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Assessment of future urban water demand and supply under socioeconomic scenarios: a case of Assosa town

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ABSTRACT

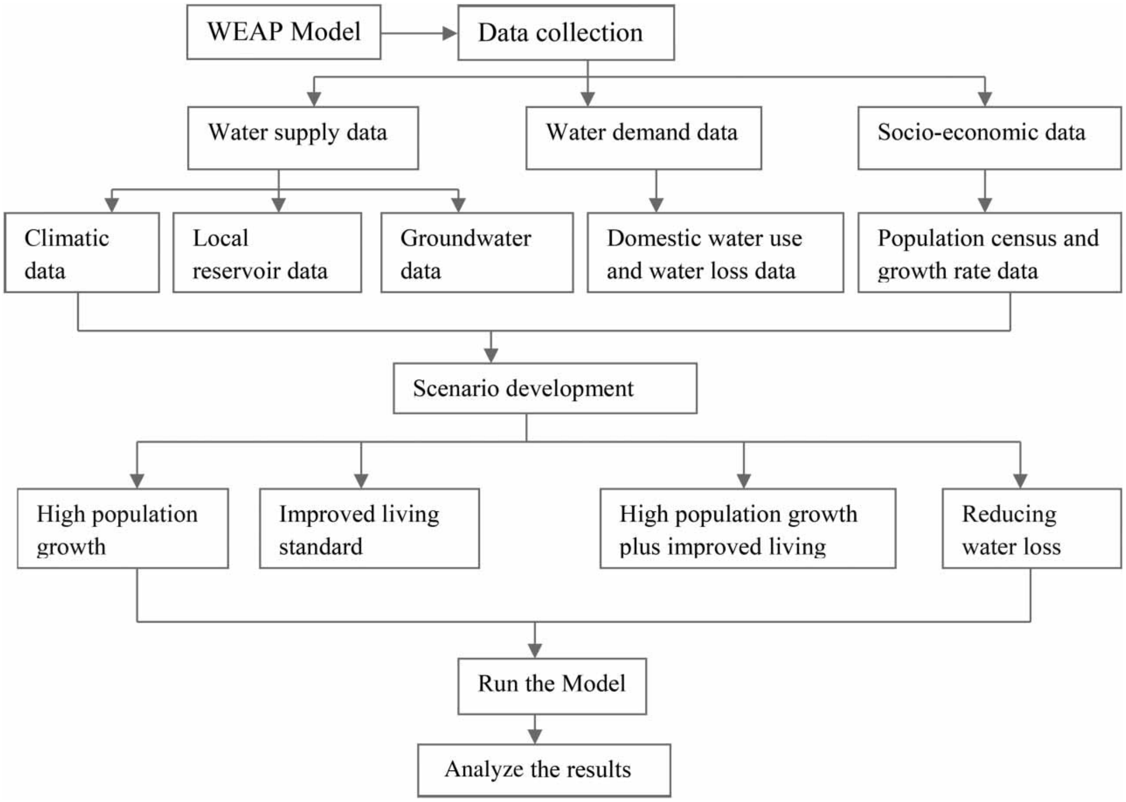
Water scarcity is becoming a progressively more serious global issue. Assosa town in Ethiopia faces serious water scarcity problems due to rapid population growth and urban expansion. This study aims to model the water demand of Assosa town using a forecasting model. Four scenarios were developed: population growth, living standards, water loss reduction, and a combination of these. The water demand and unmet demands for each scenario were evaluated. Results show that the demand for water and supply will vary significantly if the present state continues. In the base year (2018), the overall water demand is 2.07 gigalitres (GL) and the unmet demand is estimated as 0.096 GL. The water demand grows to 3.71 GL under the reference scenario in 2035. The combination of population growth and improved living standard scenarios is observed to impact greatly on water demand. The total water demand of this scenario was estimated to be 7.14 GL latterly in the projection period and the unmet demand would grow to 5.2 GL. The results confirmed that improved water management approaches are needed in the town to ensure the sustainability of water resources in the long term and outline proper water utilization policies.

Key words: population growth, scenarios, water evaluation and planning method, water scarcity, water supply

HIGHLIGHTS

- Assessing the current and future urban water demand and supply gaps provides significant information.
- The study analyzes the water demand and proposes options to improve the performance of the water supply system.
- The study helps to inform the concerned authorities in conserving water resources for sustainable use.

GRAPHICAL ABSTRACT



INTRODUCTION

Water is an essential natural resource that plays a central role in human welfare and the environment, and is the primary resource for daily human activity, industrial operation, and agricultural production (Pandey *et al.* 2019). The demand for water resources is rising all over the world (Xu *et al.* 2017). Equally, water scarcity is among the limiting factors in local socioeconomic development. Water scarcity is mainly caused by climate change, rapid urbanization, population growth, increasing demand for economic development, pollution, and over-exploitation of water resources (Divakar *et al.* 2011; MacDonald *et al.* 2011; Roozbahani *et al.* 2015). These contributory factors greatly impact the hydrological cycle and cause the decline of available water resources (Wang *et al.* 2015; Xu *et al.* 2017).

