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# Impacts of climate change and demography on surface water demand and supply in the ungauged N'Zo river basin

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## Abstract

This study was conducted in the N'ZO river basin. The population of this catchment area is growing significantly, and combined with the effects of climate change, which are likely to cause a decrease in streamflow, this worsening trend exacerbates the problem of surface water resource supply. The primary objective of this work is to evaluate the alignment between water demand and water supply in the city of Man and its surrounding localities. We utilized various climate scenarios, namely Representative Concentration Pathway 4.5 (RCP 4.5) and 8.5 (RCP 8.5), to determine the impact of climate change on surface water resources within the catchment. We employed a rainfall-runoff modelling approach using the GR2M model to simulate different river discharges from 1982 to 2050. Using the WEAP model, we developed scenarios for water demand and resource availability for the period 2021 to 2050. The results showed that temperatures are projected to increase at an annual growth rate of 1.95% according to RCP 4.5 and 2.28% for RCP 8.5, while rainfall is expected to decrease at rates of 0.75% and 0.33% respectively, for RCP 4.5 and RCP 8.5. Additionally, the GR2M model effectively simulated streamflow with satisfactory accuracy. We estimated that the average annual water inflows will be 63.34 million cubic meters (M.m3) under RCP 4.5 and 56.27 M.m3 under RCP 8.5 for 2050. The total annual water demand for the city of Man and surrounding localities is projected to be 9.52 M.m3 under the reference scenario (SR) and 11.03 M.m3 under the high-growth scenario (SC). Our adequacy analysis using the WEAP model indicates that demand remains below supply up to 2050, so there is no cause for concern.

**Keywords:** Climate Change; Socio-Economic; Scenario; Ungauged Basin; Water Supply; N'ZO Basin

## 1. Introduction

Access to drinking water is a critical global challenge, recognised in the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) [1]. Approximately 71% of the Earth's surface is covered by water, and the oceans contain around 96.5% of the Earth's total water. Notice how only 2.5% of Earth's water is freshwater, the amount needed for life to survive. Almost all of it is locked up in ice and the ground. Only a little more than 1.2% of all freshwater is surface water, which serves most of life's needs [2]. Slightly less than half of the global population, 3.6 billion people or 47%, live in areas that suffer from water scarcity for at least one month each year [3]. In Sub-Saharan Africa, 35% of the population lacks access to a basic water supply, with no regional statistics available for access to a safely managed water supply [4]. Climate change, population growth, and unsustainable consumption patterns exacerbate water scarcity, threatening half of the global population with water stress by 2025 [5].

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In Côte d'Ivoire, water resources are vital for agriculture, industry, and domestic use. Yet, unequal distribution and climate variability [6] strain supply. The Man department relies on the N'Zo River, facing mounting pressure due to population growth, climate-induced reductions in streamflow, and inadequate infrastructure to meet the rising demand. According to the 2014 General Census of Population and Housing, the local population was 182,871 in 2014 [7]. This population increased to 241,969 inhabitants in 2021 [8]. The department's population grew after the military-political crisis of 2002 to 2010, due to the redeployment of the administration and a resumption of economic activities (farming, mining, etc.). The effects of climate change on dwindling streamflow will further threaten the availability of water resources, especially since the catchment has a humid tropical climate [6,9]. Tropical regions dominate more than a third of the Earth's surface and play a key role in climate dynamics. Given this context, can the N'Zo River at Zoba sustainably meet the domestic water needs of the Man department?

The WEAP (Water Evaluation And Planning) model serves as a robust tool for simulating water supply-demand dynamics under climatic and demographic scenarios [10]. Researchers have successfully applied it in West Africa, including Côte d'Ivoire's Basin [11,12], demonstrating its efficacy in water allocation planning processes. WEAP employs an integrated approach to simulate the interactions between water balance variables such as precipitation, evapotranspiration, runoff, infiltration, and data on hydraulic structures and facilities. This method offers a more comprehensive perspective on the factors that need consideration in water management projects [13,14]. It models water demand, supply, storage, pollution, treatment, and distribution. Since the river at this outlet is not gauged, we extrapolate the streamflow using the approach described by the main objective of the work is to analyse whether the N'Zo River (Zoba outlet) can supply the town of Man by 2050 using the WEAP model. We simulate the streamflow at the N'Zo outlet at Guiglo (further downstream and partially gauged) with the Génie Rural 2-parameter monthly rainfall-runoff model (GR2M). Next, we transfer these streamflows to the Zoba outlet to estimate the current and future mobilisable surface water resources, considering greenhouse gas emission climate scenarios (RCP 4.5 and RCP 8.5). We then use the WEAP model to estimate the current and future water consumption needs of the population, taking into account scenarios for population growth and water use. Finally, we model the match between supply and demand for the year 2050. The results of this study will be essential for proposing more effective and flexible mechanisms to improve water access for all users in the Man department.

## 2. Materials and methods

### 2.1. Study area

The N'Zo catchment, with its outlet at Guiglo, covers an area of 7,084 km$^2$ and is shared by the Tonpki and Guémon regions of Côte d'Ivoire. Upstream of this catchment is a sub-catchment, which has an outlet at Zoba, covers 1,095 km$^2$, and is the focus of this study (Figure 1). The River N'Zo, a left-bank tributary of the Sassandra, originates at an altitude of 560 metres in a mountainous area situated between Biankouma and Man [6]. The N'Zo basin experiences a very wet climate, receiving between 1,600 and 2,500 mm of rainfall annually. The basin's climate is generally quite humid.

The N'Zo River supplies the town of Man near Zoba. This surface water intake point is about 30 km from Man. To ensure a sustainable water supply, new water conveyance facilities have been constructed. The infrastructure can produce 12,000 m$^3$ of drinking water daily, meeting both current and future needs of the area. Additionally, a drinking water treatment plant with a capacity of around 600 m$^3$ per hour has been built and equipped along the N'Zo River. An 800 m$^3$ treated water storage tank has also been erected, and existing equipment has been rehabilitated and reactivated [16]. Besides supplying the town of Man, the River N'Zo provides water to Sangouiné, Zoba, Kouitongouiné 2, Kassiapleu, Gbangbégouiné Yati, Zélé, and Mahapleu.

