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Future potable water supply demand projection under climate change and socioeconomic scenarios: A case of Gshba subbasin, Northern Ethiopia

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Abstract: This paper aims to quantify the subbasin's potable water supply demand forecast from 2023 to 2050 under various scenarios of climate change and socioeconomic development. The variability of the climate and the resulting problems with urbanization threaten the availability of water resources, especially in less developed countries like Ethiopia. Thus, the main objective of this study is showing the necessary to determine the amount of water needed in advance, in order to comply with the availability of water resources within a specified future period under different scenarios. Our indicator-based approach used a multicriteria decision-making technique. Accordingly, several important variables were considered, including climatological, anthropological, demographic, socioeconomic, and economic variables, in addition to water engineering-related factors (e.g. Water losses). The method also considered a number of factors, such as unexpected and extreme temperature changes, and forecasting factors studied by the Ethiopian Ministry of Water and Energy. The projected population in the subbasin is estimated at 2.52 million, so the total projected water supply demand i.e., for domestic, non-domestic, industrial, commercial, public, and institutional is approximately 126.53 MCM/yr by 2050. Our results revealed how changes in both climatic and socioeconomic factors strongly influence future water resource system performance, and this will help the water services provider better prioritize the refurbishment of existing infrastructure and investment in new infrastructure, and more importantly, manage the subbasin effectively by introducing resilient adaptation options.

Keywords: Population, Forecast, Water demand, Domestic, Non-domestic, Industrial, Ghba subbasin, Northern Ethiopia

1. Introduction

Consistent urban and rural water supply demand forecasting is important for several reasons, including helping to make operational decisions for water utilities, helping to plan for future needs, and informing strategic decisions [1-3]. It is quite significant to know what the water demand for today and tomorrow will be in order to appropriately operate water supply systems such as; treatment plants, pipe network systems, reservoirs, and wells [4, 5]. Utilities also need to forecast water demand 20-30 years in the future in order to develop new water sources and/or expand their treatment plants [6, 7]. Water demand forecasting is a complex task that is fraught with difficulties [8]. Available data is often insufficient and there are many variables that are thought to affect water demand [9, 10]. Forecasts are often made at different time scales and with different frequencies [11, 12].

Managing demand and water markets can also be very important in dealing with climate change, because it enhances efficiency and allows a great deal of flexibility in managing water resources [1, 13]. There is a distinction between conserving water and requiring more of it [14]. Water conservation is a strategy used to save water during situations where there is a water shortage [14, 15]. Normally, this is done in cases of drought. According to Hiben, Gebeyehu and Tabassum, Arsalan [16, 17] water demand can be broken down into three categories: residential, commercial, and agricultural. Thus, water demand management (WDM) is a key strategy used to manage water resources throughout the zworld, as it ensures that all users have the water they need while conserving resources [18, 19]. Water conservation measures, such as reducing water withdrawals or consumption, can be described as any socially beneficial action that helps to conserve water resources known as water demand management (WDM) [20]. These measures must be taken in a way that does not negatively impact water quality. The main objectives of water demand management are to meet the basic human needs of present and future generations, promote the efficient, sustainable and beneficial use of water, and provide for the increasing need for water [21, 22].

Water demand forecasting is a difficult task, because data is often limited and there are many variables that could affect demand [3, 23, 24]. For example, the data may be inaccurate because of the nature and quality of the data, and the variables that are thought to affect water demand can be very different from one forecast to the next [25-27]. Additionally, the forecast horizon and periodicities can also vary. These characteristics have led to a large number of studies aimed at improving forecast reliability. Despite the various efforts that have been made to forecast water demand, the practices used by utilities and their consultants vary widely in terms of the methods and models used [28, 29].

Water demand forecasting is an essential component of water supply system management. However, accurate water demand forecasting is difficult due to the complexity of the elements involved and a lack of trustworthy data[30, 31]. Population growth is a major element influencing water demand predictions. Population expansion can increase water consumption, putting strain on the current water delivery infrastructure[32, 33]. As a result, reliable population prediction factors/variables collected from the Ethiopian Central Statistical Agency (CSA) as tabulated in Table 1 are required to guarantee that the water delivery system can satisfy future water demand. In conclusion, precise water demand forecasting is critical for effective water supply system management [34]. One of the most important variables influencing water demand forecasting is population increase, and accurate population predictions are critical for anticipating future water demand [35].

Population forecasting is an important tool for policymakers and planners to use when making future choices [36]. Population forecasting time frames can vary based on the goal of the prediction and the amount of uncertainty involved. According to research by Sadovnichy, Akaev [37], the global population forecast time horizons might range from 5 to 100 years.

The temporal horizon of a prediction might be short-term, medium-term, or long-term. Short-term projections are typically less than 5 years in duration, but can be up to 5 years in length, and are used to fine-tune current plans in response to new information. Forecasts for the medium term are typically between 5 and 10 years in length and are used to drive policy choices and resource allocation. Long-term predictions, on the other hand, the time horizon chosen relies on the objective of the forecast, the amount of uncertainty involved, and the availability of data [38]. Short-term projections are more accurate but have limited application, and long-term forecasts are less accurate but give a broader view of future trends. As a result, it is very crucial.

The population projection for the proposed planning years was made based on Ethiopia's population was projected in the Central Statistical Agency Reports for the years 2014 to 2021 [39], Moreover, another strategic water resource management policy document (WRMP) created and approved by the Ministry of Water and Energy [40] as well as the study by [16]. The population projections for the planning period were made at the Kebele level using the projected growth rate proposed by the Central Statistical Agency. Only until the year 2030 can the CSA's proposed growth rates be continued. According to Table 1, the growth rates for the years beyond 2030 were projected using the regression function and is also used for this study.

