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Climate change and population growth impacts on surface water supply and demand of Addis Ababa, Ethiopia

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ABSTRACT

Addis Ababa is expected to experience water supply stress as a result of complex interaction of urbanization and climate change. The aim of this study is to investigate water demand and supply prospects for the City of Addis Ababa by applying the Water Evaluation and Planning (WEAP) hydrological model and using scenarios of population growth trends and climate change. The study includes analysis of water consumption, hydrological information and climate data which is statistically downscaled using approach used to generate climate data available at the Worldclim data center. Bias corrected climate model data of NIMR-HadGEM2-AO under a midrange RCP 4.5 scenario and RCP8.5, high emissions scenario was used for the study. The result shows that the projected population of Addis Ababa city using high population growth rate (3.3%) will be about 7 million by the year 2039. The climate change projections result under RCP 4.5 and RCP 8.5 scenarios on surface water supply shows that the level of reservoirs volume both at Legedadi/Dire and Gefersa reservoirs will be reduced in the projected years between the years 2023 and 2039. The result of the RCP 8.5 scenario with low population growth shows that the unmet water demand will be 257.28 million m^3 in 2037. The result of the RCP 4.5 scenario with low population growth shows that the unmet water demand will be 314.91 million m^3 in 2037. This indicates that the unmet water demand with the dry climate of RCP 4.5 climate change scenario is higher than RCP 8.5 scenario. Under the RCP 4.5 scenario with high population growth (3.3%) the unmet water demand is 87.42 million m^3 in 2030, 158.38 million m^3 in 2035 and 380.72 million m^3 in 2037. This indicates that the unmet water demand in both high population growth and the dry climate of RCP 4.5 climate change scenario will lead to severe shortage of water in the city. The most effective management options are water tariff increasing, domestic water use technology efficiency improvement and water harvesting which give satisfactory result in mitigating unmet demand of climate change and population growth in the city.

1. Introduction

Studies indicate that extreme variability in water resources and significant decreases in stream-flow will be major threats across sub Saharan African countries in the coming decades (Saloua et al., 2012). Water resources are among the most vulnerable as they are

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directly exposed to climate change (Ellen and Jay, 2008; Raskin et al., 2009; Saloua et al., 2012). This is important as one of the major limiting factors of economic growth is the relative availability of water (Yahaya et al., 2014). Recent research shows that climate change will increase the pace of the global hydrologic cycle with accompanied rise in temperature, variability and changes in precipitation patterns (Saloua et al., 2012; Daniel, 2011). Changes in the frequency and intensity of precipitation invariably affect stream flow and the resultant storage volumes of reservoirs. For example, such changes manifest themselves in the form of increased intensity of floods or occurrence of severe droughts which severely affect the water resources at local and regional levels (Akiça, 2012). Human induced climate change affects the quality and quantity of global water resources and this necessitates changes in the way these resources are managed (Manjarrez et al., 2010). Sub-Saharan countries are among those most threatened by water stress, in view of the likelihood of extreme variability, seasonality, and decreasing stream-flows that are predicted to occur in the coming decades (Saloua et al., 2012). Drought in Sub-Saharan Africa is the dominant climate risk; it destroys the livelihoods of farming and pastoral communities and shatters their food security, whilst it also has a significant negative effect on GDP growth (UN-Water, 2012). On the other hand, floods impact on infrastructure, transportation, goods and service flows as well as clean water supplies and health negatively (Yahaya et al., 2014; FDRE Climate Resilient, 2011).

The urbanization rate in Sub-Saharan Africa is increasing (George et al., 2011). Addis Ababa is one of these fast growing sub-mega cities in recent times (AACPPO, 2014). As the administrative seat and political capital of Ethiopia, the city attracts the highest number of migrants from other parts of the country (ORAAMP, 2002)). As the supply of water must be assured for all, to meet the basic human needs, there is a need for progressive water supply planning and management system for the city in order to bring about fundamental changes in the ways water is currently used as well as distributed among different categories of users (Foster and Morella, 2011; AAWSA, 2012). The importance of demand-side management, in particular, is vital in view of the fact that the supply of water cannot be simply increased indefinitely to meet the otherwise increasing demands from the household, commercial, construction, industry and other sectors as well as the needs of the ecological reserves (Golini et al., 2001; Mulwafu et al., 2003; Buytaert et al., 2011).

Growth in population and economic activities as well as improvements in living standards of the population would entail increasing demand for water (Bell, 2015). In case of Addis Ababa, which is evolving into a mega-city, the construction boom including the expansion of condominiums and real estate housing developments, the expansion of manufacturing and service sector establishments that has occurred during the last decade, and the significant increase in its population that is expected to occur in the coming years presupposes a sustainable water supply planning and management (AACPPO, 2014)). As water resources are susceptible not only to these pressures but also to impacts of climate change; environmental managers, urban planners and policy makers need to find solutions for climate change and urban development impact and alternative water sources for the existing and future pressures (Eriyagama et al., 2010; Kirsten and Mark, 2011; Yahaya et al., 2014; Carter et al., 2015).

Climate related risks due to increased variations in climate and weather associated with extreme events have emerged as a key natural hazard of the 21st Century (IPCC, 2013; Hayhoe et al., 2013; Dastagir, 2015). Studies on both present climate variability and future climate change impacts-vulnerability and adaptation have predominantly been derived from Global Circulation model (GCM) outputs. GCMs are the most multifaceted tools currently available for simulating the global climate system (Randall et al., 2007).

The Global Circulation models (GCMs) are not only designed to understand climate processes and reproduce observations but they are also used to predict the future climate (Nimusiima, et al., 2014). However, the future climate depends upon several factors including anthropogenic activities. As a result, defining the possible pathways of different climate components dictated by their interactions under the influence of internal and assumed external factors (e.g., internal natural and external anthropogenic factors) are important for making future projections. This constraint led to definition of different scenarios under the Special Report on Emissions Scenarios (SRES) and Representative Concentration Pathways (RCPs).

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) has been carried out using a new set of scenarios that replace the Special Report on Emissions Scenarios (SRES) (Wayne, 2013). There are four pathways: RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6. The RCPs are trajectories, based in greenhouse gas emissions, land use changes and aerosols, developed for use by the climate modeling community as a uniform basis for near-term and long-term experiments of climate modeling (Moss, 2010). Coupled with climate change, urbanization poses an added challenge to water resources around the world (Monireh et al., 2012; Larson et al., 2013; Zhou, 2014). Human induced climate change is expected to influence the quantity and quality of water resources and this require changes in the way water resources are handled (Sujoy et al., 2010). Since urban population is expected to grow increasing the amount of existing water supply to meet the rising demand. Studies shows cities have additional sources of water supply (like from the ground water) in order to maintain inhabited consumption levels (Alexander et al., 2010). Given the relationship between urbanization and water on the one hand and between climate change and water on the other, the goal of this work is therefore investigate the potential impact of climate change on urban water supply by taking the City of Addis Ababa as geographic study area.

