Modeling Long-Term Water Allocation and Analysis of Alternative Strategic Scenarios in the Catchment Area of Bilate River, Rift Valley Lakes Basin, Ethiopia

Desalegn Laelago[1], Sirak Tekleab[2], Mihret Dananto[3]

[1]*Department of Hydraulics and water resources engineering, institute of technology, Hawassa University, Post office Box: 05, Hawassa, Ethiopia, Email:desalegnlog@gmail.com;*

[2]*Department of Water Resources and irrigation engineering, institute of technology, Hawassa University, Post office Box: 05, Hawassa, Ethiopia, Email: siraktekleab@yahoo.com;*

[3]*Department of Water Supply and Environmental Engineering, Institute of Technology, Hawassa University, Post Office Box: 05, Hawassa, Ethiopia, Email:Mihret@gmail.com*

ABSTRACT

A water shortage stress might have resulted from the extensive water resources development plan in the Bilate catchment owing to the rapidly growing population, irrigation development expansion, climatic variability, and socioeconomic development. Furthermore, the lack of sufficient knowledge about available water resources and lack of coordination in water resources management skills in the basin often aggravates the competition of fixed water resources among the users. Therefore, modeling long-term water allocation should be implemented to determine the optimal allocation of water resources, maximize the overall benefits without compromising ecological requirements, and propose mitigation measures that may 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 streamflow simulations within watersheds, the Soil and Water Assessment Tool (SWAT) employed in the Bilate River and its sub-catchments. The Indicators of Hydrologic Alteration (IHA) and CROPWAT 8.0 software programs were used to estimate streamflow requirement (IFR) and the crop water requirement, respectively. Three development scenarios include the agricultural and socio-economic development effect, climatic change, and alternatives that were built in the long-term planning horizons (2013-2050). The modeling water allocation for each sub-catchment was done by considering the 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. Hence unmet water demands in different parts of the catchments were increased. Similarly, the effect of climatic variation scenarios has been increased unmet demands in the middle year of the planning horizon(2030-2050). Therefore, developing adaptation strategies scenarios helps to mitigate water scarcity and improve water availability for productive use.

Keywords: Adaptation Strategies, Bilate Catchments, Scenarios, Water Allocation, WEAP.

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1. INTRODUCTION

The water resources system is threatened by increased demands, overexploitation of water resources, climate changes, and non-cooperative developments among the upstream-downstream users (Mutiga *et al.,* 2010). Hence, effective water resource management and utilization are widely recognized as a crucial adaptation strategy. Besides, it helps to sustainable economic growth and reduces poverty (McCartney *et al.,* 2010); mitigate the ongoing and upcoming water crisis(Bekchanov, 2013); alleviate the negative impact of climate change (Fitzhorn, 2012); and maximize the ecological, economic and social benefits (Stamou *et al.*, 2015). Moreover, assessing the overall water resources potentials (Adgolign *et al.,* 2016) and quantity-based water allocation criteria (Mutiga *et al.*, 2010), determining water balance in the basins levels (Berhe *et al.*, 2013), and designing best utilization mechanisms (modeling) through an area-based development plan on a watershed level (Dinar *et al*., 2013) are indispensable activities to ensure sustainable developments and equitable allocations of available water resources among users.