Table 1. Population growth rate of Tigray

Year	Rural (%)	Urban (%)
2005-2010	4.4	4.1
2011-2015	4.3	3.9
2016-2020	4.2	3.8
2021-2025	4.1	3.7
2026-2030	3.8	3.5
2031-2035	3.6	3.2
2036-2040	2.9	2.4
2041-2045	2.7	2.1
2046-2050	2.4	1.9

Source: Central Statistical Agency 2020

The growth of the human population follows an S-shaped curve. Most of the time, arithmetic progression, geometric progression, decreasing rate of growth, or graphical extension is used to estimate the population in the next 1–20 years [41]. The "S"-shaped growth curve serves as the foundation for all three of the initial steps. Thus, when developing population projections, the three methods are compared to the past population's trends to see which one best captures the trend. For this study, the better population forecasting method is selected with CSA growth rates shown in Table 1. According to studies by Wang, Zhang [42], Raftery and Ševčíková [43], and Thomas, Syse [44] the population forecasting was done based on the time horizon 2021-2025 (short), 2026-2035 (medium) and 2036-2050 long (long).

This paper contributes to understanding future water demand forecasts by providing a framework on water demand forecasting. The framework outlines the basics of water demand forecasting variables, including the problems that water utilities face in planning and forecasting, the level of planning, the length of the forecast horizon, and the frequency of forecast updates.

2. Data and Methods

2.1 Description of the Study Subbasin

The Ghba subbasin is the northern region of Ethiopia, extending from 38°38' to 39°48' east longitude and from 13°14' to 14°16' north latitude (Figure 1). The Ghba subbasin has an area of approximately 5125 square kilometers and includes the city of Mekelle, the capital of the regional state of Tigray. The Ghba River subbasin is one of the Nile River's principal tributaries. The landscape include hills and highlands in the north and northeast, as well as highlands in the center of the watershed [45, 46]. Several rivers cut through the middle highlands before joining the major Tekeze River near Chemey in the southwest [47]. The Mugulat Mountains, which are located in the town of Adigrat and have a height of around 3,300 meters above sea level (m.a.s.l.), are the source of the subbasin's drainage region. At the subbasin outflow, where water discharge is monitored, the elevation rises to 930 m.a.s.l. [16]. The catchment area's average elevation is 2144 meters, and its standard deviation is 361 meters [46]. This demonstrates how rough the topography is [45].

2.2 Climate

The Ghba sub basin is categorized under semi-arid climate region where rainfall occurs generally from July to September and has a long period dry season. The severe weather is expected to hit from July till August [48]. The subbasin's mean annual precipitation ranges from 450mm in the east to 850 mm in parts of the north and west [47]. The intertropical convergence zone's (ITCZ) seasonal migration and the subbasin's complex topography are the primary causes of the rain fall's high variability [49, 50].