2. Methodology

2.1. Study area

Addis Ababa was established in 1889. Addis Ababa city lies between 23°21′ N to 23.35°N latitude and 85°20′E to 85.33°E longitude (Tolon, 2008). Total area covered by the Addis Ababa city is 520 km^2. The city mean annual maximum temperature is about 24 °C, and the mean annual minimum temperature of the city is about 12 °C. The mean monthly rainfall is high in July and August (about 260 mm). The mean annual rainfall in the city of Addis is about 1255 mm (NMA, 2007). Land use in the city indicate,

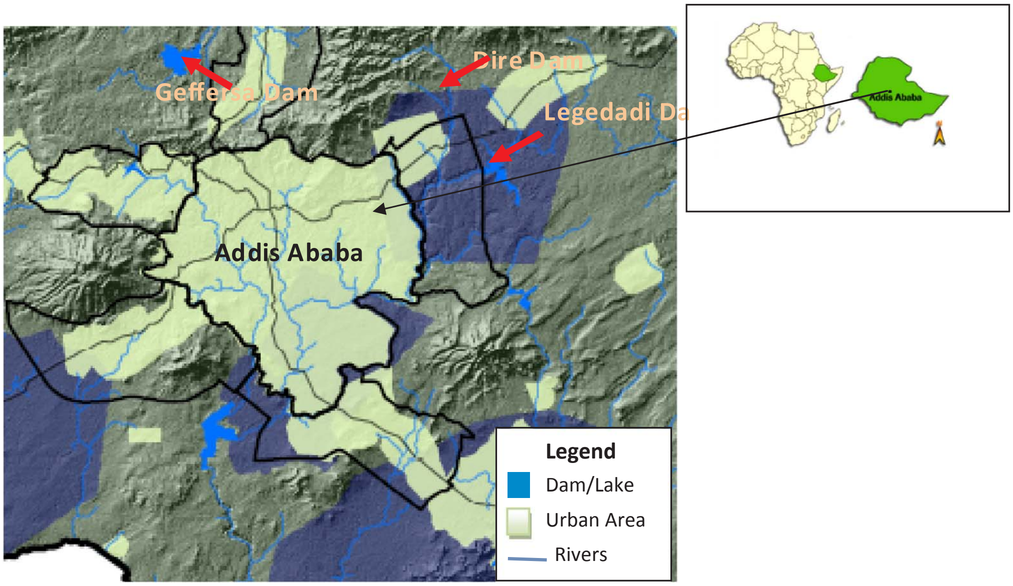

Fig. 1. Hydrological Map of the study Area (Source: Addis Ababa City Planning Project Office (AACPPO), 2014).

26% of the area comprise residential use while 37%, 10%, 9%, 3% and the remaining 15% are used for green, road network, open space, industrial and different land uses respectively (FDRE Ministry of Transport, 2011).

2.2. Data

Observed domestic and non-domestic water demand data obtained from AAWSA (2012), whereby information on the aggregate amount of water consumption for the year 2012 as indicated on the water bills of households at eight demand sites or branches of the city are used. The most important sources of water are surface and ground water systems (MESP, 2011). The main water supply elements are Legedadi, Dire and Gefersa reservoirs as well as the Akaki ground water reservoirs (Fig. 1). Daily and monthly data from Legedadi and Gefersa rainfall stations and the evaporation pans record of Legedadi and Gefersa for the year 2012 are used. Also the monthly inflow, storage capacity, and evaporation data for the year 2012 were collected from AAWSA. The preferred modality of water supply is when a given demand site is connected to more than one supply source. Water supply data for 3 reservoirs, 63 wells and 5 springs for the year 2012 were collected from Addis Ababa Water and Sewerage Authority (AAWSA) (Table 1).

2.3. Methods

2.3.1. Water Evaluation and Planning (WEAP) model

The WEAP model is used for this study. WEAP is specifically effective as a proactive management tool, while it effectively simulates water demand, supply, flow and storage. The WEAP model is being applied at national and international levels as it provides a flexible and comprehensive framework for policy analysis as well as a system for maintaining water supply and demand information (SEI, 2007).

WEAP is capable to simulate suitably for the supply of and demand for water as well as the pressure on and utilization of surface and groundwater sources. WEAP can be employed in water assessments to be conducted at various spatial levels and temporal horizons. The WEAP program developers provide technical assistance and the method is in the public domain for academic use (SEI, 2007).

Table 1
The total water supply data inputs volume of the reservoirs for the year 2012 (data source AAWSA, 2012).

Water Supply System	Sub-system	Input Volume in (m^3) for 2012
System I (Legedad and Dire) Reservoirs	Gabriel-Saris, Jan-meda, Teferi-Mekonin, Interconnection of Merkato, Entoto/Ras-Kasa and Belay Zeleke	59,425,092
System II: Gefersa Reservoir	Rufael, Core-Kolfe and St. Paul	11,306,884
System III: Akaki groundwater aquifer and other Ground water aquifer (63 wells and 5 Springs)	Akaki, Sarries and Legedadi west	41,442,775
Total		112,174,751

Table 2
Reservoirs storage capacity: (data source, AAWSA, 2012).

Reservoir	Storage capacity in MCM (2005)	Storage capacity in MCM (2012)
Legedadi and Dire	57.8	60.2
Gefersa	8.3	11.3
Akaki well, City springs and deep weels	14.6	33.6
Total	80.7	105.1

2.3.1.1. Water supply. Using the WEAP model the various water supply sources are connected to each demand site by creating a transmission link from the various supply nodes to the various demand sites in order to satisfy the aggregate demand at each demand site (MESP, 2009). The total amount of water to be delivered to the demand site equals the amount to be withdrawn from the source minus the potential amount of losses. However, data on the water loss for each demand site is not available at AAWSA. These links are also used to "transmit" from demand sites to destinations such as treatment plants or receiving water bodies (MESP, 2011). Hydrological data that include monthly inflow, storage capacity and net evaporation were collected form AAWSA. The climate model outputs of NIMR-HadGM2-AO model data for RCP 4.5 and RCP 8.5 scenarios (obtained from Mengistu Tsidu, 2016 unpublished work) and the mean precipitation for reservoirs' respective catchment areas for the period 2013–2039 were used to make assessments on the impacts of climate change on water supply- demand balance in WEAP. There has been an increase in the reservoirs storage capacity and number wells in the year 2012 as compared to the situation in 2005, due to upgrading of reservoir capacity and construction of new wells. The year 2012 water supply data presented in Table 2 was used in this study.