The Ethiopian water resources development sector is regarded as a key resource investment for development and economic growth for swiftly growing populations. These development activities encompass expanding small, medium, and large-scale irrigation infrastructure; transforming the rain-fed agricultural system; and ensuring food security at the household level. Despite this, lack of sufficient knowledge about available water resources, water allocation, and water abstractions are some of the problems. Hence, there is a need for devising new optimal water allocation approaches aimed at making available water supplies efficient and productive for different purposes. Many researchers addressed the problem of allocation of a limited water supply for various demands using applications of decision support system(Akivaga, 2010; Awadallah & Awadallah, 2014; Bekchanov, 2013; Berhe *et al.*, 2013; Chinnasamy *et al.,* 2015; Dinar *et al.*, 2013; Mayol, 2015; Mc Cartney *et al.,* 2013; Speed, R. Yuanyuan, L. Le Quesne, T. Pegram, G. Zhiwei, 2013; Tena Bekele Adgolign, 2015; Tesfatsion *et al.*, 2011; You *et al.,* 2011). Water resources planning tools like Water Evaluation and Planning (WEAP) software were used by many researchers whose focus was on water resources planning, decision making, and resource management. Gedefaw *et al.,(*2019) developed the WEAP model to allocate the water supplies to demanding sectors that are needed most based on an economic parameter to maximize the economic benefits in the Awash River Basin of Ethiopia. Adgolign *et al.*, (2016) applied the WEAP model to modeling the surface water resources allocation of the Didessa Sub-basin, and the Abbay Basin. Furthermore, the WEAP model was applied for assessment of future and current water demands (McCartney *et al*., 2009; Mounir *et al*., 2011; Rayej, 2012), to evaluate water resources development based on an equilibrium scenario of the current water demand (Mutiga *et al*., 2010), to analyze the impact of planned water resource development on current and future water demands (Chinnasamy *et al.*, 2015), to assess water demand and supply under changing climatic scenarios (Malla *et al*., 2014), and to manage water shortages (Tesfatsion *et al.*, 2011).

This paper aims to present a framework for modeling long-term water allocation and analysis of alternative strategic scenarios in the Bilate Catchments. Specifically, the objectives of this study were to assess the spatial and temporal occurrence of water resources, predict the various water demands, assess the impacts of additional socio-economic development scenarios, and analyze alternative strategic scenarios at spatial scales. The water availability assessment and optimal allocation of water resources of the catchment were evaluated using the model_ Soil and Water Assessment Tool (SWAT) and Water Evaluation and Planning (WEAP) system. Besides, the study would help planners to determine the critical water shortage locations and causes of water shortage within the sub-catchments levels and to develop adaptation strategies at spatial scales.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

Bilate River Catchment is situated in the South-Western Escarpment of the Rift Valley Lakes Basin (RVLBs), Ethiopia. The study area is situated between 6^o 35’ 00" and 7^o 57’ 00" North Latitude and 37^o 47' 00" and 38^o 18' 00" East Longitude (Figure 1). Its altitude ranges from 1175–3371 m above sea level. The total estimated area of the watershed is about 5,515 km^2. Bilate River Catchment drains from the north of the Abaya-Chamo Sub-Basin to Lake Abaya. Its shape is long and narrow; hence the flow in the tributary channel reaches the mainstream at different times, thus distributing the total runoff over a long period. The watershed is divided into three agro-climatic zones: in the upper, cool sub-humid mid-highlands; in the middle, temperate sub-humid mid-highlands; and at the lower portion, warm sub-moist lowlands (Wagesho, 2018). Long-term average daily maximum temperature ranges from 28.5-31 degrees Celsius with an average minimum temperature of 10 degrees Celsius in November and December. The distribution of rainfall is categorized under uni-modal and bimodal in the northwestern parts and the south and southwestern parts of the catchment. The average mean annual rainfall of the area is estimated to be 1232 mm. Mean monthly relative humidity ranges from 54.5 % to 80.2%. The average value of wind speed 2m above the surface of the earth is 1.4m/s, and the mean monthly sunshine hours of the study area is 7.12 hours/day.

