Surface Water Demand Analysis on South Gojjam Sub Basin of Upper Blue Nile, Ethiopia

Shegaw Mequanint Setargie[1], Abebech Abera Beyene[1,2], Asegidew Gashaw[1]

[1]Faculty of Civil and Water Resources Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia

[2]Blue Nile Water Institute Bahir Dar University

* Correspondence: misganamare16@gmail.com

Abstract

Rapid population growth and agricultural expansion strain water resources in Ethiopia's South Gojjam sub-basin, necessitating analysis of current and future surface water demands to ensure equitable allocation and prevent conflicts. Government data, with rainfall validated by non-dimensional and double mass curve methods, indicated 1,276 million cubic meters (MMC) potential. WEAP model validation using Birr gauge streamflow (1994–2022) showed strong performance: SDR = 1, RSR = 0.141, NSE = 0.976, PBIAS = -14%. Baseline (2024) demands—rural (70.88 MCM), agriculture (43.91 MCM), livestock (28.64 MCM), urban (24 MCM)—were fully met, allocating 20.8% of mean annual flow (265.83 MCM) to environmental flows. Projections to 2050 under four scenarios revealed demands of 167.72 MCM (Reference), 194.7 MCM (High Population Growth; shortages: urban 8.31 MCM, rural 7.52 MCM), 176.89 MCM (Current Irrigation Potential; agriculture 1.87 MCM shortage), and 188.32 MCM (Future Irrigation Projection; agriculture 3.47 MCM shortage). These results emphasize urgent needs for integrated water management strategies.

Keywords: Irrigation water requirement; WEAP model; ArcGIS; CROPWAT model; Water Dema

1. Introductions

1.1 General Background

Water is a fundamental requirement for life and the advancement of society, and as the population has grown throughout time, so too has the demand for it. such as industries, economic expansion, urbanization agriculture, and livestock (Cosgrove & Loucks,2015).Water plays significant role in the development of a country. Ecosystems supporting water resources are continuously under stress due to population expansion and economic development (McCright & Xiao, 2014).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). Water is not only influenced by human activities, but also by natural factors, such as climate change. Hence, the impact of climate change]on water resources is the most serious agenda in worldwide today (Sharma & Ravindranath, 2019). 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 & Loucks, 2015).

Ethiopia is also a country that is naturally endowed with an adequate amount of surface and ground water resources. The total annual runoff from 12 basins was estimated to be about 122 billion cubic meters(Awulachew, 2019)). However, its availability, quantity, distribution, and quality have been reducing over time as a result of climate change, and emerging demand due to population growth and
economic development. To solve the scarcity problem different countries of the world are implementing different policies to boost the management system of the available water resources ((Tsegaye et al., 2006).
Ethiopia is constantly affected by shortage water for irrigation mainly because of improper water re source utilization and management practice though the country is water to be of East Africa (Tefera 2017). Planned development activities encompass all major river basins of the country. Due to huge irrigation and hydroelectric power potential, Abbay basin has attracted considerable attention (Adg olign et al., 2016). Ethiopia's population is expanding at a very fast rate; it is among the nations with the fastest growing populations. The goal of the government is for a middle-income nation to develop quickly. This will cause a change in the country's water demand pattern in the near future. As a result, it is essential to examine and assess how Ethiopia's supply and demand for water resources, particularly in the study area, related. (Dong, 2016) proposes that by analyzing the supply and demand of water resources, the conflict between supply and demand can be revealed, allowing solutions to be proposed. The WEAP model combines the supply and demand for water management.
In this study, the WEAP21 model was used to simulate water resources in the South Gojjam sub bas in and to evaluate the water balance under increased service levels due to increase in irrigation development, increase in population and to determine water allocation among users.

2. Materials and Methods

2.1 Study Area Description

2.1.1 Locations

The study area of the South Gojjam Sub-Basin is found in the upper Blue Nile River Basin, in northwestern Ethiopia. It is geographically located between the longitude of 36^0 50” E to 38^0 30” E and the latitude of 9^0 30” N to 11^0 20” N (Figure 1). The South Gojjam basin has a total drainage area of 16,762km2 and is 305 km from Addis Ababa, which is the capital city of Ethiopia, and 200 km from the regional town of Bahir Dar. The altitude in South Gojjam sub basin ranges approximately between 725 masl and 3930 masl. The highlands of the sub basin are higher in altitude, greater than 2200 masl up to 3930 masl. The lowlands have lower altitude less than 1400 masl.