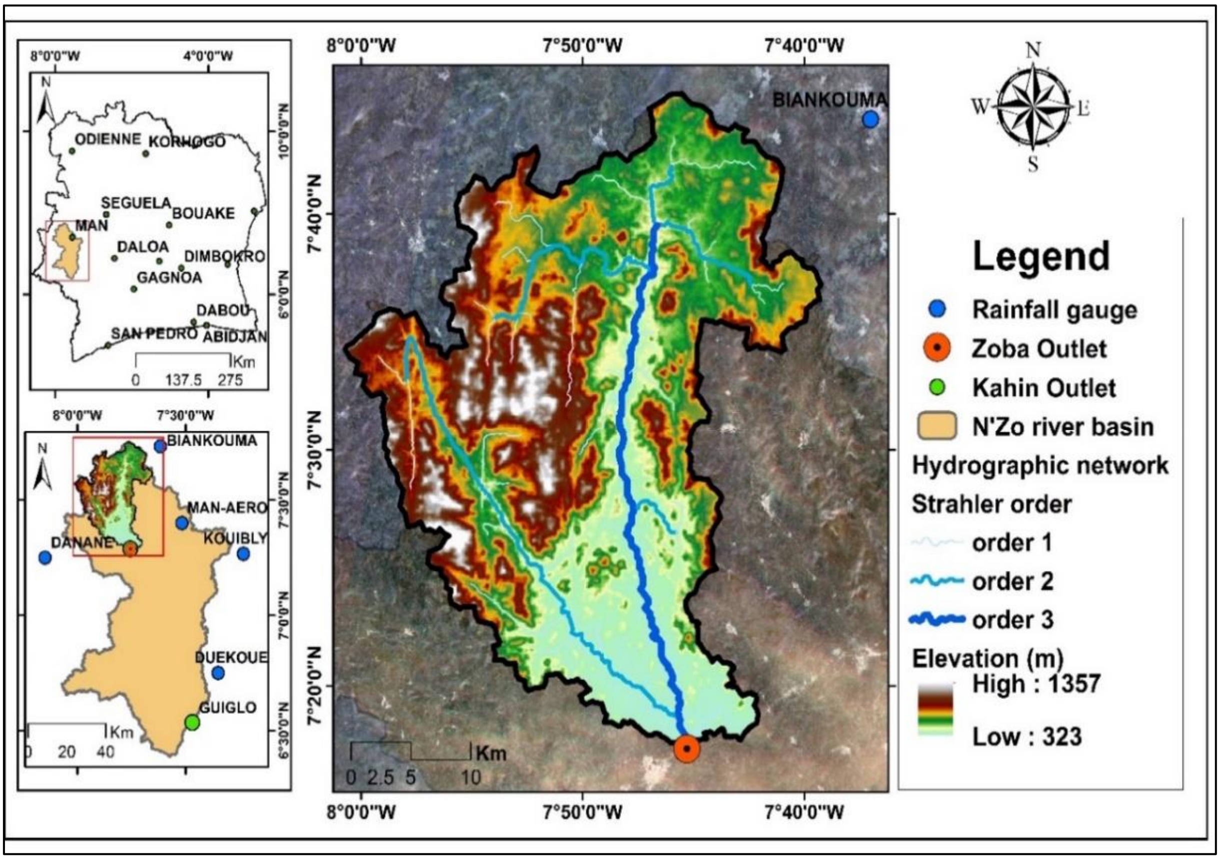


**Figure 1** Study area and localisation of the rainfall and hydrometric stations

## 2.2. Data

The historical data primarily consist of hydro-climatic, demographic, and water consumption information. For rainfall-runoff modelling on a monthly scale, six rainfall gauges are utilised (see Figure 1). Based on the availability of long-term historical climatic data, we selected monthly rainfall data from these stations spanning from 1956 to 1976. A mean rainfall for the Guiglo watershed is deduced based on Thiessen polygons from data from these rainfall stations. Additionally, monthly streamflows from the Guiglo gauge and monthly temperature data from the Man Airport station for the same period are included. These data were collected from the SIEREM database [17]. To update and extend the climatic time series (temperature and rainfall) used in the study, satellite data from NASA Power Access Climate Data. These satellite data were combined with in situ measurements through linear regression correction, resulting in an extended in situ time series covering the period from 1982 to 2022. The demographic data are from the Man department, obtained from the general population and housing census of 2021 and the population growth rate in rural (2%) and urban (3%) areas of Côte d'Ivoire is also used. Except for Man, which is semi-urban, the other localities in the department are rural. The daily water consumption is 50 litres per day per inhabitant in urban areas, compared to 30 litres per day per inhabitant in rural areas [8].

The climate model data used in this study are based on historical and future climate projections, rainfall, and temperature derived from seven CORDEX-AFRICA simulations RCP 4.5 and RCP 8.5 scenario. The available variables include rainfall and temperatures (maximum and minimum). These simulations have been validated using three statistical parameters: mean rainfall, standard deviation, and maximum for each model over the 1991-2005 historical period. These parameters were compared with those of the CHIRPS observation data over the same period in order to assess the degrees of similarity and quantify the differences between the data (the validation process is not shown in this paper).

## 3. Methods

### 3.1. Estimation of current and future mobilisable water resources

*3.1.1. Rainfall-runoff modelling for N'Zo river catchment*

The mean rainfall in the N'ZO catchment was calculated using the rainfall stations based on the Thiessen method; then, the rainfall data were integrated into the GR2M model. Potential Evapotranspiration (PET) for the N'ZO catchment was determined using Thorn software [18]. In addition to temperature, the software uses the altitude of the climate station as input data. The PET represents the climatic demand for water with the energy availability. In this water balance, PET [19] is calculated with Eq. (1):

$$PET_{\text{Hamon}} = 13.97 \times d \times D^2 \times W_t \quad (1)$$

Here, d is the number of days in a month, D is the monthly average of daylight hours in 12-hour units, Wt is a saturated water vapour density term, in g.m3, calculated by Eq. (2):

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100} \quad (2)$$

Here, T is the mean monthly temperature in Celsius degrees.

The GR2M model is used to simulate streamflows using rainfall and ETP in the N'Zo river catchment, with the Guiglo station as its outlet. This enters rainfall and potential evapotranspiration data into the model. GR2M is a rainfall-runoff conceptual model with two reservoirs (production reservoir S and routing reservoir R). The S reservoir, which represents the water stock, has a maximum water capacity (X1) for transforming rainfall and mean monthly evapotranspiration data into simulated streamflows. This is because the fraction of monthly rainfall recorded contributes to direct runoff (Figure 2). The level of water in the reservoir changes as a function of the fraction of rainfall remaining and the potential evapotranspiration via the actual evapotranspiration. A progressive emptying of this water stock produces runoff [20].

