URBAN WATER SUPPLY AND DEMAND ASSESSMENT UNDER SOCIOECONOMIC SITUATION OF CHANCHO TOWN, CENTRAL ETHIOPIA, USING WEAP MODEL

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ABSTRACT

Urban water supply and requirements evaluation is crucial for long-term management, particularly in quickly rising regions of developing countries such as Ethiopia. This article addresses the issue of urban water supply and demand under socioeconomic stress in Chancho town, Ethiopia, while highlighting potential solutions. The WEAP (Water Evaluation and Planning) model was used in the study to investigate the town's demand and supply of water trends and provide solutions for this issue in relevant regions around the world. The rainfall discharge and climate data were collected on a monthly basis for model calibration and scenario development in WEAP. The findings show that the current annual water supply of 1.53 million cubic meters meets only 51% of the total demand. Over the next 15 years, rising population and urbanization will push total annual demand from 65 to 78 million cubic meters. Additionally, the climate change scenario is expected to reduce groundwater availability by 1.68 million cubic meters annually. Supply-side management scenarios suggest that integrating surface and groundwater sources for industrial and livestock use improves water supply reliability and reduces pressure on individual sources. This strategy ensures sustainable water use, supporting both the growing population and key economic sectors. The study concluded that increased water demand under socioeconomic stress requires strategic planning and resource allocation in developing countries with limited water resources.

Keywords: *Water supply; Socioeconomic factors; Water demand; WEAP model; Urbanization; Ethiopia.*

1. INTRODUCTION

As the universal population grows and urbanization increases globally, the demand for urban water is rising (Rathnayaka et al., 2016). Currently, almost 50% of people on the globe have moved to cities (Bach *et al.*, 2014). This urban growth puts strain on urban infrastructure and service delivery and has forced governments and other organizations to come up with novel adaptation strategies. Urbanization growth contributes to climate change, which has an impact on municipal water supply systems (Herslund and Mguni, 2019). Developing countries are experiencing significant and fast urbanization, which is increasing demand for urban services, particularly those related to water supply (Panwar and Antil, 2015). Many studies show that there is limited access to water supply in numerous urban areas as a result of the significant population growth. Researchers projected that the rapid urbanization scenario will continuously threaten resource sustainability due to the exploitation of natural resources (Rufino et al., 2018; Voda et al., 2019). Water scarcity is defined as the inability to provide adequate resources of clean water to satisfy needs (Tzanakakis, Paranychianakis and Angelakis, 2020). Urban growth also reshapes the hydrologic response at city scale, with altered runoff pathways and increased surface-runoff volumes documented in long-term urban case studies (Haidu & Ivan, 2016).

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Socioeconomic shifts, such as population growth and rising living standards, are expected to cause inadequate water supply and raise water demand (Rathnayaka et al., 2016, Berredjem, et al., 2023, Tufa et al., 2024). Improper geographical population distribution and poor river basins management are also additional main drivers of the urban water supply issue (Madani, 2014, Voda et al., 2018; He et al., 2021). The demand for water resources is rising due to a multitude of factors, including population growth, urbanization, industry, climate change, tourism, and navigation(Mensah et al., 2022; Wang et al., 2021; Haque et al., 2015).

Ethiopia, a country situated in the Horn of Africa, has been grappling with significant urban water challenges that have profound implications for the well-being and development of its rapidly growing cities (Assefa *et al.*, 2018). Despite the abundance of water resources, with 12 river basins and an estimated 2.6-6.5 billion m^3 of groundwater, the distribution and availability of water are not satisfactory within time and space, leading to the country being considered highly water-scarce(Ali, M., and Terfa, 2012, Kedir, 2023). Several studies on urban areas in Ethiopia indicate significant water shortages across these regions. According to Beker B.K. and Kansal M.L.'s study, one of the primary challenges facing Ethiopia's urban centers is the inadequate provision of water supply infra-structure and services (Assefa et al., 2018, Beker and Kansal, 2024). Poor water quality and low coverage levels are Ethiopia's two main water issues (Arsiso et al., 2017). Population density, accessibility, topography, precipitation, and socioeconomic factors can all lead to an unequal distribution of water in Ethiopia’s urban area (Ali, M., and Terfa, 2012). Several studies on urban areas in Ethiopia indicate significant water shortages across these regions.

Chancho is a rapidly expanding town with high population growth and urbanization. Like other urban areas in Ethiopia facing water shortages, Chancho town encounters significant challenges in meeting the water supply needs of its expanding population. Therefore, in-depth assessment of the town's water supply and consumption circumstances, examining the factors contributing to shortages and identifying potential strategies to address the growing demand was performed. Various socioeconomic aspects, including expansion of the population, water consumption rates, urbanization, livestock reproduction water use, and climate variation are taken consideration in the study.

There are several tools for modelling water, including SWAT and MODFLOW. MODFLOW is perfect for analyzing aquifer dynamics and simulating recharge, extraction, and surface water interactions because it specializes in groundwater flow modelling. But its main focus is groundwater, and it doesn't integrate socioeconomic aspects or urban water demand very well. It also requires a lot of setup and calibration skill (Harbaugh and McDonald, 1996). SWAT is an excellent tool for long-term hydrological modelling, especially when evaluating the effects of agricultural activities, land use, and climate change. It can be data-intensive to set up, and while it is reliable for assessing water quality and sediment transport at the watershed scale, it is less successful when addressing urban water supply and demand (Douglas-Mankin et al., 2014). However, researchers have used the Water Evaluation and Planning (WEAP) model to assess the dynamics of water supply and demand in the study area in order to address the water demand challenges. The WEAP model is the most popular of the software that has been utilized significantly in various parts of the world. WEAP is a more recent and advanced approach, particularly well-suited for integrated modeling, scenario analysis, and addressing urban water demand (Purkey et al., 2018). The model was used by means of the decision support system (DSS) tool for water supply resource management in different regions (Saketa, 2022). WEAP allows different stakeholders to input their data, assumptions, and preferences, facilitating collaboration and consensus-building in water management (Al-Mukhtar and Mutar, 2021). However, the main drawback of WEAP is its dependence on reliable data sources, which can be challenging to obtain in areas with limited data availability (Al-Shutayri and Al-Juaidi, 2019). Despite this, researchers in Ethiopia rarely utilize the WEAP model to estimate urban water supply and demand. This study assesses the water supply and demand in Chancho town central Ethiopia. Previously, no studies have been conducted in the area relevant to this study issue.

In view of this, this study's primary objective is to use the WEAP model in a specific area, Chancho Town, Ethiopia to evaluate and simulate urban water availability and demand in order to accurately and effectively allocate the town's water resources. The research will highlight the main issues with this specific area's freshwater availability and demand and provide evidence-based suggestions for efficient management. Furthermore, the findings will serve as a valuable reference for other regions worldwide facing similar water-related challenges.

2. STUDY AREA

The Chancho town is located in Ethiopia's North Shewa Zone of the Oromia Regional State, in the country's center region and close to the capital, Addis Ababa (**Fig. 1**). It is found 40 kilometers north of Addis Ababa on the Gojam road. In Ethiopian history, Chancho town was established in the nineteenth century. There are currently about 98900 people living in the town, which has a total land area of 4,277 hectares, of which 88.37% is flat, 10.29% is mountainous, and 1.34% is valley. The region is situated at the crossroads of rural and urban development, and its strategic location drives rapid population growth and accelerated urbanization. Town's geographical coordinates are 38°42'55" - 39° 5' 39" East longitude and 9°15'45" - 9° 24' 4" North latitude. The elevation spans from 2,503 to 2,711 meters above sea level. The climate in the area is characterized by the short-wet season (March-May) and the lengthy rainy season (June-September), which is locally known as the Belg rains and Kiremt rains respectively. The average annual lowest record temperature for Chancho in August is 7.22°C and the highest in March 29°C degrees in a year. On aver-age, the region receives 995.63 mm of rainfall annually (**Fig 2).**

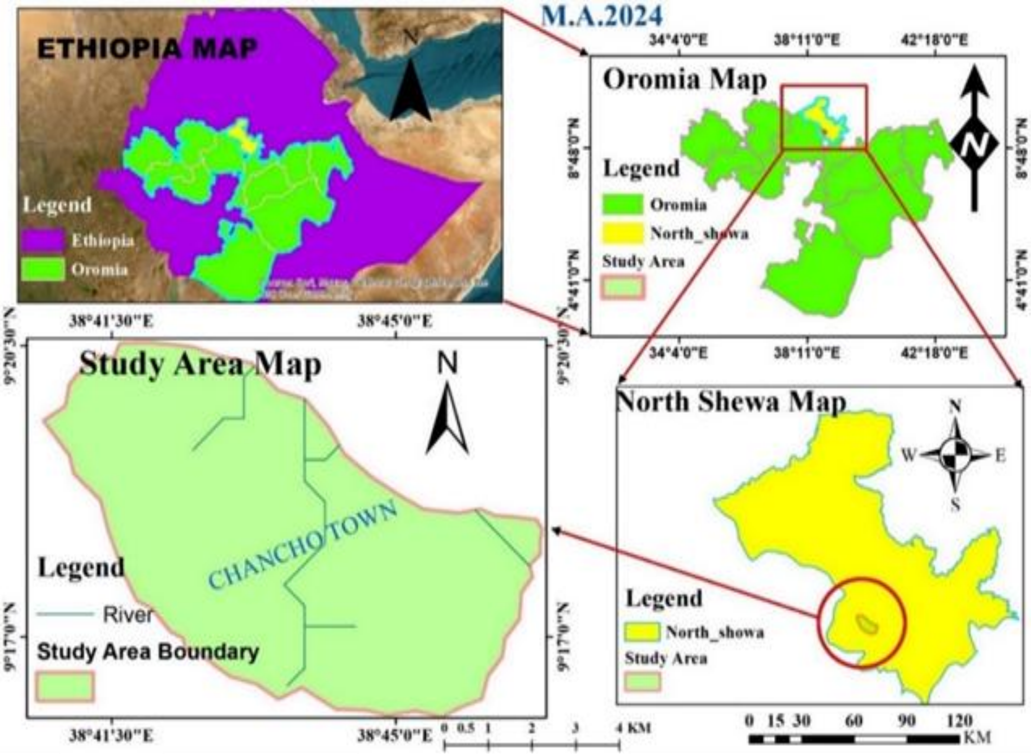

Fig. 1. Map of study area.

