International Journal of Research Studies in Science, Engineering and Technology
Volume 7, Issue 12, 2020, PP 01-10
ISSN 2349-476X

Optimization of Long-Term Water Allocation and Analysis of adaptation strategies in the Bilate River Catchment, Rift Valley Lakes Basin, Ethiopia

Desalegn Laelago Ersado, M. Sc[1], Sirak Tekleab, Ph. D[2], Mihret Dananto, Ph. D[3]

[1]Lecturer, Department of Hydraulics and water resources engineering, institute of technology, Hawassa University, Post office Box: 05, Hawassa, Ethiopia

[2]Assistant professor, Department of Water Resources and irrigation engineering, institute of technology, Hawassa University, Post office Box: 05, Hawassa, Ethiopia

[3]Associate Professor of Water Supply and Environmental Engineering, Department of Water Supply and Environmental Engineering, Institute of Technology, Hawassa University, Post Office Box: 05, Hawassa, Ethiopia

***Corresponding Author:** Desalegn Laelago Ersado, Lecturer, Department of Hydraulics and water resources engineering, institute of technology, Hawassa University, Post office Box: 05, Hawassa, Ethiopia.*

ABSTRACT

The extensive water resources development plan in Bilate catchment due to the rapidly growing population, irrigation development expansion, climatic variability, and socioeconomic development has recently embarked on a water shortage stresses. Furthermore, the lack of sufficient knowledge about available water resources and lack of coordination in water resources management in the basin often alleviates the competition of fixed water resources among the users. Therefore, optimizing long-term water allocation was implemented with the big goal of determining the optimal allocation of water resources to maximize the overall benefits without compromising ecological requirements and proposing mitigation methods to alleviate the problem of water scarcity during peak demand periods. The Water Evaluation and Planning (WEAP) model is generally used in the formulation and evaluation of alternative plans for responding to water-related problems and water resources developments. To assist in the assessment of spatial-temporal stream flow simulations within watersheds, the Soil and Water Assessment Tool (SWAT) employed for Bilate River reaches and its sub-catchments. Indicators of Hydrologic Alteration (IHA) and CROPWAT 8.0 software programs used to estimate in stream flows requirement (IFR) and the crop water requirement and CROPWAT 8.0 respectively. Three development scenarios such as Agricultural and Macro-Economic Development effect scenarios, Climatic change scenarios, and Alternatives Scenarios were built in the long-term planning horizons(2013-2050). The optimal water allocation for each sub-catchment was done by considering Ethiopian water allocation and apportionment criteria and water act priority order. The result revealed that Agriculture growth (increasing irrigation projects) and socio-economic development caused a significant increase in water demand and hence increases unmet water demand in different parts of the catchments. Similarly, the effect of climatic variation has been increased unmet demands in the last year of scenarios (2030-2050). Therefore, the evidence from this study suggests developing a comprehensive policy and applying effective structural and non- structural water conservation techniques to mitigate water scarcity and to improve water availability for productive use

Keywords: *Water Resources Optimization, Long-term Water Allocation, WEAP, Scenarios Developments, Bilate Catchments.*

INTRODUCTION

Effective water resources development and utilization are widely recognized as crucial for sustainable economic growth and poverty reduction in developing countries (McCartney et al., 2010). A challenging problem which arises in water resources domain are increasing uncertainty in supply and the growing demand, climatic changes, and non-cooperative developments among the upstream-downstream users. In order to ensure food security at the household level for Ethiopia's fast growing population, to transform the rain-fed agricultural system, which depends on rainfall into the combined rain-fed, and irrigation agricultural system, more small medium and large-scale irrigation infrastructure needs to be developed. These problems are difficult to handle easily and lead to myriad problems over fixed water resources and further results in water scarcity. There is a further problem with water abstraction, which is often being done without the basic understanding of the complex hydrological and hydrogeological system and the fragile nature of the catchment. The assessment of the potential available resources and designing best utilization mechanisms (modeling) through an area-based development plan on a watershed level used to ensure sustainable developments. An alternative approach to the problem is quantity based water allocation criteria(Mutiga *et al.*, 2010) and determining water balance in the basins levels and optimal water allocations of available water resources among users' in equitable and reasonable ways. A new approach is therefore needed to develop water resources allocation framework to optimally utilize the available water resources. A number of works have shown that this problem can be overcome by using optimal water allocations and developing integrated water resources managements (Tena et al., 2016; Awadallah et al., 2014; Speedy et al., 2013).