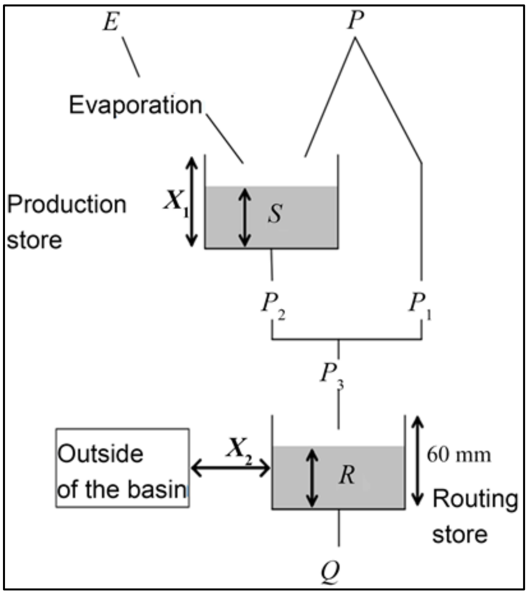


**Figure 2** Structure of the GR2M model [20]

Model validation is verified by comparing the calculated and observed streamflow's using a quality criterion. The best known and most widely used criterion for conceptual models is the Nash-Sutcliffe Efficiency (NSE) criterion (20) with Eq. (3)

$$NSE = \left[1 - \frac{\sum_{i=1}^{n}\left(Q_i^{\text{obs}} - Q_i^{\text{sim}}\right)^2}{\sum_{i=1}^{n}\left(Q_i^{\text{obs}} - Q^{\text{mean}}\right)^2}\right] \quad (3)$$

Here, Mean is the observed mean flow, Qasim is the calculated flow, Qods is the observed flow, and n is the number of observations.

This formula expresses a certain model efficiency comparable to the coefficient of determination in a regression. The better the Nash-Sutcliffe Efficiency (NSE) criterion is, the better the adjusted model. It is generally considered that a hydrological model yields acceptable results if the NSE criterion value exceeds 0.5 [22].

### 3.2. Streamflow transfer to the ungauged catchment area

The transfer of streamflow's from the gauged catchment (Guiglo outlet) to the ungauged catchment (Zoba outlet) is possible when there is a hydrometric station on the same hydro-morphological section. We will determine the flow rate QB of the catchment area B that we are looking for (Zoba outlet) with surface area SB, with the flow rates QA characteristic of the catchment area A (Guiglo outlet) with surface area SA that we know [22]. This is made possible by Eq. (4)

$$Q_B = Q_A \times \left(\frac{S_B}{S_A}\right) \quad (4)$$

The reconstructed river streamflows at the Zoba outlet using the simulated current and future streamflows at the Guiglo outlet will be entered into the WEAP software to model the balance between water needs and resources at the Zoba outlet.

*3.2.1. Estimation of current and water consumption requirements*

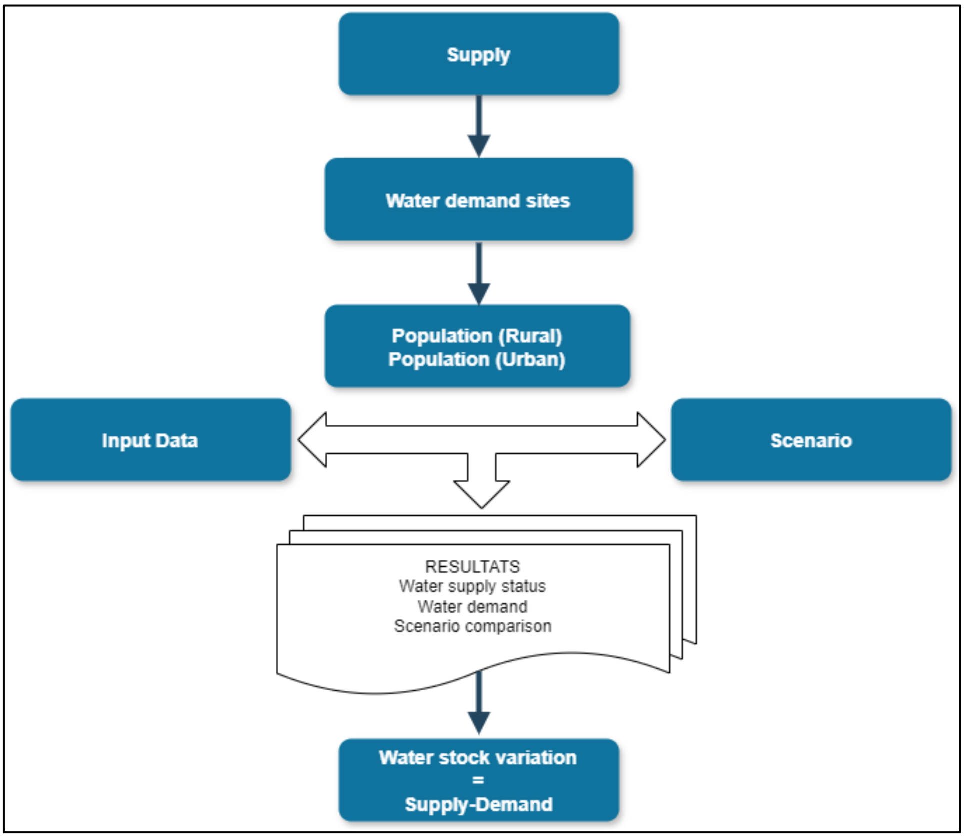


**Figure 3** Different steps implemented in the WEAP model [13]

The Water Evaluation and Planning System (WEAP) involves selecting a "Current Accounts" year as the baseline, serving also as a calibration stage. In this case, 2021 is chosen, incorporating data on water availability (supply), request sites (demand), and socio-economic factors (population). A reference scenario for 2022–2050 is developed based on this baseline to simulate the basin's resource evolution without intervention. Subsequently, "what if ?" scenarios are created to modify the baseline, enabling assessment of how planned water use changes align with potential adjustments in unit requirements [13]. These scenarios are grounded in the "Current Accounts" to reflect factors influencing demand and supply, such as population growth and climate change [23]. Finally, we compare projected changes in water availability with those in demand, considering rapid population growth and climate change impacts. The steps involved in the WEAP process are summarised as follows (see Figure 3).

### *3.2.2. Creating hypotheses and scenarios*

The project begins by importing the basin and river system outline in vector format into the model's schematic view. Next, demand sites, transmission links, and round-trip links are digitised (see Figure 4). The evolution of the "Current Account" is used to calibrate the model, with 2021 serving as the base year. Future trends are projected using two scenarios: a "Reference" scenario (SR) and a "Growth" scenario (SC). The SR is based on historical data before 2021. In the SC, growth rates derive from forecasts in the integrated water resources management plan for Côte d'Ivoire [24]. Demographic data for subsequent years are linearly extrapolated within the WEAP model. The average annual water demand of the population is calculated using estimates from the Master Plan for Integrated Water Resource Management [24], which stipulates a unit consumption of 50 litres per day per person in urban areas and 30 litres per day per person in rural areas. Based on these forecasts, population growth is expected to lead to increased water consumption by 2050. Consequently, this scenario is referred to as the "Growth" scenario.

The base year for this study is 2021, with an annual reference time. For this study, two types of assumptions are considered

- the unit of theoretical requirements of the various users converted into volume per year (unit recognised by the software);
- The different population growth rates for future scenarios.