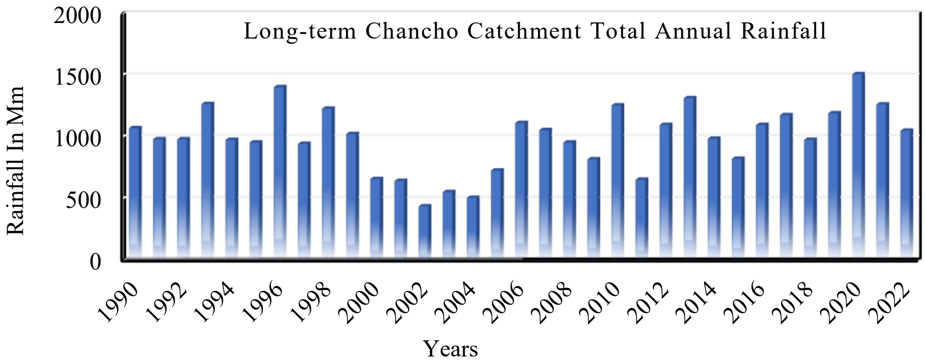

Fig. 2. Study area annual rainfall data.

2.1. Organizational Structure of the Town's Water Supply System.

The Chancho town water service office is administered under the North Shewa zone water board. The main participants in the water delivery system of Chancho town are depicted in the attached diagram. A local board was appointed by the regional water bureau to manage the utility office located in Chancho Town. As illustrated in **Fig. 3**, this utility office was founded in accordance with regional proclamation number 97/1997. The local board is responsible for managing, distributing, and supplying water for the community. It ensures the com-munity receives water services in an effective manner and manages the water infrastructure.

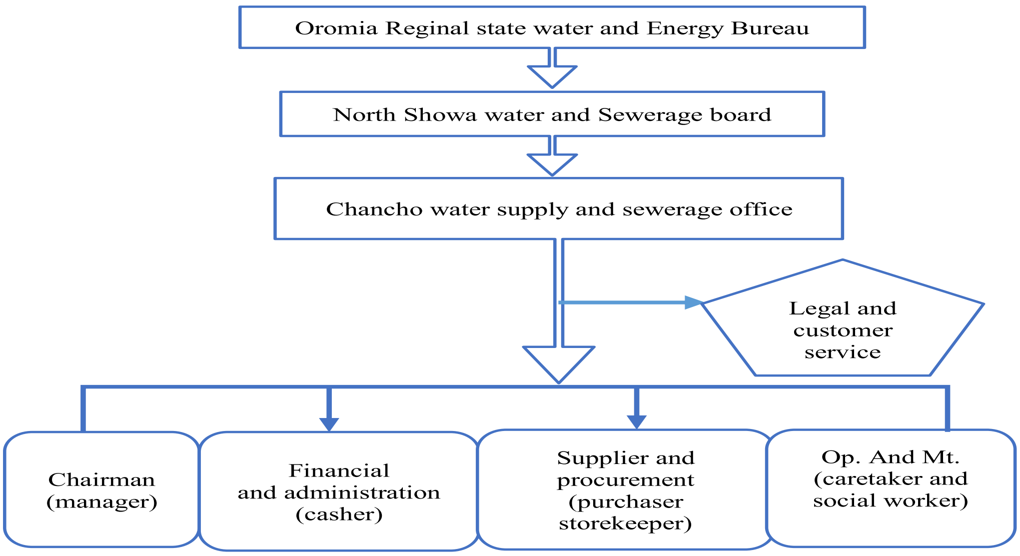

Fig. 3. The town's water utility service organizational structure.
Note: Op. is operation; Mt. is maintenance.

2.2. The Town's Current Water Supply Situation and Available Water Sources

Groundwater is the main source of water supply for the Chancho town. In 1986, the town's water supply system was first established when a borehole named Oche was drilled and connected to an elevated concrete tank (source: CHTWSS). The town's water supply currently depends on eight public boreholes, excluding those allocated for industrial use (**Table 1**). The municipality has a total of twelve boreholes, which include both publicly operated and privately-owned ones.

Table 1.
The town's public service boreholes description.

S/N	BH Name	Location			Depth (m)	working hour per day	current yield average (l/s)	daily production (Liter)
		X	Y	Z				
1	Arbi akako	38.461	9.1801	2621	88	16	1	57600
2	Oche	38.442	9.175	2552	90	16	3	172800
3	Gulele	38.445	9.182	2618	155	16	5	288000
4	Kore roba	38.46	9.1617	2585	220	16	2.5	144000
5	Lega sibilu	38.436	9.1731	2546	271	16	5	288000
6	Lega lencha	38.434	9.1721	2545	331	16	5	288000
7	Gaba robi	38.406	9.2111	2461	180	8	5	144000
8	Lega germama	38.455	9.1824	2621	500	16	12	691200
Total							38.5	2,073,600

Source: Chancho town water supply utility (CHTWSU).

These boreholes provide a mix of municipal and private water supply sources, contributing to the area's overall groundwater usage for residential, commercial, or industrial purposes. The data on borehole production was provided by the local water supply utility service, and measurements were made of the actual discharges. Knowing the borehole discharges in detail is essential to determining the monthly and annual water production of the town. Underground sources pump water out of boreholes, store it in a service reservoir, and then gravity-feed it to the customer's location. A specific formula was applied to calculate (Howard et al., 2020) the total working hours and actual discharges for each borehole in order to compute the daily, monthly, and annual water product:

$$\text{V.prod (in liters)} = \text{BH disc}\left(\frac{\text{L}}{\text{s}}\right) * \text{BH working time(s)} \quad (1)$$

where: Vprod is volume of production; BH is borehole; L is litter; S = second. Vprod was divided to 1,000 in order to determine the volume in cubic meters (because 1000 liters equal one cubic meter).

All government boreholes have a combined water production of 2,073.6 m3/day. To find out how much water is produced daily by all of the boreholes, the total volume produced (Vprod) can be calculated from liters into cubic meters. Key observation from the above table is that the most productive borehole is Lega Germama, which produces 691,200 liters per day at a rate of 12 liters per second for 16 hours per day. With a yield of 1 l/s, Arbi Akako produces the least amount of water each day, only 57.6 cubic meters. This is calculated by multiplying the yield by the total number of seconds in a day (86,400 seconds), resulting in 86,400 liters, which converts to 57.6 cubic meters. As a result, Arbi Akako contributes the smallest volume of water to the total supply in the study area. The limited production capacity of this borehole may result from its depth, constraints in the pumping or extraction equipment, or a combination of these factors.

Private boreholes collectively produce 2,937.6 cubic meters per day, which is significantly more than the 864 cubic meters produced by government-owned boreholes (**Table 2**). This higher yield from private boreholes is often due to factors such as advanced drilling techniques, better maintenance practices, and access to deeper or more productive aquifers. In contrast, government boreholes may face challenges such as limited funding, less frequent maintenance, or less optimal sitting, which can result in lower yields. The analysis revealed that the town's capacity to extract groundwater is reflected in the total borehole production, including both public and private boreholes, which amounts to 5,011.2 m³ per day, or approximately 1.83 million cubic meters annually.

Table 2.
Description of private boreholes in the town.

S/N	Private borehole	Location			Current yield average (l/s)	Daily production (Liter)
		longitude	latitude	elevation(m)		
1	Maya pp bag factory (BH-1)	38.45	9.17	2570	15	1296000
2	Abyssinia cement factory (BH-2)	38.43	9.18	2567	5	432000
3	Ethio cement (BH-3)	38.44	9.18	2552	4	345600
4	ELPA station (BH-4)	38.46	9.18	2637	10	864000
Total					**34**	**2,937,600**

Source: Chancho town business sector.

2.2.1. The Town's Existing Water Service Reservoir

This section provides an overview of the current water service reservoir in the town, detailing its capacity to meet the town's water supply needs. A reservoir's capacity is the greatest amount of water it can contain, typically measured in cubic meters (m^3), liters, or gallons. Larger reservoirs with higher capacities are better at satisfying long-term water demands, particularly during dry periods. In addition to their storage role, reservoirs can help manage the flow of water, guaranteeing a consistent and reliable supply throughout the year. To ensure an adequate supply of water and account for balancing purposes, it is recommended to have a minimum total reservoir storage capacity ranging from 30% to 50% of the average daily demand for small towns with stable water sources and minimal risk of disruption as stated in M0WR 2012 guidelines (Howard et al., 2020). In the study area, there are seven reservoirs with capacities of 500 m3, 300 m3, 200 m3, 100 m3, 50 m3, 50 m3, and 25 m3, resulting in a total reservoir capacity of 1225 m3.

Table 3 indicates that the R1 Gera Michael reservoir has the largest capacity, with a volume of 500 m^3. This means that R1 Gera Michael has the highest water storage capacity, allowing it to store more water than the other reservoirs. Such a large capacity is crucial for meeting water demand, particularly during dry periods or peak usage times, ensuring a consistent and reliable water supply to the surrounding area. Conversely, with a capacity of 25 m^3, R7 Geba Robi is the smallest reservoir. The calculated average daily demand, which is 8192 m3/day, need to be compared to the total reservoir storage capacity in order to determine whether it is adequate. In this case, this corresponds to a range of 2,457.6 m3 to 4,096 m3.

Table 3.
Existing reservoir in the town with their yield.

