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POPULATION GROWTH AND DRINKING WATER DEMAND IN CITIES: COMPARATIVE STUDY APPLIED TO THE CITY OF BUJUMBURA

**NTACONAYIGIZE Frédéric¹, Pritpal Singh², Bukuru Denis³, Uwizeyimana
Canesius⁴, Sibomana Alexis⁵**

¹PhD student, Centre de Recherche et d'Etude en Sciences Appliquées (CRESA),
Doctoral school of the University of Burundi, Burundi.

²Lecturer and Researcher, Department of Electrical and Computer Engineering,
Villanova University (USA).

³Lecturer and Researcher, Department of Applied Sciences,
Ecole Normale Supérieure du Burundi, Burundi.

⁴Lecturer and Researcher, Department of Applied Sciences,
Ecole Normale Supérieure du Burundi, Burundi.

⁵Lecturer and Researcher, Department of Applied Sciences,
Ecole Normale Supérieure du Burundi, Burundi.

ABSTRACT

Faced with the population growth and the expansion of the city of Bujumbura on the one hand and the shortage of drinking water on the other hand, there are increasing shortages of drinking water and insufficient of existing hydraulic installations capacity in the drinking water supply sector. Overcoming this problem involves forecasting the consumption of this resource based on the size of the growing population. Rapid urban population growth is putting increasing pressure on drinking water resources and water services. This article proposes a comparative study applied to the city of

Bujumbura (Burundi) aimed at quantifying the evolution of drinking water demand between 2024 and 2064, identifying the main determinants of this demand and proposing management scenarios to ensure urban water security. The approach combines demographic projections, estimation of domestic and non-domestic demand, analysis of production capacities and network losses, and formulation of adaptation strategies. The results show that at current trends, total demand could increase by 150 – 500 % between 2024 and 2064, creating a significant deficit if investments and management measures are not implemented.

Keywords: Water demand, Population growth, Bujumbura, Urban expansion, Water scarcity, Demand forecasting, Infrastructure capacity, Water management

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1. Introduction

Water in general and drinking water in particular is at the center of many debates and studies. Water is a source of life and a factor of development because there are few human activities, whether production or consumption, that do not require it. In addition, this essential economic good currently has few substitutes. At the global level, its consumption has increased over the last thirty-five years at an annual rate of 4 to 8% per year (Benalia, 2012) .

Throughout the city of Bujumbura, although the water resources of Lake Tanganyika are sufficient enough to meet the drinking water needs of the population, there is however a great lack of drinking water. The problems of water shortages are more acute in peripheral areas characterized by high population density. In some areas of the city of Bujumbura, water shortages have become routine. Residents can spend three days or more without water in their taps. In some localities, borehole water has come as a solution, but its impact remains minimal.



Figure 1: The population draws water produced by the borehole in Kamenge (photo taken on September, 2023)



Figure 2: Cans lined up on a dry tap waiting for drinking water in the Cibitoke area (photo taken on September, 2023)

Faced with this situation, it is then to be feared that this situation will worsen further with the increase in the population and the expansion of the city of Bujumbura. In anticipation of the fact that the expansion of the city of Bujumbura could further accentuate the shortage and disrupt the distribution of drinking water, it is therefore imperative to show the demand for drinking water in order to predict the drinking water needs of the populations to ensure a

sustainable supply. It is in this perspective that this study on the long-term planning of drinking water consumption is conducted.

The question of comparing the evolution of the demand for drinking water with the evolution of the population will be addressed by the comparison approach based on mechanisms of formation and evolution of the drinking water demand. From a mathematical point of view, we will first analyze the evolution of the production and consumption of drinking water. Based on the data on the number of subscribers to the drinking water supply network of the city of Bujumbura, we determine the quantity of drinking water necessary to satisfy the drinking water needs of the population of the city of Bujumbura. Based on the growth rate of the population of the city of Bujumbura, we project future needs until 2064. The quantitative evaluation to do based on standards determined according to the economic context and social to which they refer. They express themselves in general in liters per day and by inhabitant.

