Hawassa University Journals

Volume III
Article Number: 917-Article Text-4617-1-2-20231006
Pages : 105-127
Copyright©2023
Author(s) retain the copyright of this article
www.journals.hu.edu.et/hu-journals/index.php/ejet/index

Ethiopian Journal of Engineering and Technology

SWAT-WEAP Model-based Water Supply-Demand Analyses and Identification of Critical Areas under Different Scenarios in Bilate River Watershed, Ethiopia

Tewodros Assefa Nigussie[a]*

Hawassa University, Institute of Technology, Department of Water Resources and Irrigation Engineering

*Email: tewodrosa@hu.edu.et

Abstract

Water scarcity has increased the interest in improving water use efficiency and productivity in various parts of the world. As a solution to the problems associated to water scarcity, it is very useful to conduct water demand-supply and water allocation analyses (under current and future condition), even after water shortage has manifested itself, as it would lead to seeking a win-win situation among different water users (demand sites) in the watershed. Accordingly, this study focused on water allocation for existing and future demands in Bilate River Watershed using the WEAP model as by generating stream flow data using the SWAT model. For this purpose, observed meteorological and hydrological data for the period of 2010–2019 were employed. The model outputs were further analyzed to determine long-term mean flow values. Under the Current Scenario, the irrigation, domestic and livestock water demands were found to be 49.05 MMC, 21.41MMC and 8.58 MMC, respectively, with a total of 79.04 MMC. Under this scenario, the available water was not found to meet the demands in the months from October to February, particularly at Badessa and Chorake sub-watersheds. Under the reference scenario, the annual unmet water demand in the watershed as a whole changes from 1.21 MMC in 2021 (current scenario) to 1.78 MMC in 2030, which is expected to increase to 5.78 MMC in 2030 under the Increased water demand scenario with irrigation expansion, population growth, and environmental flow consideration. Thus, to address the current and eve future supply-demand gap, a storage structure needs to be constructed at appropriate place.

Keywords: SWAT; WEAP; Water allocation; Water scarcity; Demand scenarios

1. Introduction

With an estimated total annual surface flow of 123 billion cubic meters per year, Ethiopia is said to have huge water resources. Despite this, however, very little of it has been developed for various purposes such as agriculture, industry and hydropower. According to the Ministry of Water Resources (Awlachew et al., 2007), a very small portion of the potential irrigable land in the country (3.7 million ha) has been developed. Much of the water resources in Ethiopia are not utilized to meet the food demand. It is a dilemma why Ethiopia is starving while it has huge amount of surface water and perennial rivers. This is mainly because of lack of well-organized research on water resource management and finance (Tadesse, 2006). As a result, the country could still face million tons of cereal deficits by in the future (UK Trade and Investment, 2004). This is in addition to the problems related to domestic and industrial water supply.

The Rift Valley Lakes Basin (RVLB) of Ethiopia is one of the water scarce places in the Country. Despite this reality, it is also a place where there has been rapid expansion irrigation agriculture mainly for the production of market-oriented crops (Kamara et al., 2002), resulting in further water scarcity. In this area, water scarcity has resulted in competition of water among domestic, private investors, farmers and industries, which in turn, has resulted in conflicts among users. Bilate River Watershed, one of the major feeders of Lake Abaya (a lake in the RVLB), is characterized by an intensive crop production system and fast population growth (Orke and Li, 2021). The watershed is known to be a water scarce watershed.

Water scarcity has increased the interest in improving water use efficiency and productivity in various parts of the world (Abdelkhalik et al., 2019). In this regard, 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 (Loon and Droogers, 2006). As a solution to the problems associated to water scarcity, it is very useful to conduct water demand-supply and water allocation analyses (under current and future condition), even after water shortage has manifested itself, as it would lead to seeking a win-win situation among different water users (demand sites) in the watershed (Adgoligh, et al, 2016).

As stated by Jebelli (2018), in water scare conditions, the “no action” or “the conventional water balance approach” may not be adequate to address the growing challenges. Thus, given the need for a fair water distribution among all water users, a tool has to be employed to be able to develop a management strategy and to perform a rigorous water balance and water allocation analysis.

Many capable software tools could be utilized to investigate the adequacy of management strategies and conduct water allocation under various scenarios. Among these softwares, however, the Water Evaluation and Planning System (WEAP) is widely used for such purposes as the model is distinguished by its integrated approach to simulating water systems and by its capacity to accommodating water management strategies using water allocation priorities (Jebelli et al., 2018). Moreover, it is known to be a generic integrated water resources planning software tool that provides a comprehensive, flexible and user friendly framework for the development of water balance, scenario generation, planning and policy analyses (Sieber and Purkey, 2015).

This study was, therefore, initiated to study water allocation for existing and future demands in Bilate River Watershed using the WEAP model as, to the best of our knowledge, such a study has not been conducted so far in the study area. WEAP was used to allocate water in equitable manner and to investigate future development scenarios effect on water balance by linking the demand and the supply of water resource of the study areas in addition to the determinations of various current and future water demands. The general objective of this study was to conduct water balance (supply and demand analyses) under current and future scenarios in Bilate River Watershed of Ethiopia.

2. Material and Methods

2.1 Description of the study area

This study was conducted in Bilate River Watershed (BRV). The river is one of the major tributaries of Lake Abaya, which is one of the lake in the Ethiopian Rift valley Lakes Basin. BRV falls in three regions of Ethiopia: Oromia, Central Ethiopia and Southern Ethiopia Regions. The watershed extends from 6.555 Decimal Degrees (DD) North to 8.114 DD North latitude, and 37.777 DD East to 38.316 DD North Longitude with an area of about 5350 km^2. The watershed is generally located at the northwestern part of the Ethiopian RVLB (Figure 1).

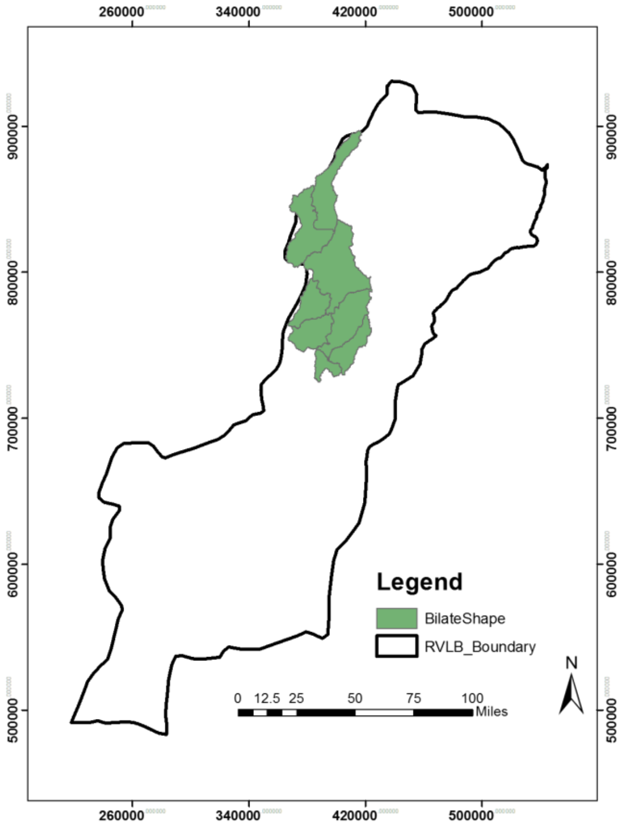


Figure 2.1. Location map of the study area

A Digital Elevation Model (DEM)-based analysis shows that its elevation ranges from 1176 m at its outlet at Lake Abaya to 3328 m around its northern part. The watershed has three seasons classified based on rainfall amount. The watershed experiences a bimodal rainfall pattern (Kiremt-the major rainy season, and Belg the smaller rainy season).

2.2. Data Collection and Analyses

2.2.1. The current water demand and supply analyses in the study area

2.2.1.1. Water Supply Analyses

In this study, in order to determine the surface water availability in the study area, stream flow data of eight sub-watersheds that were considered in the study were determined using the Soil and Water Assessment Tool (SWAT) model. The SWAT modeling procedures were followed properly in doing so. However, details of the modeling procedures could not be provided here due to space limitation. Finally, the generated stream flow data were used to determine the mean monthly stream flow values (m^3/s) for each sub-basin considered in the study. In addition, the mean monthly stream flow values were used to see the temporal distribution of the stream flow values. These watersheds are depicted in Figure 2.