Reservoirs Name	Reservoir existing area	Distance from Center of town(km)	Location			Working hour (24)	Capacity (m^3)
			X	Y	Z		
R1	Gera Michael	2	38.46	9.17	2643	Daily	500
R2	Gera Michael	2	38.46	9.17	2644	>>	100
R3	Gera Buba	1.5	38.44	9.18	2692	>>	300
R4	Gera Michire	0.8	38.44	9.18	2618	>>	200
R5	Egzarab Church	0.3	38.45	9.18	2649	>>	50
R6	Kore Roba	3.5	38.45	9.16	2607	>>	50
R7	Geba Robi	7	38.41	9.20	2613	>>	25
Total							**1,225**

Source: Chancho town water supply utility (CHTWSU).

Based on the analysis, the current reservoirs in the study area clearly do not meet the specified minimum storage capacity requirements, highlighting a significant shortfall in the system's ability to ensure adequate water storage for safety and reliability. This shortcoming makes it difficult to maintain a regular water supply, especially during peak demand or unexpected events. To address this issue, constructing new reservoirs with sufficient storage capacity is essential. Expanding the storage infrastructure will not only enhance the system's resilience but also ensure that future water demands can be met effectively while safeguarding against potential shortages.

2.3. Population Projection

To estimate population growth, the geometrical increase approach, an exponential growth model, was applied. This method is particularly suitable for estimating population increases in rapidly expanding urban areas. Based on the base year population, the annual growth rate is projected at 3.4% growth rate **(Table 4**). This approach aims to reduce the uncertainty that often arises from inaccurate estimations.

$$Pt = P0 \times e^{r \times t} \quad (2)$$

where, pt = projected population at future time, po = base population, r = growth rate in percentage, t = number of years.

Table 4.

Population projection and growth rate.

Year	Initial population	Estimated population	Growth rate (%)
2019	57387	-	-
2023	-	98900	3.4

In 2002, Ethiopia's Statistical Service (CSS) collaborated with zonal and municipal governments to establish development offices aimed at improving local population assessments. For this study, population data from the Ethiopian Statistical Service and the Chancho town administration office were considered to project the population of Chancho town, given that its data was initially grouped with Sululta Woreda. This method allowed for a more accurate population estimate by referencing unique survey data specific to Chancho town.

2.4. Water Demand Projection

Water demand is the overall amount of water needed to satisfy the demands of different sectors, such as residential, commercial, institutional, and environmental usage. The formula for calculating a town's water demand depends on various factors such as population, per capita water consumption, and specific demand categories:

$$\begin{aligned} &Total\ Water\ Demand \\ &= (Population \times Per\ Capita\ Demand) + Industrial\ Demand + Institutional\ Demand \\ &+ Commercial\ Demand \end{aligned} \quad (3)$$

The population in the area is 98,900 people, with a per capita water demand of 60 liters per day. Industrial water demand accounts for 15% of the household demand, while commercial and institutional water demand represents 25% of the domestic demand. According to the investigation, the total quantity of water that is provided is around 1.83 million cubic meters per year, which is less than the present water demand of around 3.03 million cubic meters annually (as of 2023). This indicates a shortfall in water supply, suggesting that the existing water sources may not be sufficient to meet the demand, especially during peak usage periods or in the case of population growth.

Based on the analysis, demand coverage measures the percentage of water demand that is met by the available water supply. The formula to calculate water coverage for a study area is typically expressed as:

$$Demand\ Coverage = volume\ of\ water \frac{supply}{Total\ Water\ Demand} \times 100 \quad (4)$$

This formula expresses the proportion of the total water demand that is met by the available water supply, presented as a percentage. The calculation results show that the water demand coverage in the study area is approximately 51%. This means that only about half of the total water demand is being met by the available water supply showing a significant gap between the water supply and the actual demand, meaning that nearly half (49%) of the water requirements are unmet. To ensure water security, it is crucial to explore strategies for increasing supply, improving water efficiency, and expanding infrastructure to meet the growing demand.

3. MATERIALS AND METHODS

3.1. Data Collection and Design Period

Discharge and climate data were collected on a monthly basis for model calibration and scenario development in WEAP. The Ethiopian Statistical Service (ESS) and the Chancho Town Administration Office (CHTAO) provided population size from 2007 to 2019 in order to compare the present population number, establish baseline trends, and guarantee data reliability in the study area. However, the data used for the analysis were obtained from the Chancho town administration office because the surrounding villages have merged into the town and the ESS does not have an accurate current population of the study area due to population in Ethiopia did not count after 2007. Climate data obtained from Ethiopian meteorological agencies were used to establish baseline trends for the study period. The climate data derived from historical records spanning 2003 to 2022. **Fig. 4** illustrates the average monthly climate parameters, such as temperature and precipitation, providing valuable insights for analyzing long-term climate patterns.

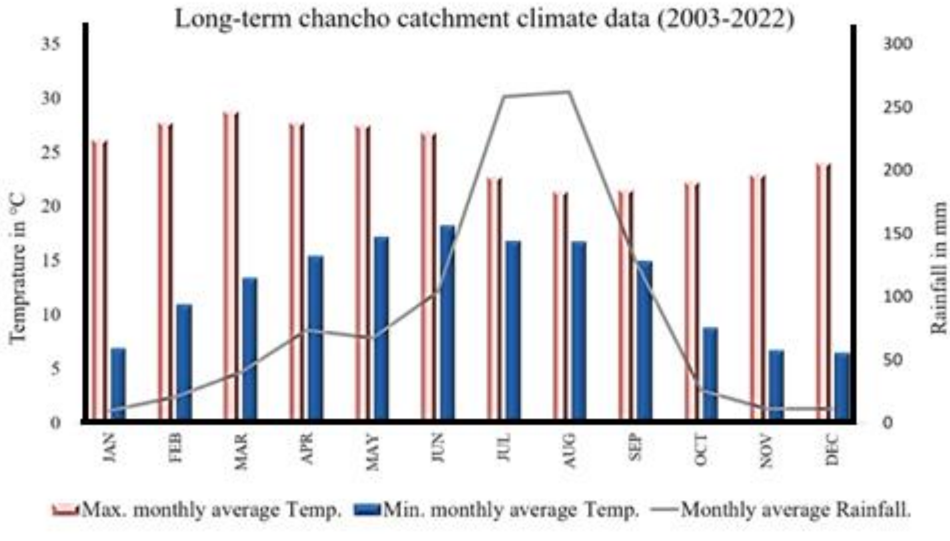

Fig. 4. Long-term Chancho catchment climate data (2003-2022).

In line with recent gridded climate-water products that emphasize actual evapotranspiration and effective precipitation for availability assessments, we use monthly climate forcings to frame supply scenarios (Nistor et al., 2022). According to the analysis, maximum temperatures reach their highest point in March (29°C) and stay high throughout February and April. This occurs at the same time that the demand for water increases due to higher evaporation rates. During the rainy season (June to August), August receives the most rainfall (262 mm), which helps restore water supplies. With little rainfall (as little as 11 mm in December) during the dry season (November to February), there may be a pressure on water supplies.

The design period for this study spans from 2023 to 2038. This 15-year timeframe was selected to analyze projected changes in urban water demand and supply under various scenarios, allowing for the assessment of long-term trends and potential water management challenges. Both primary and secondary data sources were utilized for the investigation. Using a mixed-methods approach, the study integrated quantitative and qualitative da-ta. Primary data included information on water consumption, socioeconomics, water supply, and demand. These data were gathered through observations, interviews, and field surveys. They were obtained from the Ethiopian statistical service, the Chancho town administration office, relevant water authorities, and utility companies, and through conducting interviews, surveys, and observations. Socioeconomic data, which was crucial for comprehending the elements influencing water demand, contains details on the town's population, growth rate, and eco-nomic activity. Those data helped in projecting present and future water supply and demand by taking into consideration the effects of population growth, urbanization, and changes in living standards. Information about the accessible water sources, such as groundwater, surface water, and existing infrastructure, was included in the water supply data. Those data revealed the town's ability to supply water to meet present and future demands. Demand data focused on water consumption patterns in a range of sectors, including institutional, livestock, industrial, and residential.

This study used various types of tools and approaches for modeling and data analysis. The techniques used in this study to investigate water supply and demand are made possible by the combination of many software pro-grams, including GIS (version: 10.7.11595), GPS, and Google Earth Pro (version: 7.3.6.9796) with WEAP (version: 24.0.0.0). GIS was utilized to map and analyze the study area, providing a detailed spatial representation of key features relevant to urban water demand and supply. This included defining the boundaries of the study area, which covers residential and industrial zones in Chancho town. Google Earth provided satellite imagery to verify land use classifications and validate the locations of industrial and residential areas within the study area. GPS was used to gather coordinates for groundwater and surface water sources in Chancho town, ensuring precise mapping and modeling of these resources within the WEAP model.

The WEAP model was created in 1988 by the Stockholm Environment Institute (SEI) for integrated planning and management of water resources (Purkey et al., 2018). WEAP uses a combination of algorithms and linear programming to address the issue of the water delivery challenge (Saketa, 2022). The water demand algorithm calculation used in the WEAP model is indicated as follows:

$$Total\ Demand = Total\ activity\ level * annual\ water\ use\ rate \tag{5}$$

$$Annual\ Demand = sum(Total\ activity\ levelBr * water\ use\ rateBr'x \ldots \tag{6}$$

Total activity level for a bottom-level branch is the product of the activity levels in all branches from bottom branches back up to the demand site branch (where Br = bottom-level branch, Br' = parent of Br, Br'' = grandparent of Br, etc.).

$$Total\ Activity\ level\ Br\ x\ Activity\ level\ Br\ x\ Activity\ level\ Br'' \tag{7}$$

Andersson, E. (2019) study highlights that the WEAP model allows users to simulate and analyze water supply and demand patterns, assess various water management scenarios, and evaluate the impacts of different interventions and policies on water resources (Andersson, 2019). WEAP is made up of the following five program structures:

Schematic - A graphical user interface for building the water system graphically
Data - A repository for entering and organizing all the data needed for the model
Results - Shows the model runs' outputs and visuals.
Scenario Explore-This tool enables the construction and contrast of various policy and management scenarios.
Notes: This area allows you to record assumptions, sources of data, and other details.

