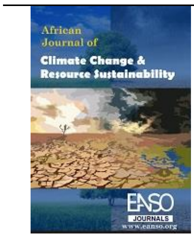


African Journal of Climate Change and Resource Sustainability
ajccrs.eanso.org
Volume 3, Issue 1, 2024
Print ISSN: 790-962X | Online ISSN: 790-9638
Title DOI: https://doi.org/10.37284/2790-9638

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Identification of Climate Change Risks to Surface and Groundwater Resources across the Central African Republic and Resilience Measures

Paul Evans[1*] *& Blandine L'hévéder*[2]

[1] Hydroconseil, 24 chemin de la Rollande, 84 140 Avignon, France.
[2] RiskWeatherTech, 133 rue St Charles, 75015 Paris, France.
[*] Author for Correspondence ORCID: https://orcid.org/0009-0007-3736-4261; Email: evans@hydroconseil.com

Article DOI: https://doi.org/10.37284/ajccrs.3.1.2506

Date Published:

10 December 2024

Keywords:

Central African Republic, Hydrology, Hydrogeology, Climate Change, Water Resource, Water Resource Management, Institutional Development, Groundwater Monitoring, River Monitoring.

ABSTRACT

The extensive hydrological and hydrogeological systems across the Central African Republic (CAR) provide essential urban and rural water supplies for the populations across the country. Hydrological and hydrogeological studies during the last 20 years are extremely limited, in part due to the complex security and socio-economic context. As a result, significant uncertainties exist related to water resource availability and infrastructure management. This paper examined the recent evolution of the meteorological, hydrological, and hydrogeological regimes across CAR and the potential future impacts of climate change on surface and water resource availability. This was undertaken by analyzing the available regional hydrometry data and using regional climate change projections to evaluate changes to rainfall and evapotranspiration patterns by 2050. A lack of long-term monitoring data and operational monitoring systems prevents a detailed assessment of these risks at local levels. Although the national scale findings suggest that water resources may slightly increase over the next 40 years, significant local risks remain due to intensifying, increasingly variable rainfall, and increasing demographic pressures. The lack of functional, national-scale water resource monitoring systems contributes to the fragile resilience of the populations across CAR in the face of increased climate-associated risks. Recommendations are included for measures to help characterize and manage the potential risks in the long-term including the implementation of robust water resource monitoring systems.

APA CITATION

Evans, P. & L'hévéder, B. (2024). Identification of Climate Change Risks to Surface and Groundwater Resources across the Central African Republic and Resilience Measures. *African Journal of Climate Change and Resource Sustainability*, *3*(1), 423-438. https://doi.org/10.37284/ajccrs.3.1.2506.

CHICAGO CITATION

Evans, Paul and Blandine L'hévéder. 2024. "Identification of Climate Change Risks to Surface and Groundwater Resources across the Central African Republic and Resilience Measures", *African Journal of Climate Change and Resource Sustainability* 3 (1), 423-438. https://doi.org/10.37284/ajccrs.3.1.2506.

HARVARD CITATION

Evans, P. & L'hévéder, B. (2024) "Identification of Climate Change Risks to Surface and Groundwater Resources across the Central African Republic and Resilience Measures", *African Journal of Climate Change and Resource Sustainability*, 3(1), pp. 423-438. Doi: 10.37284/ajccrs.3.1.2506.

IEEE CITATION

P. Evans & B. L’hévéder “Identification of Climate Change Risks to Surface and Groundwater Resources across the Central African Republic and Resilience Measures”, AJCCRS, vol. 3, no. 1, pp. 423-438, Dec.

MLA CITATION

Evans, Paul & Blandine L’hévéder. “Identification of Climate Change Risks to Surface and Groundwater Resources across the Central African Republic and Resilience Measures”. *African Journal of Climate Change and Resource Sustainability*, Vol. 3, no. 1, Dec. 2024, pp. 423-438, doi:10.37284/ajccrs.3.1.2506.