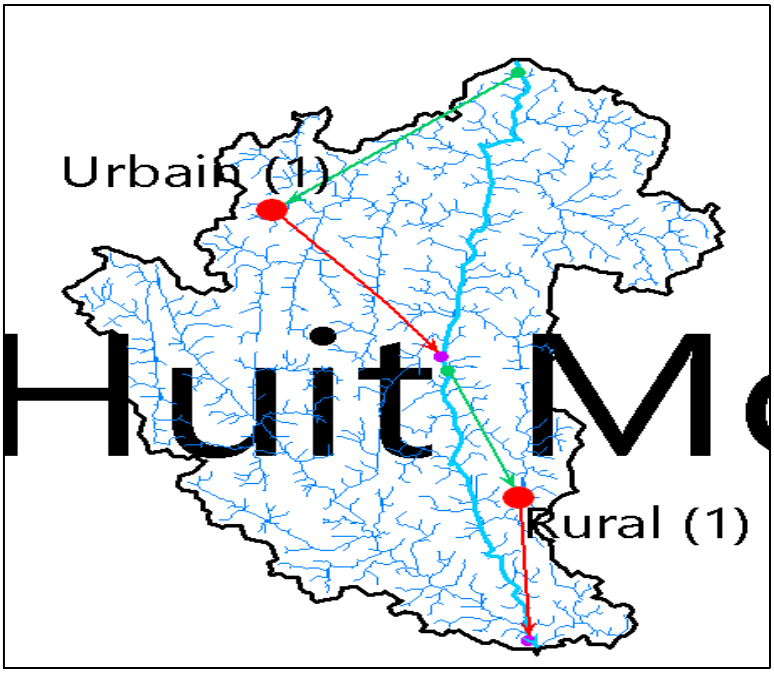


**Figure 4** Watershed management project within the WEAP model environment [13]

### *3.2.3. Water year method*

This method involved defining each climatic regime (very dry, dry, normal, wet, and very wet) and comparing it with different types of climates (Table 1), using values between 0.7 and 1.45. The value 1 is assigned to a normal year; dry years have a value less than 1, and wet years have a value greater than 1. As the simulation software only recognises numerical values, each type of climate corresponding to the year must be assigned a numerical value so that the software can proceed with the modelling [13].

**Table 1** Definition of climate types according to WEAP [13]

| Climatic regime | Very dry | Dry | Normal | Wet | Very damp |
|---|---|---|---|---|---|
| Value | 0.7 | 0.8 | 1 | 1.3 | 1.45 |

Once each type of climate has been defined, it is necessary to create a climate sequence for the coming year. Knowledge of the climatic regimes for the current year of account (2021) and future years (2022-2050) was made possible by calculating flow deciles; this makes it possible to assess the impact of climatic variation on water resources (rainfall, runoff, groundwater recharge, etc.), with the needs of users. The decile concept used in this study was developed by [25] . Table 2 below shows the decile indices used in this work.

**Table 2** Categories of dry and wet years based on decile indices [25]

| Category | Very dry | Dry | Normal | Wet | Very damp |
|---|---|---|---|---|---|
| Decile index | 1-2 | 2-4 | 5-6 | 7-8 | 9-10 |

A database has been compiled based on the table above to define the types of hydrological years for the period 2022-2050.

*3.2.4. Modelling the match between water resources and needs*

To improve water supply/demand management in the basin, various scenarios ("SR" and "SC" strong) will be used to assess water supply. The consumed flows correspond to flows linked to domestic needs. Therefore, the flow management balance is as follows, Eq. (5):

$$Q_S = Q_e - Q_u \quad (5)$$

Here, $Qs$ is the outflow at the basin outlet, $Qe$ is the inflows or outflows from all sources, $Qu$ is the flows or volume of water consumed by each branch of use.

The WEAP model is based on the available data during the reference period (2021) to simulate development and resource management scenarios. It periodically (days, months, years) calculates the conservative volume balance of inputs and outputs by solving an iterative linear programming algorithm [13].

## 4. Results

The preliminary results concern the N'Zo River basin at the Guiglo outlet. The extractable streamflows at this station are subsequently converted to estimate the streamflows of the river at the ZOBA outlet. These converted streamflows are used within the WEAP software to model the balance between water supply and demand for the purpose of supplying. Indeed, it is at this station that the river is harnessed for potable water supply to the populations of the city of Man and its surrounding localities.

### 4.1. Monthly variation in climatic parameters over N'Zo watershed

Historical mean monthly temperatures and those derived from the RCP 4.5 and RCP 8.5 climate scenarios for the N'Zo catchment are presented (Figure 5). The CORDEX model used reproduces the monthly variations perfectly, even though the temperatures are overestimated. Observed temperatures are lower than those simulated (RCP 4.5 and RCP 8.5). The simulated temperatures for the RCP 4.5 and RCP 8.5 scenarios for 2050 are practically the same for each month. From January to March, temperatures range from 25 °C to 29 °C for the simulation and from 24 °C to 27 °C for the historical temperatures. The months from March to October would be slightly warmer than currently observed.

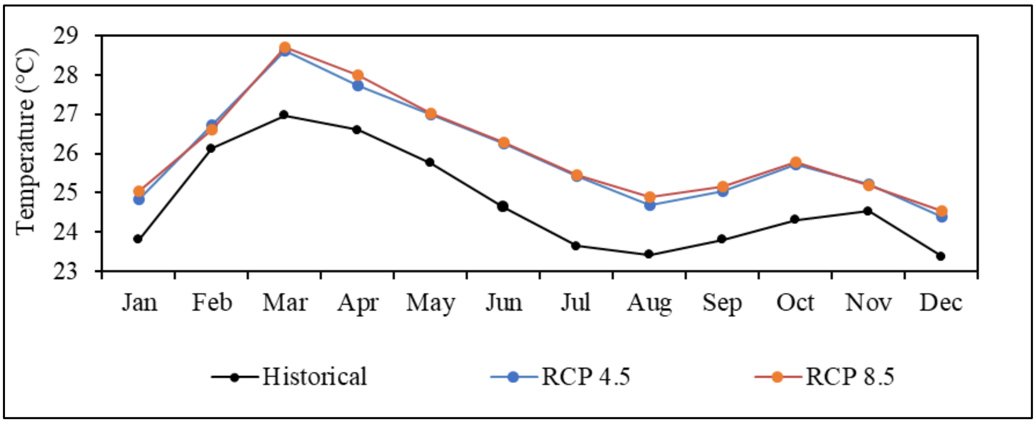


**Figure 5** Comparison of historical and future projected temperatures over the N'Zo watershed

The mean monthly rainfall for the N'Zo catchment, based on historical data, and rainfall projected from RCP 4.5 and RCP 8.5 are compared (Figure 6). The historical rainfall exceeds the simulated values under both RCP scenarios. The simulated rainfall for RCP 4.5 and RCP 8.5 is nearly identical each month, except in April, May, and November, where RCP 4.5 shows higher rainfall than RCP 8.5. Historically, rainfall increases from January to June, decreases in July, then rises again to reach about 210 mm in August and September, before declining through December. The average monthly variation indicates a significant reduction in future total monthly rainfall compared to the historical period.