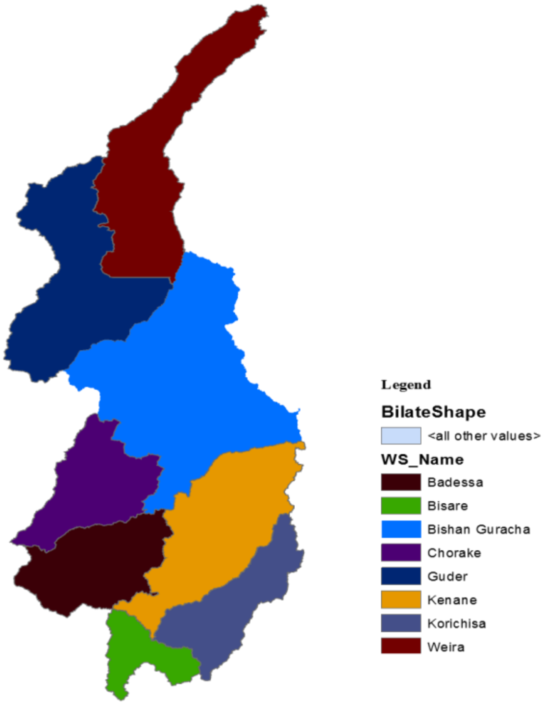


Figure 2. Bilate River Watershed and its sub-watersheds.

2.2.1.2. Water demand assessment

Water demand is defined as the total amount of water required to meet both consumptive and non-consumptive water uses such as: domestic, livestock, agricultural, industrial & commercial, environmental and hydropower water demands. Thus, water demand calculations were conducted by estimating the above water demands in the study area as required. The ways these water demands are going to be determined in this particular study are presented as follows:

I. Domestic water demand

D**omestic water demand** is defined as the water requirement to accomplish household activities that can be sub-grouped into urban and rural domestic water demand. Estimating domestic water demand and consumption at the catchment level for rural areas in Ethiopia is difficult due to the non-availability of measured data. In this regard, two main methods have been developed for assessing rural domestic water demand assessment (Wallingford, 2003). Indirect methods are where the quantity of water consumed is determined from the population level and demand levels are estimated in terms of per capita consumption. The direct methods are socioeconomic surveys and participatory techniques involving the relevant stakeholders. The indirect method of estimating demand is relatively straightforward to use and the most practical method on a sub-catchment and catchment levels. It requires population data, per capita water demand and loses/leakage. As a result, this method was used in this study.

The domestic water demands were, thus, estimated by multiplying recommended water use rates by the total population in each study catchment. The population data were collected from the Central Statistical Agency (census of 2007) and the data were projected to the targeted year (2013 EC as current and 2030 as future target years) to determine the corresponding domestic water demands. The population data were projected to the target years by Geometric Population Projection method assuming that a population will change by the same percentage rate over a given increment of time in the future similar to the base period (George et al., 2014).

$$P_t = (P_1)\,[(1 + r)^{z}] \qquad \text{Eq. 1}$$

Where Pt is the population in the target year, P_l is the population in the launch year, r is the average geometric rate of change, and z is the number of years in the projection horizon.

II. Irrigation water demand

The current agricultural water demand was estimated based on the current agricultural landuse in each sub-basin, the crops grown, and water requirement at the given area. The irrigation water requirement data were determined after determining the crop water requirement for various agro ecologies in the watershed and considering an overall efficiency value of 0.45 for furrow irrigation. The size of existing functional irrigation schemes were collected from zonal offices falling in the study area. The irrigation water demand values were processed to determine the unit values per hectare of land (in m^3/ha in this case) and the data were further processed to determine the monthly proportions of the total irrigation water requirement (in %). These values were used to see when and where there will be high irrigation water demand based on the current irrigation water demand.

III. Institutional and commercial water demand

Usually, institutional and commercial water demands are generalized as public water demand and they are considered as 5% percent of average domestic water demand (Engdaw, 2015). Thus, this approach was used to determine this water demand for each study catchment.

IV. Livestock water demand

The water demand of livestock is affected by several factors such as type of livestock, location, type of diet, temperature, weight, etc. Thus, the types and numbers of livestock in an area of interest need to be considered for determining the livestock water demand. In this case, the numbers of the livestock are be multiplied by the recommended consumption rates to determine demands. The daily water requirements (lit/day/animal) presented in the following table is recommended rates for planning purposes.

Table 1. Daily water demand of livestock under African condition

Livestock type	Daily consumption (l/day)
Cattle	25
Sheep	5
Goat	5
Horse	25

Mule	25
Donkey	25
Chicken	0.5

However, it was not possible to get the livestock data for this study. In cases where the livestock population cannot be found in the study area, Tropical Livestock Units (TLU) is used to estimate the livestock water demand.

According to MoWR (2009) Master Plan study on RVLB, the mean livestock holding for areas falling within Bilate River Watershed are 2.81 TLU per household and 0.36 TLU per person. Thus, the mean per person TLU value of 0.36 was used to determine the TLU under each watershed inn this study. Then, the water demand for livestock was calculated based on TLU per person and by taking Water consumption as 25 l/day/TLU.

V. Environmental flow water demand

Environmental flow consideration is necessary for the prevention of invasive plant species, navigations, recreations, wildlife, and other downstream water abstractors. The simplest way of determining environmental flow is based on the use of hydrological data, usually in the form of historical flow records. In this method, a proportion of flow, often termed the minimum flow which represents the environmental flow recommendation intended to maintain the fishery or other highlighted ecological features at some acceptable level is fixed (King et al., 2003). Apparently, Bilate River flows into Lake Abaya. In this regard, as lakes are sensitive water bodies that excessive abstraction of water from the rivers that feed them compromises their quality, quantity, aquatic life and the whole water balance and ecosystem, in general. In order to deal with such problems, Yasi and Ashori (2017) conducted a study in Lake Urmia (Iran) and found that a maximum of 35% of the mean flow should be allocated for maintaining an acceptable minimum environmental requirement for saving the lake. In the study by Sahoo et al. (2016), environmental flows assessment was carried out at the Lower Mahanadi Sub-basin (India) and recommended to provide 26 % of mean flows as environmental flow requirement. As a result, in this study, 30 % of the long-term mean monthly flow determined at the outlet of each sub-catchment was considered as the environmental flow requirement.

2.2.2. Projected water demand analyses

Every water resources assessment should focus not only on the current conditions, but also on the future conditions. The future water demands are determined based on scenario analyses. Scenarios are description of possible actions or events in the future. With regards to water demand and supply, scenarios are developed by taking into consideration demographic, hydrological and technological changes, and irrigation expansion starting from the current condition. In this regard, in this study, only projected water demands were determined as the study assumes that the current available surface water (stream flow) remains unchanged. Thus, the following are as to how future water demand values were projected in this study:

2.2.2.1. Projected domestic water demand

The population in the sub-catchments was projected to a target year of 2030 by making use of the Geometric Population Projection method assuming that a population will change by the same percentage rate over a given increment of time in the future similar to the base period (George et al., 2004). Equation 1 was employed for this purpose here again. The projected population size was, then, multiplied by the per capita water demand to determine the projected water demand in the target year. The value of “r” considered in this study was 2.56%.

2.2.2.2. Projected irrigation water demand

The future agricultural water demand values were estimated based on the potential agricultural lands proposed by the irrigation potential study results in each sub-basin, the crops grown, and water requirement at the given area. The projected irrigation water requirements were determined by taking into consideration the current water requirement and the change in the size of the land under irrigation landuse. The projected irrigation water demands were prepared in a monthly basis and these values were used to see when there will be high irrigation water demand based on the irrigation water demand.

2.2.2.3. Future Institutional and commercial water demand

Here again, 5% percent of future average domestic water demand was used to determine the future institutional and commercial water demand (Engdaw, 2015). Thus, this approach was used to determine this water demand for each study catchment.

