Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Optimization and planning of water resource management in the Mé watershed using the WEAP Model for Abidjan's drinking water supply

ARTICLES doi:10.4136/ambi-agua.3165

Received: 17 Mar. 2026; Accepted: 10 Sep. 2026

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Editor-in-Chief: Nelson Wellausen Dias

ABSTRACT

The availability of water resources is a key factor in the socioeconomic development of southeastern Côte d'Ivoire. The WEAP (Water Evaluation and Planning System) model was used to assess current and future water demand in the Mé watershed, in the context of its use to supply drinking water to the city of Abidjan by 2060. The analysis incorporates several key factors, including water resource availability, climate change, population growth, and deforestation, which are considered major variables influencing the balance between demand and the capacity to meet it. To this end, three scenarios were developed and evaluated: the baseline scenario (SR), the climate change and reforestation scenario (SCCR), and the scenario reflecting the combined effects of climate change, population growth, and deforestation (SCCCDD). The results highlight a continuous increase in water demand across the four municipalities supplied by the Mé watershed, underscoring the eventual need to rely on alternative sources of drinking water to address future shortfalls. However, the simulation results indicate that, despite the various pressure factors taken into account, water demand remains generally met in the four municipalities throughout the study period under the "SCCR" scenario. This demand is fully met before 2040 the year in which a 1 Mm^3 deficit appears in the "SCCCDD" scenario and before 2060 in the "SR" scenario, where the deficit would reach 6.15 Mm^3.

Keywords: Abidjan water supply, Mé River basin, prospective scenarios, water demand, water resources management, WEAP model.

Otimização e planejamento da gestão dos recursos hídricos da bacia hidrográfica do rio Mé, utilizando o modelo WEAP, para o abastecimento de água potável de Abidjan

RESUMO

A disponibilidade de recursos hídricos constitui um fator-chave para o desenvolvimento socioeconómico do sudeste da Costa do Marfim. O modelo WEAP (Water Evaluation and

Planning System) foi utilizado para avaliar a procura de água, atual e futura, na bacia hidrográfica do rio Mé, no contexto da sua exploração para o abastecimento de água potável da cidade de Abidjan até 2060. A análise integra vários fatores determinantes, nomeadamente a disponibilidade de recursos hídricos, as alterações climáticas, o crescimento demográfico e a desflorestação, considerados como variáveis fundamentais que influenciam o equilíbrio entre a procura e a capacidade de a satisfazer. Para o efeito, foram elaborados e avaliados três cenários, nomeadamente o cenário de referência (SR), o cenário de alterações climáticas e reflorestação (SCCR) e o cenário dos efeitos combinados das alterações climáticas, do crescimento demográfico e da desflorestação (SCCCDD). Os resultados revelam um aumento contínuo das necessidades de água dos quatro municípios abastecidos pela bacia hidrográfica do rio Mé, sublinhando, a longo prazo, a necessidade de recorrer a fontes alternativas de abastecimento de água potável para colmatar os défices futuros. No entanto, os resultados da simulação indicam que, apesar dos diversos fatores de pressão tidos em conta, a procura de água continua, de um modo geral, a ser satisfeita nos quatro municípios ao longo de todo o período de estudo, de acordo com o cenário «SCCR». Esta procura é integralmente coberta antes de 2040, ano em que surge um défice de 1 Mm^3 no cenário «SCCCDD», e antes de 2060 no cenário «SR», onde o défice atingiria 6,15 Mm^3.

Palavras-chave: abastecimento de Abidjan, bacia hidrográfica do rio Mé, cenários prospectivos, gestão dos recursos hídricos, modelo WEAP, procura de água.

1. INTRODUCTION

Access to safe drinking water is a fundamental challenge for sustainable urban development, particularly in large African cities facing rapid population growth and accelerated urbanization (UNESCO, 2020; UN-Habitat, 2022). In sub-Saharan Africa, the increasing demand for urban water often exceeds the adaptive capacity of water systems, a situation exacerbated by growing climate pressures and socioeconomic transformations. In Côte d'Ivoire, the Autonomous District of Abidjan, the country's major economic hub, faces increased water pressure resulting from rapid urbanization, sustained population growth, and an expansion of industrial activities (World Bank, 2018; SODECI, 2021). The main source of drinking water for this metropolis remains the Mé River watershed (Aghui and Biémi, 1984). However, this watershed is undergoing structural disruptions linked to climate change, deforestation, and changes in land use, which are affecting the hydrological regime and calling into question its ability to sustainably meet future demand. Studies conducted in various West African contexts highlight the increased vulnerability of water systems to climatic fluctuations and anthropogenic pressures. For example, Diop *et al.* (2025) demonstrated that the impacts of climate change on precipitation patterns and the occurrence of extreme events such as floods are becoming increasingly pronounced in West African river basins, which has direct implications for the design of water infrastructure and water resource management at the regional level. Similarly, studies based on local surveys, such as the one conducted by Ganni Mampo *et al.* (2025) in Benin, show that the perceptions of rural populations confirm increased variability in hydroclimatic conditions and heightened risks to water access (for domestic and agricultural use). Furthermore, the literature highlights that the interaction between climate change, population growth, and changes in land use can exacerbate imbalances between water supply and demand in urban areas of West Africa. This is consistent with the findings of studies on the combined impacts of climate change and land-use changes on African water resources (Chawanda *et al.*, 2024), as well as regional assessments of preparedness and adaptation strategies to reduce vulnerability to climate impacts (Niasse *et al.*, 2004). In light of these challenges, the use of integrated analysis tools, such as the WEAP (Water Evaluation and

Planning System) model, has become a recognized methodological approach for forward-looking water-resource planning. WEAP enables the simulation of alternative scenarios by integrating hydrological, climatic, and socioeconomic dimensions (Yates *et al.*, 2005; Sieber and Purkey, 2015). Its application has been extensively documented in contexts of water stress and increasing anthropogenic pressure, making it a relevant tool for assessing the balance between water supply and demand in complex systems. This study harnesses the potential of the WEAP model to analyze current and future dynamics of domestic water demand in Abidjan's municipalities supplied by the Mé watershed, looking ahead to 2060. The primary objective is to assess the balance between supply and demand under several scenarios that incorporate climate change, population growth, and land-use changes, in order to identify vulnerability thresholds and to develop recommendations for sustainable and resilient water-resource planning in the face of growing environmental and socioeconomic pressures.

2. MATERIAL AND METHODS

2.1. Overview of the area

The Mé River is located in southern Côte d'Ivoire, specifically in the Mé region. Its watershed, which is the subject of this study, covers an area of 4·140 km². Located between latitudes 5°20' and 6°20' North and longitudes 3°30' and 4°20' West, the Mé region has a transitional equatorial climate characterized by two (2) rainy seasons and two (2) dry seasons, with vegetation consisting of dense forest. The hydrographic network of the study area shows that the main watercourse runs north-south and is 140 km long. It also receives water from the Mafou (its main tributary) (Ahoussi *et al.*, 2021). This main watercourse and its tributaries flow into the Aghien-Potou lagoon system. The Mé River is likely to feed the Aghien Lagoon at certain times of the year. It originates north of Adzopé under the name "Min" or "Mé" (Figure 1). At the bridge on the Abobo-Alépé road, the Mé River is influenced by tidal waves (Koffi, 2021). The study area consists of several geological formations. Those of the bedrock consist of schist, biotite gneiss, biotite granodiorite, and metagranite, while the sedimentary formations are composed of sand, clay, and iron-bearing sandstone (Soro, 1987). According to the RGPH (2021), the population is estimated at 726,665 inhabitants. Agriculture is one of the main occupations of the population, with crops including rubber trees, cassava, bananas, oil palms, and cacao.