The study used a variety of methodologies and procedures to examine and model the town's water supply and demand. These techniques analyze data, anticipate future demand, and assess resource availability by using modeling tools, data collection, and analysis.

3.2. Methodology

This study follows a multi-step methodological approach that includes data collecting, processing, model creation, scenario development, and model output analysis. **Fig. 5** illustrates the methodological framework used in this investigation.

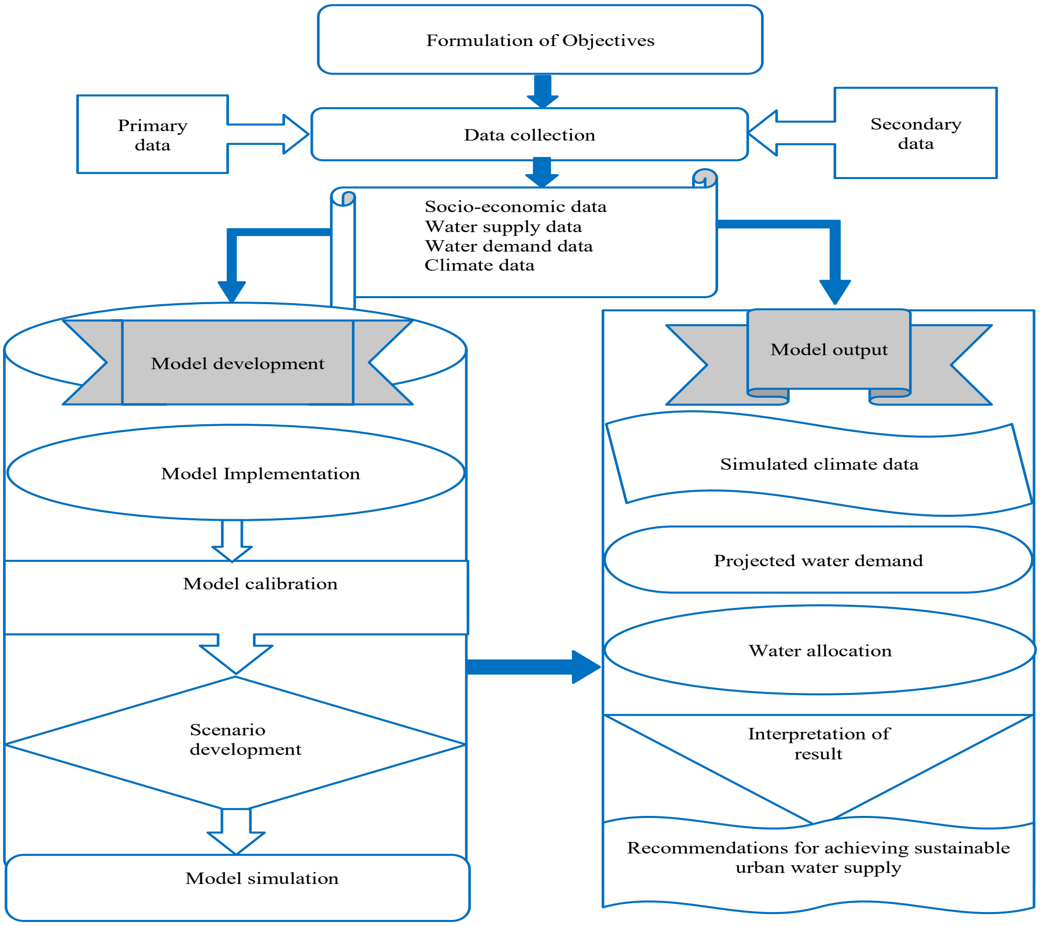

Fig. 5. Workflow of research methodology.

3.3. Future Water Supply and Demand Analysis Scenario Developed

Scenario 1: Baseline scenario or reference scenario

The existing or anticipated future state of the water supply, demand, and management practices is represented by this scenario, which is a baseline or starting point scenario (Andersson, 2019, Rathnayaka et al, 2016). All other factors and assumptions in this scenario remain consistent with the base year; however, socioeconomic demographic indicators, specifically population size, increase at the previously projected rate.

Scenario 2: External factor driven scenarios

It refers to a scenario where the drivers and assumptions are based on factors that are largely outside the control of the water management system being modeled. The key purpose is to inform strategic planning, risk assessment, and the development of adaptive water management strategies that can be managed with a wide range of potential future challenges and uncertainties. To determine the impact of external-driven scenarios (population growth (HPG), expansion of urbanization (UE), change in live standard, combination of HPG and UE, livestock reproduction enhancement, and climate variation), assumption cases were developed.

I. High population growth (HPG): In this case the population growth rate was increased from 3.4% to 5% to simulate a scenario reflecting potential future challenges, such as increased migration, urbanization, or economic developments, which could accelerate demographic growth. This adjustment helps to evaluate the potential impacts of higher population pressure on water demand, resource allocation, and infrastructure needs, enabling the development of proactive strategies for sustainable water management under such conditions.

II. Expansion of urbanization (UE): this scenario aims to assess the impacts of urbanization on water demand and supply systems. The water use rate for industry increased from 15% to 25% of domestic demand, while the rate for commercial and institutional use rose from 25% to 30%. These adjustments reflect the anticipated rise in water consumption due to urban growth. The scenario emphasizes the need for efficient resource management and infrastructure development to meet the growing water requirements of urban areas.

III. Climate change: this scenario considers an increase in temperature by 0.5°C accompanied by a decrease in rainfall. This reflects the potential impacts of global warming, where higher temperatures intensify evaporation and reduce water availability, while decreased rainfall further strains water resources. The scenario aims to evaluate the implications of these climatic changes on water demand, supply reliability, and resource sustainability, emphasizing the importance of adaptive measures such as efficient water use, enhanced storage systems, and ecosystem-based approaches to mitigate the effects of climate variability.

IV. Change of living standard (CLS): In this case water use rate was increased from 60LCPD to 80 LCPD. This indicates the effect of rising living standards, which often result in higher water usage per person because of changes in lifestyle, including greater use of goods, improved sanitation, and increased household demands. The scenario evaluates the effects of this shift on overall water demand and highlights the need for efficient water management strategies to balance rising consumption with sustainable resource availability.

V. Livestock reproduction enhancement (LRE): Each Tropical Livestock Unit (TLU) in developing nations is projected to require about 25 liters of water per day, according to research from the Food and Agriculture Organization and the Global Livestock Studies Institute (Schlink et al., 2010). The scenario includes an average increase in the daily water consumption rate for livestock from 25 liters per head (l/h/d) to 30 l/h/d. This increase to 30 l/h/d reflects an adjustment to account for higher water demands during reproductive processes, increased activity, or changing environmental conditions. The scenario assesses the impact of these changes on total water demand and resource allocation, emphasizing the importance of efficient water use practices and planning to support sustainable livestock production.

VI. High population growth and expansion of urbanization: The scenario assumed a 5% population growth rate and an increased water use rate due to urbanization. The water use rate for industries has been increased to 15% of domestic water use, while the water use rate for commercial and institutional sectors has been increased to 25% of domestic water demand. This combination reflects the significant increase in water demand driven by both a growing population and higher water consumption resulting from urbanization, including increased industrial, commercial, and institutional water use.

Scenario 3. Water management scenarios

The Demand-Side Management (DSM) Scenario focuses on strategies to regulate and reduce water usage by enhancing efficiency, minimizing waste, and encouraging conservation practices among users. This scenario assumed a 20% reduction in water usage, achieved through a combination of measures. These measures include improving water efficiency by adopting advanced technologies, reducing water losses in the distribution network through infrastructure upgrades, and promoting behavioral changes among consumers via awareness campaigns.

Supply-side management (SSM) involves implementing an integrated water source system to optimize the use of available resources. This approach combines surface water and groundwater sources to ensure a reliable and sustainable supply. By minimizing reliance on a single source and considering seasonal variations, it enhances resilience to shortages and improves the efficiency of water resource allocation.

4. RESULTS

A yearly population growth rate of 3.4% was adapted in this study to reflect the unique characteristics of the research area, where the town has rapidly grown in population by absorbing neighboring villages. The population projection was first calculated using an annual growth rate of 3.4%, resulting in an estimated population of 98,900 people in 2023. This projection served as the basis for estimating population levels during the scenario analysis period from 2024 to 2038. Following this, the water consumption in the base year 2023 was calculated to establish a reference point for analyzing future water requirements. The water demand in the current account year (2023) indicates that domestic demand is the largest, totaling 2.1659 million cubic meters (MCM), which accounts for 72.57% of the annual consumption. Institutional and commercial demand contribute 0.22 MCM, while industrial demand is 0.32 MCM (10.7%) and livestock demand is 0.28 MCM (9.36%). These components bring the total yearly water consumption to 2.99 MCM. These demand site, combined with seasonal variations and limited water sources, presented the causes of water demand within the current account framework. As result, there is a significant unmet demand of 49%, indicating water supply stress in the system, with total unmet demand projected to reach 1.46 million cubic meters over time (**Fig. 6**).

However, current water supply stands at 1.53 million cubic meters, covering only 51% of overall demand. This underscores the critical need for improved water management strategies, including the expansion of water sources, enhancement of distribution infrastructure, and the adoption of more efficient water use practices. Comparing our results with other studies is challenging due to the socioeconomic differences, which make the findings specific to our study area.