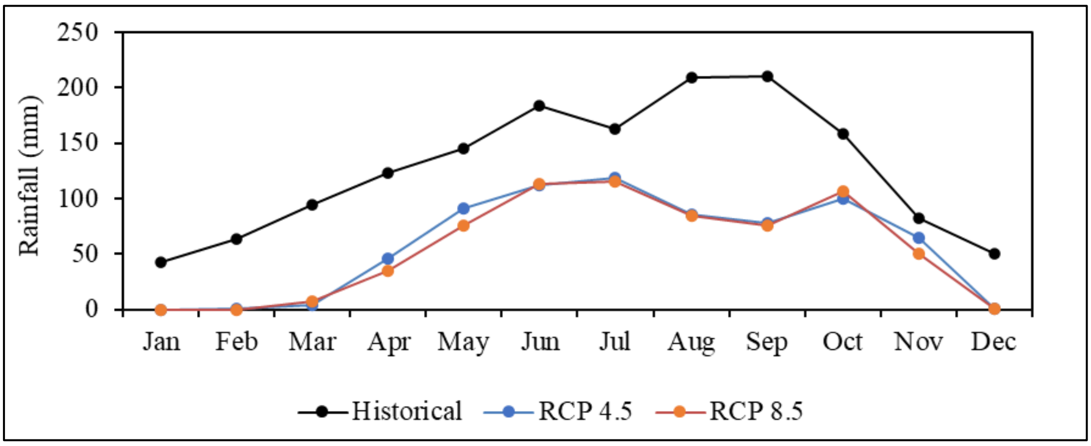


**Figure 6** Comparison of historical and future projected rainfalls over the N'Zo watershed

### 4.2. Current and future interannual climate variation in the N'Zo basin at Guiglo outlet

The rates of annual change in current and future temperatures indicate an increase under all climate scenarios (Table 3). For RCP 4.5 (1.95%), the rate will rise by approximately 1% compared to the historical rate of 0.97%. Under the pessimistic RCP 8.5 scenario, the rate is projected to reach 2.28%, an increase of about 1.2%. This rate is expected to increase from the present temperature to the future temperature. Regarding rainfall, the annual change indicates a decline by 2050. The current rate of change is around 1.43%. RCP 4.5 (optimistic) projects a lower rate of 0.75%, while RCP 8.5 (pessimistic) estimates a rate of 0.33%, both lower than the current rate.

**Table 3** Interannual variation rate of current and future temperature and rainfall over the N'ZO basin watershed

| Scenario | Interannuel variation rate (%) | |
|---|---|---|
| | *Température* | *Randall* |
| Curent | 0.97 | 1.43 |
| RCP 4.5 | 1.95 | 0.75 |
| RCP 8.5 | 2.28 | 0.33 |

The Pettitt test indicates a change point in the rainfall series in November 1972, while the Buishand test detects a break in December 1969. This date is confirmed by both the Buishand U test and the standard normal homogeneity test (Table 4). Therefore, the rainfall series in the basin experienced a significant change in December 1969. The sub-period before this break was selected as the calibration period for the GR2M modelling, while the period after the break was used for model validation.

**Table 4** Date of the change point in the rainfall time series over the N'Zo basin

| Test | Pettitt | Buishand | Buishand U | Normal Homogeneity s. |
|---|---|---|---|---|
| Date | November 1972 | December 1969 | December 1969 | December 1969 |

### 4.3. Surface water resources that can be mobilised at the Guiglo outlet using the GR2M model

#### *4.3.1. Simulated hydrological behaviour of the N'Zo basin*

Figure 7 displays the hydrographs of both simulated and observed streamflows at the Guiglo outlet. Throughout calibration and validation, the hydrographs share similar shapes, although their amplitudes sometimes differ. This indicates that the model accurately estimates streamflows during these phases.