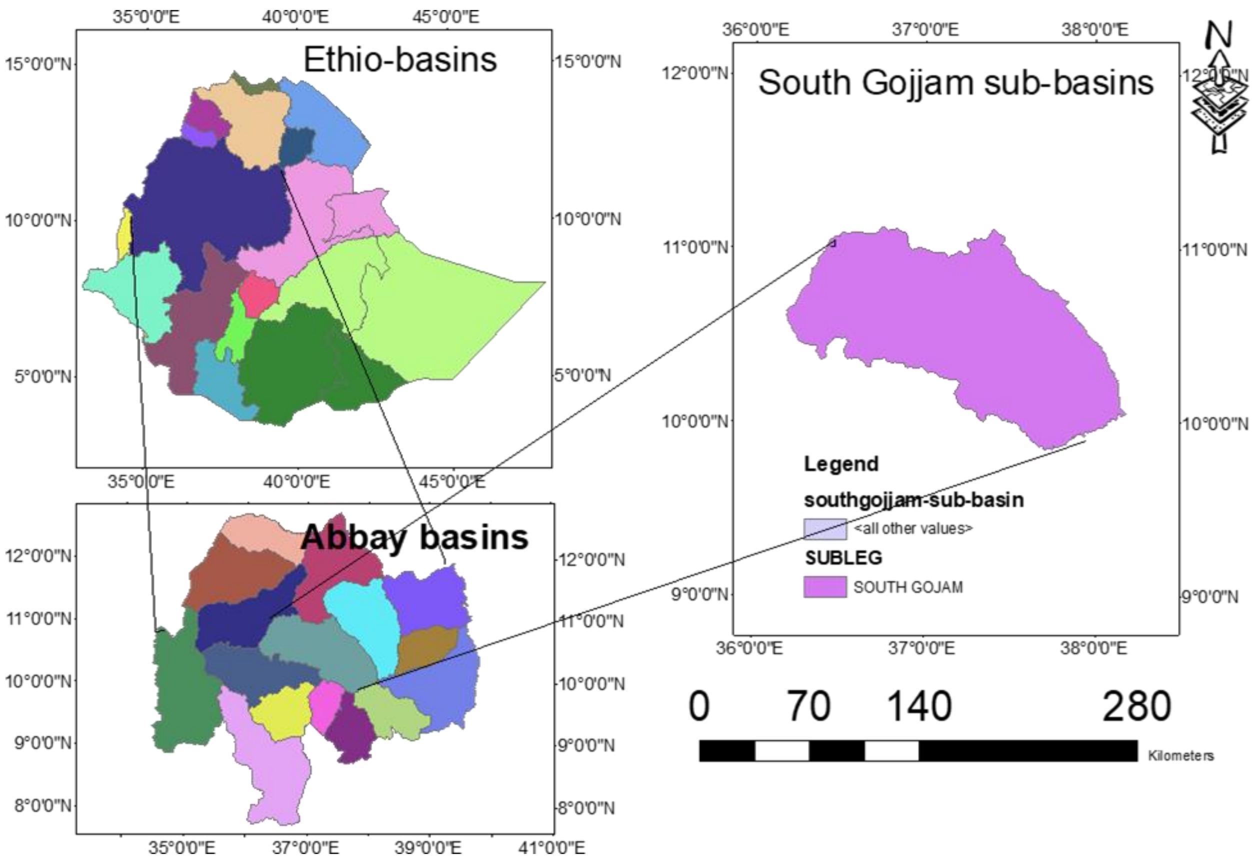

Figure 1. Location of the Study Area

2.1.3 Climate and Agro-ecology

The South Gojjam sub-basin receives annual rainfall of 845–2030 mm, with <1200 mm in the southeast and >1600 mm (up to 2025 mm) in the north. Annual maximum temperatures range from 14–33°C and minima from 10–18°C, peaking at 28–33°C max and 12–18°C min in western lowlands. Potential evapotranspiration (PET) spans 1105–2010 mm/year, exceeding 1800 mm/year in hot lowlands and dropping below 1400 mm/year in eastern highlands. Agroecologically, it features tepid to cool moist/sub-humid mid-highlands, cold to very cold moist sub-afroalpine/afroalpine highlands, and hot to warm moist/sub-humid southern lowlands.

2.2 Materials

2.2.1 Arc VIEW GIS

For any kind of hydrologic modeling involves delineating streams and river basin, and getting some basic river basin properties such as area, slope, flow length, stream network density, etc. Through the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using computerized procedures. The processing of DEM to delineate watersheds is referred to as terrain processing. In this study, for mapping and to geo-reference the collected information and generate spatial database, ArcGIS 10.4.1 was used.

2.2.2 Microsoft Office

Microsoft office include word, power point, and excel. Excel is a general-purpose electronic spreadsheet used to organize, calculate, and analyze data. This software is part of the Microsoft Office suite and is compatible with other applications in the Office suite. Excel has the same basic features as all spreadsheet applications, which use a collection of cells arranged into rows and columns to organize and manipulate data. They can also display data as charts, histograms and line graphs. In this study, it is used to import and export necessary data to and from WEAP model.

2.2.3 CROPWAT8.0 Model

The crop water requirement (CWR) is defined by the amount of water required to compensate the evapotranspiration loss (ET) from the cropped field. The CWR depends on the local climate and the crops growing in the fields. 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 (Doulgeris et al., 2015).

2.2.4 Water Evaluation and Planning (WEAP)

The Water Evaluation and Planning software is used for this study. The WEAP model essentially calculates a mass balance of flow sequentially down a river system, making allowance for abstractions and inflows. Due to the complexity of water resources management at the basin and sub- basin levels, models such as RIBASIM (Hydraulics, 1991), MODSIM (Labadie et al., 2005), WEAP (Abera Abdi & Ayenew, 2021), River Ware (Zagona et al., 2010), and Mike Basin (Kumar et al., 2021)have been developed over the last three decades to help allocate the available water resources among the different users in an optimum way. WEAP model was selected for this study because of its adaptability to whatever available data to describe a water resources system, its ability to use daily, weekly, monthly, or annual time-steps to characterize the system's water supplies and demands, its flexibility to be applied across a range of spatial and temporal scales, its usability throughout the world to analyze a diverse set of water management issues for small communities and large managed watersheds alike, its operation in an optimization of water allocation based on priorities set for each demand site (SEI, 2012).

2.3 Methods of Data Collection

Data sources included the Ministry of Water, Irrigation & Energy; Ethiopian Mapping Agency; National Meteorology Agency; and Water, Mine & Energy Department. Key datasets for WEAP modeling comprised: small-scale irrigation designs; meteorology (rainfall, temperature, humidity, solar radiation, wind speed); hydrology (streamflow); DEM; land use; water supply (population, growth rates, per capita use); and irrigation (cropland area, monthly demands, hectare requirements). Current and projected sectoral demands drew from Central Statistical Agency population data. Baseline (2022) projections used 1.6% rural and 5.2% urban growth rates; Reference Scenario extended to 2025.

Agricultural water demand

For Agricultural water demand, as per the WEAP model data input requirement, potential of irrigated land, type of crops and seasons of cultivation are important. The data for the irrigation projects were collected from ANRS Irrigation and low land Development Authority of Bahir Dar office branch. Irrigation projects that were selected for this study in the catchment are listed in Table 1 below with their areas.

Table 1. Selected irrigation projects and their areas

Irrigation projects	Net irrigated area(ha)	Scale
Lah finote selam	208	medium
Borebor	152	Small
Taba	1000	Meduim
Gudmen	300	Meduim

(Source; ANRS Irrigation and Low land development bureau, 2024)

In order to model the irrigation water demands both in the base year and in the future, annual activity level, annual water use rate, consumption rate and monthly variation is necessary. The crop water requirements were determined by using the CROPWAT. Finally, the consumption rate was obtained from the design document of the projects. Accordingly, the consumption rate of 50% was used for small-scale projects.

2.4 Methods of Data Analysis

2.4.1 Filling of Missing Rainfall Data

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. The surrounding stations located within the sub-basin help to fill the missing data on the assumption of hydro meteorological similarity of the group of stations. All stations' missing data in the sub- basin were less than 10%. Therefore, the station average method was used for filling missing data in this study. This method is accurate when 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). The following equation was used to filling missing data (station average method formula).

$$.PM = \frac{P1 * N1 + P2N2 + P3N3 + \cdots + PnNn}{N1 + N2 + N3 + \cdots + Nn} \quad (1)$$

Where, N1, N2, N3 and N represent the average annual rainfall at station 1, 2, 3 and n respectively; and P1, P2, P3 and Pn represent their respective precipitation data of the day for which data is missing at station M.

2.4.2 Filling in Missing Stream Flow Data

There are three stations in the basin namely (Birr gauge station, Chemoga gauge stations, and Temcha gauge stations) that have incomplete records. Such gaps in the record were filled by developing correlations between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods. Recorded stream flows were less than 10%. Therefore, the arithmetic mean value of the (1990-2022) was used to fill the missed records for all gauge stations.

2.5 CROPWAT Analysis

Computer model simulation is an emerging trend in the field of water management. CROPWAT is a powerful simulation tool which analyzes complex relationships of on farm parameters such as the crop, climate, and soil, for assisting in irrigation management and planning. CROPWAT facilitates the estimation of the crop evapotranspiration, irrigation scheduling and agricultural water requirements with different cropping patterns for irrigation planning. Reference Crop Evapotranspiration (ETo) values calculated using the Penman-Monteith equation.

2.5.1 Penman-Monteith Approach

From the Penman-Monteith equation and the equations of the aerodynamic and surface resistance, the FAO Penman-Monteith method to estimate ETo is expressed as:

$$ET = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \qquad (2)$$

Where: ETo is reference crop evapo-transpiration (mm day^{-1}); R_n is net radiation at the top surface (MJm^{-2}/day^{-1}); G is soil heat flux density (MJm^{-2}/day); T is mean daily air temperature at 2m height (^oC); u_2 is wind speed at 2 m height ($m\ s^{-1}$), e_s is saturation vapour pressure (kPa); e_a is actual vapor pressure (kPa); $e_s - e_a$ is saturation vapor pressure deficit (Kpa); Δ is slope vapor pressure curve (kpa^oC^{-1}); and γ is psychometric constant (kpa^oC^{-1}).

