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DRINKING WATER SUPPLY ISSUES: MODELLING AND INTEGRATED MANAGEMENT FOR FUTURE SUSTAINABILITY. THE CASE OF THE CITY OF GUELMA, NORTH-EAST ALGERIA

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ABSTRACT

The city of Guelma has experienced remarkable urban sprawl over the last few decades, with a continuous expansion of the urban area to accommodate a growing population. This phenomenon is particularly accentuated by a high demographic growth rate, which increases the pressure on infrastructure and basic services, especially drinking water supply, due to the increasing needs of households. The main objective of this study is to analyse the contribution of the WEAP model to the management of drinking water supply in the different sectors of the city of Guelma. This approach aims to ensure effective and sustainable planning of water resources to meet the growing needs of the population in each sector, while preserving this essential resource. The results show that water resources are limited, with projected consumption increasing from 6 million m³ in 2008 to around 47 million m³ in 2050, while the population is expected to reach almost 800,000 inhabitants. All scenarios show a water deficit, where demand exceeds supply. The study therefore emphasises the need for integrated water resource management to ensure sustainability. It uses hydrological and demographic data to guide supply decisions and aims to develop effective strategies to address the growing water challenges in the city of Guelma.

KEYWORDS

Drinking Water, City of Guelma, WEAP Model, Water Demand, Water Modelling, Future Sustainability

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INTRODUCTION

Drinking water supply (DWS) is essential for the proper functioning and development of cities. Population growth, urban development, industrial growth, and the expansion of agriculture and tourism have significantly increased the demand for water (Mensah et al., 2022), posing significant challenges to urban communities. According to the United Nations, nearly 68% of the world's population will live in urban areas by 2050, increasing pressure on water resources (United Nations, 2018).

Algeria, with its vast territory and climatic variations, faces significant drinking water challenges. According to the Ministry of Water Resources, the country has experienced an increase in demand for drinking water due to population growth and urbanisation (Ministry of Water Resources, 2020).

In this context, the use of advanced water resources modelling and management tools, such as WEAP (Water Evaluation and Planning system), is essential to optimise drinking water supply and distribution. WEAP could be used to simulate the impact of urban expansion on the demand for drinking water in residential areas, while taking into account the pressure of agriculture on available water resources (Ouamane, 2009). One of the advantages of WEAP is its ability to simulate different management scenarios, allowing local decision-makers to test the impact of different water management strategies. For example, the impact of wastewater reuse, the introduction of more efficient management techniques or improvements in distribution infrastructure can be modelled to assess their effectiveness in reducing pressure on water resources.

The application of WEAP to water resource management at the scale of the city of Guelma is part of a global context in which water resource management is increasingly supported by modelling tools. According to Shiklomanov and Rodda (2003), models such as WEAP play a fundamental role in understanding and anticipating water needs at regional and local scales, especially in developing countries where water resources are often limited. These authors also emphasise the importance of integrated water resources management to meet the growing needs of populations and economic sectors.

The work of Yates et al. (2005) and Husain and Rhyme (2021) shows that WEAP can be used to assess the impact of climate change and seasonal variations on water availability, a critical factor for cities such as Guelma that are subject to significant climate variability. Mensah et al. (2022) show that the tool can also be used to model climate change adaptation strategies by integrating different resource management parameters.

Other studies, such as those by Yazdanpanah et al. (2008) and Höllermann et al. (2010), have also shown that WEAP is an excellent tool for simulating the impact of water management policies on the sustainability of supply systems, particularly in regions where water resources are limited. These studies have confirmed that the integration of water resource management models such as WEAP into decision-making processes is essential to ensure optimal and resilient management of water resources.

The main objective of this study is to examine the contribution of WEAP to the management of the drinking water supply in the different sectors of the city of Guelma, as a strategic opportunity to improve the efficiency and sustainability of the drinking water supply. This approach aims to ensure optimal and sustainable management of water resources to meet the growing needs of the population in each sector, while preserving this essential resource and ensuring an equitable and sustainable supply for the entire city.

1. MATERIALS AND METHODS

1.1 Description of the study area

The city of Guelma, the capital of the wilaya, is located in north-eastern Algeria, 60 kilometres south of the Mediterranean Sea, 100 kilometres east of Constantine and approximately 537 kilometres from the capital, or 491 kilometres since the construction of the East-West motorway. Its geographical coordinates are 36°27′43″ north and 7°25′33″ east (Figure 1). Located 2 km south of the Seybouse River, it is bordered to the north by the communes of Héliopolis and El Fedjoudj, to the south by the commune of Ben Djerrah, to the east by the commune of Belkheir and to the west by the commune of Medjez Ammar. Surrounded by mountains (Maouna, Dbegh, Houara), it is nicknamed "the city of plates".

Guelma also has a significant regional road network, including National Road No. 20 towards Constantine, National Road No. 21 towards Annaba, National Road No. 80 towards Skikda and Communal Road No. 123 towards the municipality of Ain Makhlouf.