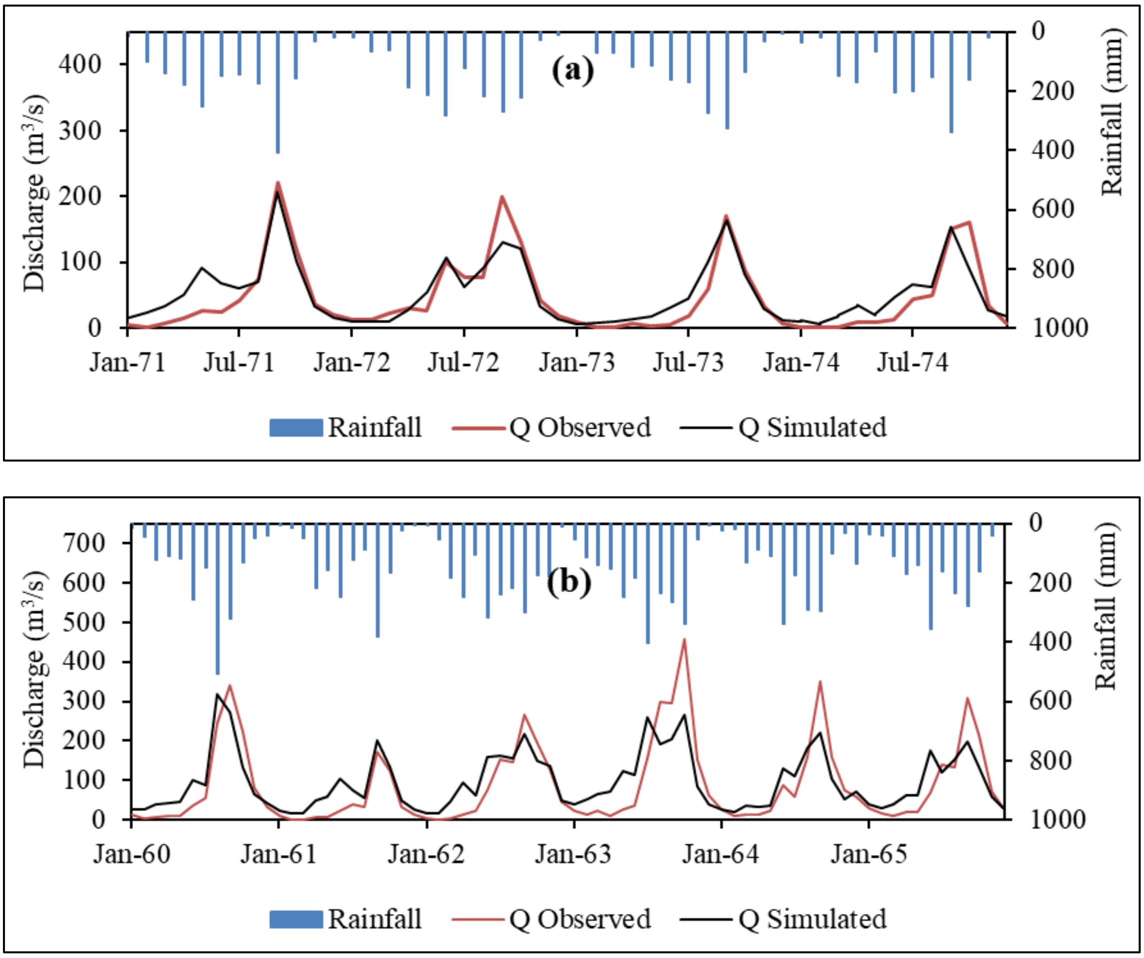


**Figure 7** Hydrographs observed and simulated by the GR2M model of the N'Zo watershed, calibration (a) and validation (b)

The Nash efficiency criterion values exceed 60% (NSE calibration = 66.3%, NSE validation = 66.4%) (Table 5). An analysis of these hydrographs reveals that the model tends to overestimate flow during flood and high-flow periods. This overestimation is evident as simulated streamflows are generally higher than observed values. Conversely, the model underestimates peak flood flows, especially during flood peaks.

**Table 5** Nash values for calibration and validation of the GR2M model

| Calibration | Validation | Parameter | | Nash-Sutcliffe Efficiency (NSE) (%) | |
|---|---|---|---|---|---|
| | | *$X_1$(mm)* | *$X_2$(mm)* | *Calibration* | *Validation* |
| 1956 - 1965 | 1970 - 1974 | 7.01 | 1.12 | 66.3 | 66.4 |

*4.3.2. Streamflow's reconstructed by the GR2M model over the current period*

The use of the GR2M model provided satisfactory results in capturing the streamflow dynamics over this period (Figure 8). The flood hydrograph is synchronised with the histogram, although there is a slight lag, which reflects the catchment area's response time to the rainfall event. The data indicate that streamflow levels started to decline significantly from 1999 to 2008, reaching lows of less than 50 $m^3/s$. Following this period, streamflows began to increase from 2008 onward. This rising trend continued into 2009, culminating in a maximum flow of approximately 250 $m^3/s$ around 2019.

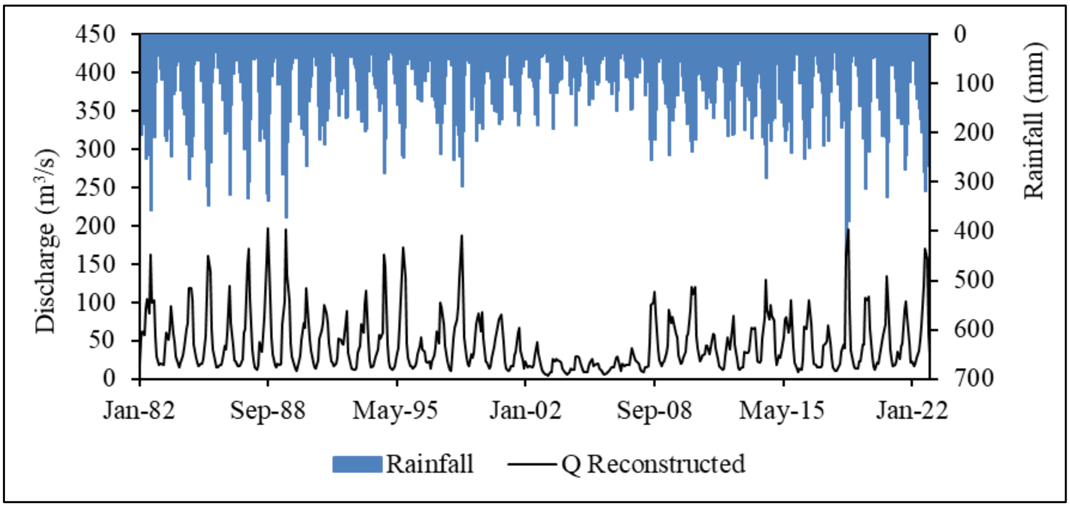


**Figure 8** Reconstructed hydrograph of historical streamflows of the river N'Zo at Guiglo from 1982 to 2022

## 4.4. Comparison of historical and future monthly streamflows of the N'Zo river at Guiglo

Historical monthly streamflows are significantly higher than those projected for 2050 under RCP 4.5 and RCP 8.5 (Figure 9). Both future scenarios produce very similar streamflow patterns each month. Historically, flows increase from January to September, peaking at around 125 $m^3/s$, then decline through October to December. By 2050, however, projected flows decrease markedly, ranging between 0 and 25 $m^3/s$, indicating a substantial decline in water availability.

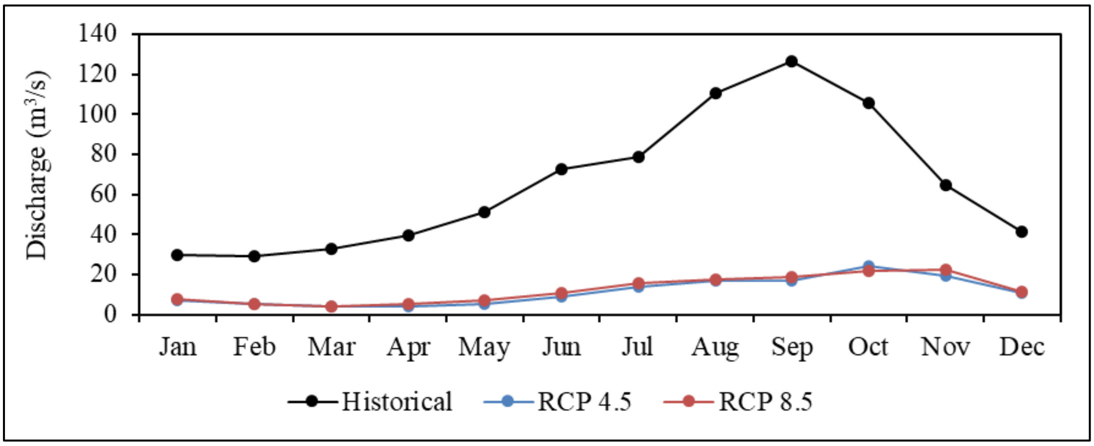


**Figure 9** Comparison of historical and future monthly streamflows in the N'Zo river

### 4.5. Historical and future water input (or supply) at the ZOBA outlet

Interannual inflows were estimated using the hydrological year method, which assigns each year to a specific climate type based on climatic variations. Figures 10a and 10b illustrate the impact of climate change on inflows. Historically, inflows mean is 336.82 $M.m^3$, with a minimum of 220 $M.m^3$. Under future scenarios, inflows decrease substantially, averaging 63.34 $M.m^3$ for RCP 4.5 and 56.27 $M.m^3$ for RCP 8.5 (Figure 10b). The inflows projected under RCP 4.5 are slightly higher than those under RCP 8.5. Notably, a pattern emerges of alternating wet years with high inflows and dry years with low inflows. By 2050, minimum inflows could fall to around 40 $M.m^3$.