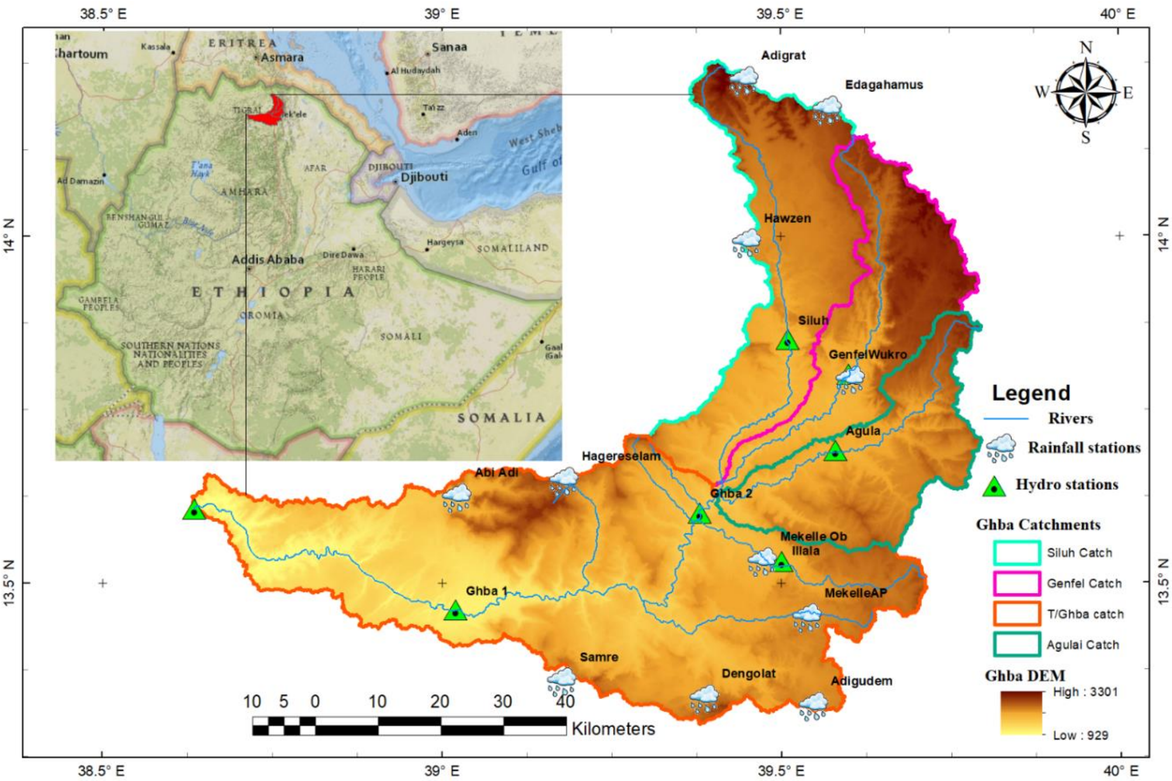

Figure 1. Study area location map

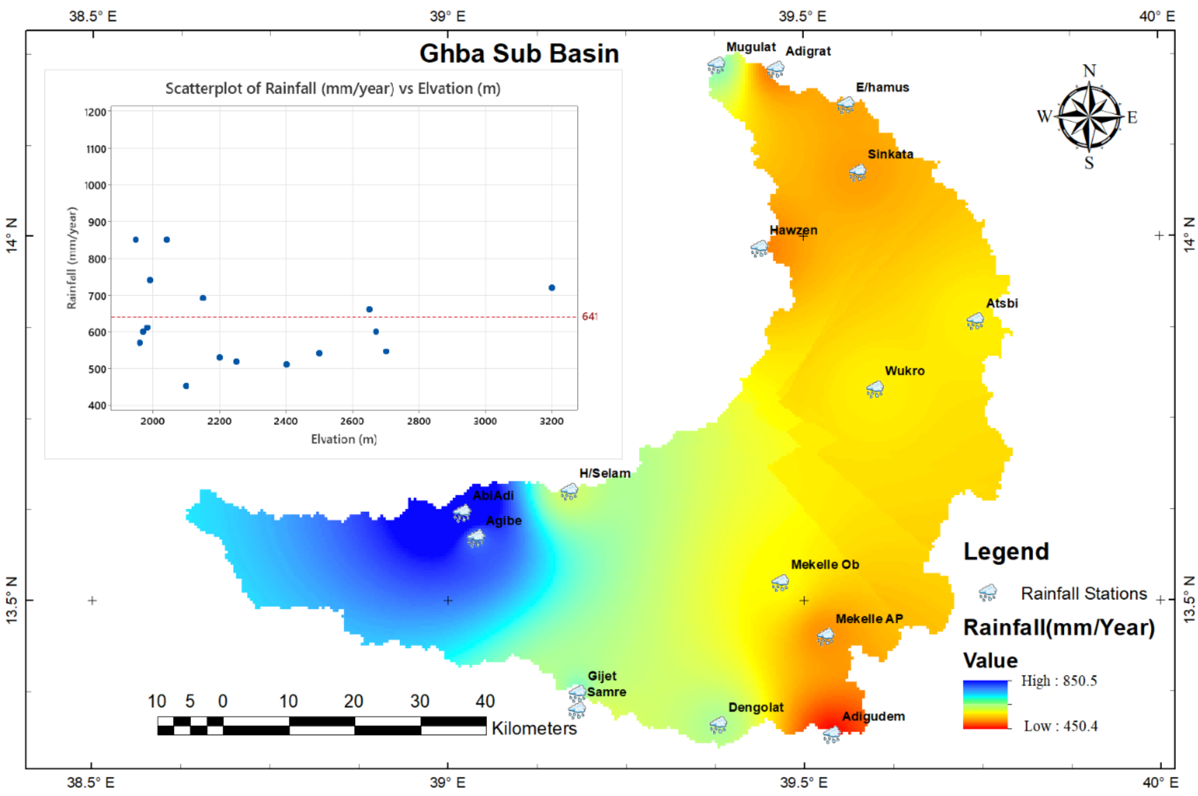

Figure 2. Distribution of annual average rainfall over the Ghba sub basin for the period of 1981- 2017, and scattered plot of annual average point (station) rainfall against elevation of each station

As a result, the wet season, which lasts from June to September, receives above 85% of the overall rainfall , with the maximum effective rainfall lasting no longer than 60 days, and the dry season, which can last between 10 months [51]. The seasonal movement of the Inter-tropical convergence zone (ITCZ) is typically linked to the changes. ITCZ over the highlands of Ethiopia alters annually both in its beginning and end, which regularly causes inter annual rainfall variability [52] And, the rainfall in the Ghba is highly variable in space and time [49]. The overall trend of the sub basin's rainfall is characterized by the complex topography which favors the movement of air moisture that can significantly enhanced to generate rainfall regimes due to orographic effect [53]. The rapid variations in elevation can hinder the air mass movement to produce a microclimate at the foothills to make orographic rainfall [54, 55]. While in most of the Tekeze basin shows that incremental of rainfall with elevation due to the orographic effect [e.g.,56, 57] , this is not the case in the Ghba sub basin. A research by Gebrehiwot, van der Veen [58], and Mohammed, Yimer [59] revealed that the Tigray region had rainfall increases with elevation to the south while it decreases with elevation in northern and north-eastern parts. This shows that the connection between rainfall and elevation in the subbasin is varying as it lies in northern and north east of the region. This attributed to the complex nature of topography and seasonal movements of the ITCZ which alters proximity to the sources of moist air [60, 61]. Figure 2 demonstrates the distribution of areal averaged rainfall over the subbasin. it indicates that rainfall increases with elevation in the south whereas it decreases with elevation in northern and north-eastern regions of the subbasin. This implies that there is no consistent link between elevation and rainfall.