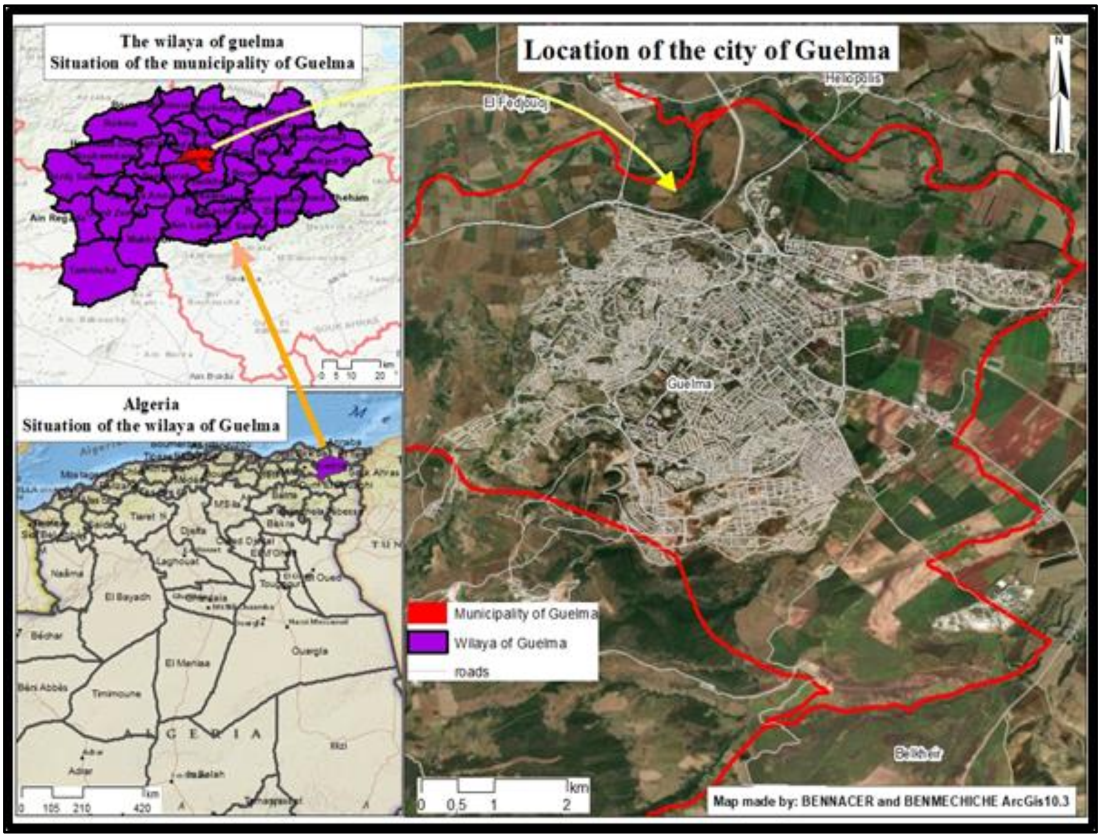

Fig. 1. Geographical situation of the city of Guelma

1.2 Water Resources (Surface and Groundwater)

Surface and groundwater resources play a crucial role in the supply of drinking water. The surface waters primarily come from the Seybouse River and its significant streams, which are mainly replenished by rainfall. The Seybouse River flows through the Guelma plain, extending over 45 km from south to northeast, with a total estimated flow of 408 Hm³/year at the Boudaroua station (Directorate of Hydraulic of Guelma). Groundwater comes from several aquifers, characterized by a wide geographical distribution, thus ensuring the supply of drinking water to urban centers. Among these aquifers, the Guelma alluvial aquifer and the Hammam Bradaa aquifer are particularly noteworthy.

The study area we have chosen has a semi-arid climate, characterized by variations in monthly and annual precipitation. The average annual rainfall is 531.339 mm for the studied period (2012 to 2022), while the average annual temperature reaches 18.15 °C. This climatic regime is divided into two distinct seasons: one is cool and wet, and the other is hot and dry.

The hydrological balance shows a real evapotranspiration of 403.9 mm and a runoff deficit of 525.4 mm, with a runoff of about 66.6 mm. These results clearly indicate that the region is facing water stress conditions. The real evapotranspiration and the runoff deficit suggest that the available water is mainly used to meet the needs of the atmosphere and vegetation, leaving little water for runoff and aquifers.

To meet the demand for drinking water, the water is pumped from the Hammam Debagh Dam, located 3 km upstream of Hammam Debagh, with a capacity of 220 HM³.

1.3 Demographic estimates of the city of Guelma by sector

The city of Guelma has experienced significant population growth. This growth is putting considerable demographic pressure on the main urban centres, particularly the capital of the wilaya, which has almost 187,259 inhabitants. These inhabitants are spread over eight sectors, with an average density of 3,250 inhabitants per km² (Figure 2).

The population growth rate is 2.3% (Direction of Programming and Budgetary Monitoring, Monograph of the Wilaya of Guelma 2023). We estimate the future population using the average annual growth rate and applying the following formula:

$$FP = P0\ (1+a)\ n$$

Where:
FP: Future population
P0: Reference census population
n =PF-P0=2030–2008=22 years
n =FP-P0=2050–2008 =42 years
a = Growth Rate %