Several countries in the world face a significant problem in sustaining reliable water supplies. This phenomenon is anticipated to continue in the future (Kassa 2017). In Ethiopia, the distribution and availability of water are spatially and temporary erratic and water scarcity is the most important problem (Seleshi 2006; Kassa 2017). In urban centers, for instance Addis Ababa, the gap between water supply and water demand is huge. The non-functionality of water supply sources, increasing problems of water shortage, high population growth and related factors are the main factors for supply–demand imbalance and are most challenging to water supply sectors (Alemu & Dioha 2020).

Similarly, Assosa town is one of the water-scarce areas in Ethiopia where water management in a sustainable way is not considered in addressing the issue of increasing water demand. The inhabitants in Assosa town are in a severe water shortfall, getting water just once per week and sometimes once in two weeks. The limited freshwater resources and progressive growth in water demand are likely to increase in the future. This identifies the importance of using water demand prediction tools as a possible approach for optimizing the management of water and planning for future water status under various scenarios.

Precisely assessing the water demand plus water supply in areas with water scarcity provides significant information to support water resources management. However, water utilities directors are facing a challenge owing to the improbability of getting information about the capability of the existing water system under possible rapid increase in urban water demand.

These issues inspire me to take part in the urban water planning that would provide managers with technical and more precise approaches regarding future water demand to reduce uncertainty. This involves analyzing the current water system, estimating the future unmet demand, and identifying the supply–demand gap to administer an efficient and regulated water supply system.

Researchers in different parts of the world have used different models for water resource assessments. Of these, the Water Assessment and Planning Tool (WEAP) has been widely used in different areas of the globe in recent decades (Asghar *et al.* 2019). The WEAP model is commonly utilized due to its effectiveness in analyzing the designed strategies along with scenarios based on 'what if' conditions (SEI 2012). Kou *et al.* (2018) used the WEAP to develop a water resource simulation. The authors evaluated different water-saving scenarios to produce water-saving potentials and established that preclusion of future water shortages necessitates the realization of water-saving actions and the use of new water supply sources. Albalwai (2015) investigated ways to take action over increasing water demand through a water demand management approach in Saudi Arabia.

Brown *et al.* (2019) also estimated the water shortages using the WEAP model in watersheds of the USA. The authors discussed the impacts of population increase and climate change, and analyzed the monthly water demand and water supply. The result of their study indicated measures such as enhancements in reservoir storage, reducing water demand, and withdrawal efficiency improvements as possible adaptations to overcome future demand shortages. Metobwa *et al.* (2018) used the WEAP system to assess the demand for water and the supply of the Mara River, Kenya. The study focused on scenario-based future water demand evaluation and addressed the growing water demand affecting the Mara River, and different approaches were considered to alleviate overuse practices. Alemu & Dioha (2020) employed the WEAP modeling structure to examine water demand and supply using different scenarios in the capital city of Ethiopia.

Although the applications of the WEAP system have been frequent in different parts of the world, studies that analyze water demand strategies in Ethiopia's particular urban water system are still limited. Therefore, this study evaluates the existing condition of water demand and investigates scenarios for water demand in Assosa town. The study considers different socioeconomic factors like population growth, water use rates and leak reduction in the distribution system. The result of the study can be used to inform the urban water management sector and other concerned authorities.

MATERIALS AND METHODS

Study area

Assosa town is situated in the western part of Ethiopia in Benishangul Gumuz Region with a total urbanized area of about 2,000 hectares. The town's average altitude is 1,550 m and it lies between 10°00′ and 10°07′ north and between 34° 30′ and 34°35′ east (Figure 1). The temperature ranges from 14 °C to 39 °C and average yearly rainfall of the area is about 1,200 mm (Kebede *et al.* 2021). In 2018, the projected population number of Assosa town was 93,870, but experienced fast growth as a result of natural increases and rural–urban migration. The Assosa Town Water Supply and Sewerage Enterprise (ATWSSE) is responsible for supplying adequate water for the community of the town. The town is facing a significant water scarcity problem. The limited water resources in the town have become among the most important obstacles to the sustainable economic development of the town.

Status of the present water supply sector in Assosa town

The present water supply source of Assosa town is groundwater from boreholes constructed in different years. The first borehole source was developed in the year 1984. At present, there are 11 existing boreholes; of these only eight are giving service for the town whereas the other three wells are not functioning because of low yield and drainage. The total yield of water from these well is 63.3 litres per second (ATWSSE 2019). The water from these wells is pumped to service reservoirs and then distributed to consumers through private connections and public fountains.