2.3.1.2. Water demand. Fig. 2 shows the schematic presentation of water demand sites or branches and supply for Addis Ababa. The courses of the main rivers are shown in blue lines, whilst the reservoirs are indicated with green triangle symbols. Ground water supply from wells and springs is indicated using green square symbol. The transmission links (in green lines) and the return flows (in red lines) are marked with arrows to show the flow directions. The main demand nodes considered in the model (red points) are for domestic and non domestic distribution centers: For this study, the eight customer distribution centers or branches in the city are identified as demand nodes. The distribution centers include Arada, Mekanissa, Gulele, Addis Ketema, Megenagna, Akaki, Gurd Shola and Nefassilk. When a demand point is created, it is important to indicate the level of priority given to it for allocation of water (MESP, 2011). The model will attempt to supply the highest demand priority first, and then move to lower priority points until all the points are covered. For the baseline scenario, the demand priority setup is water supply and flow requirements for domestic

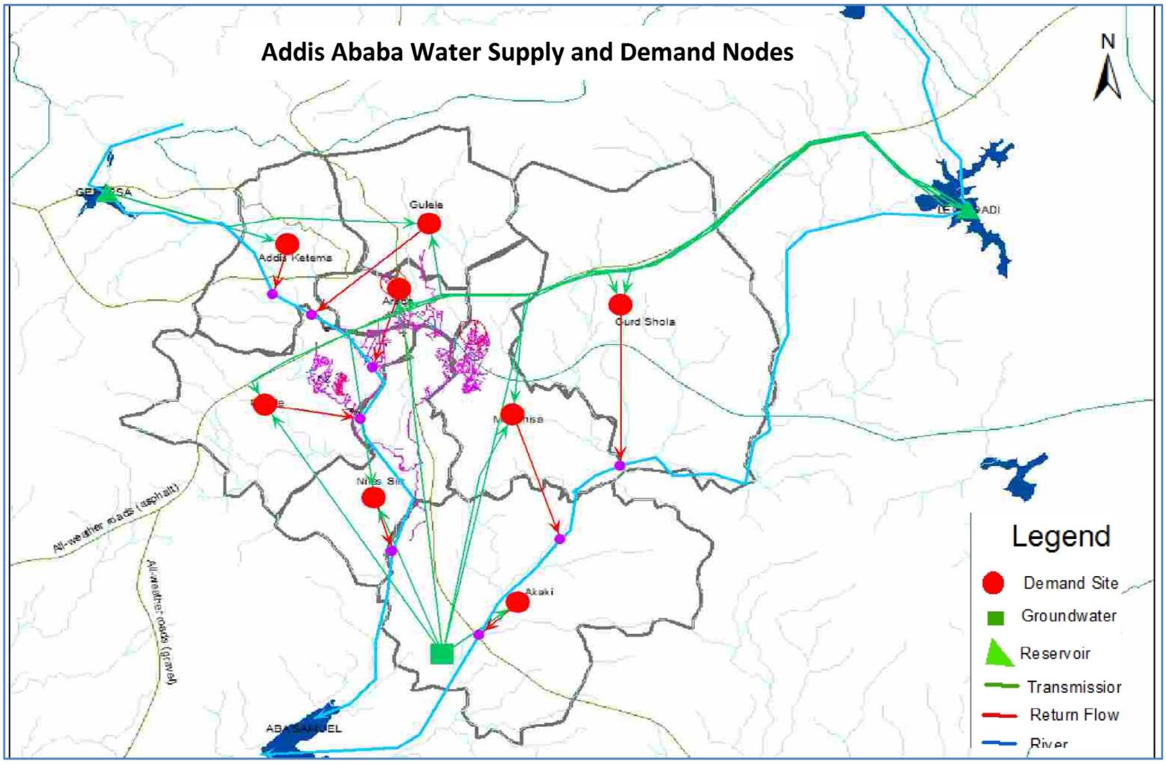

Fig. 2. The schematic views of water demand branches and supply areas in the city of Addis Ababa.

(households) and non-domestic (industry, commerce and construction) use. Each demand site is connected with a supply source using a Transmission Link (green line in Fig. 2). Portion of the already used water flows back, into the river systems (Return Flow - red line in Fig. 2) and ground aquifers indicated in green square. To determine the water demand for each demand node indicated in Fig. 2, data on yearly demand and monthly variation will be employed in WEAP model.

The demand for water is calculated as follows:

$$Total\ demand = Total\ activity\ level \times Water\ use\ rate \tag{1}$$

Using WEAP, demand for water is analyzed as the sum of the demands of demand sites (DS) for all the demand site's bottom-level branches (Br):

$$Demand\ Annual_{DS} = \sum_{Br} (Total\ Activity\ Level_{Br'} \times Water\ use\ rate_{Br''} \times \ldots) \tag{2}$$

Bottom-level branch is the total activity level for the product of the activity levels for all branches from the bottom branch back up to the demand site branch (where Br is the bottom-level branch, Br′ is the parent of Br, Br″ is the grandparent of Br, etc.) (SEI, 2014).

2.3.1.3. Key assumptions. The key assumptions refer to user-defined variables that can be referenced for the analysis of the water supply and demand systems (Leevite et al., 2003). The key assumption was made mainly because of difficulty to obtain data. Both population growth and climate change have an impact on increasing water demand, whilst climate change reduces water supply. It is also important to ensure that the units (for example m^3 per month verses m^3 per year, etc.) of the parameter value for key assumptions match the units for variables in the WEAP data tree (MESP, 2011). The key assumptions about water demand, water supply and water management are given in Table 3. The following demand and supply management options are considered in the key assumptions:

- **The consumption per capita** is anticipated to increase from 110 l/c/day in 2012 to 135 l/c/d by 2039.
- **The World Bank calculated the Ethiopian gross domestic product** (GDP) to be 8.0% in 2010 and 7.0% in 2012. Projected Per capita GDP is expected to grow at around 8.5% annually between 2013 and 2030 (FDRE, 2011). This will contribute to the growth of Addis Ababa and increase the average amount of water consumption in the city.
- **Price of water** (water tariff) from AAWSA (2011): the average tariff (price/m^3) for customers in the lowest consumption users in Addis Ababa is Birr 2.60/m^3 or 0.12 USD per m^3 in 2012 (at the average exchange rate for 2012). The unit price of water in Addis Ababa has shown a slight change in the last 6 years. For this study it is assumed the unit price has increased and will reach Birr 4.40/m^3 by 2039.
- **Technology innovation:** it is assumed that water leakage and other factors that contribute to water losses will be reduced from the current 39.85% to 10% by 2039 (AAWSA, 2012).
- **Water use efficiency** (leakage improvement and other growth of technology for efficiently water supply) is improved by 2% for the reference year (2012); and annual improvement in efficiency is expected to increase by 5% until 2039 (AAWSA, 2012).

2.3.1.4. Scenario development for future water supply and demand. Scenarios were developed by considering various factors that impact on future water security. The essential principle in WEAP is the establishment of scenarios (Roberto and Matthew, 2007). In WEAP the differences among the various scenarios could be considered against the baseline or reference scenarios. According to Addis Ababa City Planning Project Office (AACPPO, 2014), the low population growth scenario is about 2.5% and the high population growth scenarios is about 3.3%. For this study, two scenarios for population growth rates are used. The first scenario is the reference period or the base scenario, which is 2.5% per year. The second scenario is the high population growth scenario, which is 3.3% per year. The third is climate change scenarios with result of urban climate projection under both RCP 4.5 and RCP 8.5, which will be used in WEAP as climate change impact assessment. The activities performed include incorporation of domestic, non domestic water use demands, and inserting climatic and hydrologic parameters. Also the assessment of the different management options that correspond to scenarios will be demonstrated using WEAP model. Scenarios method was built in WEAP, and then their impacts on water supply and unmet water demands in the city were assessed for future planning.

Table 3
Key Assumptions for water demand and supply system and Model inputs for the Management options.