The main objective of this study is to determine the optimal allocation of water resources to maximize the overall benefits without compromising ecological requirements and to assess the impacts of additional socio-economic development scenarios in Bilate River Catchments on water availability using the Water Evaluation and Planning (WEAP) system. With this in mind, the critical water shortage locations and causes of water shortage within the sub-catchments levels, and adaptations strategies developed at spatial scales.

MATERIALS AND METHODS

Location of the Study Area

Bilate River Catchment is situated in South Western Escarpment of the Main Ethiopian Rift. The study area is situated between 6° 35’ 00" and 7° 57’ 00" North of latitude and 37° 47' 00" and 38° 18' 00" East of longitude. The total area of the watershed is about 5,515 km^2. the altitude of the region varies between 3371 masl and 1175 masl. Bilate river catchment drains from the north of the Abaya-Chamo Sub-Basin to Lake Abaya. The shape of the Bilate River Catchment is long and narrow because of this the flow in the tributary channel reaches the mainstream at different time, thus distributing the total runoff over a long period. The major water resources development activities and demand sites to be input to the analysis in this study are distributed on the eight sub-catchments, namely Weira, Guder, Bishan Guracha, Cherake, Kenene Boga, Korichasha, Kerisa, Bedesa and Bisare Sub-Catchments. Figure 1 shows Location of Bilate River Catchment.

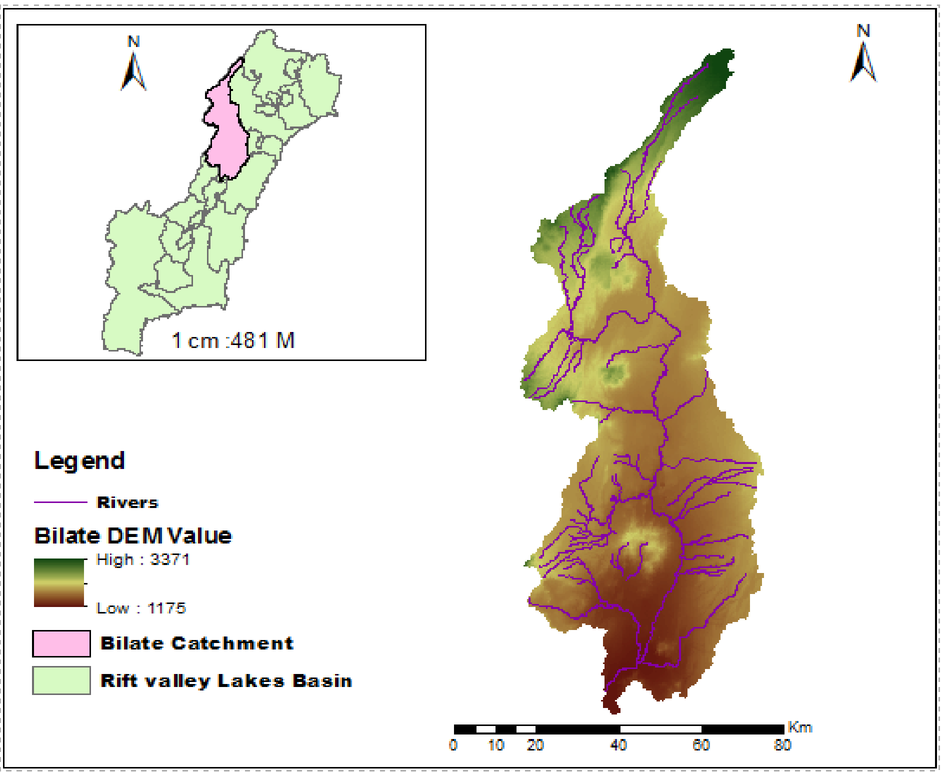

Figure1. *Map showing the location of Bilate River Catchment*

Dataset and Data Sources

The major data types that are used in this study are hydro- metrological data, digital elevation map(DEM), water demands data and water supply schemes, and their corresponding geographical locations. Existing and future irrigation potential sites in Bilate River catchment have been included in the model and cropping pattern of sub-catchments were determined from secondary data from woredas(Agriculture office and rural development office) and consultation with the beneficiaries in different kebeles(questionnaires). The potential surface flows data for each sub-catchments have been included using the output of the SWAT hydrological model of the sub-basin by following approaches used by Tena et al.,(2016). The common data collections sources are through field visits, the Rift valley lakes Basin integrated master plan(MoWR,2008), Ethiopian meteorological agency, Ministry of Water resources Irrigation and Electricity(MoWRIE), Regional governmental institutions, Irrigation Development Authority, Past researches those focused on the water-related studies done on rift valley lakes basin and Bilate River catchments, and NGO's documents. We used an established technique, namely normal ratio method and station average methods to replace missing data values. We explicitly accounted for the homogeneity test, which is used to determine the nature of rainfall distribution during different rainfall seasons for the selected station of the basin. We analyzed the data consistency test as a function of a double mass curve, relative standard error, outlier test, and quintile plots methods. Results provide a good fit to the data.

