub-catchment scale. The catchment hydrologic cycle involves many processes. The basis of generating rainfall-runoff processes lies in the hydrological cycle. The hydrological cycle can be explained by the interdependence and movement of all forms of water on earth. It usually is described in terms of six major components which are precipitation, infiltration, evaporation, transpiration, surface runoff and groundwater flow (Mao *et al*., 2019).

2.3 Irrigation Potential in the River Basin

Agriculture is the pillar to the economy of Ethiopia. It contributes about 48% to the national gross domestic product (GDP) regarding export, employment and subsistence. Recently, policies of the Ethiopian government strongly support export-oriented irrigated horticulture and private large scale floriculture as a means to increase foreign exchange earnings and employment opportunities (Assefa *et al*., 2018).

The food security strategy, in the other hand, has become a growing motive behind rapid expansion of irrigated agriculture in Ethiopia. The strategy clearly inspires construction of more SSI schemes as well as motivates individual landholders to extract more river water using their small transportable pumps (Jebelli, 2018). The Central Rift Valley is a region in Ethiopia where such strategies have resulted in massive scale investments in floriculture greenhouses and in a strong development in smallholder irrigation schemes. The associated with increase in irrigation water extraction from surface water and groundwater resources puts an increasing over scarce water resources in the area (Shumet & Mengistu, 2016).

A majority of the population lives in rural areas depending on agriculture for their livelihood. The agricultural practices are mainly traditional and using rain fed systems (Assefa *et al.* 2018). From Katar river about 9.8 Million cubic meter per year are diverted to irrigate 856 ha (Shumet & Mengistu, 2016). With the increasing water demand of other sectors and environmental constraints, water resources available for agriculture will decrease in the next decades (Loukas *et al.*, 2017). Therefore, in future sensible use of water in agricultural sector will be necessary because day to day water scarcity is increasing and this can be achieved by applying exact or correct amount of water on exact or specific time from the available water in the river or another artificial storage of water since the watershed provides water for domestic (rural and urban water supply) and agriculture sectors (Chandio, 2018). Generally, to follow deeply the principle of IWRM approach, more information on actual and future water demand and specifically water applied to agriculture is needed (Candela *et al.*, 2015).

2.4 Surface Water Resources Potential

Ethiopia is endowed by sufficient amount surface and subsurface of water resources. The Ethiopian surface water potential is identified and estimated to be around 124 Billion cubic meter, which is an indicator to shows abundant amount of water. The River basins of the country have different properties in terms of yearly average discharge rate to its exits with different flow directions, terminals and also water sources. Those water accounts the large portion of water resources than other sources like ground water and other lakes and reservoirs (Ayalew, 2018).

The water resources potential and its utilization rate are in dissimilar in the country. There are huge amounts of both surface and ground water resources but the utilization of it is in kid rate. It is clearly marked that the economic development of the country is never go far without exploitation of water resources appropriately. But under current situation, the country is not used their water resources properly due to different political, natural, technical and economic factors. On the other side, the water sector development programs are performing well to increase the utilization potential and at the same time there are different eye opening future opportunities to develop the water resources development and utilization (Ayalew, 2018)

2.5 Water Resources Management Models for River Basin Simulation

Water resources management involves development, control, protection, regulation, and helpful use of surface (rivers and reservoirs) and groundwater resources. Computer models play an essential role in almost all parts of water resources management including in the whole water resources management decision-making process. Computer-based Decision Support Systems (DSS) are useful tools for this because they allow the user to estimate and assess the impacts of different possible future trends and management tactics before applying them (Minal *et al*., 2016). Further, the use of different models in order to predict the surface water availability and demand of a particular catchment is crucial to ensure the sustainability of the water resources

There are several basin wide simulation models that have been used in IWRM studies (Dariane & Eamen, 2017). In the following sub-topics, some hydrological model commonly used for studying the water demands of river basins and used as decision support tools in water resources planning and management are briefly discussed

2.5.1 MIKE BASIN

MIKE BASIN was developed by the Danish Hydraulic Institute (DHI) in 2001. It is a computerized decision support system for the management of water resources in river basin. The main areas of work that MIKE BASIN supports are: water allocation scenario modelling, reservoir/hydropower operation, hydrological modelling, irrigation demand and yield assessment, in-stream nutrient modelling and catchment nutrient load assessment (Doulgeris *et al*., 2015). This software allows to conduct quantitative and qualitative balance analysis in the basin of the river as well as some part of river.

The model runs on a Geographic Information System (GIS) to perform hydrologic modeling at basin-scale. In this model the network is constructed in which the rivers and their tributaries are represented by branches and nodes. The branches and nodes of the rivers are also edited in ArcView (Doulgeris *et al*., 2015). Bangash *et al.* (2012) used the MIKE BASIN model as a tool for watershed planning, water resource assessment and ultimately water allocation purposes using historical data of river Francolin. Hassaballah *et al.* (2012) developed a methodology based on coupled simulation–optimization approach for determining filling rules for the proposed reservoir in Ethiopia with minimum impact on hydropower generation downstream using the MIKE BASIN model for the simulation of filling rules. Fernandez *et al.* (2013) used the MIKE BASIN model to determine whether water availability will be enough to meet present and future demands. Jaiswal *et al.* (2014) used a MIKE BASIN-based decision support tool to compute inflows to the Rangawan Reservoir in India during dry, average and wet periods and to address water distribution and irrigation management in actual considering demand-supply scenarios.

2.5.2 River Basin Simulation Model (RIBASIM)

The River Basin Simulation Model (RIBASIM) is a generic model package for simulating river basins under several hydrological situations, (Ramadan *et al*., 2011). It was developed in 1985 at Deltares (formerly Delft Hydraulics) in the Netherlands. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and to see the results in terms of water quantity, water quality and flow composition. It can also generate flow patterns which provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Typically, RIBASIM is designed for Evaluation of the alternatives and potential for development of water resources in a river basin, Assessment of infrastructure, and operational and demand management measures. In addition to this it is designed for any analysis which requires the water balance of a basin to be simulated.

The resulting water balance provides the basic information on the available quantity and quality of water as well as the composition of the flow at every location and any time in the river basin. The Required data for model are data on hydrological time series (for example of surface water runoff, rainfall and open water evaporation), aquifers, water users, infrastructure and its operation (dams, weirs, pumps, canals) and priorities for water allocation. Depending on the detail of modeling data are needed on crop, cultivation, yield and production costs, number of inhabitants per population type, concentration of various substances in drainage flows, and reservoir sedimentation data. Especially, RIBASIM is designed for any analysis which requires the water balance of a basin to be simulated. The resulting water balance provides the basic information on the available quantity of water as well as the composition of the flow at every location and any time in the river basin. RIBASIM provides the means to prepare such balances in required detail, taking into account drainage from agriculture, discharges from industry and the downstream re use of water. A number of basin performance parameters are generated for evaluation of the simulated situations (http://www.deltares.nl/en/software/101928/ribasim).

RIBASIM model would have been used in the case of the Ganga river basin assessment. Model results show that reduced discharges caused by water abstractions and dams are the main driver behind deteriorating ecological and socio-economic quality

2.5.3 Modular Simulator (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 (Vaghefi *et al*., 2017), making it the longest continuously maintained river basin management software package currently available. It was designed specifically for developing basin-wide strategies for short-term water management, long-term operational planning, drought contingency planning, water rights analysis and resolving conflicts between urban, agricultural and environmental concerns (Emami & Koch, 2018)**.** An example of its recent use is by Vaghefi *et al* (2017) used for Modeling Crop Water Productivity Using the MODSIM Coupled with SWAT Model.

Implementation of the coupled model improve the calibration and validation of the simulation of the study. The time series of actual irrigation demands of agricultural regions was dynamically simulated by the SWAT model and fed into the MODSIM water allocation model. Through an iterative procedure, the irrigation operation of SWAT was updated based on allocated water by MODSIM. The analysis shows that there were considerable differences in crop yields and productivity of water in irrigated areas of the five agricultural regions of lower Karkheh River Basin.

2.5.4 Resource Allocation Model (REALM)

Resource Allocation Model (REALM) is a generalized computer simulation software package model which is used for harvesting and bulk distribution of water resources within a water supply system. Attractive features of REALM include generality in modelling a wide range of water supply systems with diverse forms of operating rules, flexibility in terms of analyzing "what if" scenarios, and high reliability of the package obtained through extensive testing and use in practical applications. It has been developed in close conjunction with its major users, and many enhancements were made in response to suggestions and feedback from these users (Victoria University & Department of Environment and Primary Industries, 2013). As a result, not only is it now able to meet the needs of a diverse set of users in the water industry, but it has also developed into a comprehensive tool for water supply planning and management. There are now REALM water resource planning models of all major water supply schemes in Victoria, Australia. The states of Western Australia and South Australia are also major users of REALM (http://www.nre.vic.gov.au/vro/water)

2.5.5 Water Evaluation and Planning Model (WEAP)

Water managers and policy makers require tools in order to achieve a balance in water supply and demand, to ensure equitable use of water resources, protect the environment, promote efficient use of water and develop priorities in shared water resources. The Water Evaluation and Planning System version 21 (WEAP21) model is one of such tool used for many river basins when dealing with the stochastic nature of streamflow and water use variables. This model was developed by the Stockholm Environment Institute's (SEI) center in the United States in 1990. It is a generic, integrated water resources planning software tool that provides a comprehensive, flexible and user-friendly framework for the development of water balances, scenario generation, planning and policy analyses (Sieber & Purkey, 2015).

Hydrologic and water resources management modelling have been implemented using the Water Evaluation and Planning system (WEAP), which is a conceptual model based on water balances (Psomas *et al.*, 2017). It is a microcomputer tool for integrated water resources planning. It also provides a comprehensive, 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. WEAP is comprehensive, straightforward, and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information (SEI, 2015). As a forecasting tool, WEAP simulates water demand, supply, flow, and storage, and pollution generation, treatment and discharge (SEI, 2015). 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 & Purkey, 2015).

The WEAP model addresses a number of water problems including the agricultural sector, surface and groundwater sources, sectoral (domestic, agricultural, and industrial) demand analyses, water management, water allocation using priorities, conjunctive use, reservoir operations, and the cost management by financial planning. Based on the linear programming structure, it solves the water allocation problems at user-defined times (Amin *et al.*, 2018).

The WEAP has an integrated approach to simulate both natural and engineering components such as reservoirs, groundwater discharge and water demand and supply, which can give water planner a broader view of the comprehensive range of factors that must be considered in handling water resources for present and future uses. It can analyze a diverse range of issues such as climate variability, watershed conditions, anticipated demands, ecosystem needs, available infrastructures and operational objectives in a transparent manner (Metobwa *et al*., 2018).

The WEAP model elements fall into two categories: nodes and links. Nodes are where water is demanded and supplied, and links are places that transfer water between nodes. A linear program is used at every node to calculate and evaluate the satisfaction of demand site and user-specified instream flow requirements based on a daily or monthly basis. It operates on a monthly step water balance equation (Yang *et al*., 2018)

Wide range of professionals find the Water Evaluating and Planning (WEAP) model as powerful tool to simulate water resources and demands of river basins and investigate results of different development, water policy and other scenarios on water balance of the basin (Dariane & Eamen, 2017). Recently, it has been applied in the sub-basin of Abaya-Chemo, Ethiopia to model Integrated water resources management under climate change scenarios (Hussen, Mekonnen & Pingale, 2018).

Kishiwa *et al*. (2018) use WEAP model coupled with SWAT model to Assess the impacts of climate change on surface water availability. It has also been used to simulate Water Demand in Mara River Basin, Kenya. The proposed scenarios in Mara River Basin showed that enhancing policy implantation and raising awareness coupled with the demand management strategies will sustain water resources at all the time at the basin (Metobwa *et al*., 2018). Hence, WEAP model becomes a powerful tool for modeling the water demand in the study area

2.6 Model Selection

2.6.1 Problems to be Considered

Hydrological practice would be improved if models were objectively chosen on the basis of making the best use of the information available and following some systematic procedure of selection and verification (Doulgeris *et al*., 2015. The choice of the best model depends to a large extent on the problem. Generally speaking, items that should be considered in the selection process include: The nature of the physical processes involved, The use to be made of the model, The quality of the data available; and The decisions that rest on the outcome of the model's use (Loucks *et al.*, 2015). Several models may be capable of describing the same process, and to a great extent, selection of the one to be used depends on a comparison of sampled data and model output.

2.6.2 Criteria of Selection

So far the problems to be considered in choosing a suitable model in general have been discussed. In most situations, however, absolute objective methods of choosing the best model for a particular problem have not yet been developed, so this choice remains a part of the art of hydrological modeling. Loucks *et al*. (2015) suggests four criteria that can be used to choose between alternative models, those are; Accuracy of prediction, Simplicity of the model, Consistency of parameter estimate; and Sensitivity of results to change in parameter values.

Accuracy of prediction of system output is clearly very essential; it is preferred when all other factors being equal, the model with minimum error of variance would be superior. Simplicity refers to the number of parameters that must be estimated and the ease with which the model can be clarified to clients or public bodies. When all other factors are being equal, one should choose the simplest model. Reliability of parameter estimation is an important consideration in developing hydrological models using parameters estimated by optimization techniques. If the optimum values of the parameters are very sensitive to the particular period of the record used, or if they vary widely between similar catchments, the model will probably be unreliable. Finally, models should not be extremely sensitive to input variables that are difficult to measure. Generally the model to be used in this study is passed through Figure (2.2) evaluation process.

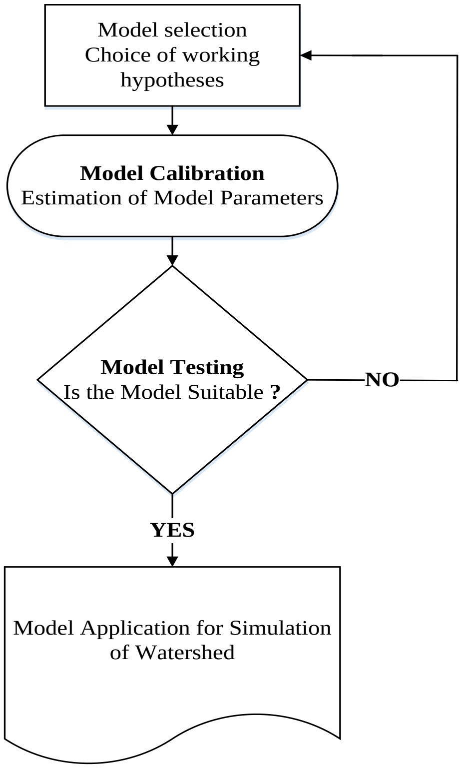


Figure 2.1: Phases of model selection and evaluation (Visio 2016)

The WEAP model which provides comprehensive, flexible and user-friendly framework for policy analysis is distinguished by its integrated approach and policy orientation to simulate water supply and demand balances in Katar watershed.

2.7 Water Evaluation and Planning (WEAP) Modelling Process

The modelling process consists of two main components, namely, the supply and demand components. The supply component comprises of the hydrological analysis of the river and the demand component comprises a growth projection based on domestic, livestock, industrial, environmental flow requirements (EFRs) and irrigation activities. To allow for simulation of water demand balance and water allocation, the elements that comprise the water demand-supply system and their spatial relationships are characterized for the catchment under consideration. The starting point of the analysis is the development of catchment water demands (Sieber & Purkey, 2015).

The process of modelling and simulation using WEAP in the catchment makes use of the following steps. Firstly, problem definition including time frame, spatial boundary, system components and configuration. This step involves setting area boundaries, mapping, problem identification and the collection of data. The required data was collected such as population, historical river flow, rainfall, catchment characteristics, present water supply, future development plan and standards and guidelines. Secondly, establishing current accounts. The “Current Accounts” is defined, which is a baseline representation of the system-including the existing operating rules for both supplies and demands. The current accounts serve as the point of departure for scenarios that characterize alternative sets of future assumptions pertaining to policies, costs, and factors that affect demands, pollution loads, and supplies. The current accounts are viewed as a calibration step in the development of an application and they provide a snapshot of the actual water demand, pollution loads, resources and supplies for the system. This forms the basis for the modelling process. In this study the current account is set at 2019 (Jariwala & Vadher, 2016).

Thirdly, building scenarios based on future assumptions. Scenario development forms the core of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated. The scenarios will be used to address “what if” questions such as: What if the current population growth changes? What if industrialization expands? What if the irrigation systems are developed in the watershed? Finally, Evaluating the water balance and allocation with respect to scenarios. The results generated from running the model will be used as a decision support system for decision makers (DSS) (Jariwala & Vadher, 2016).

2.8 Demand Priorities and Supply Preferences

A standard linear program which uses mixed integer linear programming (MILP) in WEAP model to solve the water allocation problem whose objective is to maximize satisfaction of demand, subject to supply priorities, demand site preferences, mass balances, and other constraints. The constraint set is iteratively defined at each time step to sequentially consider the ranking of the demand priorities and supply preferences (Agarwal1*et al.*, 2018).

Demand priorities allocate water among competing demand sites and catchments, flow requirements, and reservoir storages. The demand priority is specified for every demand site, catchment, reservoir, or flow requirement. Priority numbers in WEAP range from 1 to 99, with 1 being the highest priority and 99 the lowest. Many demand sites can share the same priority, which is useful in representing a system of water rights, where water users are defined by their water usage and/or seniority. In cases of water shortage, higher priority users are satisfied as fully as possible before lower priority users are considered. If priorities are the same, shortage will be shared equally (as a percentage of their demands) (Agarwal *et al*., 2018).

When demands sites or catchments are connected to more than one supply source, the order of withdrawal is determined by supply preferences. Similar to demand priorities, supply preferences are assigned a value between 1 and 99, with lower numbers indicating preferred water sources. The assignment of these preferences usually reflects some economic, environmental, historic, legal and/or political realities. In general, multiple water sources are present when the preferred water source is insufficient to satisfy all of an area's water demands. WEAP treats the additional sources as supplemental supplies and will draw from these sources only after it encounters a capacity constraint (expressed as either a maximum flow volume or a maximum percent of the demand) associated with the preferred water source (World Bank, 2017).

2.9 Model Calibration

The quality of the calibration varies from a catchment to catchment based on several factors, the most important of which, are the length and completeness of available flow records (Elshamy *et al.*, 2017). Calibration includes changing the model parameters to better simulate historic patterns. WEAP21 has no automatic calibration routine; therefore, calibration involves manually comparing the simulated and observed time series. If the resultant fit is acceptable then the model's prediction is valid and reliable (Jariwala & Vadher, 2016).

3. MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

Katar watershed is located in the Central Rift Valley basin of Ethiopia which is situated in the Oromiya Regional State and northern part of Central Rift Valley (CRV) lakes basin in the part of Batu-Shala basin. In terms of geographic coordinate system, the watershed lies between 7°20′00″ to 8°10′00″ North latitudes and 38°40′00″ to 39°40′00″East longitudes. Katar river and its tributaries start from the eastern parts of mountains Chilalo, Galema and Kakka of Arsi Zone, Oromiya and drains to Lake Dambal. The over flow of Lake Dambal drains to Lake Abiyata through bulbula river (Tufa *et al.*, 2015). Topographically, the Katar watershed shows variation with altitude ranging from around 1627 m near Abura (at gauging Station) to about 4181 m above mean sea level on the high volcanic ridges along the eastern watershed. The watershed covers a total area of approximately 3181 km^2.