Key Assumptions	Base period (2012)	Scenario period (2013–2039)	Unit
Population growth	2.1	2.5 and 3.3	Percent/year
*Annual water use	37.9	65.5	m^3
GDPgrowth of Ethiopia for living standard	7.0	GDP Growth by 8.5%	Percent/year
Management Options			
Price of water average of domestic and non-domestic	2.60	Growth by 2%	ETH birr/year
**Water supplier and users Technology Innovation (leakage control)	39.85	10	Percent/year
***Water use Efficiency annual improvement (water use method)	2	5	Percent/year

* Total water use/person/year.

** driver to improve of water use technology for domestic and non domestic customers (e.g. water taps, toilet flush).

*** Leakage improvement and other growth of technology for efficiently supply water by water suppliers.

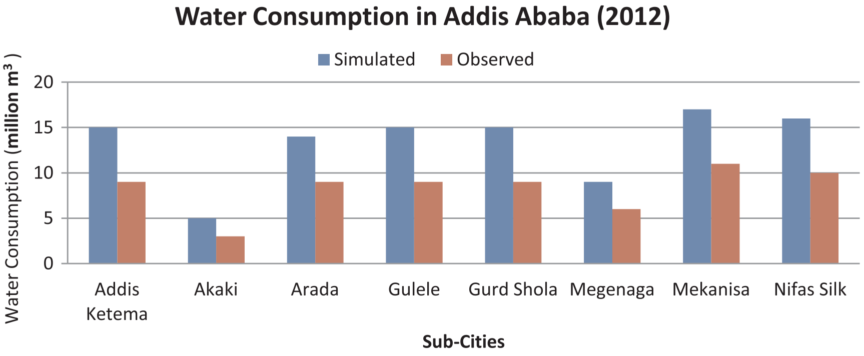

Fig. 3. Observed water consumption of Branches versus WEAP generated data for water consumption (2012).

The proposed planning management options for the different scenarios were assessed using WEAP model. The interval between 2013 and 2039 were used as the planning period. The main factors of uncertainties for supply of and demand for water are climate change and population growth rate as well as socio economic improvements that imply increased level of both domestic (or household) and non domestic consumption including industrial and commercial uses.

3. Result of existing water supply and consumption

3.1. WEAP comparison of water consumption

Comparison was made using distribution of total observed water consumptions data from AAWSA and WEAP generated data using key assumptions with respect to 2012 base period as shown in Fig. 3. The comparison made between simulated WEAP water consumption data for the year 2012 and the observed data at the various demand sites shows WEAP assumes that all of the water supplied will reach the demand site. As there is a data gap regarding water loss or leakage for each demand site, WEAP's result for total consumption of the city is found to be 112.2 million m^3. As also confirmed in AWSSA's year 2012 business plan, from a total of 112 million m^3 of water produced, only 66 million m^3 (60.15%) was actually consumed, whilst the remaining 34 million m^3 (39.85%) was lost.

3.2. Observed water consumption

The data obtained from AAWSA's water customer's information (2012) shows an upward trend in demand in the year 2012. The total number of connections has increased by 96,140 between 2005 and 2010, indicating an annual growth rate of 8.3%. Non-domestic clients exhibited an annual growth of 2% during the period. The total population of Addis Ababa in 2011 was 2,979,615 with 697,815 housing units. The 2012 Addis Ababa total connected customers both domestic and non domestic were 327,996. The total observed domestic and non domestic water consumption for the year 2012 was 66.7 million m^3. By looking at the total consumption and estimated total population of the city, the city's water consumption (demand) is found to be 110 l/c/day which is more or less similar with the observed data for 2012 that is obtained from AAWSA.

The consumption levels in September, October, November, December, April, May and June are high. This shows that during dry seasons people consumed more than wet seasons. Also in all demand sites the consumption during August is much less than that of June. During July and August and May the consumption rates are lower than other months. The combined domestic and non-domestic consumption of all demand sites and the monthly variations of rainfall at the demand sites in 2012 are given in Fig. 4. At the onset of rainy season in June, the consumption rate reaches its peak (Fig. 4).

3.3. Water supply system

Water from Legedadi and Dire reservoirs is treated in Legedadi treatment plant and supplied to demand sites as an integrated water supply system. In this study discussions about the Legedadi reservoir refer to the Dire reservoir as well. The head flows of Gefersa and Legedadi rivers to the two reservoirs are high during July–October (Fig. 5a). Head-flow represents the average inflow from rivers to the first node of a reservoir. Input data used to calculate inflow are daily values of precipitation obtained from stations representing the catchments under consideration. In this study, the inflow is calculated by a reverse water balance approach and calibration for all catchments is considered as observed inflow.

The return flow is the total outflow of water (in percentage) and the amount of water being returned into the river or the underground aquifer systems. In the case of Addis Ababa only 7% of the waste water is linked to a sewerage system, the remained return flow goes through pit-latrine/septic tank emptied by vacuum truck and nearby river. Fig. 5b shows the inflow in the reservoir (positive values) and outflows from both Legedadi and Gefersa reservoir (negative values) in 2012. The comparison between the inflow and outflow values of each month shows that enough water is available in the system with distinct seasonal differences between wet and dry seasons of 2012. These results do not take into consideration the water cumulative effect of the reservoir.

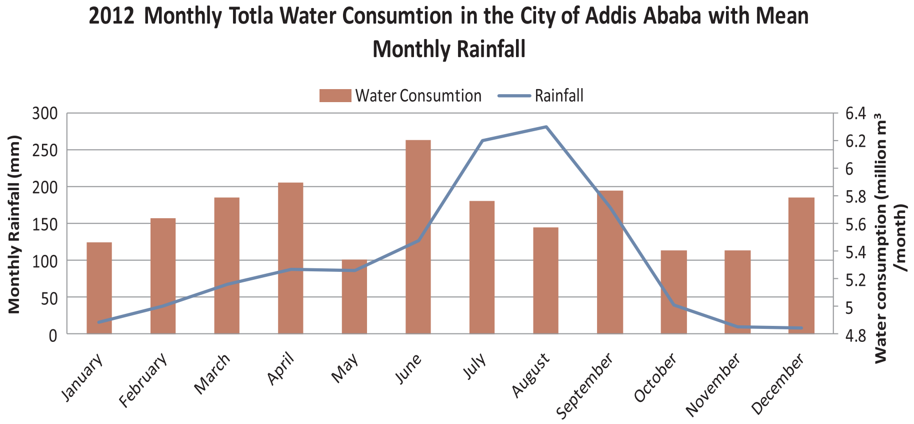

Fig. 4. Monthly observed water consumption versus mean monthly rainfall (2012).