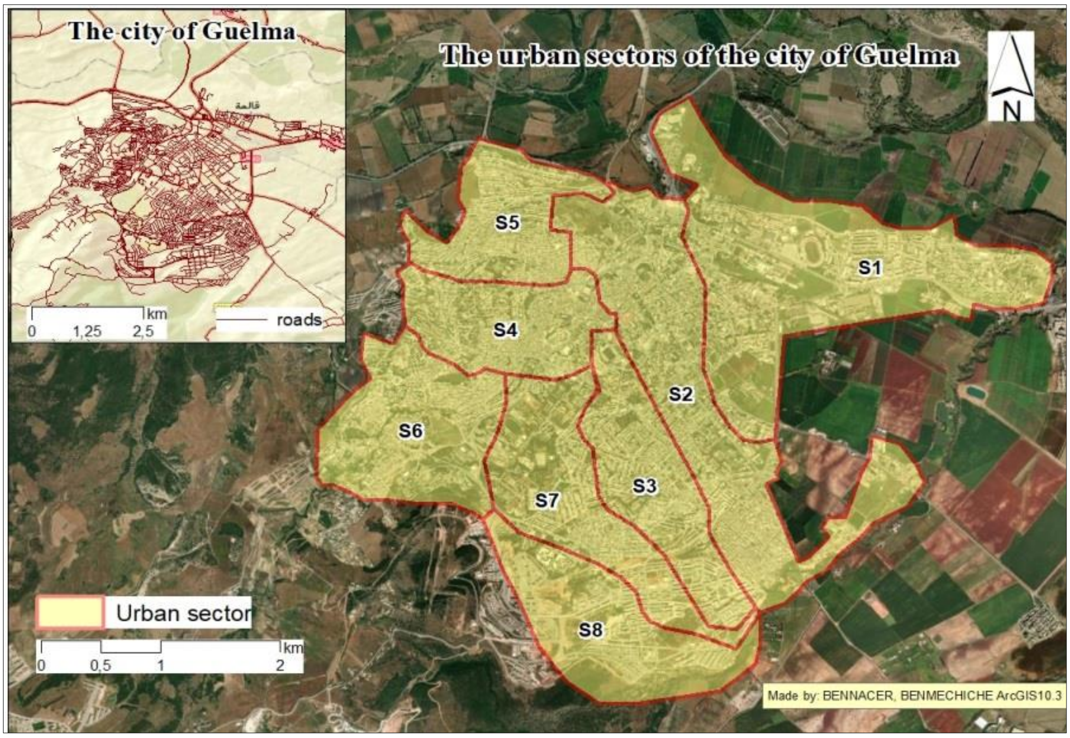

Fig. 2. The urban sectors of the city of Guelma.

Applying the formula to estimate the future population yields the results shown in the map below (Figure 3), which illustrates the projected demographic changes and distributions over the coming years.

1.4 Supply and distribution of drinking water sources by type of resource in the city of Guelma

The supply of drinking water plays a crucial and fundamental role in dynamic urban societies. The demand for drinking water is strongly influenced by a variety of different factors, in particular population growth, higher standards of living, agricultural and industrial practices, and changing climatic conditions.

In the city of Guelma, the main source of drinking water supply is the Bouhamdene dam, which provides 25 hm³/year, an essential resource for its inhabitants. In addition, 4 hm³/year of groundwater complements this supply source, providing an additional resource for the city (Water resources department of the wilaya of Guelma, 2023).

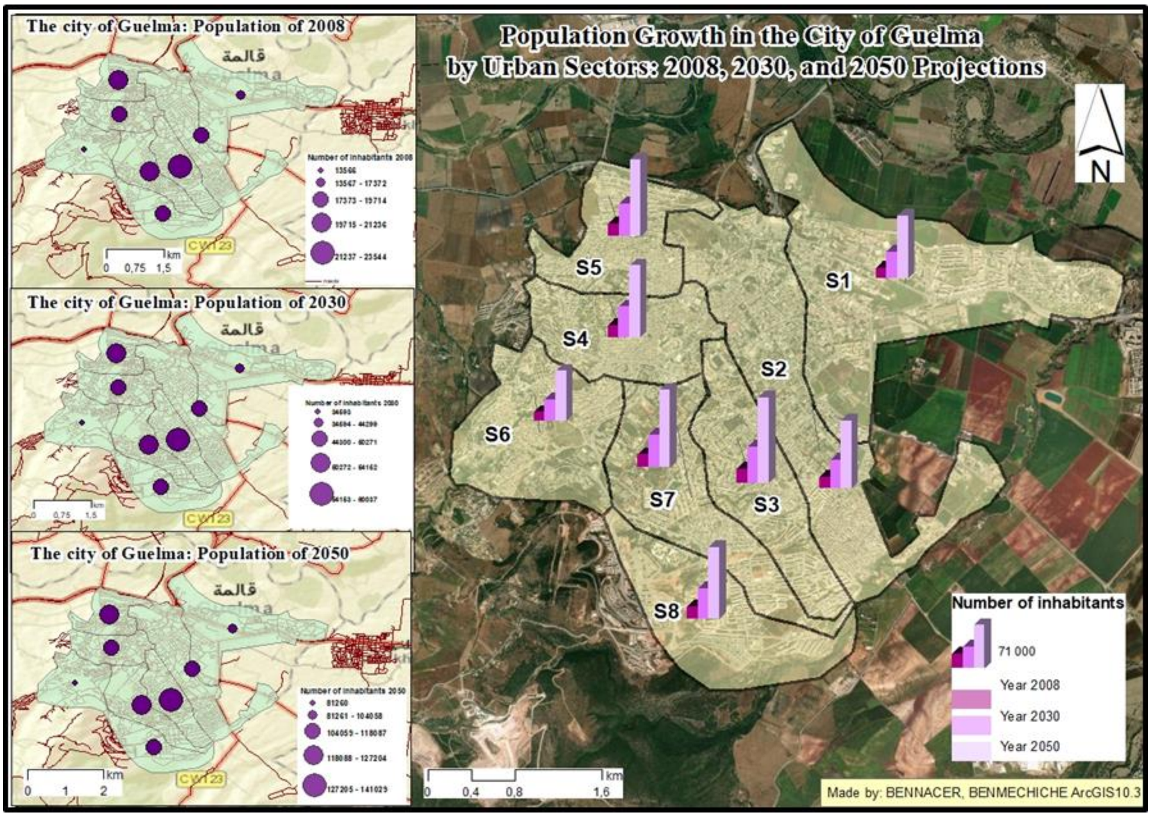

Fig. 3. Population growth in the city of Guelma by urban sectors: 2008, 2030 and 2025 projection.