2.2.3. WEAP-based water allocation modeling

In order to evaluate future water demand and supply, and to identify water shortage areas, an extensive modeling exercise was carried out using the WEAP tool. The scenario-based projections stated in here under and the current conditions were used to establish the WEAP-based modeling. It is known that a scenario can be developed from the reference scenario with an alternative assumption of what would happen in future development. Scenarios could be developed based on factors affecting water demand such as population increase, expansion of efficient and modern irrigation techniques, and expansion of irrigated potential. Future water development projects such as dams, groundwater developments etc… could also be used for developing scenarios.

WEAP applications generally involve the following steps:

- Study definition: The time frame, spatial boundaries, system components, and configuration of the problem are established.
- Current accounts: A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed.
- Scenarios: A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored.
- Evaluation: The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

In WEAP, the typical scenario modeling consists of three steps. The first (**current account** year) is chosen to serve as the base year of the model. The second (reference scenario) is established from the current accounts to simulate the likely evolution of the system without intervention. Finally, a what-if scenario can be created to alter the reference scenario and evaluate the change in policies and/or technologies (SEI, 2016).

The reference scenario, in this study, was developed from the current account of 2021 based on a linear population growth rate of 2.56% per annum from the year 2021 to 2030. The assumption made for this scenario was that the currently available stream flow continues in the future with similar condition. All the demand sectors are unchanged in the future except for the population increment at the aforementioned growth rate (and related water demands such as institutional and commercial).

Increased water demand (Irrigation expansion scenario), in this study, analyses were carried out to investigate what would happen to the water demand in the watershed if the irrigable area increases by 2030. However, the same irrigation technique with the same irrigation water management in the current account year were considered in this scenario as not much is expected to change in this regard by 2030.

The following flowchart is provided to show the WEAP-based modeling workflow.

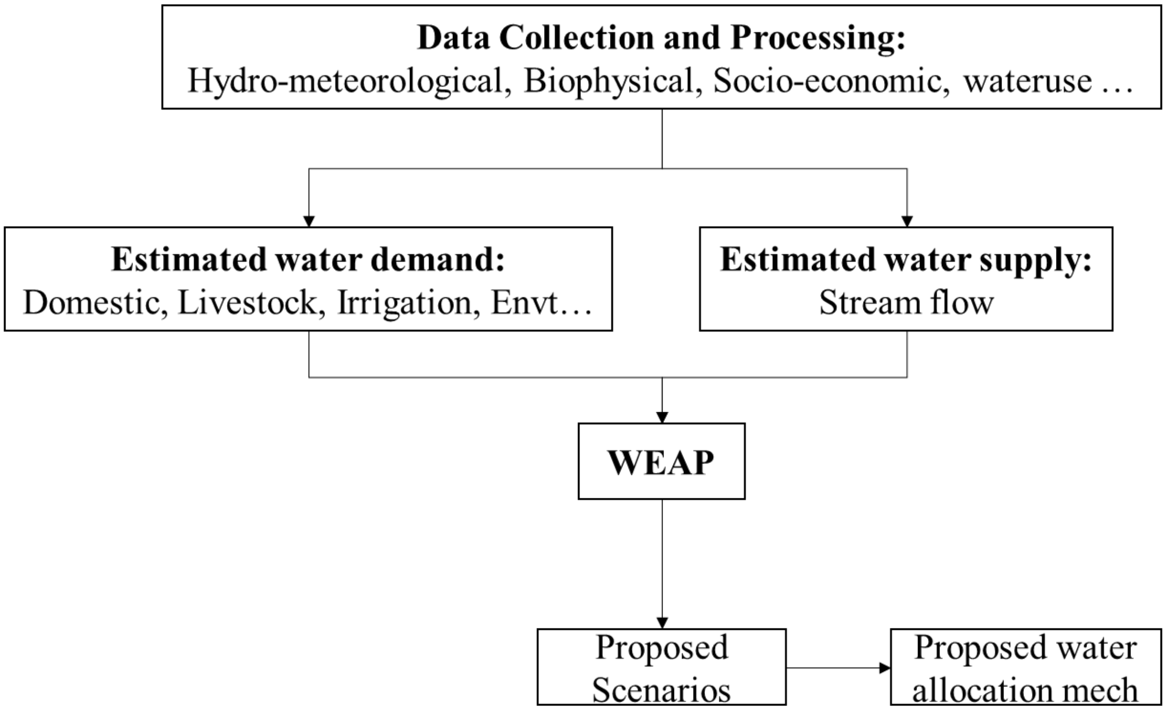


Figure 3. Simple flowchart for WEAP-based water allocation modeling

To allow simulation of water allocation, elements that comprise the water demand and supply system and their spatial relationship should be connected with transmission link* for each sub-catchment under consideration. A graphical interface facilitates visualization of the physical features of the system and their layout within the catchment.

Once the WEAP model water demand architecture is fixed, the next step is defining self-contained set of data and assumptions about a system of linked demands and supplies. The data are divided into Current Accounts and a number of alternative scenarios. The data entry tables are used to enter expressions that define Current Accounts and Scenario values of variables.

Data required for fixing supply values for each sub-catchment (river flow data generated by SWAT model) were entered as head flow to represent the average inflow to the first node on a river. In addition, all water demand data were entered in the model following appropriate procedures and then the model was run to obtain required results.

3. Results and Discussion

3.1.1 Current water supply and demand analyses results.

3.1.1.1 Current water supply

As stated earlier, the SWAT model results were used to determine the surface water availability in each study watershed. The long-term mean monthly flow rate of the tributary rivers in Bilate Watershed is presented in the table below.

Table 2. Long-term mean flow (m^3/s) of the rivers in Bilate River Watershed.

Name of sub-watershed	**Months**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Weira	1.16	1.98	2.69	6.17	7.02	8.76	19.56	20.09	23.69	8.96	5.17	2.61
Gudar	1.12	1.94	2.54	6.02	7.06	8.64	19.53	20.09	23.65	9.22	5.32	2.65
Bishan-Guracha	2.13	4.55	7.99	18.48	18.74	20.41	45.36	46.48	56.52	21.28	11.27	5.41
Chorake	0	0.12	0.37	0.31	0.30	0.12	0.15	0.15	0.62	0.11	0.04	0
Kenene	1.87	4.63	9.37	20.83	20.87	21.37	47.01	47.79	59.95	21.92	11.23	5.19
Badesa	0	0.04	0.22	0.39	0.34	0.15	0.26	0.22	0.54	0.15	0.04	0
Bisare	1.79	4.59	9.60	21.22	21.24	21.53	47.23	47.98	60.57	22.03	11.19	5.11
Korchisa	1.01	0.74	6.20	16.20	10.42	16.98	40.17	32.71	39.66	9.45	4.59	1.34

3.1.1.2. Results of current water demand analyses

1. Domestic water demand

In order to determine the current (2021) domestic water demand in the sub-watersheds, first, population in the sub-watershed were projected from previous census by considering annual growth rate of 2.65%. In this regard, the projected population of the sub-watersheds in Bilate River Watershed is presented in the following table.

Table 3. The projected population (for 2021) in the sub-watersheds of Bilate River Watershed.

Sub-watersheds	**Rural**	**Urban**	**Total**
Weira	305315	6286	311601
Gudar	443583	129175	572758
Bishan-Guracha	725466	89796	815262
Chorake	165638	55559	221197
Kenene	381819	10985	392804
Badesa	98996	9743	108739
Korchisa	157733	0	157733
Bisare	84306	0	84306

The population sizes depicted in the above table were used to determine domestic water needs by considering recommended per capita water demands for rural, and urban population and for various purposes (such as for commercial, industrial and other institutions). The water demand results determined for 2021 are presented in the following table. The indirect water demands that consist of commercial and other institutions were calculated as 15% of the urban water demand.