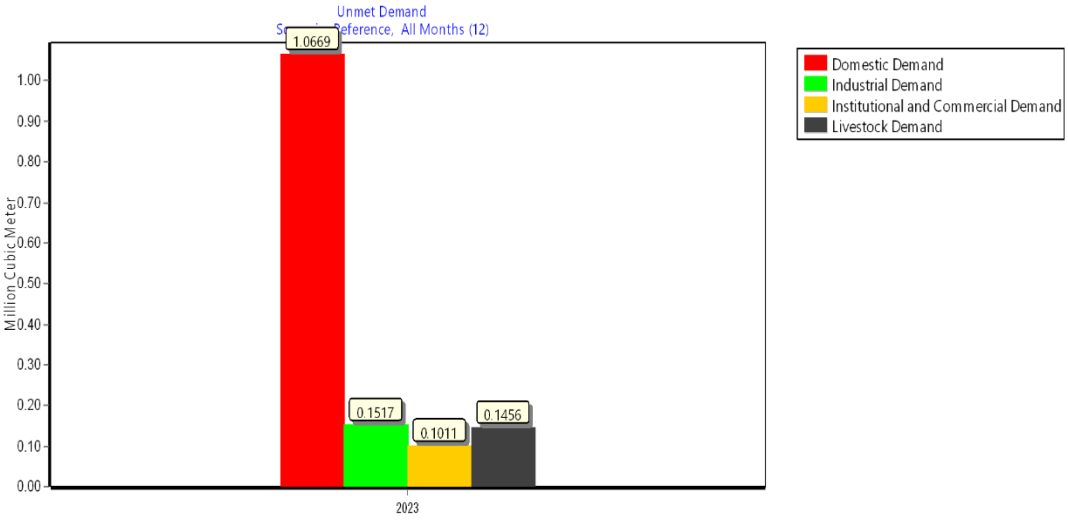

Fig. 6. Annual unmet water demand per all demand site in current account year.

Even so, our examination of the model's output reveals that our study and Alemu and Dioha's (2022) work, which employed the WEAP model to evaluate Addis Ababa's water supply and demand prospects, have comparable unmet water demand. While our analysis similarly demonstrates notable increases in unmet demand, driven by factors such as population growth and urbanization, their study anticipates a 48% increase in unmet demand in Addis Ababa by 2030, highlighting the necessity of proactive water management (Alemu & Dioha, 2020). A similar study conducted in Pakistan identified a predicted unmet water demand of 134 million cubic meters (Amin et al., 2018).

In the current account year (2023), there were also noticeable seasonal fluctuations in the demand for water, with residential, livestock and industrial activity being the main drivers of peak usage from February to May. Monthly total water demand was increased from 305.5 thousand cubic meter (in august) to 417.0 thousand cubic meters (in march). During the dry season, warmer temperatures accelerate the pace at which water evaporates from soil, rivers, and reservoirs. A greater reliance on stored water, which can need extra extraction efforts, results from the dry season's decreased rainfall, which restricts the natural replenishment of water sources like rivers and underground aquifers. Municipal and industrial water requirements rise to address the resulting shortage. In order to stay hydrated and maintain cooling systems, people and animals frequently use more water in hotter climates.

4.1. Reference scenario

In the reference scenario, the total requirement for water is expected to rise from 3.42 million cubic meters in 2024 to 5.37 million cubic meters in 2038, totaling 65.04 million cubic meters over 15 years.

Table 5.

Scenario: Reference, All Branch, Annual Total.

Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Domestic Demand	2.24	2.32	2.39	2.48	2.56	2.65	2.74	2.83	2.93	3.03	3.13	3.24	3.35	3.46	3.58
Industrial Demand	0.56	0.57	0.59	0.61	0.63	0.65	0.67	0.69	0.71	0.73	0.75	0.77	0.80	0.82	0.84
Institutional and Commercial Demand	0.33	0.34	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.44	0.45	0.46	0.48	0.49	0.51
Livestock Demand	0.29	0.30	0.31	0.32	0.33	0.35	0.36	0.37	0.38	0.40	0.41	0.42	0.43	0.44	0.44
Sum	**3.42**	**3.54**	**3.65**	**3.77**	**3.90**	**4.03**	**4.16**	**4.30**	**4.44**	**4.59**	**4.74**	**4.89**	**5.04**	**5.21**	**5.37**

Note: Water Demand (not including loss, reuse and DSM) (in million Cubic Meter).

As shown in **Table 5**, this scenario was created using the current account year 2023 as a basis and extended future estimates up to 2038 without any interventions. Assuming no changes with all other factors, including urbanization expansion (UE), changes in living standards, livestock reproduction, and climate variation, remaining constant, the population is expected to grow from 98,900 in 2023 to 198,830 by 2038, reflecting an annual growth rate of 5%. The outcome shows that demand has been steadily rising as a result of population growth. The total water demand increases significantly from 3.42 million cubic meters (MCM) in 2024 to 5.37 MCM in 2038, representing a 57% growth over 15 years. Domestic demand remains the largest contributor, rising MCM (15.6%), reflecting steady industrial expansion. Institutional and commercial demand also shows consistent demand grows moderately from 0.56 MCM (16.4%) to 0.84 from 2.24 MCM (65.5%) in 2024 to 3.58 MCM (67%) in 2038, driven by population growth and lifestyle changes. Industrial growth, increasing from 0.33 MCM (9.6%) to 0.51 MCM (9.5%), while livestock demand rises gradually from 0.29 MCM (8.5%) to 0.44 MCM (8.2%). Domestic water use contributes the largest share of the overall growth, accounting for 67% of the total increase, followed by industrial, institutional/commercial, and livestock demands. The consistent increase in water demand across all sectors underscores the critical need for proactive water resource planning. In comparison to the reference scenario results, Shahraki et al. (2016) found that unmet demand in the Hirmand catchment in Iran increased from 193 to 200 million cubic meters, highlighting a similar upward trend in water demand, which aligns with the growth observed in our study (Shahraki et al., 2016).

4.2. High population growth model scenario

In this scenario, the population is expected to grow from 98,900 in 2023 to almost 198,830 by 2038, reflecting an increase in the population growth rate from 3.4% to 5%. The projected population growth rate of 3.4% to 5% is a hypothetical scenario designed to evaluate the potential impacts of rapid demographic changes. The scenario assumes accelerated growth driven by increased migration from rural areas to the town and significant changes in socioeconomic conditions (Tegegne, 2019). Given a 5% annual population growth rate, the high population growth scenario forecasts significant increases in water usage. The results show that rapid population growth will lead to a projected water demand of 6.68 million cubic meters, an increase of 1.31 million cubic meters (20.53%) compared to the reference scenario. **Fig. 7** illustrates the water demand trend corresponding to a 5% annual population growth rate from 2024 to 2038. As the population increases consistently each year, the water demand rises significantly over the design period. Specifically, the demand grows from 3.42 million cubic meters (MCM) in 2024 to 6.7 MCM in 2038, reflecting the direct correlation between population growth and water consumption. Dividing the annual water demand reveals that the average monthly water demand increases from 4.3 thousand cubic meters to 4.9 thousand cubic meters, representing a 12.5% increase over the period. This trend highlights the potential for significant water supply shortages due to the rapid population growth. A similar study by Unto, P. B. (2024) utilized the WEAP model to project water demand in Addis Ababa, assuming an annual population growth rate of 4.46%.

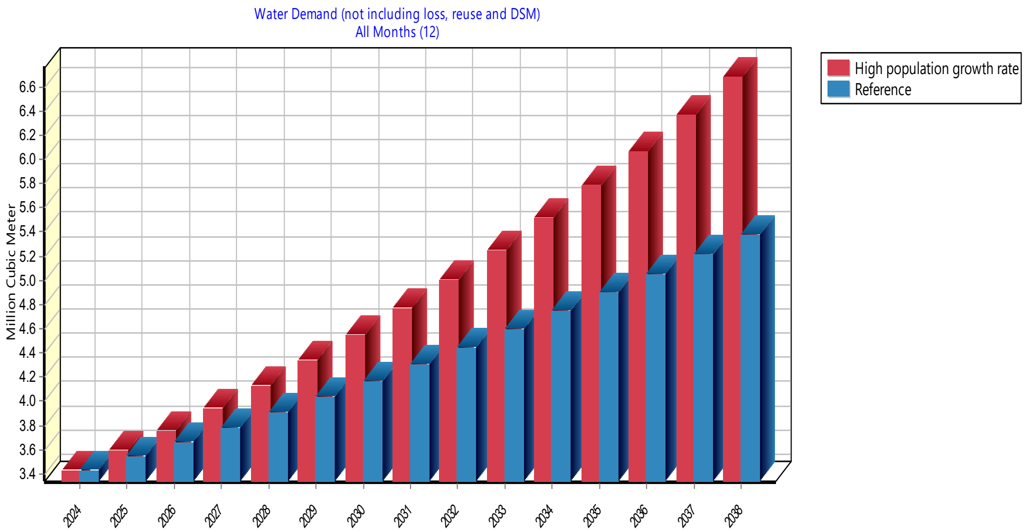

Fig. 7. Annual water demand of high population growth rate scenario.

The projections revealed a substantial increase in water demand, rising from 382 million cubic meters (Mm³) in 2023 to approximately 915 Mm³ by 2043. This trend underscores the significant challenges that rapid population growth presents to water supply systems, necessitating effective water resource management and planning to meet future demands (Unto, 2024). Another related study utilized the WEAP model to analyze various water supply and demand scenarios in the Yala Catchment, Kenya. The analysis revealed substantial increases in water demand under different scenarios, underscoring the urgent need for effective water resource management to address the challenges posed by population growth (Okungu, Adeyemo and Otieno, 2017).