Crop - Evapotranspiration (ET)

Crop evapotranspiration is calculated by multiplying ETo by Kc, a coefficient expressing the difference in evapotranspiration between the cropped and reference grass surface. ETc is determined by the crop coefficient approach whereby the effect of the various weather conditions are incorporated into ETo and the crop characteristics into the Crop coefficient:

$$\boldsymbol{ET_c = K_c \times ET_o} \qquad (3)$$

Where: ET_C is crop water requirement (mm day^{-1}); K_C is crop coefficient; and ET_O is reference evapo-transpiration (mm day^{-1}).

The effect of both crop transpiration and soil evaporation are integrated into a single crop coefficient. The amount of water required by the crop during whole season is defined as crop water requirement.

2.6 Creation of Scenarios

Scenarios outline plausible future system evolutions under specific socioeconomic, policy, and technology conditions (SEI, 2012). In WEAP, they enable comparison of water demands, costs, and environmental impacts to explore "what-if" questions (Raskin et al., 1992). This study developed four: Reference, High Population Growth, Current Irrigation Potential, and Future Irrigation Projection. They assessed impacts of changing population/economic patterns and irrigation efficiency on domestic and agricultural demands, informing adaptive water management.

2.6.1 Reference scenario

The reference scenario was developed from the current account to simulate the likely evolution of the system without intervention; it only increasing in population growth. In this study, the reference scenario was created from 2020 to 2050.

2.6.2 High population growth scenario

Policy scenarios can be established from the reference scenario with alternative assumptions about future development. These scenarios can address a broad range of "what if" questions, such as: what if population growth pattern changes?

2.6.3 Current irrigation potential scenario

This scenario shows the impact of additional identified irrigation areas full development. This scenario is implemented in the model by increasing the irrigation area. In South Gojjam sub-basin many irrigation areas are identified suitable for irrigation yet not developed because of financial and other factors so this scenario shows the impact in water demand ''what if'' this identified irrigation areas are fully developed.

2.6.4 Irrigation projection scenario

This scenario was created; the sub-basin is not fully developed in terms of irrigation; there are potential areas suitable for irrigation. The South Gojjam sub-basin, part of the Upper Blue Nile Basin in Ethiopia, has significant potential for irrigation development. A study assessing land suitability and water availability identified approximately 2,263 square kilometers (226,300 hectares) in South Gojjam as suitable for surface irrigation using stream flow. In practice, irrigation activities are underway in various parts of the Gojjam zones. For instance, in Mecha Woreda, West Gojjam Zone, around 92,500 farmers have initiated irrigation projects covering over 19,000 hectares.

In summary, while South Gojjam has a considerable potential irrigable area of approximately 226,300 hectares, the actual extent of land currently under irrigation is likely lower, with specific figures varying across different woreda within the sub-basin. Hence this scenario shows what if the impact of irrigation development increased four times the current account (from 19,000ha to 226,300 ha)? What will be the effect in water demand in projection in irrigation scenario?

3.Result And Discussion

3.1 CROPWAT Model Analysis

3.1.1 Reference Evapotranspiration (ETo)

The reference evapotranspiration ranged from 2.43 mm/day to 4.44 mm/day maximum was in April and the minimum was in September respectively, as shown in Table 2. It was observed that ETo is high in winter due to the high temperature and decreases in summer due to the low temperature. The annual average mean ETo was calculated as 3.40 mm/dec. The low relative humidity, high temperatures and high wind increased evapotranspiration during the dry season (Canton, 2021).

Table 2. Reference evapotranspiration (ETo) of Debre Markos stations.

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/d Ay	ETo mm/day
January	8.3	23.7	36	78	7.8	18.8	3.5
February	9.6	24.6	36	86	7.8	20.1	3.93
March	11.3	24.9	42	86	6.1	18.6	3.93
April	11.3	24.5	44	95	8.1	22	4.44
May	11.6	23.7	51	61	6	18.4	3.7
June	10.1	20.3	72	43	4.6	16	3.01
July	10.3	18.9	81	52	2.6	13.1	2.5
August	10.4	18.7	82	43	2.3	12.9	2.43
Sept	9.9	19.9	71	52	5	16.9	3.05
October	9.2	21.3	58	86	7.2	19.4	3.55
Nov	8.3	22.4	48	78	7.6	18.7	3.41
Dec	8.3	22.8	48	78	7.7	18.2	3.29
Average	9.9	22.1	56	70	6.1	17.8	**3.4**

3.1.2 Effective Rainfall

Using the USDA Soil Conservation Service method, which utilizes the total rainfall value, effective rainfall was calculated. The maximum and minimum values of effective rainfall were found to be 155.1 mm in July and 11.8 mm in January, respectively. Further, the results showed in Annex 1 that the effective rainfall was the same as the total rainfall for most of the months except June, July, August, and September, due to the high temperatures and wind speeds in these months.

3.1.3 Crop Water Requirements (ETc) and Irrigation Water Requirements (IWR)

The irrigation water requirements calculated by the CROPWAT model for the crops included in the study area. The total water requirements maize was 385.3 mm/Dec. The results showed that the crop water requirements of the selected crops of the study area were higher during the dry season than in the rainy season, which reflects that the crops grown in the dry season need more water than those grown during the rainy season and require a large amount of water due to the hot climate of Debre Markos (Khan et al., 2010). This parallels the FAO report (Canton, 2021) which asserts that crops grown in the rainy season need less water than those grown during the dry season

Table 3 Irrigation water requirement of maize for Debre Markos stations.

Month	Decad E	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.7	2.33	18.6	4.5	13
Dec	2	Init	0.7	2.3	23	4.6	18.4
Dec	3	Deve	0.71	2.39	26.3	4.4	21.9
Jan	1	Deve	0.81	2.79	27.9	3.9	24
Jan	2	Deve	0.93	3.27	32.7	3.4	29.3
Jan	3	Deve	1.06	3.86	42.5	4.6	37.9
Feb	1	Mid	1.17	4.42	44.2	5.6	38.6
Feb	3	Mid	1.18	4.63	37.1	9.3	27.8
Mar	1	Mid	1.18	4.63	46.3	12.8	33.5
Mar	2	Mid	1.18	4.64	46.4	15.7	30.7
Mar	3	Late	1.1	4.5	49.5	16.6	32.9
Apr	1	Late	0.89	3.84	38.4	16.8	21.7
Apr	2	Late	0.68	3.1	31	17.6	13.4
Apr	3	Late	0.57	2.44	2.4	2.1	2.4
				Total	512.6	128.3	**385.3**

3.2 Surface Water Resources Availability

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 total annual river flow of the South Gojjam sub-basin at outlet Birr gauge station has been estimated to be 1276 MCM. In this result considering all runoff in South Gojjam sub basin sub basin lumpsum totally. Out of the mean annual surface runoff of the sub-basin, 84.3% the mean annual surface runoff of the sub-basin is produced from the heavy rainy months (i.e. August, and September). Average monthly surface runoff of the sub- basin is shown in Figure 4.1.To model the river flow system of the catchment in both upstream and downstream of the catchment to be well understood the capability of the study area based on monthly and yearly available water, the monthly average stream flow of 1994 -2022 from Dembecha near to Birr station was used as WEAP input. The result of the average monthly surface water resources availability of the South Gojjam sub basi n is shown in the figure 2