The water demand of Assosa town has progressively increasing and it is the main task of ATWSSE to supply safe and adequate drinking water for the population. In the town, the main water supply requirement originates from domestic consumption. The domestic customers are those that are registered as private users and those that obtain water from a public fountain. Since Assosa town has experienced serious water deficit problems, ATWSSE has been attempting to conquer this problem. The need for a sufficient water supply system for the town has been acknowledged by the ATWSSE as one of the most important factors affecting public health and socioeconomic development in the town. However, the water requisite of

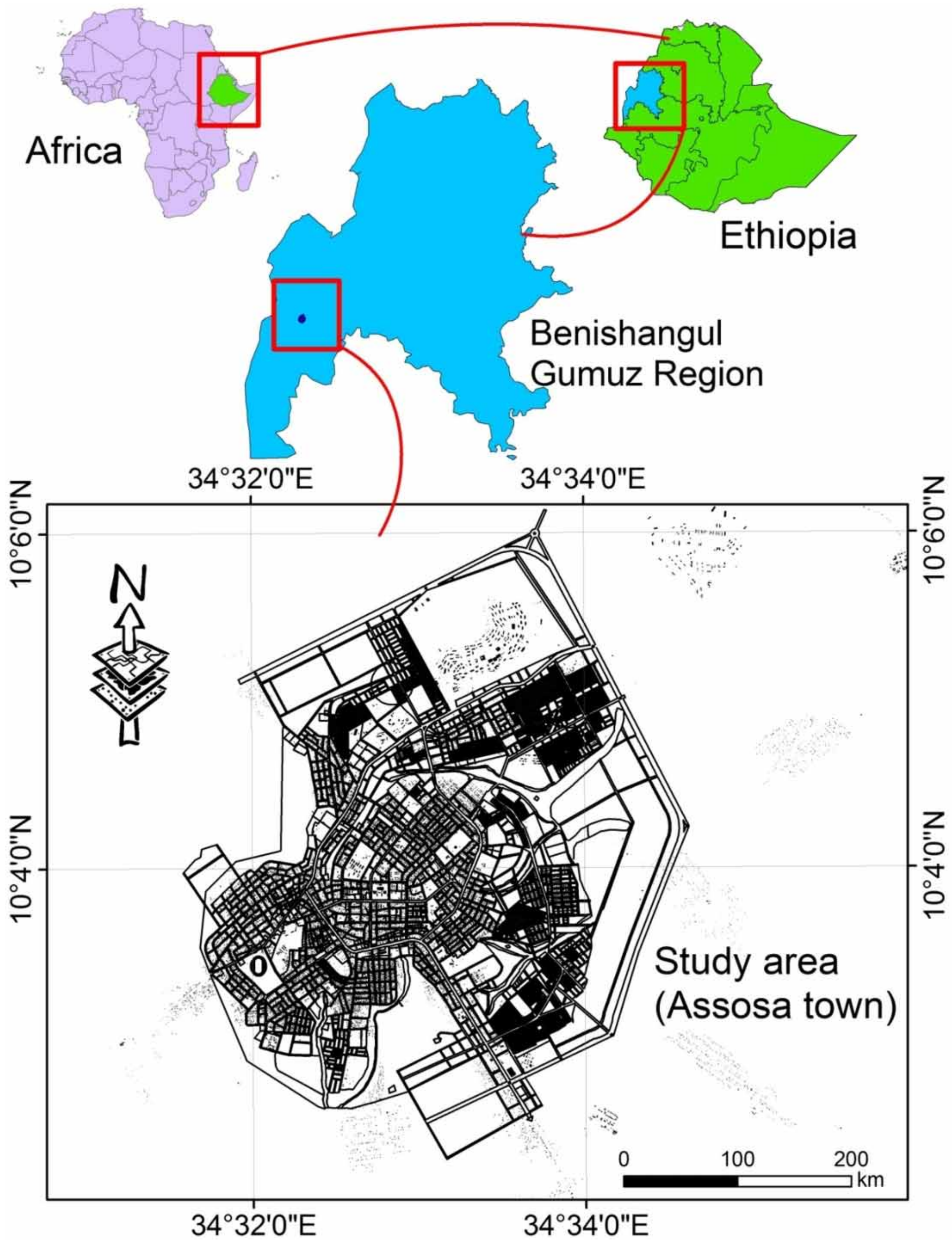


Figure 1 | Location map of the study area.

the town is still uncertain. This makes desirable a variety of water evaluation and planning systems, which is helpful in using the available water wisely and efficiently besides increasing the number of water sources.