4.3. Change in living standards model scenario

In accordance with the recommendations from the relevant study by Crouch, M. L., et al. (2021), the domestic water use rate in this scenario was increased from 60 liters to 80 liters per person per day (Crouch et al., 2021). By applying a domestic water use rate of 80 liters per person per day, the WEAP results demonstrate the impact of rising per capita water demand due to lifestyle changes. Table 6 compares water demand trends under two scenarios change in living standards and reference over a 15-year period from 2024 to 2038. Both scenarios show a gradual increase in water demand, with the Change in living standards scenario rising from 3.42 million cubic meters (MCM) in 2024 to 6.56 MCM in 2038, while the reference scenario increases from 3.42 MCM to 5.37 MCM over the same period. The cumulative water demand for the change in living standards scenario is 73.63 MCM, which is 8.58 MCM higher than the 65.05 MCM recorded for the reference scenario. This difference highlights the significant impact of improved socioeconomic conditions, such as increased per capita water usage, on water demand. Yearly increments are slightly higher in the change in living standards scenario. For instance, between 2024 and 2025, the demand increases by 0.19 MCM, compared to 0.12 MCM in the reference scenario. By 2038, water demand under the change in living standards scenario is 22.15% higher than in the reference scenario. These findings emphasize the need for proactive water resource management to accommodate the rising demand associated with socioeconomic development (Ernawati et al., 2018). A relevant study by Soula et al. (2020) in Tunisia's Nabhana watershed, study analysis stressed the importance of integrated strategies for managing rising water demand owing to socioeconomic growth (Soula et al., 2020). Similarly, Alemu and Dioha (2020) conducted a study in Addis Ababa, Ethiopia, examining the ways in which socioeconomic advancements influence water availability and demand, considering factors such as improved living standards. The analysis underscores the importance of integrating socioeconomic factors into future water planning to mitigate potential shortages. In order to meet rising demand and prevent shortages, it underlined the necessity of sustainable water management techniques (Alemu and Dioha, 2020).

Table 6.

All Scenario Branch: Demand site and Catchment, Annual Total.

Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	Sum
Change in Live Standard	3.42	3.61	3.81	4.02	4.24	4.47	4.66	4.87	5.08	5.29	5.52	5.77	6.02	6.29	6.56	73.63
Reference	3.42	3.54	3.65	3.77	3.90	4.03	4.16	4.30	4.44	4.59	4.74	4.89	5.04	5.21	5.37	65.05

Note: Water Demand (not including loss, reuse and DSM) (Cubic Meter).

4.4. Expansion of urbanization model scenario

In this scenario, the water use rate for industries is increased to 25% of domestic water use, while the rate for commercial and institutional sectors rises to 30% of domestic water demand over the 15-year period from 2024 to 2038. This increase in the water use rate was made to better reflect the growing water requirements driven by urbanization and the expansion of infrastructure (Paul and Elango, 2018). This adjustment led to an increase in water demand, as shown in **Fig. 8**, which compares two scenarios: the expansion of urbanization and the reference for the years 2024 to 2038. In the expansion of urbanization scenario, water demand increases steadily from 3.4 in 2024 to 6.6 in 2038, resulting in a total cumulative demand of 74.9 cubic meters over 15 years.

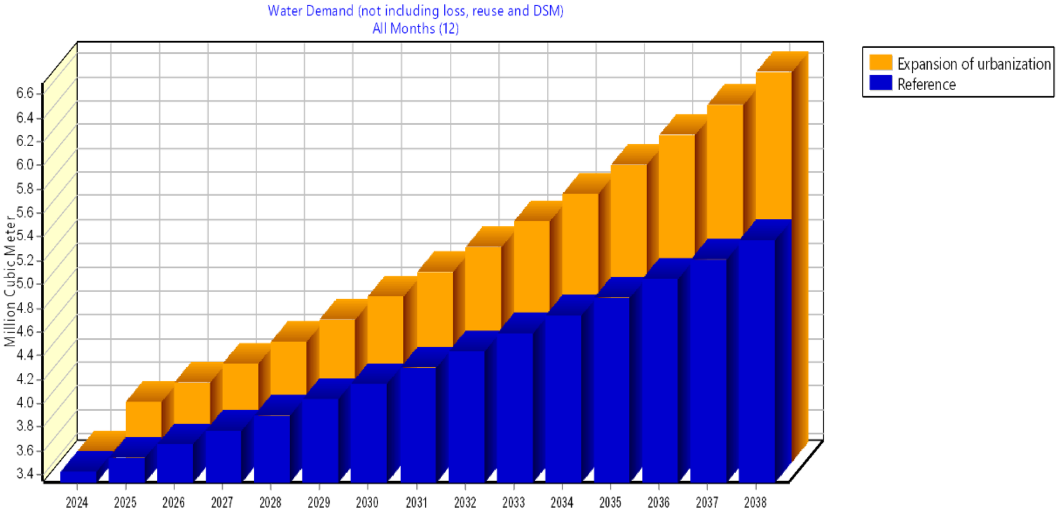

Fig. 8:Annual water demand for expansion of urbanization scenario

This growth reflects the increasing water usage driven by urbanization, which includes the expansion of residential, commercial, and industrial infrastructure. In contrast, the reference scenario exhibits a more moderate rise in water demand, starting at 3.4 in 2024 and reaching 5.4 by 2038, with a cumulative total of 65.0 cubic meters. The demand in this scenario is primarily influenced by factors such as population growth and general economic development, without the additional pressure of urban expansion. The difference in total demand between the two scenarios (9.9 cubic meters) highlights the significant impact of urbanization on water requirements. The unmet demand increased by 1.25 million cubic meters, reflecting the additional water demand from urbanization and limitations in water supply to meet this growth. Relative to comparable research conducted in South Chennai City, India by Arunprakash, M., and Giridharan, the high-growth scenario in this study aligns with their findings, demonstrating a typical pattern where rapid urban growth significantly increases water demand (Arunprakash et al., 2015). Another study conducted in Xiamen City, China, by Tang et al. (2013), examined urban development and planning strategies under rapid urbanization. The research analyzed the relationship between urbanization and water resource management, highlighting the need for adaptive measures to support sustainable growth (Tang *et al.*, 2013; Li *et al.*, 2023).

4.5. Livestock reproduction model scenario

The scenario created for domestic animal reproduction assesses the impact of improved livestock reproductive methods on water use. Improved breeding practices result in higher reproduction rates, enhancing livestock production efficiency and significantly increasing the water demand needed to support the expanding animal population. Using an average water consumption rate of 30 liters per animal per day in the livestock reproduction enhancement scenario throughout the design period, there is a corresponding increase in water demand (Mekonnen et al., 2011). As shown in **Table 7**, the comparison between the livestock reproduction enhancement and reference scenarios from 2024 to 2038 reveals notable differences in water demand trends. In the livestock reproduction improvement scenario, water demand starts at 3.4 million cubic meters in 2024 and increases steadily to 5.8 million cubic meters in 2038, with a total increase of 2.4 thousand cubic meters over the 15- year period. In comparison, the reference scenario shows a slightly lower increase, starting at 3.4 million cubic meters in 2024 and reaching 5.3 million cubic meters in 2038, with a total increase of 1.9 million cubic meters.

Table 7.

All Scenario, Branch: Demand site Catchment, Monthly Average.

Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	Sum
Livestock reproduction improvement	3.4	3.6	3.7	3.8	4.0	4.1	4.3	4.4	4.6	4.8	5.0	5.1	5.3	5.5	5.8	67.3
Reference	3.4	3.5	3.6	3.8	3.9	4.0	4.1	4.3	4.4	4.6	4.7	4.8	5.0	5.1	5.3	64.6

Note: Water Demand (not including loss, reuse and DSM) (Cubic Meter).

The livestock reproduction enhancement scenario projects a total water demand of 67.3 million cubic meters, which is 2.7 million cubic meters higher than the reference scenario. This notable increase in yearly water demand is primarily attributed to improved breeding practices and a broader diversity of livestock species, highlighting the impact of enhanced reproduction on water resource requirements. A study conducted by Wisser et al. (2024) globally investigates water use in livestock-based agri-food systems, employing regionally distributed models to determine the extent to which livestock production contributes to local water scarcity. The research identifies hotspots where water consumption exacerbates scarcity and underscores the importance of sustainable livestock water management to alleviate pressure on water resources and adapt to the growing food demand in water-limited regions (Wisser *et al.*, 2024). Similarly, Potopová et al. (2023) analyzed historical water use in livestock systems and projected future trends under varying climate change scenarios. The study highlights challenges in meeting livestock water demands within changing climatic conditions and proposes adaptive strategies to mitigate future water stress. By emphasizing long-term trends and climatic impacts, it offers valuable insights for sustainable livestock management in water-scarce areas (Potopová et al., 2023).

4.6. High population growth and expansion of urbanization model scenario

The high population growth + urban expansion (HPG + UE) scenario presents significant challenges to the sustainability of water supply and demand in the towns. **Fig. 9** compares the water demand trends between the HPG + UE and Reference scenarios from 2024 to 2038. In the HPG + UE scenario, water demand begins at 3.4 million cubic meter in 2024 and steadily increases, reaching 7.8 million cubic meters by 2038, with a total cumulative demand of 82.0 million cubic meters over the 15 years. This notable rise reflects the combined effects of high population growth and urban expansion, resulting in increased water needs across both residential and commercial sectors. The water demand in this scenario grows at a faster rate compared to the reference scenario, which aligns with the assumption that urbanization and rapid population growth drive higher water consumption. In contrast, the reference scenario exhibits a more moderate increase in water demand, starting at 3.4 million cubic meter in 2024 and reaching 5.4 million cubic meters by 2038, with a total cumulative demand of 65.0 million cubic meters.

The cumulative demand difference of 17.0 million cubic meters between the two scenarios underscores the significant impact of high population growth and urban expansion on water demand. This highlights the need for strategic planning and resource management to address the growing water requirements in areas undergoing rapid urbanization and population growth. Saketa, Y. (2022) conducted a relevant study in Assossa, Ethiopia, examining the effects of socioeconomic shifts on water supply and demand.

