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Modelling scenarios for sustainable water supply and demand in Addis Ababa city, Ethiopia

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Abstract

Background: The city of Addis Ababa is under rapid development and there are enormous construction activities along with rapid urbanization, and industrialization. These anthropogenic actions combined with population growth rate are affecting the water demand of the city. The overall purpose of this study is to model water supply and demand of the city and to identify potential water management strategies that supports the sustainable development goal number six (SDG6)—clean water and sanitation.

Methods: We employed the Water Evaluation and Planning system (WEAP) modelling framework to analyze different scenarios for water demand and supply. The scenarios include population growth, living standard, as well as other supply and demand strategies.

Results: For the modelling period, the reference scenario shows unmet water demand increases by around 48%, from 208 to 307 million cubic meter in 2015 and 2030 respectively. High population growth rate and high living standard scenarios have a great negative impact on the water supply system.

Conclusions: Satisfying the future water demand of Addis Ababa will depend on the measures which are taken today. The integrated water management practices such as reuse of water and the selected future scenarios are proposed to decrease and manage the unmet water demand of the city. Hence, future predicted scenarios which is the combination of the external factors (i.e. population growth rate and living standard) and water management strategies were considered. From the analyzed scenarios, optimistic future strategies will support the management of the existing water supply and demand system of the city. Similarly, in the integrated management strategies scenario, it was assumed that measures were taken at both the demand and supply side to improve the efficiency of water in the entire chain. Thus, if the water sector professionals and other concerned bodies consider the selected scenarios, it will go a long way to solve the water shortage problem in the city, and this will also help to promote sustainable water management.

Keywords: Water supply, Water demand, WEAP model, Scenarios, Addis Ababa

Background

Water supply is an important segment of development. However, in Addis Ababa, Ethiopia, the availability, adequacy and the quality of water are in danger, and the water demand of the city is unmet. Addis Ababa city population is increasing alarmingly due to internal migration and high population growth rate of the city. Furthermore, the city is under rapid development and there are enormous construction activities along with rapid urbanization, and industrialization (i.e. small-scale and large-scale industries). Sufficient and safe drinking water is a precondition for the realization of all human rights. Safe drinking water is a basic need for human development, health and well-being (OHCHR 2002). The

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growing problem of water shortage, the non-functionality of water supply sources like some of the ground water sources along with high water use, urbanization, geographical setup of the city and the high number of population are most problematic to water supply sectors, and this will be challenging to the service of giving adequate and safe drinking water supplies to the communities.

Many countries face major problems in maintaining reliable water supplies, and this is expected to continue in upcoming years (Kassa 2017). Addis Ababa city has very limited resources of surface and ground water which plays an important role in the support of domestic needs in mass condominium houses (Admasie 2016). Inadequate effort is devoted to addressing this issue in an integrated approach which combines the supply and demand side management in a sustainable approach. Integrated water supply planning is a significant issue for sustainable development to maximize economy, secure production and reduce environmental impacts. Nevertheless, the water managers and planners have given high priorities to locating, developing and managing new water resources as a result, emphasis has been given to the supply side of water development but, demand side management and improvement of patterns of water use has received less attention (Dalle 2016).

Climate change has become of the most important issue in the domain of sustainable development and its impacts (e.g. rising of sea levels, melting of polar ice caps, wild bush fire, intense drought etc.) can be felt in different parts of the world (Dioha and Kumar, 2019). Developing countries are likely to be affected mostly by climate change, and Ethiopia is one of the most vulnerable countries (Cherie and Fentaw 2015). Climate change, urbanization, and rapid population growth along with migration from rural to urban areas poses a major challenge for city planners; extending basic drinking water and sanitation services to each urban and slum areas (WHO and UNICEF 2006). The transition of people from rural areas to urban cities represents a major and permanent demographic shift. This movement to cities creates many problems, particularly when housing and infrastructure are unable to keep pace with population growth, and this makes difficulty in giving adequate and safe drinking water (Thompson et al. 2007). Population growth is increasing alarmingly in urban areas particularly the capital city of Addis Ababa and therefore, the population growth of the city has an excessive impact on existing water supply infrastructures. The city has always suffered from serious water shortage problems and one of the major factors affecting the public health and socio-economic development of urban communities (WWDSE 2014). Therefore, residents in Addis Ababa are suffering from acute shortage of water and are often hardest hit by the disruption, and thus get water supply just once a week and sometimes once in 2 weeks (Misikir 2015).

As stated by the consultancy service for NRWR in 1995 and 1996, the revenue from water decreased from 65.67 to 60.02% whereas the non-revenue water (or water loss) increases from 34.43 to 39.98% in 1995 and 1996 respectively (Consultancy Service for NRWR 1997). One of the major bottlenecks for the water utilities is large number of water losses in the distribution network system as well as demand side, and quantification of this water loss (Ephrem 2016). Hence, over the period of 1990 to 2004, the number of people without access to drinking water increased by 23% and the number of people without sanitation increased by over 30% (WHO & UNICEF 2006).

So, the study on sustainable use of drinking water resources is geared towards achieving the United Nations sustainable development goal number 6 (Clean Water and Sanitation), and therefore there is a need for integrated water planning management in the future because, many people are exposed to lack of water in terms of quality and quantity. Water supply and sanitation situation in Ethiopia is very poor since most of the population does not have access to safe and adequate water supply and sanitation facilities (Getachew 2003). Hence, limited availability of water as a resource, the population pressure, the limited financial resource and other socio-economic factors, the traditional approach of endless investment is found not to be a sustainable solution to water supply problems (Dalle 2016). As a result, lack of clean or potable water supply and sanitation services in the country has been a serious problem and statistics show that more than 60% of health-related deaths in Ethiopia is caused by water borne diseases (Ethiopian-WFFC 2007). Unsafe drinking water along with poor sanitation and hygiene, are the main contributors to an estimated four billion cases of diarrheal disease annually (WHO 2005). Every year, at least 1.6 million children under the age of 5 years die from unsafe water, coupled with lack of basic sanitation (WHO and UNICEF 2006).