Table 4. Domestic water demand (Million m^3/year) for the sub-watershed in Bilate River Watershed**.**

Sub-Catchments	**Rural**	**Urban**	**Indirect demands**	**Total**
Weira	2.29	0.07	0.01	**2.37**
Gudar	3.33	1.46	0.22	**5.00**
Bishan-Guracha	5.44	1.01	0.15	**6.60**
Chorake	1.24	0.63	0.09	**1.96**
Kenene	2.86	0.12	0.02	**3.01**
Badesa	0.74	0.11	0.02	**0.87**
Korchisa	1.18	0.00	0.00	1.18
Bisare	0.63	0.00	0.00	0.63
Total	17.71	3.40	0.51	21.63

2. Livestock water demand

As stated earlier, it was not possible to obtain the livestock population in the study area. As a result, indirect method of livestock water demand calculation method was employed. In this regard, the TLU was estimated from the population of the watersheds. Then, a 0.36 TLU/person and 25 liter day/person were used to determine the total livestock water demand. The corresponding values are presented in the following table.

Table 5. Livestock water demands

Watershed	Population	Total TLU	Demand (MMC)
Weira	319577.99	115048.07	1.05
Gudar	587420.60	211471.42	1.93
Bishan-Guracha	836132.71	301007.77	2.75
Chorake	226859.64	81669.47	0.75
Kenene	402859.78	145029.52	1.32
Badesa	111522.72	40148.18	0.37
Korchisa	161770.96	58237.55	0.53
Bisare	86464.23	31127.12	0.28

3. Current irrigation water demand.

With regards to the determination of the current irrigation water demand in each sub-watershed (as required by WEAP), the sizes of current irrigation schemes in each sub-watershed, irrigation water requirement (lit/s/h) in each sub-watershed and the monthly proportion of the water requirement (%) need to be determined. These values were determined based on the data obtained from zonal offices and the data obtained from the irrigation study team with regards to irrigation water requirement. The values are presented in the following tables.

Table 6. Sizes of current irrigated lands,

Sub-watershed	Irrigated area (Ha)
Weira	226
Gudar	120
Bishan-Guracha	607.53
Chorake	140
Kenene	4802.3
Bisane	310
Korchisa	0
Badesa	188.1
Total	**6393.93**

As can be seen in the table, based on the data collected from zonal offices, the total amount of the land under irrigation agriculture currently is 6393.93 ha. It should be noticed that there is no land under irrigated agriculture in Korichisa sub-watershed currently.

Table 7. Water requirements and monthly proportions

Month	**Weira sub-watershed**			**Guder sub-watershed**			**Bishan Guracha sub-watershed**			**Chorake sub-watershed**			**Kenane sub-watershed**			**Bisare sub-watershed**			**Badessa s watersh**	
	A*	**B***	**C***	**A***	**B***	**C***	**A***	**B***	**C***	**A***	**B***	**C***	**A***	**B***	**C***	**A***	**B***	**C***	**A***	**B***
Jan	0.1	0.07	3.38	0.03	0.01	2.22	0.35	0.57	14.00	0.10	0.04	3.53	0.07	0.86	2.23	0.33	0.28	16.95	0.10	0.05
Feb	0.17	0.12	5.74	0.07	0.02	5.22	0.15	0.24	6.00	0.13	0.05	4.59	0.10	1.29	3.33	0.23	0.19	11.86	0.10	0.05
Mar	0.2	0.14	6.76	0.1	0.03	7.46	0.15	0.24	6.00	0.17	0.06	6.01	0.23	3.00	7.77	0.23	0.19	11.86	0.20	0.10
Apr	0.23	0.16	7.77	0.1	0.03	7.46	0.2	0.33	8.00	0.17	0.06	6.01	0.27	3.43	8.90	0.17	0.14	8.50	0.20	0.10
May	0.27	0.19	9.13	0.17	0.05	12.70	0.2	0.33	8.00	0.23	0.09	8.13	0.30	3.86	10.00	0.07	0.06	3.41	0.27	0.13
Jun	0.37	0.25	12.50	0.23	0.07	17.17	0.25	0.41	10.00	0.37	0.14	13.08	0.33	4.28	11.10	0.03	0.03	1.67	0.40	0.20
Jul	0.43	0.29	14.52	0.3	0.10	22.41	0.05	0.08	2.00	0.47	0.18	16.60	0.37	4.72	12.23	0.00	0.00	0.00	0.47	0.24
Aug	0.43	0.29	14.53	0.17	0.05	12.70	0.1	0.16	4.00	0.43	0.16	15.20	0.53	6.86	17.77	0.07	0.06	3.40	0.53	0.27
Sep	0.33	0.23	11.15	0.07	0.02	5.22	0.1	0.16	4.00	0.33	0.12	11.66	0.40	5.14	13.34	0.07	0.06	3.40	0.37	0.18
Oct	0.2	0.14	6.76	0.07	0.02	5.22	0.35	0.57	14.00	0.20	0.07	7.06	0.20	2.57	6.67	0.20	0.17	10.18	0.177	0.08
Nov	0.13	0.09	4.39	0	0.00	0.00	0.25	0.41	10.00	0.13	0.05	4.59	0.10	1.29	3.33	0.20	0.17	10.18	0.13	0.07
Dec	0.1	0.07	3.38	0.03	0.01	2.22	0.35	0.57	14.00	0.10	0.04	3.53	0.10	1.29	3.33	0.37	0.30	18.59	0.10	0.05
Total		**2.03**	**100**		**0.43**	**100**		**4.07**	**100**		**1.06**	**100**		**38.59**	**100**		**1.63**	**100**		**1.53**
Annual water (*1000 m^3/ha)		**7.66**			**3.59**			**6.70**			**7.58**			**8.04**			**5.27**			**8.13**

*A= Irrigation Water Requirement (L/s/ha), B= Monthly water demand (MMC), C= monthly %age out of the annual total.

4. Environmental flow requirement

As stated in the Material and Methods chapter, the environmental flow requirement was determined as 30% of the long-term mean monthly flow rate at the outlets of the sub-watersheds. In this regard, the environmental flow requirement of the various sub-watersheds of the Bilate River Watershed determined as 30% of the long-term mean flow values are presented in the following table. It should be noted here that the environmental water requirement was non under current scenario as water for this sake is not being released currently.

Table 8. Environmental flow requirement (m^3/s) of the sub-basin in Bilate River Watershed.

Name of sub-watershed	**Months**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Weira	0.35	0.60	0.81	1.85	2.11	2.63	5.87	6.03	7.11	2.69	1.55	0.78
Gudar	0.34	0.58	0.76	1.81	2.12	2.59	5.86	6.03	7.09	2.77	1.60	0.80
Bishan-Guracha	0.64	1.36	2.40	5.54	5.62	6.12	13.61	13.94	16.96	6.38	3.38	1.62
Chorake	0.00	0.04	0.11	0.09	0.09	0.03	0.04	0.04	0.19	0.03	0.01	0.00
Kenene	0.56	1.39	2.81	6.25	6.26	6.41	14.10	14.34	17.99	6.57	3.37	1.56
Badesa	0.00	0.01	0.07	0.12	0.10	0.05	0.08	0.07	0.16	0.04	0.01	0.00
Bisare	0.54	1.38	2.88	6.37	6.37	6.46	14.17	14.39	18.17	6.61	3.36	1.53
Korchisa	0.30	0.22	1.86	4.86	3.13	5.09	12.05	9.81	11.90	2.83	1.38	0.40

3.1.2 Optimal water allocation in Bilate Watershed under current condition

3.1.2.1. Modeling supply resource and demand nodes

To allow simulation of water allocation with WEAP, the elements that comprise of the water supply and demand systems and their spatial relationship should be connected with transmission links in each sub-watershed. A schematic diagram of the WEAP model for the Bilate River Watershed and the sub-watersheds developed based on the surface water supply and the current demand sites is presented in the following figure.