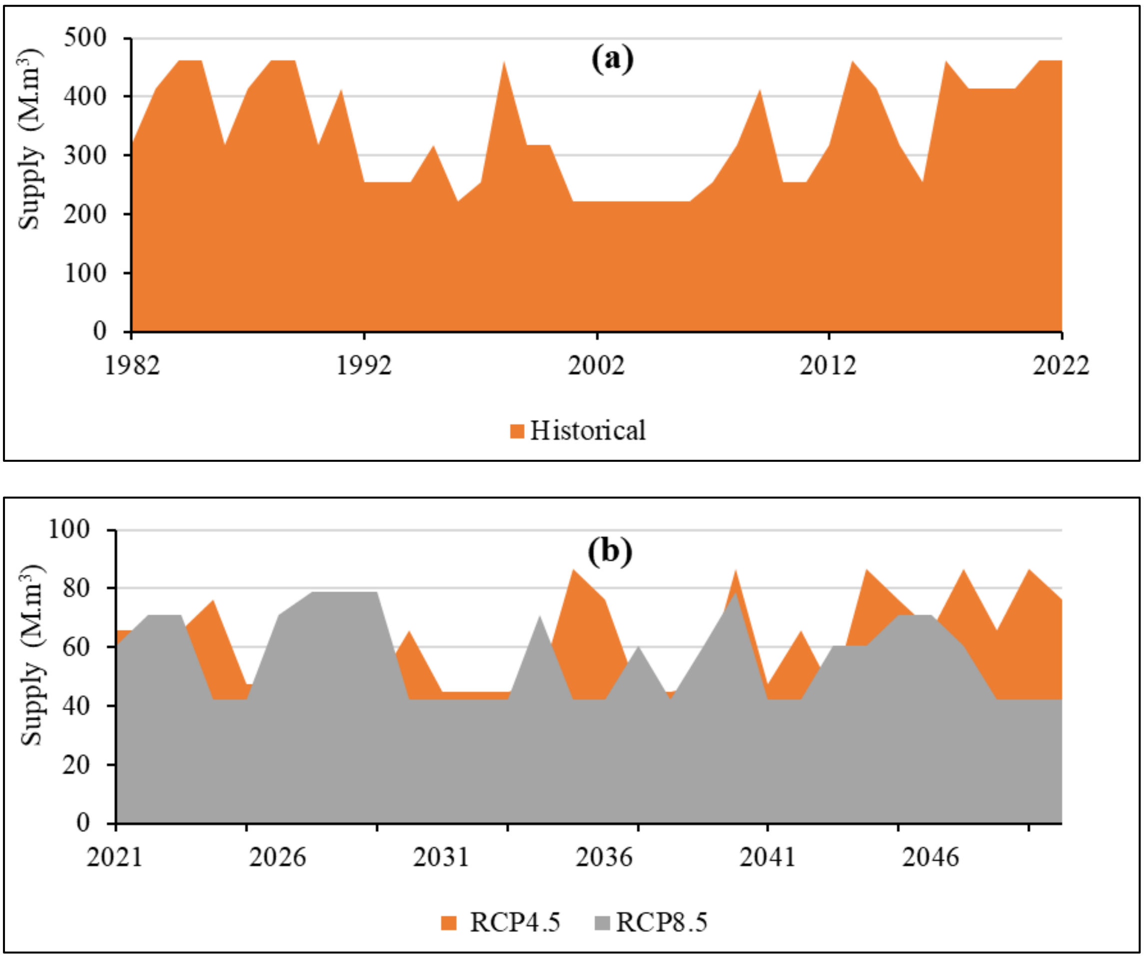


**Figure 10** Interannual water input at the ZOBA outlet over the historical period (a) and over the future period (b)

### 4.6. Rural and urban water requirements for the reference scenario (SR) and growth scenario (SC)

Figure 11a shows water demand under the Reference Scenario (SR). Demand increases from 2021 to 2050, with urban demand surpassing rural demand. In 2021, demand was lowest, at 1.78 $M.m^3$ in rural areas and 4.41 $M.m^3$ in urban areas. By 2050, it rises to 3.72 $M.m^3$ and 10.40 $M.m^3$, respectively. Figure 11b illustrates demand under the High Population Growth Scenario (SC), which follows a similar increasing trend. Urban demand remains higher than rural demand throughout. The minimum demand is 1. $M.m^3$ (rural) and 4.59 $M.m^3$ (urban), while the projected maximum demand in 2050 reaches 3.65 $M.m^3$ (rural) and 13.77 $M.m^3$ (urban).