Many countries are entering a period of severe water shortage and the construction of new dams need very big investment as compared to the current economic situation of the city and it may be difficult to implement these projects in short period of time, rather wisely use of the water resource is becoming more important. Thus, selecting different water management system with the help of software tools is very necessary (Amsal and Mebrate 2016). Water Evaluation and Planning system (WEAP) software is common in scenario analysis of water supply and demand. This model helps to understand the impact of external factors on the current water supply and demand system. Hence, the WEAP model is widely documented in various literatures, as a well-organized modeling tool in effective analysis of urban water management and this model also preferred over other models because of its usefulness in analyzing the designed strategies and scenarios based on 'What-If' conditions (WEAP 2014). WEAP is a microcomputer/software tool for integrated water resources planning and it provides a comprehensive, flexible and user-friendly framework for policy analysis (SEI 2016). Thus, by accessing different measures in order to conserve water usage and to increase the water use efficiently, WEAP modelling study is essential to integrate both supply and demand side water management strategies.

There are numerous examples of WEAP model application such as Rheinheimer et al., who employed the WEAP model to develop a water resource management for the upper west slope of Sierra Nevada and to predict the potential effects of regional climate warming on hydropower at the watershed scale (Rheinheimer et al. 2014). Similarly, Al-Omari et al. used WEAP to establish water management support system for Amman Zarqa Basin by likening various management plans and creating a theoretical basis for watershed water management. The study found that in 2005, both agricultural and domestic water demand was not met (Al-Omari et al. 2009). Haddad et al. applied WEAP to investigate water management and water trading scenarios for the reduction of future water demand in Tulkarem basin (Haddad et al. 2007). The authors opined that WEAP can serve as a good decision support system to promote local water resource system. In a different context, Baharati et al. used WEAP to evaluate emerging water scarcity problems by transferring water from well-endowed to more deficient areas. The result revealed that the proposed water storage and transfer will reduce water deficit within the project command area (Bharati et al. 2009). Hamlat et al. used WEAP to evaluate and analyze the existing balance and expected future water resources management scenarios in watersheds of western Algeria. They found that both domestic demand and agricultural demand was not met for the base year of 2006 but argued that water demand management will be needed for managing the available resources (Hamlat et al. 2013).

Li et al. applied WEAP to estimate the sustainability of limited water resources management strategies in the Binhai New Area (BHNA) and to study the advantages of WEAP model for analyzing and simulating different water systems. The results indicated that the pressure on the BHNA water resources will increase in the future (Li et al. 2015). Kou et al. used WEAP to develop a water resource simulation by using subsystems from each district and detailed descriptions of industrial sectors and analyzing various water saving scenarios to generate water saving potentials plus water shortage problems. The study found that prevention of future water shortages requires the implementation of water-saving measures as well as the use of new water supplies (Kou et al. 2018). Abdelmalek et al. also employed WEAP to study the hydrology of Nabhana watershed in central Tunisia. The modeling results showed that the annual inflow to Nabhana dam for the driest year was around 16 MCM in 2011, and the maximum inflow was about 81 MCM for the hydrological year 2012 (Abdelmalek et al. 2017). Yates et al. used WEAP to analyze a climate-driven water resource model of California's Sacramento River Basin and reported that the model is useful for many California water planning processes. The results displayed that the model can reproduce both local and regional water balances to track water balance changes in terms of both magnitude and seasonality in heavily managed watersheds (Yates et al. 2009). In a different study, Vicuña et al. applied WEAP to investigate the outcome of temperature and precipitation on surface hydrology, performance of water infrastructure, and irrigation coverage in the Limarí basin (Vicuña et al. 2012). Höllermann et al. used WEAP to analyze Benin's future water situation under different scenarios of socio-economic development and climate change (Höllermann et al. 2010). For additional information on WEAP model usage, see selected applications for WEAP model on the website (SEI 2014).

Despite the numerous applications of WEAP model in different parts of the world, studies analyzing water demand and supply strategies in Ethiopia are still limited. Therefore, the overall purpose of this study is to explore scenarios for water supply and demand of Addis Ababa city that supports the realization of SDG6. Thus, this study will serve as a basis for other future studies on water management that will be conducted in the city and other towns of Ethiopia as well as other developing countries. The result of the model can be used to inform urban water management especially water sector professionals, and other concerned bodies. The water modelling tools are cost effective and are also used to predict the future water scenarios and its implications. So, study on sustainable use of drinking water resources is needed to help in conserving resources and minimizing the ground water extraction. Therefore, there is a need for integrated water planning management study to support the use of water resource in a sustainable manner.

The remainder of this paper is structured as follows. "Features of Addis Ababa city water sector" section discusses the specific feature of Addis Ababa city water sector. "Methods" section explains the research methods used in the study which incorporates the WEAP model structure, input data and scenarios development. "Results and discussion" section presents the results and discussions as well as further research areas, whereas the conclusions from the study are stated in "Conclusions" section.

Features of Addis Ababa city water sector

In this section, we review the current water scenario of Addis Ababa in order to understand the basis and methodologies for our water demand projection. Water need of the city of Addis Ababa has progressively been increasing from time to time. One of the main objectives of the AAWSA has been to provide/supply adequate and safe drinking water for the capital city by increasing deep wells water supply and combining it with the surface water sources. However, almost all of the surface water sources are located on special zone of Oromia regional administrative state. The demand for water originates from four main sources, specifically, agriculture, production of energy, industrial uses and human consumption. The research report of David and Upali concluded that the increase in demand for water by the year 2025 can be met by small dams and conjunctive use of aquifers, and medium and large dams will almost certainly be needed (David and Upali 2014).