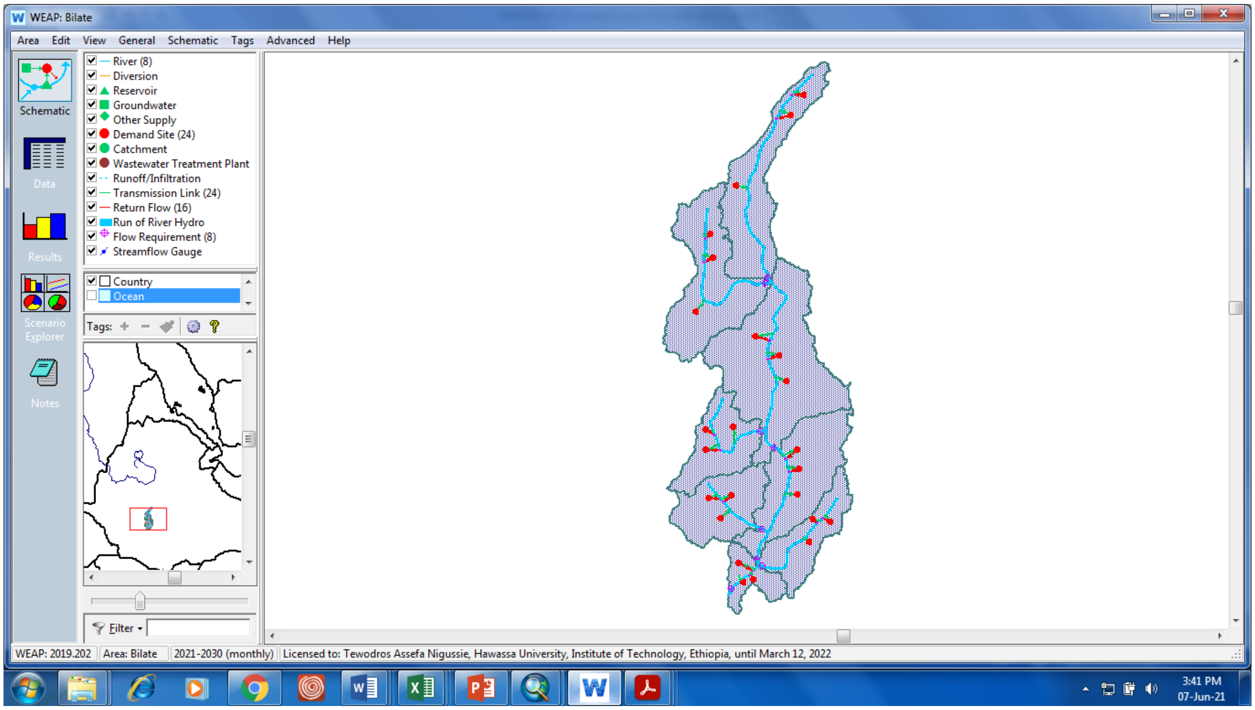


Figure 4. Schematic diagram showing the setup of the WEAP model based on the current demand and supply values

After the WEAP model setup was conducted, self-contained set of data and assumptions about a system of the linked demands and supplies were defined. The required data of the supply and the demands were entered following standard procedures. It should be noted here that the mean monthly flow values were considered on the supply side.

3.1.2.2. Model result analyses on Current Account

As stated earlier, one of the uses of the WEAP model is to compare current values with future projections and alternatives (scenarios). The time step for assessing the current and future scenarios in this study is from 2021-2030. The Current account year is represented by 2021 and 2030 was set as the last year of the future scenarios.

A. Water Demands, Supply Requirement and Supply Delivered

The total annual demand (excluding loss, reuse and demand side managements (DSM)) of all the watershed is depicted in the figure given below. The sum of these demands was found to be 79.67 million meter cube (MMC).

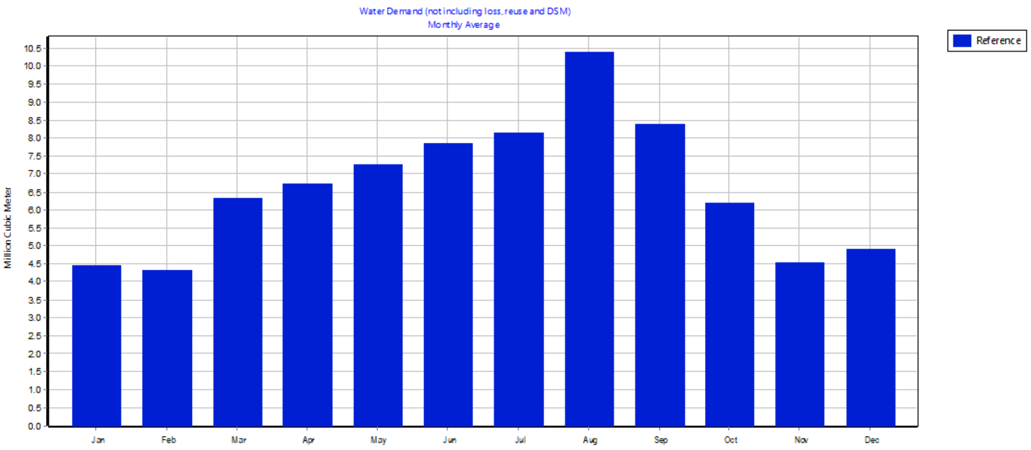


Figure 5. Monthly average water demands in the Bilate River Watershed.

Further analyses on the results show that irrigation water demand has been the dominant water demand (62.06%) in the Bilate River Watershed, followed by domestic and livestock water demands (Table 9)

Table 9. Sector-based water demand analyses results

No	Demand	Demand (MCM)	Percent (%)
1	Irrigation	49.05	62.06
2	Domestic	21.41	27.09
3	Livestock	8.58	10.86
	Total	**79.04**	**100**

The monthly average water demand (excluding loss, reuse and DSM) of all the developed branches in each sub-watershed is depicted in the figure given below.

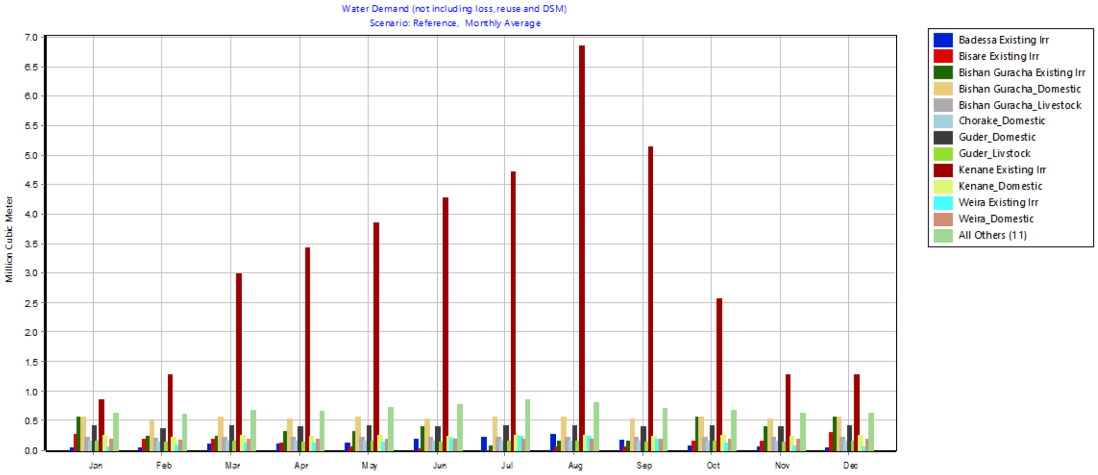


Figure 6. Monthly average water demand (excluding loss, reuse and DSM) of all the developed branches.

B. Unmet water demands

Further analyses on the demand and supply analyses (unmet water demands) showed that most of the demands in all months and in all the sub-watershed are fully met, showing that the water supply is enough to meet all the demands. However, there has been less than 100% coverage for some demands and in some months in Badessa and Chorake sub-watersheds. These results are given in the following figure.