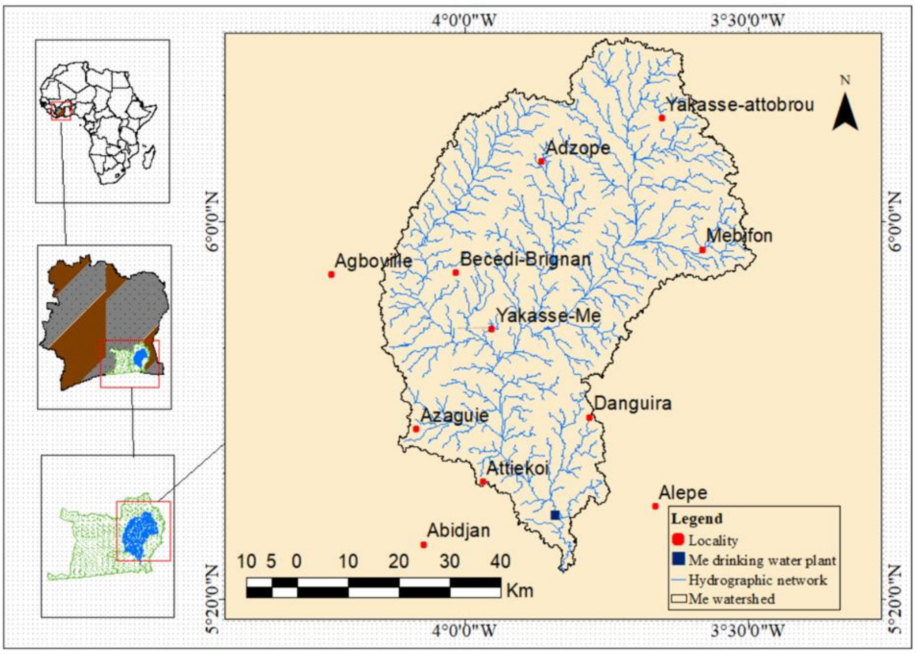


Figure 1. Map of the study area.

2.2. Data Characteristics

2.2.1 Hydrometric data

The hydrometric data are derived by converting the river's water level into flow rate using the calibration curve; specifically, a limnigraph was installed at the Mé River hydrometric station to measure water levels as part of the Aghien project. The data from this station will be used at a daily time step for the period from 2016 to 2022 to simulate water demand fulfillment. This project aims to strengthen the drinking water supply to the country's economic capital by producing 240,000 m^3 per day (or 87.7 Mm^3 per year) from the Mé River, with two water towers, each with a capacity of 10,000 m^3 built in Abobo to store water from the treatment plant. The withdrawal rates from the Mé River by the water treatment plant were obtained from the Ivorian Water and Environment Company (SIEE). Based on the river flow rates and the pumping rate of the Mé water treatment plant, the model simulates the flow rates entering each demand site in an effort to meet the water needs of these populations.

2.2.2. Satellite Data

The 30-meter resolution digital elevation model (DEM) is provided by the Shuttle Radar Topographic Mission (SRTM). This ASTER (Advanced 52 Spaceborne Thermal and Reflection Radiometer) satellite image, which is a type of, enabled the extraction of the watershed boundary as well as the hydrographic network. In this section, land-use maps for the years 1987, 2005, and 2023 were produced. The areas of the five (5) land-use classes from the historical land-use maps were used for modeling.

2.2.3. Demographic data

The demographic data are derived from the latest General Population and Housing Census (RGPH) of 2021. They are presented here by municipality (Table 1). However, demographic data for subsequent years will be extrapolated for the SR scenario, assumed to remain constant for the SCCR, and then assumed to grow at 8% for the SCCCDD in the WEAP project implementation.

Table 1. Population distribution of the study area and the service area.

DEPARTMENT	MUNICIPALITIES	2014 CENSUS POPULATION	2021 CENSUS POPULATION	GROWTH RATE
NAME	NAME	NUMBER OF PEOPLE	NUMBER OF PEOPLE	
ABIDJAN	ABOBO	1,030,658	1,340,083	3.7%
	ADJAME	372,978	340,892	- 1.1%
	COCODY	447,055	692,583	6.3%
	YOPOUGON	1,071,543	1,571,065	5.6%
TOTAL		2,922,234	3,944,623	

2.3. Methods

Water demand is the amount of water that must be drawn from the resource to meet various needs in a given location and over a given period of time. The quantitative assessment of water demand is based on standards determined according to the relevant economic and social context.

2.3.1. Application of the WEAP model to the Me basin

The WEAP system operates in several stages. The process begins by selecting a reference year, referred to as "Current Accounts," which is used to calibrate the model. In this case, the year 2021 was selected. It includes data on available resources, water demand areas, and the socioeconomic context, particularly population. Based on this foundation, a baseline scenario is developed for the period 2022–2060. This scenario simulates the basin's evolution if no interventions are made in other words, if the situation remains as it is. Next, so-called "What-if?" scenarios are developed by modifying this baseline scenario. They make it possible to determine whether the projected trends in water use and population growth remain compatible with changes in needs and in agro-pastoral infrastructure (Sieber and Purkey, 2015). These scenarios are all based on the "Current Accounts" and seek to represent the factors that influence water resources and water demand. In particular, they address population growth, climate change, and deforestation (McCartney and Arranz, 2007).

2.3.2. Project Implementation

The project was created within the model's schematic view. The basin outline and the hydrographic network were imported from QGIS in shapefile format. Next, demand sites, withdrawal points, and transmission links were created. The project created in WEAP included the following objects (Figure 2):

- 04 demand sites, namely: the domestic water demand sites in Abobo, Adjamé, Yopougon, and Cocody. These represent the municipalities of Abidjan supplied by the Mé water treatment plant.
- The Mé River, whose behavior is simulated by the WEAP model;
- The Mé River watershed: the physical, hydrological, and climatic characteristics of the watershed, as well as the areas of the land-use classes, were entered into the model;
- The hydrographic network.
- Four transmission lines to supply demand sites from the station node (Mé water treatment plant).