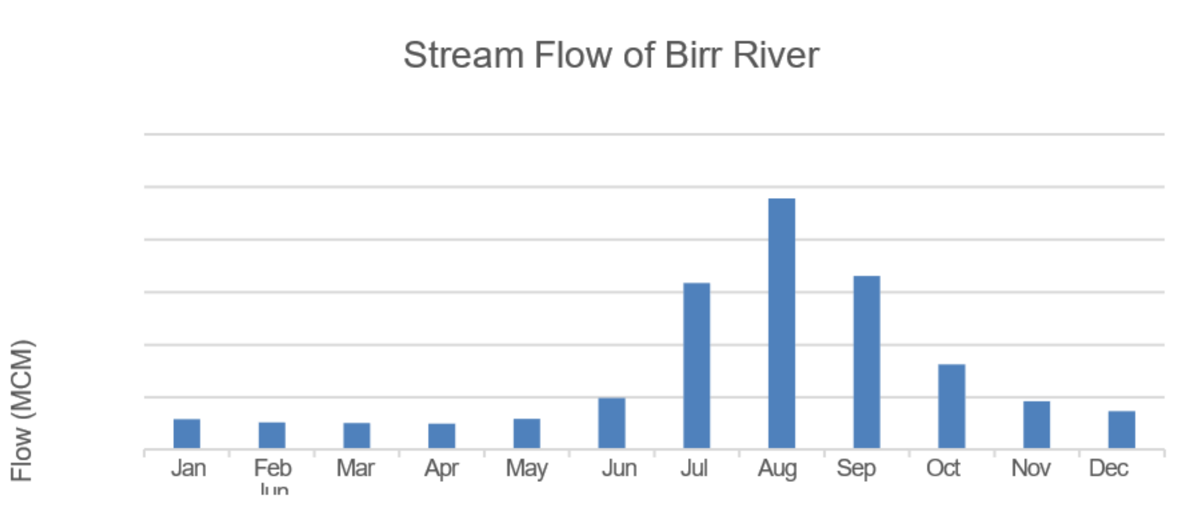

Figure 2. Monthly Average Stream Flow of Birr River

As shown in Figure 2 above, the total annual stream flow of birr River has beenestimatedtobe1276MCM.Thismeanscurrentlythecatchmenthasthesurfacewateravailability at the outlet of the catchment from which all the demand sites abstract their sources to fulfill their demand. The peak flow in Birr River is occurring on August to October. The highest monthly average flow occurs in August and the lowestoccurringinFebruarywithvalues570.948 MCM and 38.26MCM respectively.

3.3 Model Performance Evaluation

Calibration of the model means adjusting some parameters in such that there is good match between the simulated and observed data at selected stations (SEI, 2015). Observed data is required for calibration of the model and sufficiently long continuous observed data is available for all sub catchments in the sub-basin. Calibration of the WEAP model was based on the flow at the Birr gauging stations was done for the period 1994-2022. The accuracy of the model was assessed by simulated and observed stream flow, results was estimated that the simulated and observed flows were comparable in Birr main river, there was good match between monthly average stream flow of the outlet gauge Birr and runoff from the respective sub catchment values, and Nash-Sutcliffe Efficiency (NSE) Excellent performance, indicates predictions closely match observed data. Percent of Bias (PBIAS), Acceptable bias; model slightly underestimates but within an acceptable range. Ratio of Standard Deviation of Simulated Versus Observed (SDR), Strong performance. Lower value indicates better fit to the observed data, and Ratio of the Root Mean Squared Error to the Standard Deviation (RSR), Within target range; model captures variability effectively with appropriate prediction accuracy. Therefore, the model performance is perfect and provides a good estimate.

Table 4. Statistical Analysis Values of the Model Performance

Standard Statistical Parameters Range	Statistical Analysis Values	Remark
NSE≥0.5	NSE=0.93	Excellent performance.
PBIAS±25%	PBIAS =-12%	Acceptable bias
RSR ≤ 0.7	RSR=0.12	Strong performance
0.9≤ SDR≤ 1.1	SDR=1.0	Within target range

3.4 Water Demand in the Current Account Year (2024)

The current total water consumption for all consumers (domestic (Urban and Rural), agriculture and livestock water demand within the sub-basin was estimated to be 146.29 MCM. From this result agriculture and rural sites consumed the highest demand share which is 43.91 MCM and 56.56 MCM respectively. Livestock and Urban nodes consume 28.66 MCM and 15.07 MCM respectively. The result of the water demands for as elected demand sites in the catchment is depicted in the Figure3 below.

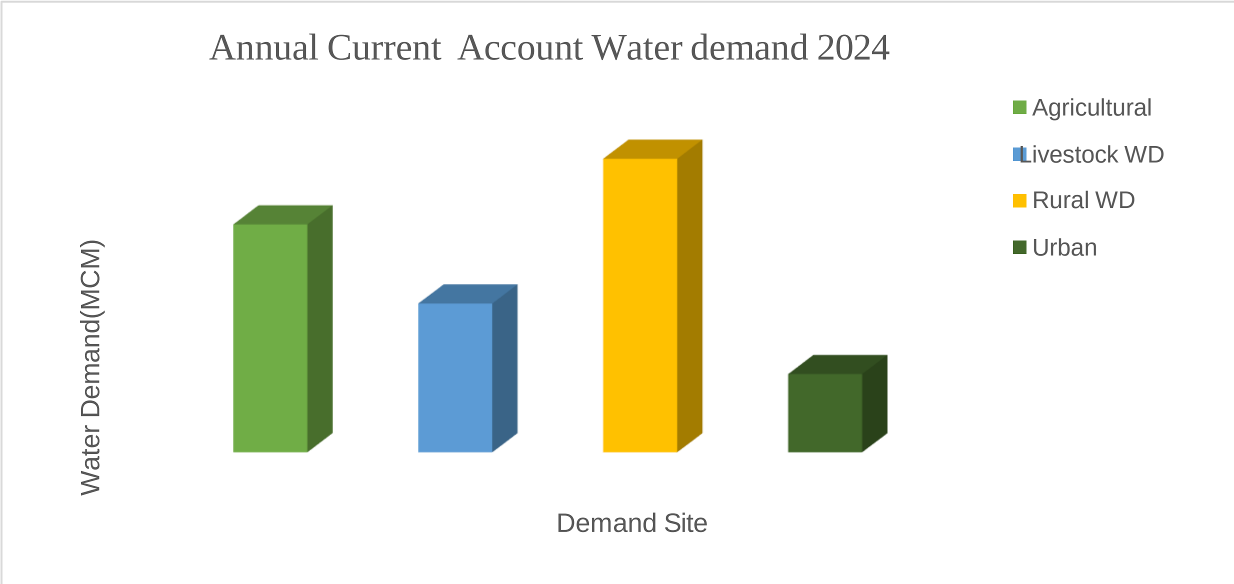

Figure 3 Annual Water Demand in a current account year2024

- **Unmet Water Demand in the Current Account Year(2024)**

The overall unmet demand of all demand sites in the current account year is found to be 0.01 %. This implies that the overall coverage of supply is 99.9% in the current account year.