WEAP model

The WEAP model, originally developed by the Stockholm Environmental Institute, is a scenario-based water assessment and planning system tool which is very practical for water resource assessment (Gao *et al.* 2017). Its system plus the data structure and level of detail may be easily adapted to meet the requirements of a particular study (Alemu & Dioha 2020). The model applies a scenario approach to assess water resources availability and socioeconomic activities with water and their allocation for present and future periods. The WEAP model contains different approaches for modeling water balance processes (Sieber & Purkey 2015). The Soil Moisture Model is considered the most efficient method for simulating the processes of the hydrological cycle (Ougougdal *et al.* 2020). The model requires various input variables like precipitation, temperature, vegetation cover, relative humidity, and latitude; using these variables, the water balance components such as infiltration, runoff and evapotranspiration are estimated (Olsson *et al.* 2017).

Input data

The input data in this study are grouped as water supply, water demand, and socioeconomic data. The water supply data includes climatic data such as temperature and rainfall, which are used to characterize the area. The other water supply data includes the local reservoir and groundwater data. The water demand data contains domestic water use and water loss data in the distribution system. The home water utilization rate data and other related information were collected from ATWSSE. Furthermore, the socioeconomic data, which includes the population census data for Assosa town and population growth rate, was used to project the population of the town. The standard water use rate was obtained from the Ethiopia GTP (Growth and Transformation Plan) 2 document and WHO (2006). The population data and water use are used to develop alternative scenarios that examine how the total as well as the disaggregated water uses change in due course.

Study procedures

The methodology adopted was based on a series of stages as shown in Figure 2. Firstly, all necessary data sets were collected from concerned agencies and processed to be included in the model. Secondly, the current water supply and demand system of the town was recognized. In this step, the water supply computations to meet the demand were calculated. The third step involved scenario development (2018–2035). The year 2018 was chosen as a base year where all of the data of the system, water supply data, water consumption data, and application sites exist. Lastly, analysis of the model results such as the year of unmet demand and the future water resources management option were outlined.

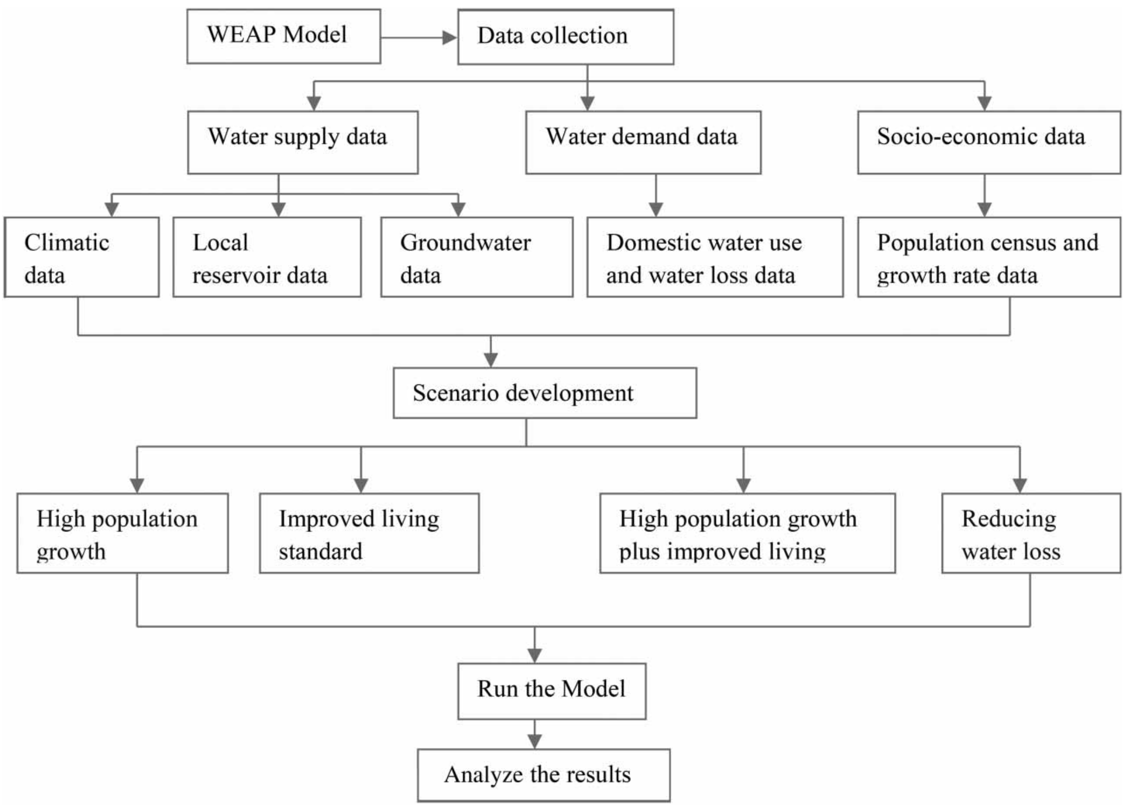


Figure 2 | Study framework.