2. METHODOLOGY

The Water Evaluation and Planning System (WEAP21) is a modelling and planning tool developed by the Stockholm Environment Institute, in particular by the Boston Centre of the Tellus Institute in the United States. This tool offers great flexibility to adapt to different levels of data availability and has an intuitive graphical user interface.

The WEAP methodology was chosen because of the need to understand the current and future state of water resources for effective management. It allows the modelling of available resources as well as the drinking water needs of the population of the city of Guelma.

To operate WEAP, it is essential to input a comprehensive database for each element of the network. The data structure and level of detail can be easily adapted to the specific needs of an analysis, taking into account constraints related to data availability (YATES et al. 2005).

The methodology adopted begins with a presentation of the study sites. The first site concerns water resources, illustrating the layout of the hydrographic network, including the Bouhamdane and Seybouse rivers, as well as the surface water site of the Bouhamdane dam and the groundwater site, which groups together all the boreholes (Figure 4).

The second site is dedicated to the water needs corresponding to the eight sectors of the city of Guelma. It is identified as a group of water users that share a physical distribution mechanism located in a specific area, or that have access to a major abstraction point [HASSAN et al. 2019].

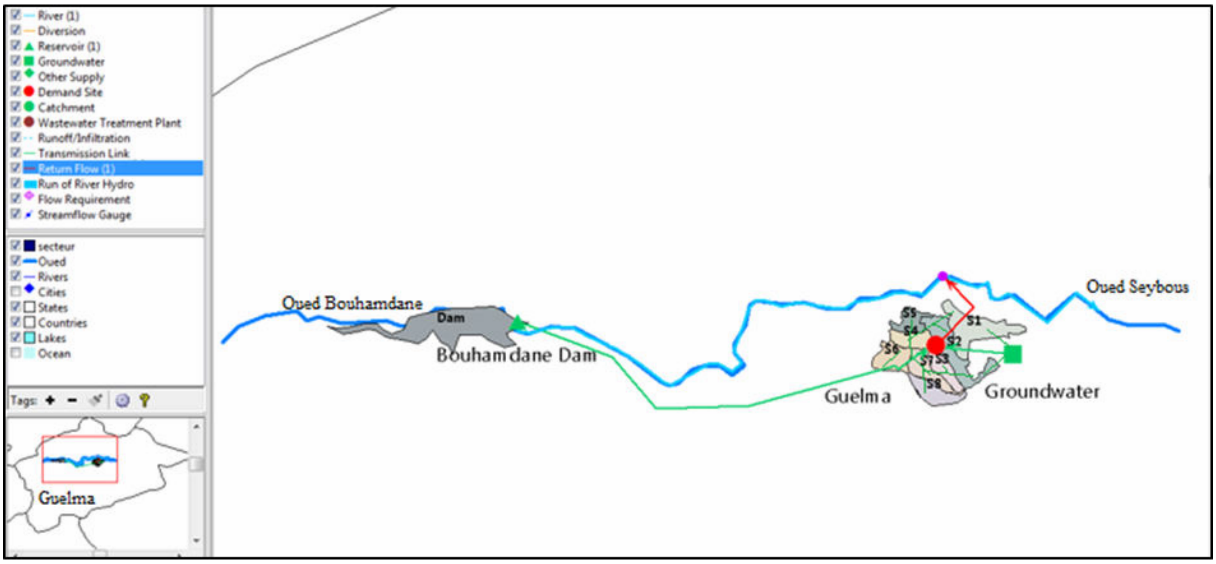

Fig. 4. Final diagram of the WEAP model.

In WEAP, the baseline scenario is derived from the Current Account, which integrates all the data in the baseline to simulate the evolution of the system without intervention (SEI, 2008). The year 2008 is taken as the reference year and its data make up the current account used for this study. Based on this account, scenarios are developed to model the drinking water demand of the eight urban sectors. These scenarios examine potential changes in the system over the coming years. The reference scenario covers the period from 2008 to 2050 and serves as a point of comparison for other scenarios where some of the system data may be modified. The main assumptions in our study are:

The main assumptions in our study are

- Population growth rate.

- An allocation of 90 litres of water per inhabitant per day, based on a survey. This qualitative study, carried out through interviews and questionnaires with households in the city of Guelma, aims to analyse the interactions between water consumers and available resources. To build a database, numerous visits were made to different areas of the city, selecting up to 100 households per sector, taking into account the diversity of age and socio-economic levels. A total of 800 random interviews were conducted, representing approximately 2.13% of the total population of the city of Guelma.

For the alternative scenarios, the daily supply provided by the wilaya's official water services is set at 120 litres per day per inhabitant. The theoretical allocation recommended by international bodies is 180 litres. Finally, the population growth rate is estimated to be around 2.3% (Figure 5).

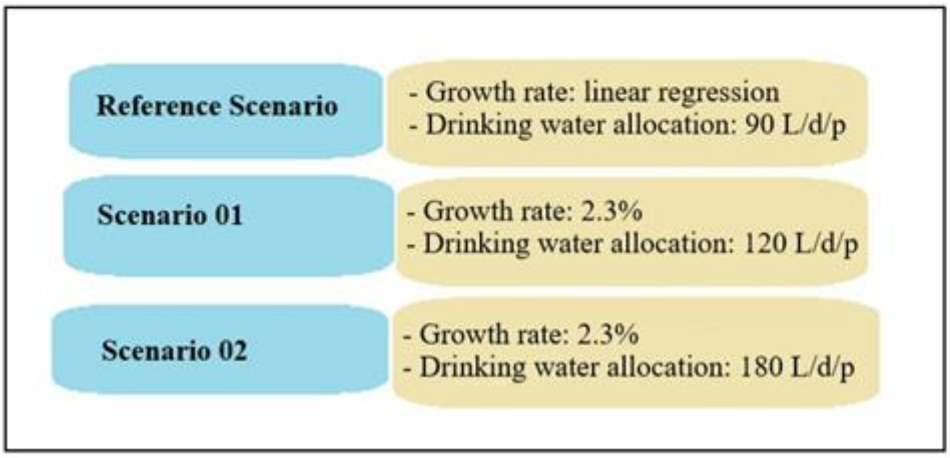

Fig. 5. Organisational chart for the creation of the scenarios.