3.5 Environmental Flow Requirement

For South Gojjam sub-basin 20.8% of total annual runoff was allocated to the environment. This was estimated from the available 28-year river flow; the flow duration curve is one of the common methods which was used in determining environmental flows using the 90% flow as the minimum environmental flow.

3.6 Future Scenario Analysis

3.6.1 Reference Scenarios

Reference scenarios represent the change that is likely to occur in the future without any intervention or no new policy measures. Thus, according to this scenario, what happen to the future water demands if no policy change occurs between the years 2025to 2050?

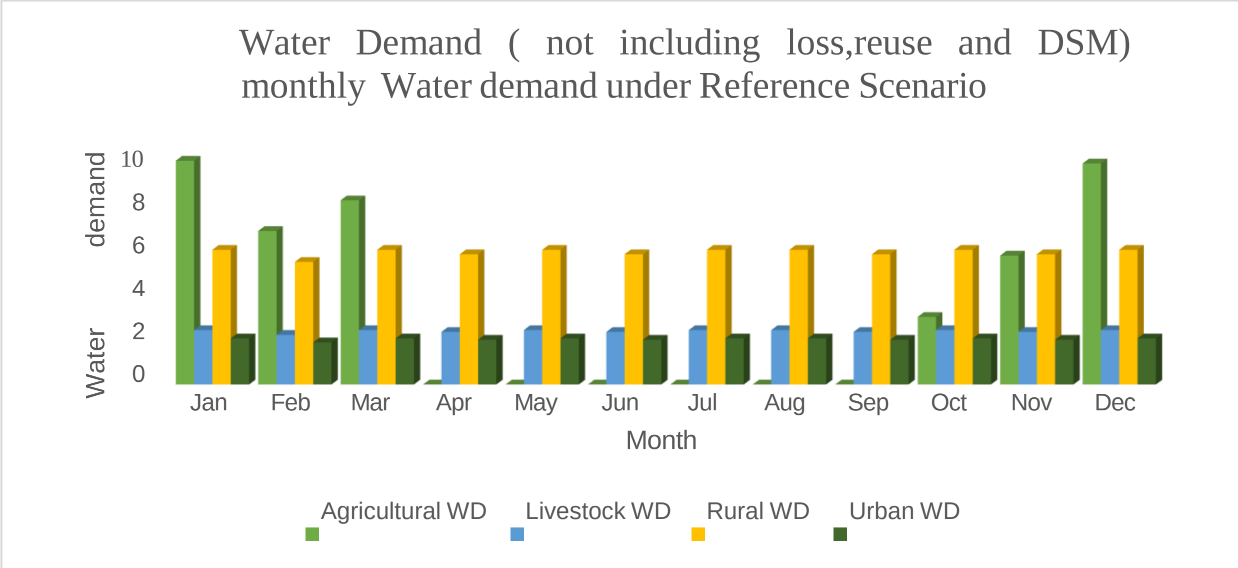

Figure 4. Annual monthly demand (MCM) for all demand site under reference scenarios

Under this Scenario, As Figure 4 shows, from monthly annual water demand, agricultural water demand site has got higher water demand in the month October to march. Livestock, rural and urban demand sites use water all months. In this scenario Annual Water Demand is increasedMCM which increased by 14.65% from base year (2024).

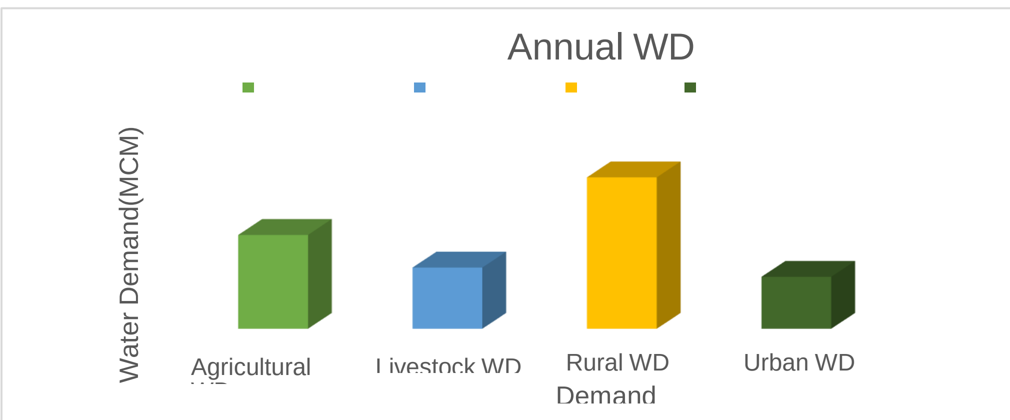

Figure 5. Annual water demand for all demand site under the reference scenario

As shown in Figure 5, from annual monthly unmet demand, rural and urban demand sectors have got scarcity the months between Novembers to March. Agricultural unmet demand seen on month march. Livestock has got fully coverage. Under this scenario, the annual unmet water demand was estimated to be 13.99 MCM. Among this unmet demand, 0.27 MCM, 8.33 MCM, and 5.4 MCM water shortages faced under agriculture, rural and urban demand sites respectively and livestock demand site has not faced to unmet demand (full coverage). Sectoral each month's annual unmet water demand is summarized on Annex B II

3.6.2 High Population Growth Scenario

This scenario shows what will happen if the population growth rate is set to greater growth rate than the reference scenario population growth rate? In this scenario, the population growth rate was raised to 5% for Urban and 2% for rural to simulate the water supply demand in the future.