The main water supply requirement of Addis Ababa city is giving its service commonly for domestic purpose, non-domestic purpose, and public fountain. Domestic purpose customers are mostly those that are registered as private users, whereas non-domestic customers are those registered as large-scale and small-scale industries, organization, and other hotels, and finally public fountain customers are people who use the service as a group most commonly known as users of bono/one pipe served for many people. The capital city of the country (Addis Ababa), has always suffered from serious water shortage problems and thus to overcome this problem, the city water supply and sewerage authority has been making effort to pursue this difficulty. Addis Ababa Water and Sewerage Authority (AAWSA) through its Water Supply and Sanitation Development and Rehabilitation Project Office different contract agreements are conducted. As per the contract agreement between AAWSA and WWDSE, many wells were drilled and the location of bore holes completed and under progress are in Legadadi, Legatafo, and Ayat ground water prospective sites (WWDSE 2011).

The need for proper water supply system for the city has been recognized by the Addis Ababa city administration & Addis Ababa water and sewerage authority, as one of the major factors affecting the public health and socioeconomic development of urban communities. Nevertheless, the water demand of the city is still unsolved and needs different water evaluation and planning system. This will help to use the supplied water wisely and efficiently apart from increasing the number of drilled ground water sources in order to preserve the ground water aquafers and to minimize the expensive drilling costs.

Methods

Assumptions

In this paper, the WEAP model is applied to modelling of water supply and water demand for sustainable water resource management for the capital city of Addis Ababa (Ethiopia) for the design period of 2015 to 2030. Water modelling and scenario analysis are the best methods for water evaluation and planning system analysis. Efficient and sustainable use of water resources is useful in addressing the problem of access to clean water supply especially for the low-income peoples and school children in the city as well as to ensure the population in the city gets an adequate and reliable supply of water for a long period of time.

Study area

Addis Ababa city is geographically located at longitude of 38° 44′ E and latitude of 9° 1′ N. The AAWSA in Ethiopia is a public institution in the city, which is responsible for the supply of potable water. Currently, Addis Ababa gets its water supply from both surface water and ground water sources. Hence, the city water supply sources will be categorized into four clusters based on the type of water resources and geographical locations. The first cluster is Gefersa Dam-I/II which has a conventional treatment plant that is located 18 km west of Addis Ababa and initially constructed in 1943. Later, in 1996, Gefersa Dam-III was constructed to serve as silt trap and additional water storage for the main dam (Gefersa Dam-I/II) and it is located around 800 m up stream of Gefersa Dam-I/II. The second cluster is Legedadi surface water subsystem which comprised both Legedadi and Dire Dams which has a conventional treatment plant and located 25 km east of Addis Ababa. The third cluster is Akaki ground water sources which is within and near Addis Ababa and the final cluster is the spring water sources located at the foot of Entoto Mountain. Figure 1 shows the map of the study area.

The WEAP model structure

WEAP is a scenario-based water evaluation and planning system modelling tool developed by Stockholm Environmental Institute (2019). The WEAP model simulates water scenarios with several segments and it is user-friendly and cost-effective. The WEAP approach works on the basic principle of a water balance. Water Evaluation and Planning system and the data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the