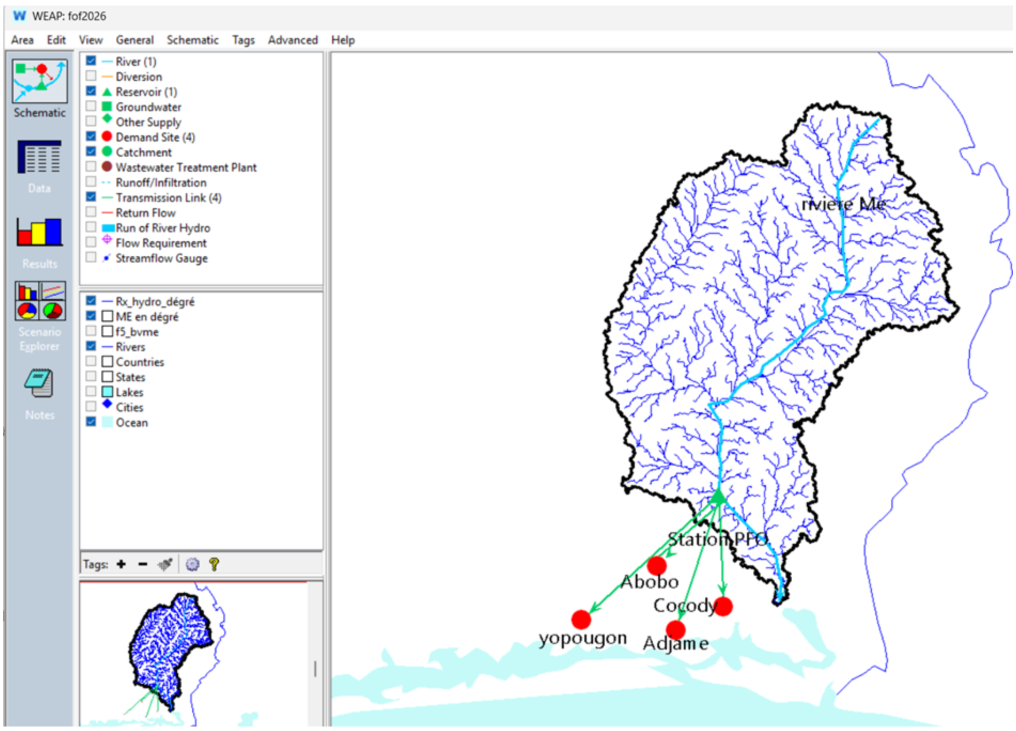


Figure 2. Application of WEAP in the Mé watershed.

2.3.3. Creation of the current account

The creation of the base year serves as a calibration phase for the model. The base year (current year) for this study is 2021, using data at monthly intervals. The year 2021 was chosen as the base year due to the availability of data for all parameters used by the model. The year

2060 was chosen as the long-term horizon for developing scenarios for optimal water resource allocations.

2.3.4. Assumptions for simulating water demand in the Me basin

To develop the scenarios, we used available data on the climatic and hydrological characteristics, water withdrawals at the monitoring station, water consumption, land use, and physical characteristics of the study basin. These scenarios enabled us to make predictions. To this end, two main scenarios were developed: the baseline scenario and the alternative scenario.

2.3.5. Reference scenario (or trend scenario)

The reference scenario represents the future evolution of the watershed and the various water uses while following the trend observed in the base year. In other words, the coming years were simulated under the assumption that there have been no major changes in water uses, water resources, climatic conditions, or the sociodemographic characteristics of the study area. Its purpose is to assess the foreseeable evolution of the state of water resources by assuming a continuation of the current pattern. In other words, the trend scenario is developed by inputting current data without modification into the model regarding water consumption, water production, population growth rates (1.1% to 6.3%), etc.

2.3.6. Alternative scenario

This scenario takes into account changes that could impact the watershed in terms of climate, land use, and sociodemographic factors. It is the scenario that allows for the prediction of all major changes that may occur in the study basin. These include, among others: the scenario combining climate change, strong population growth, and deforestation, which reflects the future evolution of the watershed and its various water uses based on an upward trend of an 8% growth rate, a decrease in land cover, and changes in climate parameters (temperature and precipitation).

Next is the scenario combining climate change and reforestation, which reflects the future evolution of the watershed and its various water uses based on a moderate trend.

Here, the population growth rate is assumed to be constant, with moderate climate variation and the implementation of land management and land-use projects.

2.3.7. Hydrological year method

This method is a simple way to define different climate regimes (very dry, dry, normal, wet, very wet) and to compare them with a normal year by assigning a value between 0.7 and 1.45 to each climate type. A value of 1 is assigned to a normal year; dry years have a value less than 1, and wet years have a value greater than 1. Since the simulation software only recognizes numerical values, each climate type corresponding to a given year must be assigned a numerical value (Table 2) so that the software can perform the modeling.

Table 2. Definition of climate types according to WEAP.

Types of Hydrological Years	Very dry	Dry	Normal	Wet	Very wet
Corresponding figures	0.7	0.8	1	1.3	1.45

After defining each climate type, the next step was to create a climate sequence for the coming year. Understanding the climate patterns for the current reporting year (2021) and future years (2022–2060) was made possible by calculating flow deciles; this allowed for an assessment of the impact of climate variability on water resources (precipitation, runoff, groundwater recharge, etc.), in relation to user needs. The concept of deciles used in this study was developed by Gibbs and Maher (1967) to address the limitations of the percentage-of-normal method. This approach provides information on the frequency of an event. It divides the frequency distribution of events into 10 parts, each representing 10% of the distribution. Table 3 below presents the decile indices used in this study.

Table 3. Categories of dry and wet years based on decile indices.

Categories	**Very dry**	**Dry**	**Normal**	**Wet**	**Very humid**
Decile indices	1–2	2–4	5-6	7–8	9–10

Based on Table 3, a database was created to define the types of hydrological years for the period from 2022 to 2060.

2.3.8. Calculation of water demand

Water demand for domestic use (DED) depends on parameters such as population size and per capita consumption. For this study, we determined the total water demand for domestic use, taking into account both connected and unconnected populations.

According to studies, the average daily water consumption (Cm) per capita is estimated at 72 l/capita/day (Diakité and Thomas, 2011). It is assumed to remain constant throughout the simulation period (Equation 1).

$$Ded_g = Cm * N \tag{1}$$

Where:

Cm: Average per capita consumption (l/capita/day); N: Number of inhabitants.

Figure 3 summarizes the methodological framework of this study.

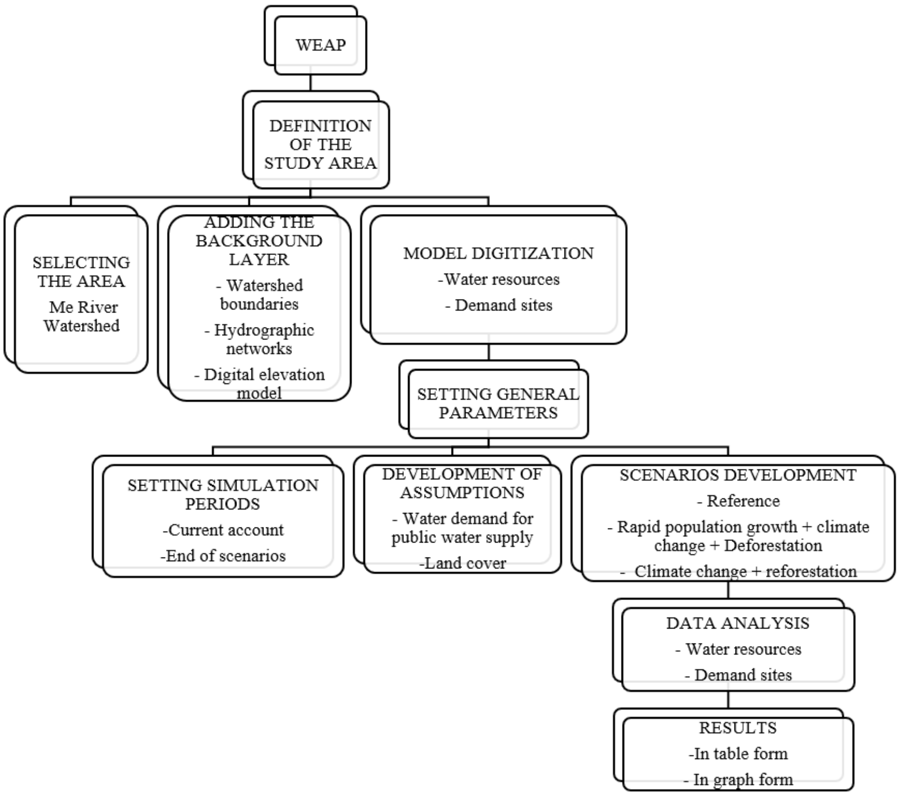


Figure 3. Flowchart of the WEAP project implementation process.