INTRODUCTION

The serious military-political crisis in 2013 had devastating consequences in the Central African Republic (CAR), both for the population and the country’s institutions, preventing the country from focusing on fundamental development activities. With the support of the international community, the country is gradually recovering and regaining stability at the central government level, enabling a return to constitutional order. While security and peace are among the government's top priorities, it has also reaffirmed the importance of interventions in the social sphere as a key lever for peacebuilding.

The rate of rural access to clean drinking water in the Central African Republic was reported as 36% by the Joint Monitoring Programme (JMP) in 2022 (WHO et al. 2022). According to the JMP, the access rate is decreasing due to numerous complex contributing factors including the fragile security situation and rapid population growth accentuating inequalities. The population’s access to water is particularly affected due to: low levels of investment in the sector over many years, exacerbated since 2013 by the security situation, which has impacted the government’s capacity to deliver public services; a chronic lack of investment particularly across rural areas in water supply infrastructure which continues to result in a high rate of non-functioning existing water points; lack of adaptation solutions implementation to protect water infrastructures and population’s access to water in case of flooding, exacerbated by climate change; ongoing migration of the rural population to urban centres putting increased pressure on already stressed public services.

Around 43% of the population lives in the country's major cities. The continued insecurity across certain areas of the country has increased the urbanization rate putting extra pressure on the already limited resources, including access to water. According to the United Nations Department of Economic and Social Affairs, the country's total population is estimated around 8.8 million in 2050[1]. It is assumed that the significant population growth contributes to a significant "urban explosion", which will have major effects on water demand in the country.

This study uses publicly available data as well as personal communications with various CAR-based institutions. We present the hydrological and hydrogeological contexts across CAR before reviewing the available meteorological data across the last 40 years to identify recent trends. Finally, we use bias-corrected and downscaled regional climate models to assess the projected climate variations across CAR through to 2050. Together these various data sources have been used to assess the potential implications for future water resource exploitation as well as considerations related to long-term climate change risk management and mitigation.

STATE OF KNOWLEDGE OF THE HYDROGEOLOGICAL AND HYDROLOGICAL CONTEXT

Hydrogeological context

The understanding of groundwater resources in the Central African Republic is limited to various historical high-level studies and geological mapping projects. Most recently this includes a study carried out by the PRACTICA Foundation (2014) which evaluated characteristics of the various aquifer types to define the potential of

---

[1] https://countrymeters.info

groundwater exploitation via shallow manual drilling techniques. At a local level, however, detailed hydrogeological data is generally lacking which is required to understand and evaluate local groundwater resource supply potential. Data gaps include the definition of local scale aquifer parameters, aquifer geometry, groundwater quality and groundwater level dynamics. The main aquifer groups across CAR are summarized as follows.

Precambrian non-carbonate formations: cover around 75% of the country's surface area and include the entire basic complex of highly recrystallized rocks, as well as the poorly metamorphosed Upper Precambrian rocks and dolerites of the western part of the country. A base complex is subdivided into two groups: an upper group of quartzites and schists; and a lower group of gneisses, mica schists, amphibolites, granulites, migmatites and anatectic granites (United Nations, 1988). These generally form low-productivity, local and discontinuous aquifers, controlled by the presence of fractures at depth, as well as by the degree and nature of near-surface climatic conditions, which increase the permeability of the largely impermeable, unweathered base rocks. Alterations are generally a few tens of meters thick. Typical sustainable yields from drilling in basement aquifers are in the order of 300 to 1,000 litres/hour. However, it has also been reported that some boreholes have produced more than 10 m³ / hour (UNICEF 2010). Groundwater levels in aquifers are generally between 5 and 20 m deep (UNICEF 2010). The productivity of this type of aquifer is classified as "Low to Moderate" (Upton et al., 2018).