1.1 Study site

Bujumbura, the capital of the Republic of Burundi, an East African country, is located in the west of the country on the shores of Lake Tanganyika (a lake with an area of over 34,000 km²) which is used more than 90% for the drinking water supply of the city of Bujumbura. The city of Bujumbura corresponds to the geographical coordinates 29°21 ' 51 " East longitude and 3°22 ' 55 " South latitude. The city of Bujumbura today has an area of 14,500 hectares, the relief is characterized by a low-lying plain that rises from west to east with an average altitude of 820 meters. The climate, tropical, offers dominant sunshine all year round and an average temperature of 23°C, with peaks at 28°-30°C during the hottest periods. Bujumbura, like the rest of the country, has four seasons: the long and short dry seasons, the long and short rainy seasons (*Geology and Pedology of Burundi | Burundi Information Exchange Center* , n.d.) .

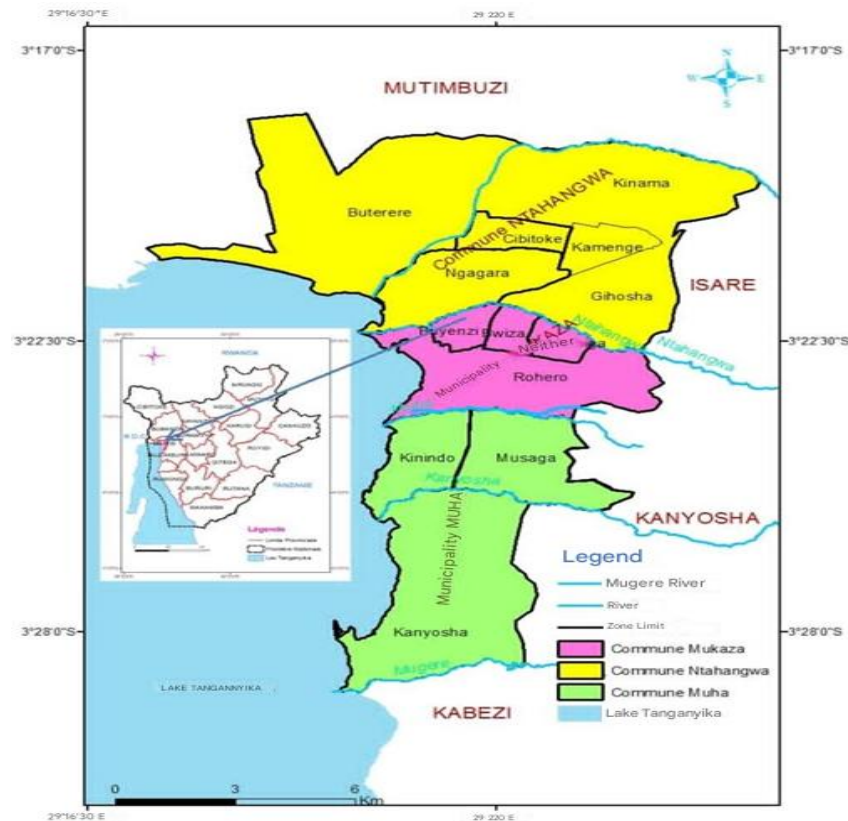


Figure 2: Location and administrative subdivision of the city of Bujumbura (2014 division)

2. Materials and methods

2.1 Model construction

Distribution of the needs

From a methodological point of view, water needs are assessed on the basis of the quantity of drinking water distributed to subscribers, which constitutes a very important aspect in any integrated spatial planning of drinking water resources. The distribution of water needs is a very important element because it allows the sources to coincide with the location of the consumers of water (Benalia, 2012). This breakdown is therefore a synthesis of the criteria of mobilization of the resources water with as corollaries taking into account geomorphology and their distribution of the economic activities of their population. As a result, the drinking water supply network of the city of Bujumbura is divided into four zones: Southern zone (Muha commune), central zone (Mukaza commune), north-east (Ntahangwa commune) and the north-west part (Gatumba zone of Mutimbuzi commune).

Approach

Once the hypotheses have been clearly identified, the demand for water will be evaluated and approached by a model prospective formalized by scenarios. These are simulated

to understand the trends and behavior of aggregate demand at a defined stage of development in the time. The interest of the model is to show current and future needs for drinking water as well as the effects on the expansion of the city which generates a new demand for drinking water.