Water Demands

The major demand sites in the catchments are irrigation, domestic Water, Livestock and Wildlife Water Demand and Environmental Flow Requirement sites.

Domestic Water Demand

Water demands for domestic water demand purposes used for indoor and outdoor household purposes. Water demand analysis is based on collecting information on how many people are living and how much amount does an individual needed in each sub-catchment in both urban and rural centers. Based on UNICEF (2000) guidelines a standard of 50 liters per capita per person per day (lpcd) for urban population and 20 liters per capita per person per day for rural consumption was used to determine domestic demands for each sub-catchment. Water demands for domestic demands industrial purposes are clustered under current domestic water demand and future domestic water demand as shown in **Table 1.** Based on past population growth rate trends of sub-catchment, there will be three scenarios developed on future domestic water demands to describe the uncertainty in the evolution of the domestic water demands. These scenarios include lower growth scenarios, medium growth scenarios, and higher growth scenarios including population change and an increase in the per capita usage of water due to anticipated socio-economic development. The method of population projection for the future period was selected by examining the growths of the community that have occurred between recent censuses.

Table1. *Domestic water Demands*

Sub-catchment	Baseline Demands (Mm^3)		Scenarios Demands (Mm^3)					
			Low Growth		Medium Growth		High Growth	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Weira	2.23	0.05	2.80	0.10	2.80	0.11	3.22	0.13
Gudar	3.24	1.01	4.07	2.13	4.07	2.20	4.68	2.75
Bishan-Guracha	5.29	0.70	6.66	1.49	6.66	1.54	7.65	1.92
Chorake	1.21	0.44	1.52	0.92	1.52	0.95	1.75	1.19
Kenene	2.79	0.09	3.51	0.18	3.51	0.19	4.03	0.24
Badesa	0.72	0.08	0.91	0.16	0.91	0.17	1.04	0.21
Korchisa	1.15	0.00	1.45	0.00	1.45	0.00	1.66	0.00
Bisare	0.62	0.00	0.77	0.00	0.77	0.00	0.89	0.00
Total	17.24	2.38	21.69	4.98	21.70	5.15	24.93	6.44

Irrigation Water Demands

Irrigation development is a key for reliable and sustainable agriculture developments, which leads to overall development of a country (Haile and Kasa, 2015). The Irrigation demands in each sub-catchment were calculated for existing irrigation projects and potential irrigable lands areas that will be developed in the future periods. The total area under existing irrigation projects in the catchment is about 16,199 ha and potential areas for irrigation development are 436,5852ha. Irrigation water demand for the catchment was calculated by multiplying the total area under irrigation with the average water requirement for each cropping pattern. Irrigation water requirement (IWR) of the irrigated crops was calculated using CROPWAT version 8.0, a program developed by the Food and Agricultural Organization of the United Nations (FAO, 2006) using the climatic data, cropping pattern, planting dates, and area of each crop.

The future irrigation water demand was emphasized on potential land for irrigation developments those identified from the master plan of study areas, feasibility, landform, topographic suitability(remote sensing techniques), and proximity to rivers, availability of water sources, and from different design documents.

Livestock and Wildlife Water Demand

Water consumption by livestock was considered as well in the WEAP model, given the importance in many parts of study areas. Livestock water use is water associated with livestock watering, feedlots, dairy operation, and other on-farm needs. A unit water requirement of 25 l/day (Zinash et al., 2003) for each tropical livestock unit(TLU) was given as the unit consumption rate to estimate the water demand for all livestock and wildlife in each catchment. Livestock and wildlife figures were also based on agricultural sample survey data (CSA, 2017) estimated to about 907,109 TLU for the whole catchments, and the total estimated annual demands of livestock were 8.28 Mm^3.

Environmental Flow Requirement

Environmental flow is the amount of water needed for the maintenance of both spatial and temporal patterns of river flow (Smakhtin *et al*., 2006). The key water allocation policies in Ethiopia (MOWR, 2010) recognized the basic minimum requirement as the reserve has the highest priority in any water allocation plan. Environmental flows are one of the various water demands that need to be incorporated into water resource allocation modeling(Tena et al.,2016). The environmental flow requirement (EFR) is calculated by using Indicators of Hydrologic Alteration (IHA) software (The Nature of Conservancy, 2009).