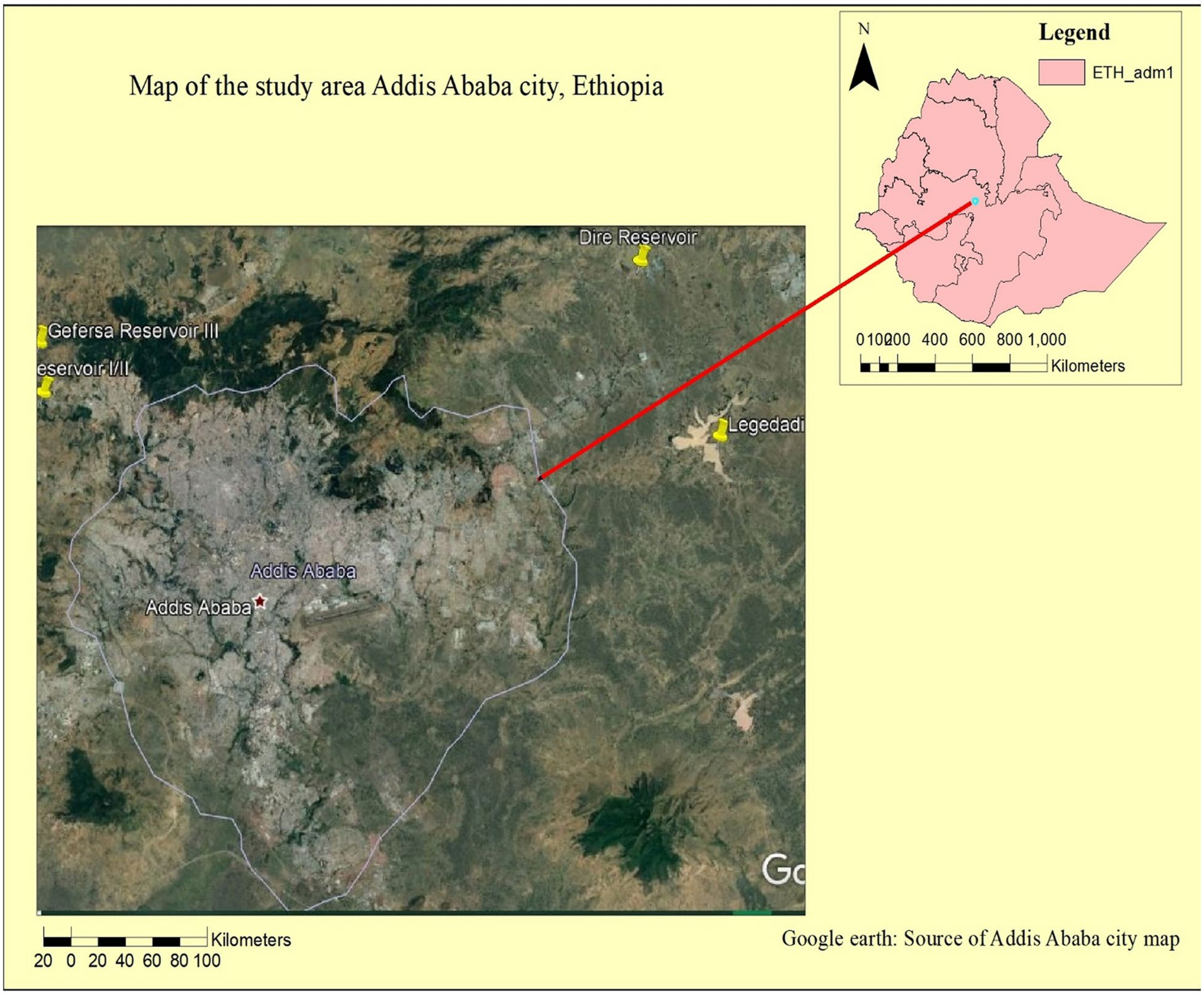

Fig. 1 Map of the study area Addis Ababa city, Ethiopia

limits imposed by restricted data. The Current Accounts, which can be viewed as a calibration step in the development of an application, provide a snapshot of actual water demand, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent factors that affect demand, pollution, supply and hydrology. Scenarios build on the Current Accounts can allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (WEAP 2016).

WEAP is structured as a set of five different "views" onto the software area which is called Schematic, Data, Results, Scenario Explorer, and Notes. The Schematic View is the starting point for all activities in WEAP. In the Data View, the screen is divided into four panes. On the top left, a hierarchical tree is used to create and organize data structures under six major categories: Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Environment, and Other Assumptions. The Results View displays a wide variety of charts and tables covering each aspect of the system such as demand, supply, costs, and environmental loadings. The Scenario Explorer View is used to group together "Favorite" charts (created earlier in the "Results" view) into "Overviews" for simultaneous display. Finally, the Notes View is a simple word processing tool with which we can enter documentation and references for each branch of the tree (SEI 2011).

A demand site's (DS) demand for water is calculated as the sum of the demands for all the demand site's bottom-level branches (Br). A bottom-level branch is one that has no branches below it.

$$\text{Total demand} = \text{Total activity level} \times \text{water use rate} \quad (1)$$

$$\text{Annual demand}_{\text{DS}} = \text{Sum}\big(\text{Total activity level}_{\text{Br}'} \times \text{water use rate}_{\text{Br}'} \times \cdots\big) \quad (2)$$

The total activity level for a bottom-level branch is the product of the activity levels in 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.).

$$\text{Total activity level}_{\text{Br}} = \text{Activity level}_{\text{Br}} \times \text{activity level}_{\text{Br}'} \times \text{activity level}_{\text{Br}''} \times \cdots \quad (3)$$

All the above Calculation Algorithms were collected and referenced from WEAP software (WEAP 2017).

Input parameters and data collection

The study was conducted through institutional integration/supports since this modelling of water supply and water demand needs different institutional data as input for the software. The design period for this study was simulated between the year 2015 and 2030. For that, past climatic data such as precipitation, relative humidity, sunshine duration, evaporation, maximum temperature, and minimum temperature were obtained from the NMA. Observed domestic and non-domestic water demand data plus other supportive documents were collected from AAWSA. In addition to this, the population census data for Addis Ababa city are attained from the CSA, and also, the United Nations Medium Variant Population projection is considered for the population growth of Ethiopia and this was used for calculating and estimating the population growth of Addis Ababa. The overall research data for this study were collected based on primary and secondary data sources to address the goals of the study.

Data analysis tools

The WEAP software was used to study the modelling of water supply and water demand by using different institutional data sources for predicting the future water scenarios and its implications. The Population projections and their integration graph was analyzed with Microsoft Excel. SPI Generator software and Microsoft excel was used for the analysis of Standard Precipitation Index (SPI). SPI was used long time historic climatic data (i.e. precipitation) for the characterization of hydrological water year method. In this study spi12 was used and spi12 refers to spi with a time scale of 12 month.

Population trend and non-revenue water

The population of Addis Ababa in 2015 was around 3.65 million and the population projection has been estimated to grow nearly to 4.58 million persons by 2025 and 5.06 million persons by 2030. However, as indicated in Table 1, the population growth of Addis Ababa city increases from year to year (CSA 1984, 1994, 2007). The population projection graph was used during the formulation of the scenario in the WEAP software as well as the total population for the year 2015 were used as a current account. The water sector of the city integration with the support of Consultancy Service for NRWR reported that the non-revenue water in Addis Ababa is between the range of 34.43% and 39.98% (Consultancy Service for NRWR 1997).

Scenarios development

In this study, our scenarios refer to a series of assumptions or storylines depicting how the future of Addis Ababa water system might unfold. The future water demand of the city is affected by different factors such as population growth, family income, urbanization, living standard etc. The values of these factors are diverse according to the scenario configuration. Different assumptions are needed to test the effects of these factors. Hence, scenario analysis is used in this study to explore the water supply and demand of Addis Ababa city to support the water sustainability goal. In doing the same, four clusters of scenarios are developed, namely:

Table 1 Performance indicator of population trend

Year	NRW (%)	Total population		Remark
		Ethiopia	Addis Ababa	
1984		40,378,624	1423182	Population census 1984
1994		52,743,917	2,112,737	Population census 1994
2007		73,750,932	2,739,551	Population census 2007
2012		84,320,987	3,041,002	Projection ICP 2012
2015	34.43–39.98 (for AA)	99,873,000	3,652,141	Projection from graph

Reference, External Driven Factor, Water Management, and Future Predicted scenarios.

Reference (Ref) scenario

This is the basic task in establishing scenarios for future water demand and supply and it is sometimes referred to as the business-as-usual scenario. In this case, all key assumption and other factors are assumed to remain the same as in the base year while socioeconomic and demographic factors are assumed to grow at the official projected rate. This scenario also serves as the benchmark for comparing the outcome of other scenarios.

External driven factor scenarios

Saraswat et al. argued that external factors will increase the pressure on the current water supply system and exacerbate the water scarcity situation (Saraswat et al. 2017). Therefore, to predict the effect of external factors on water demand, different assumptions are considered as indicated below:

High population growth (HPG) From the population projection result, we assume that the total population growth rate will be increasing by 4.5% annually.