3. RESULTS

3.1. Water demand situation in 2021 and changes in water requirements

3.1.1. Estimating water demand satisfaction using the WEAP model

3.1.1.1. Estimation of domestic water demands in the Me river basin

In 2021, the demand for domestic water among households in the municipalities served by the Mé water treatment plant was 106 Mm^3/year. The municipality of Yopougon ranked first with the highest estimated demand at 42 Mm^3, followed by the municipality of Abobo with 36 Mm^3 per year. The other municipalities ranked third and fourth, respectively, with Cocody at 19 Mm^3 per year and Adjamé at 9 Mm^3 per year. The upward trend in this water demand is illustrated in Figure 4.

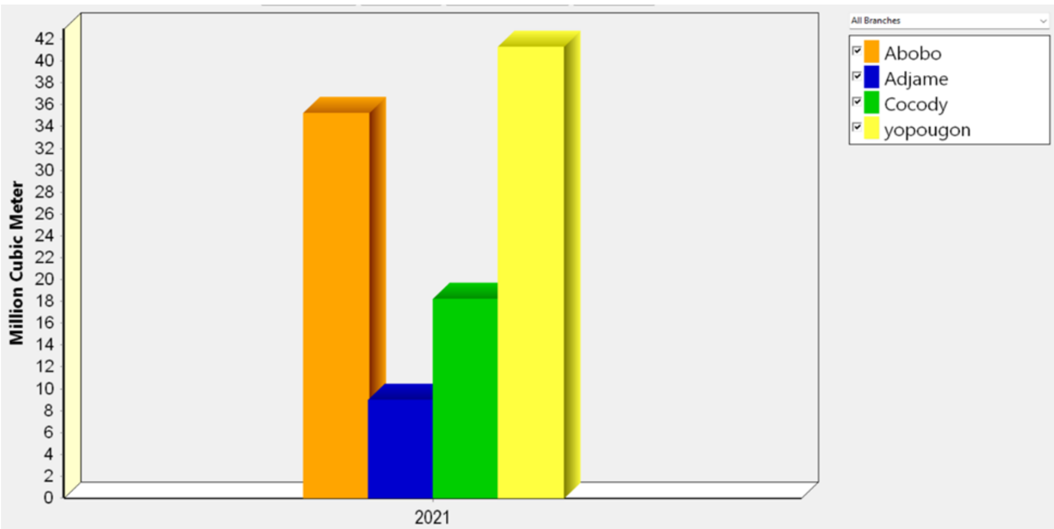


Figure 4. Domestic water demand per capita in 2021.

3.1.1.2. Water Demand Collection in 2021

Figure 5 illustrates the monthly coverage rate and the unmet water demand (UWD) for the various target localities from January through December 2021. This figure shows that drinking water demand was fully met for each of the municipalities served throughout all months of 2021. In 2021, the unmet water demand (DNS) was zero, indicating that the water needs of the served municipalities were fully met.

3.2. Scenario of balance between water resources and demand with weap

3.2.1. Simulation of domestic water demand in the Me river basin by 2060

According to the baseline scenario, water demand will trend upward, reaching high levels by 2060.

The highest domestic water demand (DED) is recorded in Yopougon, with a value of 42 Mm^3in 2021 and projected to reach 346 Mm^3 in 2060. Demand in Abobo is projected to reach 151 Mm^3 in 2060. As for the municipalities of Cocody and Adjamé, their water demand will follow the same trend as the other two municipalities, reaching 205 Mm^3 and 14 Mm^3, respectively by 2060. The growth trend in water demand is shown in Figure 6. The same trend is observed for the climate change + high population growth + deforestation scenario (SCCCDD), with peak values in 2060 when water demand in the municipality of Abobo will reach 709 $Mm^3$and that of Yopougon 831 Mm^3. Furthermore, water demand in the “climate change + reforestation” scenario will remain virtually stable and lower than the values in the baseline scenario. By 2060, water demand in the municipalities of Yopougon, Abobo, Cocody, and Adjamé will reach 42 Mm^3, 36 Mm^3, 19 Mm^3, and 9 Mm^3, respectively.

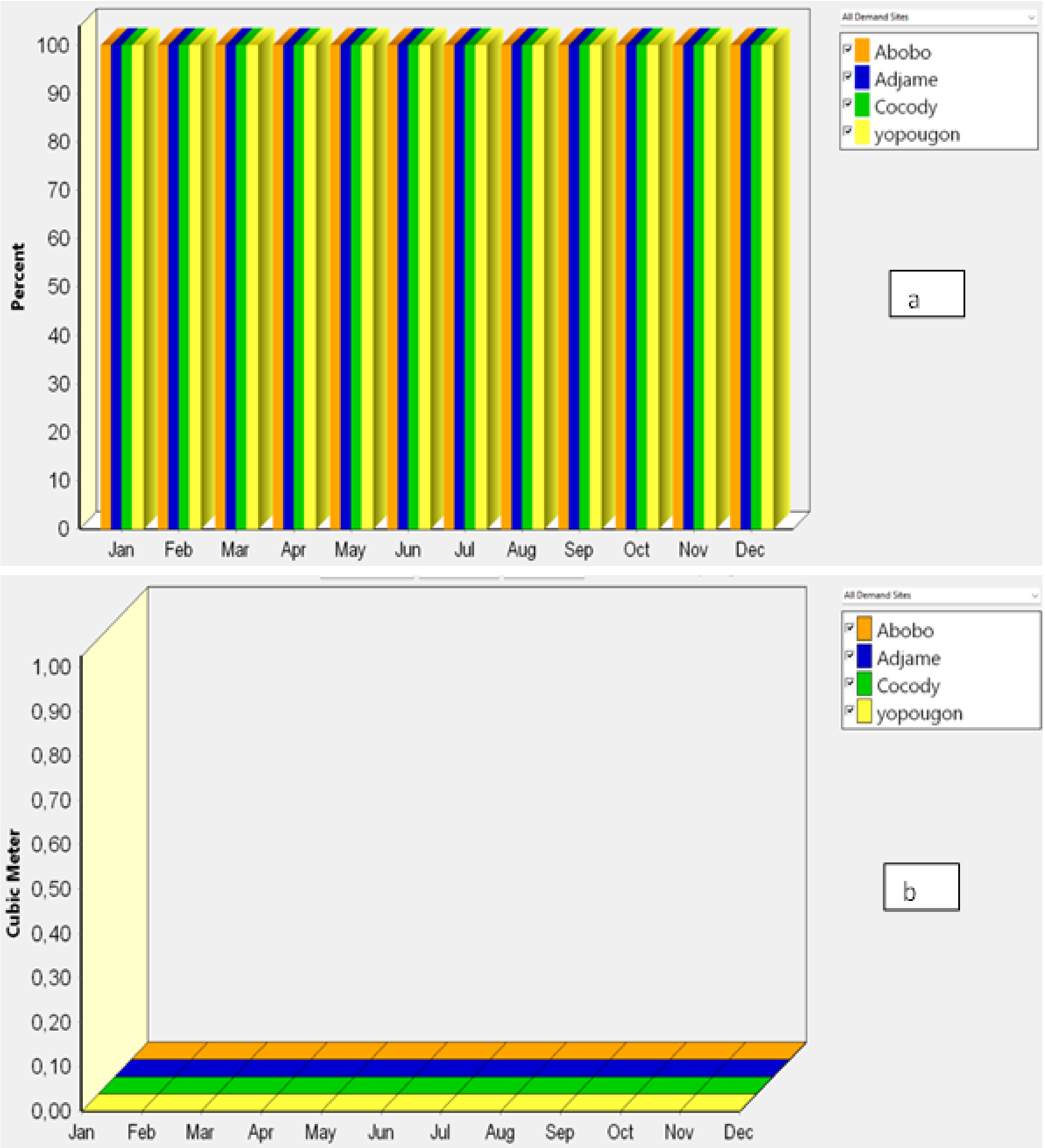
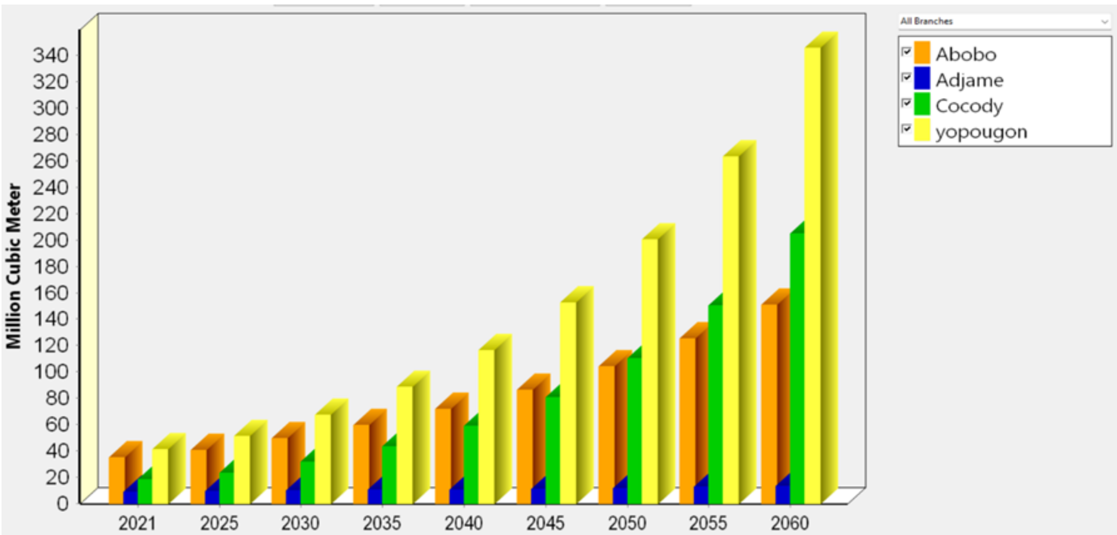