3. RESULTS AND DISCUSSION

The results are presented in the form of graphs and tables, including data for the reference year (2008) and for the scenarios considered. In order to gain a better understanding of the dynamics between water supply and demand in the city of Guelma, we will carry out a forecast analysis of population development and future drinking water demand. This evolution will be illustrated by three detailed scenarios, as shown in the diagrams below. These visual representations will make it possible to assess the potential impact of population growth and variations in water consumption on the management of the city's water resources.

- Water demand

The demand sectors are based on the current population, calculated using the WEAP software. This estimate is based on available population data as well as the demographic growth rate recorded since 2008. By integrating these elements, the software enables accurate modelling of resource demand, providing a clear vision of the needs of different sectors according to demographic changes.

- Annual demand

The water demand of a demand point is obtained by summing the demands of all the lower branches associated with that point. A lower-level branch is defined as a branch with no sub-branches. The total demand for a lower level branch is obtained by multiplying the activity levels of all branches up to that of the demand site.

- Monthly demand

Monthly resource requirements are calculated using the specific fraction corresponding to each month, which is provided in the form of precise data. This process allows estimates to be adjusted for seasonal variations and consumption patterns, ensuring a more accurate assessment of water requirements.

- Reference scenario

As a result of population growth in urban areas, drinking water consumption in the baseline scenario increases steadily between 2008 and 2050. From 6.1 M m³ in 2008 to about 13 M m³ in 2030, it is projected to increase to almost 21.2 M m³ in 2050. The graph below (Figure 6) shows that sectors S3, S8 and S5 are the largest consumers of water for domestic use. This is due to their large populations and lifestyles, which result in high demands on water resources.

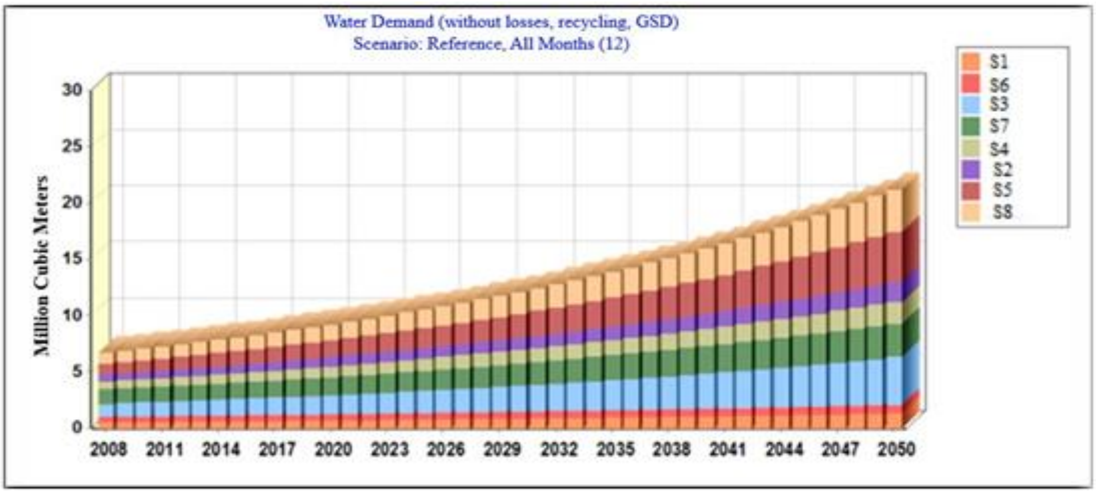

Fig. 6. Evolution of water demand in the city of Guelma – reference scenario; Source: author's study

Scenario 01

Scenario 01 assumes a growth rate of 2.3% and a demand of 120 litres per inhabitant per day. The visual assessment shows a significant increase in drinking water consumption between 2008 and 2050: from 13.1 million m³ in 2008 to around 20.09 million m³ in 2030 and almost 31.1 million m³ in 2050. The graph below (Figure 7) also shows that sectors S3, S5, S7 and S8 are the largest consumers of water for domestic use, while the other zones have lower consumption. This shows a significant increase in demand for drinking water compared to the previous scenario.