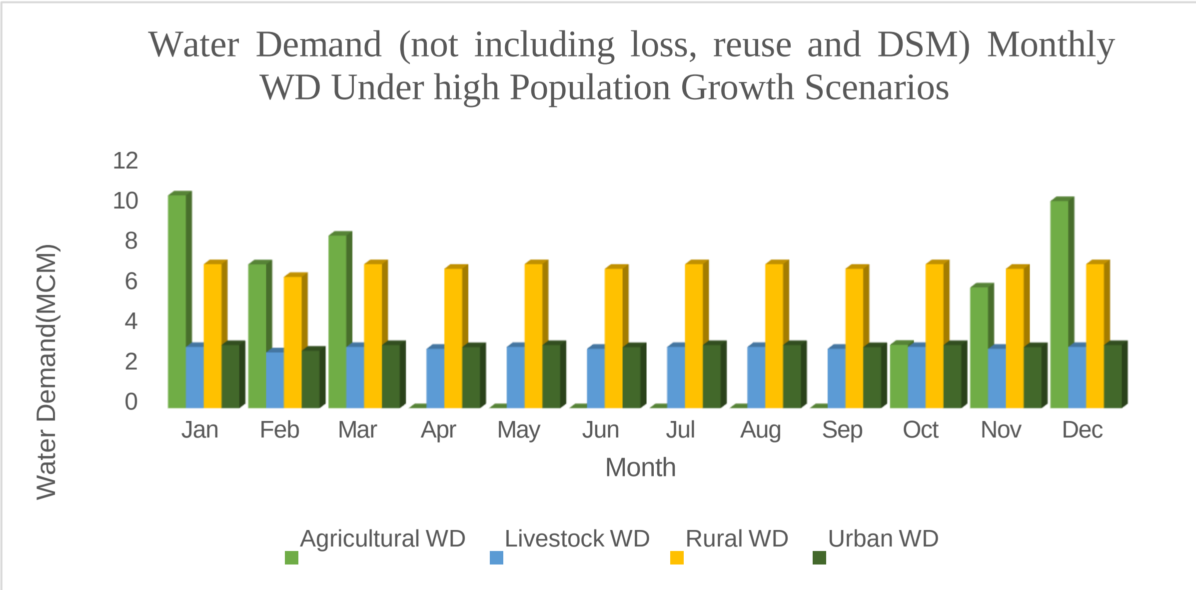

Figure 6. Annual monthly water demand for high population growth scena

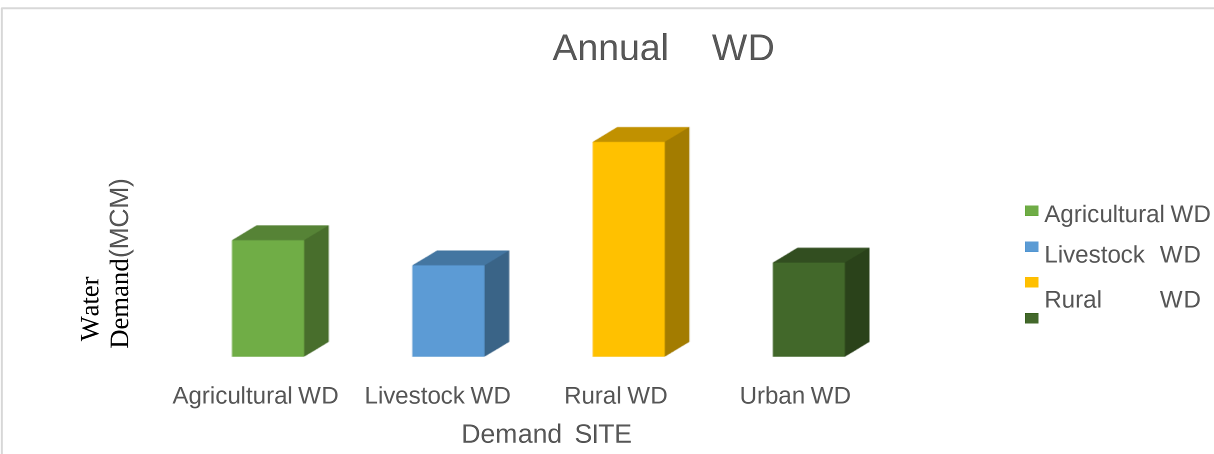

Figure 7. Annual water demand for demand site under HPGS.

Figure 8 result shows that the annual monthly unmet water demand for high population growth scenario is higher than the annual unmet demand under the reference scenario for all water supply demand sites. The result of reference scenario is 13.99 MCM which increased to 1621 MCM under High population growth scenario.

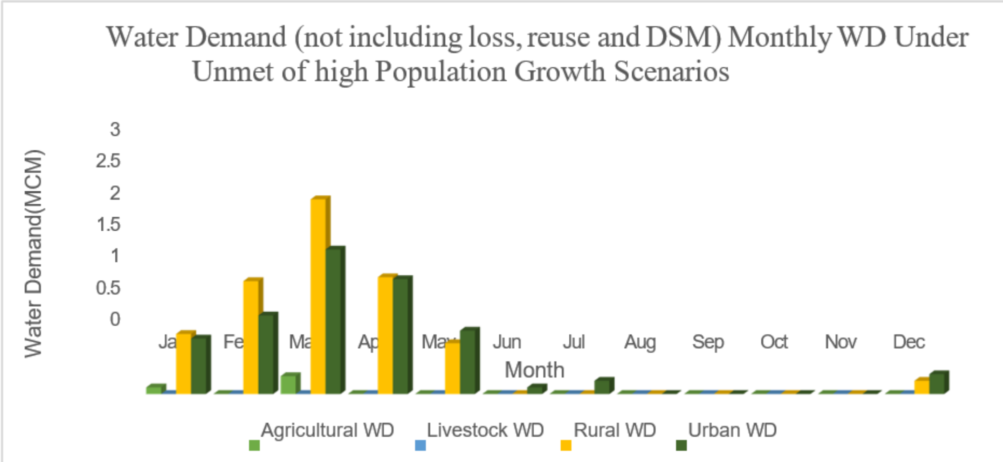

Figure 8. Annual monthly unmet water demand for demand site under HPGS.

3.6.3 Current Irrigation Potential Scenario

This scenario shows the impact of additional identified irrigation areas full development. This scenario is implemented in the model by increasing the irrigation area. In South Gojjam sub- basin many irrigation areas are identified suitable for irrigation yet not developed because of financial and other factors so this scenario shows the impact in water demand if this identified irrigation areas are fully developed. For this scenario, increasing irrigation land to studied potential of 46,623 ha which is increased 2.66 times the current irrigable land 19,000 ha. As illustrated in Figure 9 the annual monthly water demand share under this scenario agriculture demand has increased in the month October to march. This comprises that, the annual water demand was increased from 43.91 to 74.61MCM compared to reference scenario.

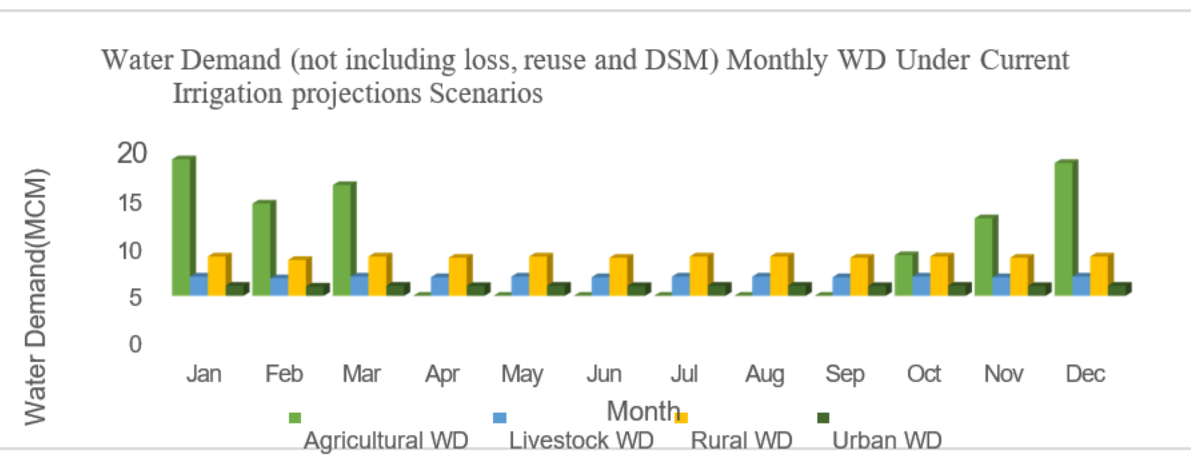

Figure 9. Annual monthly water demand under CIPS.

As in Figure 10 illustrates, regarding to sectoral aspect of water demand, agriculture demand site is dominating under this scenario which share 74.61 MCM. Livestock, rural and urban consumes the remaining demand share 28.66 MCM, 58.56 MCM and 15.07 MCM respectively from the annual water demand 176.89 MCM. Annual each month's water demand under current irrigation potential scenario is presented on Annex B V.