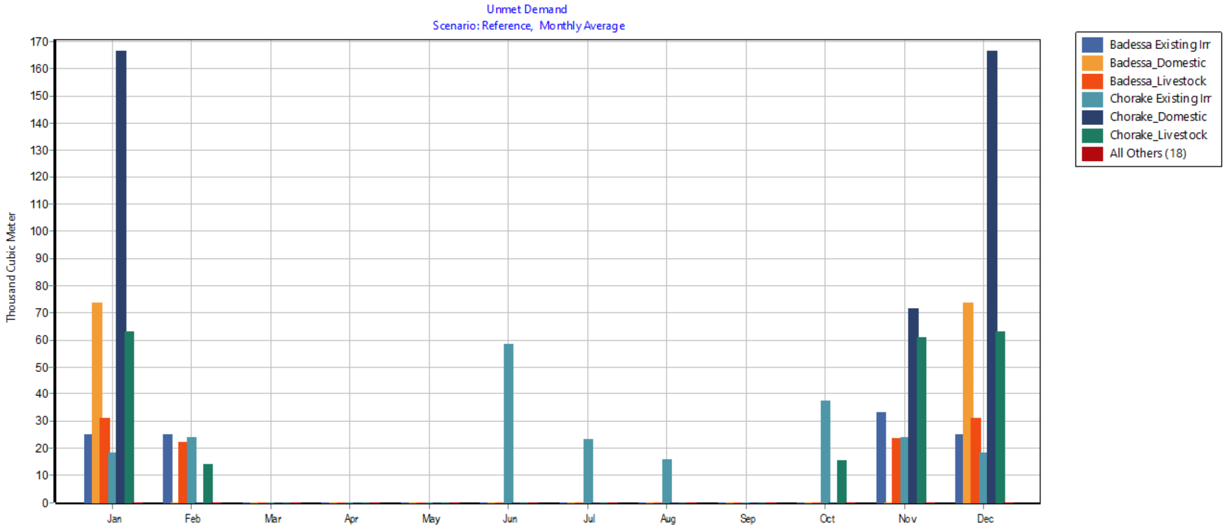


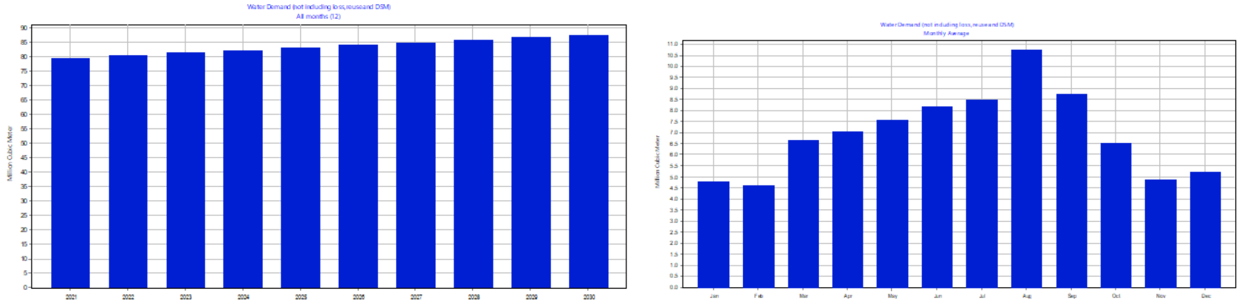
Figure 7. Unmet water demand chart of Badessa and Chorake sub-watersheds

As can be seen from the figure given above, most of the unmet demands (love coverage) in this study (particularly for Badesa and Chorake Sub-watersheds) happen in the months of January, February, November and December. In June, July and August, the available water does not meet the existing irrigation water demand in Chorake Sub-watershed. Thus, storage structures should be constructed and/or groundwater should be developed to meet the demands and improve the coverage.

3.1.3. Results under Reference Scenario

As stated in Section 2.3.3, the Reference Scenario represents the changes that are likely to occur in the future without intervention or new policy measures. It is also known as a business-as-usual scenario. In this scenario, no changes were made. However, as it carries forward the data of the current account, human population as projected from the current account with annual growth rate of 2.56%. The results under this scenario for each sub-basin are given hereunder.

The following figures are given to show the annual water demand (a) and the mean monthly water demand values (b) in the reference period (2022-2030) in the watershed as a whole. As can be seen from the figures, what was estimated to be 79.67 MMC in 2021 is estimated to reach 87.62 MMC in 2030. In addition, it can be seen that the largest mean monthly water demand in the reference scenario occurs in August with water demand amount of 10.74 MMC



(a) (b)

Figure 8. Annual water demand (a) and the mean monthly water demand values (b) in the reference period (2022-2030)

The total annual unmet water demand in the watershed under the reference scenario is depicted in the following figure. As can be seen from the figure, the annual unmet water demand in the watershed as a whole changes from 1.21 MMC in 2021 to 1.78 MMC in 2030.

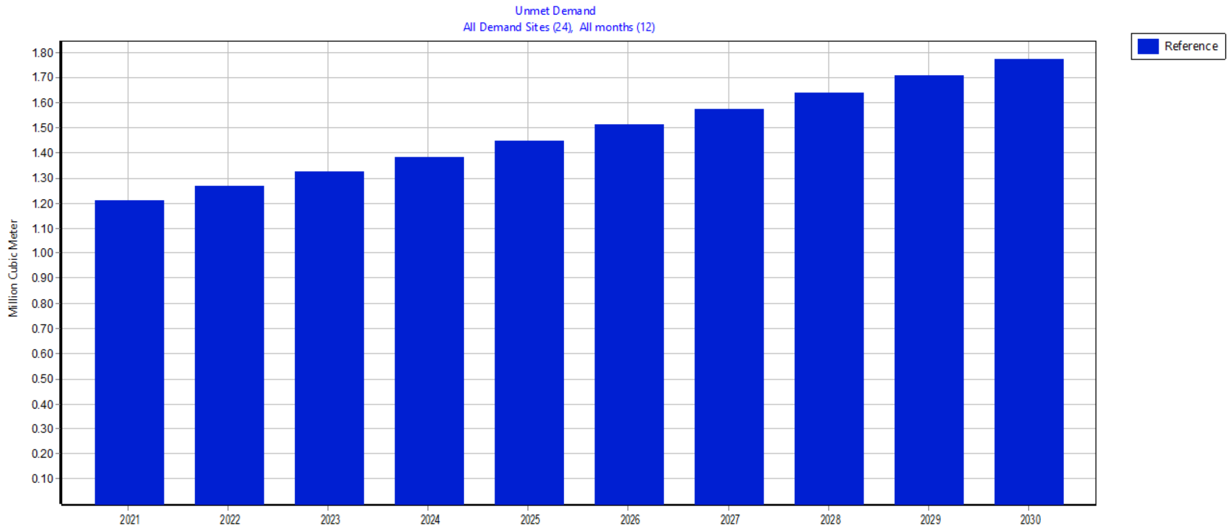


Figure 9. Annual unmet water demand values as a watershed

Demand site-based unmet demand analyses results for the reference scenario are given in the following figure. The results show that there will be increasing unmet demand for irrigation, domestic and livestock water demands in Badessa and Chorake Sub-watersheds

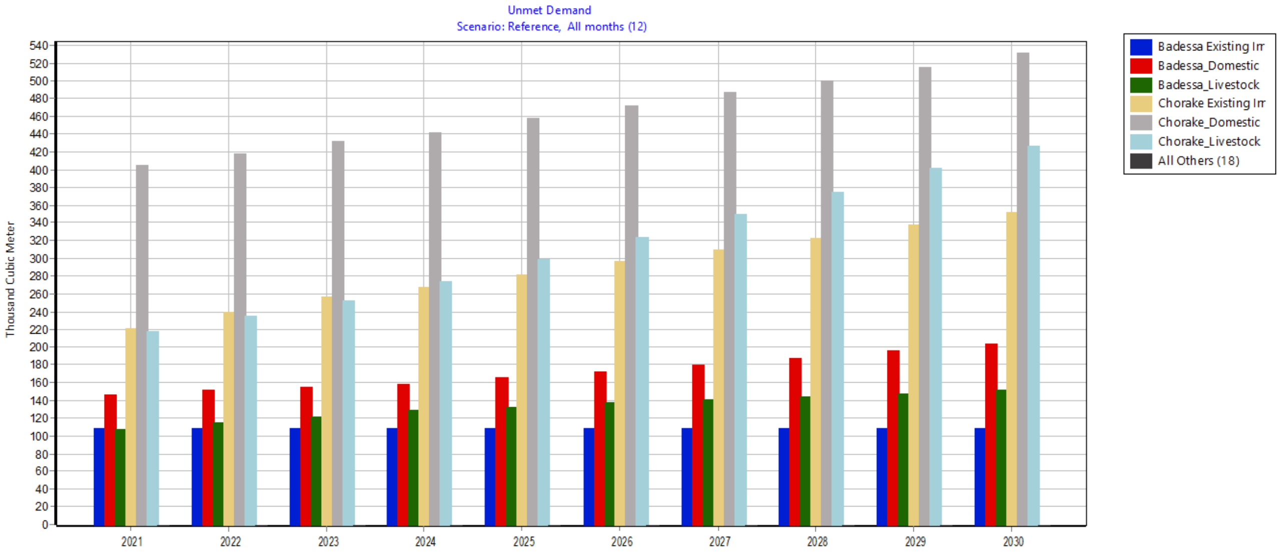


Figure 10. Demand site-based unmet demand analyses.