2.3 Structure for Water Demand Forecasting

Figure 3 illustrates how the research area's Potable water demand forecasting is structured, and is discussed briefly from section 2.3 through 2.9. There are two primary phases to all planning studies for the water supply. The first step in generating water demand predictions is to use statistical approaches to take trend and seasonality into account on historical consumption data for both short- and long-term timeframes. Second, several water management strategies are evaluated for a certain water demand prediction using a diverse range of quantitative and qualitative criteria. Models for optimization can simply incorporate quantitative evaluation criteria. However, it can be challenging to quantify and measure qualitative variables like public approval and environmental friendliness using statistical techniques. Due to the unpredictability in the criteria set required for projecting water demand, thus the research is motivated to apply Multi-Criteria Decision Making (MCDM) methodologies for a full assessment of water management choices.

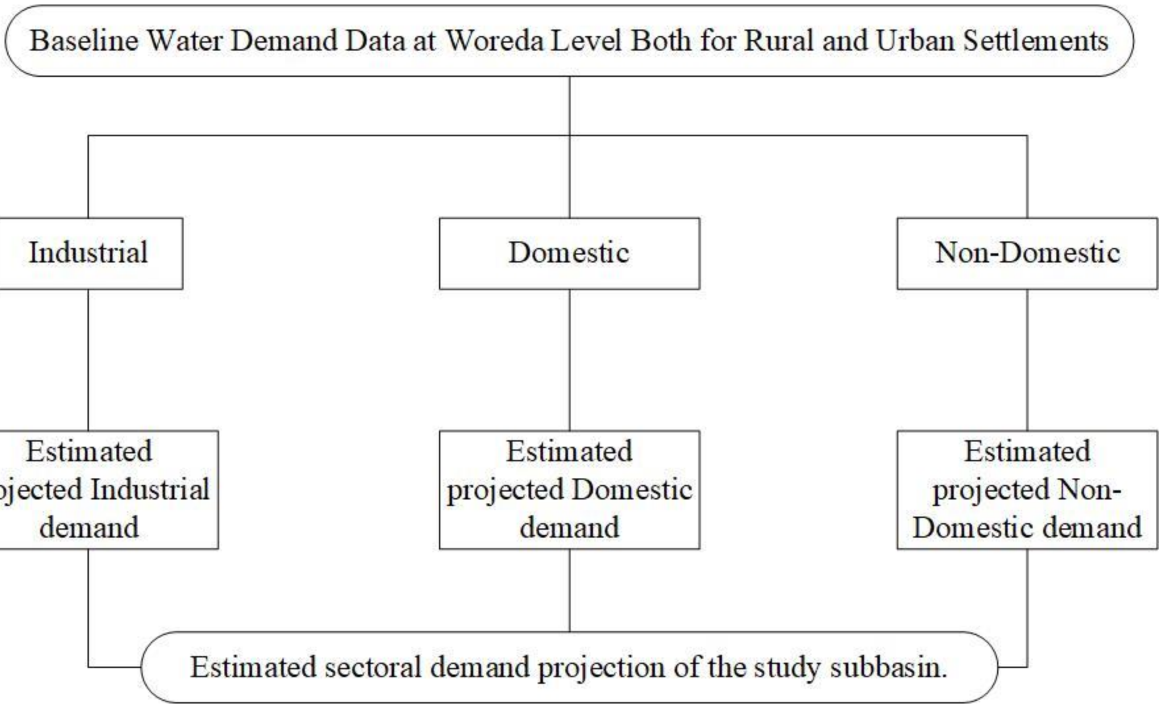

Figure 3. Overall methodology to estimate total projected water demand in the research area

2.4. Methods of Projected Population

The methodology employed to choose the better population focusing approach is done first by calculating prediction errors and selecting the method with the lowest error from four population forecasting methods. This is accomplished by Considering that the populace in 2020 is known, computing it using all techniques, utilizing the previous dataset to compute error by subtracting values of the voluntarily omitted dataset with the computed one, and then comparing the results to choose the method with the least error. These include the exponential growth rate method, the geometric progression method, the incremental increase approach, and the arithmetic progressive method, and are described as follows:

2.4.1 Exponential Growth Rate Method

The Ethiopian central statistics authority, employs this technique. The following equation 1 describes it.

$P_n = P_o * e^{r*n}$ .... Equation 1, Where Po is current population, e is exponential, r is growth rate, P_n is future population at the nth period and n is number of decades.

2.4.2 Geometric Progression Method

This strategy is predicated on the ten-year population growth rate being constant. The population projection approach analyzes the average percentage increase during the previous few decades and expects that the rate of growth will remain constant every ten years. To determine the average percentage growth every decade, the most recent census statistics are used. Equation 2 describes it.

$P_n = P_o(1 + G)^n$.................Equation 2, Where Po is current population, G is average percentage increase per decade, P_n is future population at the nth period and n is number of decades.

4.2.3 Arithmetic Progressive Method

The average population growth rate is considered in this strategy and is thought to remain constant over time. Data from the previous census are used to calculate the average growth each decade. Thus, the estimate of the forecasted population is given by equation 3.

$P_n = P_o + n * K$ .... Equation 3, Where Po is current population, K is average increase per decade, P_n is future population at the nth period and n is number of decades.

4.2.4 Incremental Increase Approach

In this approach, the arithmetic method is used to determine the pace of population growth on average, and the average of the net incremental growth rate is added once for each subsequent decade. Equation 2 describes it.