Figure 5. Domestic water demand coverage rate for the population in 2021 (a) and unmet water demand (UWD) for the population in 2021 (b).

3.2.2. UWD analysis based on scenarios
3.2.2.1. Reference scenario

Figure 7 shows the trend in unmet water demand (UWD) within the municipalities studied. The results indicate full coverage of the population's water needs through 2060, after which a deficit will be observed, reflecting the system's inability to fully meet demand. The volumes of unmet water demand are estimated at 3 Mm^3 for the municipality of Yopougon, 1.3 Mm^3 for Abobo, 1.75 Mm^3 for Cocody, and 0.1 Mm^3 for Adjamé.

a



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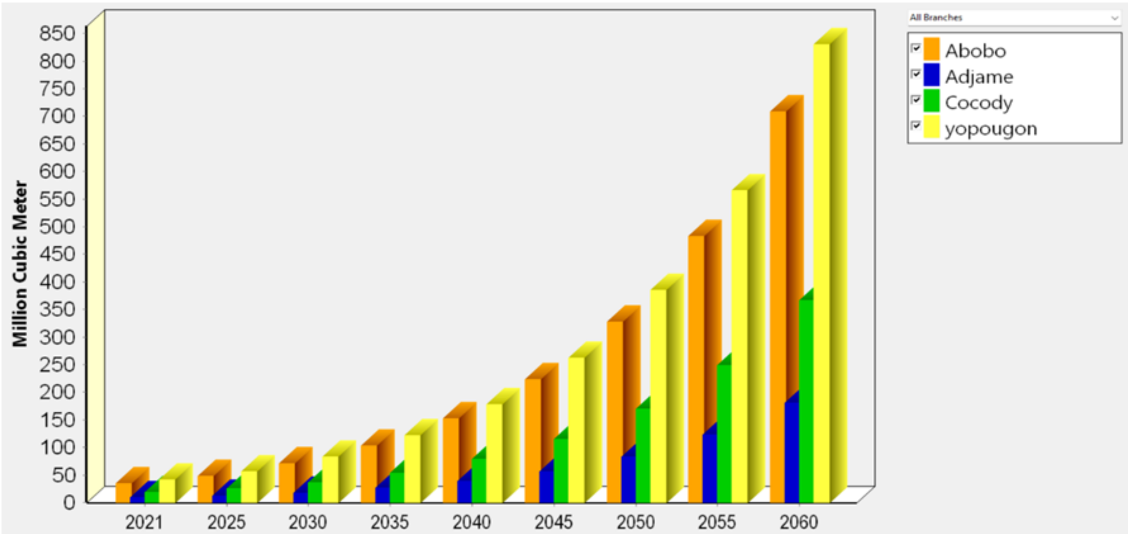

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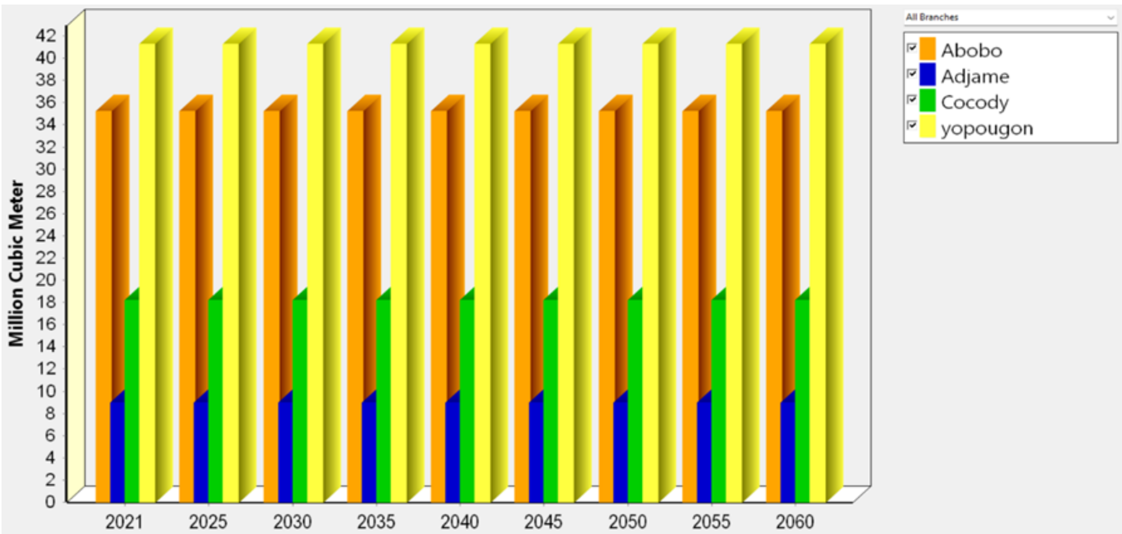

Figure 6. Domestic water demand per capita based on scenarios for 2060: (a) baseline; (b) population growth + deforestation + climate change; and (c) climate change + reforestation.