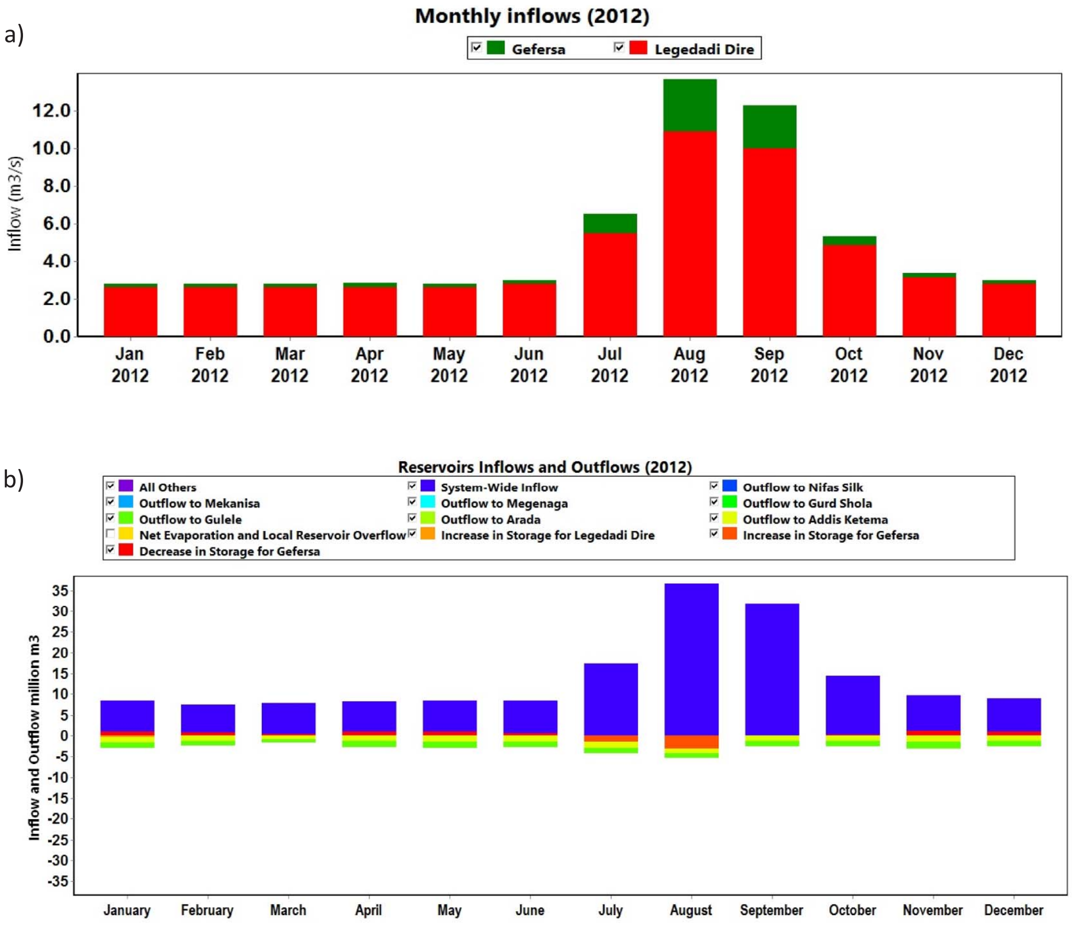

Fig. 5. WEAP generated reservoir a) monthly inflow and b) inflow and out flow of reservoirs in million m^3 (MCM) for the year 2012.

3.4. Future water demand under low population growth scenario

With 2.5% population growth rate, the WEAP predicts the population of Addis Ababa to be 5.5 million by 2039. The total demand in this scenario would grow from 110 million m^3 in 2012 to 664 million m^3 in the year 2039. The key assumption is that the consumption per capita is anticipated to increase from 110 l/c/day in 2012 to 135 l/c/d by 2039. In this case, the result shows an increase in demand as the population grows. The water availability under low population growth scenario would result in insufficient amount of water supply in some sub-cities. As a result, the unmet demand is estimated at about 364.77 million m^3 in year 2039,

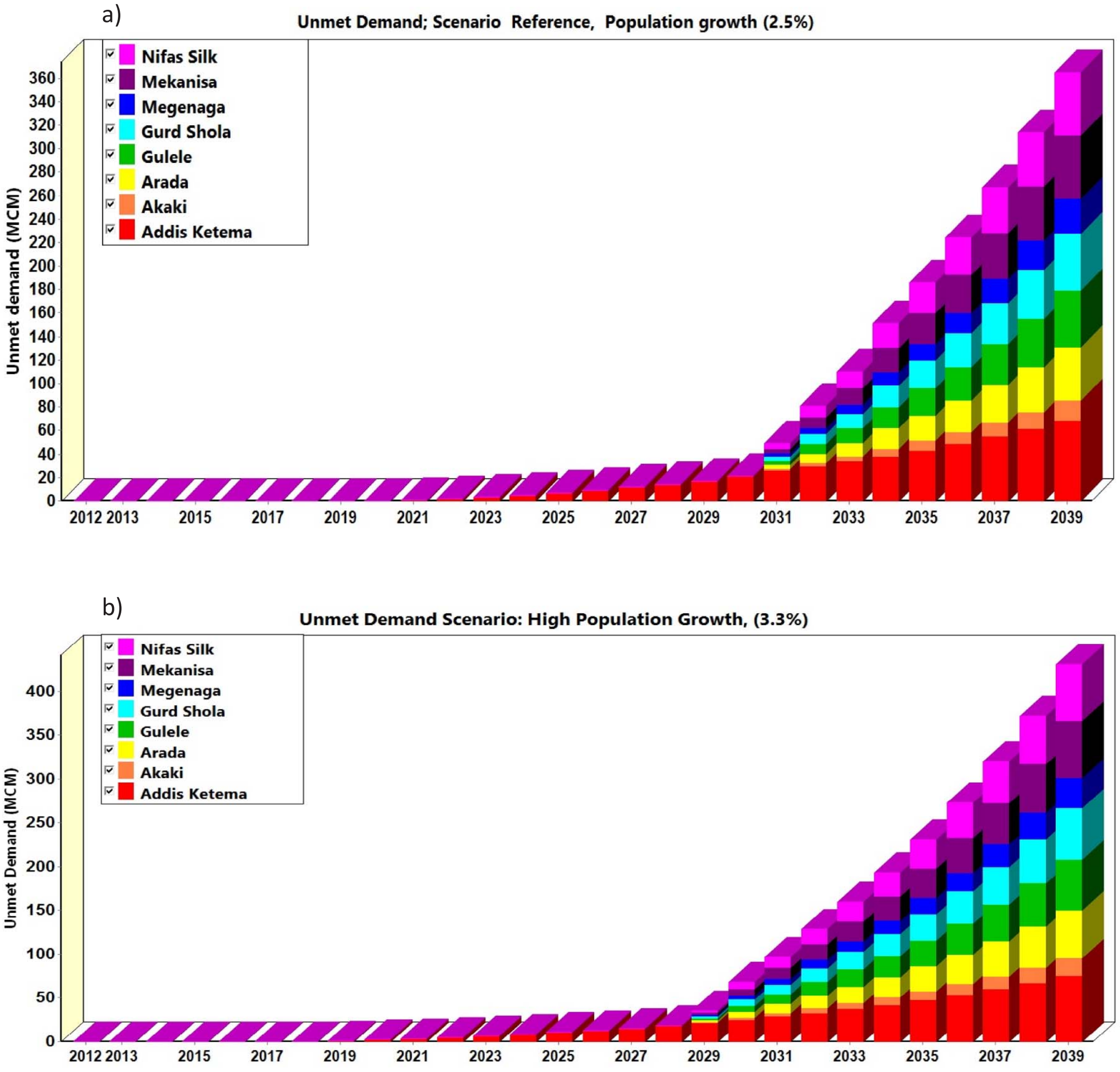

Fig. 6. Projected annual total water demand a) in low population (2.5%) b) in high population (3.3%) growth scenario.

whereby the supply- demand gap will be high in Addis Ketema (68.89 million m^3), Mekanisa (54 million m^3) and Megenagna (29 million m^3) (Fig. 6a).