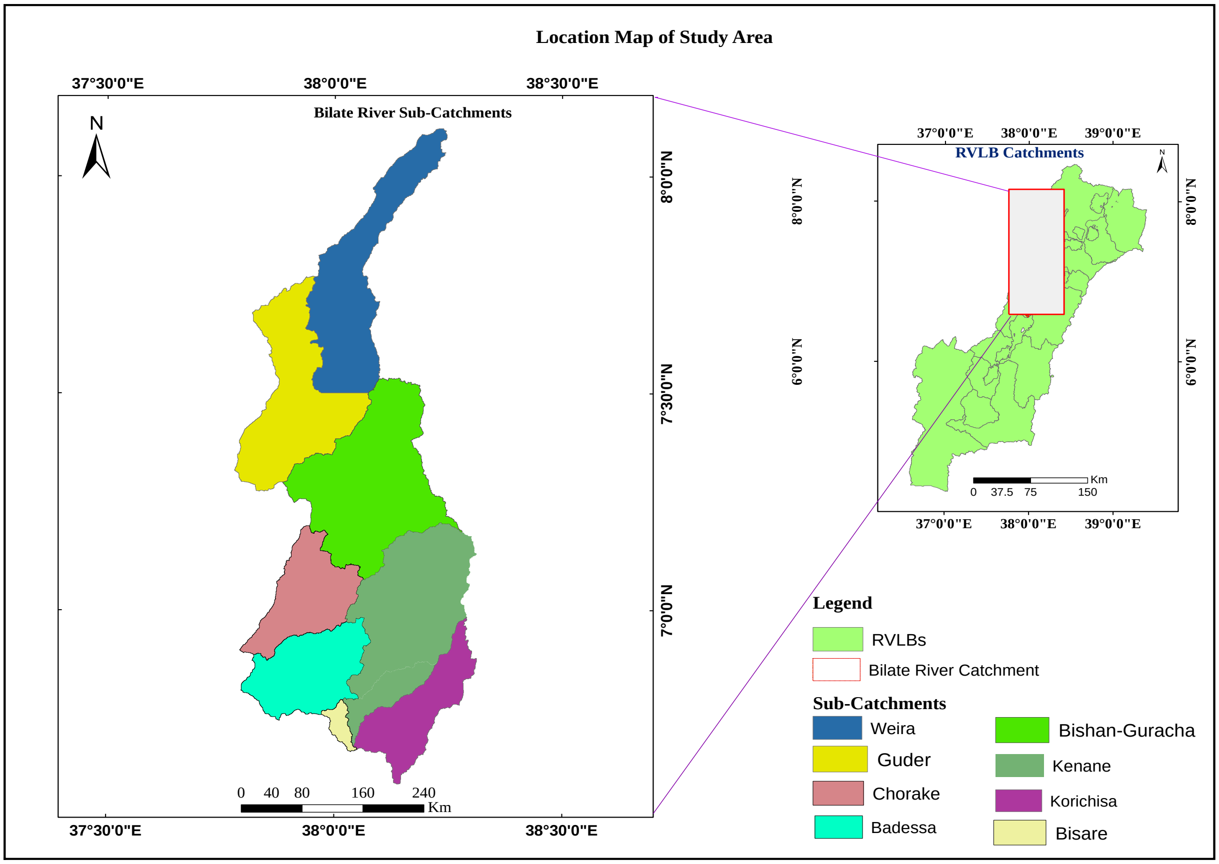

Figure 1: Map showing the location of the Bilate River Catchment and its main sub-catchments

2.2 Dataset collection and Analysis

Different datasets were used to establish the WEAP and surface water simulation hydrological model for the study catchment. The major data types included hydro-metrological data, digital elevation map(DEM), water consumption data, water supply schemes, and their corresponding geographical locations. A 30m by 30m resolution DEM was taken from the Ministry of Water, Irrigation, and Energy (MoWIE, 2018). The DEM was used to delineate the watershed and analyze the drainage patterns of the land surface terrain.The meteorological (temperature, precipitation, relative humidity, sunshine hour, and wind speed), hydrological, observed land use and land cover, and soil data were collected from the Ministry of Water Resource, Irrigation, and Energy office (MoWIE, 2018) and National Meteorological Agency of Ethiopia (NMA,2018). Digital Elevation Model (DEM) was obtained from RVLBs of the Department of GIS and remote sensing (MoWIE, 2018).

The Livestock and wildlife populations were collected from agricultural sample survey data (CSA, 2017). Water use and population data were collected from various socioeconomic surveys (RVLB Materplan, 2009) and the statistical agency of Ethiopia (CSA, 2017). The total population of the basin was estimated to be 2,450,405. Different annual population growth rates were obtained from the Federal Democratic Republic of Ethiopia Central Statistical Agency (CSA, 2013).