Medium population growth (MPG) For this medium population growth rate, around 2.5% annual growth rate is used and this is expected and selected based on the consideration of high and low population growth rate.

Low population growth (LPG) Here, we assume the lowest population growth rate by comparing from other expected population growth rate during this study and thus the annual population growth rate is taken as 1.5%.

High living standard (HLS) As the standard of living increases, it is expected that the household demand for water will also increase. Here, we assume that the rate of water use is the only factor to be considered for high living standard. For this study, 150 LPD is taken.

High population growth + high living standard (HPG + HLS) Like the above external driven factors, the high population growth rate is assumed as 4.5% and the high living standard is also assumed as 150 LPD.

Water management scenarios

The purpose of integration of different kind of management strategies is to discover the ideal solution for achieving water security in the region (Saraswat et al. 2017). Thus, different strategies are identified in achieving the water demand of the city and can be summarized as follows:

Demand side management-sustainable water resource and reuse (DSM-SWSR) The water use practice is different for all the consumers and here we assume and expect that all the consumers (i.e. domestic and nondomestic) are applying good water management strategies such as recycle, reuse, and use less water in day-to-day activities.

Supply side management and non-revenue water reduction (SSM-NRW) The water supply sector faces many challenges such as the geographic set up of the city, the old pipe lines, power interruption, linkages etc. Here, we assume that the water sector applies different technologies and changes the old pipe lines by the new one in order to reduce the NRW reduction by different percentages.

Integrated management strategies (IMS) Here, we assume that the government starts to minimize the non-revenue water and incorporates the practice of demand side management strategies by creating awareness programs. However, the result of integrated management strategies begins from the combination of the two management strategies, i.e., supply side management and NRW reduction by water sector professionals or by the supplier and the other is the demand side management strategies which is sustainable water resource and reuse by the water consumers.

Future predicted scenarios

Here, we attempt to build futures which combines the external factors and water management strategies to see how the true picture of water demand in Addis Ababa might unfold in the future. According to the analysis of different scenarios and combination of other management options, in this study, three possible cases were considered and they are explained below:

Pessimistic future (PF) In this scenario, the different factors were assumed to be changing through time based on 'what if' condition or question. For this scenario, different factors are considered and can be summarized as follows:

- 50% of NRW and we assume that there is no any measure taken to reduce the NRW.
- 2% sustainable water sources including reuse rate.
- 4.5% population growth rate estimation.

Moderate future (MS) This scenario is design based on moderate future predictions to consider different strategies based on 'what if' condition. We assume sustainable water use and reuse as well as supply side measure like NRW practices in such a way that the percentage change is medium; it is above the reference scenario and below the assumptions of the optimistic future. For this scenario, different factors are considered and can be summarized as follows:

- 29% of non-revenue water and here we undertaken that if ten percent of the nonrevenue water is reduced from the total estimated nonrevenue water.
- 7% Sustainable water sources including reuse rate.
- 2% population growth rate here we are considering the nearest medium population growth rate.

Optimistic future (OF) The scenario is formulated by considering different strategies such as supply and demand side measures and population growth control. For this scenario, different factors are considered and can be summarized as follows:

- 10% of NRW and 30% of the nonrevenue water reduction takes place by the supply management strategies.
- 15% sustainable water sources including reuse rate and the demand side management strategies are applied.
- 1.5% population growth rate estimation.

The overall methodological framework used in this study is shown in Fig. 2.

Results and discussion

Reference scenario

Current account and reference scenarios were assigned first before other scenarios were considered to achieve the scenario simulation and data analysis. The current accounts represent the basic definition of the water system as it currently exists, and the reference exemplifies business-as-usual scenario. The Ref scenario projection depicts a situation in which there is no improvement in water supply and demand infrastructures with respect to the base year. Figure 3 shows the simulation results of the Ref scenario. Driven by rapid population growth and urbanization, the unmet water demand of Addis Ababa is expected to grow from 208 MCM in 2015 to about 307 MCM in 2030. This result corresponds to about 48% increase in unmet water demand in the city within 15 years. The alarming increase of unmet water demand in the city therefore calls on the government to develop practical strategies to avert water crisis in the future. It is not easy to compare our results with other findings owing to the limited studies in this area for Addis Ababa. However, our analysis of the model results shows that there are significant differences in unmet water demand between current study and the work of Arsiso et al., who have attempted to use WEAP to investigate water demand and supply prospects for the City of Addis Ababa. The study developed scenarios of population growth trends and climate change (i.e. RCP 8.5 scenario and RCP 4.5 scenario) up to 2039 by applying the WEAP model. The variation in our results is because of difference in number of years and assumptions used in the two studies (Arsiso et al. 2017). Other studies showed that the result of some scenario studies were mostly different from the current account. According to Shahraki et al., unmet demand compared to the current account increased from 193 to 200 million cubic meters, respectively (Shahraki et al. 2016).

External driven factor scenarios results

Figure 4 reports the projections of unmet water demand for the external driven factor scenarios. The result indicates that the projected population of Addis Ababa city using low population growth rate (1.5%) and high population growth rate (4.5%) will be about 4.57 and 7.07 million people respectively by 2030. The total unmet water demand by 2030 for the HPGR + HLS scenarios would grow to 583 MCM; this represents about 90% increase in comparison to the Ref case. However, considering only living standard; as incomes grow and the household water requirements increase, the unmet water demand of Addis Ababa in HLS scenario is expected to grow to around 410 MCM by 2030; indicating about 34% increase when compared with the Ref scenario. In the HPG scenario, a high population growth rate is assumed and the unmet water demand is seen to grow to 440 MCM by 2030. This value corresponds to 43% increase in comparison to the Ref scenario. Another study indicated that increasing number of population affects the water demand of the city. As Zhang et al. study revealed that the higher population growth rate is especially due to migration and results in an increased pressure for land and water resources (Zhang et al. 2008). Finally, analysis of the LPG scenario where a low population growth rate was assumed showed that unmet water demand will reach 274 MCM by 2030. In comparison with the Ref case, this value suggests a decrease of 11%. Considering the entire external driven factor scenarios, it can be observed that an increase in population growth rate coupled with an increase in living standards will create water crisis for the city in the future. Thus, proactive steps need to be taken to avert this situation.