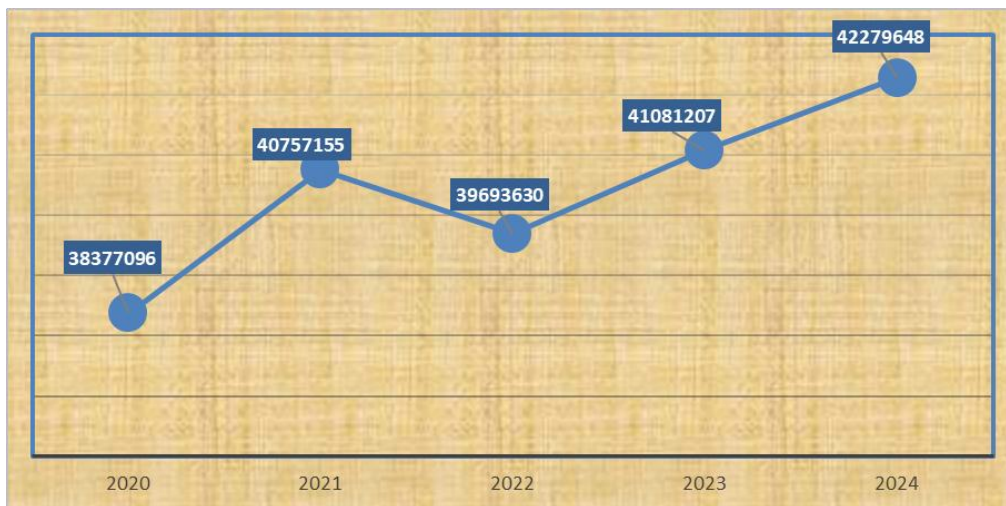
3. Basic data

3.1 Total drinking water production in the city of Bujumbura

The city of Bujumbura is supplied by surface and underground resources: water from Lake Tanganyika, the Ntahangwa River, 5 springs from the reliefs of the east of the city and 2 boreholes in the northwest of the city. Table 1 and graph 1 show respectively the total drinking water production of the city of Bujumbura from 2020 to 2024.

Table 1. Total drinking water production in the city of Bujumbura from 2020 to 2024 (REGIDESO, 2024c)

Year	2020	2021	2022	2023	2024
Total water produced	38377096	40757155	39693630	41081207	42279648



Graph 1. Total drinking water production in the city of Bujumbura from 2020 to 2024

3.2 Total drinking water consumption in the city of Bujumbura

According to REGIDESO data, the majority of consumption is attributed to domestic consumption around 60% and non-domestic consumption around 40%. Water leaks represent

45% and the yield is 55%. Table 2 and Graph 2 show respectively the drinking water consumption of the city of Bujumbura from 2020 to 2024

Table 2: Drinking water consumption in the city of Bujumbura from 2020 to 2024 (REGIDESO, 2024a)

Year	2020	2021	2022	2023	2024
Drinking water consumption	21107403	22416435	21831497	22594664	23253806



Graph 2: Drinking water consumption in the city of Bujumbura from 2020 to 2024

3.3 Drinking water leaks in the city of Bujumbura from 2020 to 2024

Table 3 and graph 3 show drinking water leakages for the period 2020 to 2024 respectively.

Table 3: Drinking water leaks in the city of Bujumbura from 2020 to 2024 (REGIDESO, 2024b)

Year	2020	2021	2022	2023	2024
Leaks	17269693	18340700.75	17862136	18486560	19025895.6



Graph 3: Drinking water leaks in the city of Bujumbura from 2020 to 2024

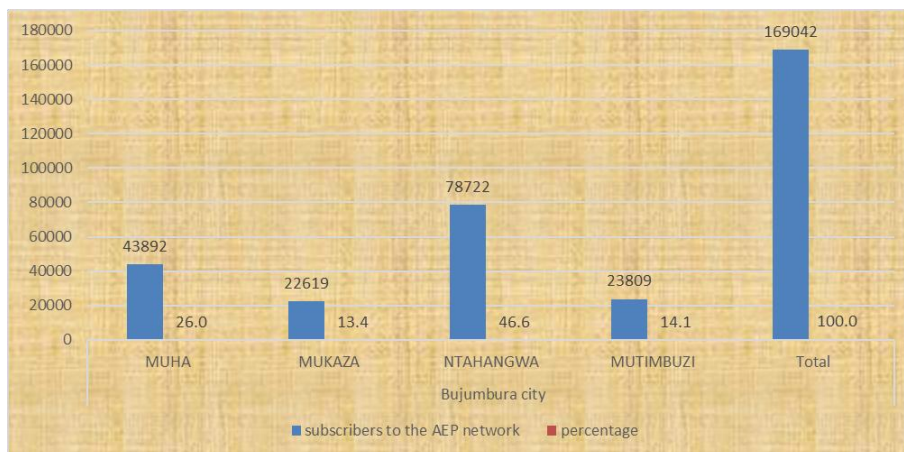
3.4 Calculation of the current demand of subscribers to the DWS network of the city of Bujumbura