Existing and planned demand sites, their corresponding annual activity levels, and cropping patterns of the catchment were drawn from project documents entitled as Integrated Development Master Plan, retrieved from the Rift Valley Lakes Basin(RVLB) and South Nation Nationality People Region(SNNPR) Irrigation Development Authority. The major demand sites in the catchments included: Domestic Water, Livestock and Wildlife Water, and Environmental Flow Requirement sites. The total area under existing irrigation projects in the catchment was about 16,199 ha and the potential area for irrigation development was 436,585 ha (RVLB Masterplan, 2009). Domestic water demand analysis was based on the total number of people living in the area and the amount of water consumed by an individual in each sub-catchment of urban and rural centers.

2.3 Surface Water Supply

The hydrological systems in the WEAP model are depicted as nodes and links. The main river is drawn as a series of nodes, showing points of inflows from each sub-catchment. The River confluence is linked to each other by river reaches. The recorded observed data obtained from stream gauge stations did not show 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) package is used to generate the upstream (outlet of each-sub-catchments) streamflow of the data set.

Basin areas, the length of the main channel, land use/cover, soil types, and climatic weather data served as inputs for the SWAT hydrological model. However, the sub-catchment slope gradient, slope length of the terrain, and the stream network characteristics were derived from the DEM. Table 1 shows the computations of long-term variation in surface water at the outlet of each sub-catchment.

The SWAT model output was evaluated with numerical model performance measures such as coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE, 1970). These statistical quantifications could testify the accuracy of the model by representing current account conditions. Therefore, the accuracy of the model simulation should be checked by comparing the simulated streamflow data with measured data in Halaba Kulito gauging stations. The model was calibrated using observed streamflow data for the period (1998 to 2008). Hence, by adjusting the most sensitive parameters, the calibration values were a coefficient of determination (R^2) of 0.71 and Nash–Sutcliffe efficiency (NSE) of 0.64, which showed that there was an agreement between measured and simulated monthly flows. The validation results of monthly observed and simulated streamflow (2009 to 2013) using performance statistics of R^2, NSE were 0.67 and 0.65, respectively. Therefore, the model simulation could be judged as satisfactory results.

Table 1: 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

2.4 Water Uses Rates Analysis

The major water resources development activities and demand sites to be input to the analysis in this study were distributed to the eight sub-catchments: Weira, Guder, Bishan Guracha, Cherake, Kenene Boga, Korichasha, Kerisa, Bedesa, and Bisare Sub-Catchments. Therefore, the water use rates for the major demand sites were calculated as follows:

I. Domestic Water Demand:

Water demands for domestic purposes are used for indoor and outdoor household purposes. Water demand for current and future study was calculated using the equation (Equation below:

Domestic water demand = activity level * water use rate per activity

Where activity level indicates the number of population in each sub-catchment.

Domestic Water demands are clustered under current domestic water demand and future domestic water demand (2050) as shown in Table 1. Based on UNICEF's (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.

The simple arithmetic method of population projection for the future period was selected by examining the growth of the population that has occurred since the last census. Based on past population growth rate trends of sub-catchment, three scenarios were developed to predict future domestic water demands until 2050 for urban and rural demand sites. These may help to describe the uncertainty in the evolution of the domestic water demands. The baseline or current scenario (2004-2013), the medium-term development (2014–2030), and the long-term development (2031–2050) were used to calculate water demands in the WEAP model. Accordingly, the urban growth scenarios for planning horizons of 2050 for lower growth scenarios, medium growth scenarios, and higher growth scenarios were 3.4%, 4.05%, and 4.7 % respectively. However, 1.1%, 1.8%, and 2.5% were considered as lower growth scenarios, medium growth scenarios, and higher growth scenarios for analysis of rural domestic water demands, respectively. Table 2 presents the end period of long-term development domestic water demands for various population change scenarios and an increase in the per capita usage of water rate because of anticipated socio-economic development.