Precambrian carbonate formations, *(not extensively metamorphosed)* overlie the basic complex and are subdivided into three units: an upper unit with a series of schists, quartzites, limestones and sandstones; a central unit consisting mainly of carbonate formations with a glacial conglomerate at the base; and a lower unit represented by quartzites alternating with sericite schists (United Nations 1988). Limestones and other carbonate formations, notably dolomitic limestones and dolomites (UNICEF 2010), play an important role in groundwater potential. These aquifers have karst characteristics (fractures aggravated by chemical and mechanical alteration), which can lead to very high permeability. Karst aquifers can be highly productive, but they can also be vulnerable to contamination and seasonal and long-term variability in precipitation. The productivity of this type of aquifer is classified as "High" (Upton et al., 2018).

Mesozoic sandstone formations are the Carnot and Mouka Ouadda sandstones, Mesozoic sedimentary rocks, probably mainly or entirely Cretaceous in age, which form thick continental sequences resting with angular unconformity on the basement complex, in two outcrops forming distinct plateaus. These formations are predominantly sandstone and probably have moderate to high permeability. This, combined with their thickness, extent and the likelihood that they receive a large number of resources through direct infiltration of precipitation, means that they are likely to form a moderately to highly productive aquifer (Upton et al., 2018). The productivity of this type of aquifer is classified as "Moderate".

Tertiary and Quaternary sand and clay formations represent the northeastern fringe of the country where Tertiary and Quaternary sediments outcrop, themselves resting on Mesozoic sediments or Precambrian formations. They have several superimposed aquifers; aquifer productivity is largely controlled by lithology; sands, and gravels in particular, are generally highly permeable and have high storage potential (Upton et al., 2018). The productivity of this type of aquifer is classified as "High".

Although surface water is widely exploited across CAR for potable supplies, groundwater represents an essential resource at a national and local scale across CAR for populations without access to surface water. Many communities across villages and peri-urban areas depend upon small-scale groundwater supplies exploited via boreholes and shallow wells using either manual pumps, solar-powered systems or large-scale systems. A number of secondary towns across CAR also depend upon groundwater exploitation for wider supplies. For example, the secondary cities of Bozoum, Berberati and Bossangoa depend on groundwater supplies with daily production rates of 75,000 m^3, 160,000 m^3 and 25,000 m^3 respectively (SODECA personal communication, 2023).

Hydrological context

CAR straddles two international river basins, the Lake Chad basin and the Congo basin. At the national level, the transboundary Lake Chad basin is fed by the waters of the Chari and its tributaries, the Bar Sara in the west, the Bamingui in the centre and the Bahr Aouk in the east, while the transboundary Congo basin has two main sub-basins: the Ubangi and Sangha basins.

The rivers of the Chad basin are characterized by alternating high flows (typically between July and September) and low flows throughout the rest of the year. The eastern tributaries of the Chari have modest flows, such as the Bahr Aouk, with a mean annual discharge of around 80 m^3/s. The Chari's western tributaries, such as the Ouham and Aouk, have more abundant flows, with considerable annual variations: from 50 m^3/s in March-April to 800 m^3/s from August to October for the Ouham. Most rivers extend over their floodplains during the rainy season.

The rivers of the Congo basin, and in particular the Oubangui River, are characterized by higher flows; for example, the Zinga hydrometric station[2] located on the Oubangui River has a long-term average of over 3,800 m^3/s. The annual flood extends over a longer period than that of the Chad Basin tributaries but is much less marked. By way of illustration, the ratio between maximum and minimum monthly flow is 18.8 for the Bahr Aouk at Golongosso and only 9.6 for the Oubangui at Zinga.

Numerous urban centres across CAR, including Bangui, rely upon surface water as the principal water source. These urban water supplies are operated by SODECA (Société de distribution d'eau de Centrafrique) although apart from basic water quality parameters, very limited hydrological monitoring is undertaken across these zones of abstraction. As such SODECA has extremely limited visibility on long-term hydrological trends and their potential implications for the long-term operational abstractions.