3.5. Future water demand with high population growth scenario

According to the WEAP model, the projected population for Addis Ababa under the high population growth scenario (3.3% per year) is about 7 million by the year 2039. The impact of high population growth on water demand is reflected in the increase from 233 million m^3 in 2025 to 686 million m^3 in 2039. This high demand also puts significant pressure on the storage volume of Legedadi and Gefersa reservoirs. The water availability under high population growth would cause much more insufficient water in some sub-cities. As a result the unmet demand is estimated at about 430.84 million m^3 in the year 2039 (Fig. 6b), with the highest supply demand gaps in Addis Ketema (75.64 million m^3), Mekanisa (65 million m^3) and Megenaga (34 million m^3).

Fig. 7 shows monthly variation of unmet demand during the period from 2013 to 2039 shows that under the high population growth scenario, the unmet demand is high during May to June in branches like Addis Ketema 2021 to 2039. The shortage of water in other branch like Arada, Gulele, GurdShola, and Mekanisa and Nefasilk Laafto will be very high and will occur during November to March and April to July 2033 to 2039.

3.6. Climate change scenario

The rainfall data from NIMR-HadGEM2-AO climate model under a midrange RCP 4.5 scenario and RCP8.5 high emissions

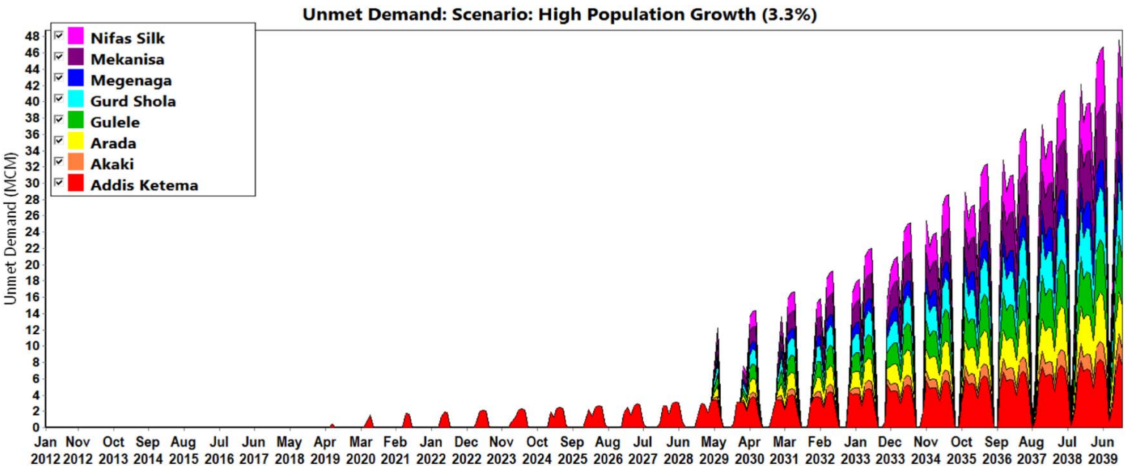

Fig. 7. Projected monthly total water demand in high population (3.3%) growth scenario.

scenario for 2030s have already been corrected for possible biases (Fig. 8a). The performance of NIMR-HadGEM2-AO climate model scheme employed has been assessed for present climate using historical observational data.

3.7. Impact of climate change on water supply

The comparison between the inflow and outflow values for each month shows that there is enough water in the reservoirs under RCP-8.5 scenario during the rainy seasons of July, August and September and there will be shortage during the dry months of November, December, January and May. The future reservoir inflow of Legedadi and Gefersa (i.e., during 2010–2039 period) cal-

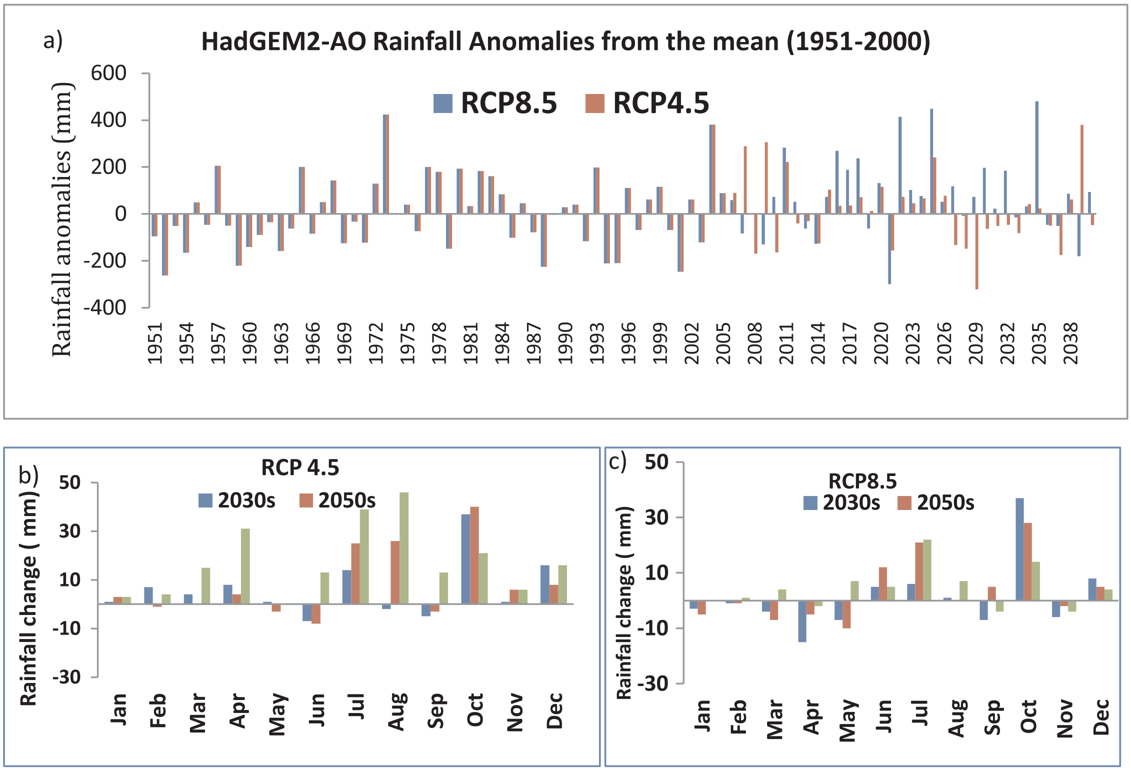

Fig. 8. Addis Ababa a) annual average rainfall anomalies (relative to the 1951–2000 average) for 1951–2040, under RCP 4.5 and RCP 8.5 Scenarios; b and c) mean monthly change in rainfall in the 2030 s and 2050 s under RCP 4.5 and RCP 8.5 scenarios with respect the baseline period (1950–2000) mean.