Subscribers to the REGIDESO¹ drinking water network in the City of Bujumbura are divided into four zones: Muha , Mukaza , Ntahangwa and Mutimbuzi (REGIDESO, 2024a) . Table 4 and graph 4 show respectively the number of subscribers by zone as well as the total number of subscribers in 2024.

Table 4. Number of subscribers in the city of Bujumbura in 2024 (REGIDESO, 2024a)

SITE		Staff	Percentage
City Bujumbura	MUHA	43892	26.0
	MUKAZA	22619	13.4
	NTAHANGWA	78722	46.6
	MUTIMBUZI	23809	14.1
	Total	169042	100.0

⁶ Régie de Production et de Distribution d’Eau et d’Électricité du Burundi

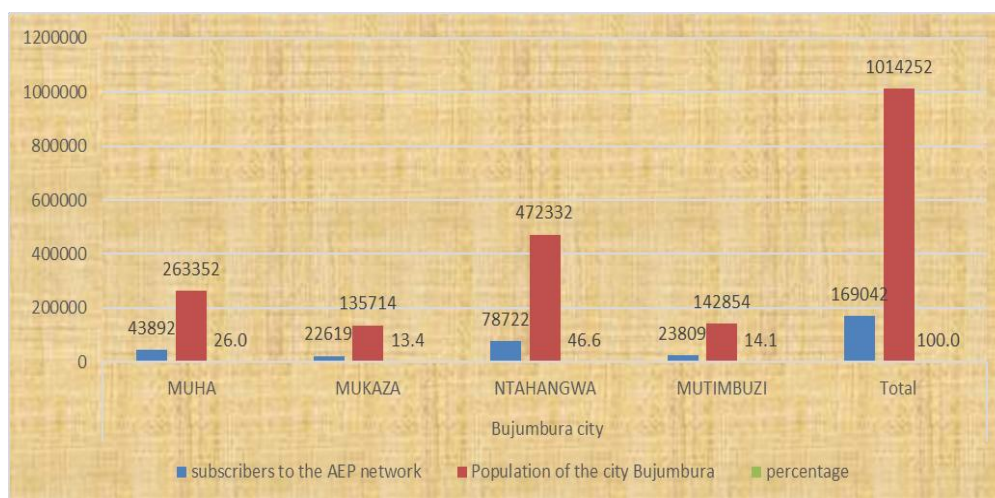


Graph 4. Number of subscribers in the city of Bujumbura in 2024

If we take into account an average of 6 people per subscriber, the total population and per site are indicated respectively in table 5 and graph 5

Table 5: Population of the city of Bujumbura subscribed to the DWS network in 2024 (REGIDESO, 2024a)

SITE		Subscribers	Population	Percentage
City Bujumbura	MUHA	43892	263352	26.0
	MUKAZA	22619	135714	13.4
	NTAHANGWA	78722	472332	46.6
	MUTIMBUZI	23809	142854	14.1
	Total	169042	1014252	100.0



Graph 5: Population of the city of Bujumbura subscribed to the DWS network in 2024

3.5 Calculation of average daily and annual flow rates

According to REGIDESO data, the average allocation is 120 litres per day per inhabitant.

The average daily requirements in (m³ per day and per inhabitant) are estimated by equation (1) and the average flow rate in l/s by equation (2) (Abdelbaki, 2014) .

$$Q_{avg} = \frac{P \times D}{1000} [m^3 / d] \tag{1}$$

The average flow rate in liters per second for a population P at horizon n is given by the following equation:

$$Q_{avg} = \frac{P \times D}{86400} [l / s] \tag{2}$$

With:

Q_{avg}: average flow rate in (l/s)

P: population number

D: water supply in l/d/ inhab.