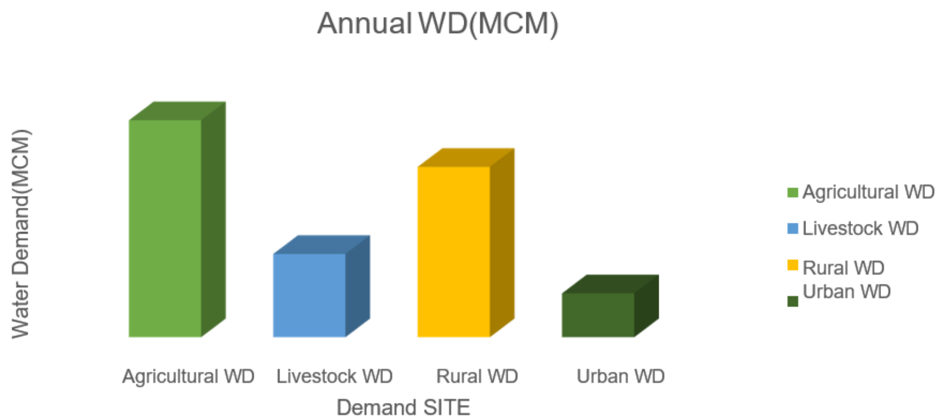

Figure 10 Annual water demand for demand site under CIPS.

Under this scenario the overall unmet demand is 7 MCM. Among this result as shown in figure 11 agriculture, rural, and urban (1.87 MCM, 3.59 MCM and 1.54 MCM) faced to unmet demand respectively. Livestock demand site got full coverage also in this scenario. Annex2 VI summarizes the unmet water demand of each month for all demand consumers.

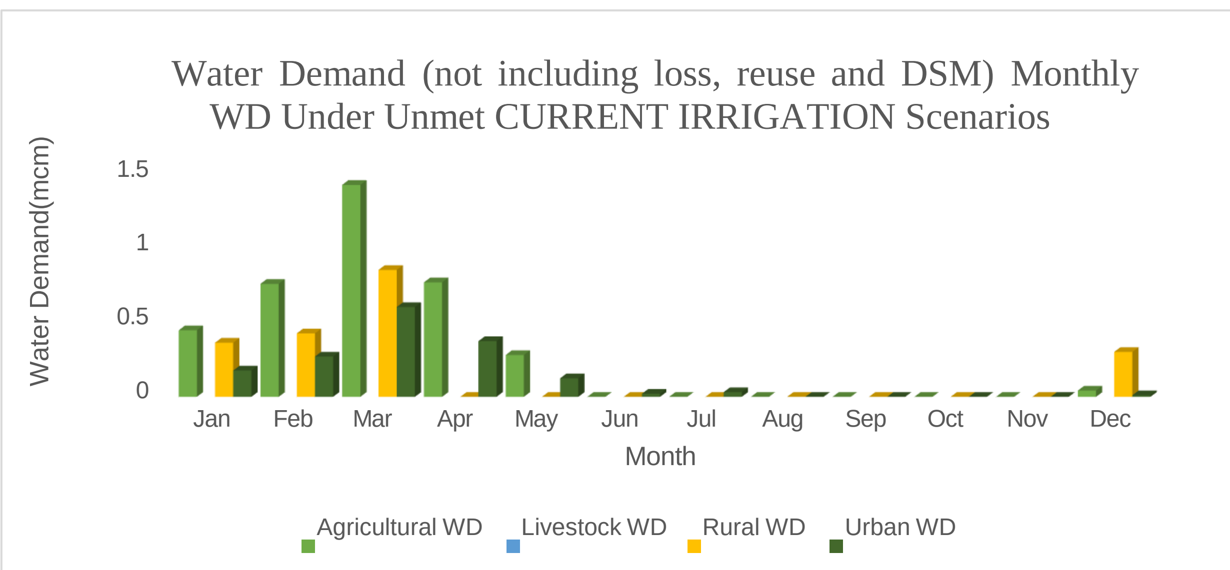

Figure 11. Annual monthly unmet demand for demand site under CIPS

3.6.4 Future Irrigation Projection Scenario

The sub-basin is not fully developed in terms of irrigation; there are potential areas suitable for irrigation. According to Abay basin authority office report (2018), additional irrigation projects are under study by different institutions and in the sub-basin, yet the developed irrigation projects are quite small. Hence this scenario shows what if the impact of irrigation development is increased from the current account 19,000ha to 226,300 ha? What will be the effect in water demand in projection in irrigation scenario? As the figure 12. shown, under irrigation projection scenario annual monthly water demand is increased by 20.6 MCM compared to reference scenario and 11.43 MCM from current irrigation potential scenario.

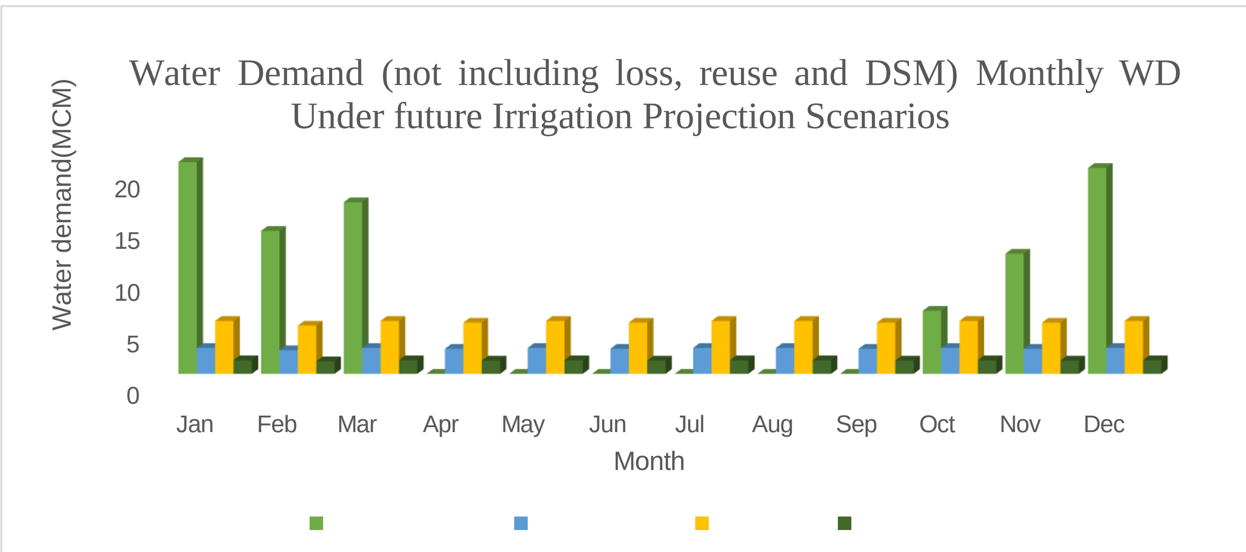

Figure 12 Annual monthly water demand pattern under IPS

The annual Sectoral water demand under this scenario as shown in figure 13, agriculture demand site shared the largest demand 86.04 MCM. Rural, urban and livestock shared 28.66 MCM, 58.56 MCM and 15.07 MCM respectively from total water demand 188.32 MCM. The annual each month water demand under irrigation projection scenario is shown in Annex B VII:

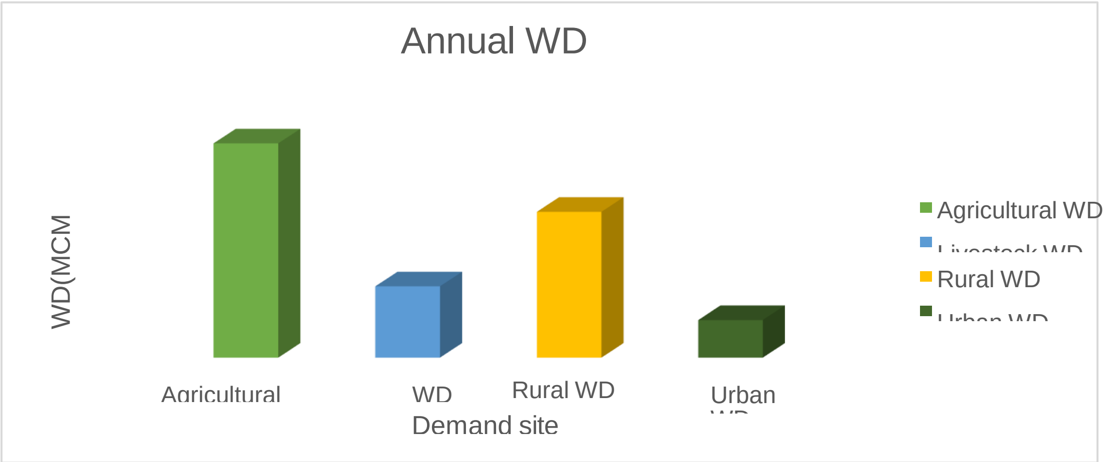

Figure 1 3 . Annual water demand for all demand site under IP.

The annual unmet water demand under this scenario is 8.6 MCM which is increased by 1.6 MCM from current irrigation potential scenario. Among this value as shown in the Figure 14 agriculture
3.47 MCM, rural 3.59 MCM and urban 1.54 MCM. Livestock demand site got full coverage (no unmet demand). Annex B VIII summarizes annual each month sectoral unmet water demand under irrigation projection scenario.

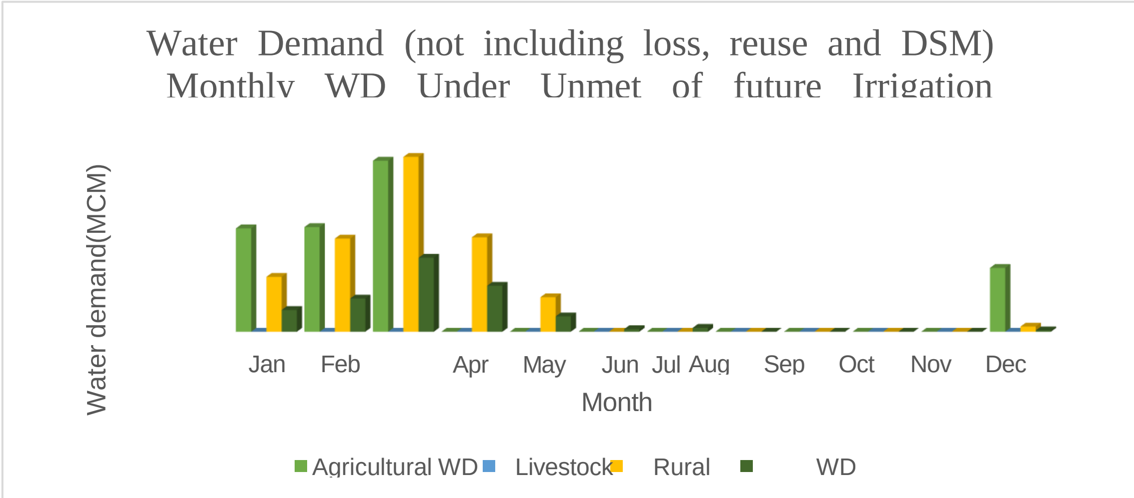

Figure 1 4 . Annual monthly unmet demand for all demand site under IPS.

3.8 Effect of Water Demand on Future Water Resources

The South Gojjam sub-basin's future water resources will be greatly impacted by both irrigation expansion and population growth. Water demand is expected to increase from 167.72 million cubic meters (MCM) to 194.7 MCM under the high population growth scenario, with rural areas having the highest demand (80.93 MCM). Unmet demand rises to 1621 MCM in this scenario as well, suggesting possible shortages. This problem is made worse by irrigation expansion; according to the Current Irrigation Potential Scenario (CIPS), agricultural water demand rises to 74.61 MCM, and according to the Irrigation Projection Scenario (IPS), overall demand rises to 188.32 MCM, leaving

8.6 MCM of unmet demand. These patterns draw attention to the conflict between the urban, rural, and agricultural sectors for water resources and raise issues related to ecological sustainability and food security.

4. Conclusion and Recommendation

Creating a model for the water demand analysis of South Gojjam sub-basins was the main goal of this study. This objective was accomplished by effectively determining if the available surface water potential is adequate to meet water needs using the Water Evaluation and Planning (WEAP) model. The current total annual water consumption of about 2.8% of the sub-basins 1,276 MMC surface water potential is much less than the basin's potential. This suggests that there are currently enough water resources available to satisfy the needs of many sectors, such as urban, animal, agricultural, and rural water needs. Variability in Seasonal Runoff: The results show a notable 9.5% drop in availability and a notable decrease in runoff during the dry season (January to June). Meeting water demand during these months may be difficult due to this fluctuation, particularly for industries that depend on timely water access.

Using 44.4% and 45.7% of total demand, respectively, Irrigation was the sector that used the most water, especially when considering current irrigation potential and irrigation projections. This implies that agriculture heavily depends on water supplies, which may raise competition for water as demand rises. In some situations, the agricultural sector had the largest unmet water demands, suggesting possible vulnerabilities in the event that future demands rise or water availability changes. In order to properly control agricultural water use, proactive actions could be required, as indicated by the unfulfilled expectations in both the CIPS and IPS scenarios.

Due to increased irrigation and population growth, the South Gojjam sub-basin's future water demand is expected to increase by 16%, from 167.72 million cubic meters (MCM) to 194.7 MCM, with rural areas seeing the highest demands. Due to the agricultural water needs, which are estimated to be 44% (74.61 MCM) under the Current Irrigation Potential Scenario (CIPS) and 112% (188.32 MCM) under the Irrigation Projection Scenario (IPS), there is a concerning unmet demand of 966% (1,621 MCM). In order to avoid future shortages, maintain ecological sustainability, and guarantee food security, it is imperative that sustainable water management solutions receive rapid attention as competition for scarce water resources increases among the urban, rural, and agricultural sectors.

The study evaluated surface water availability and demand in the South Gojjam sub-basin using integrated modeling approaches. The results indicate that current water resources are sufficient to meet present demand; however, future increases in irrigation development and population growth may lead to water shortages in certain sectors.

Effective water management strategies such as improved irrigation efficiency, development of water storage infrastructure, and integrated basin management are necessary to ensure sustainable water resource utilization.

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