MATERIALS AND METHODS

Hydrogeological and hydrological data

Long-term groundwater resource monitoring

Numerous academic studies and NGO projects have been undertaken across CAR to characterize hydrogeological conditions at a local scale and to assess the viability of small-scale groundwater supply development. However, no systematic long-term groundwater monitoring systems or temporal historical datasets (groundwater level or groundwater quality) exist across the country. Similarly, no active, systematic, long-term groundwater level or quality monitoring networks are currently in existence, operated via NGOs or national institutions. This lack of long-term groundwater monitoring data is a significant gap with potentially serious implications for long-term groundwater resource management with regard to both sustainable exploitation at a local level and the potential long-term impacts on groundwater resources resulting from climate change. The available data is limited to databases listing boreholes and water points across the country, presenting a static snapshot of the location of these different infrastructure types but no indication of long-term groundwater level responses to ongoing and increased exploitation.

Long-term hydrological monitoring

Surface water flow monitoring (both flow rates and/or river water levels) was historically managed by the France-based Office de la Recherche Scientifique et Technique Outre-Mer

---

[2] ORSTOM station 1060700126 on the Oubangi River, active between 1950 and 1994

(ORSTOM). The historical surface water monitoring network consisted of 38 hydrometric stations across CAR as presented in Figure 1. The work carried out by ORSTOM in the region provides an excellent historical dataset for the hydrological regime of CAR rivers and their tributaries, which was the subject of a comprehensive study as detailed in Boulvert et al. (1987). Unfortunately, most of the hydrometric stations across CAR ceased operating by 1994 and we understand that as of June 2023, only three of these stations are functional, namely: Oubangui at Sofitel, Oubangui at SCEVN and Oubangui at Boloko.