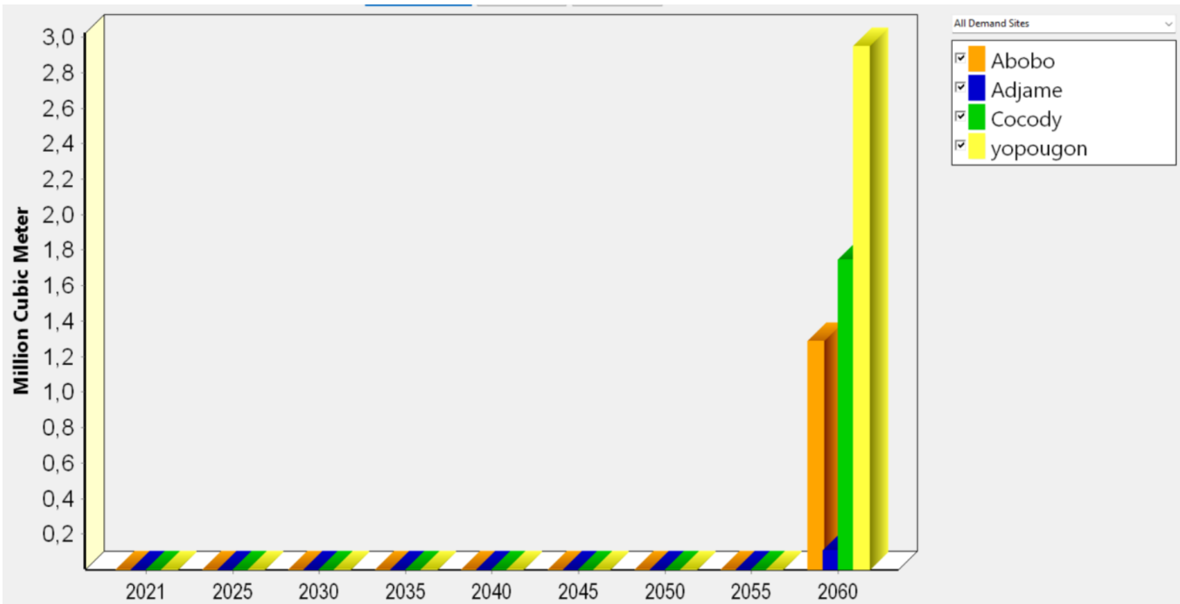

Figure 7. Unmet water demand of the population according to the baseline scenario by 2060.

3.2.2.2. Scenario Regarding Climate Change and Reforestation

In the scenario designed to assess the impact of climate change, it appears that unmet water demand (UWD) remains the same as that observed in the base year across all sites considered. However, full coverage of water needs is ensured through 2060 (Figure 8).

Figure 8. Unmet water demand according to the climate change and reforestation scenario by 2060.

3.2.2.3. Combined Impact of Climate Change, Deforestation, and Population Growth

Figure 9 shows the unmet water demand (UWD) under a combination of climate change, deforestation, and strong population growth scenarios. Unlike the previous scenarios, unmet water demand (UWD) emerges earlier, as early as 2040, with an estimated total value of 1 Mm^3. It then rises steadily, reaching extreme levels by 2060 (Table 4). The municipality of Yopougon will have the highest unmet water demand at 407.79 Mm^3, followed by Abobo at 347.84 Mm^3. The municipalities of Cocody and Adjamé will have unmet water demand of 179.64 Mm^3 and 88.46 Mm^3, respectively.

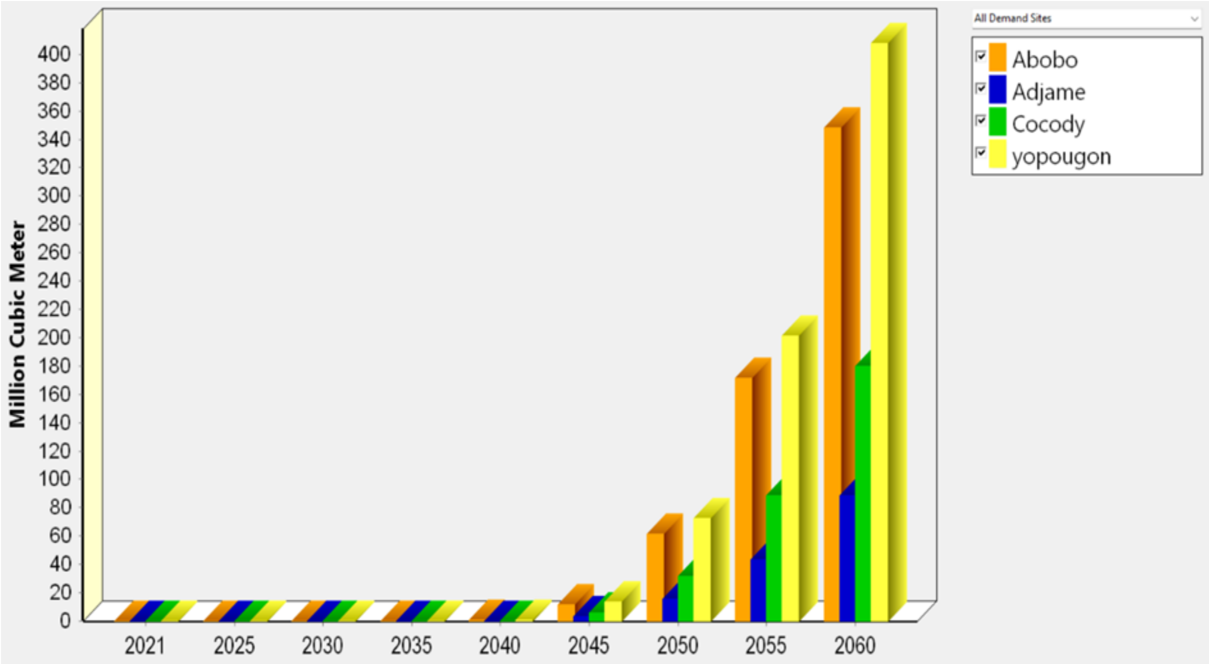

Figure 9. Unmet water demand based on the climate change + deforestation + high population growth scenario by 2060.

3.2.2.4. Assessment of water demand and supply capacity by site based on scenarios : five-year management plan

The assessment of changes in water needs and unmet water demand (UWD), prepared every five years according to the various scenarios and for all demand sites, is presented in the tables below (Tables 5 and 6). Analysis of these results reveals that the water needs of the four localities studied are not fully met under the baseline and high-growth scenarios. According to the reference scenario, total water demand would rise from 106 Mm³ in 2021 to 716 Mm³ in 2060, while it would reach 2,088 Mm³ in 2060 under the scenario of high population growth, deforestation, and climate change. In fact, the DNS does not appear until 2060 in the baseline scenario, compared to 2040 in the high-growth scenario; this reflects the full satisfaction of water needs before 2060 and 2040, respectively, for these two scenarios. From 2040 to 2060, the DNS for the four municipalities under the scenario combining high population growth, deforestation, and climate change would be higher, reaching 923.73 Mm³ (or 44.24% of the DED) in 2060, while that of the baseline scenario would reach 6.15 Mm³ (or 0.86% of the DED). Unlike the previous scenarios, the water demand deficit (DED) in the climate change + reforestation scenario would be fully met through 2060. The adoption of sustainable water resource management policies could help alleviate this growing pressure on water demand.

Table 4. Changes in annual inflow by scenario (Mm³).