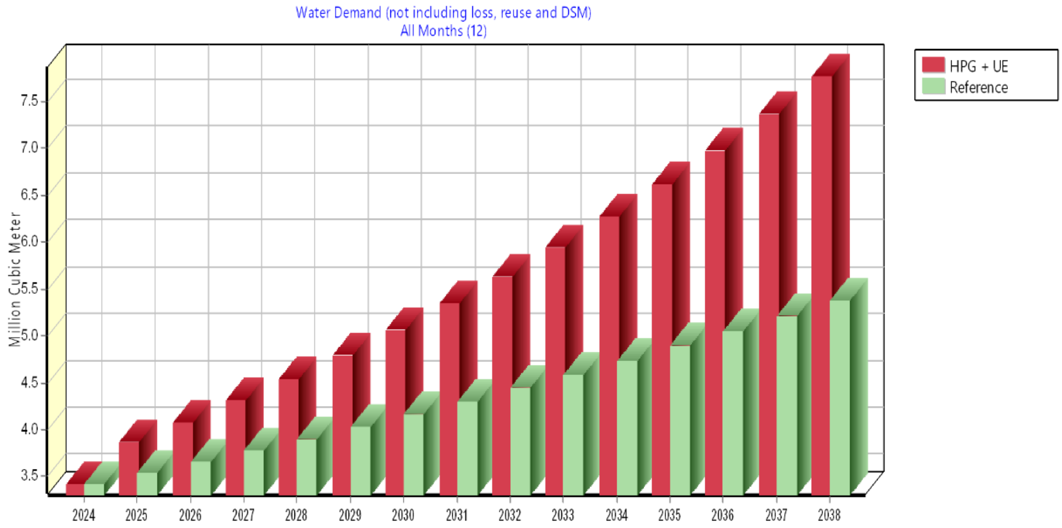

Fig. 9. High population growth and urban expansion water demand scenario.

The study emphasized the importance of proactive policy measures to balance water demand and supply in the face of rapid urbanization and changing socioeconomic conditions (Saketa, 2022). Similarly, a study conducted in Kampala, Uganda, by Vermeiren et al. (2012) explored urban water challenges arising from population growth and increased urbanization. The findings highlighted that enhanced water storage and distribution systems could significantly reduce unmet water demand (Vermeiren et al., 2012). This comparison underscores the need for integrated urban planning and strategic water resource management to address the challenges posed by urban growth in different regions.

4.7. Climate change model scenario

The climate change scenario predicts a temperature increase of 0.5 degrees Celsius and a reduction in rainfall. Under this scenario, total groundwater storage is projected to decrease to 42.95 million cubic meters, compared to 44.63 million cubic meters in the reference scenario. This results in an annual decrease of 1.68 million cubic meters throughout the 15-year study period. This significant reduction may lead to more severe water supply shortages during high-demand periods and the dry season, impacting local ecosystems and straining community water supply (**Fig.10**).

The climate change scenario investigated how water availability and demand would be affected by anticipated temperature rises and less rainfall (Ayt Ougougdal et al., 2020; Alamanos *et al.*, 2020). All demand sectors see an increase in water demand when temperatures rise, whereas home demand is particularly high, resulting in higher household water use for personal use and cooling. At the same time, less rainfall lowers the amount of surface water available and lowers the rate at which groundwater recharge occurs, which lowers the availability of water resources overall. These changes put additional strain on an existing stressed water delivery system and increase the likelihood of water shortages, especially during the dry season and during periods of high demand from February to May. This hypothetical situation highlights how urgent it is to include climate change adaptation strategies in the town's water management plans in order to prevent future water shortages and preserve a steady supply in the face of shifting climate conditions. According to a related study conducted by Cosgrove and Loucks (2015) and Paul and Elango (2018), the analysis emphasized the growing gap between water supply and demand, especially under deficit and normal conditions (Cosgrove and Loucks, 2015, Paul and Elango, 2018).

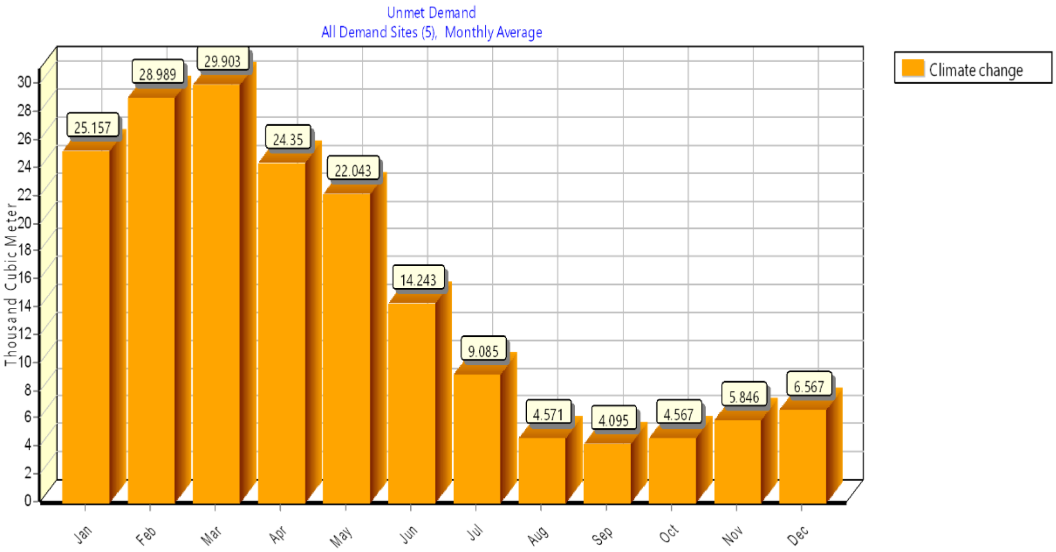

Fig. 10. Monthly unmet water demand under climate variation scenario.

To address these challenges, the studies suggested the adoption of sustainable water management practices.

4.8. Demand side management model scenario

Demand-Side Management (DSM) aims to regulate water usage by enhancing water efficiency, reducing wasteful spending, and modifying user behavior to guarantee that the available water supply adequately satisfies demand. A 20% reduction in water usage was assumed in this scenario, achieved through a combination of strategies. Based on this assumption, **Fig.11** compares the water demand trends for the DSM and reference scenarios from 2024 to 2038. In the DSM scenario, water demand starts at 3.4 million cubic meters in 2024, decreases to 2.9 million cubic meter in 2025, and then gradually increases, reaching 4.3 cubic meters by 2038.

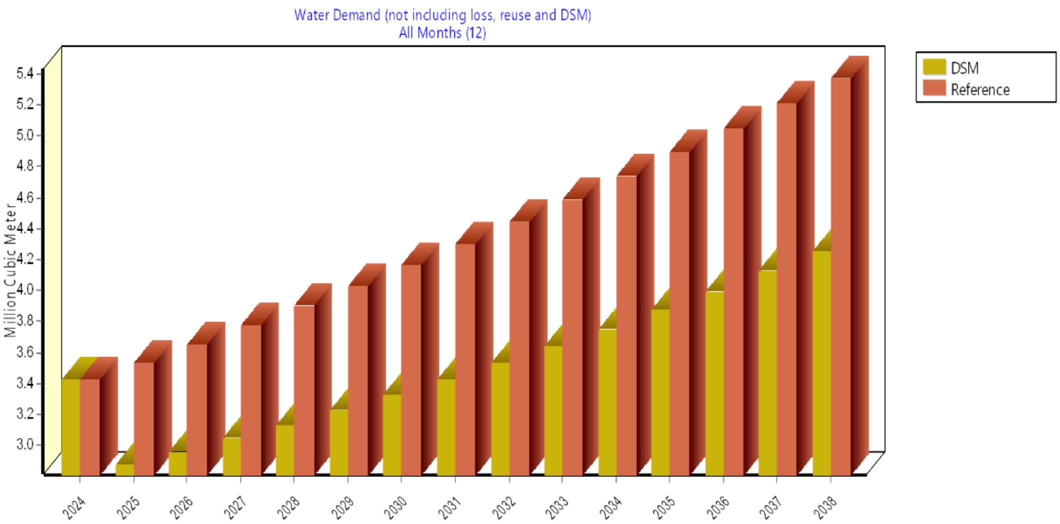

Fig. 11. Annual water demand under demand side management scenario.

The total cumulative demand for this scenario is 52.6 million cubic meters over 15 years, reflecting a 19.08% reduction in water usage compared to the reference scenario. This reduction is attributed to the implementation of water conservation strategies, including reducing losses in the distribution network and promoting efficient water use through behavioral changes among consumers.

In contrast, the reference scenario shows a steady increase in water demand, starting at 3.4 million cubic meters in 2024 and reaching 5.4 million cubic meters by 2038, with a total cumulative demand of 65.0 million cubic meters. Consequently, the total annual unmet demand is reduced by 11.41%, with the difference in cumulative water demand between the two scenarios amounting to 12.4 million cubic meters, highlighting the significant impact of DSM measures in reducing water demand. This analysis emphasizes the effectiveness of demand-side management strategies in minimizing water consumption, which can help address growing water demands while optimizing the available water supply. A similar study conducted in South Africa's water-stressed basins found that DSM strategies included scenarios with 10%, 20%, and 30% reductions in water demand to address future water scarcity (Lévite et al., 2003). Another Research conducted by Assefa et al. (2018) on Ethiopian household and industrial water use utilized the Water Evaluation and Planning (WEAP) model to assess DSM scenarios, focusing on enhancing domestic water efficiency and reducing industrial water consumption. Their findings demonstrate that water conservation strategies significantly mitigate water scarcity issues while ensuring a consistent water supply. It emphasized integrating water management with urban planning to address the challenges posed by increased demand, urban expansion, and limited (Assefa *et al.*, 2018).

4.9. Supply side management model scenario

The results reveal significant differences between the reference and supply-side management (SSM) scenarios from 2024 to 2038, highlighting variations in cumulative totals and annual trends in water supply delivery. The total cumulative water supply delivery for the reference scenario is 63.6 million cubic meters, whereas the SSM scenario achieves a lower total of 53.5 million cubic meter, representing a reduction of 10.1 million cubic meter or 15.9% (**Fig. 12**).