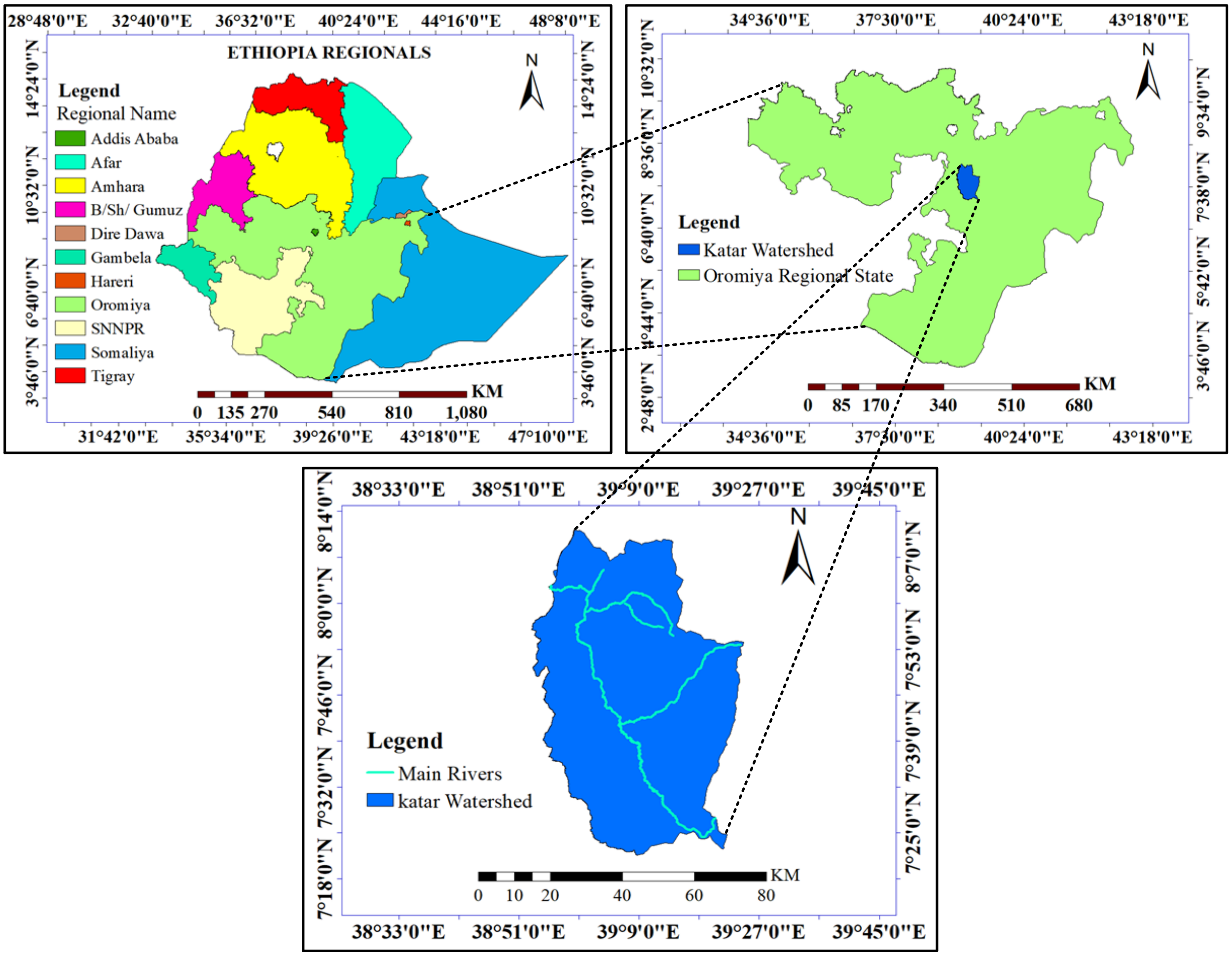
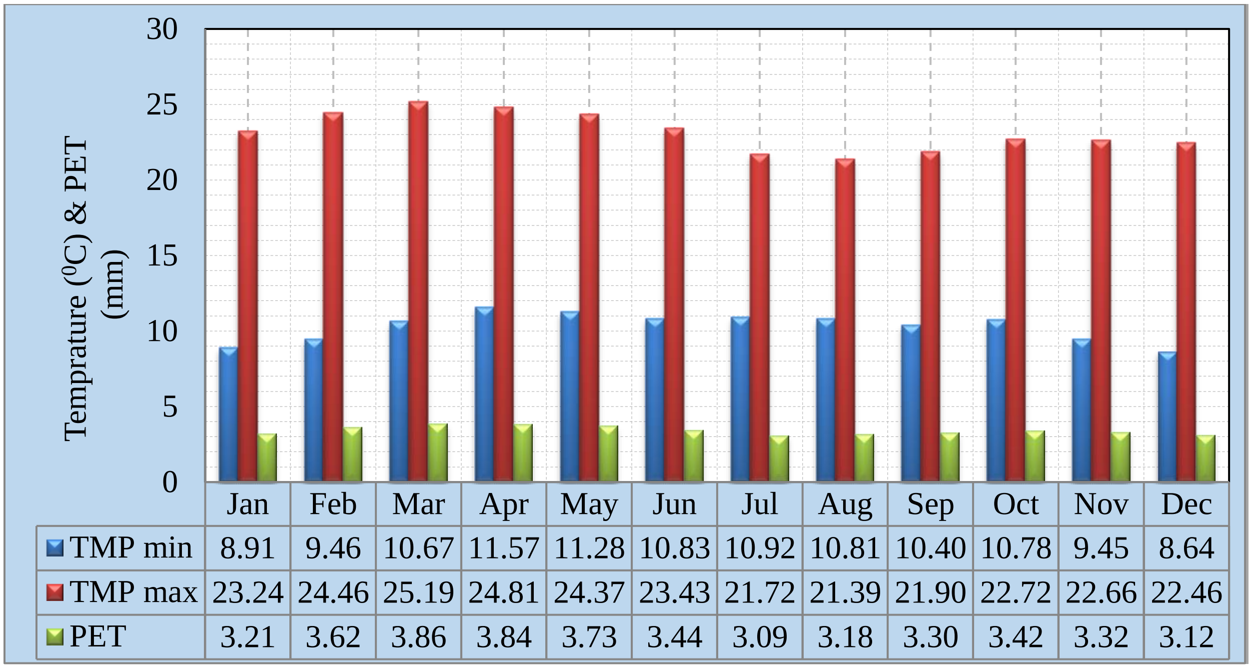


Figure 3.1: Location of the study Area

3.1.2 Climate

Katar watershed is characterized by a semiarid to sub-humid climate with mean annual temperature varying from 700 mm and 20 ^{0}C on the rift floor, to 1200 mm and 15 ^{0}C on the humid plateau and escarpments, respectively. The watershed is characterized by three main seasons. The long rainy season in the summer (June to September; summer monsoon rainfall, locally known as 'kiremt') is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) which lies to the north of Ethiopia at that time. The 'Kiremt' rain represents 50-70% of the mean annual total. The dry period extends between October and February (known as 'baga') when the ITCZ lies south of Ethiopia. The 'small rain' season 'belg' representing 20-30% of the annual amount occurs during March to May when the ITCZ moves from south to north over the country (Tufa *et al.*, 2015).

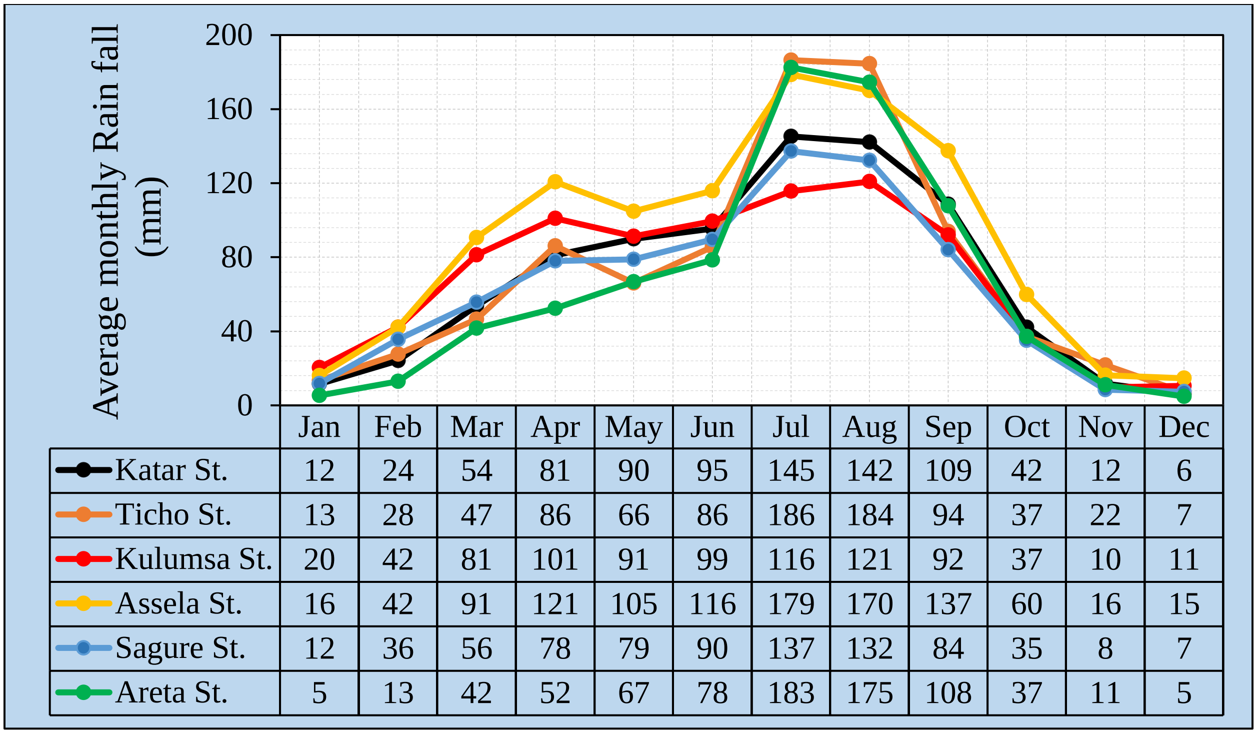


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 TMP min	8.91	9.46	10.67	11.57	11.28	10.83	10.92	10.81	10.40	10.78	9.45	8.64
🟥 TMP max	23.24	24.46	25.19	24.81	24.37	23.43	21.72	21.39	21.90	22.72	22.66	22.46
🟩 PET	3.21	3.62	3.86	3.84	3.73	3.44	3.09	3.18	3.30	3.42	3.32	3.12

Figure 3.2: Temperature and potential evapotranspiration

3.1.3 Rainfall

The pattern of increasing rainfall associated with increasing altitude is modified in the high altitude area by the influence of the high mountains which may cause either rain shadows or areas of heavy orographic rainfall. Highlands flanking the Rift Valley intercept most of the monsoonal rainfall in the region, resulting in a strong moisture deficit in the rift floor in general and near the lakes in particular. The pattern of the precipitation in the rift floor is more of stormy type with relatively high intensity (up to 100mm/hr) compared to the highlands with only 60 -70 mm (Tufa *et al.*, 2015).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Katar St.	12	24	54	81	90	95	145	142	109	42	12	6
Ticho St.	13	28	47	86	66	86	186	184	94	37	22	7
Kulumsa St.	20	42	81	101	91	99	116	121	92	37	10	11
Assela St.	16	42	91	121	105	116	179	170	137	60	16	15
Sagure St.	12	36	56	78	79	90	137	132	84	35	8	7
Areta St.	5	13	42	52	67	78	183	175	108	37	11	5

Figure 3.3: Average monthly rainfall data (mm/d) series for years 1987 to 2017

3.1.4 Soil Types

On the plateau, above 2000 m, the basalt, tuff and ignimbrite with additional volcanic ash give rise to soils wit high silt and clay contents. These vary from relatively deep (often more than 2 m thick), dark brown silty clay loam and clay loam, to red clays with up to 80% clay content on the well-drained undulating terrain around Assela and poorly drained greyish brown to black silty clays on more gentle slopes around Sagure. On the low land area around lake d, the soils are developed on lacustrin sediments and are predominantly of sandy texture. These are generally thin with less than 1 m thickness. The soils on the higher volcanic ridges are generally poorly developed. (Abraham & Nadew, 2018).

For this study, the soil raster data, FAO data base set was taken from Ethiopian MoWIE and there are five major soil types in the study area. These are: Dystric Regos, Eutric Nitosols, Pellic Vertisols, Haplic Xerosols and Lithosols. The most dominant soil type in this study is Nitosols. Nitosols accommodates deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30% clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhydric (nutty) elements. Nitosols are strongly weathered soils but far more productive than most other read tropical soils. Generally, it is considered to be fertile soils in spite of its low level of available phosphorus and normally low base status.

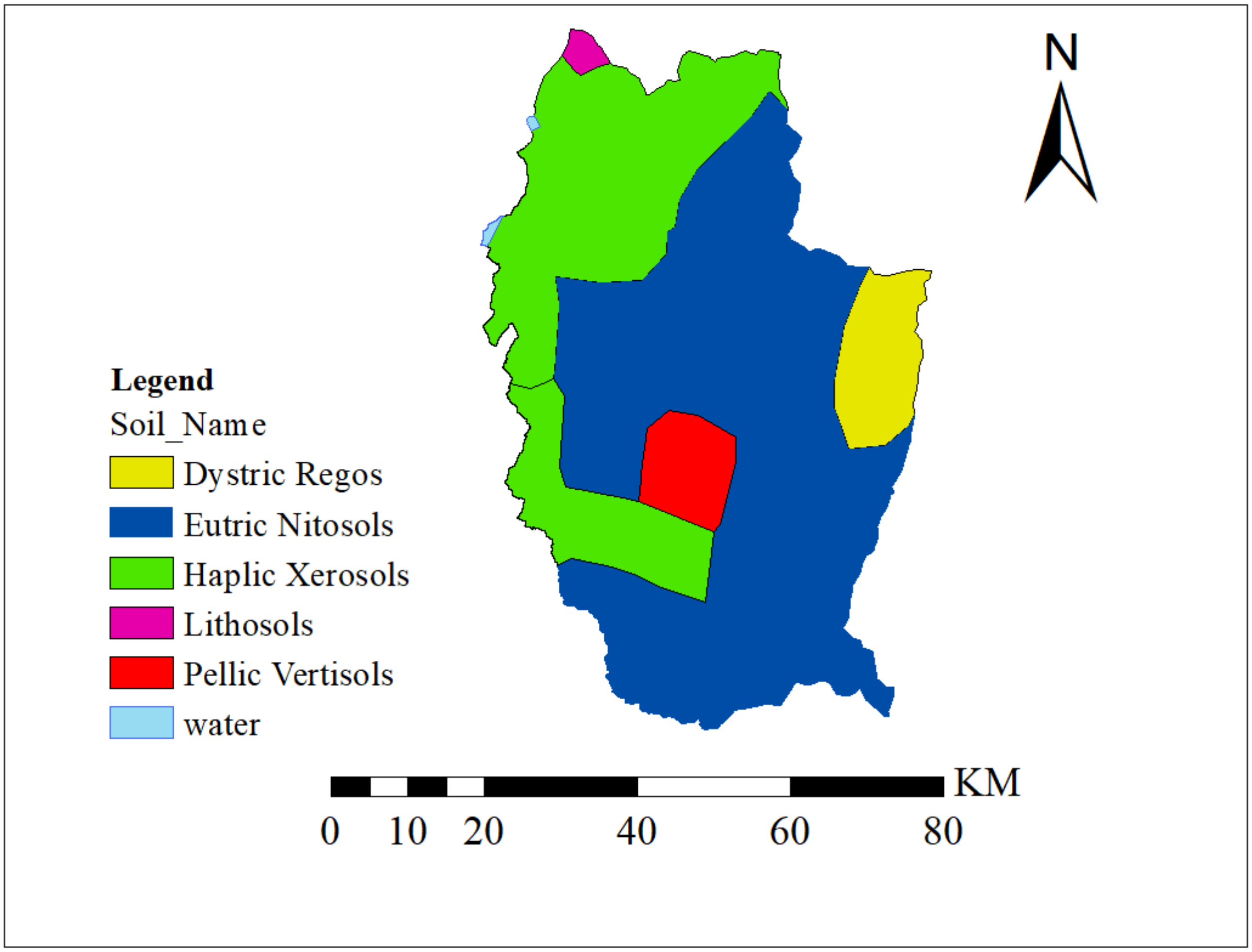


Figure 3.4: The major soil types in Katar watershed

3.1.5 Geology

Katar watershed is part of Batu – Shala basin (the lake region) in the Main Ethiopian Rift (MER). there are six different stratigraphic units, which are highly affected by faults. The oldest volcanic rocks unit consist of basaltic lava flows; with inter bedded ignimbritic beds, topped by massive rhyolites and intervening tuffs and basalts. This unit covers much of the central part of the catchment. The second stratigraphic unit covers the eastern part of the area and it consists of trachyte with subordinate basalts and mugerites, and phonolites. the rift floor ignimbrites unit dominate much of the western part and contain silicic pyroclastic materials mainly per alkaline rhyolitic ignimbrites, inter layered with basalts and tuffs, and associated with coated un bonded pumices. Small part in the north western of the area is covered by most recent volcanic unit which is made up of basaltic lava flows, associated with hayaloclastitites and scoria cones. Another comprises young volcanoes and calderas made up of rhayolitic lava flows, un bonded pumice flows, pumice falls and ashes. The sixth unit found in the area is part of lacustrine deposits, which consists of palustrine clay, organic clay and peat. It covers small part in the study area with in the rift floor ignimbrites.

3.1.6 Major Socio- economic Activity

There are six administrative district that lie within the Katar watershed. From the total population of the watershed 13% are living in Urban and 87% in rural areas. Among the population living in the rural area 12% of the farmers are the owners of the land while the rest of them engaging in the agricultural activity by renting the land from the land owner. The dominant land used in the Katar watershed is agriculture. The watershed is as a whole intensively cultivated and different crops are grown in the watershed using both rain and irrigation. The main crops produced in the study area are: onion, cabbage, potato, sugarcane and carrot. Crops like teff, maize and bean are also cultivated during the rainy season. Rain fed farming has always been the main livelihood for most people in the study area this is because of the use of irrigation technology currently not widespread, this intern leads to risk and un improve production.

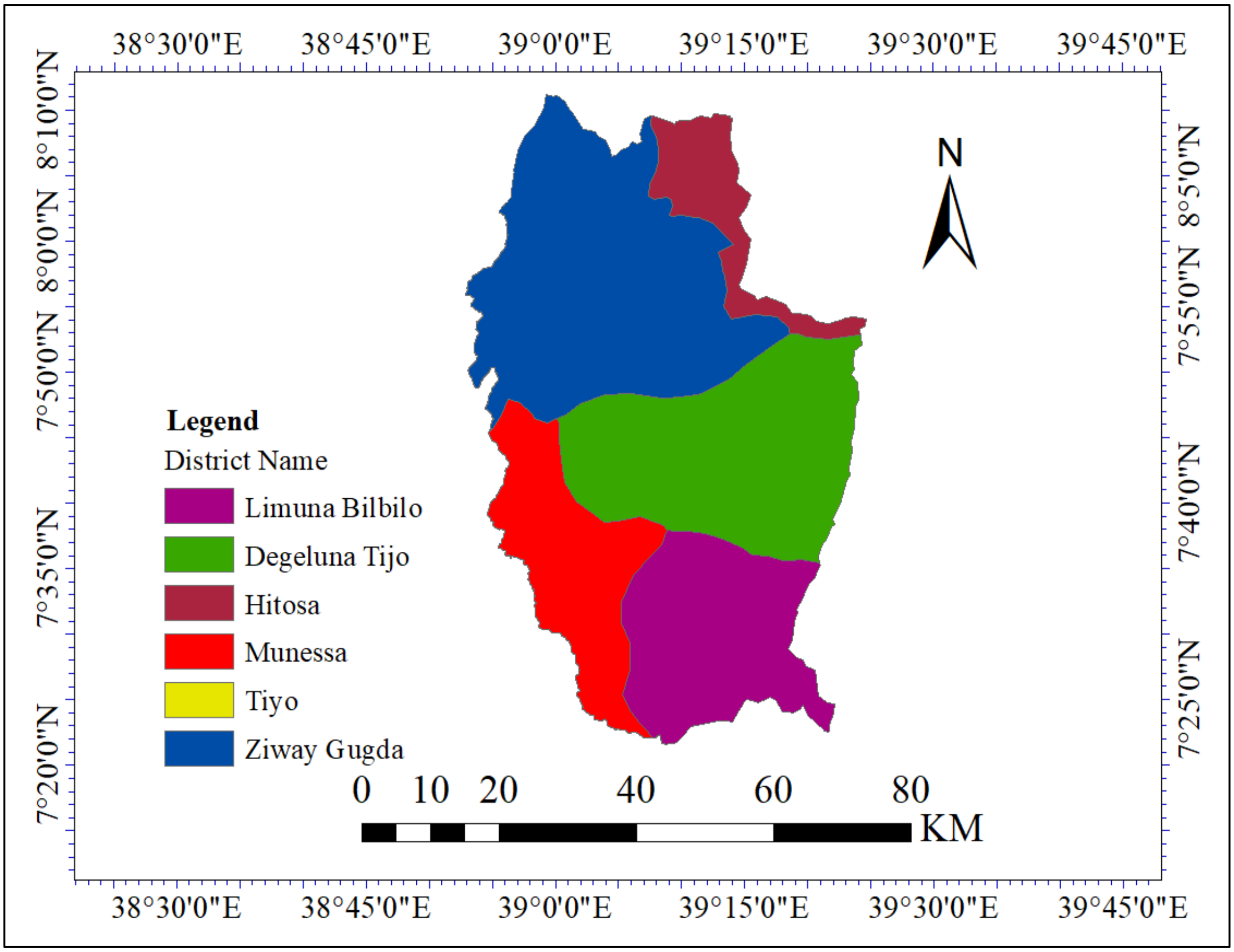


Figure 3.5: The district that are in Katar watershed

3.2 Data Collection and Analysis

Data gathering is always one of the hardest parts about doing an analysis. The fuller data available gives the better output from the model. Also, monthly time series data is helpful in calibration/validation. The assessment of water demands through a WEAP model requires a certain set of Spatial data and hydrological data, as well as data on water supply and water demand in order to map the existing water resources and their utilization within the basin (Dimova *et al*., 2013). The necessary data for this study were obtained in two ways: by visiting responsible government institutions in Ethiopia, in the area of watershed as well as from websites.