Water demand calculation algorithm

Water demand analysis is the initial stage in carrying out integrated water resources planning. In WEAP all supply and resource calculations are done by the optimization routine. These establish the ultimate delivery of water at each requesting node, based on user-specified priority options. Water demand at a demand site (DS) is calculated as the sum of water demands for all the demand site's bottom-level branches (Br). Br is one that has no branches below it.

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

Annual water demand was calculated as:

$$\text{Annual demand DS} = \text{Sum (total activity level Br} \times \text{water use rate Br)} \tag{2}$$

The total activity level for Br was calculated as follows:

$$\text{Total activity level for Br} = \text{Activity level Br} \times \text{level Br}' \times \text{activity level Br}'' \times \cdots \tag{3}$$

where Br is the bottom-level branch, Br′ is the parent of Br, Br″ is the grandparent of Br, etc. The calculation algorithms shown above were collected from the WEAP software.

Scenario development

Scenarios are self-consistent storylines showing how the future system might evolve under a specific set of policy improvement or technology conditions and in specific socioeconomic states (Sieber & Purkey 2011). The scenario analysis enables the answering of 'what if' questions. The future water demand of the town might be affected by various socioeconomic factors such as population growth, the living standards of the people, water losses, and others. To understand the effects of these, different assumptions are proposed. In this study, four scenarios were set up to explore the water demand and supply of Assosa town. The water demand, water delivered, supply requirement, and the unmet demands for each scenario were evaluated using the WEAP model.

Basic assumptions

The basic assumptions in the WEAP model incorporate population number, per capita daily consumption (litre/day), annual water consumption (m^3/capita/year), growth rate (%), and losses in the water distribution network (%). The year 2018 is taken as the base year to set up the model. The total population of the town in the base year is 93,870. The per capita daily water use rate is considered as 50 litres per day based on the Growth and Transformation Plan 2 of Ethiopia. The population growth rate is taken to be 3.4%. The current water losses in the distribution network are assumed to be 25% (Kassa 2017).

Reference scenario

In the reference scenario, all assumptions remain the same. All the socioeconomic factors, population factors, and water use rates are assumed to grow at the growth rate of 3.4% with existing policies. It is used as a point of reference for comparison with other scenarios. Other scenarios are described below.

Scenario-1: high population growth (HPG)

Assosa town is characterized as having fast population growth due to natural factors and local migration from rural areas to the town. This scenario considers the consequences of an increase in population on water supply and demand. This scenario assumes an annual population growth rate of 4.5% for the years 2019 to 2035.

Scenario-2: improved living standards (ILS)

It is predictable that the water demand of the household will increase consistent with improved living standards of the people. This implies the per capita water demand will be increased and considered for the indication of improved living standards. Hence 100 litres per day per capita is taken in this scenario.

Scenario-3: high population growth plus improved living standards (HPG + ILS)

This scenario considers the combined effects of a high population growth rate and the improved living standards of the people. Thus, an annual growth rate of 4.5% and per capita water demand of 100 litres per day is used.

Scenario-4: reducing water loss (RWL)

The water supply system faces various challenges like the old pipelines of the distribution system and leakage. The current water loss in the Assosa town water distribution network is taken as 25%, caused by leaks in the distribution system. Hence, it is assumed that the water supply sector applies different water-saving technologies and replaces the old pipelines with new ones to reduce the water losses in the water distribution network. By applying different water-loss-lessening strategies this scenario considered loss reduction to be 10% in the distribution networks.

RESULTS AND DISCUSSION

Water demand of the town

Municipal water resource evaluation is essential for increasing water efficiency, particularly in severe water scarcity areas. In this paper, the evaluation of the impact of the major socioeconomic issue on water demand is predicted through the formation of scenarios in the WEAP model which are developed in the form of key assumptions reflecting the different scenarios to be scrutinized. In the current account year, the entire water requirement is 2.07 GL and unmet demand is observed to be equal to 0.096 GL. The unmet demand, which represents the gap between water supply and water required, is the lowest accounting for 4.6% of the total demands. From the model result, the domestic water demand is 95.4% met in 2018. The water demand between months appears to be different. These monthly changes in water demand are related to the monthly variation in water consumption. The demands are larger during the months of March (0.32 GL), April (0.31 GL), and February (0.29 GL) and lower during August and September (0.17 GL). The results show that Assosa faces severe water shortfall during its dry season: February, March, and April. The monthly water requirement changes are estimated by assigning the yearly demands into months based on the exact number of days in each month. Hence, the monthly unmet water is anticipated only on the supply side. Nevertheless, the water shortage is related to both water demand and supply. The water system of the town is a significant element for optimal water resources utilization and it is imperative to collect the long-term basic data on a monthly and daily basis for WEAP modeling in the future.