Sites	Scenarios	2021	2025	2030	2035	2040	2045	2050	2055	2060	**Total**
The four application sites	SCCCDD	106	142	209	306	451	625	786	915	1,066	4,606
	SCCR	106	106	106	106	106	106	106	106	106	954
	SR	106	127	160	204	260	333	428	553	710	2,881

Table 5. Changes in Annual Water Demand by Scenario (Mm³).

Site	Scenarios	2021	2025	2030	2035	2040	2045	2050	2055	2060	Total
Abobo	SCCCDD	36	48	71	104	152	224	329	483.1	709	2,156.1
	SCCR	36	36	36	36	36	36	36	36	36	324
	SR	36	41	50	60	72	87	104	126	151	727
Adjamé	SCCCDD	9	13	18	27	39	57	84	123	181	551
	SCCR	9	9	9	9	9	9	9	9	9	81
	SR	9	10	10	11	11	12	12	13	14	102
Cocody	SCCCDD	19	25	37	54	79	116	170	250	367	1,117
	SCCR	19	19	19	19	19	19	19	19	19	171
	SR	19	24	32	44	60	81	110	151	205	726
Yopougon	SCCCDD	42	57	83	122	179	262	385	566	831	2,527
	SCCR	42	42	42	42	42	42	42	42	42	378
	SR	42	52	68	89	117	153	201	264	346	1,332

Table 6. Changes in Annual DNS Based on Scenarios.

Site	Scenarios	2021	2025	2030	2035	2040	2045	2050	2055	2060	Total
Abobo	SCCCDD	0.00	0.00	0.00	0.00	0.34	11.63	61.73	171.48	347.84	593.02
	SCCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.3	1.3
Adjamé	SCCCDD	0.00	0.00	0.00	0.00	0.08	2.94	15.65	43.56	88.46	150.66
	SCCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.1
Cocody	SCCCDD	0.00	0.00	0.00	0.00	0.17	6	31.87	88.54	179.64	306.22
	SCCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.75	1.75
Yopougon	SCCCDD	0.00	0.00	0.00	0.00	0.41	13.64	72.36	201.03	407.79	695.23
	SCCR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3	3

A combined analysis of Tables 4 through 6 and Figures 5 through 9 revealed several insights into the dynamics of water demand and the mechanisms that lead to unmet demand in the Mé watershed. First, a comparison of the three scenarios reveals that population growth is the main driver of the increase in domestic water demand (DED). Indeed, the formula used in this study to calculate DED ($Dedg = Cm \times N$) depends only on the population served and specific consumption, both of which are held constant or extrapolated linearly; climate change does not directly affect demand but rather supply; that is, the availability of the resource that can be mobilized by the Mé water treatment plant. This explains why the scenario combining climate change and reforestation (SCCR), which does not anticipate additional population growth, shows a strictly stable DED (42 Mm^3 for Yopougon, 36 Mm^3 for Abobo, 19 Mm^3 for Cocody, and 9 Mm^3 for Adjamé from 2021 to 2060), whereas the baseline (SR) and high-growth (SCCCDD) scenarios show average annual growth rates ranging, respectively, from 1.1% to 6.3% and from 7.9% to 8.0%, depending on the municipality (Table 7). The demand multiplier between 2021 and 2060 thus reaches nearly 20 in the SCCCDD scenario for all municipalities, compared to 1.6 to 10.8 in the reference scenario.

Table 7. Multiplicative factor and average annual growth rate (AAGR) of DED between 2021 and 2060, and share of DNS in DED in 2060, by scenario and municipality.

Municipality	SR Multiplier 2021–2060	SR CAGR (%/year)	SCCCDD Factor 2021–2060	SCCCDD CAGR (%/year)	SR DNS/DED 2060 (%)	DNS/DED SCCCDD 2060 (%)
Abobo	4.2	3.7	19.7	7.9	1.3	62.9
Adjamé	1.6	1.1	20.1	8.0	7.1	46.4
Cocody	10.8	6.3	19.3	7.9	1.0	46.6
Yopougon	8.2	5.6	19.8	7.9	9.0	65.7

Next, a spatial analysis of the results reveals a consistent hierarchy among the municipalities, reflecting their population size: Yopougon and Abobo, the most populous, consistently account for the highest volumes of DED and DNS, while Adjamé, the least populous, records the lowest absolute values. However, this hierarchy in absolute terms masks a more nuanced reality when DNS is expressed as a percentage of DED for each municipality (Table 7): in 2060, under the baseline scenario, the relative deficit ranges from 1.0% (Cocody) to 9.0% (Yopougon), while under the SCCCDD scenario, it ranges from 46.4% (Adjamé) to 65.7% (Yopougon). Thus, under the most unfavorable scenario, all four municipalities would experience severe water stress, with a deficit accounting for nearly half or even two-thirds of their needs, including for Adjamé and Cocody, whose absolute volumes nevertheless appear modest. This result suggests that the water vulnerability of the study area is less a function of the municipality's size than of the magnitude of the cumulative pressures (climate, demographics, land use) exerted on the resource. Furthermore, the temporal analysis reveals a marked threshold effect. While the baseline scenario does not show a deficit until 2060 (6.15 Mm^3, or 0.86% of the total DED), the scenario combining climate change, population growth, and deforestation (SCCCDD) shows this deficit as early as 2040, twenty years earlier, reaching 1,023.73 Mm^3 in 2060 (49.02% of the total DED). This time lag reflects a nonlinear dynamic: the simultaneous combination of several pressure factors rather than their simple sum accelerates the onset of the deficit and amplifies its final magnitude. The average monthly recovery rate calculated over the 2022–2060 period (87% for Yopougon, 90% for Abobo, 99% for Cocody and Adjamé) confirms this hierarchy of vulnerability and shows that Yopougon, despite its large population, would be proportionally the most exposed municipality in the long term.

Finally, the near-stability of water demand (DNS) observed in the climate change scenario combined with reforestation (SCCR) comparable to that of the baseline scenario with the exception of the year 2060 indicates that limiting deforestation could offset, at least partially, the effect of climate change on water availability. This result underscores the role of land-use management as a lever for adaptation, on par with measures directly targeting water demand or supply.

4. DISCUSSION

4.1. Summary of the main results and interpretation of water demand dynamics

In the baseline scenario, the water demand (DED) of the four municipalities served by the Mé station would rise from 106 Mm^3in 2021 to 716 Mm^3in 2060, an increase of approximately sevenfold in less than forty years, with Yopougon alone accounting for 42 Mm^3 (39.6%) of the initial demand. This result confirms, as the analysis of the results shows, that population growth is the primary determinant of this trend: the SCCR scenario, without any additional demographic assumptions, leaves the DED virtually unchanged, whereas the SCCCDD scenario, which combines all three pressure factors, increases it by a factor of nearly 20. This interpretation aligns with studies conducted on other Ivorian watersheds: Dao *et al.* (2018) on the Marahoué and Yao *et al.* (2021) on the Lobo reach the same conclusion, that there is growing pressure from demand, driven by demographic dynamics and urbanization, on resources already weakened by climate change. This assessment is also consistent with demographic projections for the Abidjan district, with Côte d'Ivoire expected to become the most urbanized country in the UEMOA by 2030; the urban profile of Abidjan compiled by UN-Habitat further highlights that urban growth there has consistently outpaced the capacity to plan basic infrastructure, including drinking water (UN-Habitat, 2012).