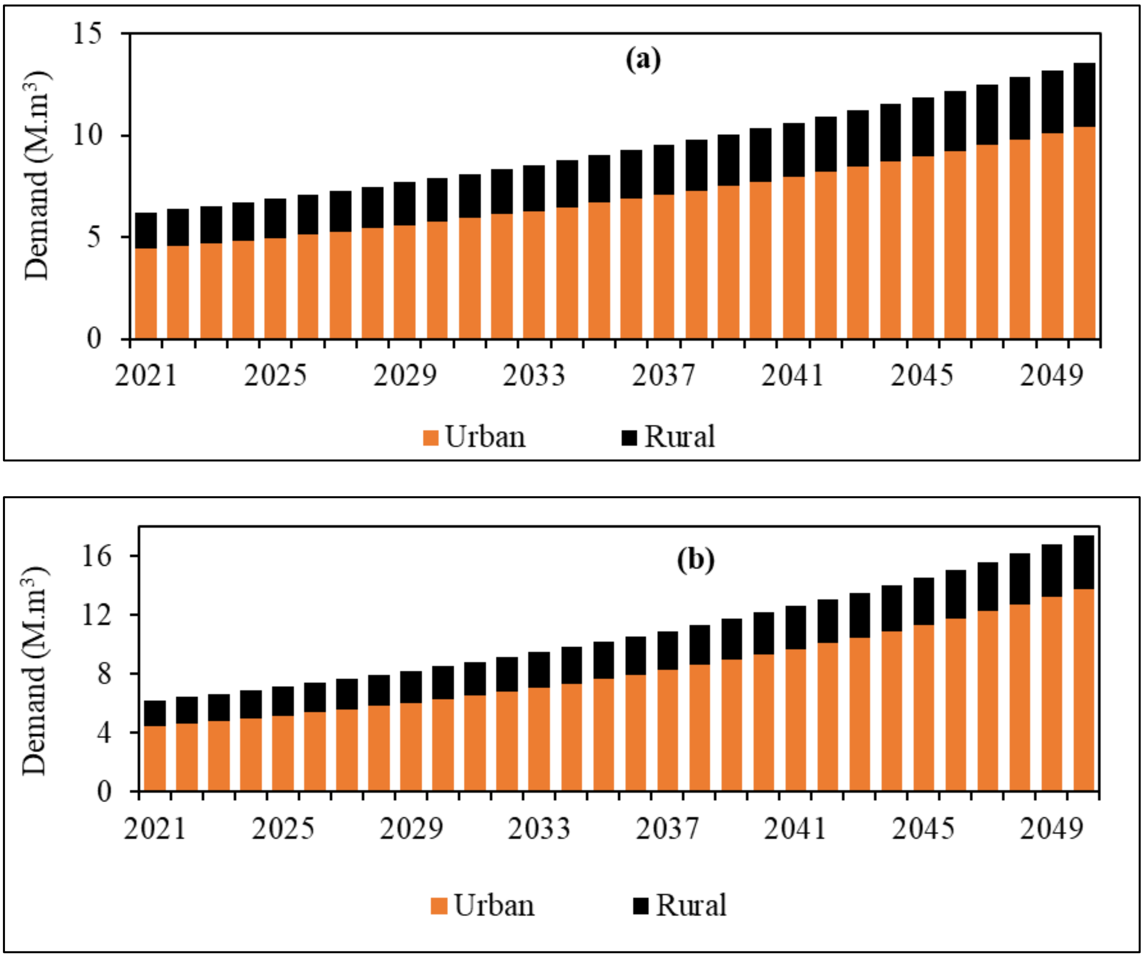


**Figure 11** Rural and urban water requirements for the reference scenario (a) and growth scenario (b)

### 4.7. Adequacy between water demand and supply in the Man department

The average overall demand for domestic water (urban + rural) would be 9.53 M.m3 for the SR scenario, while it would be 11.03 M.m3 for the SC scenario. The stock change (Δ), which represents the difference between supply and demand in a given year, would remain in surplus (largely positive values) over the period 2022-2050 (Table 6). This indicates that, whatever the population increase scenario (SR, SC) and/or the climate change scenario (RCP 4.5 and RCP 8.5), the water inflow (supply) from the River N'Zo at ZOBA would be able to meet the domestic needs (demand) of the population of the town of Man and the surrounding area. Consequently, the balance is more positive for the RCP 4.5 simulation than for RCP 8.5, with average annual stock variations around 50 M. m3.

**Table 6** Interannual stock variation statistics for the water supply/demand balance in the Man department

| **Paramètre** | **Δ.SR (M.m³)** | | **Δ.SC (M.m³)** | |
|---|---|---|---|---|
| | *RCP 4.5* | *RCP 8.5* | *RCP 4.5* | *RCP 8.5* |
| Mean | 53.81 | 46.74 | 52.31 | 45.25 |
| Standard deviation | 15.67 | 15.54 | 15.45 | 15.95 |
| Minimum | 33.45 | 28.47 | 31.14 | 24.62 |
| Maximum | 77.68 | 71.55 | 76.55 | 71.181 |

## 5. Discussion

The analysis of rainfall from 1956 to 1976 identified two potential change points, with three statistical tests confirming 1969 as the most significant. These findings align with previous studies [26-28], which indicate that most climate shifts in West and Central Africa occurred between 1960 and 1970. Based on this, the rainfall data was split into calibration (1956–1965) and validation (1970–1974) periods for the hydrological modelling. The GR2M model performed well during both periods, with Nash-Sutcliffe Efficiency (NSE) values of 66.3% and 66.4%, respectively. These results are consistent with previous research in Côte d'Ivoire [29,30] and indicate the model's robustness for simulating the catchment's hydrology. The generated hydrographs generally overestimate streamflows, with peaks often underestimated, but overall, the model accurately reflects the hydrological behaviour.

Applying the GR2M model to data from 1982 to 2022, and under future climate scenarios (RCP 4.5 and RCP 8.5), yielded satisfactory results, aligning with findings by [31] for similar catchments. The subsequent climate analysis shows increasing temperatures and decreasing rainfall, consistent with studies [9,32–34]. Under RCP 8.5, the climate becomes more extreme, with warmer temperatures and lower rainfall compared to RCP 4.5, reflecting the more pessimistic emission pathway. These climate trends adversely affect streamflows, which are projected to decline in the future, supporting the notion that climate change threatens water hydraulicity, a finding also reported in the Aghien and Banco catchments [9].

The population growth in the N'Zo to Zoba catchment would drive an increase in water demand between 2021 and 2050. The WEAP model estimates suggest that, despite this increase, water resources will remain sufficient to meet needs under both RCP scenarios, owing to the abundant resources in the catchment. Historical studies [23,35–37] have shown the complexity of water management involving multiple uses, but overall, the supply-demand balance appears positive. According to a report by [24], the hydrological balance of the major rivers indicates that inflows are adequate to satisfy water demands throughout the year, despite demand increases and reduced historic supply levels. The catchment remains one of Côte d'Ivoire's wettest regions, with minimal hydrological drought episodes, ensuring consistent water availability for the foreseeable future.

## 6. Conclusion

This study highlights the critical need for sustainable water resource management amid climate change and population growth. It assessed the climate impact on the N'Zo River using RCP 4.5 and RCP 8.5 scenarios for 2050. Under RCP 8.5, climate effects are more significant, with temperature rising from a current increase of 0.97% to 2.28%, and precipitation declining. Using the GR2M model and projected climate data, streamflow's up to 2050 were successfully simulated. The analysis with the WEAP model estimated that water supplies, averaging 336.82 million $m^3$ historically, will decrease to 63.34 million $m^3$ and 56.27 million $m^3$ under RCP 4.5 and RCP 8.5, respectively. Water demand, initially 1.78 million $m^3$ (rural) and 4.41 million $m^3$ (urban), is projected to rise to 3.72 million $m^3$ and 10.40 million $m^3$ in the reference scenario by 2050. Under the high population growth scenario, demand would increase from 1.83 million $m^3$ (rural) and 4.59 million $m^3$ (urban) to 3.65 million $m^3$ and 13.77 million $m^3$, respectively. Urban areas exhibit higher demand levels compared to rural areas. Despite growing demand, simulations indicate that water needs will be met across scenarios, emphasizing the resilience of the resource system. To ensure long-term sustainability, the study recommends installing water quality monitoring instruments, which are vital for effective resource management.

## Compliance with ethical standards

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### *Disclosure of conflict of interest*

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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