$P_n = P_o + n * (K_1 + K_2)$ .... Equation 4, Where Po is current population, K_1 and K_2 is average increase per decade, P_n is future population at the nth period and n is number of decades.

2.5 Forecasting Techniques for Domestic Water Demand

Forecasting in the water sector is based on planning for decision-making [62]. Differentiating forecast practices by the level of planning associated with the forecast [63], or according to the time horizon for the forecast [64] provides a means to forecast water demand. Water demand forecasting exercises can be employed for strategic, tactical, or operational decision-making, depending on the level of planning required [65]. These areas of decision-making concern expanding the system's capacity, investing in new resources, operating the system, managing it, and optimizing it, planning for future water demand can be classified into short-term, medium-term, and long-term forecast horizons, which reflect different planning levels [66, 67]. There is no generally accepted timeframe for these periods. Different researchers have proposed different time horizons for what constitutes a long-term, medium-term, or short-term projections [24, 68]. For example, in Ethiopia [69] proposed different time horizons every one of these projection types. Accordingly, projection horizons in this study is classified as forecasts spanning longer than thirty years as long-term, those from 20 years to 30 years as medium-term, and forecasts for 5 to 10 years as short-term. These classifications may not necessarily be similar with other same studies as described above. Studies by [41] shows the term "domestic water demand" refers to the used water for everyday tasks such as cooking, cleaning, and washing, among others. This water is typically supplied through public fountains, yard connections, and house connections, which vary depending on the economic conditions of the community and the water utility's capacity. In general, the amount of water needed (known as the "Per Capita Demand") is calculated using the actual service needs of both the urban and rural populations. Although reliable data on domestic water demand was not available, recommendations from studies were used to estimate the present and upcoming demand both in rural and urban settings. A study by the Ministry of Water and Energy [69] found that per capita water demand is expected to grow during the next few decades, as shown in Table 2 and is used for this study.

2.6 Climate and socioeconomic adjustment factor

The climate is among the factors that affects people's daily water consumption [70]. In addition, the economic situation of the consumer also affects water use and demand [71].

Table 2. Future domestic water needs per person

Settlement	Per capita water demand, l/c/d		
	2025 (Short term)	2035 (Medium term)	2045 (Long term)
Rural	30	40	50
Urban: <20,000 population	50	60	70
Urban 20,000-50,000 population	60	70	80
Urban: 50,000-100,000 population	70	80	90
Urban: 100,000-1,000,000 population	90	100	110
Urban: >1,000,000 population	110	120	130

Source: Assessment of National Water Use & Demand Forecast, MOWIE, 2020

Table 3. Domestic water demand correction factors under socioeconomic and climate change

Region	Correction factor	Basin	Correction factor
Addis Ababa	1	Abbay & Tekeze	1
Tigray	1.1	Awash	1.1
Amhara	1	Aysha	1.2
Benishangul-Gumuz	1.1	Baro-Akobo	1.1
Dire Dawa	1.1	Denakle	1.1
Gambella	1.1	Genale-Dawa	1.1
Harari	1.1	Mereb	1.1
Oromia	1.1	Ogaden	1.2
Somali Region	1.2	Omo-Gibe	1.1
Southern Region	1.1	Rift Valley	1
Afar	1.1	Wabi Shebele	1.1

Source: Assessment of National Water Use & Demand Forecast, MOWIE, 2020

Therefore, the water a person uses depends on the socioeconomic and climate conditions of the area. This suggests that water usage is higher in hot climates than in cold climates [72]. Additionally, those with more wealth tend to consume more water than those with less wealth. This will be adjusted by multiplying the adjustment factors by total domestic demand. The characteristics of the sites being considered are determined by their altitude. Similar studies by the Ethiopian ministry of water and energy [40] have proposed an adjustment factor for the Tekeze basin (Table 3), which was adopted for this study.

2.7 Methods of Nondomestic Water Demand Forecasting

The nondomestic sector includes commercial, institutional, and industrial activities. In this research, as shown in Table 4 the nondomestic demand is assumed to vary from 5-40%, depending on the degree of urbanization, as proposed and adopted by previous similar studies. These demands can be further categorized into demands from industry, commerce, the public, and institutions, which can help ease planning and understanding the significance of each type of water demand.

2.7.1 Industrial Water Demand

The industries in the water basin have no documented statistics on water use, hence their water needs were inferred from domestic water demand. Furthermore, since the development plan of such industries is not articulated, the projected demand could not be estimated independently. For planning purposes, it was always assumed that the industrial water demand would be 30% of major and midsize towns' residential water needs and 10% of domestic water needs in small towns is used according to the recommendation of MOWIE, 2020.

2.7.2 Public, Commercial, and Institutional Water Demand

If complete data on existing and future development plans could be obtained, it would be possible to accurately estimate water demands. However, since this data is not available, based on home water consumption, water demands are predicted, which is assumed to be 5% of the total. Non-domestic water demands for rural areas are estimated based on this domestic water consumption according to the recommendation of MOWIE, 2020.

2.7.3 Unaccounted for/Nonrevenue Water Loss

The term "unaccounted for water" refers to water that is lost due to leaks or unauthorized connections in a supply of water system. This water loss is typically calculated as a proportion of the overall demand, and can range from 5-30%. An acceptable level of water loss is a balance between the price of the water saved and the price of minimizing water loss. Table 5 is used to compute future unaccounted.