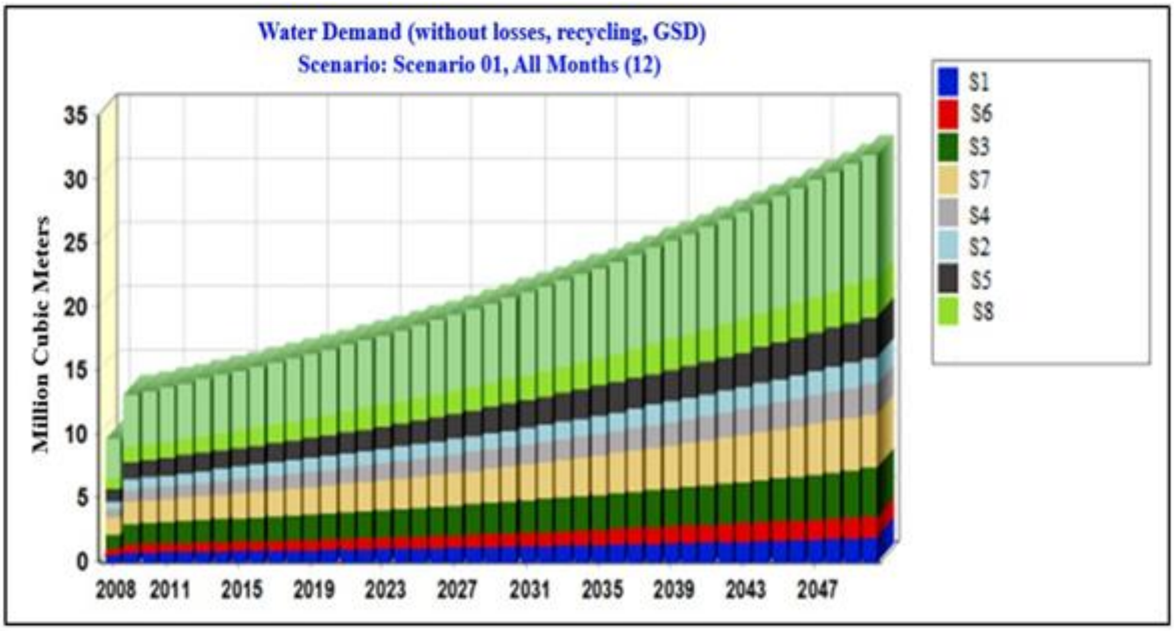

Fig. 7. Evolution of water demand in the city of Guelma - Scenario 1; source: author's study.

Scenario 02

This scenario shows a growth rate of 2.3%, with an allocation of 180 litres per inhabitant per day. The trends also show a significant increase in demand for drinking water between 2008 and 2050. It rises from 20.2 million m³ in 2008 to almost 30 million m³ in 2030 and is expected to reach around 47.5 million m³ in 2050.

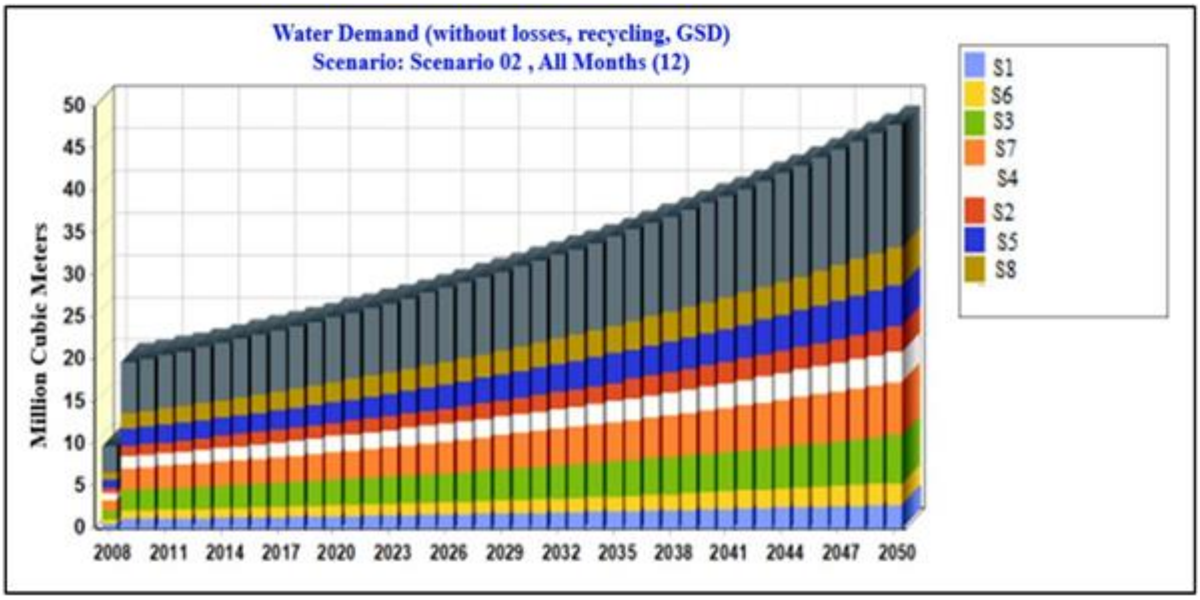

Fig. 8. Evolution of water demand in the city of Guelma - Scenario 2; source: author's study.

Total monthly water demand

Total monthly water demand increases steadily between 2008 and 2050 for all scenarios. It can be seen that demand is highest between May and September due to intensive use during the summer, the reduction of resources due to climate variability and the increase in recharge. The results show that the water demand for January 2010 varied between 13 million m³ in the Reference Scenario and 13.5 million m³ in Scenario 01 (Figure 9). This demand continues to increase throughout the period and reaches 14 million m³ in Scenario 2. In addition, water demand for this scenario shows strong growth from March 2029, reaching 16.2 million m³, and will continue to grow to reach 17.8 million m³ in December 2047, exceeding the values for Scenario 01 and the Reference Scenario.