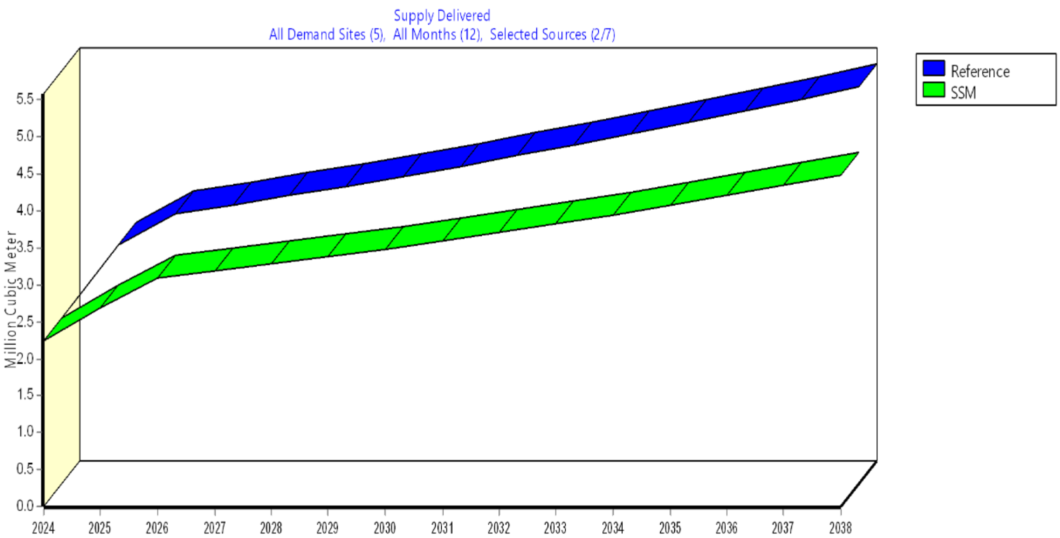

Fig. 12. Annual water supply under supply side management scenario.

This reduction reflects implementing measures in the SSM scenario aimed at managing and optimizing water supply delivery. Both scenarios start with the same value of 2.3 million cubic meter in 2024. However, from 2025 onward, the SSM scenario consistently delivers less water than the reference scenario. For instance, in 2025, the SSM scenario delivers 2.7 million cubic meter, 0.5 million cubic meters less than the reference scenario's 3.2 million cubic meter. By 2038, this gap will widen to 0.9 million cubic meters, with the reference scenario delivering 5.4 million cubic meter and the SSM scenario delivering 4.5 million cubic meters. The average annual growth rate of water supply delivery is approximately 0.22 million cubic meter per year for the reference scenario and 0.15 million cubic meter per year for the SSM scenario. Over the entire period, the SSM scenario achieves 84.1% coverage of the reference scenario's total water supply delivery. This indicates that the SSM scenario fulfills most of the projected demand while achieving a 15.9% reduction in total delivery through the implementation of efficiency measures.

The findings emphasize the effectiveness of the SSM scenario in sustainably managing water supply by integrating surface and groundwater sources. This approach enhances water availability for livestock and industrial use, ensuring that demand is met more efficiently while reducing pressure on individual sources. By integrating multiple water sources, the SSM scenario supports balanced resource utilization, minimizes the risk of shortages, and promotes long-term water sustainability in the face of growing demand. The relevant study by RaziSadath et al. (2023) examines several future scenarios, assessing their potential impacts on water resources and proposing strategies to ensure sustainable water management in the region. The study underscores the importance of integrating water demand management, conservation strategies, and alternative water supplies to mitigate water scarcity challenges arising from urbanization, climate change, and increasing demand (RaziSadath et al., 2023). Additionally, the study by Koop et al. (2022) explores the integration of technological advancements and policy changes in supply-side water management approaches, with an emphasis on sustainable urban water management techniques (Omar and Nangia, 2023).

5. DISCUSSION

The demand and supply dynamics for urban water in Chancho town underscore the critical need for sustainable and adaptable water management strategies to address increasing socioeconomic pressures. The primary aim of the study is to provide insights into the town's water supply and demand status using the WEAP model. The analysis revealed a significant water deficit across all demand locations, with unmet demand accounting for 49% of total water needs. As the town's population grows from 98,900 in 2023 to 198,830 in 2038, water demand increases substantially, indicating that existing infrastructure and water resources are insufficient to meet future needs (He et al., 2021, Hassan et al., 2019). Water demand rises by 70.63% during the dry season, which runs from March to May, when temperatures reach their highest point in March at 29°C. The reference scenario, developed using the current account year 2023 as a baseline, extends forecasts to 2038 without any interventions. The results demonstrate that population growth drives a continual rise in water demand. Annual water demand under external factor-driven scenarios considers the influence of factors such as rapid population growth and urban expansion. Population growth increases water requirements for households, public services, and infrastructure(Rachidi, 2014).

Similarly, urbanization increases demand by introducing new public spaces, transit systems, and industries. Beyond volumetric demand growth, urban expansion typically modifies runoff pathways and peak volumes, which complicates storage and reliability planning (Haidu & Ivan, 2016). Water consumption for businesses, organizations, and industries has increased from 3.42 million cubic meters to 6.62 million cubic meters as a result of the area's urban expansion scenario. Lifestyle changes associated with rising living standards also contribute to increased water demand. Higher living standards have resulted in increased consumption of water-intensive products and services, such as landscaped areas and improved residential water use. Sensitivity analysis identified population growth and urban expansion as the most critical drivers of water demand, followed by urbanization and lifestyle changes. To address these challenges, effective water resource management must prioritize strategies to mitigate the impacts of rapid urban growth and increasing water demand (Nivesh et al., 2022).

The climate change scenario further revealed that rising temperatures and reduced rainfall exacerbate water shortages, leading to a projected annual reduction of 1.7 million cubic meters in groundwater storage compared to the reference scenario. Incorporating adaptive measures into water management plans is essential to mitigate the potential impacts of climate variability These measures include building climate-resilient infrastructure, implementing flexible resource allocation plans, and anticipating future changes in temperature and precipitation patterns (Gedefaw and Denghua, 2023). The primary source of groundwater recharge is runoff and infiltration from the catchment, contributing 67.57 million cubic meters in total. On the outflow side, domestic water demand is the largest consumer, withdrawing 41.11 million cubic meters, followed by industrial demand (9.95 million cubic meters), institutional and commercial demand (5.97 million cubic meters), and livestock demand (5.32 million cubic meters). These withdrawals exceed the groundwater replenishment rate, leading to a continuous decline in storage.

The balance of inflows and outflows fluctuates slightly, but overall, the system is experiencing depletion, with groundwater loss increasing over time. This trend indicates a long-term risk of groundwater depletion, which could lead to water shortages in the future. With growing water demand across all sectors, sustainable management strategies such as efficient water use, recharge enhancement, and alternative water sources will be essential to prevent severe water stress. Tracking availability through effective precipitation and AET-based indicators provides a scalable lens for anticipating storage deficits under warming (Nistor et al., 2022).

Integrating groundwater and surface water sources for industrial and livestock use increased overall water supply availability in the supply-side scenario. Diversifying water sources for non-potable uses can help reduce reliance on groundwater and storage tanks(Bahri, Brikké and Vairavamoorthy, 2016). This approach balances demand across resources, alleviating pressure on individual sources and promoting sustainable water management.

Demand-side management strategies focus on improving water-use efficiency, reducing waste, and encouraging behavioral changes to ensure that available supplies meet demand. Expanding the storage capacity of existing reservoirs or constructing new ones would allow for better management of excess water during peak demand periods. Promoting water-saving technologies and reducing waste in the commercial, industrial, and residential sectors can significantly lower overall water demand(Dos Santos *et al.*, 2017). Active stakeholder engagement spanning local governments, industries, and communities is crucial for enhancing coordination, accountability, and the success of water management programs.

6. CONCLUSION

The study's findings emphasize the significance of appropriate water management techniques for the town, especially in terms of growing urbanization, population increase, and climate change. Based on the WEAP findings, there was an observable water shortage in demand during the analyzed time span, particularly during the dry season. It shows a current annual unmet of 1.16 million cubic meters (MCM) between the supply of 1.83 MCM and the demand of 2.99 MCM. This confirmed that the water resources and infrastructure were inadequate to meet the increasing demand.

A significant rise in water demand over the baseline levels set in the reference scenario was predicted by future scenarios, which include rapid population growth, changes in living standards, and urbanization. These forecasts indicate that water consumption will climb sharply as the population grows and urban areas spread and the changes in lifestyle that frequently accompany urban expansion. Such scenarios highlight the necessity of capacity expansion and strategic planning to meet the expected increase in demand, guaranteeing that the water supply will be robust and able to sustain important economic sectors as well as the expanding population in the face of future demands.

On the other hand, supply-side management scenarios predicted that integrating surface water and groundwater sources for industrial and livestock use proved to be an effective solution for balancing demand and improving water supply reliability. This approach reduced strain on individual sources and promoted sustainable water usage, ensuring that both the growing population and key sectors, like industry, were supported. The increasing demand emphasizes the need for proactive planning, infrastructure development, and efficient water management practices. Overall, ongoing monitoring and management will be crucial for addressing future challenges and ensuring water availability for all sectors.

The study recommends that further research is required to examine how climate change affects the region's water supply and demand. Furthermore, by integrating data from supply sources, future research should also use the model to assess water quality across the system.

The study considered climate change by analyzing its potential impact on water demand and availability in the town. It particularly investigated the consequences of rising temperatures and shifting precipitation patterns, predicting an increase in water demand during times of higher temperatures and lower rainfall. The study also looked at how these climate changes may increase water scarcity, especially during peak demand months. The study highlighted the need for adaptive water management measures to ensure a reliable and sustainable water supply under future climate conditions.

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