Table 2: Domestic water Demands (MCM)

Sub-catchment	Baseline Demands		Scenarios Demands					
			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

II. Irrigation Water Demands

Irrigation development is a key for reliable and sustainable agriculture developments, which leads to the overall development of a country (Haile and Kasa, 2015). The irrigation demands in each sub-catchment were calculated for existing irrigation projects and potentially irrigable land areas that would be developed in future periods. 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), which used the climatic data, cropping pattern, planting dates, and area of each crop. In some irrigation schemes, the lack of climatic information needed for CROPWAT 8.0 was compensated by using the climatic database CLIMWAT 2.0 for CROPWAT. Crop coefficient (Kc), crop growth stages, rooting depths, critical depletion fraction, yield responses factor, maximum crop height, and length of growth stage were fixed for different crops according to FAO standards and local conditions of the study area. Kc coefficients were obtained from the FAO drainage paper (FAO, 2006).

The future irrigation water demand calculation was based on potential land for irrigation developments identified from the master plan of study areas(RVLB Masterplan, 2009). Besides, the feasibility of landform, topographic suitability, and proximity to rivers were also considered. The irrigation water requirement calculations were based on the commonly grown commercial or high-value crops. Their water demands were determined for three planting seasons and late early and mid-planting scenarios. Therefore, total water demands for irrigation for each sub-basin were thus estimated by multiplying the total area under irrigation with the average water requirement for the main crops.

III. Livestock and Wildlife Water Demand:

Water consumption by livestock was considered in the WEAP model, considering its 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 Water Demand = Per capita water consumption (l/d) x livestock population

Hence, the estimated TLU for the whole catchments was about 907,109, and the total estimated annual demand of livestock was 8.28 Mm^3.

IV. 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) regarded the basic minimum requirement as the highest priority level in any water allocation plan. Environmental flows are one of the various water demands that need to be incorporated into water resource allocation modeling(Adgolign *et al.*, 2016). The environmental flow requirement (EFR) was calculated by using indicators of Hydrologic Alteration (IHA) software(The Nature Conservancy, 2009).

2.5 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; for instance, people adjust their management strategies to cope better with change (Wollenberg.,2010). Scenarios development would evaluate the implications of different internal and external drivers of change, and mitigate the resulting changes 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 the system without intervention but including population growth and slight improvement of irrigation demands. agricultural and macro-economic development scenarios were based on potentially irrigable areas derived from the land use map (279,258 ha) ((RVLB Materplan, 2009).

WEAP software packages allow to quickly create 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 to 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.

2.6 The WEAP Model for Water Allocation

I. Background

Stockholm Environmental Institute (http://www.weap21.org/) developed the Water Evaluation and Planning (WEAP) system. The WEAP model is a 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 it attempts to assist rather than substitute 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 sets the baseline that is used to compare current values with future projections and alternatives.

This model is selected for this study as it takes an integrated approach to water resource planning, has a GIS-based graphical drag and drop interface, considers downstream consequences of the development of physical infrastructure, forecasts future water allocation and scenario management capability(SIE, 2015).

II. Model Setup

The WEAP model for the Bilate River Catchment was set up to simulate the base year (2004) situation and three subsequent scenarios. The scenario analysis confirmed the findings for the reference situation (2004-2013), the medium-term future development (2014–2030), and the long-term future development (2031–2050) scenarios. The WEAP set-up gives flexibility to the user to add more detailed data without having to start from scratch.

The fundamental assumptions of the models are all demands data entered into WEAP as consumption values expect irrigation demands data. Irrigation demands are entered as a gross requirement because they have return flow back to supply sources. Therefore, irrigation efficiency for each irrigation project determines actual water demands on nodes.