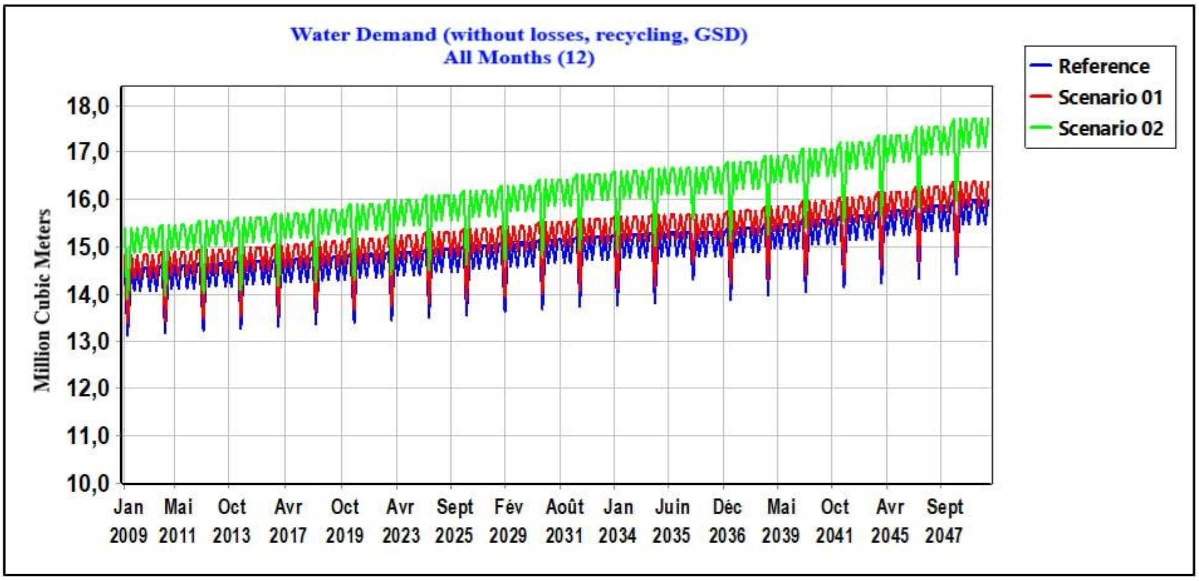

Fig. 9. Evolution of Monthly Water Demand for All Scenarios; source: author's study.

Unmet demand

Unmet water demand, also known as water deficit, refers to the part of water demand that cannot be fully met due to constraints such as water shortages due to drought, inadequate infrastructure, distribution constraints or other limiting factors (Psomas et al., 2017). Analyses of unmet demand show a persistent shortage of drinking water in all scenarios considered. There is a steady increase in unmet demand throughout the simulation period, starting from the base year. This deficit is particularly pronounced in the Reference Scenario (Figure 10), where unmet demand remains in sectors S4 and S2 from 2015 onwards. This unmet demand reaches significant levels, with around 4.5 million m³ projected for 2040 and 5.2 million m³ for 2050. This situation highlights the urgent need for action to improve water resource management and meet the growing needs of the population in these sectors.

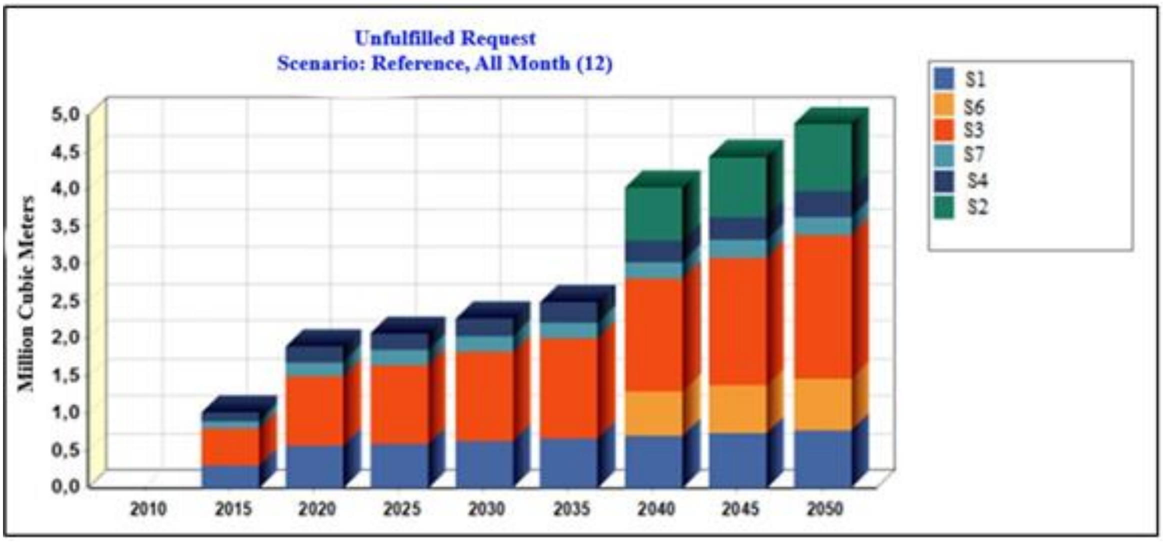

Fig. 10. Evolution of Unsatisfied Demand, Reference Scenario; source: author's study.

In Scenario 1, the unmet demand for drinking water is significantly higher than in the Reference Scenario (Figure 11). This situation is particularly pronounced in sectors S2 and S6, where demand remains unsatisfied throughout the simulation period. This highlights the significant water supply challenges faced by these sectors.