Surface Water supply

The efficient and responsible management of water resources relies on accurate streamflow records. However, recorded observed data obtained from stream gauge stations do not provide continuous streamflow within the entire region of study areas. Therefore, the amount of streamflow from each sub-catchment river network was developed from separate hydrological modeling, the Soil and Water Assessment Tool (SWAT) packages that are used to generate the streamflow upstream of the data set (outlet of each-sub-catchments. The long-term variation in surface water at the outer let of each sub-catchments were calculated for eight sub-catchment is depicted in Table 2.

Table2. *Long-term monthly surface water flows*

sub-catchment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Weira	3.1	4.8	7.2	16	18.8	22.7	52.4	53.8	61.4	24	13.4	7
Gudar	3	4.7	6.8	15.6	18.9	22.4	52.3	53.8	61.3	24.7	13.8	7.1
Bishan-Guracha	5.7	11	21.4	47.9	50.2	52.9	121.5	124.5	146.5	57	29.2	14.5
Chorake	0	0.3	1	0.8	0.8	0.3	0.4	0.4	1.6	0.3	0.1	0
Kenene	5	11.2	25.1	54	55.9	55.4	125.9	128	155.4	58.7	29.1	13.9
Badesa	0	0.1	0.6	1	0.9	0.4	0.7	0.6	1.4	0.4	0.1	0
Korchisa	4.8	11.1	25.7	55	56.9	55.8	126.5	128.5	157	59	29	13.7
Bisare	2.7	1.8	16.6	42	27.9	44	107.6	87.6	102.8	25.3	11.9	3.6
Total	24.3	45	104.4	232.2	230.3	253.9	587.2	577.2	687.3	249.3	126.7	59.9

Scenarios Developments

Scenarios are defined as alternatives or a set of assumptions such as operating policies, pricing, and demand management strategies and alternative supply sources (Mutiga et al., 2010). Scenarios can be used in adaptive management that means the process by which people adjust their management strategies to cope better with change (Wollenberg., 2010). WEAP scenarios development will evaluate the implications of different internal and external drivers of change, and how the resulting changes may be mitigated by policy and/or technical interventions (Ahmed, 2015). We explicitly accounted for the Scenario projections in the WEAP modeling framework by considering demographic and irrigation change, hydrological trends, or climatic change scenarios starting from a “reference” or “business-as-usual” point to distant planning horizon (2050). A “Reference” scenario is established from the Current Accounts to simulate the likely evolution of system without intervention but including population growth and slight improvement of irrigation demands. In addition to the Rift valley lakes Basin River Basin integrated development master plan MWR (2009), the potential irrigable areas derived from the land use map (279,258 ha) for future periods, has been the basis to build agricultural and macro-economic development effect scenarios.

WEAP software packages allow to quickly creating different climatic situations ranging from very wet to very dry based on analysis of past years. Alternatives (sometimes referred to as interventions, adaptations, or implementation scenarios) are decisions initiated by policymakers and implemented by water managers that will optimize water resources management (Droogers et al., 2017). These scenarios included alternatives such as improving irrigation water use efficiency, construction of storage dams for flood harvesting at critical shortage areas, allocating water equitably, demand management strategies, and exploiting groundwater with full potential in the catchment.

The WEAP Model for Water Allocation

Background

Stockholm Environmental Institute (http://www.weap21.org/) developed the Water Evaluation and Planning (WEAP) system. The WEAP model is a reservoir system water balance accounting model that allocates water from surface and groundwater sources to different types of demands. The modeling system is designed as a tool for maintaining water balance databases, generating water management scenarios, and performing policy analyses. WEAP is comprehensive, straightforward and easy-to-use, and attempts to assist rather than a substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, runoff, stream flows, storage, pollution generation, treatment and discharge, and in stream water quality.

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 (SEI , 2015). The WEAP model was used to set the baseline that is used to compare current values with future projections and alternatives.

This model was selected for this study due to it takes an integrated approach to water resource planning, have GIS-based graphical drag and drop interface, consider d/s consequences of the development of physical infrastructure, forecast the future water allocation and Scenarios management capability(SIE, 2015)

Model Setup

The WEAP set-up gives the user the flexibility to add data that are more detailed when it becomes available, without having to start from scratch with every updated data set.

The fundamental assumptions of the models are all demands data expect irrigation data entered into WEAP as consumption. Irrigation demands were entered as a gross requirement due to it has return flow back to supply sources. Therefore, irrigation efficiency for each irrigation project was determined to determine actual water demands on demands node.