Table 6 shows the average daily and annual flow rate for each zone and total drinking water consumption in the city of Bujumbura

The population at the horizon of year *n* can be approximately evaluated by the following equation 3 (Ahmed, 2017) :

$$P_n = P_0 (1 + \alpha)^n \tag{3}$$

With:

P_n: is the population at the horizon of year *n*,

P₀: is the population of the reference year 0,

α: is the population growth rate.

Table 6: Average daily and annual flow of the population of the city of Bujumbura subscribed to the DWS network in 2024

SITE		Subscribers	Population	Qmoyd (l/s)	Qmoyd (m ³ /day)	Qmoy (m ³ /year)	Percentage
City Bujumbura	MUHA	43892	263352	373.5489362	31602.24	11376806.4	26
	MUKAZA	22619	135714	192.5021277	16285.68	5862844.8	13.4
	NTAHANGWA	78722	472332	669.9744681	56679.84	20404742.4	46.6
	MUTIMBUZI	23809	142854	202.6297872	17142.48	6171292.8	14.1
	Total	169042	1014252	1438.655319	121710.24	43815686.4	100

3.6 Calculation of future consumption of subscribers to the DWS network of the city of Bujumbura

Based on data from the population censuses of 1979, 1990, 2008 and 2024, we estimate the population of the city of Bujumbura and the annual flow of drinking water until 2064. For a good estimation, three scenarios are highlighted: the Natural Trend Scenario (NTS), the Moderate Scenario (MS) and the Extreme Scenario (ES) (Atba, 2013) .

3.7 Population of the city of Bujumbura from 1979 to 2024

Table 7 and graph 6 show respectively the evolution of the population of the city of Bujumbura

Table 7: Population of the city of Bujumbura from 1979 to 2024 (*Annuaire-Statistique-du-Burundi-2021vf.pdf*, n.d.)

Year	1979	1990	2008	2024
Population	168368	235440	497 166	1277050



Figure 6: Population of the city of Bujumbura from 1979 to 2024

3.8 Average intercensal growth rate

This rate expresses the average annual growth for the period between two censuses when it is assumed that it is constant over the period considered. The average intercensal growth rate is given by the following formula 3 (*Annuaire_statistique_2008.pdf*, n.d.) :

$$r = \left(\frac{P_n}{P_0} \right)^{\frac{1}{t}} - 1 \tag{4}$$

P_n = population at the current census;

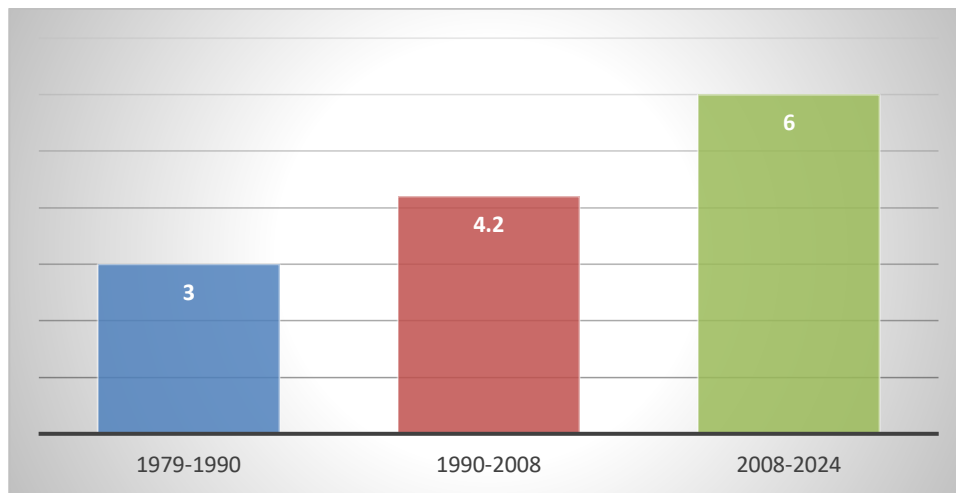
P_0 = population at previous census;

t = number of years between the two censuses;

r = average annual growth rate;

Table 8: Average intercensal population growth rate of the city of Bujumbura (*2008 Burundi Population Survey_Status and Structure of Population.pdf* , n.d.)