The results of the mean monthly-based unmet demand analyses are given in the following figure.

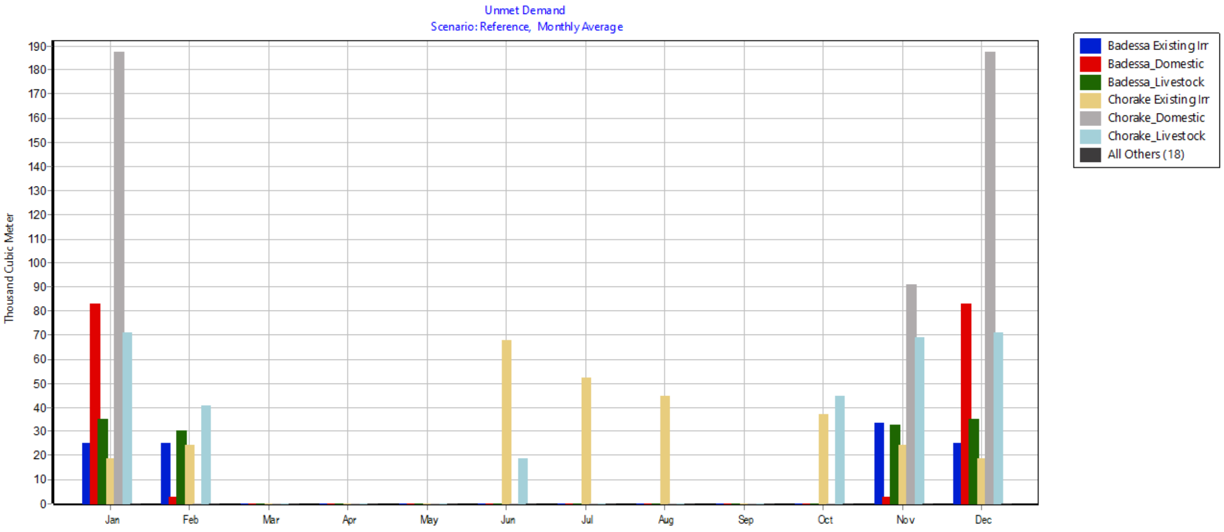


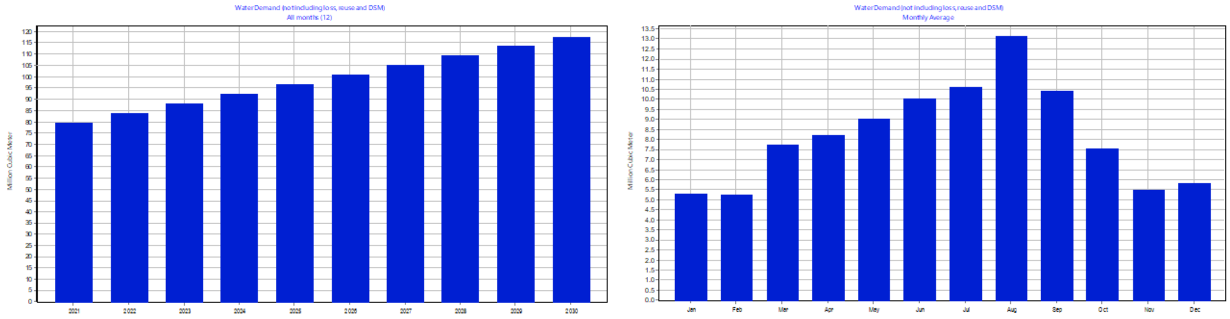
Figure 11. Mean monthly-based unmet demand

It can be seen from the figure that the water resource in the watershed is enough to cover all the demands in the months of March, April, May and September in under the reference scenario.

3.1.4. Results under Increased demand scenario

In this scenario, the additional irrigation areas were assumed to be developed by 2030. The proposed sites and sizes of the command area were taken from the group that studied this particular topic. In addition, the conditions under the reference scenarios were retained with respect to population and livestock population.

The following figure is given to show the annual (a) and mean monthly(b) water demand under this scenario for the whole watershed. The water demand under this scenario is expected to reach be 117.89 MMC in 2030 from what was 79.67 MMC in 2021. The maximum mean monthly water demand in the same scenario was found to be in August with value of 13.14 MMC.



(a) (b)

Figure 12. Annual (a) and mean monthly (b) water demand under Increased Water demand scenario

Further analyses showed that the water in the watershed would not be enough to cover all the water demands under this scenario. The total annual unmet water demand in the watershed under this scenario is depicted in the following figure. As can be seen from the figure, the annual unmet water demand in the watershed as a whole changes slightly from 1.12 MMC in 2021 to 5.78 MMC in 2030.

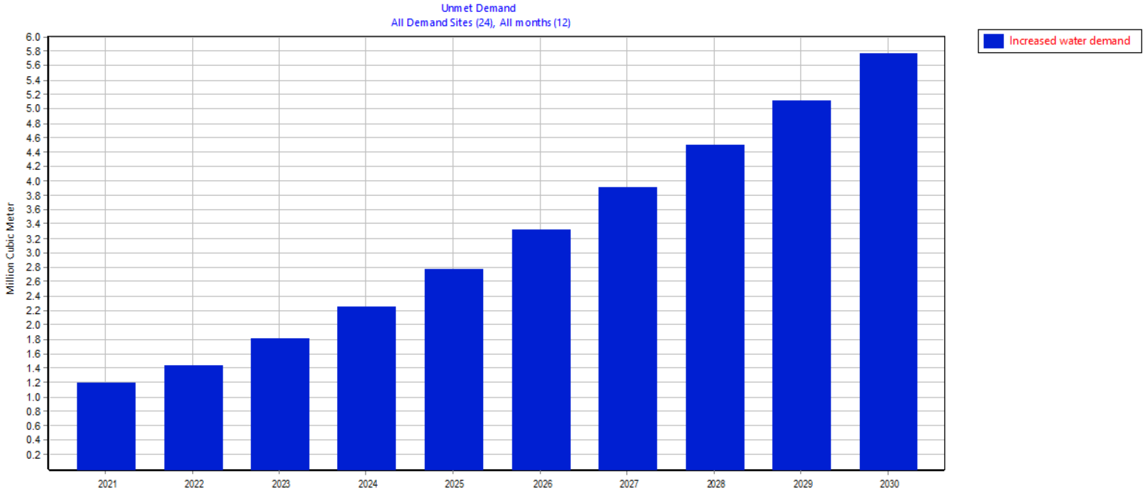


Figure 13. Annual unmet water demand values in the watershed as a whole

Demand site-based unmet demand analyses results for the Increasing water demand scenarios are given in the following figure. The results show that there will be unmet demand for irrigation (particularly in Badessa Sub-watershed) under this scenario.