All demand sites were designated demand priority level according to the water acts (MoWR, 2010). Accordingly, rural, urban water demands sites and environmental flow requirement was designated the highest priority over the other demand sites. For a demand site connected to more than one supply source (streams, groundwater, and dams), we have ranked its choices for supply with supply preferences. The runoff from the catchment nodes in WEAP21 represented the head flow of the streams. Head flow represents the average inflow to the first node on a river. Head flow data were entered on each sub-catchments river network from separate hydrological modeling(SWAT) that are used to generate the streamflow upstream of the data set(outlet of each-sub-catchments). The model simulates water system operations within a basin system with basic principles of water accounting on a user-defined time step, usually a monthly time series.

Modeling Demand and Supply

To allow simulation of water allocation, the elements that comprise the water demand and supply system and their spatial relationship have connected with transmission link for each sub-catchment under considerations. A graphical interface facilitates visualization of the physical features of the system and their layout within the catchment. A schematic diagram of the WEAP model for the Bilate River catchments that shows all the demand sites and various water sources connections is shown in Figure 2.

Once the WEAP model water architecture is fixed, the next step is defining the self-contained set of data and assumptions about a system of linked demands and supplies. The data is separated into current accounts and any number of alternative scenarios.

Calibrations and Validations

The accuracy of model simulation should have checked by comparing the simulated data with measured data. According to Moriasi et al. (2007) model simulation can be judged as satisfactory if NSE > 0.50, RSR < 0.70, and PBIAS < 25%. These statistical quantifications can help to understand how accurate the model by representing current account conditions for representing future scenarios developments. The model has been calibrated using observed stream flow data for the period 2004 to 2013 for the hydrological component. The water that percolates into the river from precipitation plus return flow from demands nodes on stream flow paths were checked with gauged stream values at the lower reach of study areas

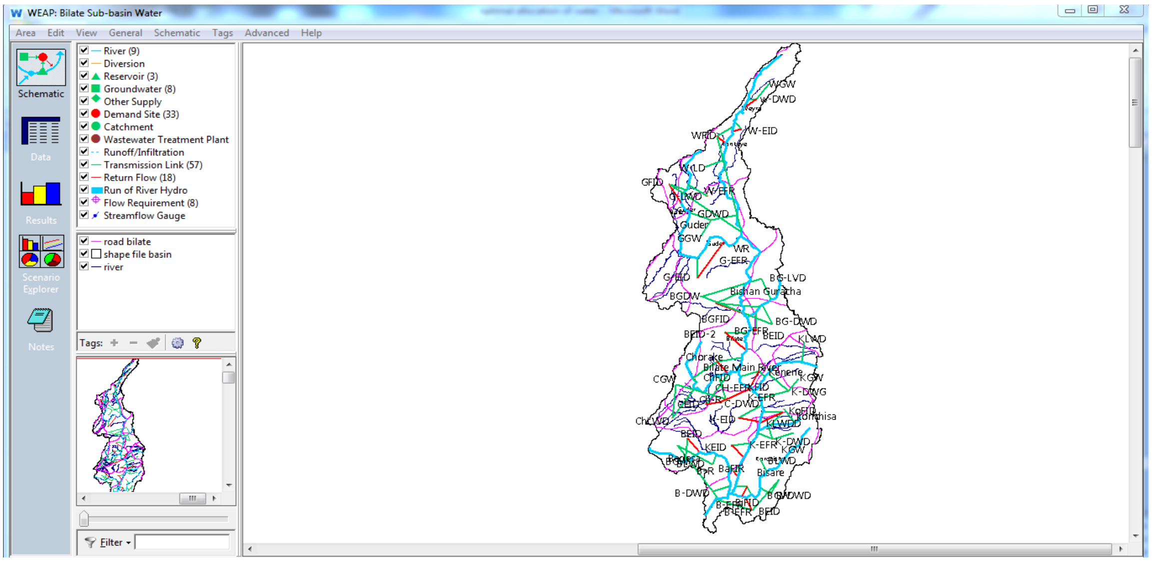

Figure2. *Screenshot of Schematic diagram of Bilate River catchment WEAP model*

RESULTS AND DISCUSSION

The WEAP model for Bilate River catchment was set up to simulate the base year (2008) situation and three subsequent scenarios. The scenarios analysis confirmed the findings for the Reference situation (2008-2013), the Medium-term future development (2014–2030), and the long-term future development (2031–2050) scenarios. This section summarizes the findings and contributions made for further research activities.

Analysis of the Model Result on Current Account

The current accounts represent the basic definition of the water system, as it currently exists. This baseline can be considered as the current situation and was analyzed by using data and information from ten years (2004-2013). For eight demonstrative catchments, a WEAP model was built to improve the understanding of past water allocations and water balances and to have a tool to undertake scenario analysis.