4.2. Unmet Demand Reveals Structural Vulnerabilities

The DNS analysis provides further insight into the pressure on the water supply system. By 2060, demand is projected to reach 6.15 Mm^3 (0.86% of the DED) in the baseline scenario, compared to 1,023.73 Mm^3 (49.02% of the DED) in the SCCCDD scenario, with the municipalities of Yopougon and Abobo being the hardest hit (407.79 and 347.84 Mm^3, respectively). The considerable discrepancy between these two scenarios illustrates the non-additive nature of the pressures studied: it is their combination, rather than each one taken in isolation, that pushes the system into a severe deficit. This conclusion is consistent with the findings of Diabagaté *et al.* (2016) on the persistence of drinking water shortages in major Ivorian cities, as well as with those of Agarwal *et al.* (2019), who argue that unmet demand is difficult to address amid combined rapid population growth and climate change. At the sub-Saharan African level, Dos Santos *et al.* (2017) show that the continent's urban expansion structurally exceeds the capacity of infrastructure to guarantee universal access to water, while Van den Berg and Danilenko (2017), in a comparative study focusing in particular on SODECI, note that between 2000 and 2015 the relative share of the urban population with access to piped water declined because investments failed to keep pace with urbanization. The case of the Mé thus illustrates, at the local level, a tension already documented on a continental scale between the pace of demand and the pace of investment in supply.

4.3. Climate Change and Deforestation : A Cross-Reference with Regional Literature

The decline in precipitation observed in West Africa since the early 1970s continues (Yao *et al.,* 2012; Kouassi *et al.,* 2013; Fossou *et al.,* 2015; Kouassi *et al.,* 2017) and is accompanied by a reduction in flow rates at water infrastructure facilities and the drying up of certain boreholes (Koumassi, 2017). This trend is confirmed at the Bandama basin scale by Goula *et al.* (2006), who project a 21–22% decrease in available water resources by mid-century due solely to climate change, consistent with the increase in the DNS of the SCCCDD scenario. Several authors agree that river flows are expected to decrease at the local level by 2030 (Koua, 2014; Biao, 2017). The near-stability of the DNS in the "climate change + reforestation" scenario, with the exception of 2060, suggests that maintaining forest cover would mitigate part of this climate-driven effect. This result, however, warrants qualification: in the Senegal River basin, Thiam *et al.* (2022), using a WEAP21 model calibrated to the 1989–2020 period, observed a paradoxical increase in runoff despite a decline in precipitation over thirty years, attributed in particular to changes in land use. This counterexample calls for further investigation, specifically for the Mé River, into the precise mechanisms by which reforestation influences the water balance (infiltration, evapotranspiration, runoff) rather than generalizing a one-to-one relationship between vegetation cover and water resources.

4.4. The Mé Basin in Light of WEAP Experiments Conducted in Other African Basins

The approach followed here is part of a now-established practice of prospective modeling in West Africa. In Ghana, in the Volta River basin, Amisigo et al. (2015) show that none of the climate scenarios tested not even the wet ones can simultaneously meet municipal, hydroelectric, and agricultural demands, and they recommend integrated water-resource management (IWRM) to balance competing uses; this finding is consistent with that of the present study, where surface water resources from the Mé River would not be sufficient, under unfavorable scenarios, to meet domestic demand alone, which argues for a diversification of sources (groundwater, Aghien Lagoon). This convergence among the Ghanaian, Senegalese, and Ivorian basins reinforces the relevance of WEAP in documenting the growing gap between resources and needs, and suggests that lessons learned from the Mé could inform a broader discussion on IWRM in West Africa, as promoted by the West African Water Partnership, which emphasizes the need to integrate climate adaptation with the balancing of competing water uses (GWP West Africa, accessed in 2026).

4.5. This pressure is likely amplified by factors not fully incorporated into the model

The DNS values presented here relate only to domestic demand. The actual pressure on the Abidjan system could be greater if network physical and commercial losses are taken into account: Van den Berg and Danilenko (2017) note that unaccounted-for water remains a persistent challenge for West African operators, and SODECI is no exception. Added to this is a documented social dimension in Abidjan: Angoua *et al.* (2018) show that access to water in peri-urban neighborhoods depends heavily on households' socioeconomic status, with a portion of the population having more precarious access than the municipal averages used here suggest. These findings do not call into question the general trend highlighted by WEAP, but they do suggest that the DNS values should be considered a conservative estimate of the actual deficit a conclusion also supported by UN-Habitat's (2012) urban profile of Abidjan, which links the growth of outlying municipalities to a relative deterioration in access to basic services.

4.6. Implications for Resource Management and Outlook

This study has limitations; notably, industrial, commercial, and institutional water uses, groundwater withdrawals, and the environmental flow rates necessary to maintain the river's ecosystem are not explicitly incorporated into the analysis of the dynamic interactions between climate, land use, and demographics (Yates *et al.,* 2009; Hirko *et al.,* 2025). However, these limitations do not invalidate the operational relevance of the results: the increasing DNS reflects real pressure on Abidjan's water supply system, in a context already marked by difficulties in accessing water (Angoua *et al.,* 2018). Strengthening the water supply through other surface water sources, such as the Aghien lagoon, is a viable option that is already being implemented. This initiative illustrates the relevance of the management strategies discussed here, while also highlighting that the scale of the deficits projected for 2060 particularly for Yopougon and Abobo will require substantial additional investments, in line with the $825 millions multi-phase program approved in 2024 to ensure urban water security in Côte d'Ivoire (World Bank, 2026). Following the recommendations made for the Volta River in Ghana (Amisigo *et al.,* 2015), integrated water-resource management in the Mé River basin combining diversification of water sources, reduction of network losses, and planning for population growth appears to be the most realistic approach to reconciling the demand trajectory highlighted by this study with the sustainable preservation of the resource.

5. CONCLUSION

As part of this study, a decision-support system was developed to model water demand and water resource capacity in the Mé River basin, with the aim of meeting future water needs under various scenarios. The WEAP model was used to estimate the five-year water needs through 2060 for the municipalities supplied by the Mé River watershed. The results show that the municipality of Yopougon has the highest water needs, with estimated volumes of 346 Mm^3, 42 Mm^3, and 831 Mm^3 under the baseline scenario, the climate change plus reforestation scenario, and the scenario combining climate change, rapid population growth, and deforestation, respectively. It is followed by the municipality of Abobo, whose water needs reach 151 Mm^3, 36 Mm^3, and 709 Mm^3 for the same scenarios. Third place is held by the municipality of Cocody, with estimated needs of 205 Mm^3, 19 Mm^3, and 367 Mm^3, while the municipality of Adjamé has the lowest volumes, estimated at 14 Mm^3, 9 Mm^3, and 181 Mm^3, respectively, according to the three scenarios considered. Furthermore, with the exception of the climate change and reforestation scenario in which all needs are met the results for unmet demand (UMD) across all demand sites show that deficits were observed during the simulation period for the "SR" (2060) and "SCCCDD" (starting in 2040) scenarios. Thus, the available water resources are limited, and inflow rates will not be sufficient in the long term. The DNS for the four demand sites in the "SR" scenario begins in 2060 at 6.15 Mm^3. In the "SCCCDD" scenario, it begins in 2040 at 1 $Mm^3$and reaches 1,023.73 Mm^3 by 2060. Overall, the results therefore show that problems related to water availability could arise starting in 2040 and continue through 2060. Given the rapid increase in unmet water demand (DNS) highlighted by the model, it is essential to adopt a rational management approach for available water resources. Furthermore, to address the water deficit, policymakers should consider constructing water infrastructure, including surface water treatment plants, expanding water distribution networks, and tapping into other surface water sources located on the outskirts of Abidjan.

6. DATA AVAILABILITY STATEMENT

Data availability not informed.

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