Demand priority levels for all demand sites were designated according to the water acts principles (MoWR, 2010). Accordingly, the environmental flow requirement of rural and urban water demand sites was designated as having the highest priority over the other demand sites. An attempt was made to rank choices of a demand site having more than one supply source (streams, groundwater, and dams) for supply with supply preferences. The runoff from the catchment nodes in WEAP21 represented the head flow of the streams. Head flow represented 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 were used to generate the streamflow upstream of the data set (outlet of each sub-catchments). The model simulated water system operations within a basin system with basic principles of water accounting on a user-defined time step, usually a monthly time series.

III. Modeling Demand and Supply

To allow simulation of water allocation, the elements that comprise the water demand and supply system and their spatial relationship are connected with the transmission link for each sub-catchment under consideration. A graphical interface facilitates visualization of the physical features of the system and its layout within the catchment. A schematic diagram of the WEAP model for the Bilate River Catchment shows all the demand sites and various water source connections as 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 are sorted out into current accounts and several alternative scenarios.

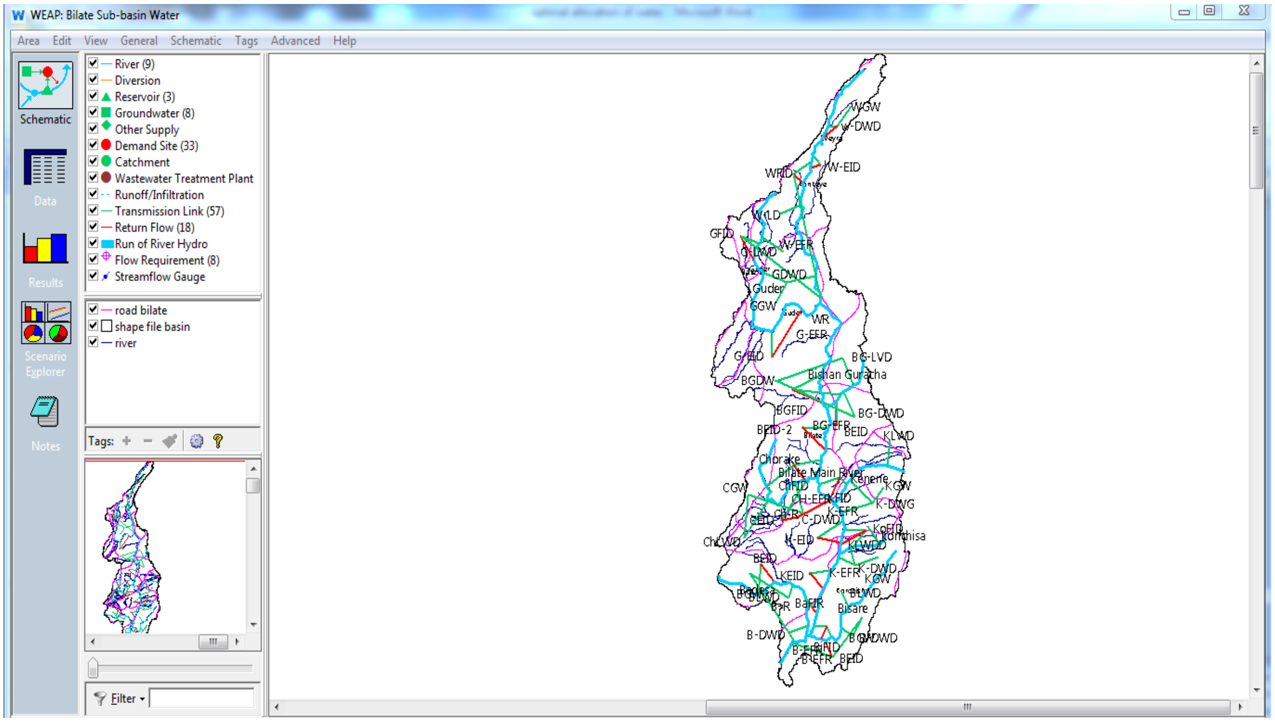

Figure 2: Screenshot of Schematic diagram of the Bilate River catchment WEAP model

3. RESULTS AND DISCUSSION

3.1 Analysis of the Model Result on Current Account

The current accounts represented the basic definition of the water system. This baseline could be considered as the current situation since it drew data from 2004-2013. For eight demonstrative catchments, a WEAP model was built to improve people's understanding of past water allocations and water balances and undertaking scenario analysis.