Water Demands, Supply Requirement, and Supply Delivered

WEAP algorithm was applied to calculate annual demand, monthly demands, and monthly supply requirements. The total annual demand for all demands node is 64.93MCM. Considering reuse effects on total demands annual supply requirement and annual supply delivered to demands site were 64.93MCM and 64.44 MCM respectively. Together, these findings confirm that demand-side management (DSM), water recycling use (reuse) rate, and loss rate consideration is almost negligible. The analyses revealed that irrigation demands is was the main cause of excessive water abstraction with annual demands of 37.8 MCM , which will accounts 57.73% of total demands in the basin. This irrigation demand is high particularly in the Kenane sub-catchments, which is 33.68 % of total irrigation demands of Bilate River Catchments. Another promising finding was that the unmet in stream flow requirement is zero in all sub-catchments expects for Badesa sub-catchment in November and December months. This suggests that the environmental flow amount varies depending on the seasonal flow condition of stream flow.

Temporal Occurrence of Unmet Demands

Annual unmet demand in the current account year is 495.14 Thousand Cubic meters (TCM). The results demonstrated that the annual unmet demands occur in lower basin areas in Chorake and Badesa sub-catchment in November, December, and January months. In the Chorake sub-catchments for irrigation demands, domestic water demands node, livestock water demand nodes not able to get water in December and January months. As mentioned earlier, a shortage of water has been a common problem in the middle and lower streams of the Bilate River catchments in dry seasons. This is because of natural shortfalls in precipitation or stream flow in dry seasons. From these results, it is clear that of comprehensive *approaches* and good water management strategies required to provide enough water to meet established human and environmental uses and to cope with *water scarcity*. It is also possible to significantly reduce water scarcity by providing structural and non-structural solutions.

Scenarios Developments

Scenario projections were developed in the WEAP modeling framework based on demographic and irrigation change, hydrological, and technological trends starting from a "reference" or "business-as-usual" point. Note that these scenarios were evaluated for two-time horizons: namely (2030) to reflect the result of the first implementation goal and by taking it as target year of the sustainable development goal. The second one is the (2050) distant planning horizon.

A Reference Scenario

A “Reference” scenario is established from the current accounts to simulate the likely evolution of system without intervention but including population growth and slight improvement of irrigation demands. It was observed that increasing the human population and irrigation water requirement variations cause a significant increase in annual water demand from 64.9 MCM to 70.44MCM. Hence, the average annual unmet water demand from the baseline condition increased by about 5.8 thousand cubic meters (TCM). Similarly, in the second phase of the planning horizon period (2030-2050), total annual demands increased to 95.4MCM with 305.6 thousand cubic meters (TCM) unmet demands. These total unmet demands will occur in December and January months. Therefore, in the catchment, it is essential to understand total water issues it not a scarcity of water in different catchments but ways of conserving water in the surplus period to reduce water scarcity in unmet periods (December and January months).

Agricultural Growth and Macro-Economic Development Effect Scenarios

The irrigation projects expansion and socio-economic development cause a significant increase in water demand and hence increases in unmet water demand in different parts of the catchment. New irrigation potential areas are about 279,258 ha, which account of about 94.5 % of potential areas in the catchment. Annual Water demand is expected to increase substantially in the future from currently periods of 64.92 MCM to 335.43 MCM at the end of the first planning periods(2030) and to 782.29 MCM at the end of second planning periods (2050) . Our results demonstrated that water demand in the first planning periods would be 4 to 6 times higher than baseline conditions in different parts of catchments. The annual unmet demands will be increased from baseline 495 TCM to 610 TCM. However, these total annual unmet demands comparisons among catchment revealed that it is not uniformly distributed, as shown below in **Table 3**. Unmet demand due to climatic variation will be changed from reference condition due to variation of stream and land use and land cover changes in future periods. Therefore, the effect of climatic variation on the surface water balance of sub-basin was has been increasing unmet demands to 876.5TCM. The results demonstrate in the future planning periods critical water shortage probably will occur in Bishan Guracha, Chorake , Weira, and Guder sub-catchments. However, unmet demands not occurring throughout the year but only within three months(December, January, and February). Therefore, this spatial and temporal water un-availability requires large-scale water supply management actions.

Table2. ***Average***

Sub-catchments	Un Demands(TCM)	Percentage (%)
Weira	37.86	6.21
Guder	42.48	6.96
Bishan Gurach	272.43	44.65

Kanane	0	0
Badesa	1.12	0.18
Korichisa	0	0
Bisare	0	0
Chorake	256.22	42
Total	610.11	100

Annual Unmet Demands Distributions

Adaptation Strategies Scenarios

In these scenarios, adaptation strategies such as improving irrigation water use efficiency, construction of storage dams for flood harvesting at critical shortage areas, allocating water equitably, demand management strategies, and exploiting groundwater with full potential in the basin.