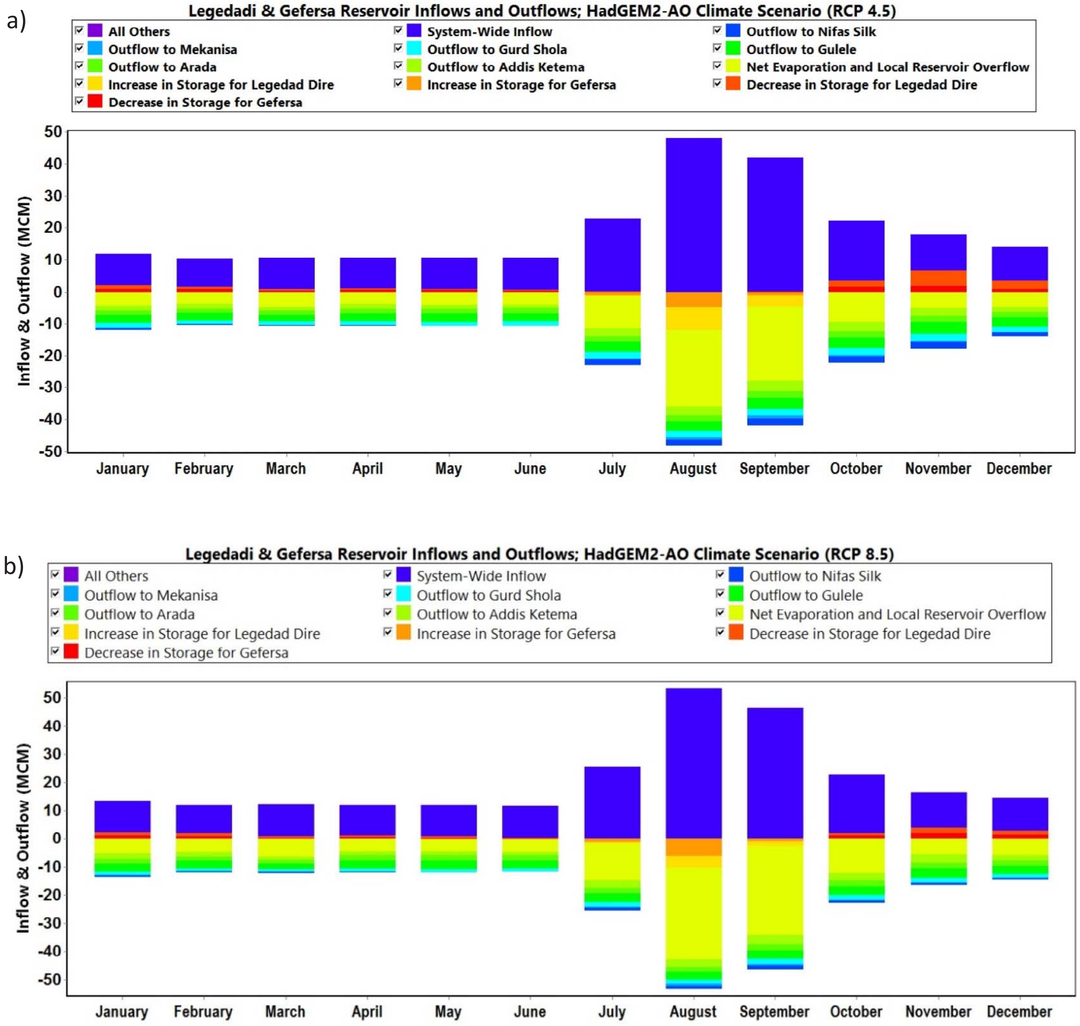

Fig. 9. a) Average monthly storage inflow/outflows of Legedadi and Gefersa reservoirs under RCP 4.5 scenario and b) Average monthly storage inflow/outflows of Legedadi and Gefersa reservoirs under RCP 8.5 scenario 2030 s (2010–2039).

culated under both RCP 4.5 and RCP 8.5 scenarios indicate that the offset of the Kiremt or the long rainy season inflow in September is slightly decreased (Fig. 9a and b). This result will affect the monthly demand in the various sites.

3.8. Population growth and climate change impact on water demand

Table 4 shows the annual unmet demand for RCP4.5 and RCP 8.5 with low (2.5%) population growth scenarios. The result of the RCP 8.5 scenario with low population growth shows that the unmet water demand will be 11.75 million m^3 in 2030, 49.6 million m^3

Table 4
Unmet Demand comparisons with six Scenarios.

Scenarios	Unmet Water Demand (million m^3/year)								
	2012	2015	2020	2025	2027	2030	2035	2037	2039
Reference (2.5%)	0.0	0.0	0.0	7.26	11.82	21.41	185.71	266.65	364.77
High Population Growth (3.3%)	0.0	0.0	0.0	10.54	15.41	67.90	231.02	319.95	430.54
Climate Change (RCP 4.5) with pop. growth (2.5%)	0.0	0.0	0.0	3.76	12.62	76.09	103.23	314.91	168.13
Climate Change (RCP 8.5) with pop. growth (2.5%)	0.0	0.0	0.0	3.21	6.78	11.75	49.66	257.28	372.87
Climate Change (RCP 4.5) with pop. growth (3.3%)	0.0	0.0	0.0	4.35	14.22	87.42	158.38	380.72	261.72
Climate Change (RCP 8.5) with pop. growth (3.3%)	0.0	0.0	0.0	3.77	7.65	13.40	78.51	319.94	462.77

in 2035 and 257.28 million m^3 in 2037. The result of the RCP 4.5 scenario with low population growth shows that the unmet water demand will be 76.09 million m^3 in 2030, 103.23 million m^3 in 2035 and 314.91 million m^3 in 2037. This indicates that most of the years the unmet water demand with RCP 4.5 climate change scenario is higher than that of RCP 8.5 scenario.

However, the projected rainfall for the year 2039 will expected to be very wet in RCP 4.5 and very dry in RCP 8.5 (see Fig. 9a). As the result the annual unmet demand for RCP8.5 and RCP 4.5 with low (2.5%) population growth scenarios will be 372.8 million m^3 and 168.13 million m^3 respectively for the year 2039. The RCP 4.5 scenario with high population growth (3.3%) shows that the unmet water demand will be 87.42 million m^3 in 2030, 158.38 million m^3 in 2035 and 380.72 million m^3 in 2037. In addition, the result of the RCP 8.5 scenario with high population growth (3.3%) shows that the unmet water demand will be 13.40 million m^3 in 2030, 78.51 million m^3 in 2035 and 319.94 million m^3 in 2037. The annual unmet demand for RCP 8.5 and RCP 4.5 with high (3.3%) population growth scenarios will be 462.77 million m^3 and 261.72 million m^3 respectively in 2039. This indicates that the unmet water demand in both high population growth and the dry climate of RCP 4.5 & RCP8.5 climate change scenario will lead to substantial shortage of water in the city.