Period	1979-1990	1990-2008	2008-2024
Average growth rate in %	3	4.2	6



Graph 7: Average intercensal growth rate of the population of the city of Bujumbura

The experiments conducted throughout the world and the specificity of the region studied seem to favor the prediction of a development model with simulation steps of 10 years [12]. The year 2024 was chosen as the base year representative of the homogeneity of the statistical data.

3.9 Study of the scenarios

In our research, we apply three scenarios:

The Natural Trend Scenario or Low Scenario (LS): corresponds to the extrapolation of the current situation to 2064. This scenario is characterized by a very low growth trend observed by the closure of industries and the stagnation of the expansion of the city. In addition, this scenario does not envisage real control of demography and management of urbanization. The spatial distribution of the population will be unbalanced and the improvement of the water supply situation will be slow in coming. All unfavorable assumptions will be taken into account

Population Growth and Drinking Water Demand in Cities: Comparative Study Applied to the City of Bujumbura (Coumba, 2019) . Here we will use the average growth rate from 1979 to 1990. Table 9 and graph 8 respectively show the evolution of the population according to the said growth rate.

Table 8: Evolution of the population of the city of Bujumbura (2024 to 2064) according to the low scenario (LS)

Year	2024	2034	2044	2054	2064
Population	1277050	1716248	2306494	3099735	4165785



Graph 7: evolution of the population of the city of Bujumbura (2024 to 2064) according to the Low Scenario (LS)

The Moderate Scenario or Medium Scenario (MS): characterized by a recovery of the economy but in a timid way whether it is the extension of the city and industrial development. However, the water supply would still be failing whether it is for domestic or non-domestic drinking water. Here we will use the average growth rate from 1990 to 2008. Table 9 and graph 8 respectively show the evolution of the population according to the said growth rate.

Table 9: Evolution of the population of the city of Bujumbura (2024 to 2064) according to the Moderate Scenario (MS)

Year	2024	2034	2044	2054	2064
Population	1277050	1927014	2907784	4387725	6620894

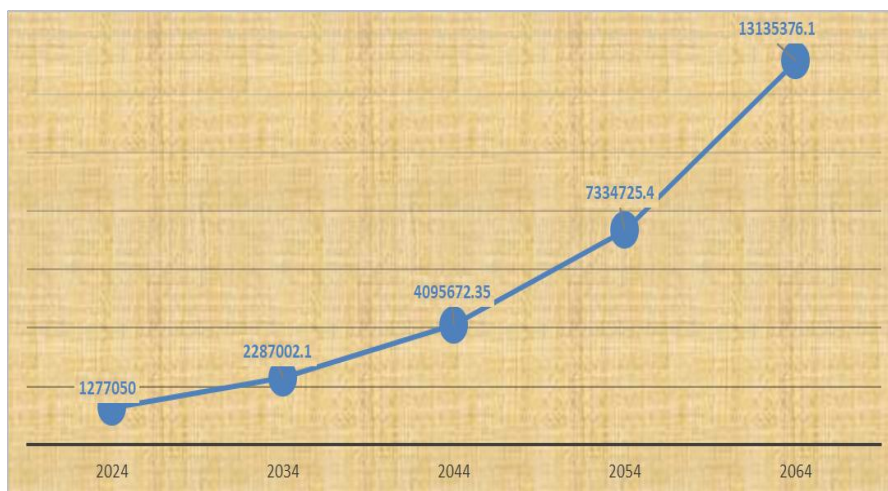


Graph 8: evolution of the population of the city of Bujumbura (2024 to 2064) according to the Moderate Scenario (MS)

The Extreme Scenario (ES): more optimistic would include a real management of demographic, urbanization and environmental problems thanks to a global economic recovery of the city. Table 10 and graph 9 show respectively the evolution of the population according to the said growth rate.