Improving Irrigation Efficiencies

If Irrigation application efficiency increased from baseline values to 80%, then the average annual water demand is expected to decrease substantially to 304.52 MCM. Consequently, annual unmet water demands were reduced by about 42.3% in full projected periods. Implementation of these improving irrigation efficiency scenarios significantly reduced irrigation water demand for the basin by about 24 % and significantly improves water supply requirements thus making more water available for the other sectors.

Improved irrigation efficiency can be achieved by managing demand through the lining of the intake canals, proper maintenance of gravity pipelines, and promoting water-saving technologies for irrigation such as drip irrigation instead of the commonly used portable overhead sprinklers.

Groundwater Use Scenarios

The groundwater usage in major sub-catchment was calculated using the yield of wells by clarifying the current yield (2013) and the estimated yield in each sub-basin at the time of 2030 and 2050. According to JICA(2012), groundwater drilling well yield to groundwater recharge is 4.92%. Annual groundwater recharge of the basin estimated is about 316.72MCM and currently, the yield from existing well is about 15.6MCM.

It was observed that annual unmet water demand would be decreased **from 37.7 TCM to zero, 3.7TCM to zero and 3.1 TCM to zero in Bishan-Guracha, Weira and Guder sub-catchments respectively.** However, in the lower Catchment areas(Chorake and Badesa sub-catchments) unmet demands will be occur planning periods in dry seasons of the catchments(January and February months). The Upper Bilate River catchment can produce sufficient water supply from groundwater abstraction to meet the total water demands especially domestic water demands purposes.

Water Storage Options Scenario

If three multipurpose dam provided in Weira, Chorake and Badesa sub-catchments for supporting socio-economic development activities, then annual unmet water demand would be decreased by about 83.7 %(610.1 TCM to 97.9TCM) from Agricultural development and socio-economic change scenarios. Therefore, these scenarios have a significant contribution toward making more water available in the dry season by storing surplus water during peak flow seasons. The diagrammatic comparison among scenarios and corresponding unmet demands are portrayed in Figure 3 below.

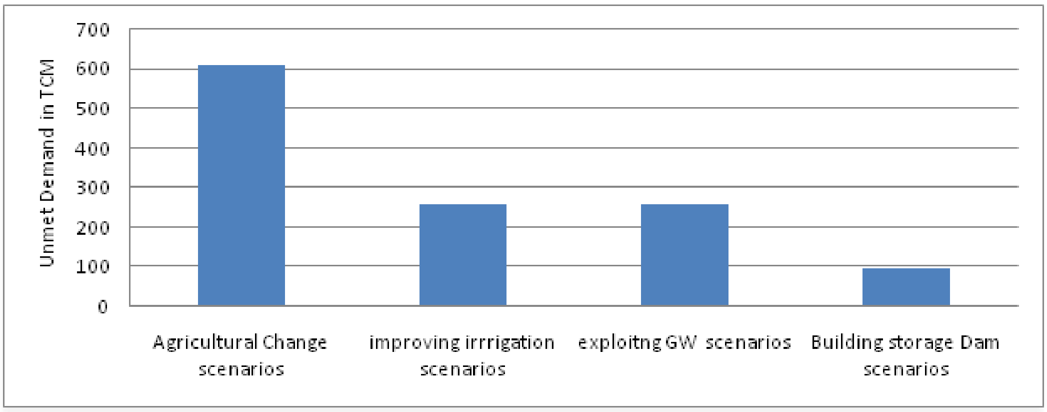

Figure3. *Annual unmet demand per alternatives scenarios*

Our findings would seem to show the alternative scenarios performs well, giving good results in reducing water shortages during dryer months. From all listed alternatives, increasing water storage options or building storage dam scenarios is more effective in reducing water shortages. We have verified that using combined alternative scenarios and all effective water management principles will decrease unmet demands with full extents in whole planning periods.

CONCLUSION

The objective of optimizing long-term water allocation in Bilate Catchment is to develop effective water resources management approaches to contribute to sustainable socio-economic developments. The optimal water allocation planning was done by considering demand analysis and identifying total available water resources in the whole study area. As part of the analysis to explore, the impact of existing and planned water resources developments, the water evaluation and planning (WEAP) model has shown in the sub-catchment level. It has been shown that starting from current planning periods to at the end of the long-term future development scenario period (2050), the Bilate River catchment will fall under a water shortage situation. This water scarcity has a strong spatial and time dimension. Therefore, developing different initiatives that will optimize water resources management by incorporating stakeholders, policymakers, and water managers are bases for future sustainable developments. The broad implication of the present research is that providing different alternatives strategies such as expansion storage options, improving irrigation application efficiency, dependence on multiple supply sources in the future planning periods will alleviate water supply shortages in the different areas of the catchments.