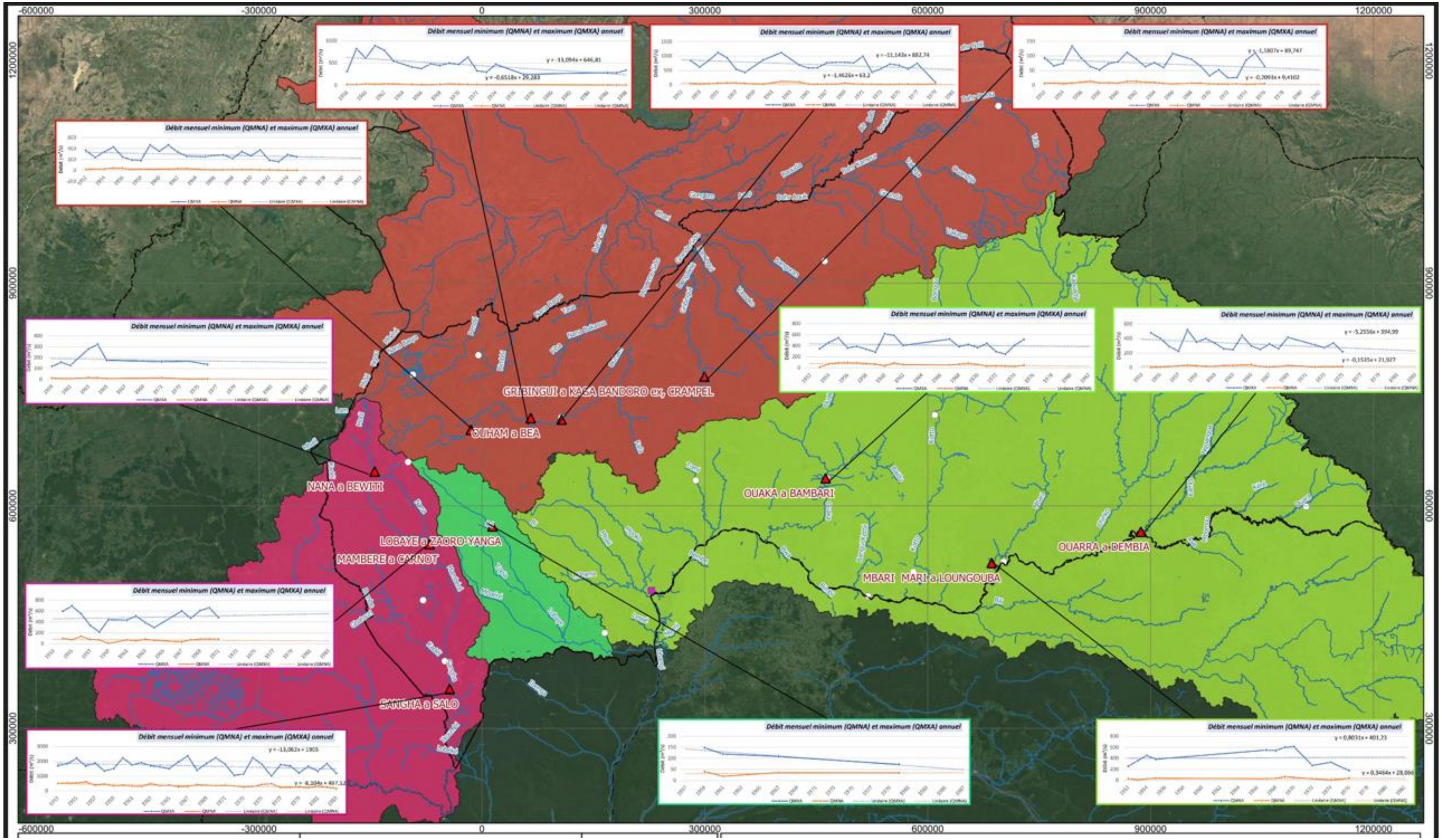
In addition, the researchers consulted the African Database of Hydrometric Indices (ADHI)[3]. This database also provides valuable hydrological data for the region, including various hydrometric indices describing runoff characteristics, seasonality, flooding and low flows between 1950 and 2018. This database also presents the main characteristics (catchment area drained, altitude, coordinates, etc.) of each of the stations inventoried in CAR, as well as their main characteristic flows.

The study used the available historical data (largely predating 1994) to calculate minimum (Q95) and maximum (Q5) monthly flows. A selection of these hydrographs is shown in Figure 1 to indicate flow trends across the country. A combination of low-increase, low-regression and stable trends are apparent. A slight regression in maximum and monthly flows is evident for all four hydrographers in the Chari watershed (north of the country), but the lack of recent data limits the analysis to before 1990. No clear geographical pattern stands out on these trends across the country.

---

[3] developed and made available by SIEREM (Système d'Informations Environnementales sur les Ressources en Eau et leur Modélisation) managed by the University of Montpellier

Figure 1 Hydrometric monitoring station locations and hydrographs



Climate data and methodology

Climate data

To estimate recent climate trends, precipitation and evapotranspiration data sets available over the last 40 years across CAR were analyzed. To characterize the precipitation climatology, the TAMSAT (Tropical Applications of Meteorology using SATellite data and ground-based observations) daily precipitation data from IRT satellite data have been used. This dataset covers the period 1983-2020 at a spatial resolution of 4 km x 4 km over Africa (Maidment et al., 2017). For the potential evapotranspiration (PET), the "hPET Bristol" database (Singer et al., 2020) produced at the University of Bristol and using the FAO Penman-Monteith formula and hourly climate variables from ERA5-Land has been selected. This database covers the period 1981-2022 at 10 km x 10 km spatial resolution over the world.