Table 3.1: Data Collection and Sources

Data Requirements		Sources
	Soil data	RVLB Master Plan, Ministry of Water and Energy of Ethiopia
	Land cover	Ethiopian Ministry of Water, Irrigation and Electricity
Meteorological	Temperature, Precipitation, solar radiation, relative humidity	Ethiopia National Metrological Agency
Hydrological data	Stream flow	Ethiopian Ministry of Water, Irrigation and Electricity
Demand data	Population data	Ethiopian Statically Agency or Zonal or District office
	Water use rate, Irrigation data, Hydropower data	Ethiopian Ministry of Water, Irrigation and Electricity
	The future development plans in industries and other water use sectors	Ethiopian Ministry of Water, Irrigation and Electricity.

3.2.1 Spatial data

3.2.1.1 Digital Elevation Model (DEM)

The topography of any point in the watershed can be described by Digital Elevation Model (DEM). The DEM with resolution (12.5 m x 12.5 m) used to delineate the watershed boundary, stream network and create watershed. The development of the automatic river network extraction technology on DEM plays a significant role in river research and access to hydrological information (Chen *et al.*, 2018). Ideally, Maps of the watershed will be in a vector or raster format for easily uploading into WEAP. The maps of the watershed formats in Geographic coordinates (preferably, in WGS84) and it includes GIS layers of DEMs, rivers, land use, vegetation cover, soil type, geology, irrigated areas, and location of relevant infrastructure (i.e. reservoirs, hydropower plants, irrigation channels) (Tufa *et al.*, 2015). Katar Watershed DEM clipped from Ethio DEM and used in ArcGIS to delineate the topographic features of Katar watershed in order to determine the hydrological parameters of the watershed. It is projected to Use specific coordinate system either WGS84 or Adindand UTM Zone 37 to create overlay with soil and land use raster data which is finally used as the WEAP model background

3.2.2 Hydro-Meteorological Data analysis

Hydrological modeling largely depends on meteorological (precipitation, temperature, relative humidity, wind speed and sunshine hours), Stream flow data (Tena *et al.*, 2019). Hydrological data are the principal data set in the study work. Continuous stations hydrological data was obtained from the Ministry of Water and Energy, Hydrology Directorate.

3.2.2.1 Missing Data Completion

Missing data is a common problem in hydrology. Failure of any rain gauge or absence of observer from a station causes short break in the record of rainfall at the station. These gaps should be filled before using the rainfall data for analysis. A number of methods have been proposed to estimate missing rainfall data (Pingale *et al.*, 2018). This are the station average method, the Normal ratio, Quadrant method and the regression method. For this study station average method was used because of the total annual rainfall at any of the n region gauges differs from the annual rainfall at the point of interest by less than 10% (Garg, 2005).

If N_1, N_2, N_3 and N_n represent the average annual rain fall at station 1, 2, 3 and n respectively; and P_1, P_2, P_3 and P_n represent their respective precipitation data of the day for which data is missing at station M; then

$$P_M = \frac{P_1+P_2+P_3\ldots+P_n}{n} \quad 3.1$$

Table 3.2: Meteorological Stations Percentage of Missed Summary

Meteor-Stations	latitude	longitude	Record period	% of Missed
Areta	7.98	39.06	1987-2015	9.64
Assela	7.96	39.14	1987-2017	5.95
Kulumsa	8.01	39.16	1987-2017	2.29
Sagure	7.46	39.09	1987-2016	9.87
Katar Genet	7.83	39.1	1987-2017	5.41
Ticho	7.68	39.24	1987-2017	5.48

3.2.2.2 Filling in Missing Stream Flow Data

In the analysis of hydrological data, the stations were required to have daily records for the required period of simulation (1987-2017) years. It may so happen that a particular flow-gauge was not functional for a part of a month or year. Therefore, it is necessary to fill missing records. In this study, arithmetic mean value of the entire period was used to fill the missed records for Abura and Ashebeka gauge stations with less than 10 percent missed records.

3.2.2.3 Checking Consistency and Adjustment of rainfall stations

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. Checking for inconsistency of the record is done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent. The double mass curve technique is used to adjust precipitation records to take account of non-representative factors such as change in location or exposure of rain gauge (Garg, 2005). The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauges. If significant change in the regime of the curve is observed, it should be corrected using Eq. (3.2)

$$P_x{}^c = P_x{}^o * \frac{M^c}{M^o} \quad 3.2$$

Where: $P_x{}^c$= corrected precipitation at station x, $P_x{}^o$=original recorded precipitation at station x, M^c =corrected slope of the double mass curve, M^o= original slope of the double mass curve According to the double mass curves, all the stations were consistent. The double mass curves for Kulumsa station is presented in the Figure 3.6 while the rest stations were listed in Appendix A

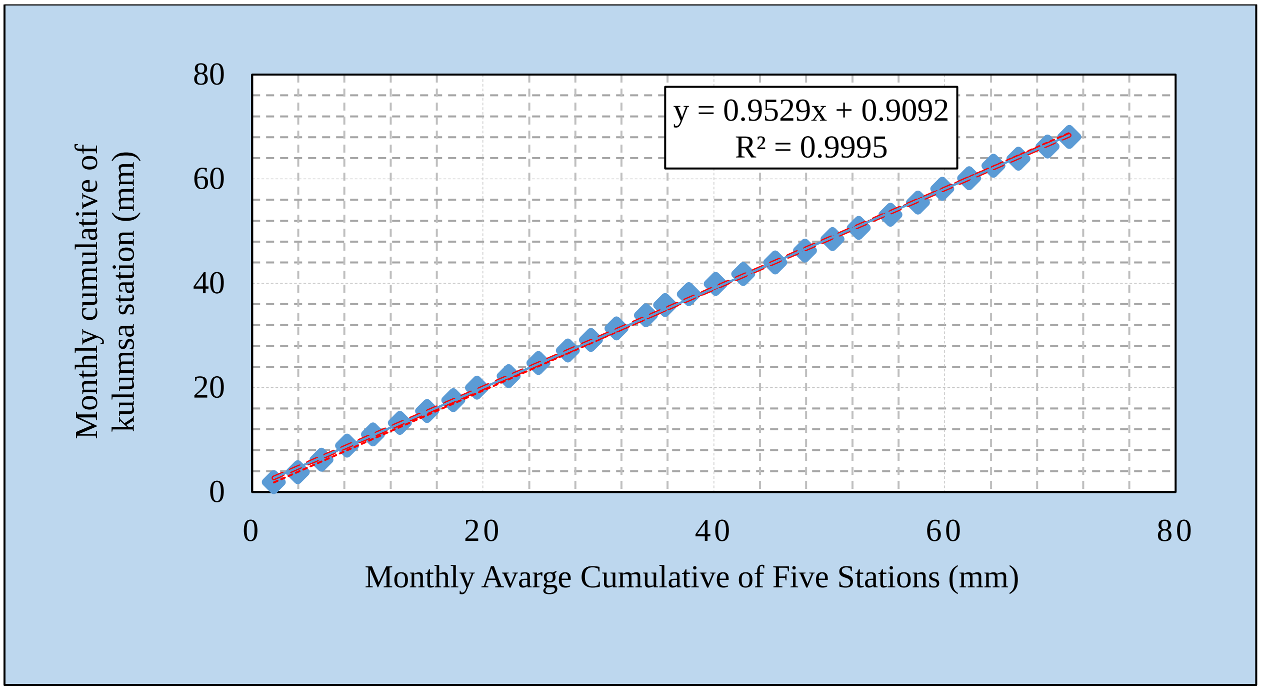


Figure 3.6: The Double mass curves for Kulumsa Station

3.2.2.4 Checking homogeneity of selected rainfall station

Homogeneity analysis was used to separate a change in the statistical properties of the time series data. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation gauging station. Therefore, in order to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations daily rainfall records were carried out by non-dimensional Eq. (3.3).

$$P_i = \frac{\bar{P}_i}{\bar{P}} \text{x}100 \qquad 3.3$$

Where: P_i = Non dimensional Value of precipitation for the month i, P_i = Over years averaged monthly precipitation for the station i, P = Over year’s average yearly precipitation of the station.

According to Homogeneity test analysis, the selected stations were plotted for comparison with each other; for illustration Figure 3.7 below shows the result of homogeneity analysis result. Same mode and pattern of the stations are observed and hence group stations selected were homogenous.

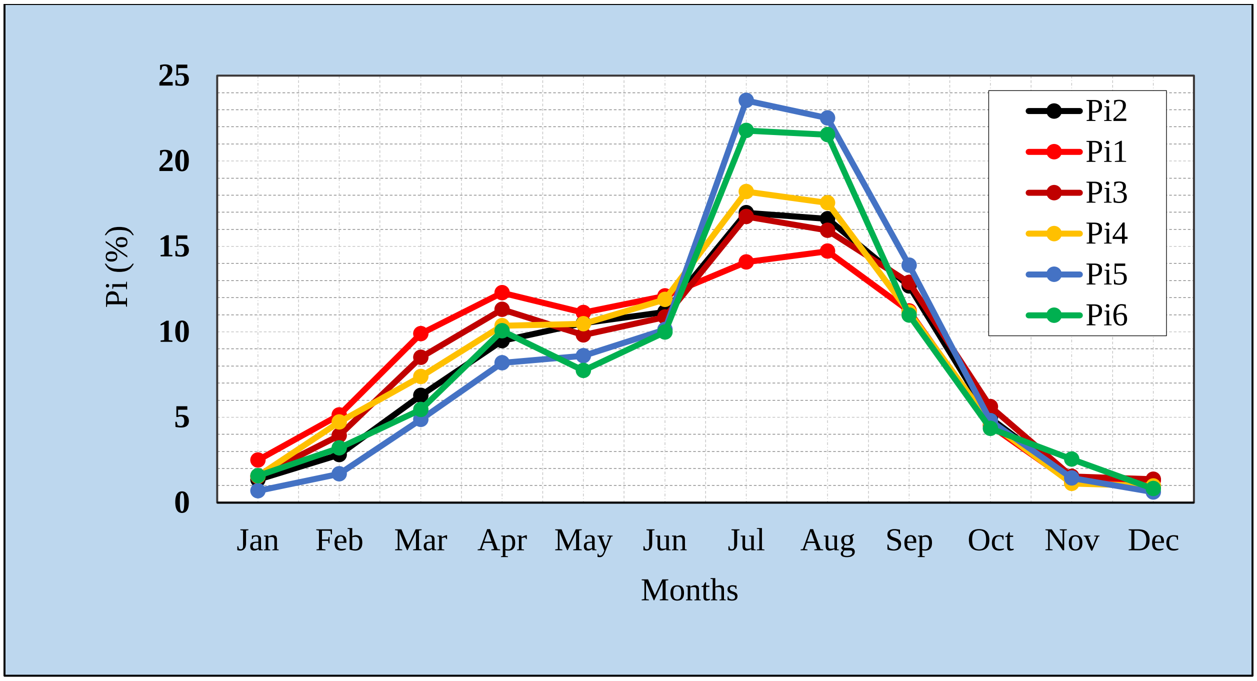


Figure 3.7: Homogeneity analysis of group stations

3.3 Materials

3.3.1 ArcView GIS

Geographic information systems (GIS) were devised in the 1960s as computer applications for handling large volumes of information obtained from maps, and for performing operations that would be too tedious, expensive, or inaccurate to perform by hand. Now a day it is used for land use planning, utilities management, ecosystems modelling, landscape assessment and planning, transportation and infrastructure planning, market analysis, visual impact analysis, facilities management, tax assessment, real estate analysis and many other applications (Jariwala & Vadher, 2016). In the case of this study area it is used for delineation of the study area that is used as background for the WEAP model as the shape file.

3.3.2 Microsoft Excel 2016

Particularly, in this study it is used to import and export necessary data to and from the WEAP model. When importing data, the WEAP is also import and update the scale and units associated with key assumptions and demand annual activity levels. Thus, Excel is used both to edit data and units. This can be particularly useful if it is necessary to change the scale or units of many branches at the same time (e.g. if changing the currency unit for a whole study). To do this (1) export a variable from the WEAP to Excel, (2) change the units by copying and pasting ranges of cells in Excel, then (3) re-import the spreadsheet. Note however that in the WEAP, scaling factors and units apply across Current Accounts and all scenarios. Hence the WEAP is only import changes to scaling factors and units specified for Current Accounts. Export Expressions to Excel process will allow how to link the WEAP expressions to Excel values for later import back into the WEAP. In addition, Excel, with its filtering capabilities, provides a convenient way to view the data (Sieber & Purkey, 2015).

3.3.3 CROPWAT8

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (Vozhehova *et al*., 2018).

Depending on the setting general parameters, the values for effective rain fall and ETo can either be entered once for each watershed and applied to all the land use branches within that watershed, or it were entered separately for each branch within each watershed. entering separately is very necessary if there is a large variation in the elevation among different land uses within a watershed. Alternatively, the watershed could be divided into several different sub-watershed nodes according to elevation, so the effective rain fall varies by climate according to location of the stations. In this study to enter effective rain fall and ETo manually, the output obtained from CROPWAT8 was used as an input for WEAP model as indicated in table 3.2 for Areta Station. The output of CROPWAT8 for the rest of Stations were listed in appendix J(a), J(b), J(c) and J(d)

Table 3.3: Shows The Areta Station CROPWAT8 output used as input for WEAP model

	Min Temp	Max Temp	RH	Wind	Sun	Rad	ETo	Eff rain	Kc
Months	°C	°C	%	km/d	hr	MJ/m²/d	mm/d	mm	coeff
Jan	6.2	22.1	48	2	9.5	21.7	3.02	0.2	0.62
Feb	7.3	23.3	47	2	10	23.7	3.47	0.4	0
Mar	8	23.3	54	3	9.9	24.6	3.83	1.3	0
Apr	8.3	22.2	64	3	9.3	23.8	3.8	1.6	0
May	8	22.3	62	2	8.8	22.4	3.55	2.1	0
Jun	8.7	22	73	2	7.5	20	3.31	2.5	0
Jul	8.8	18.7	85	2	6.5	18.7	3.06	5.8	0
Aug	8.3	19.1	84	2	7.5	20.7	3.32	5.5	0
Sep	8.1	19.2	75	2	7.5	20.8	3.3	3.5	0.3
Oct	6.5	19.6	65	2	8.8	22.1	3.29	1.2	0.36
Nov	5.5	21.3	54	3	9.7	22.2	3.13	0.4	1.03
Dec	5.5	21.8	47	3	9.6	21.3	2.92	0.1	1.1
Avge	7.4	21.2	63	2	8.7	21.9	3.33	2.05	0.28

3.4 WEAP21 Model Background

3.4.1 Overview

WEAP is structured as a set of five different "views": Schematic, Data, Results, Scenario Explorer and Notes (Figure 3.8). These views are listed as graphical icons on the View Bar located on the left side of the screen. Schematic is GIS tool for configuring the system by dragging and dropping to create and position. Adding ArcView or other standard GIS vector or raster images as background layers. It is an instant access to data and results for any node. Data view is used to build Model. It creates variables and relationships, enter assumptions and projections using mathematical expressions, and dynamically link to Excel. Notes are views where data and assumptions are documented. Results view displays detailed model outputs in the form of charts, tables and maps. Scenario Explorer is high-level view of data and results. The slider moves to change the value of the associated scenario data variable and WEAP recalculates so that the impact on user-selected key results are displayed. The main menu at the top provides access to the most important functions of the program. A status bar is located at the bottom of the screen showing the current area name, current view, licensing information and other status information. The layout of the rest of the screen depends on which view is selected.

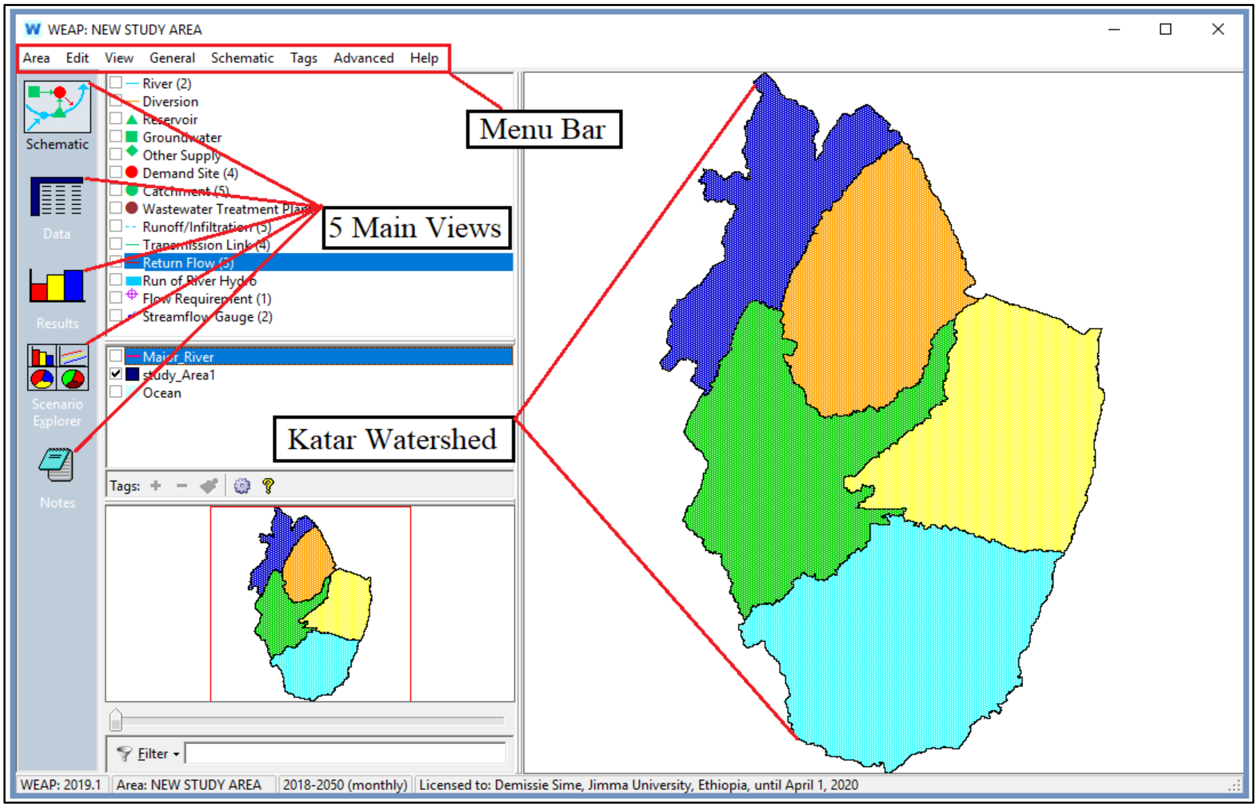


Figure 3.8: WEAP Screen Views, Menu Bar Schematic View Katar Watershed

3.4.2 Data Requirements and Collection

The necessary data for this study were obtained in two ways: by visiting responsible government institutions in Ethiopia, in the area of watershed as well as from websites.