Scenario evaluation

Base-case scenario

To examine the future conditions of the municipal water system in Assosa, the WEAP model was firstly run with the reference scenario. This scenario projection illustrates a situation in which there is no water supply and demand infrastructure development. It takes into account a population growth rate of 3.4%. Using this growth rate, the population is projected to be 168,466 by 2035. Since the demand for water use is reflected in population growth, it will continue to grow at the same rate as the population. The WEAP model result for water demand indicates that the water requirement is likely to grow from 2.07 GL in 2018 to about 3.71 GL in 2035. This shows the increase in water demand will be about 44.2% in 17 years. The increase in water demand is primarily caused by an increase in future population, while the water supply remains constant. The water delivered is maintained constantly until 2035. The unmet water demand starts in 2018 at 0.096 GL and rises to 1.74 GL in 2035. This result shows an increase of unmet water demand in the town by 94.48% within 17 years. The disquieting rise of unmet demand is a call to the relevant authority to develop realistic strategies to prevent water shortage crisis in the future.

Scenario-1: high population growth (HPG)

This scenario corresponds to the change in population growth rate from 3.4% to 4.5%. The result of population projection using this growth rate shows a rise in the population to 198,382 capita in 2035. This indicates that rapid population growth will expose the town to a water shortage problem in 2035. The WEAP model result of water demand analysis shows that the water demand will increase from 2.07 GL in 2018 to 4.36 GL in 2035. The sum of water demand is increased by 0.65 GL from the reference scenario. The increase in water demand affectes the supply requirements and conforms to population growth having a very important long-term impact on municipal water demand. The water demand shortfall is seen to grow to 2.4 GL by 2035, which is 0.66 GL higher than the reference scenario. This shows a need for the implementation of effective water resources management strategies and adaptation of new technologies to address the water deficit problems.

Scenario-2: improved living standards (ILS)

This scenario scrutinizes the impact of increased per capita water demand. As the incomes of a household grow, the living standards of people will be enhanced and the household water requirements will increase. In this scenario, 100 litres per capita is considered based on the WHO (2006) guidelines to be used for basic human needs. The other parameters affecting water demand remain the same as the reference scenario. The water demand increases to 5.17 GL from the reference scenario (1.74 GL) in 2035 (Figure 3). Consequently, the unmet water demand is estimated at 4.1 GL in 2035 (Figure 4). This unmet demand is caused largely by the high per capita water use assumed in this scenario and the population growth indicated in the reference scenario.

Scenario-3: high population growth plus improved living standards (HPG + ILS)

The combination of these two scenarios has significant impact on the future water demand of the town. Water demand greatly increased for this scenario. The result indicates water demand was estimated to increase from 2.07 GL in 2018 to about 7.14 GL in 2035 (Figure 3). This implies that an increase in population growth together with an increase in living standards will create serious water scarcity problems for the town in the future, requiring a practical step to be taken to prevent this circumstance. The water demand shortfall for the high population growth plus improved living standard scenarios will grow to 5.2 GL (Figure 4). This represents about 98.2% increase from the reference scenario.

Scenario-4: reducing water loss (RWL)

This scenario was proposed to investigate the effects on water supply of water loss reduction from 25% to 10%. Results of this scenario show that the water demand is the same as the reference scenario over the demand years. Leakage primarily increases water losses in the water distribution system. Thus, reducing water loss in the supply system has a noteworthy impact on reducing unmet water demand. The result of the reducing water loss scenario in distribution networks shows that the unmet water demand is reduced from 1.74 GL to 1.22 GL in 2035 in the reference scenario (Figure 5). This indicates 0.52 GL of water will be saved if the water loss in the distribution system is managed or reduced to 10%. When water leakage

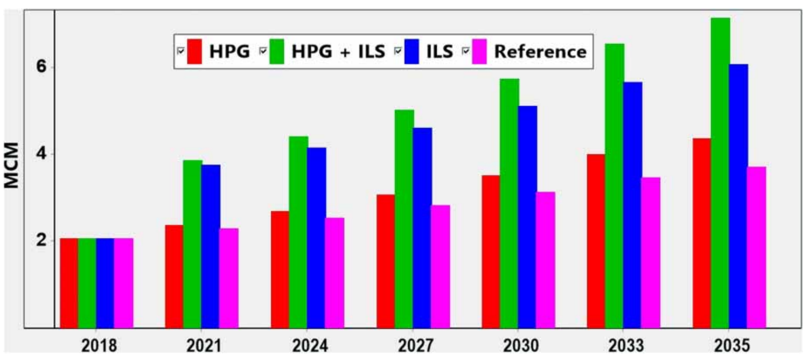


Figure 3 | Water demand under the reference and three scenarios (MCM = 1GL).

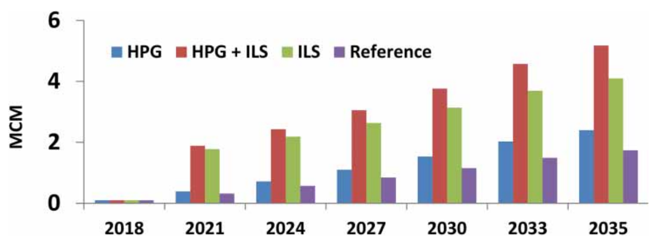


Figure 4 | Unmet water demand of the reference and three scenarios.