Table 4. Future non-domestic water demand

Settlement	Non-domestic demand (% total demand)
	2025-2045
Rural	5
Urban: <20,000 population	10
Urban 20,000-50,000 population	15
Urban: 50,000-100,000 population	20
Urban: 100,000-1,000,000 population	30
Urban: >1,000,000 population	40
Source: Assessment of National Water Use & Demand Forecast, MOWIE, 2020.	

Table 5. Future unaccounted for water

Settlement	**Real water loss (% total demand)**		
	2025	**2035**	**2045**
Rural	5	5	5
Urban: <20,000 population	10	10	10
Urban 20,000-50,000 population	10	10	10
Urban: 50,000-100,000 population	15	10	10
Urban: 100,000-1,000,000 population	20	15	10
Urban: >1,000,000 population	25	20	15

Source: Assessment of National Water Use & Demand Forecast, MOWIE, 2020.

2.8 Overall Projected Water Supply Demand

The predicted total of residential and nondomestic water consumption is included in this section.

3. Findings and Discussion

3.1 Projected Population

3.1.1 Choosing of Forecasting Estimation Method

According to contests outlined in the methodology, the geometric increase method was picked as one of the best ways regarding the Ghba subbasin, which are listed in table 6 below.

Table (6) Error competition of the forecasting estimation methods based on the geometric increase method the population estimate shows that 670,069 and 541,121 people live in both the subbasin's urban and rural settings respectively as of 2020 [16]. The projected population of rural and urban residents in the subbasin will be 1.16 and 1.36 million, respectively in the projected year of 2050. Figure 4 below show the projected populations of throughout the subbasin, both city and rural settings in every five years for the coming thirty years.

3.2 Projected Domestic Water Demand Estimate

The projected domestic water demands of the subbasin's urban and rural residents will be 50.68 and 21.31 MCM, respectively in the projected year of 2050. Figure 5 show the projected demands of rural and urban settings of the subbasin in every five years for the coming thirty years.

3.3 Projected Industrial and Nondomestic Water Demand Estimate

The data collected by Hiben, Gebeyehu [16] was used as a baseline demand of 2020 to project the nondomestic and industrial demand as per discussed on the methodology. Accordingly, the projected nondomestic water demands between urban and rural settings of the subbasin will be 34.45 and 2.76 MCM, respectively in the projected year of 2050. Figure 6 show the projected demands of nondomestic during each of the subsequent thirty years, within the research area.

3.4 Projected Nonrevenue Water Loss Estimate

As the steps explained on the methodology the projected nonrevenue losses between urban and rural settings will be 16.71 and 1.2 MCM, respectively in the projected year of 2050. For the next thirty years, the predicted non-revenue losses within the research area are depicted in Figure 7 every five years.

Table 6. Error competition of the forecasting estimation methods

Year	Exponential	Geometric	Arithmetic	Incremental
2020 (Actual)	1,211,190	1,211,190	1,211,190	1,211,190
2020 (Computed)	1,203,591	1,205,200	1,202,195	1,220,495
Error	0.0063	0.0051	0.0075	-.0077