3.5 Input Data Preparation for WEAP Model

3.5.1 Population Projection

Population projection deals with computations of future projection size and characteristics based on assumptions about future trends in fertility, mortality and migration. Since it is not possible to predict the future trends in fertility, mortality and migration, it is also difficult to predict the future size and characteristics of a population accurately. The growth of urban population occurs on account of four factors, such as: natural growth, migration, emergence of new towns and expansion of new towns. This is almost impossible to measure these components for the past and project them separately into the future. So a method that takes into consideration the net effect of all these is required (CSA, 2013).

Projection of urban and rural population is done by projecting the proportion of urban population based on the assumptions regarding pace of urbanization. United Nations have proposed projection of the Urban-Rural Growth Differential (URGD) which measures the tempo of urbanization as a method of population projection. The difference in the growth rate between rural and urban areas would include the effect of all factors, such as natural growth, migration, emergence of new urban areas and expansion of boundaries of existing urban areas (CSA, 2013).

The accuracy of population projections is generally considered directly proportional to the size of the existing population and the historical rate of growth, and inversely proportional to the length of the time projection (Goldstone *et al*., 2016). Therefore, population prediction is a very important aspect in environmental engineering that helps in determination of certain factors that helps in the future planning and for accurate determination of the certain requirement in the future. The common methods by which the Population Projection will be done are: Geometric increase method, Incremental increase method, Decrease rate method, Simple graphical method, Master plan curve method, Logistic curve method and Ration & correlation method.

The projected number of population for urban and rural of 2017 for the study was taken from population projection of Ethiopia for all regions at wereda level from 2014 – 2017 (CSA, 2013). For the future case of projection geometric increase method was used up to the base year of study since this method is based on the assumption that the percentage of increase in population remains constant and it is applicable for growing towns and rural having vast scope of expansion. The equation for the Geometric growth method in Eq. (3.4).

$$\mathrm{P} = \mathrm{P_o} \mathrm{x} (1+\rho)^{(\mathrm{T}-\mathrm{T_o})} \tag{3.4}$$

Where; P= Projected population in number, $\mathrm{P_o}$=Baseline population in number**,** T= Projected year, $\mathrm{T_o}$=Baseline year , ρ= growth rate in percentage

The Expression Builder is a “GrowthForm” function built into the WEAP model that helps project the population of the reference period (2019-2050). It is a general purpose tool to construct WEAP expressions by dragging and dropping the functions and WEAP branches into an editing box (SEI, 2015). The input data in GrowthForm field within WEAP for projecting the population for reference period are: Year of last census, Population at Current and Estimated growth rates.

Table 3.4: Percentage of rural and urban population growth rate in Ethiopia (EDRI, 2018)

Year	Growth rates (%)	
	Urban	Rural
1990-2000	6.2	3.5
2000-2010	5.5	2.8
2010-2020	6.2	2.2
2020-2030	5.2	1.6
2030-2040	4.2	1.0
2040-2050	3.5	0.6

Table 3.5: Projected number of population for baseline year 2018

Districts name	Population 2017		Population 2018	
			Rural ρ= 2.2 %	Urban ρ = 6.2 %
	Rural	Urban	Rural	Urban
Ziway Dugda	147,992	7,272	151248	7723
Hitosa	134,482	29,835	137441	31685
Tiyo	102,049	10,537	104294	11190
Munesa	192,530	24,483	196766	26001
Digluna Tijo	160,753	22,730	164290	24139
Limuna Bilbilo	200,145	37,675	204548	40011
Total	937,951	132,532	958,586	140,749
			1,099,335	

3.5.2 Livestock Population Projection

Valid sources of information and appropriate methods of forecasting data from the sources are crucial to both public and private sectors. Reliable information and estimation are necessary for organizations in public sector to develop, implement and monitor policies. Therefore, use of application of mathematical theories, methods and models can be utilized to assess the substantial consideration circumstances and produce effective and efficient solutions. This study was applying logistics growth technique for forecasting each livestock species: horse, cattle, sheep and goat. A logistic forecast is most appropriate when a variable is expected to show an “S “shaped curve over time. This makes it useful for forecasting shares, populations and other variables that are expected to grow slowly at first, then rapidly and finally more slowly, approaching some final value (the “B” term in the equation (3.5)) (Chandio *et al.,* 2018). Therefore, in this study the average value of 1.31%, 1.85% and 0.93% was used which is equal to 1.36% to project the livestock population for the referenced period within WEAP model. The historical number of livestock population to use Logistic forecasting method which fit “S “shaped curve over time were 2446736, 2274725 and 2340610 on 2015, 2016 and 2018 respectively. For 2015 & 2016 see appendix I (a) and I (b)

Table 3.6: Number of livestock population in Katar watershed at 2018 (AZLFDO, 2018)

Districts	Cattle	Sheep	Goats	Horse	Mule	Donkey
Ziway Dugda	134,512	28140	46620	4923	1969	12801
Hitosa	165,185	75,874	58,628	3,694	334	26,899
Tiyo	108,663	96,241	17,540	11,830	1,280	20,783
Munesa	212,733	122,352	8,460	38,216	820	24,858
Digluna Tijo	239,517	128,084	10,314	25,477	335	17,464
Limuna Bilbilo	263,450	297,110	29,441	58,574	3,891	43,693
Sub Total	1,124,060	747,801	171,008	142,714	8,529	146,498
Total	2,340,610					

Table 3.7: Percentage of livestock population growth rate in Ethiopia (FAO, 2004)

Livestock type	Growth rates (%)			
	1980-1993	1993-2000		2012-2050
Sheep	1.1	0.3		1.31
Goats	1.1	0.3		1.85
Cattle	1.1	1.9		0.93

The new values are predicted using an approximate fit of a logistic function by linear regression. A logistic function takes the general form of equation (3.5):

$$y = A + \frac{B - A}{1 + e^{(-aX+b)}} \qquad 3.5$$

Where: The Y terms corresponds to the variable to be forecasted and the X term is years. A, B, a and b are constants and e is the base of the natural logarithm (2.718…). period within WEAP model.

3.5.3 Water Demand

3.5.3.1 Domestic Water Demand

In Ethiopia, as the first growth and transformation plan was finalized on the mid of 2015 the Second Growth and Transformation Plan (GTP-2) covering the period from 2016-2020 is prepared. As per the GTP-2 water supply service level standard, it is required to provide safe water in minimum 25 l/c/day within a distance of 1 km for rural, while in urban areas it is required to provide safe water in minimum 100 l/c/day for population more than 1 million. In case of this modeling the number of population on the study base line years lies in the range of 100,000-1million. Therefore, as per the GTP-2 water supply service level standard the minimum 80 l/c/day was taken from GTP-2 master plan (MoWR, 2002).

But in this study, the water demand is forecasted up to the year 2050 which lies in the third Growth and Transformation Plan (GTP III), therefore, the per capita demand will increase beyond 80 l/c/day and assuming 25% increment from GTP II to GTP III, it becomes 100 liters per capita per day for urban and 32 liters per capita per day for Rural was used.

3.5.3.2 Industrial Demand

The water required in the industries mainly depends on the type of industries, which are existing in the city. The water required by factories, paper mills, Cloth mills, Cotton mills, Breweries, Sugar refineries etc. comes under industrial use. The quantity of water demand for industrial purpose is around 20 to 25% of the total demand in the watershed (MoWR, 2002). For this study 25% was used.

3.5.3.3 Institution and Commercial Demand

Universities, Institution, commercial buildings and commercial centers including office buildings, warehouses, stores, hotels, shopping centers, health centers, schools, temple, cinema houses, railway and bus Quantity of water required for public utility purposes such as for washing and sprinkling on roads, cleaning of sewers, watering of public parks, gardens, public fountains comes under public demand. To meet the water demand for public use, provision of 5% of the total consumption is made in most developing countries for designing the water works for a city (MoWR, 2002).

3.5.3.4 Fire Water Demand

Fire may take place due to faulty electric wires by short circuiting, fire catching materials, explosions, bad intension of criminal people or any other unforeseen miss happenings. If fires are not properly controlled and extinguished in minimum possible time, they lead to serious damage and may burn cities (MoWR, 2002). In this study 5% of domestic water demand was used

3.5.3.5 System losses (SL)

Losses from water supply systems vary considerably according to diverse factors. SL are a function of the quality of construction, the type and age of the pipes in the distribution network, and pressure within the system. In estimating water losses in the water supply system, a percentage of 20% of the total of domestic, commercial, institutional and industrial demands is assumed in the basin (MoWR, 2002).

Average Daily Demand (ADD)

The average daily demand is taken to be the combined total of the domestic, commercial, institut ional, industrial and livestock demands and the system losses. Average Daily Demand = Demands for Domestic + Commercial & Institutional + Industrial + Livestock + Losses

Maximum Daily Demand (MDD)

The daily water consumption in a town varies depending on time of day, the season and climatic conditions. Therefore, the Maximum Daily Demand (MDD) has been taken as 1.15 times the Average Daily Demand (ADD) for all towns in the basin (MoWR, 2002).

$$MDD = 1.15\ ADD \tag{3.6}$$

The Maximum Daily Demand sets the requirements from the sources. Thus, the water demands of urban centers were calculated using Eq. 3.6.

Annual Water Use Rate

The WEAP model needs annual water use rate as a basic input. Based on the standard given by Ministry of Water, Irrigation and Energy for River Basin, the Maximum Demand per person per year in the rural and urban were calculated for this study according summary obtained from Tables 3.8, 3.9 and 3.10 respectively.

Annual Water Use Rate for Urban

Domestic Water Demand (DWD) = 100 l/c/d = 0.10 m^3/c/d, CIWD = 5% DWD = 0.05 x 0.10= 0.005m^3/c/d, IWD = 10% DWD = 0.10 x 0.10 = 0.01 m^3/c/d, LWD = 3 x 25 l/day = 75 l/c/d = 0.075 m^3 /c/d, System Losses = 25% (DWD + CIWD + IWD) =0.25(0.10+0.005+0.01) =0.02875, Average Daily Demand (ADD)=0.10+0.005+0.01+0.075+0.02875=0.21075 m^3 /c/d, Maximum Daily Demand (MDD) = 1.15 ADD=1.15 x 0.21075=0.242 m^3 /c/d, Maximum Demand per person per year = 0.242 x 365 m^3=88.5 m^3/year

Annual Water Use Rate for Rural

Domestic Water Demand (DWD) = 32 l/c/d = 0.032 m^3/c/d, CIWD = 5% DWD = 0.05 x 0.032= 0.0016 m^3/c/d, IWD = 10% DWD = 0.10 x 0.032 = 0.0032 m^3/c/d, LWD = 3 x 25 l/day = 75 l/c/d = 0.075 m^3 /c/d, System Losses = 25% (DWD + CIWD + IWD) =0.25(0.0032+0.0016+0.032) =

0.0092 m³ /c/d, Average Daily Demand (ADD)=0.032 +0.075+0.0092=0.0662 m³ /c/d, Maximum Daily Demand (MDD) = 1.15 ADD=1.15 x 0.0662 = 0.07613 m³ /c/d, Maximum Demand per person per year = 0.07613 x 365 m³=27.3 m³/year

Therefore, 88.5 m³/year and 27.3 m³/year were used us annual water use rate for urban and rural respectively in the model.

Table 3.8: Water use rate assumptions in percentage of DADD (MoWR, 2002)

Water use for	Consumption rates
Domestic ADD	ADD in ℓ/c/d*
Commercial and institutional water demand (CIWD)	5 % of DWD For small- and medium-sized towns
Industrial water demand (IWD)	10 % of DWD in small towns
Firefighting water demand	5 % of DWD
System losses (SL)	25 % (DWD + CIWD + IWD)
Maximum peak factor	1.15

Table 3.9: Urban water use rate assumptions in the Katar watershed (MoWR, 2002)

Water use for	Consumption rates
Domestic AADD	100 ℓ/c/d
commercial and institutional	5% of domestic demand
Industrial	10% of domestic demand
System Losses	25 % (DWD + CIWD + IWD)
Maximum peak factor	1.15

Table 3.10: Rural water use rate assumptions in the Katar Watershed (MoWR, 2002)

Water use for	Consumption rates
Domestic AADD	32 ℓ/c/d
Livestock Water Demand (LWD)	25 liters per LU per day
System Losses	25 % (DWD + CIWD + IWD)
Maximum peak factor	1.15

3.5.3.6 Irrigation Water Demand

The irrigation water demand is one of the key assumptions in scenario development when evaluating the impact of future water use in the study watershed. Because it is highly related to investment activities in the area. The water demand varies inter-annually, depending on the type of crops grown and evapotranspiration. In some demand sites, such as industrial sites, water use may remain constant throughout the year, while other demands may vary considerably from month to month. If demand does not vary, all months are assumed to use the same amount, according to the number of days in the month. For example, the default annual share for January is 31/365=8.49%, whereas February is 28/365=7.67%. Otherwise, the percentage of annual water requirement (WR) in each month is entered in to WEAP model (Sieber and Purkey, 2015). For this study it was obtained by using CROPWAT8 for all selected representative plant in Katar watershed. See Appendix E.

Table 3.11: Monthly share of annual irrigation WR used as input for WEAP model

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WR (%)	24	28	18	7	3	0	0	0	0	0	8	12

The Katar Watershed consists of irrigated lands which are operated by both licensed and non-licensed water users. This study consider only water used by licensed water users due to the unavailability of data on non-licensed water users. The total irrigated land by licensed water users in Katar watershed along the side of the river is 4700 ha. The major sources of water supply for irrigation are dams, boreholes and rivers, followed by piped water distribution systems. In this study, rivers were only considered water supply sources, whereas dams and boreholes were not considered due to the unavailability of data. The water supply per hectare for this study was 6000 m³/ha per year was taken from Table 3.12 (http://www.fao.org/3/W4347E/w4347e0l.htm).

Table 3.12: Rift Valley Irrigation Potential Water Requirements

Country	Irrigation	Gross potential irrigation WR		Area under irrigation
	(ha)	(m³/ha / yr)	total (km³/yr)	(ha)
Djibouti	450	12000	0.005	100
Eritrea	0	8000	0	0
Ethiopia	790000	5000-10000	7.315	166396
Sudan	0	7000	0	0
Uganda	0	5500	0	0
Kenya	52500	10500-12000	0.576	27000
Tanzania	1060	12000	0.013	0
Sum	844010		7.91	193496

3.5.3.7 River Flow

The river system management and water allocation practices were simulated using the measured stream flow for 1987 to 2017 to represent the Katar watershed hydrology.

3.6 WEAP Model Setup

The general framework used for the modeling of water demand in this study area was illustrated in Figure (3.9) flowchart.

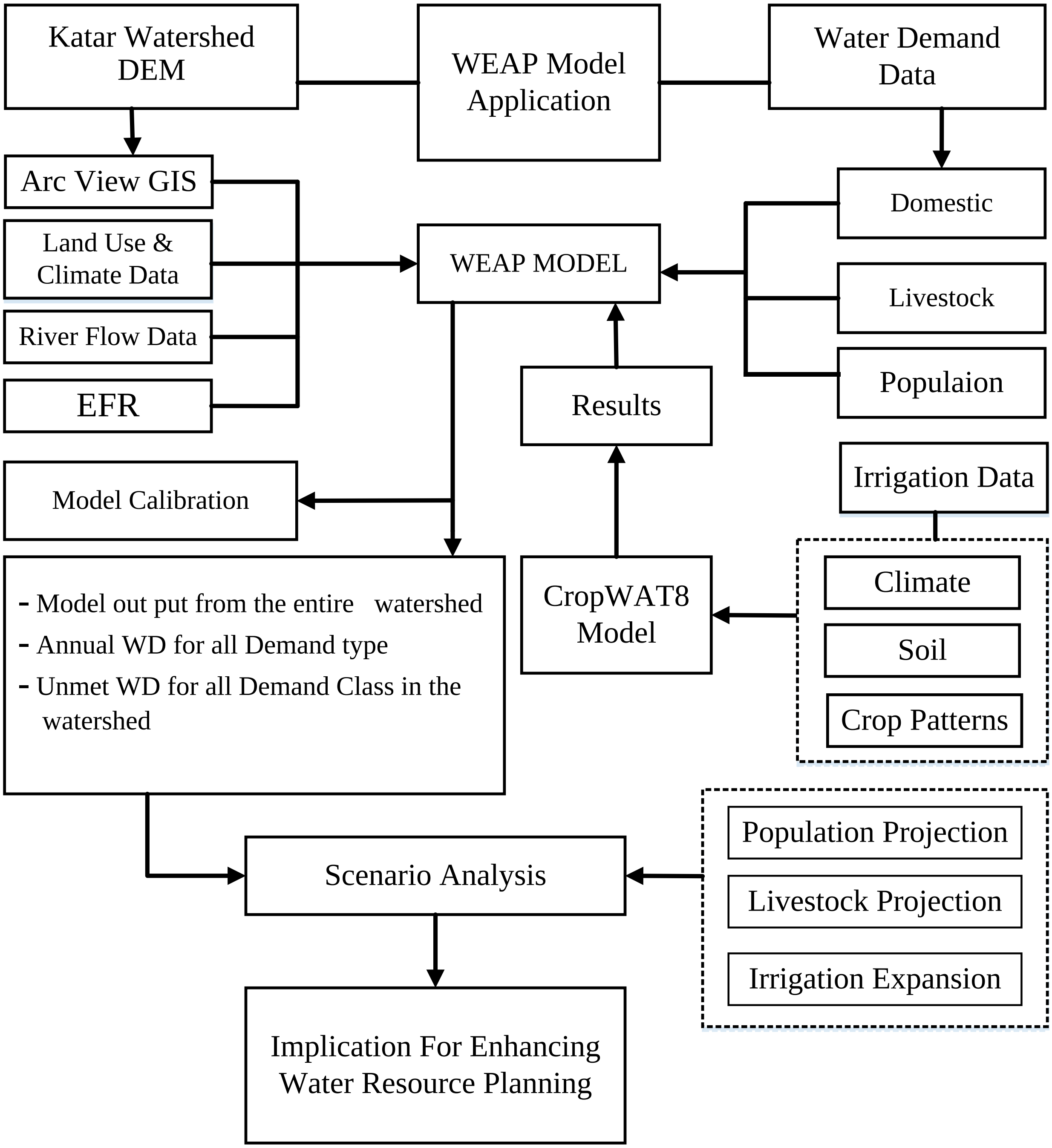


Figure 3.9: General framework flowchart for water demand modeling

3.7 Calibration of WEAP Model

WEAP includes a linkage to a parameter estimation tool (PEST) that allows the user to automate the process of comparing WEAP outputs to historical observations and modifying model parameters to improve its accuracy. Parameter Estimation Tool (PEST) is a computer software, for model-independent parameter estimation and uncertainty analysis. PEST is able to ‘‘take control’’ of a model, running it as many times as it needs to while adjusting its parameters until the discrepancies between selected model outputs and a complementary set of field or laboratory measurements is reduced to a minimum in the weighted least squares sense (SEI, 2016)

The WEAP model was calibrated using the observed streamflow data. NSE is commonly used for measuring the goodness of fit in hydrological modeling. It defines the relative magnitude of the residual variance (noise) compared to the observed data variance. The NSE combines the correlation of observed and simulated data, and also averages and standard deviations, which is calculated as given by Equation (3.7). The NSE coefficient ranges between -∞ and 1.0. Values of NSE is between 0.0 and 1.0 indicates that the performance of the method is at an acceptable level. However, if it is lower than 0, it indicates that the simulated value is worse than the mean observed value, so model performance cannot be accepted (Yaykiran *et al.*, 2019 & Tena *et al.,* 2019).

$$\mathrm{NSE} = 1 - \left[\frac{\sum(\mathrm{Q_{obs}} - \mathrm{Q_{sim}})^2}{\sum(\mathrm{Q_{obs}} - \mathrm{Q_{obs}})^2}\right] \qquad 3.7$$

NSE is a useful one-value indicator of model performance, it is biased by high flows. Additionally, it only captures certain aspects of the model flow deviations from observed. To fully understand and evaluate model performance, NSE must be used in conjunction with other metrics that consider seasonal variation, flow duration curves, and annual totals of the modeled and observed flows. To this end, considering the ratio of the root mean squared error to the standard deviation (RSR) as a measure of how much the simulated flows deviated from the observed hydrographs was important. consider the ratio of simulated versus observed flow standard deviation (SDR) as a measure of how well the simulated flows match the flow variability within the historical record. Lastly, see the percent bias (PBIAS) as a measure of the model’s ability to match the total volume of the flow. In general, the model can be judged as satisfactory if the NSE ≥ 0.5, PBIAS ±25%, RSR ≤ 0.7, and 0.9 ≤ SDR ≤ 1.1 (World Bank , 2017). The equations for PBIAS, RSR, and SDR are given in Eqs. (3.8), (3.9) and (3.10), respectively.

$$\mathrm{PBIAS} = 100 * \left[\frac{\sum(\mathrm{Q_{obs}} - \mathrm{Q_{sim}})}{\sum(\mathrm{Q_{obs}})}\right] \qquad 3.8$$

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\left[\sqrt{\Sigma(\mathrm{Q_{obs}}-\mathrm{Q_{sim}})^2}\right]}{\left[\sqrt{\Sigma(\mathrm{Q_{obs}}-\bar{\mathrm{Q}}_{\mathrm{obs}})^2}\right]} \tag{3.9}$$

$$\mathrm{SDR} = \frac{\mathrm{STDEV_{\,sim}}}{\mathrm{STDEV_{\,obs}}} = \frac{\left[\sqrt{\Sigma(\mathrm{Q_{sim}}-\bar{\mathrm{Q}}_{\mathrm{sim}})^2}\right]}{\sqrt{\Sigma(\mathrm{Q_{obs}}-\bar{\mathrm{Q}}_{\mathrm{obs}})^2}} \tag{3.10}$$

where: Q_{obs} = Observed Flow Rates, Q_{sim} =Flow Rate Model Results and $\bar{Q}$ =Average Flow Rate Values.