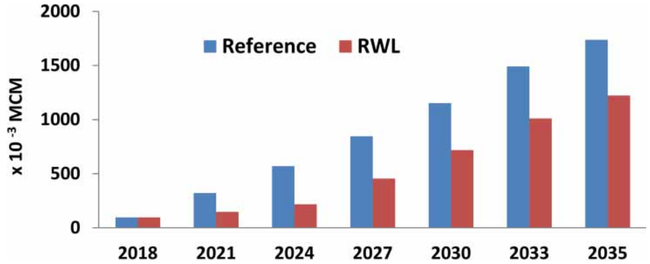


Figure 5 | Unmet demands under reducing water loss scenario.

is reduced, the highest storage capacity of service reservoirs will be reached, which will require the establishment of new reservoirs to meet future water demand.

The findings of this study showed that water deficiency was observed in the dry season, especially in March. All scenarios except water loss reduction showed an increase of unmet demand over all the simulation years. The shortage of water is aggravated by the high population growth and improved living standards. The population in Assosa town is likely to rise in the future and put more pressure on the limited water resources of the town. The trend of higher per capita water utilization coupled with a high population growth scenario in the town could mean that it faces more water deficit in the future. However, sustainable water management strategies in the town may conquer the practical problems that could affect the available water resources. This may be done by rainwater harvesting, the application or inclusion of a sustainable urban drainage system, developing reservoirs to store more water to use during the dry season, and creation of awareness among the public on the efficient and sustainable utilization of water. Further, additional water supply exploitation should be done to improve the water scarcity and expansion of supplementary water supply lines or reservoirs should be considered.

The WEAP model in this study could have advantages in water resources optimization studies, as it calculates water demand at all water use sites. In advance, WEAP can evaluate the realization effects of all significant policies and measures. The socioeconomic assumptions used are derived from official projections, which are uncertain and possibly will influence the results in long-term perceptions. This study will go far to notify decision-makers and relevant authorities about the challenges facing the town in realizing the supply of adequate water to its communities. The private groundwater and other non-counting water sources are not considered in this study and hence need further study. As a result, this study has a set of inferences for the municipality level or regional government and could be used as a preliminary study for future research. The results confirm the need to establish the way of integrating best practices for water resources management such as rainwater recovery and the need to renew the ageing infrastructures of the water supply utility for water loss reduction. This involves repairing the broken water distribution pipelines, water distribution system inspection, immediate detection of leakage sites, and overall maintenance works of the water supply utilities. The other basic strategy to be considered to make a safe water supply is to implement policies that will limit population growth.

CONCLUSIONS

The WEAP system was used to model water demand and create scenarios to assess future water availability in Assosa town. The result shows that water scarcity is a challenge in the future in the town. High population growth and improved living standards will be the main drivers of domestic water scarcity and exacerbate the difference between water demand and unmet demand. The findings of this study can be summarized as: (1) the model gives a reasonable evaluation of future water demand of the town. The results indicate that more than 3.71 GL of water will be required in 2035 to satisfy water needs with the current water supply and socioeconomic trends. (2) The model results show that the water demand would reach about 4.36 GL in 2035 at a population growth rate of 4.5%. (3) Leakage reduction in the water distribution system is a significant aspect of reducing the water supply requirement. It is observed that reducing the water loss in the distribution networks from 25% to 10% reduces the unmet demand from 1.74 to 1.22 GL in 2035 under the reference scenario. (4) In the improved living standards scenario the total water demand in 2035 is estimated as 5.17 GL and the unmet demand is 4.1 GL. (5) The water requirement under the combined effects of the high population growth and improved living standards scenario would be 7.14 GL. The unmet demand is found to be 5.2 GL in 2035. Based on the analysis, all scenarios reveal water deficiency in the future. Thus, enhanced water management plans are needed in the town such as pertaining to a water management plan to conserve water at the household level; arrangement for maintenance of the water distribution system network to reduce water losses and leakage; and supplementary development of water storage reservoirs to increase the quantity of water delivered plus storage of water during the rainy season.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The author declares there is no conflict.

REFERENCES

Albalwai, K. 2015 *Curtailing Reliance on Water Desalination in Saudi Arabia: The Role of Water Demand Management Approaches*. Master's thesis (unpublished), De Montfort University, Leicester, United Kingdom.

Alemu, Z. A. & Dioha, M. O. 2020 Modelling scenarios for sustainable water supply and demand in Addis Ababa city, Ethiopia. *Environ. Syst. Res.* **9**, 7.