Future research should further develop and confirm these initial findings by developing water-harvesting technology, providing storage hydraulic structure (Dams, weir), or develop a comprehensive policy to supply enhancement and demand management options to improve water resource balances in the catchments.

ACKNOWLEDGMENTS

The authors sincerely acknowledge the National Meteorological Agency of Ethiopia (NMA) for the climate data and the Ministry of Water, Irrigation, and Electricity of Ethiopia (MoWIE) for the hydrologic data. The authors also would like to thank the reviewer for constructive feedback.

REFERENCES

[1] Awadallah, A.G. and Awadallah, N.A. (2014) An Integrated Water Resources and Economic Approach for Optimizing Water Allocation Policies. *Journal of Water Resource and Protection*, **6**, 1444-1456.

[2] Ahmed Mohamed Hassan. 2015. Surface Water Availability and Demand Analysis In Implication for Enhancing Water Resource Planning at Shabelle Basin in Southern somalia. M.Sc Thesis. Mekelle University, Ethiopia. 120p

[3] Federal Democratic Republic of Ethiopia Central Statistical Agency (CSA), 2017. Livestock and Livestock Characteristics Report, Statistical Bulletin 585, 193p

[4] Haile Gebremedhin Gebremeskel and Kasa Asfaw Kebede. 2015. Irrigation in Ethiopia A Review. Academia Journal of Agricultural Research 3(10): 264-269.

[5] Mutiga, J.K. S. T. Mavengano, S· T. Woldai , Robert Becht.2010. Water Allocation as a Tool to Minimise Water Use Conflicts in the Upper Ewaso Ng'iro North Basin, Kenya. Water Resources Management 24:3939–3959

[6] United Nations. 2000. Principals and Practices of Water Allocation Among Water-Use Sectors. Water Resources Series No. 80. United Nations, New York.

[7] Mc Cartney, M.; Alemayehu, T.; Shiferaw, A.; Awulachew, S. B. 2010. Evaluation of current and future water resources development in the Lake Tana Basin, Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 39p. (IWMI Research Report 134).

[8] Ministry of Water Resources Ethiopia. 2010. Ethiopian Water Resources Management Policy, 41p

[9] Ministry of Water Resources. 2009. Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project, Phase (2), Addis Ababa, Ethiopia. Halcrow Group Limited and Generation Integrated Rural Development (GIRD) Consultants; 612p

[10] Smakhtin, V. and Anputhas, M. 2006. An Assessment of Environmental Flow Requirements of Indian River Basins. International Water Management Institute, Colombo, Sri Lanka; 42p. (IWMI Research Report 107)

[11] Stockholm Environment Institute (SEI), USA. 2015. ''WEAP: Water Evaluation and Planning System.'' User Guide For WEAP21, Boston. USA Http://Www.Weap21.Org/Downloads/Weapuserguide.Pdf

[12] Speed R., Liy., T. LE Quesne, G. Pegram and Z. Zhiwei. 2013. Basin Water Allocation Planning. Principles, procedures and approaches for basin allocation planning UNESCO, Paris.

[13] Tena Bekele Adgolign, G. V. R. Srinivasa, Ra Yerramsetty Abbulu. 2015. WEAP modeling of Surface water resource allocation in Didessa Sub-Basin, West Ethiopia. Sustainable Water Resources Management 2:55–70

[14] The Nature Conservancy. 2009. Indicators Of Hydrologic Alteration Version 7.1 User's Manual. Software Design and Smythe Scientific Software. 81p.

[15] Wollenberg EVA, David Edmunds, Louise Buck. 2000. Scenarios as A Tool For Adaptive Forest Management A Guide. Center for International Forestry Research Bogor, Indonesia, 44p.

[16] Zinash Sileshi, Azage Tegegne, and Getnet Tekle Tsadik. 2003. Water resources for livestock in Ethiopia: Implications for research and development. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia: 66-79

Citation: *Desalegn Laelago Ersado, Sirak Tekleab, Mihret Dananto, "Optimization of Long-Term Water Allocation and Analysis of adaptation strategies in the Bilate River Catchment, Rift Valley Lakes Basin, Ethiopia", International Journal of Research Studies in Science, Engineering and Technology. 2020; 7(12): 1-10.*