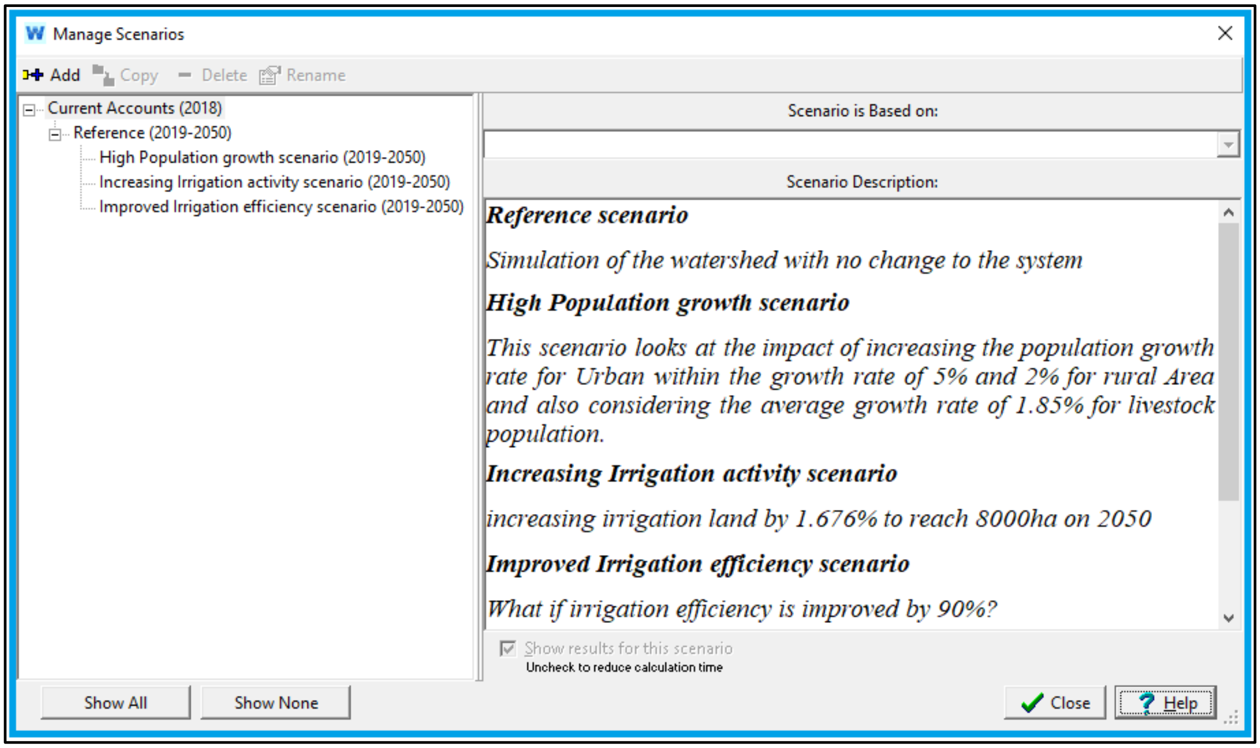
3.8 Estimation of Environmental Flow

In rift valley river basin, the minimum environmental flow has not been established as standard to allocate water for the environment. Due to this reason, the minimum environmental flow was determined by flow duration curve which was the common method in determining environmental flows using the 90% flow (Q_{90}) as the minimum environmental flow. The basic time unit used in preparing a flow duration curve was determined by sorting average monthly discharges for period of record from the largest value to the smallest, involving a total of n values. The sorted daily discharge values are assigned a rank (M) starting with 1 for the largest and the probability of exceedance (P) calculated by equation (3.11)

$$\mathrm{P} = \left[\frac{\mathrm{M}}{(\mathrm{n}+1)}\right] * 100 \tag{3.11}$$

3.9 Scenario Development

A scenario can be defined as a reasonable description of how the future may develop, based on a coherent and internally consistent set of assumptions about key relationships and driving forces. Scenarios are neither predictions nor forecasts. Since it is not possible to predict exactly how the water demands and other factors that affect water resources are going to change in the future it was decided to use scenarios in the current study. Scenarios are self-consistent storylines of how a future system might evolve over time in a particular socioeconomic setting and under a particular set of policy and technological conditions (Sieber & Purkey, 2015). Using the WEAP model, scenarios can be built and then compared to assess water requirements, costs and environmental impacts. All scenarios start from a common year for which the current accounts data is established.



Reference scenario

Simulation of the watershed with no change to the system

High Population growth scenario

This scenario looks at the impact of increasing the population growth rate for Urban within the growth rate of 5% and 2% for rural Area and also considering the average growth rate of 1.85% for livestock population.

Increasing Irrigation activity scenario

increasing irrigation land by 1.676% to reach 8000ha on 2050

Improved Irrigation efficiency scenario

What if irrigation efficiency is improved by 90%?

Figure 3.10: Scenario development within the WEAP model

3.9.1 Reference Scenario

In this study reference scenario was applied to analyze the situation of Katar watershed without any development change in the system except the population growth rate. For the reference Scenario in the next 30 years from 2020-2050 the population growth rate within the interval of ten years are (5.2, 2.2), (4.2, 1.6), (3.5, 0.6) percent for Urban and Rural respectively as discussed in table 3.4. But for this particular study the average percentage growth rate was used, which was 4.3% for Urban and 1.48% Rural to extend the number of population in watershed. The annual growth rate for livestock population shows decrease in percentage due this constant number of population was considered for this scenario. See the projected number of population for urban and rural under this scenario in Appendix B.

3.9.2 High Population Growth Scenario

After analyzing the possible impact in current scenarios WEAP was configured in high growth scenario, these scenario is targeted to evaluate the impact of a population growth rate and extended irrigated area by the same pattern in the watershed. High growth scenario it is assumed that, what if population growth rate for livestock, rural and urban are growing by 1.85%, 5% and 2% per annum respectively. See the projected number of population under HPGS in Appendix C

3.9.3 Increase in Irrigation Activities Scenario

Currently, the irrigation activities in the watershed are not well developed relative to the land that should be irrigated. Therefore, this scenario assumes if the non-licensed irrigation land is considered and irrigable area will be expanded by 1.676% per annual to reach 8000ha on 2050. See appendix D for increased irrigation activity on each year under this scenario.

3.9.4 Improved Irrigation Efficiency

This scenario was modeled to assess the impact of improved irrigation efficiency, well managed surface irrigation methods that implement technologies which deliver water directly to the root zone, like drip irrigation that saves a large volume of water by reducing seepage and evaporation losses, and what if the overall irrigation scheme efficiency of 90% can be attained.

4. RESULTS AND DISCUSSIONS

4.1 Computing Water Use Rate

4.1.1 Domestic Water Demands

The current water demand for domestic in the Katar watershed is estimated about 16.07 Mm^3, and with the total population of 1,099,335 (2018). Over the last year from 2010 to 2017 the population growth rate of the study area was 2.2% for rural and 6.2% for urban per annum.

Table 4.1: Domestic water demand for year 2018

Katar Watershed	2018	
	Rural	Urban
Population Number	958586	140749
Demand per Capita(l/d)	31.25	100
water demand(Mm3/yr)	10.93	5.14
Total Water Demand	16.07	

Currently the total livestock population in Katar Watershed is 2,340,610 and 17.25 Mm^3 in annual water demand as shown in Table 4.2.

Table 4.2: Livestock water consumption in year 2018 (AZLFDO, 2018)

Kinds of Animals	Number	Consumption (l/animal/d)	Total consumption (m^3/d)	Total consumption (Mm^3)
Cattle	1124060	30	33721.80	12.31
goat	171008	5	855.02	0.31
Sheep	747801	5	3739.01	1.36
Donkey	146498	30	4394.94	1.60
Horse	142714	30	4281.42	1.56
mule	8529	30	258.87	0.09
Total	2340610		47251.05	17.25

4.1.2 Environmental Flow Requirement

In order to maintain the ecological services as well as the natural channel habitat associated to the historic flow regimes of Katar River, a certain reserve flow has to be maintained and could be considered as a sectors demand on its own.

Studies indicate that environmental flows vary from year to year, depending on rainfall, where it ranges from between 15.7% to 33.5% of the annual flow, in dry seasons going up to 78% of the natural river flow (Shumet & Mengistu, 2016). In Ethiopia, like other developing nations environmental flow research is new and has not developed very much, but the Ethiopian water resources management policy recognizes that water is a basic for human and livestock needs as well as the environmental reserve as highest priority water users with regard to water allocation. Despite this provision, there is no standard method or national framework for environmental flows estimation.

However, lack of standard method or framework for environmental flows does not mean that the environmental flow component is totally ignored during design and implementation of water resources projects. Due to this, in this study EFR was estimated by using flow duration curve.The EFR studies done so far in Ethiopia in the Blue Nile river basin indicated that 21–28% of the mean annual flow may be sufficient to sustain basic ecological functioning (Teklu *et al*., 2019). From the Figure 4.1. The 90 % flow of Katar river was estimated as 2.40 m^3/sec, this flow is equivalent to 6.221 Mm^3 per month and maximum annual is 75.7 Mm^3 and it was account 26.90% of total stream flow flowing in the river throughout the year. During the high flow of river in rain season the EFR demand coverage reached 100% while in dry season of the year specially in January and February the demand coverage goes to 95.7% and 94.0% respectively.

Therefore, during these two months of the year if additional source of water about 0.268 Mm^3 and 0.339 Mm^3 for January and February was utilized, the demand coverage can have reached 100%. Flow has meet in the environmental water demand but in dry Season it is need to Priorities in the environment which can be alarm in unmet water demand.

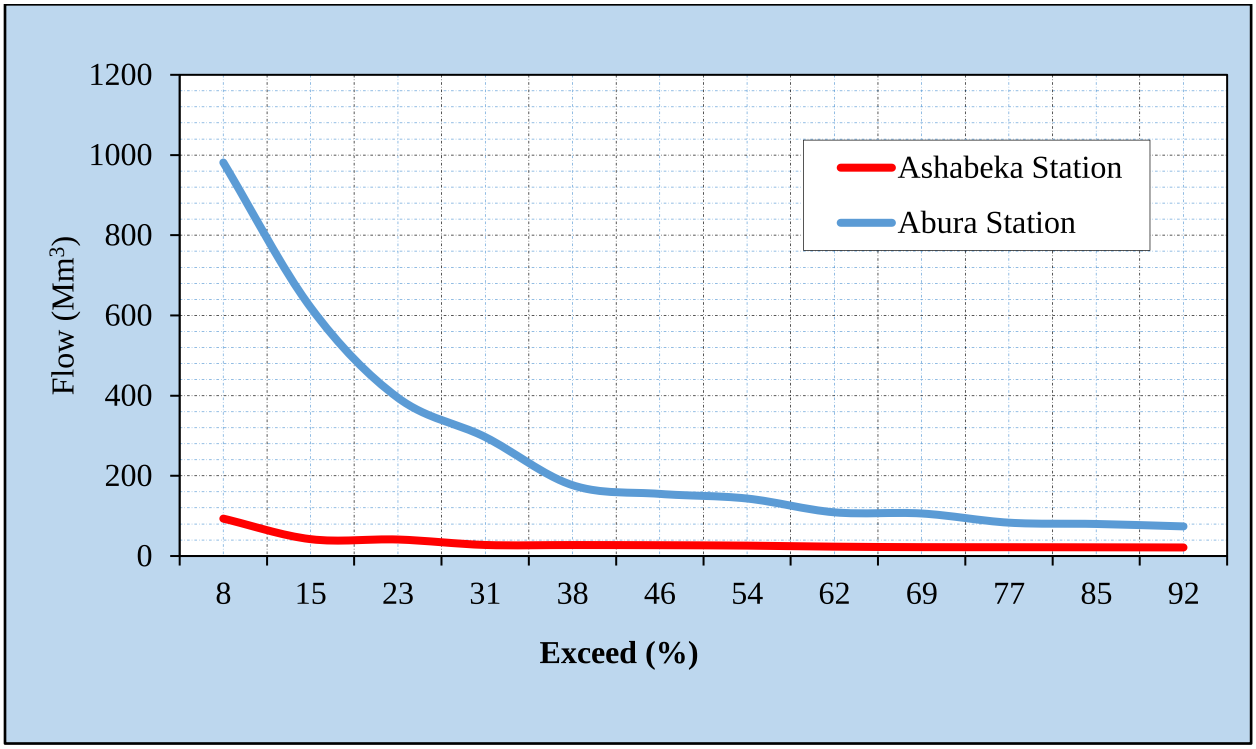


Figure 4.1: Flow duration curve of Ashebeka and Katar River

4.2 Model Performance

Calibration is an iterative exercise used to establish the most suitable parameter in modeling studies. It includes changing the model parameters and comparing the model output and observed flow values through statistical parameters to simulate a better historic patterns (Jariwala & Vadher, 2016). Calibration of the WEAP model was based on the stream flow at the Abura gauging station with relative to the simulated runoff obtained from the entire watershed for the period 1987-2017. The statistical measures commonly used were the coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE), Percent of Bias (PBIAS), Ratio of Standard Deviation of Simulated Versus Observed (SDR) and Ratio of the Root Mean Squared Error to the Standard Deviation (RSR).

Table 4.3: Continuous statistical analysis values of the model performance

Standard Statistical Parameters Range	Continuous Statistical Analysis Values	Remarks
$NSE \geq 0.5$	NSE = 0.971	Ok!
PBIAS ±25%	PBIAS =-9.38%	Ok!
$RSR \leq 0.7$	RSR = 0.158	Ok!
$0.9 \leq SDR \leq 1.1$	SDR =1.1	Ok!

From Table 4.3, it can be observed that the analyzed Statistical Parameters were lies in the accepted Range of interval. Hence, there is good match between simulated and observed flow values.

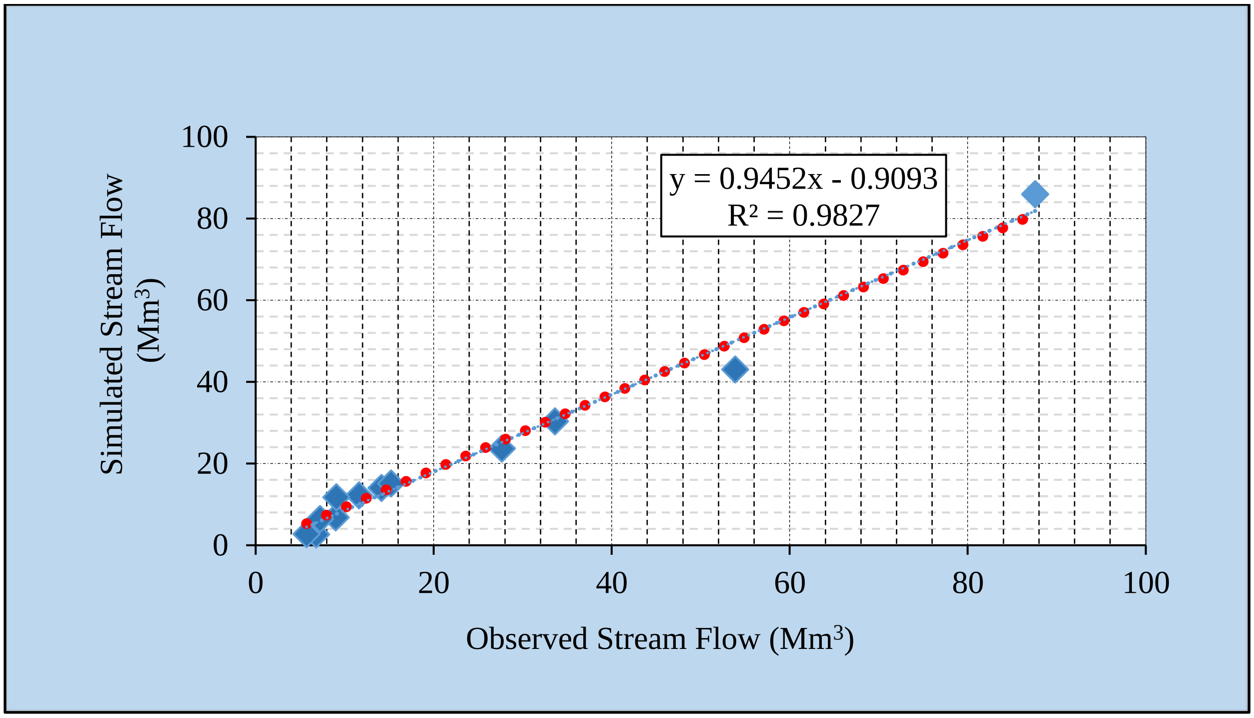
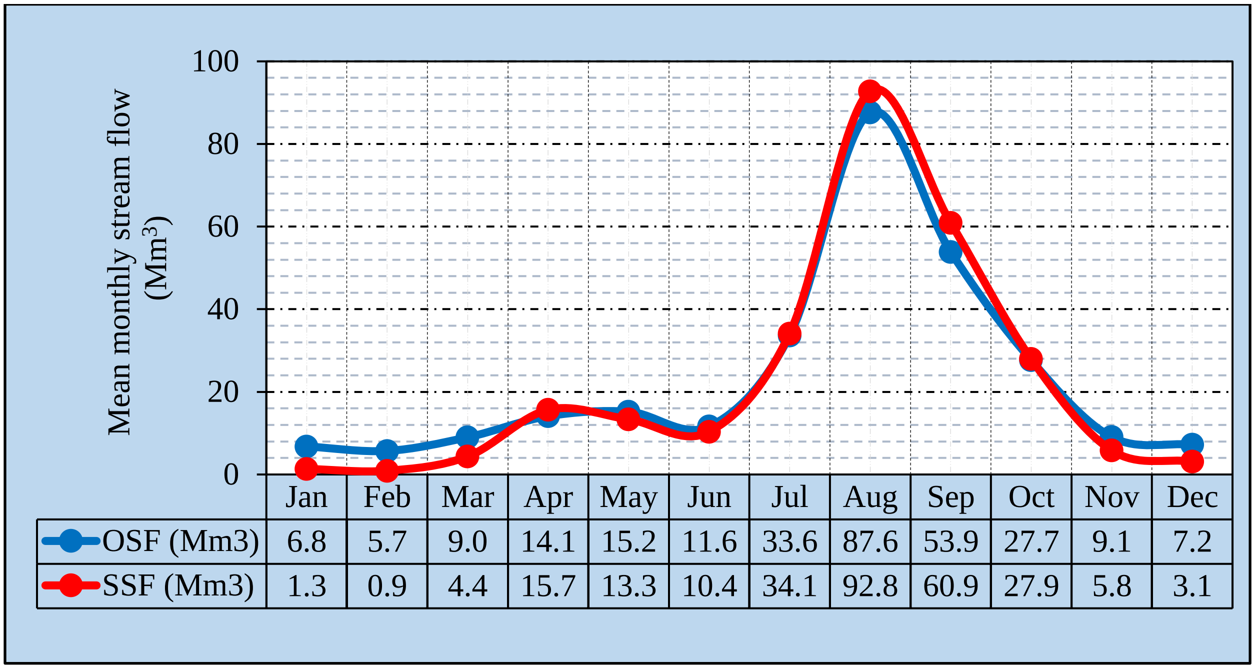


Figure 4.2: Mean Monthly Observed and Simulated Stream Flows linear fitting

From Figure 4.2 based on the model performance evaluation parameter numerical values of determination coefficient ($R^2 = 0.9827$) and Nash-Sutcliff's simulation efficiency (NSE = 0.971) assures that the model shows a good performance during calibration so it was valid to simulate the runoff in the study area.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
OSF (Mm3)	6.8	5.7	9.0	14.1	15.2	11.6	33.6	87.6	53.9	27.7	9.1	7.2
SSF (Mm3)	1.3	0.9	4.4	15.7	13.3	10.4	34.1	92.8	60.9	27.9	5.8	3.1

Figure 4.3: WEAP model stream flow calibration result at Abura station

Generally, the statistical parameters seen between the simulated and observed values indicate that the WEAP model can be efficiently applicable for water resource management and best strategic plan for enhancing economic improvement if the situation examined in this study would have been perfectly put into practice for the future development related to water resource in Katar watershed.