I. 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 demand nodes was 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 confirmed that demand-side management (DSM), water recycling use (reuse) rate and loss rate consideration were almost negligible. The analyses revealed that irrigation demands were the main cause of excessive water abstraction with annual demands of 37.8 MCM, which would account for 57.73% of total demands in the basin. This irrigation demand was high particularly in the Kenane Sub-catchment, which was 33.68 % of the total irrigation demands of the Bilate River Catchment. Another promising finding was that the unmet in-stream flow requirement was zero in all sub-catchments except for Badesa Sub-catchment in November and December months. This suggests that the environmental flow amount varied depending on the seasonal flow condition of streamflow.

II. Temporal Occurrence of Unmet Demands

The annual unmet demand in the current account year was 495.14 thousand cubic meters (TCM). The results demonstrated that the annual unmet demands occurred in lower basin areas in the Chorake and Badesa Sub-catchment in November, December, and January months. In December and January, water was scarce in the Chorake Sub-catchment for irrigation demands, domestic water demands nodes, and livestock water demand nodes. 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 could be ascribed to natural shortfalls in precipitation or streamflow in dry seasons. Hence, comprehensive approaches and good water management strategies were required to provide enough water to meet established human and environmental uses. Furthermore, it was possible to significantly reduce water scarcity by providing structural and non-structural solutions.

3.2 Scenarios Development

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 from two-time horizons: the first is 2030 which is target year of sustainable development goal; whereas the second one is (2050), distant planning horizon.

3.2.1 A **Reference Scenario**

A "reference" scenario was established from the current accounts to simulate the likely evolution of the 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 caused 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 was increased by about 5.8 thousand cubic meters (TCM). Similarly, in the second phase of the planning horizon period, 2030-2050, the total annual demand has been increased by 95.4MCM which yielded 305.6 thousand cubic meters (TCM) unmet demand. This total unmet demand occurs in December and January. Therefore, it should be noted that despite the total available water is sufficient, it may not satisfy the demand or there are unmet periods and hence appropriate conservation mechanisms shall be entertained.

3.2.2 Agricultural Growth and Macro-Economic Development Effect Scenarios

The expansion of irrigation projects and socio-economic development might cause a significant increase in water demand and thereby increasing unmet water demand in different parts of the catchment. New irrigation potential areas are expected to be about 279,258 ha, which may account for 94.5 % of potential areas in the catchment. Annual Water demand is expected to increase substantially from 64.92 MCM to 335.43 MCM at the end of the first planning period (2030) and 782.29 MCM at the end of the second planning period (2050). Our results demonstrated that water demand in the first planning period would be 4 to 6 times higher than baseline conditions in different parts of catchments. As in Table 3, the annual unmet demands will increase from baseline 495 TCM to 610 TCM. However, these total annual unmet demands comparisons among catchment revealed the absence of uniform distribution. Unmet demand due to climatic variation may be changed from reference condition due to variation in streamflow which could be resulting from land use and land cover changes in future periods. Therefore, the effect of climatic variation on the surface water balance of the sub-catchment brought about an increase in unmet demands of 876.5TCM. The results indicated that there might be critical water shortages in the future planning periods at Bishan Guracha, Charake, Weira, and Guder sub-catchments. However, unmet demands might not occur throughout the year but only within three months (December, January, and February). Therefore, this spatial and temporal water scarcity might require large-scale water supply management actions.

Table 3: Average Annual Unmet Demands Distributions

Sub-catchments	**Unmet 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

3.3.3 Adaptation Strategies Scenarios

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

I. Improving Irrigation Efficiencies

If the efficiency of irrigation application was increased from baseline values to 80%, then the average annual water demand would be expected to decrease substantially to 304.52 MCM. Consequently, annual unmet water demands were reduced by about 42.3% in full projected periods. In other words, improving irrigation efficiency scenarios significantly reduced irrigation water demand for the basin by about 24 % and significantly improved 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.