Water management scenario results

Figure 5 depicts the results of the water management scenarios. Analysis of DSM-SWSR scenario indicates that with the effective implementation of different management strategies at the demand side, unmet water demand will grow to 262 MCM by 2030. This value is about 15% decrease when compared with the Ref scenario. In the SSM-NRW scenario, it was assumed that measures were taken at the supply side to improve the efficiency of water supply system in the city. Consequently, analysis of this

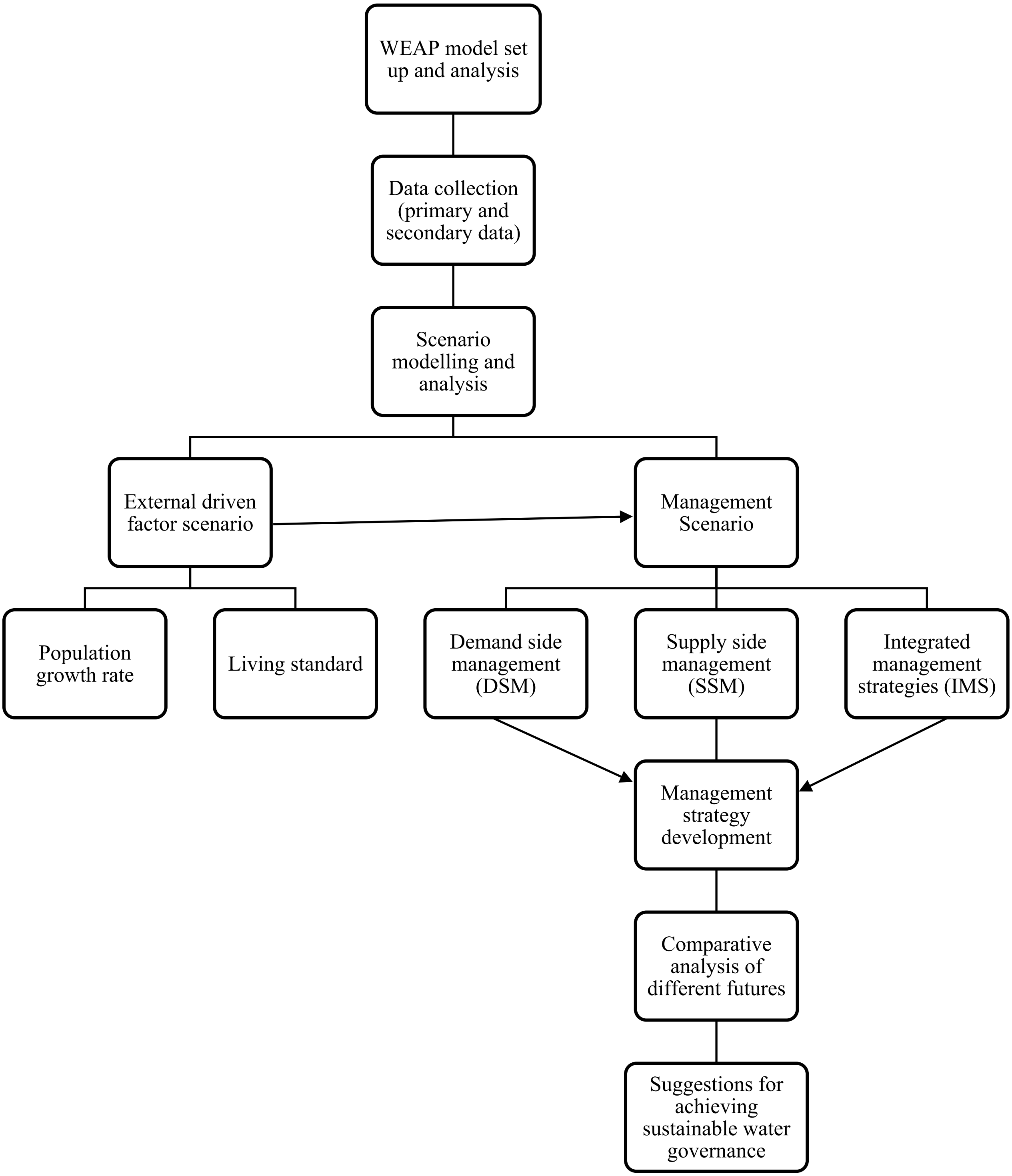

Fig. 2 General study framework

scenario shows that unmet water demand will reach 227 MCM by 2030, which represents about 26% reduction in unmet water demand with respect to the Ref case. Finally, in the IMS scenario, it was assumed that measures were taken at both the demand and supply side to improve the efficiency of water in the entire chain. Consequently,