Asghar, A., Iqbal, J., Amin, A. & Ribbe, L. 2019 Integrated hydrological modeling for assessment of water demand and supply under socio-economic and IPCC climate change scenarios using WEAP in Central Indus Basin. *J. Water Supply Res. Technol. Aqua* **68**, 136–148.

Assosa Town Water Supply and Sewerage Enterprise 2019 *Existing Water Supply Situation, Main Report*. Assosa Town Water Supply and Sewerage Enterprise, Assosa, Ethiopia.

Brown, T. C., Mahat, V. & Ramirez, J. A. 2019 Adaptation to future water shortages in the United States caused by population growth and climate change. *Earth's Future* **7**, 219–234.

Divakar, L., Babel, M. S., Perret, S. R. & Das Gupta, A. 2011 Optimal allocation of bulk water supplies to competing use sectors based on economic criterion – an application to the Chao Phraya River Basin, Thailand. *J. Hydrol.* **401**, 22–35.

Gao, J., Christensen, P. & Li, W. 2017 Application of the WEAP model in strategic environmental assessment: experiences from a case study in an arid/semi-arid area in China. *J. Environ. Manage.* **198**, 363–371.

Kassa, M. 2017 Evaluation of water supply and demand: the case of Shambu town, Western Oromia, Ethiopia. *Int. J. Water Resour. Environ. Eng.* **9** (5), 96–101.

Kebede, Y. S., Alene, M. M. & Endalemaw, N. T. 2021 Urban landfill investigation for managing the negative impact of solid waste on environment using geospatial technique. A case study of Assosa town, Ethiopia. *Environ. Chall.* **4**, 100103.

Kou, L., Li, X. & Lin, J. 2018 Simulation of urban water resources in Xiamen based on a WEAP model. *Water* **10**, 732.

MacDonald, R. I., Green, P., Balk, D., Fekete, B. M., Revenga, C., Todd, M. & Montgomery, M. 2011 Urban growth, climate change, and freshwater availability. *PNAS* **108** (15), 6312–6317.

Metobwa, O. G. M., Mourad, K. A. & Ribbe, L. 2018 Water demand simulation using WEAP 21: a case study of the Mara River Basin, Kenya. *Int. J. Nat. Resour. Ecol. Manag.* **3**, 9–18.

Olsson, T., Kämäräinen, M., Santos, D., Seitola, T., Tuomenvirta, H., Haavisto, R. & Lavado-Casimiro, W. 2017 Downscaling climate projections for the Peruvian coastal Chancay-Huaral Basin to support river discharge modeling with WEAP. *J. Hydrol. Reg. Stud.* **13**, 26–42.

Ougougdal, H. A., Khebiza, M. Y., Messouli, M. & Lachir, A. 2020 Assessment of future water demand and supply under IPCC climate change and socio-economic scenarios, using a combination of models in Ourika Watershed, High Atlas, Morocco. *Water* **12**, 1751.

Pandey, C. L., Maskey, G., Devkota, K. & Ojha, H. 2019 Investigating the institutional landscape for urban water security in Nepal. *Sustainability* **12** (3), 173–181.

Roozbahani, R., Schreider, S. & Abbasi, B. 2015 Optimal water allocation through a multi-objective compromise between environmental, social, and economic preferences. *Environ. Model. Softw.* **64**, 18–30.

SEI 2012 *WEAP Water Evaluation and Planning System, User Guide for WEAP21 and Software Help Page*. Stockholm Environment Institute, Boston, MA, USA.

Seleshi, B. 2006 *Assessment of Water Resources and Recommendation to Improve Water Resources Management (Ref. Adaa Pilot Learning Site of the Project, Improving Productivity and Market Success of Ethiopian Farmers', Oromia, Ethiopia)*. Final Draft Report, International Water Management Institute, Nairobi, Kenya.

Sieber, J. M. & Purkey, D. 2011 *Water Evaluation and Planning System (WEAP), User Guide*. Stockholm Environment Institute (US Center), Somerville, MA, USA.

Sieber, J. & Purkey, D. 2015 *Water Evaluation and Planning System; User Guide*. Stockholm Environment Institute (US Center), Somerville, MA, USA. Available from: https://www.weap21.org/downloads/WEAP_UserGuide.pdf (accessed on 23 May 2021).

Wang, X., Luo, Y., Sun, L. & Zhang, Y. 2015 Assessing the effects of precipitation and temperature changes on hydrological processes in a glacier-dominated catchment. *Hydrol. Process.* **29**, 4830–4845.

WHO 2006 *The World Health Report 2005: Make Every Mother and Child Count*. WHO, Geneva, Switzerland.

Xu, M., Li, C., Wang, X., Cai, Y. & Yue, W. 2017 Optimal water utilization and allocation in industrial sectors based on water footprint accounting in Dalian City, China. *J. Clean. Prod.* **176**, 1283–1291.

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