4.3 Watershed Simulation Method

The river system was schematized from an ArcView GIS layer. The runoff from the sub-watershed nodes in WEAP21 represented the head flow of the streams. There are five methods to simulated the catchment. These are: Rainfall Runoff Method (Simplified Coefficient Method), Irrigation Demands Only Method (Simplified Coefficient Method), Rainfall Runoff Method (Soil Moisture Method), MABIA Method (FAO 56, Dual Kc, Daily) and Plant Growth Method (PGM). In this study to calculate the runoff the rainfall-runoff method was used to simulate watershed processes (runoff). This method defines land use by crop coefficients, Kc, sub watershed area and effective precipitation while the climate is defined by precipitation and reference evapotranspiration, ETo. The Rainfall Runoff method also determines evapotranspiration for irrigated and rain fed crops using crop coefficients, the same as in the Irrigation Demands Only method. The remainder of rainfall not consumed by evapotranspiration is simulated as runoff to a river, or can be proportioned among runoff to a river and flow to groundwater via runoff/infiltration links

4.4 Katar Watershed Water Resources

The total annual flow of the Katar watershed amounts to 281.4 Mm^3 at its downstream end at Abura Stream flow gauge station before it joins the Dambal lake. It can be seen from figure 4.4 the minimum flow occurs in the month of February and peak flows occur from July to September.

Out of the mean annual surface runoff of the sub-basin, 76.17% of the runoff is generated from June to October and the rest 20.62% of the surface runoff is generated from December to May. About 55. 20% the mean annual surface runoff of the sub-basin is produced from the heavy rainy months (i.e. July, August and September).

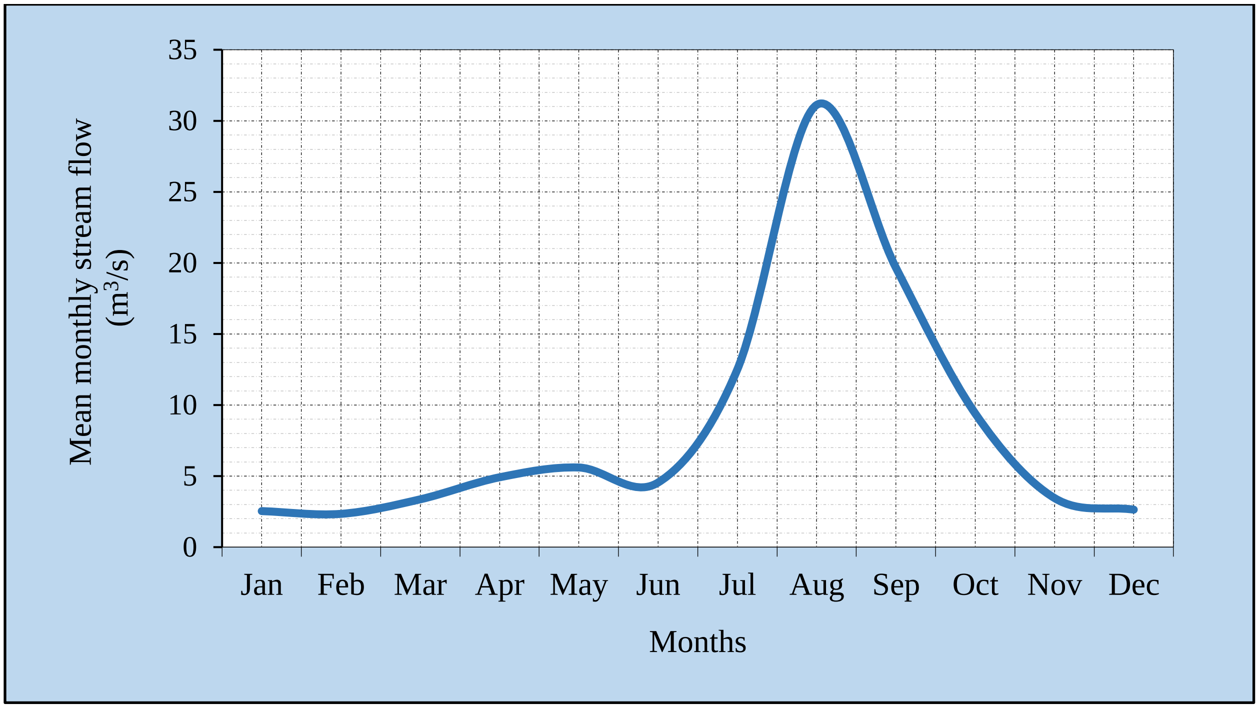


Figure 4.4: Stream Flow at Abura Gauge Station

4.5 Water Demand of the Year 2018

The annual water demands for agriculture, livestock, urban and rural for the year 2018 in Katar watershed are presented in Figure 4.5. The demand shows that most of the water, about 37.18%, was utilized for agricultural activities. The livestock, rural and urban demands were 28.16, 34.50 and 0.17% respectively.

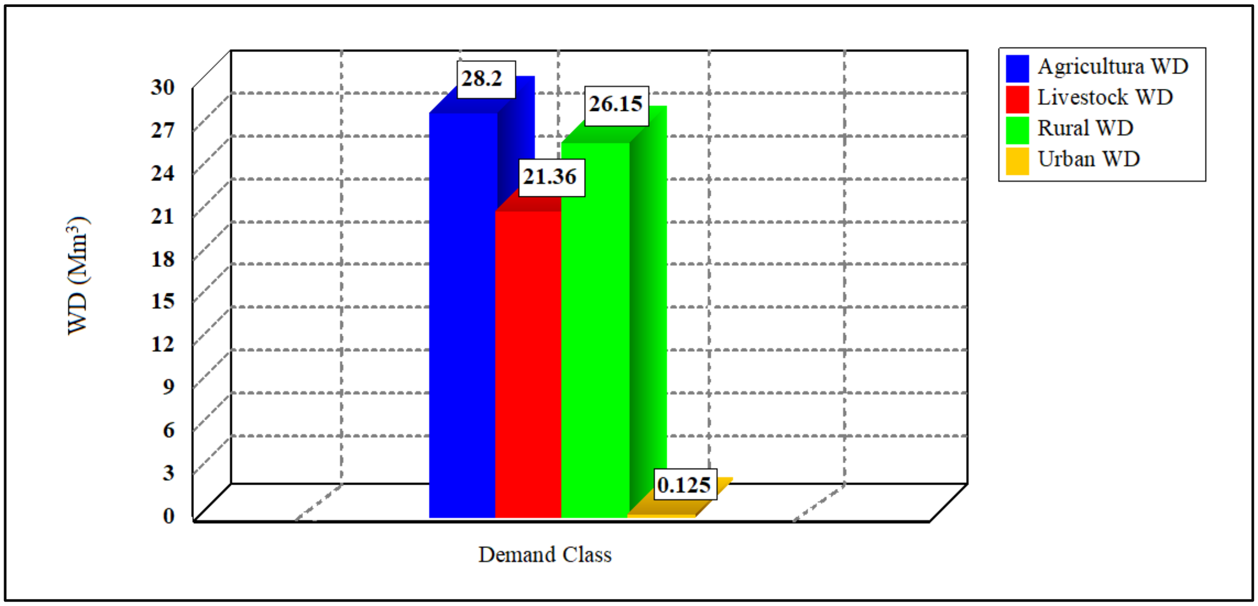


Figure 4.5: Annual water demand of year 2018

4.5.1 Unmet Water Demand in the Year 2018

The unmet demand result shows that urban and rural demand sites were fully provided during each month of the year except in case of agriculture and livestock which had got averagely unmet demand of 2.025 (12.98%) and 0.289 Mm^3 (8.35%) in January and February respectively. This implies that the overall coverage of supply during these two months were 87.025% and 91.65% respectively as shown in Figure 4.6. Generally, the result obtained for 2018 in this study on water demand coverage were exceeded the GTP-2 plan which targets to attain 75%, 60% and 73% water demand coverage for rural, urban and total respectively by the year 2018. This is because of the modeling of water demand in this study did not covered the large scale of irrigation project and small water demand sectors at each community level stage. This leads to the conclusion the estimation obtained in this study was exceeded the GTP-2 plan because of the estimation did not include deep study at small stakeholder's level.

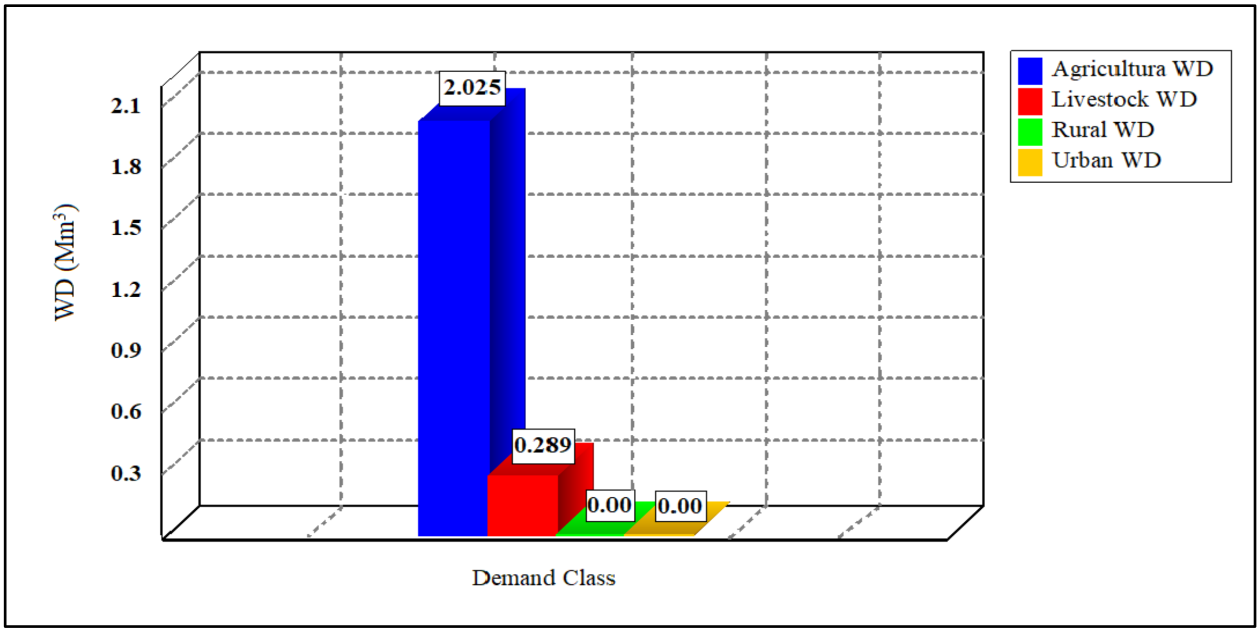


Figure 4.6: The unmet demand class in Year 2018

4.6 Water Demand Patterns for High Population Growth Scenario

Under this scenario the population growth rate was raised to 2% and 5% for rural and urban respectively to simulate the water supply demand pattern for (2019-2050).

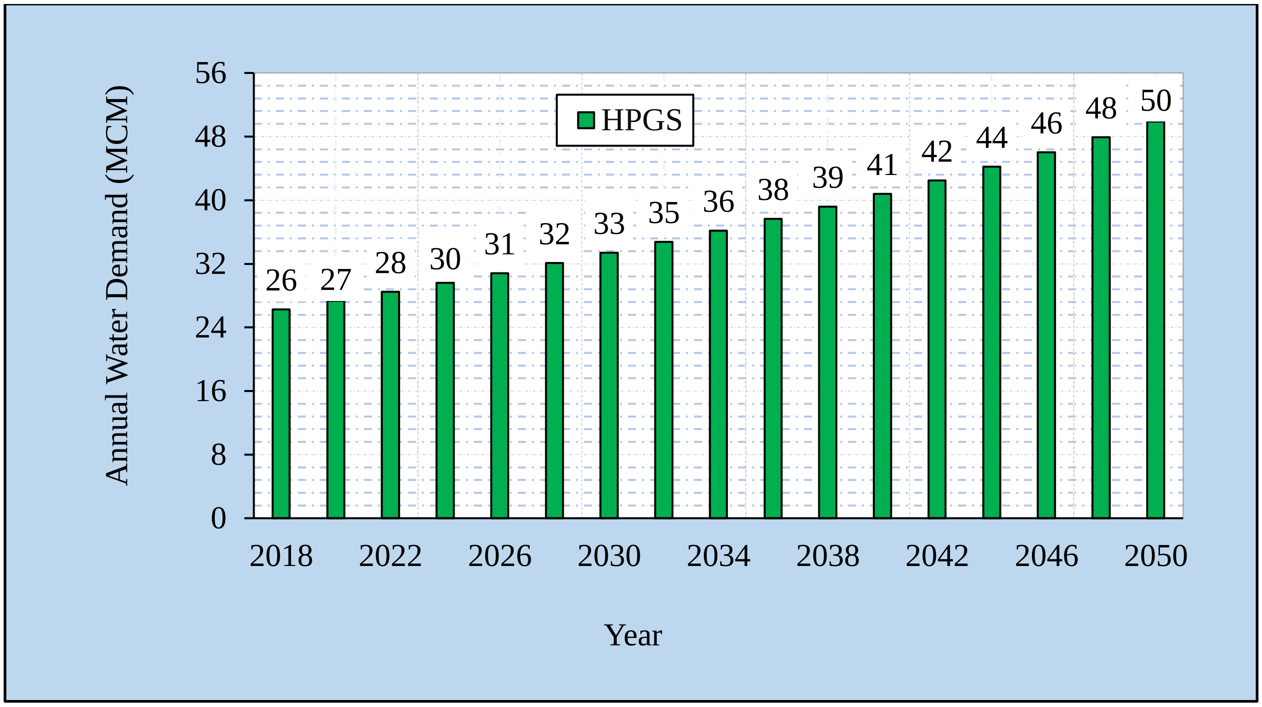
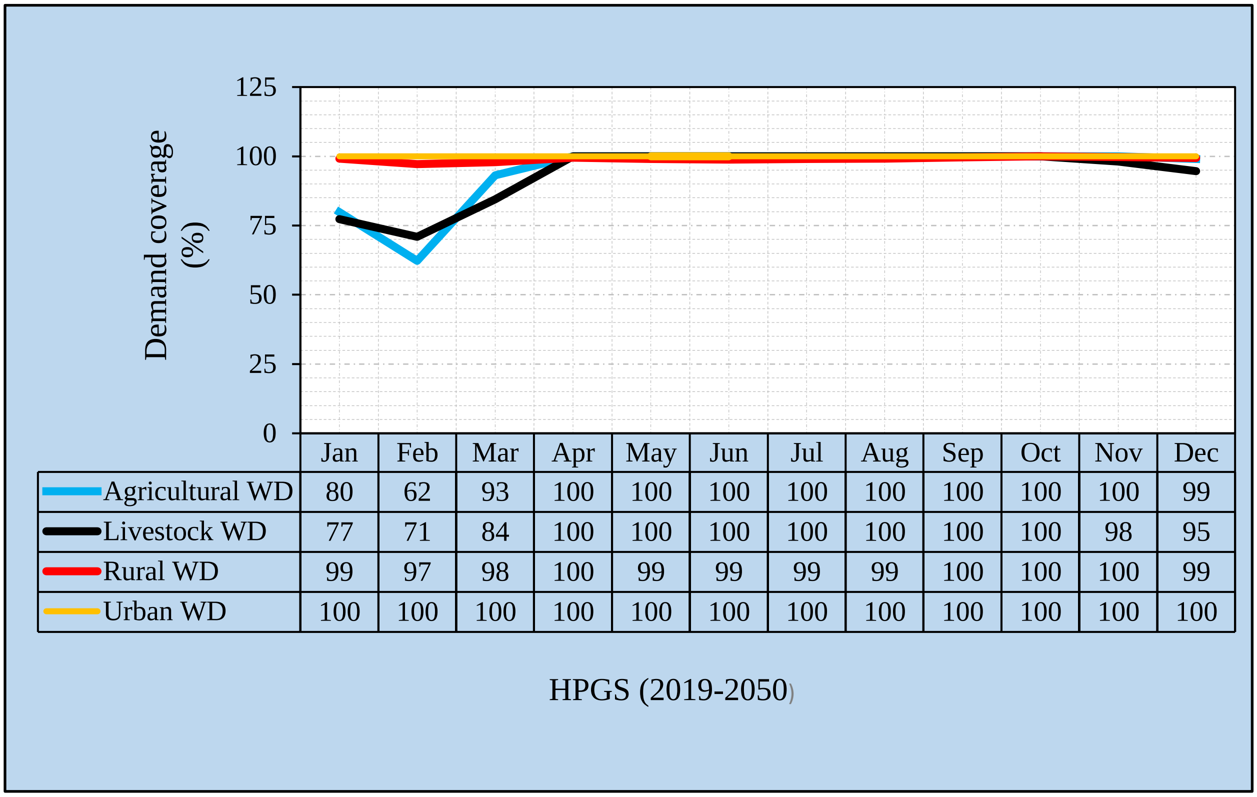


Figure 4.7: The water demand patterns under high population growth scenario

As illustrated in Figure 4.7, the water demand will be increased by double on 2050 when compare to the year 2018 water demand situation. On the other hand, if compare high population growth scenario with respect to the reference scenario there is an increment of water demand by 20% on the year 2050. So as water becomes more valuable, water use is expected to be more economical if including reuse and recycling to overcome the problem connected to water demand.

4.6.1 Annual Unmet Water Demands for High Population Growth Scenario

As indicated in Figure 4.8, the result obtained from the model shows that there was the water shortage for all water use sectors in the watershed during dry season except for the urban. Under a high population growth scenario, the unmet demand occurred from December to March and this accounts to 7.53% of the total water demand in the scenario. For annual unmet demand for period (2019-2050) see Appendix F and Appendix G



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural WD	80	62	93	100	100	100	100	100	100	100	100	99
Livestock WD	77	71	84	100	100	100	100	100	100	100	98	95
Rural WD	99	97	98	100	99	99	99	99	100	100	100	99
Urban WD	100	100	100	100	100	100	100	100	100	100	100	100

Figure 4.8: Monthly average demand node coverage (%)

4.7 Increasing Irrigation Activity Scenario

By 2050, in order to meet growing demand for food, agricultural production will have to increase by 60 percent. Particularly for developing countries to bring strong production levels the irrigation activities must be doubling in South Asia and tripling in sub Saharan Africa (FAO, 2017).

Irrigated agriculture, moreover, plays important role because it is generally two to three times more productive than rain-fed agriculture (Emami & Koch, 2018). But in katar watershed still rain-fed irrigation system was dominant this intern cannot fully cover the food needs of the watershed as well as extra production for exports. This situation leads to the conclusion if the land suitable for irrigation areas are fully developed what will be happen on the water demand pattern of the watershed?