Table 10: Evolution of the population of the city of Bujumbura (2024 to 2064) according to the Extreme Scenario (ES)

Year	2024	2034	2044	2054	2064
Population	1277050	2287002.1	4095672.35	7334725.4	13135376.1



Graph 9: Evolution of the population of the city of Bujumbura (2024 to 2064) according to the Extreme Scenario (ES)

3.10 Calculation of average annual flow rates according to the scenarios

Table 11 and graph 10 respectively show the estimated annual flow of the population of Bujumbura from 2024 to 2064 according to the low scenario (SF)

Table 11: Drinking water flow rate for the population of the city of Bujumbura (2024 to 2064) according to the Low Scenario (LS)

Year	2024	2034	2044	2054	2064
Q _{awf} (m ³ /year)	55188000	741419136	996405408	1339085520	1799619120

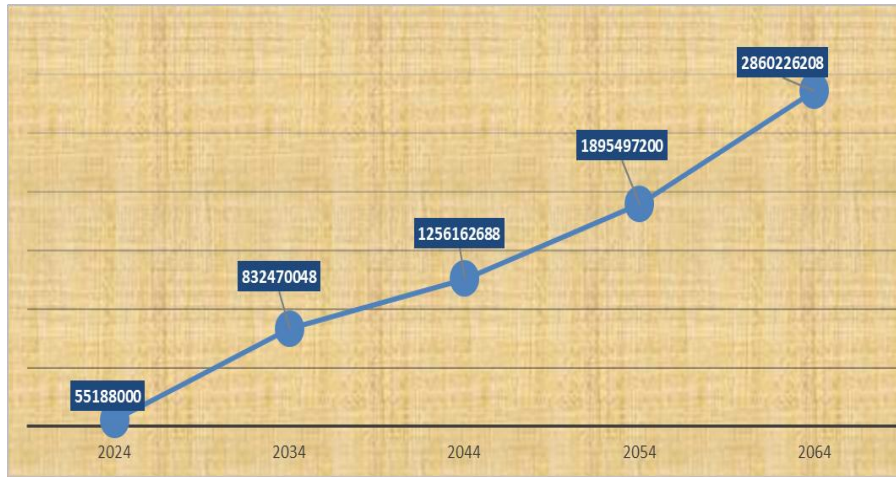


Graph 10: Drinking water flow rate for the population of the city of Bujumbura (2024 to 2064) according to the Low Scenario (LS)

Table 12 and graph 11 show respectively the estimated annual flow of the population of Bujumbura from 2024 to 2060 according to the Moderate Scenario (MS)

Table 12: Drinking water flow rate for the population of the city of Bujumbura (2024 to 2064) according to the Moderate Scenario (MS)

Year	2024	2034	2044	2054	2064
Q _{awf} (m ³ /year)	55188000	832470048	1256162688	1895497200	2860226208



Graph 11: Drinking water flow rate for the population of the city of Bujumbura (2024 to 2064) according to the Moderate Scenario (MS)

Table 13 and graph 12 show respectively drinking water flow rate for the population of Bujumbura city from 2024 to 2060 according to the Extreme Scenario (SM)

Table 13: Drinking water flow rate for the population of the city of Bujumbura (2024 to 2064) according to the Extreme Scenario (ES)

Year	2024	2034	2044	2054	2064
Q _{awf} (m ³ /year)	55188000	987984864	1769330304	3168601200	5674482432

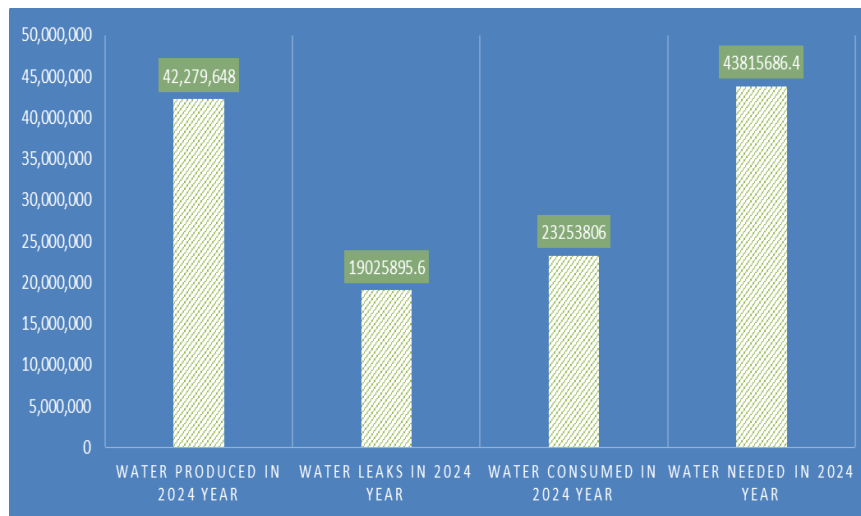


Figure 12: Drinking water flow rate for the population of the city of Bujumbura (2024 to 2064) according to the Extreme Scenario (ES)