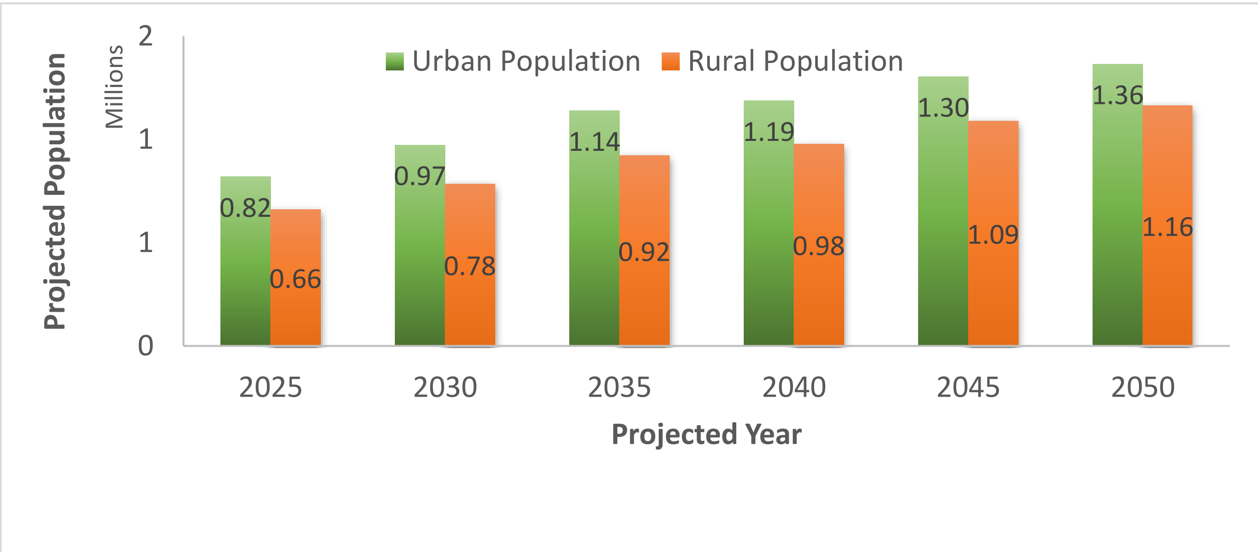

Figure 4. Projected human population of Ghba Subbasin for the projected years

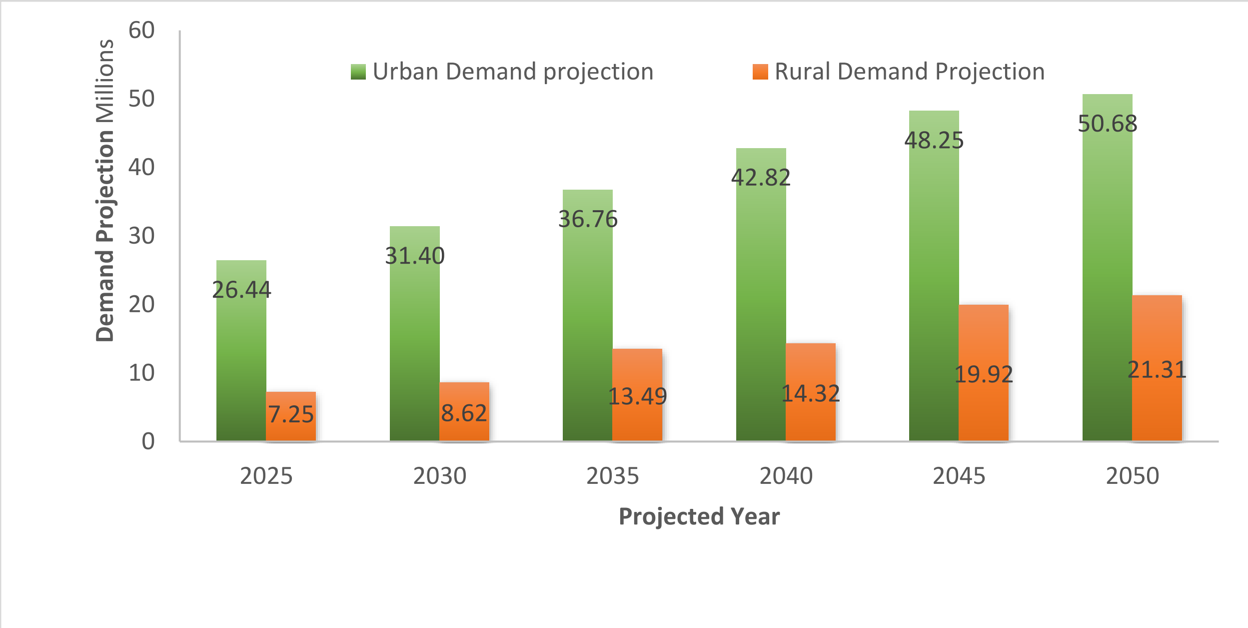

Figure 5. Climate adjusted domestic water supply demand projection of the study subbasin

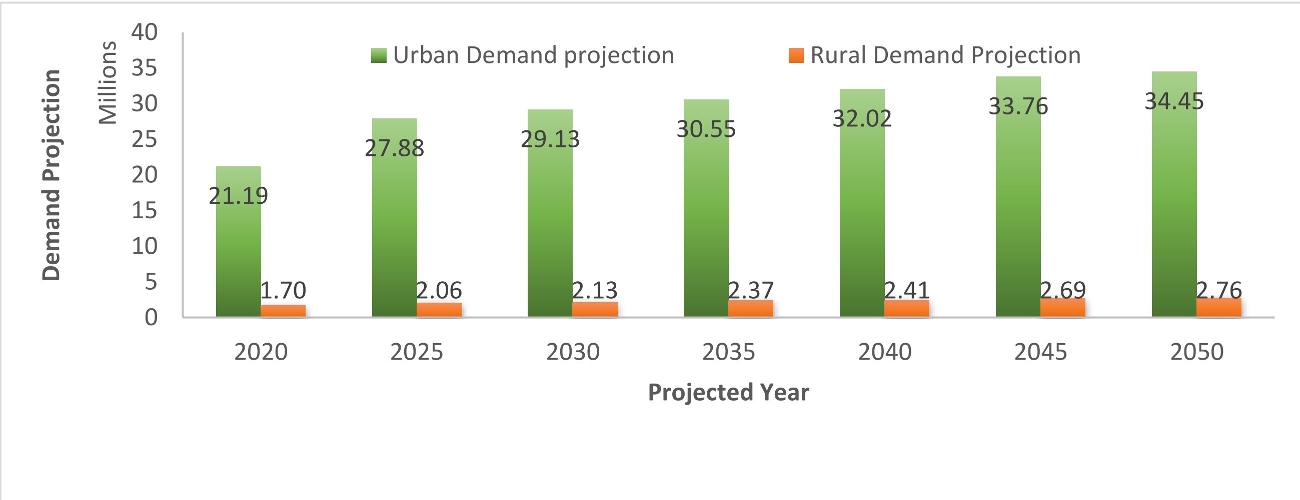

Figure 6. Non-domestic and Industrial water supply demand projection of the study subbasin