As shown in Figure 4.9 the monthly average water demand is increasing by 32.27% from reference scenario to increasing Irrigation activity scenario that is from 28.2 to 37.3 Mm^3. This percentage of increase relatively approaching to the assessment done by (Boretti & Rosa, 2019) the global water demand for all uses, will be increased by 20 to 30% on 2050. The averagely water supply demand coverage during dry season of the year in increasing irrigation activity scenario estimated to be 80.10%.

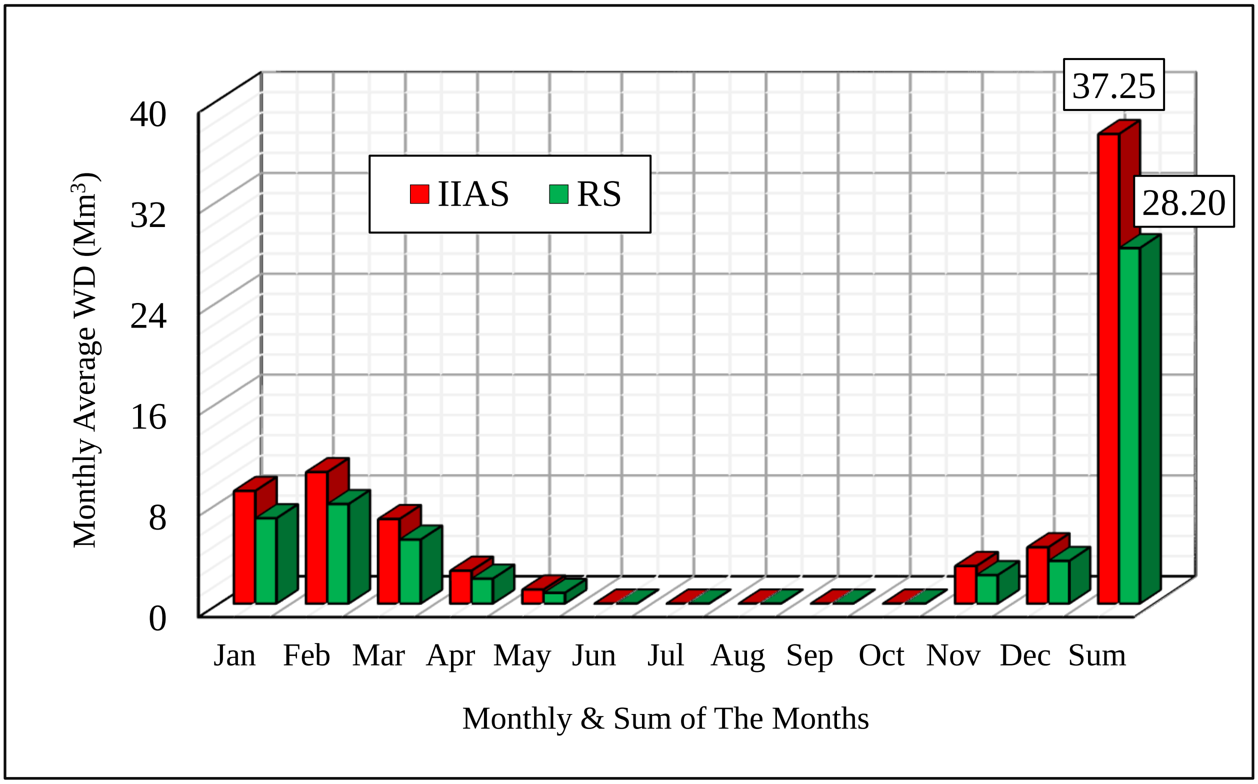
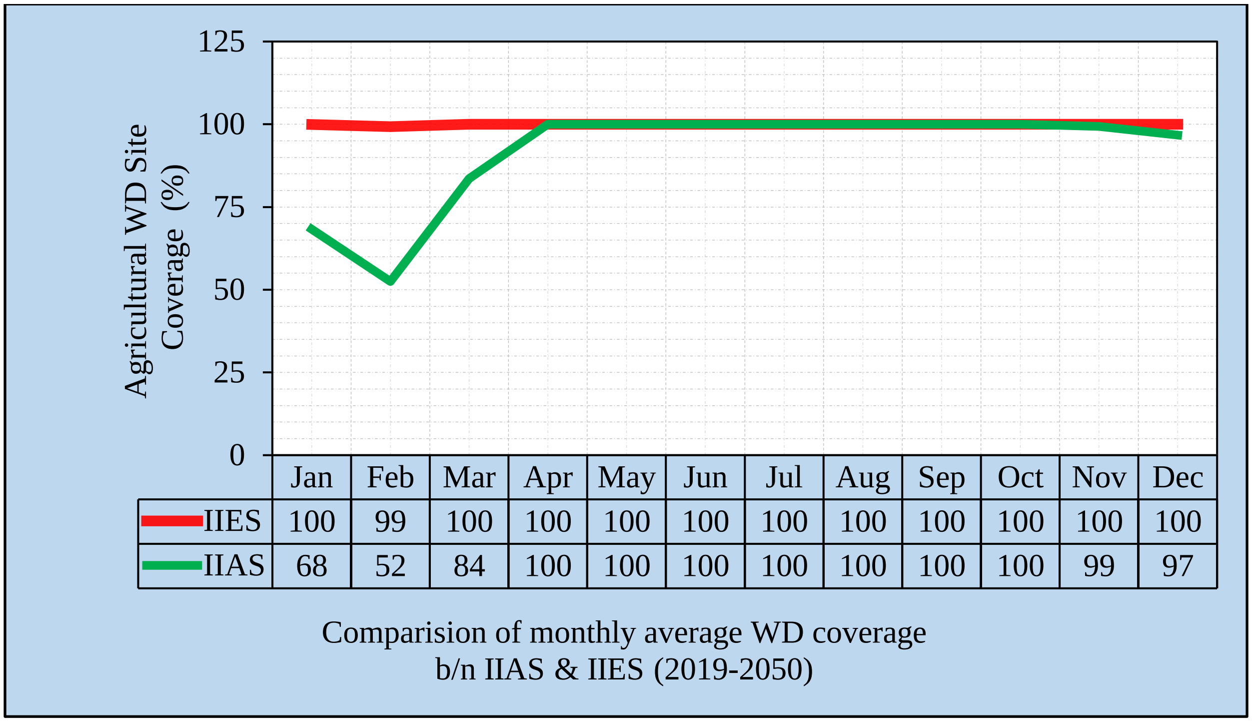


Figure 4.9: Comparisons of IIAS to Reference Scenario

4.8 Improved Irrigation Efficiency Scenario

In this case, the impact of changing irrigation methods on irrigation water demand is analyzed. As the irrigation techniques are improved and irrigation methods are changed from flooding of water through un lined canal to either sprinkler or drip irrigation methods, the irrigation water demand will be decreases, because a sprinkler irrigation system (saves 35% of agricultural water demand), a drip irrigation system (saves 25% of agricultural water demand) and Canal lining (may reduce seepage losses by as much as 50%) (Hassan *et al.*, 2017). Therefore, applying improved irrigation techniques from year to year by using new technological approaches to decrease the irrigation water demand is very essential.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟥 IIES	100	99	100	100	100	100	100	100	100	100	100	100
🟩 IIAS	68	52	84	100	100	100	100	100	100	100	99	97

Figure 4.10: Agricultural Sector WD coverage

Figure 4.10 shows the irrigation water demand coverage will increase as the irrigation techniques are improved and new technological approaches were involved. Improved irrigation efficiency scenario indicates that irrigation water demand during dry season of increasing irrigation activity scenario are adjusted to well fitted demand coverage condition. In December, January, February and March coverage are increased from (97-100%), (68-100%), (52-99%) and (84-100%) respectively. Clear and consistent results from the scenario analysis indicate that using efficient irrigation technique can improve water demand coverage. Demand coverages for urban, rural and livestock were also indicated in Appendix H.

4.9 Comparisons with Among Different Scenarios

After analyzing the 2018 baseline data and the impact of the river flow, the WEAP model was configured for the reference scenario, high population growth scenario, increasing irrigation activity scenario and improved irrigation efficiency scenario. From the model result the average annual unmet demands over the 31 years of hydrology were 5.87 Mm^3 (1.70% of the total annual demand), 6.403 Mm^3 (1.86% of the total annual demand), 10.84 Mm^3 (3.14% of the total annual demand) and 0.24 Mm^3 (0.069% of the total annual demand) for reference scenarios, high population growth scenario, increasing irrigation activity scenario and improved irrigation efficiency scenario respectively. The Table 4.4 shows that the greatest shortfalls for all scenarios were experienced during the January and February where the river flow is low. For annually patterns see Appendix G.

Table 4.4: Comparison of monthly average WD and UWD under all scenarios

Months	Monthly average WD (Mm^3)				Monthly average UWD (Mm^3)			
	HPGS	IIES	IIAS	RS	HPGS	IIES	IIAS	RS
Jan	11.708	11.439	13.612	11.439	1.80	0.00	3.30	1.70
Feb	12.397	12.151	14.686	12.151	3.50	0.10	5.60	3.40
Mar	10.016	9.747	11.377	9.747	0.70	0.00	1.50	0.60
Apr	6.755	6.494	7.128	6.494	0.00	0.00	0.00	0.00
May	5.786	5.517	5.788	5.517	0.00	0.00	0.00	0.00
Jun	4.781	4.520	4.520	4.520	0.00	0.00	0.00	0.00
Jul	4.940	4.671	4.671	4.671	0.00	0.00	0.00	0.00
Aug	4.940	4.671	4.671	4.671	0.00	0.00	0.00	0.00
Sep	4.781	4.520	4.520	4.520	0.00	0.00	0.00	0.00
Oct	4.940	4.671	4.671	4.671	0.00	0.00	0.00	0.00
Nov	7.037	6.776	7.500	6.776	0.00	0.00	0.10	0.00
Dec	8.324	8.055	9.141	8.055	0.20	0.00	0.30	0.10
Sum	86.406	83.232	92.286	83.232	6.40	0.24	10.84	5.87

The model output for each scenarios shows that there is a huge water demand in the study area in the likely future development scenarios which is linearly an increase state since the annual activity level and fully ploughing of land for irrigation expansion in the area increased linearly. Due to these there will be a critical impact on the water resources availability of the watershed to fulfill their needs (demands). From Figure 4.11 it was indicated that the maximum water demand about 3045.42 Mm^3 is consumed by increasing irrigation activity scenario, HPGS on the other hand needs about 2851.39 Mm^3 and the IIES reduce the water demand to RS if simultaneously applying the best and economical irrigation techniques methods for future development. For all scenarios annual case of water demand situation see Appendix F

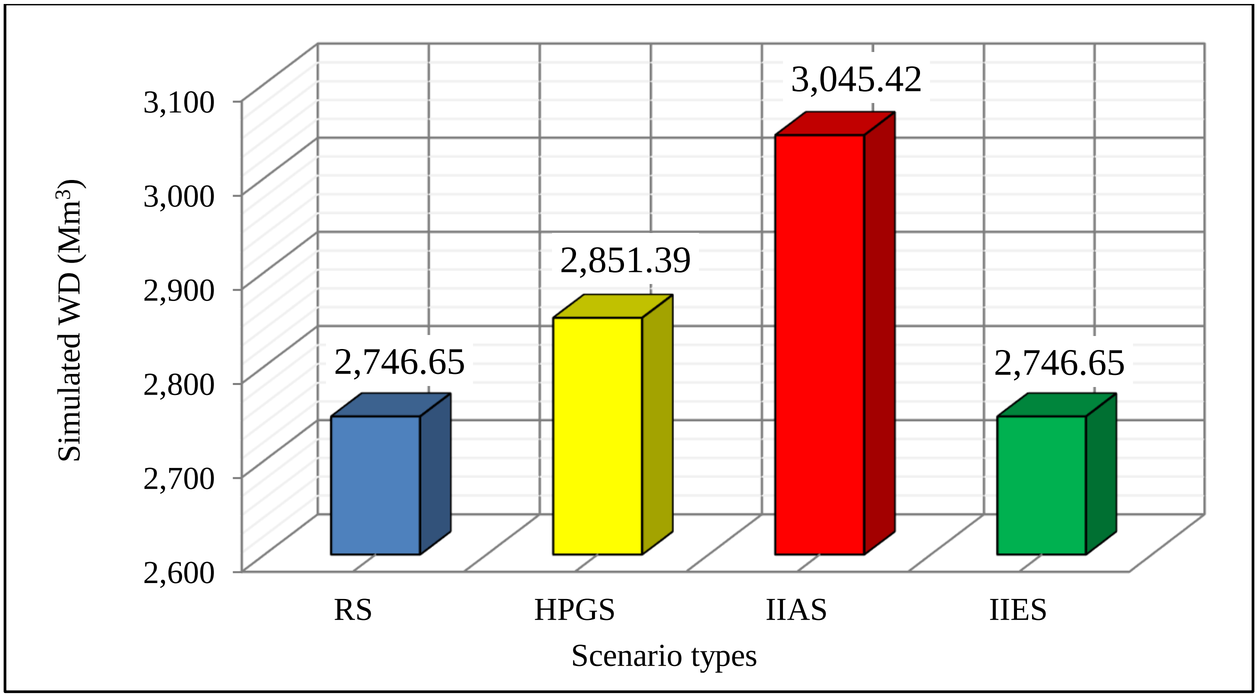


Figure 4.11: Comparison of total WD in (2019-2050)

As shown in Figure 4.12 under all scenarios analyzed in this study also indicates that increasing irrigation activity will face, about 47% of unmet demand in dry season of the year while high population growth and reference scenario unmet demands will account 27 and 25% during minimum rain fall season of the year respectively. But the improved irrigation efficiency scenario demand coverage can reach 99%. These value indicates that using the most efficient irrigation technique can improve the demand coverage of irrigation sector even in dry season of the year.

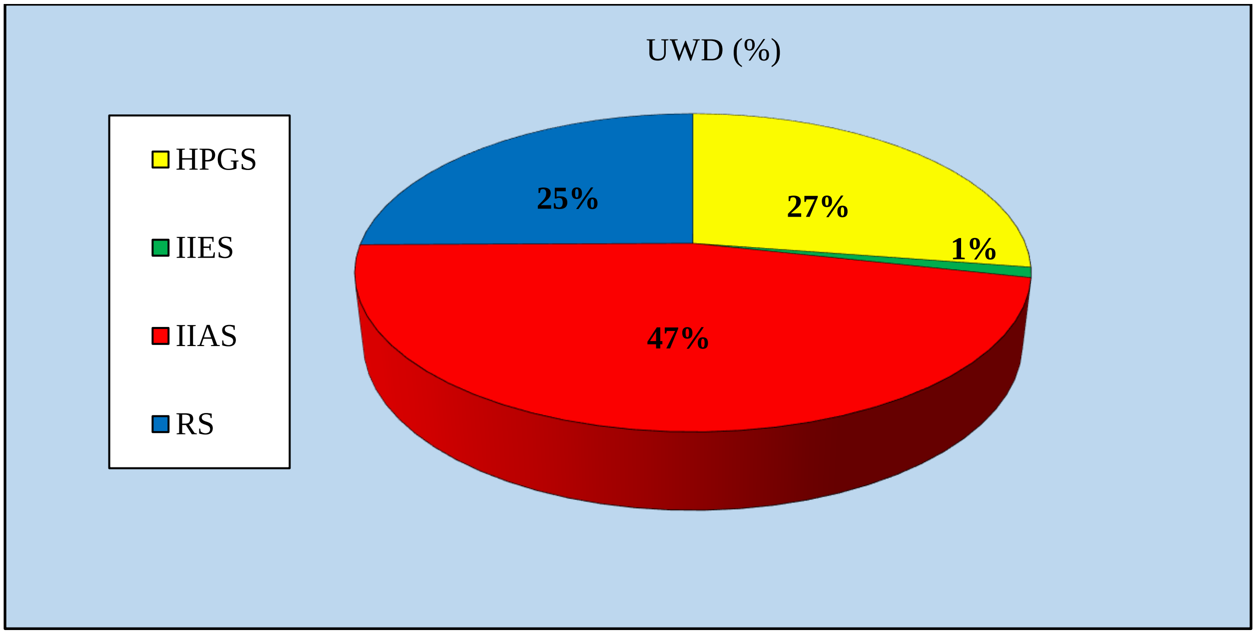


Figure 4.12: Comparison of monthly average UWD (%) in (2019-2050)

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was undertaken to modeling surface water demand balances in Katar watershed with Water Evaluation and Planning (WEAP21) model in terms of water demand, supply delivered, unmet demand and demand site coverage at sectoral level. The modeling of water supply and demand using WEAP was conducted based on the reference data of Year 2018. The modeling was based on four scenarios. For reference scenario, overall monthly average unmet demand was 5.9 Mm^3 and demand site coverage was 93% on 2050. For increasing irrigation activity scenario, overall monthly average unmet demand will rise to $10.8Mm^3$ and demand site coverage will be decreased to 88.30% during scenario period this is because of no additional supply with irrigation expansion.

On the other hand, applying the water to the farming land for irrigation as a flood can increase the water wastage that leads to the water demand coverage problem. Therefore, using improved irrigation techniques by applying new technological approaches is very essential to decrease the water wastage which interns increasing demand coverage.

In estimating the availability of water resources, consideration must be given to requirements for environmental flows to maintain the ecosystems of the river, to consider the obligations, and maintain streamflow levels of downstream users. The environmental flow of Katar watershed in this study was adopted 26.30% of the river flow to be allocated to the environment needs in order to fulfill the downstream requirement.

Under high population growth scenario, demand site coverage for all sectors under analysis will accounts 92.59%. For improved irrigation efficiency scenario, the demand coverage show that the unmet water demand will go to zero if the irrigation efficiency properly has been implemented.

Generally, this study output can be used for the different stakeholders in the watershed specially to encourage well fitted irrigation activities and water supply division on equal basis, so that food security can be achieved in the watershed as well as in the region.

5.2 Recommendations

Since the livelihoods and wellbeing of many people are directly dependent on the ecological character of the ecosystems, river basins, very careful consideration needs to be given to determining how the water is best utilized.

Division of the available water between upstream and downstream areas is often a problem encountered the water resource management sectors, this was raised from illegal obstruction of river water without considering the other water user sectors. Therefore, strengthening a good management between upstream and downstream is the condition that did not ask time.

Study should be conducted to determine water quality objectives and reserve flows for Katar river to enhance proper management and regulation, especially when the new proposed hydraulic structures projects in the upstream areas are proposed during the likely future development scenarios.

When unmet water demand increases, water supply coverage will decrease. This is an indication that dependence on surface water resources alone is not sufficient to satisfy the water demand. Thus, exploring groundwater, the reuse of wastewater and building storage reservoirs should be part of the solutions for long-term water use sustainability. Similar researches should be extended using higher resolution digital elevation models to see the variation in results of surface water availability which insure equitable water sharing patterns in the watershed.

This study did not cover all demand types found in the watershed for water demand modeling. Only two rivers and four demand nodes were involved in the estimation. Hence, researches should be conducted by considering detail demand types and small rivers drains to the Katar river in the watershed in order to figure out the full water demand patterns in the watershed for the future development.

Giving full awareness for irrigation sectors to use the most efficient irrigation technique in the watershed is the best way to solve the water demand coverage problem and to increase the productivity on the other hand.