Q_{awf}: Average water flow

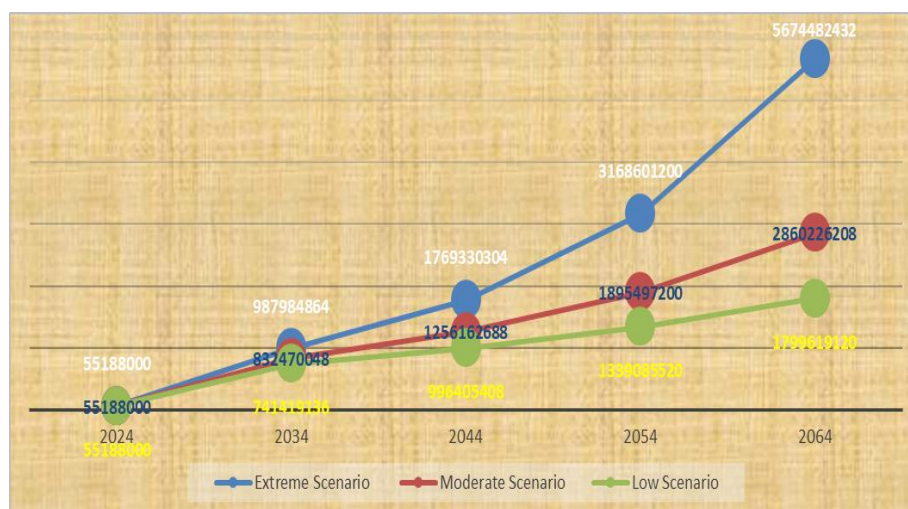
4. Discussion of results

Results of our research show this:



The total production of drinking water in the city of Bujumbura for the year 2024 is **42,279,648 m³ per year**.

Drinking water leaks are estimated at **19,025,895.6 m³ per year** and the total consumption of drinking water is **23,253,806 m³ per year**. Calculations based on the number of subscribers to the drinking water supply network of the city of Bujumbura and based on the daily allocation of each inhabitant show a demand of **43,815,686.4 m³ per year in 2024**. This value is the one that is necessary to satisfy the drinking water consumption of the population of the city of Bujumbura for the year 2024. The projections of the drinking water demand of the city of Bujumbura show the annual water flows until 2064 with a 10-year step. This projection shows the drinking water flows in three scenarios: Low Scenario (LS), Moderate Scenario (MS) and Extreme Scenario (ES) as shown in the following graph



5. Analysis

The results of our research estimate the annual consumption of drinking water required at 43,815,686.4 m³ per year for the population of the city of Bujumbura in 2024. Our study shows that the consumption rates provided by REGIDESO do not correspond to actual consumption but correspond to installed capacities. The study also showed that drinking water leaks are around 45%, which constitutes enormous losses for a drinking water supply network. Projections of drinking water demand up to 2064 show that the drinking water supply (DWS) network of the city of Bujumbura will consist of a dense network of several reservoirs, several pumping stations and pipelines. As the Lake Tanganyika plant produces 92% of the city's drinking water resources, supplemented by the treatment of river water and springs from the surrounding mountains, numerous pumping stations will allow water, mainly produced from the lake, to be pumped up to the tanks which will be distributed at altitude towards the east and west.

6. Conclusion

This work constitutes a first step in a global process whose aim is to develop techniques to help manage drinking water networks in general and urban drinking water networks in particular. It emerges from this study that the use of data on the population's drinking water consumption does not lead to good estimates of water consumption in the city of Bujumbura. But the determination of drinking water demand based on the population and on the allocation in liters per day and per inhabitant has led to good estimates of drinking water demand in the city of Bujumbura. The projection of drinking water demand in the city of Bujumbura will allow decision-makers to plan the extension of the drinking water supply network in the city of Bujumbura.

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