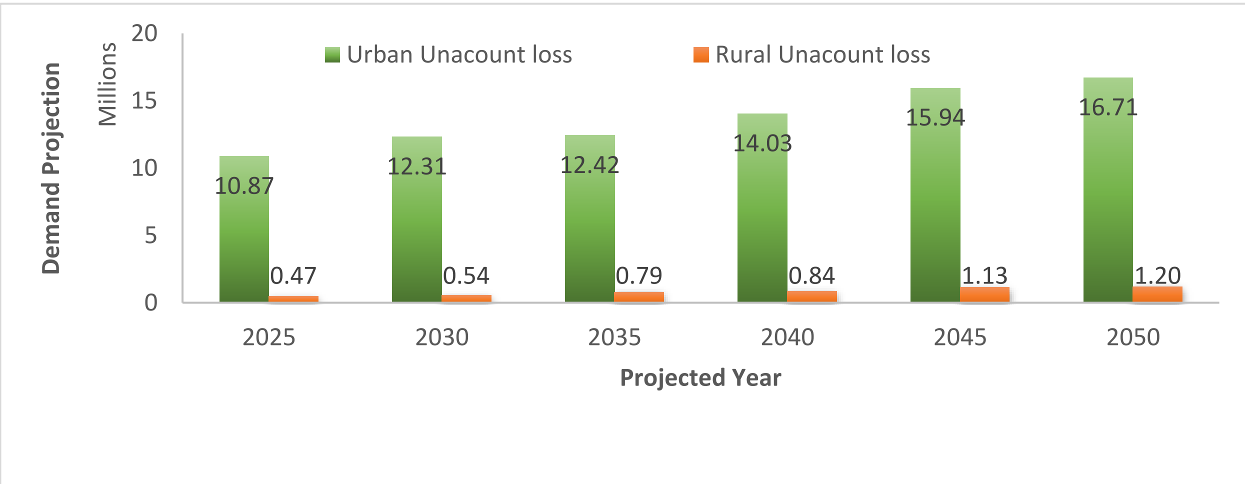

Figure 7. Nonrevenue water supply demand loss projection of the study subbasin

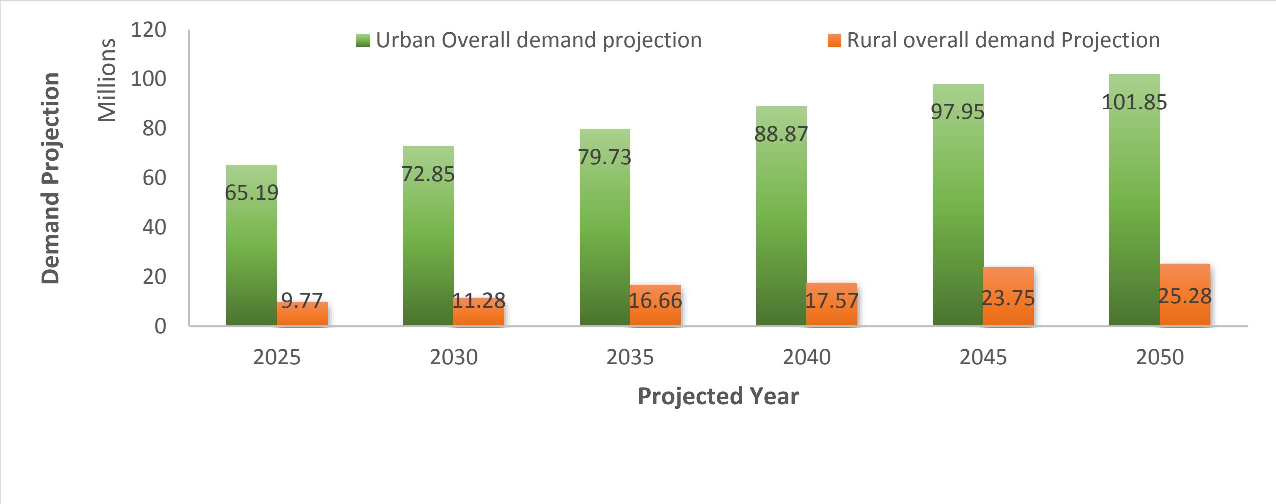

Figure 8. Overall water supply demand projection of the study subbasin

3.5 Projected Overall Water Supply Demand Estimate

As explained on the methodology the projected overall demand of the subbasin's urban and rural settings will be 101.85 and 25.28 MCM, respectively in the projected year of 2050. Figure 8 show the projected demand within the research area as a whole in every five years for the coming thirty years.

4. Conclusions and Recommendation

The methods suggested by the Ethiopian Ministry of Water and Energy for evaluating and forecasting water supplies as well as with continuous conflicting water demand due to climate change and socioeconomic development were investigated in this study. This required customization and simplification of methods to suit the decision context, data constraints, and political sensitivities. This study forecasts the present use of water for Potable water supply purposes. The forecast by 2050 shows that the rural subbasin's residential and non-domestic demand will be 21.31 Mm^3/year and 2.76 Mm^3/year, respectively. Similarly, the domestic municipalities in the subbasin's water demands are forecasted to be 50.68 Mm^3/year while the industrial and nondomestic are forecasted to be 34.45 Mm^3/year. The forecasted real loss for the entire supply of water demand is 17.91 Mm^3/year.

The research revealed that some categories of users are more influenced by weather, underscoring the relevance of adding the socioeconomic position of the consumers when investigating the impacts of weather on water. Climate change, population growth, and socioeconomic development according to the findings, worsen the gap between water demand and unmet needs.

In conclusion, the uncertainty associated with future precipitation and demand for water has a critical feature of adaptation decision-making and infrastructure planning in the Ghba Subbasin. Our results revealed how changes in both climatic and socioeconomic factors strongly influence future water resource system performance. We initiate an iterative approach and made the analysis to change to meet the decision context and stakeholder requirements. However, this study's anticipated water demand model's methodology may not be final, as testing these products under various study circumstances and time frames might yield various demand results. Despite of the uncertainties explained, this research will be a good reference of water demand forecasting techniques to insure climate resilient plans for managing and allocating water.

Recommendations, it is highly concerning that the catchment yield of the subbasin allocated for Potable Water Ssupply is almost equal to the predicted water demand. This indicates that much more investigation is required to critically understand the anticipated water demand in order to design a better water management system within the research area.

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