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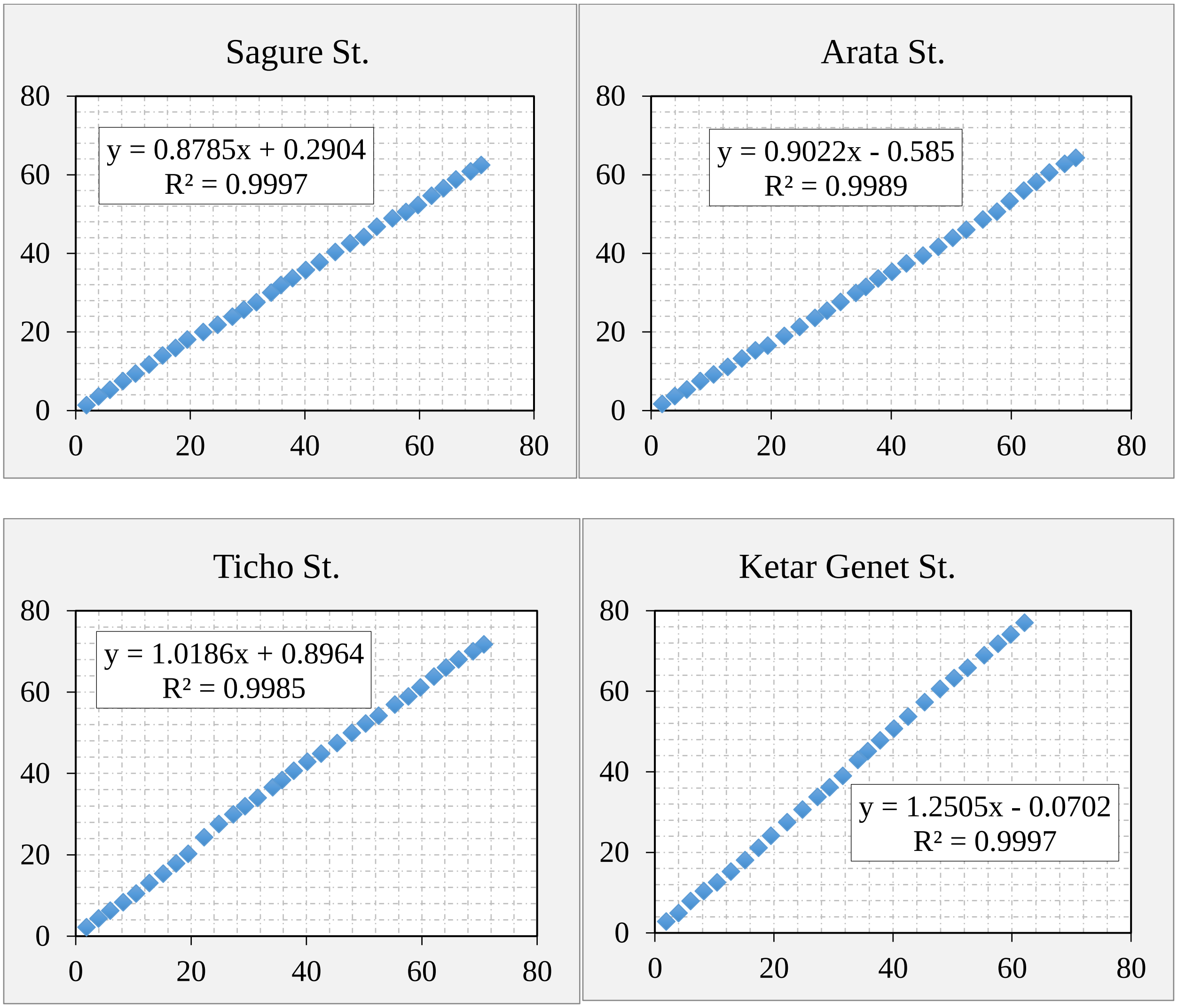
APPENDIX

APPENDIX A

The double mass curves for Areta, Ketar genet, Sagure and Ticho weather stations (mm).



APPENDIX B

Projected number of population for urban and rural area with their respective WD under RS (2019-2050)

Years	RS		WD under RS	
	Urban Population	Rural Population	Rural WD (Mm^3)	Urban WD (Mm^3)
2019	146801	972773	26.541	0.130
2020	153114	987170	26.934	0.136
2021	159698	1001780	27.333	0.141
2022	166565	1016607	27.737	0.147
2023	173727	1031652	28.148	0.154
2024	181197	1046921	28.564	0.160
2025	188989	1062415	28.987	0.167
2026	197115	1078139	29.416	0.174
2027	205591	1094095	29.851	0.182
2028	214431	1110288	30.293	0.190
2029	223652	1126720	30.741	0.198
2030	233269	1143396	31.196	0.206
2031	243300	1160318	31.658	0.215
2032	253761	1177491	32.127	0.225
2033	264673	1194918	32.602	0.234
2034	276054	1212602	33.085	0.244
2035	287924	1230549	33.574	0.255
2036	300305	1248761	34.071	0.266
2037	313218	1267243	34.575	0.277
2038	326687	1285998	35.087	0.289
2039	340734	1305031	35.606	0.302
2040	355386	1324345	36.133	0.315
2041	370667	1343945	36.668	0.328
2042	386606	1363836	37.211	0.342
2043	403230	1384021	37.762	0.357
2044	420569	1404504	38.320	0.372
2045	438654	1425291	38.888	0.388
2046	457516	1446385	39.463	0.405
2047	477189	1467792	40.047	0.422
2048	497708	1489515	40.640	0.440
2049	519109	1511560	41.241	0.459
2050	541431	1533931	41.852	0.479

APPENDIX C

Projected number of population for urban and rural with their WD under HPGS (2019-2050)

Years	HPGS		WD under HGS	
	Urban Population	Rural Population	Urban WD(Mm^3)	Rural WD(Mm^3)
2019	147786	977758	0.131	26.677
2020	155176	997313	0.137	27.211
2021	162935	1017259	0.144	27.755
2022	171081	1037604	0.151	28.310
2023	179635	1058356	0.159	28.876
2024	188617	1079524	0.167	29.454
2025	198048	1101114	0.175	30.043
2026	207950	1123136	0.184	30.644
2027	218348	1145599	0.193	31.257
2028	229265	1168511	0.203	31.882
2029	240729	1191881	0.213	32.519
2030	252765	1215719	0.224	33.170
2031	265403	1240033	0.235	33.833
2032	278673	1264834	0.247	34.510
2033	292607	1290131	0.259	35.200
2034	307237	1315933	0.272	35.904
2035	322599	1342252	0.286	36.622
2036	338729	1369097	0.300	37.354
2037	355666	1396479	0.315	38.102
2038	373449	1424408	0.331	38.864
2039	392121	1452897	0.347	39.641
2040	411728	1481954	0.364	40.434
2041	432314	1511594	0.383	41.242
2042	453930	1541825	0.402	42.067
2043	476626	1572662	0.422	42.909
2044	500457	1604115	0.443	43.767
2045	525480	1636197	0.465	44.642
2046	551754	1668921	0.488	45.535
2047	579342	1702300	0.513	46.446
2048	608309	1736346	0.538	47.374
2049	638725	1771073	0.565	48.322
2050	670661	1806494	0.594	49.288

APPENDIX D

Irrigated area in (ha), WD (Mm^3), UWD (Mm^3) and demand coverage in percent under increasing irrigation activity scenario

Years	Increasing Irrigation activity scenario			
	Irrigated area (ha)	Water Demand (Mm^3)	Unmet demand (Mm^3)	Demand coverage (%)
2019	4779	28.67	1.97	98
2020	4859	29.15	0.33	100
2021	4940	29.64	2.00	98
2022	5023	30.14	5.08	95
2023	5107	30.64	5.59	94
2024	5193	31.16	8.75	91
2025	5280	31.68	8.98	90
2026	5368	32.21	8.10	92
2027	5458	32.75	5.73	95
2028	5550	33.30	5.99	94
2029	5643	33.86	2.33	98
2030	5737	34.42	10.84	90
2031	5834	35.00	11.09	89
2032	5931	35.59	10.10	91
2033	6031	36.18	8.69	92
2034	6132	36.79	12.53	88
2035	6235	37.41	16.54	84
2036	6339	38.03	16.87	82
2037	6445	38.67	15.31	87
2038	6553	39.32	18.08	82
2039	6663	39.98	18.71	84
2040	6775	40.65	14.59	87
2041	6888	41.33	1.89	99
2042	7004	42.02	0.00	100
2043	7121	42.73	0.00	100
2044	7241	43.44	11.85	91
2045	7362	44.17	16.93	86
2046	7485	44.91	17.09	87
2047	7611	45.67	6.70	96
2048	7738	46.43	13.29	90
2049	7868	47.21	13.42	91
2050	8000	48.00	16.89	88

APPENDIX E

The calculated crop water requirements, irrigation schedules and Percentage of annual share for WEAP model input.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Barley	99.20	109.30	92.9	5.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.90
2. Spring Wheat	110.10	96.50	24.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.50	60.80
3. Sorghum (grain)	32.10	74.50	110.2	89.10	11.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4. Potato	111.00	105.40	48.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39.30	78.30
5. Maize (grain)	80.70	113.60	112.0	17.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.50
Net scheme irr. req.												
in mm/d	3.00	3.60	2.30	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.40
in mm/month	93.00	101.90	70.90	14.70	1.30	0.00	0.00	0.00	0.00	0.00	14.30	42.70
in l/s/h	0.35	0.42	0.26	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.16
Irrigated area (% of total area)	100	100	100	53	11	0	0	0	0	0	47	89
Irr. req. for actual area (l/s/ha)	0.35	0.42	0.26	0.11	0.04	0.00	0.00	0.00	0.00	0.00	0.12	0.18
Annual Share (%)	24	28	18	7	3	0	0	0	0	0	8	12

APPENDIX F

Comparison of Annual water demand of all demand site under four scenarios in (2019-2050)

Years	RS	HPGS	IIAS	IIES
2019	76.23	76.37	76.70	76.23
2020	76.63	76.91	77.58	76.63
2021	77.03	77.46	78.47	77.03
2022	77.44	78.02	79.38	77.44
2023	77.86	78.59	80.30	77.86
2024	78.28	79.18	81.24	78.28
2025	78.71	79.78	82.19	78.71
2026	79.15	80.39	83.16	79.15
2027	79.59	81.01	84.14	79.59
2028	80.04	81.64	85.14	80.04
2029	80.50	82.29	86.15	80.50
2030	80.96	82.95	87.19	80.96
2031	81.43	83.63	88.23	81.43
2032	81.91	84.31	89.30	81.91
2033	82.39	85.02	90.38	82.39
2034	82.89	85.73	91.48	82.89
2035	83.39	86.47	92.60	83.39
2036	83.90	87.21	93.73	83.90
2037	84.41	87.97	94.88	84.41
2038	84.93	88.75	96.05	84.93
2039	85.47	89.55	97.25	85.47
2040	86.01	90.36	98.46	86.01
2041	86.55	91.18	99.69	86.55
2042	87.11	92.03	100.93	87.11
2043	87.68	92.89	102.20	87.68
2044	88.25	93.77	103.49	88.25
2045	88.83	94.67	104.81	88.83
2046	89.43	95.58	106.14	89.43
2047	90.03	96.52	107.49	90.03
2048	90.64	97.47	108.87	90.64
2049	91.26	98.45	110.27	91.26
2050	91.89	99.44	111.69	91.89
Sum	2670.82	2775.59	2969.58	2670.82

APPENDIX G

Unmet Demand of all scenarios under each years of the study (Mm^3)

Years	RS	HPGS	IIAS	IIES
2019	1.939	1.953	2.166	0.000
2020	0.065	0.078	0.332	0.000
2021	2.192	2.219	2.538	0.000
2022	4.869	4.939	5.877	0.000
2023	5.271	5.397	6.881	0.000
2024	8.709	8.877	10.779	0.000
2025	8.478	8.675	11.025	0.000
2026	7.306	7.457	9.392	0.000
2027	4.130	4.211	6.344	0.000
2028	4.236	4.413	6.582	0.000
2029	0.631	0.746	2.542	0.000
2030	9.937	10.318	14.246	1.487
2031	8.225	8.632	12.987	0.000
2032	7.350	7.646	11.629	0.000
2033	5.017	5.302	9.270	0.000
2034	8.440	8.968	14.825	0.000
2035	12.505	13.273	20.055	0.000
2036	12.897	13.882	21.420	0.083
2037	11.009	11.577	17.874	0.065
2038	12.745	13.904	21.864	0.269
2039	14.358	16.604	22.604	0.954
2040	11.533	14.001	19.273	2.731
2041	0.000	0.000	1.886	0.000
2042	0.000	0.000	0.000	0.000
2043	0.000	0.000	0.000	0.000
2044	2.899	3.581	12.491	0.000
2045	6.992	8.075	19.151	0.000
2046	7.062	8.206	18.761	0.000
2047	1.922	2.297	6.812	0.000
2048	2.362	3.206	13.758	0.000
2049	4.197	5.072	14.081	0.000
2050	4.133	5.481	17.938	0.000
Sum	191.409	208.990	355.383	5.589

APPENDIX H

The overall monthly average demand coverage of four demand nodes from 2019 to 2050 under all scenarios

Months	Rural				Urban			
	HPGS	IIES	IIAS	RS	HPGS	IIES	IIAS	RS
January	99	100	100	100	100	100	100	100
February	97	98	98	98	100	100	100	100
March	98	99	99	99	100	100	100	100
April	100	100	100	100	100	100	100	100
May	99	100	100	100	100	100	100	100
June	99	99	99	99	100	100	100	100
July	99	99	99	99	100	100	100	100
August	99	99	99	99	100	100	100	100
September	100	100	100	100	100	100	100	100
October	100	100	100	100	100	100	100	100
November	100	100	100	100	100	100	100	100
December	99	100	100	100	100	100	100	100

Months	Livestock				Agriculture			
	HPGS	IIES	IIAS	RS	HPGS	IIES	IIAS	RS
January	77	100	78	78	79	100	67	81
February	70	100	72	72	62	100	52	63
March	84	100	83	85	93	100	83	94
April	100	100	100	100	100	100	100	100
May	100	100	100	100	100	100	100	100
June	100	100	100	100	100	100	100	100
July	100	100	100	100	100	100	100	100
August	100	100	100	100	100	100	100	100
September	100	100	100	100	100	100	100	100
October	100	100	100	100	100	100	100	100
November	98	100	98	98	100	100	99	100
December	95	100	92	95	99	100	97	99

APPENDIX I (a)

Number of Livestock population in Ketar watershed in 2015 (AZLFDO,2018)

No	Districts	Cattle	Sheep	Goats	Horse	Mule	Donkey
1	Ziway Dugda	124,512	26140	46621	4923	1969	12801
2	Hitosa	190,185	75,874	58,628	3,694	334	22,899
3	Tiyo	108,663	81,241	17,540	11,830	1,280	20,783
4	Munesa	212,733	122,352	18,460	38,216	820	24,858
5	Digluna Tijo	239,517	128,084	10,314	25,477	365	17,464
6	Limuna Bilbilo	263,450	297,110	29,441	170,574	3,891	33,693
	Sub Total	1,139,060	730,801	181,003	254,714	8,629	132,498
	Total						2,446,736

APPENDIX I (b)

Number of Livestock population in Ketar watershed in 2016 (AZLFDO,2018)

No	Districts	Cattle	Sheep	Goats	Horse	Mule	Donkey
1	Ziway Dugda	124,512	26140	46620	4943	1969	12801
2	Hitosa	140,185	75,874	58,628	3,694	334	22,899
3	Tiyo	108,663	81,241	17,540	11,830	1,280	20,783
4	Munesa	212,733	122,352	8,460	38,216	820	24,858
5	Digluna Tijo	239,517	128,084	10,314	25,477	335	17,464
6	Limuna Bilbilo	263,450	297,110	29,441	58,574	3,891	33,693
	Sub Total	1,089,060	730,801	171,003	142,714	8,629	132,498
	Total						2,274,725

APPENDIX J (a)

Ticho Station									
Month	Min Temp	Max Temp	RH	Wind	Sun	Rad	ETo	Eff rain	Kc
	°C	°C	%	km/d	hours	MJ/m²/d	mm/d	mm	coeff
Jan	8	22.3	49	2	9.7	22	3.25	0.5	0.62
Feb	8.8	23.5	47	2	10.2	24.1	3.71	1	0
Mar	9.4	23.5	56	2	9.6	24.2	3.98	2	0
Apr	9.9	22.7	66	3	9.1	23.5	3.99	2.6	0
May	9.8	22.7	63	2	8.9	22.6	3.8	2.4	0
Jun	10.3	21.2	76	2	7.3	19.7	3.43	2.6	0
Jul	10.1	18.7	89	2	5.7	17.5	3.06	3	0
Aug	10.1	19.6	87	2	6.8	19.6	3.38	3.1	0
Sep	9.5	20.3	78	2	7.2	20.4	3.48	2.4	0.3
Oct	7.8	20.6	65	2	8.9	22.3	3.54	1	0.36
Nov	7	21.4	57	3	9.7	22.2	3.35	0.2	1.03
Dec	7	21.6	50	3	9.6	21.4	3.1	0.2	1.1
Avge	9	21.5	65	2	8.6	21.6	3.51	21	**0.28**

APPENDIX J (b)

Sagure Station									
Month	Min Temp	Max Temp	RH	Wind	Sun	Rad	ETo	Eff rain	Kc
	°C	°C	%	km/d	hours	MJ/m²/d	mm/d	mm	coeff
Jan	7.5	24.3	44	2	9.7	22	3.24	0.2	0.62
Feb	8.6	25.8	42	2	10.1	23.9	3.68	0.4	0
Mar	9.2	26.6	49	2	9.9	24.7	4.07	1.3	0
Apr	9.6	25.8	57	2	9.6	24.3	4.14	1.6	0
May	9.2	24.9	59	2	8.9	22.6	3.84	2.1	0
Jun	9.8	22.4	73	2	7.6	20.2	3.5	2.5	0
Jul	9.7	19.3	83	2	6.8	19.1	3.25	5.8	0
Aug	9.5	20.4	82	2	7.6	20.8	3.52	5.5	0
Sep	8.8	22.1	72	2	8	21.6	3.64	3.5	0.3
Oct	7.5	22.6	59	2	9.2	22.7	3.6	1.2	0.36
Nov	6.8	23.8	49	2	9.7	22.2	3.34	0.4	1.03
Dec	6.9	23.9	43	2	9.7	21.5	3.11	0.1	1.1
Avge	8.6	23.5	59	2	8.9	22.1	3.58	2.05	**0.28**

APPENDIX J (c)

Ketar Genet Station									
Month	Min Temp	Max Temp	RH	Wind	Sun	Rad	ETo	Eff rain	Kc
	°C	°C	%	km/d	hours	MJ/m²/d	mm/d	mm	coeff
Jan	7.5	24.9	44	3	10	22.5	3.32	0.5	0.62
Feb	8.3	26.3	42	2	10.6	24.7	3.79	0.5	0
Mar	8.9	26.9	47	2	10.5	25.6	4.17	2	0
Apr	9.8	26.6	53	2	10.3	25.4	4.28	3.9	0
May	9.9	26.1	54	2	9.7	23.8	4.02	2.7	0
Jun	11	23.9	68	2	8	20.7	3.64	2.5	0
Jul	10.9	20.8	80	2	7	19.4	3.38	4.1	0
Aug	10.4	21.8	79	2	8	21.4	3.69	4.2	0
Sep	8.9	23.6	68	2	8.7	22.7	3.85	3.4	0.3
Oct	7	23.7	55	2	9.9	23.8	3.76	2.5	0.36
Nov	6.2	24.1	49	3	10.1	22.8	3.42	0.9	1.03
Dec	6.4	24.1	45	3	10	21.9	3.17	0.4	1.1
Jan	8.8	24.4	57	2	9.4	22.9	3.71	2.3	0.28

APPENDIX J (d)

Kulumsa Station									
Month	Min Temp	Max Temp	RH	Wind	Sun	Rad	ETo	Eff rain	Kc
	°C	°C	%	km/d	hours	MJ/m²/d	mm/d	mm	coeff
Jan	8.9	23.3	58	2	8.9	20.9	3.2	0.5	0.62
Feb	9.5	24.5	55	2	9.4	22.8	3.62	1	0
Mar	10.7	25.2	58	2	8.8	22.9	3.86	2	0
Apr	11.6	24.8	62	2	8.2	22.1	3.84	2.6	0
May	11.3	24.4	64	2	8.2	21.5	3.74	2.4	0
Jun	10.8	23.4	69	2	7.3	19.7	3.44	2.6	0
Jul	10.9	21.7	75	2	5.7	17.5	3.09	3	0
Aug	10.8	21.4	78	2	5.8	18.1	3.18	3.1	0
Sep	10.4	21.9	75	1	6.4	19.1	3.3	2.4	0.3
Oct	10.8	22.7	61	2	7.9	20.7	3.42	1	0.36
Nov	9.4	22.6	58	3	9.1	21.3	3.32	0.2	1.03
Dec	8.6	22.5	58	3	9.2	20.8	3.13	0.2	1.1
Avge	10.3	23.2	64	2	7.9	20.6	3.43	1.75	0.28