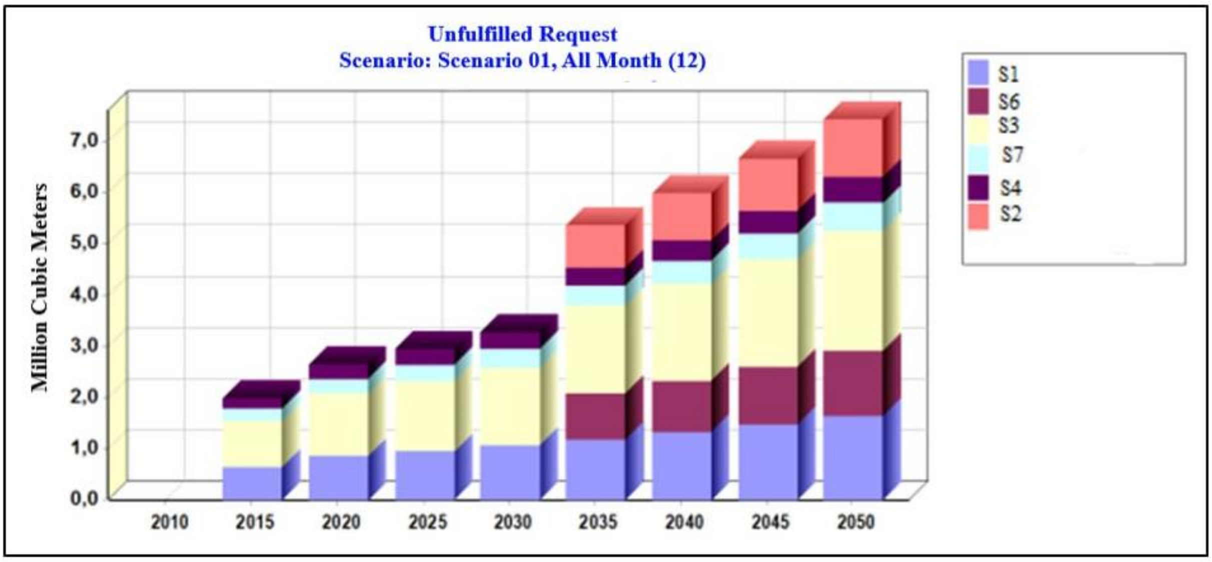

Fig. 11. Evolution of the unsatisfied demand, scenario 01; source: author's study

Since 2015, unmet water demand has been a concern in sectors S2 and S4, raising increasing concerns about water resource management across sectors. In addition, sectors S6, S2 and S7 will also face a water supply crisis from 2030 onwards. This highlights the critical importance of implementing effective water demand management strategies to prevent future shortages and ensure sustainable access to this vital resource for local communities (Figure 12).

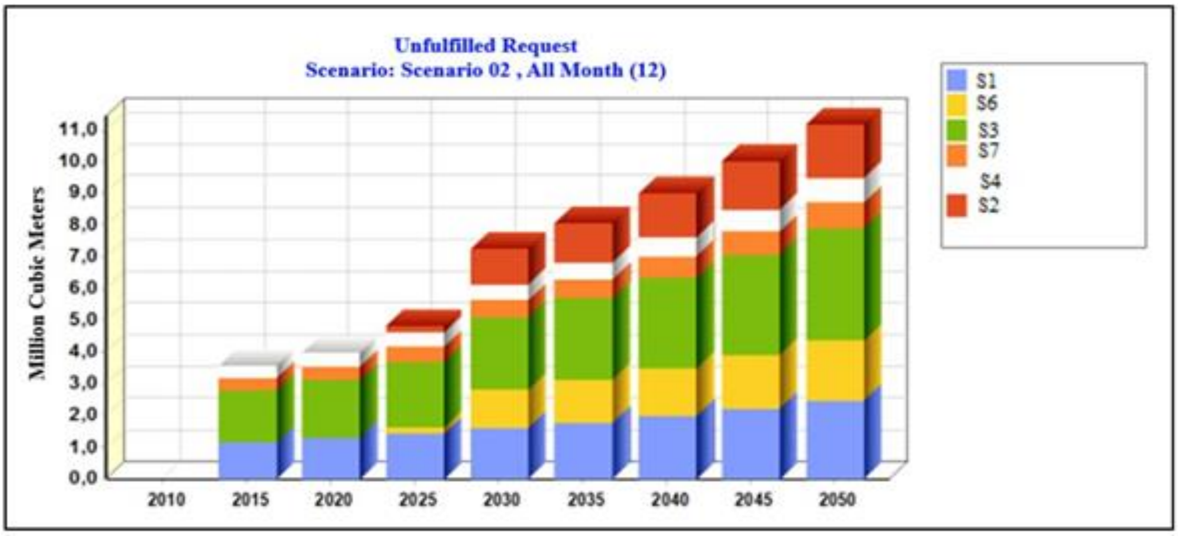

Fig. 12. Evolution of Unsatisfied Demand, Scenario 01; source: author's study.

CONCLUSIONS

The high demand for drinking water, coupled with the growing population in the city of Guelma, is causing instability in water resources, leading to shortages in urban areas. To address this issue, we are using an integrated water management model, WEAP, to project water demand up to 2050 and create scenarios to assess future water availability in different sectors of the city. The aim is to ensure the sustainable use of this vital resource.

The results show that water resources are indeed limited, while the demand for drinking water continues to grow steadily from 2008 to 2050 in all scenarios. Specifically, consumption rises from 6 million m³ in 2008 in the reference scenario to around 47 million m³ in 2050, with a per capita allocation of 180 litres. Meanwhile, the population is projected to grow from 154,716 inhabitants in 2008 to 799,545 inhabitants in 2050.

The result of this unmet demand is a drinking water deficit in all scenarios. The amount of unmet demand exceeds the amount of water supplied, indicating that the available water resources are insufficient to meet the current and future needs of all sectors in the city.

This study highlights the importance of integrated water resource management to ensure sustainable water use in Guelma. By using hydrological and demographic data, the model facilitates informed decision-making on water supply. The scenarios developed provide a forward-looking perspective aimed at ensuring the sustainability of water resources in the region.

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