4. Possible solutions to the projected water supply deficit

4.1. Demand-management through water tariffs

A pricing system based on efficiency criteria does not only aims for this level of service but also acts as a built-in regulator of demands and system growth as water supply management. For the demand management scenario the price of water starts at 0.12 USD/m^3 (ETB 2.60/m^3), proposed to increase at a rate of 2% per year. Also the demand management option considered here promotes water saving through seasonal water price increment. The result of this policy measures shows that the unmet demand under the high population growth (3.3%) scenario and dry climate scenario of RCP 4.5 can be mitigated with only 6 million m^3 deficits.

4.2. Supply and demand measures

The Impact of climate change on reservoir's storage volume, which is shown in Fig. 10, will be managed and mitigated by supply measures that consist of upgrading or increasing the capacity of existing reservoirs and constructing new reservoirs.

According to AAWSA business plan (2012), an additional new reservoir (dam) will be constructed at Gerbi (29.2 million m^3 per year) by the year 2016, but not done yet, the Legedadi Reservoir will be upgraded to add 11 million m^3 by 2014, and new wells will be developed that will supply about 90.1 million m^3 from 2014 to 2020. This additional supply (a total of 130.3 million m^3) will be taken into consideration in management options as one of the supply measures. Fig. 10 shows that after upgrading the capacity of existing reservoirs, reducing leakages in water transmission lines from the current 34.3% to 10% and constructing new reservoirs with full capacity holding of water, there is a possibility to adapt to the future climate change impacts. With supply measure, there will be unmet deficit of 174.19 million m^3 for future domestic and non domestic water demand (see Fig. 11).

5. Conclusion

Based on WEAP model, the population of Addis Ababa will increase to 5.5 million by 2039 at 2.5% annual growth rate, which is the low population growth scenario. Given this projected population figures, there will be deficiency in water availability in some of the sub-cities. Under this scenario, the total demand would grow from 110 to 664 million m^3 by 2039. The consumption per capita is assumed to increase from 110 l/c/day in 2012, which is already below the standard set by WHO, to the standard of 135 l/c/day by 2020. As a result, the shortfall unmet demand is estimated to be 364.77 million m^3 in the year 2039, with the shortfall expected to be high in Addis Ketema (68.89 million m^3), Mekanisa (54 million m^3) and Megenagna (29 million m^3). According to WEAP model, the

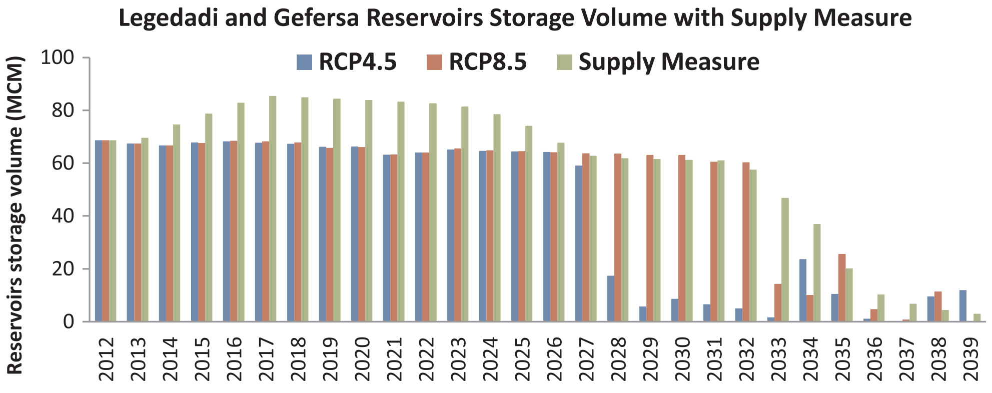

Fig. 10. Supply Side Management Option for the Impact of Climate Change on the Storage Volumes of Legedadi and Geferssa Reservoirs.

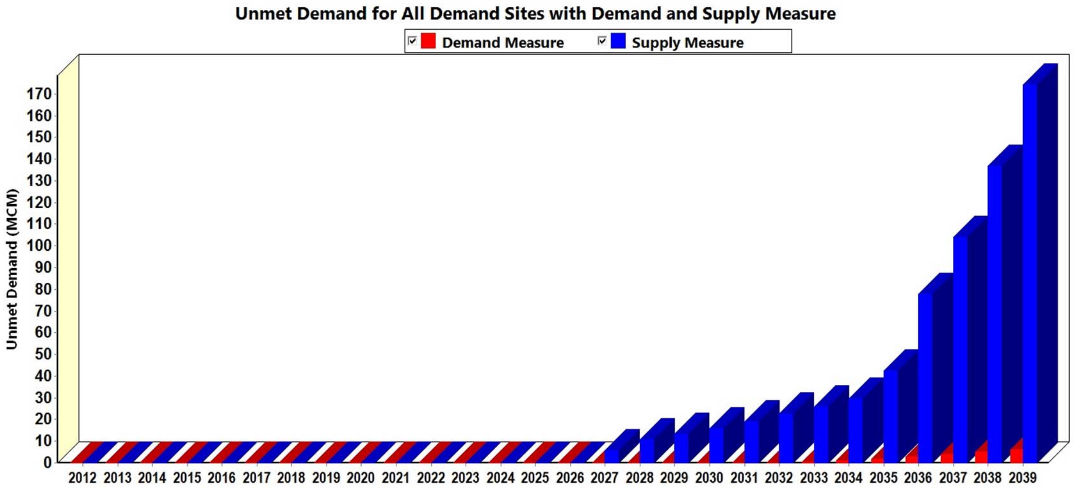

Fig. 11. The unmet demand after demand and supply measures are employed.

size of the city's population when projected using the high population growth rate scenario (3.3%) will be 7 million by the year 2039.This higher increase in population will have an impact on the aggregate water demand of the city that rises to 686 million m^3 in 2039. The reservoirs inflow under the RCP 8.5 scenario is higher than what is to be found under the RCP 4.5 scenario which satisfied all its demands. However, the RCP 8.5 scenario shows that there is a shortage of up to 3.9 million m^3 of water in November. Given current capacities and future plans to upgrade the city's water supply system, there will be sufficient water supply only up to 2027.

The results of the WEAP model for the RCP 8.5 scenario combined with the low population growth scenario shows that the unmet water demand will be 372.8 million m^3 by 2037. On the other hand, the result of the RCP 4.5 and low population growth scenarios suggests a deficit of 314.91 million m^3 by 2037. The model's result for the RCP 8.5 and high population growth (3.3%) scenario shows that the unmet demand will be 319.94 million m^3 by 2037. This indicates that the highest volume of unmet water demand is expected to occur under the high population growth and dry climate years that will have big repercussions on water shortages in the city (Table 4).

To manage the water shortage, updating water tariffs is suggested as a better option with seasonal water price adjustments. Even after implementing the supply measures planned by AWSSA the future unmet demand for both domestic and non domestic use will be 174.19 million m^3 (Fig. 11). Adopting a seasonal adjustment of water tariffs as well as the construction of new reservoirs and wells will contribute towards reducing the future unmet demand. It is therefore crucial to take measures aimed at ensuring the sustainability of the water sources by using the different research finding and options reported here. Particular attention should be drawn to optimize the supply and promote demand side management practices as workable climate change adaptation measures.

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