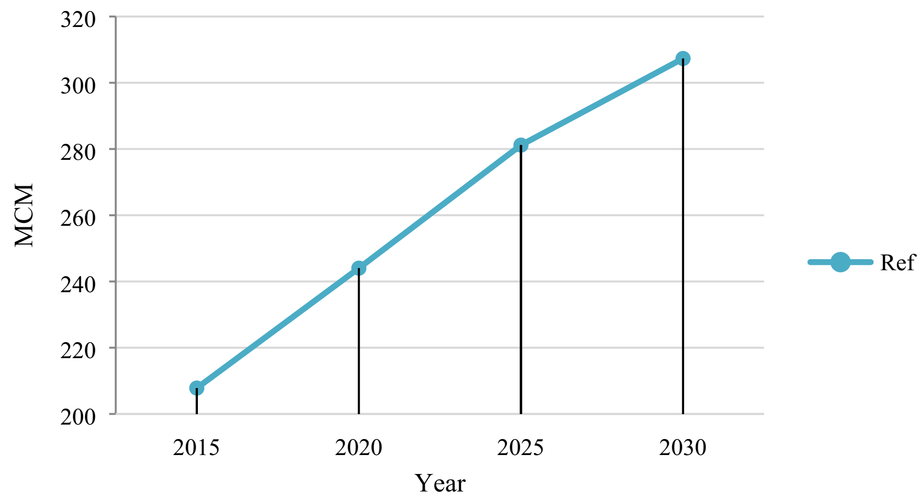

Fig. 3 Reference scenario of unmet water demand in Addis Ababa city

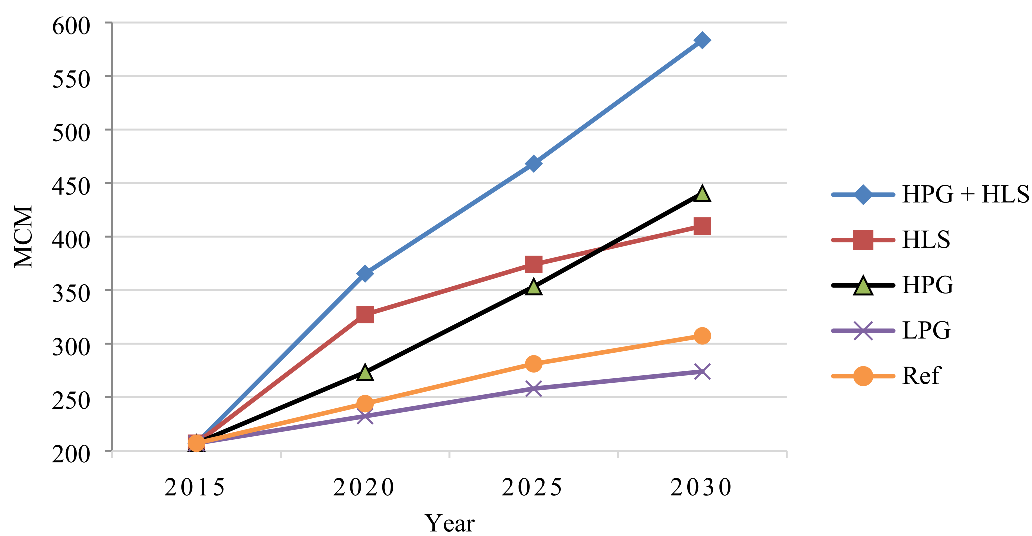

Fig. 4 Unmet demand for reference and external driven factor scenarios

analysis of this integrated approach suggests that unmet water demand will reach 215 MCM by 2030 or 30% reduction in comparison to the Ref scenario. From the foregoing results, it is clear that an integrated approach is needed to reduce the unmet water demand of the city. Thus, the unmet water demand of the city will be minimized most in the IMS scenario and this will support the achievement of SDG6. Other studies showed that integrated management strategies saves more water than individual management approaches. Hence, Kou et al. study stated that industry restructuring (structural water-saving scenario) and advanced water-saving technology (technical water-saving scenario) can result in water saving potentials of 6.97% and 9.82% by 2050, respectively, while adopting both strategies (double water-saving scenario) can save 16.44% (Kou et al. 2018).

Future predicted scenario results

According to the analysis of different scenario and combination of other management options during this study, three possible cases for future water scenarios were considered (i.e. Optimistic, Moderate, and Pessimistic futures). Figure 6 presents the results of the future predicted scenarios. Based on the listed evaluation, future

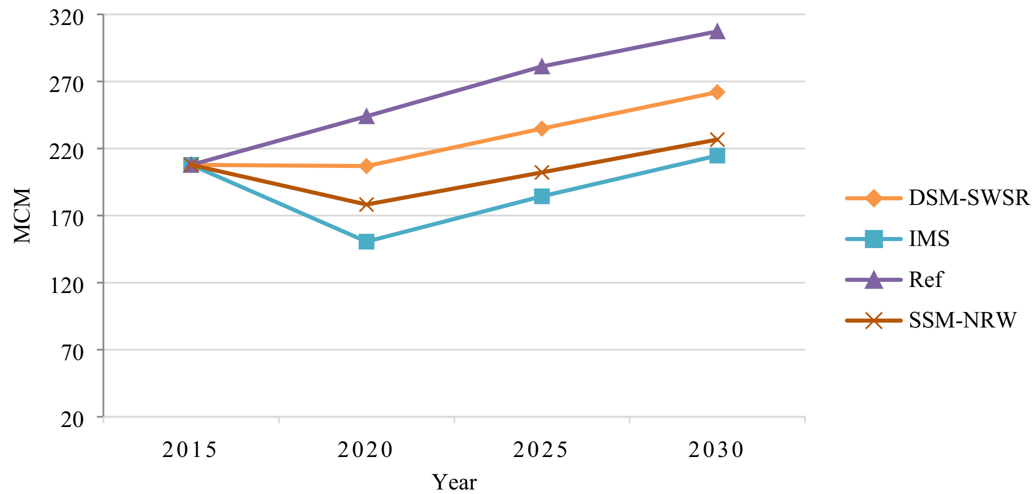

Fig. 5 Unmet demand for management and reference

predicted scenario analysis and their comparative analysis with the reference scenario indicates that unmet water demand in the PF scenario will reach 728 MCM by 2030—over 130% increase compared to the Ref scenario. But, in the MF scenario, unmet water demand is expected to reach 283 MCM by 2030; about 8% reduction in comparison to the Ref scenario. On the other hand, the unmet water demand for the OF scenario grows to 164 MCM or 47% reduction in unmet water demand relative to the Ref case. This significant unmet demand reduction in OF scenario is because of the supply and demand side management improvement in in terms of percentage reduction of NRW by supply side and water reuse and recycle practice by the demand side management which in turn, reduce the amount of water wastage and increasing awareness in use of the water efficiently. Thus, from the analyzed scenarios, optimistic future strategies will support the management of the existing water supply and demand system of the city and it will also contribute to the realization of SDG6.