II. 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-catchment from 2030 to 2050. According to JICA(2012), groundwater drilling might yield a groundwater recharge of 4.92%. The annual groundwater recharge of the basin estimated was about 316.72MCM and currently, the yield from the existing well was 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 would occur during planning periods in the dry seasons of the catchments(January and February months). The Upper Bilate River Catchment could produce sufficient water supply from groundwater abstraction to meet the total water demands, especially domestic water demands.

III. Water Storage Option Scenarios

If three multipurpose dams were provided in Weira, Charake, 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) with respect to agricultural development and socio-economic change scenarios. Therefore, these scenarios had 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.

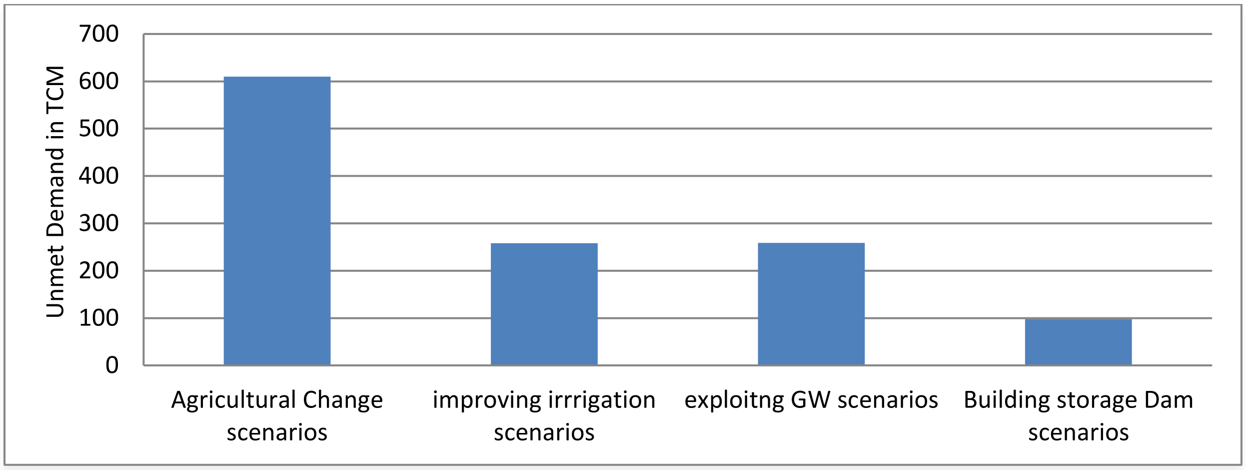

Figure 3: Annual unmet demand per alternatives scenarios

Our findings show that the alternative scenarios perform well, giving good results in reducing water shortages during dry seasons. From all listed alternatives, increasing water storage options or building storage dam scenarios was found to be more effective in reducing water shortages. Using combined alternative scenarios and effective water management principles would decrease unmet demands with full extents in whole planning periods.

4. CONCLUSIONS

The objective of optimizing long-term water allocation in the Bilate Catchment was to develop effective water resources management approaches that would 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 resource developments, the Water Evaluation and Planning Model (WEAP) has shown good performance at the sub-catchment level. It has been shown that starting from the current planning period to the end of the long-term future development scenario period (2050), the Bilate River Catchment might fall under a water shortage situation. This water scarcity may have a strong spatial and time dimension. Therefore, developing different initiatives may optimize water resources management by incorporating stakeholders, policymakers, and water managers.. The broad implication of the present research will be to provide different alternatives strategies such as expansion storage options, improving irrigation application efficiency, dependence on multiple supply sources to alleviate water supply shortages in the different areas of the catchments. It is also recommended that research should further develop and confirm these initial findings by developing water-harvesting technology, providing storage hydraulic structure (Dams, weir), or developing a comprehensive policy to supply enhancement and demand management options to improve water resource balances in the catchments.

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