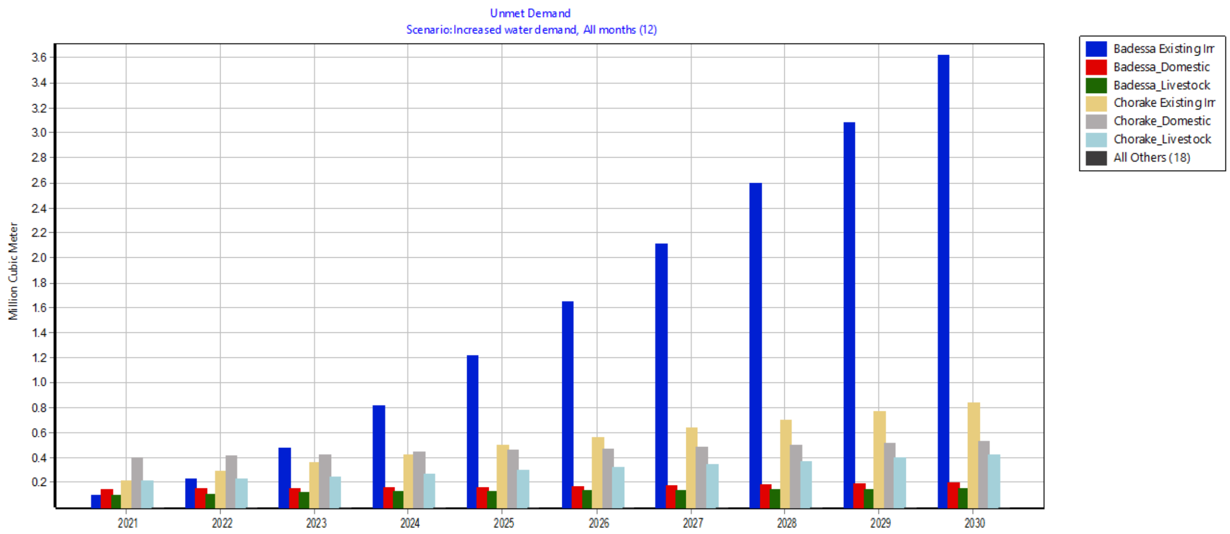


Figure 14. Demand site-based unmet demand analyses.

The results of the mean monthly-based unmet demand analyses are given in the following figure.

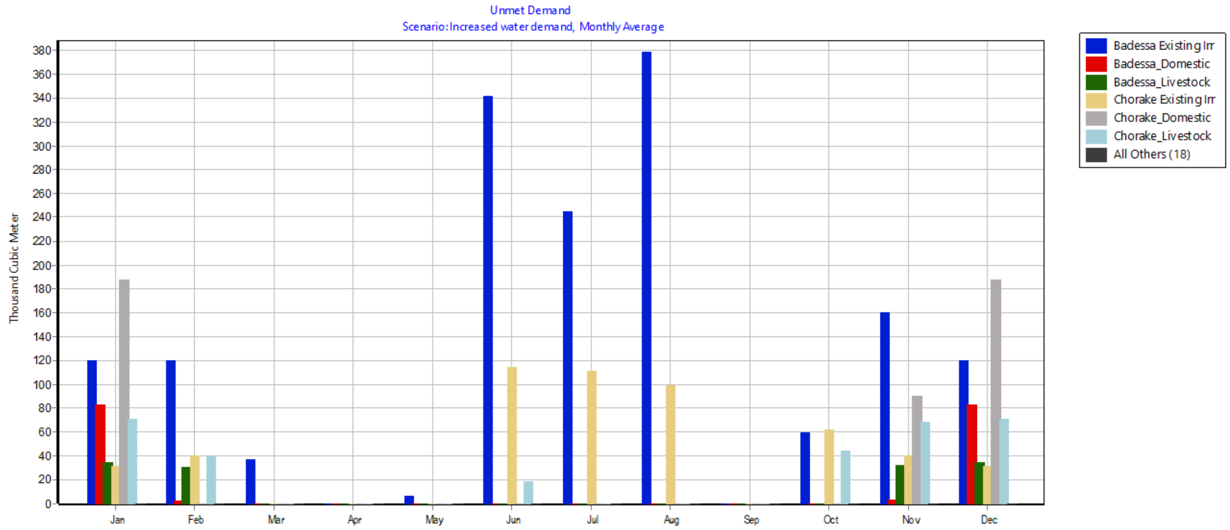


Figure 15. Results of mean monthly unmet demand analyses.

As can be seen from the above figure, the largest mean monthly unmet demand are found in the above mentioned sub-watershed for irrigation purposes. In addition, it can be seen from the same figure that the water resource in the watershed is not enough to cover all the other demands in all months except April and September. However, the dam recommends by the Irrigation study team was considered and the result of the analyses showed that the presence of the storage facility could reduce the demand-supply gap considerably. Thus, additional storage facility needs to be constructed and/or groundwater needs to be developed taking into consideration the quality of the groundwater for various purposes. Moreover, watershed management measures need to be implemented in the watershed so that stream flow of the river and its tributaries is regulated and baseflow is increased.

4. Conclusion

It can be seen from the results of this study that WEAP model can successfully be used to assess the demand-supply condition in the study area under various scenarios. It also has the ability the tile and location of scarcity for a given water use considering the demand-supply balance and water use (allocation) priority. The results of the study showed that even under the current scenario, there is a water scarcity in the watershed particularly in the dries months where irrigation water requirement is expected to increase considerably. The scarcity is expected to increase with increase in water demand for irrigation purpose in the future. Thus, construction of a storage structure that can store excess water in the Kiremt season to balance the supply-demand gap should be constructed.

References

Abdelkhalik, A., Pascual, B., Najera, I., Baixauli, C., Pascual-Seva. N. (2019). Deficit Irrigation as a Sustainable Practice in Improving Irrigation Water Use Efficiency in Cauliflower under Mediterranean Conditions. *Agronomy. 9*:732.

Adgolign, T.B., Rao, G.S., & Abbulu, Y. (2016). WEAP modeling of surface water resources allocation in Didessa Sub-Basin, West Ethiopia. Sustainable Water Resources Management, 2(1), 55-70.

Awulachew, S.B., Yilma, A.D., Loulseged, M., Loiskandl, W., Ayana, M., Alamirew, T. 2007. Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 78p. (Working Paper 123)

Engidew, K. (2015). Assessment on surface water potential and demands of Wabishebele Basin in Ethiopia. Thesis, Addis Ababa University, Ethiopia.123p.

George, M. V., Smith, S. K., Swanson, D. A., and Tayman, J. (2004). Population Projections. In J. S. Siegel and D. A. Swanson (Eds.), The methods and materials of demography (2nd ed., pp. 561–602). Elsevier Academic Press.

Jebelli, J. (2018). Water Allocation to Small Scale Irrigation Schemes using the Results of Analysis from WEAP Model: An Application to Mekabo Scheme in Tigray, Ethiopia. European Journal of Engineering Research and Science Vol. 3, No. 7: 88-95

Kamara AB, Van Koppen B, Magingxa L (2002). Economic Viability of Small Scale Irrigation Systems in the Context of State Withdrawal. The Arabie Scheme in the Northern Province of South Africa. Physics and Chemistry of the Earth. 27: 815-823.

King, J., Brown, C., and Sabet, H. (2003). A scenario-based holistic approach to environmental flow assessments for rivers. River Research and Applications, 19:619–639.

Loon, V.A., Droogers, P. (2006). Water Evaluation and Planning systems in Kitui, Kenya. http://www.futurewater.nl/watmansup,

MoWR (2009). Rift Valley Lakes Basin Integrated Resources Development Master Plan Study. Addis Ababa: HALCROW and GIRD, Ethiopian Ministry of Water Resources.

Orke, Y.A., Li, M.H. 2001. Hydroclimatic Variability in the Bilate Watershed, Ethiopia. *Climate*, *9*, 98. https://doi.org/10.3390/cli9060098

Sahoo, S., Dhar, A., Kar, A. 2016. Environmental vulnerability assessment using Grey Analytic Hierarchy Process based model. Environ Impact Assess Rev 56:145–154

Sieber, J., Purkey, D. (2015). WEAP - Water Evaluation And Planning System: User Guide for WEAP 2015, Stockholm Environment Institute - US Center, Somerville, USA, 2015.

SEI (2016) Water Evaluation and Planning System (WEAP) Tutorial Modules. A collection of stand-alone modules to aid in learning the WEAP software. USA

Tadesse, N. (2006). Surface waters potential of the Hantebet basin, Tigray, northern Ethiopia. Agricultural Engineering International: CIGR Journal. V.8: LW 05 010.

UK Trade and Investment (2004). http://www.tradepartners.gov.uk/water/ethiopia/opportunities/opportunities.shtml

Yasi, M. and Ashori, M. 2017. Environmental flow contributions from in-basin Rivers and dams for saving Urmia Lake. Iran. J. Sci. Technol. Trans. Civ. Eng., 41: 55-64, 10.1007/s40996-016-0040-1