This study is not without limitations. The socio-economic and demographic assumptions used in this study are based on historical and official projections. However, these projections are uncertain and

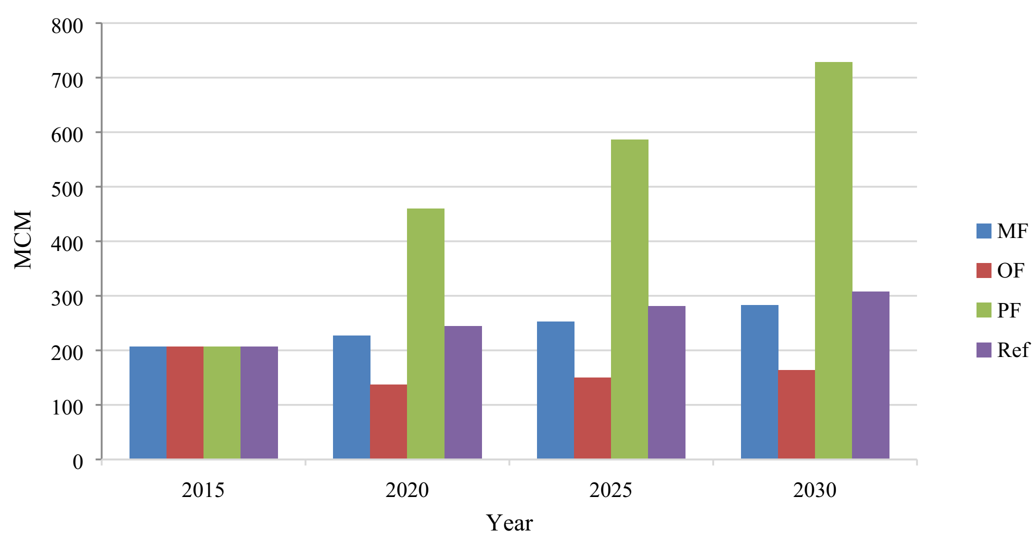

Fig. 6 Unmet demand for future predicted scenarios

may influence the results in long term perspectives. It is worthwhile to mention that factors like private ground water sources and water prices may affect water demand. Additionally, sedimentation and loss to ground water inside the reservoir may affect the amount of water supply. However, we did not consider these latent issues in this paper. While drawing on these limitations, it is believed that this study will go a long way to inform decision makers about the challenges and opportunities facing the country towards realizing SDG6. For future research, socioeconomic study is needed to evaluate the scenario when the price of water is changing over time as well as the investigation and acceptance of price and non-price policy. Further study could also consider private ground water sources and other non-counting water sources.

Consequently, the current study has a set of implications for the ordinary Ethiopians and the government. As can be seen in the external driven factors, increase in population and living standard will reduce water security in the country. Thus, there is a need for better synergy between the two desirable's goals of water security and improved standard of living. At the demand side, households need to start incorporating best practices for water management. These practices include metering/measurement, replacing restroom fixtures with improved features such as sensors and low flow rate, rain water recovery among others. While these practices will improve water management, acquiring them will incur huge financial burden on the households given the current socioeconomic condition of the country. Thus, government need to provide targeted subsidies for these water smart appliances. At the supply side, government need to refurbish the infrastructures of the utility companies. This can be done by repairing the broken water pipelines, quick detection of leakages, distribution system audit and general maintenance of the water supply machines. Additionally, there will be need for massive awareness/campaign programs on different strategies to improve water security in the country. This can also be achieved via mainstream and social media. Other strategies in which the government can consider is to implement policies that will curtail population growth in the country. However, this will be very difficult to be implemented in a country like Ethiopia, where birth rate is also influenced by cultural and religious factors.

Conclusions

The study has used the WEAP model to explore different future strategies for improving water security in Addis Ababa, Ethiopia. The study considered different cluster of scenarios which encompasses external driven factors, water management options, and future predicted scenarios (i.e., a combination of the external driven factors and water management strategies). An increase in population growth and living standard will reduce the water security in the city and vice versa. However, the water management scenarios indicate that strategies such as recycling, reuse, better piping etc. can boost water security in the country. In fact, the study further suggests that low population growth rate combined with better demand and supply side management techniques will further boost the city's water security as confirmed in the OF scenario of the Predicted Future scenarios cluster. Thus, to improve water security and achieve the SDG6 in Ethiopia will require the adoption of the strategies embedded in the OF scenario. In terms of policy options, government need to renovate and expand the infrastructures of the water utilities as well as provide targeted subsidies for households who cannot afford efficient potable water supply.

Abbreviations

AAWSA: Addis Ababa Water and Sewerage Authority; CSA: Central Statistical Agency; DSM SWSR: Demand Side Management Sustainable Water Sources and Reuse; EPHI: Ethiopian Public Health Institute; HLS: High living standard; HPG: High population growth; ICP: Inter census projection; IMS: Integrated Management Strategy; LPD: Litters per day; LPG: Low population growth; MCM: Million cubic meter; MF: Moderate future; NMA: National Meteorological Agencies; NRW: Nonrevenue water; NRWR: Nonrevenue water reduction; OF: Optimistic future; OHCHR: Office of the High Commissioner for Human Rights; OSF: Open Society Foundation; PF: Pessimistic future; Ref: Reference; SDG6: Sustainable Development Goal number six; SEI: Stockholm Environment Institute; SPI: Standard Precipitation Index; SSM NRW: Supply Side Management Nonrevenue Water; UNICEF: United Nations International Children's Emergency Fund; WEAP: Water Evaluation and Planning; WFFC: World Fit for Children; WHO: World Health Organization; WWDSE: Water Works Design and Supervision Enterprise.

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Authors' contributions

ZA performed the data entry in WEAP, statistical analysis of results, data interpretation and writing the manuscript. MO performed the study design and helped to draft and edit the manuscript. Both authors read and approved the final manuscript.

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