To estimate the impacts of future climate variations, the study analyzed the CMIP6 global climate projections from the latest IPCC report (IPCC AR6, 2021). These projections were bias-corrected and downscaled to 25 km spatial resolution by a NASA program (NASA Earth eXchange Global Daily Downscaled Projections - Thrasher et al., 2022). The climate projections cover the period 1950-2100 and are driven by observed greenhouse gas emissions over the historical period (1950-2014) and by potential future emissions scenarios thereafter: the Shared Socioeconomic Pathways (SSP) scenarios for which socio-economic factors are associated with greenhouse gas concentrations. Among the climate scenarios, the ssp585 "no climate policy" scenario with very high GHG emissions was selected for this study. The study of climate requires working over long periods (30 years) in order to define an average state of the current and/or future climate independent of natural climate variability.

Climate projections were therefore analyzed on a set of 22 CMIP6 corrected global climate models (listed in Table 1), for the ssp585 scenario by 2050 (period 2035-2064), for comparison against the historical period (1985-2014).

Table 1 List of Climate models whose projections have been used in the study

Country	Institute	Climate model
England	Natural Environment Research Council (NERC)	UKESM1-0-LL
Thailand	Research Center for Environmental Changes	TaiESM1
Norway	NorESM Climate Modeling Consortium (NCC)	NorESM2-MM NorESM2-LM
China	Nanjing University of Information Science and Technology	NESM3
Japan	Meteorological Research Institute	MRI-ESM2-0
Japan	Research Center for Advanced Science and Technology	MIROC6 MIROC-ES2L
Germany	Max Planck Institute	MPI-ESM1-2-LR MPI-ESM1-2-HR
England	Met Office	HadGEM3-GC31-MM HadGEM3-GC31-LL

| This work is licensed under a Creative Commons Attribution 4.0 International License.

US	Goddard Institute for Space Studies, NASA	GISS-E2-1-G
China	Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG)	FGOALS-g3
Canada	Canadian Centre for Climate Modelling and Analysis	CanESM5
Europe	Euro-Mediterranean Center on Climate Change	CMCC-ESM2 CMCC-CM2-SR5
US	National Center for Atmospheric Research (NCAR)	CESM2-WACCM CESM2
China	Beijing Climate Center (BCC)	BCC-CSM2-MR
Australia	Centre for Australian Weather and Climate Research	ACCESS-ESM1-5 ACCESS-CM2

For each of the 22 Climate models, the parameters required for the study were the daily cumulative precipitation and minimum and maximum temperature (necessary to compute PET) across CAR for the two periods defined.

PET calculation method

Evapotranspiration is an important climatic parameter, as it permits the estimation of the amount of water "lost" to the surface and groundwater resource recharge. It is the sum of canopy transpiration (via plant stomata) and soil evaporation. The value of this flow at a given time or its average over a given period is referred to as real evapotranspiration. However, it requires knowledge of the soil water content and the nature of the vegetation cover. When water availability is not limited, this flow tends towards a limit called potential evapotranspiration (PET). This last concept, introduced by Thornthwaite (1948) is essentially theoretical and depends mainly on meteorological factors (humidity, temperature, wind and incident solar radiation). It is therefore possible to calculate it from climatic data. However, it is noted that actual evapotranspiration is lower than potential evapotranspiration, especially during the dry season, when soil water availability is very low, and vegetation dried out by lack of water transpires less. However, it is interesting to calculate the PET to evaluate the future evolution of water resources related to climate change.

In this study, for climate projections, we calculated potential evapotranspiration using the Hargreaves formula (Hargreaves et al., 1985).

$$PET = 0.0023\, R_a \left(Tmean + 17.8\,^\circ C\right)\left(Tmax - Tmin\right)^{0.5}$$

Where Ra is the incident solar radiation, and Tmax, Tmin and Tmean are the maximum, minimum and mean daily temperatures.

This formula is based essentially on temperature variables, which are relatively reliable in the models and do not add uncertainty related to humidity and surface wind variables, which are unreliable in global and regional models over the African continent.

Multi-model approach and uncertainty assessment

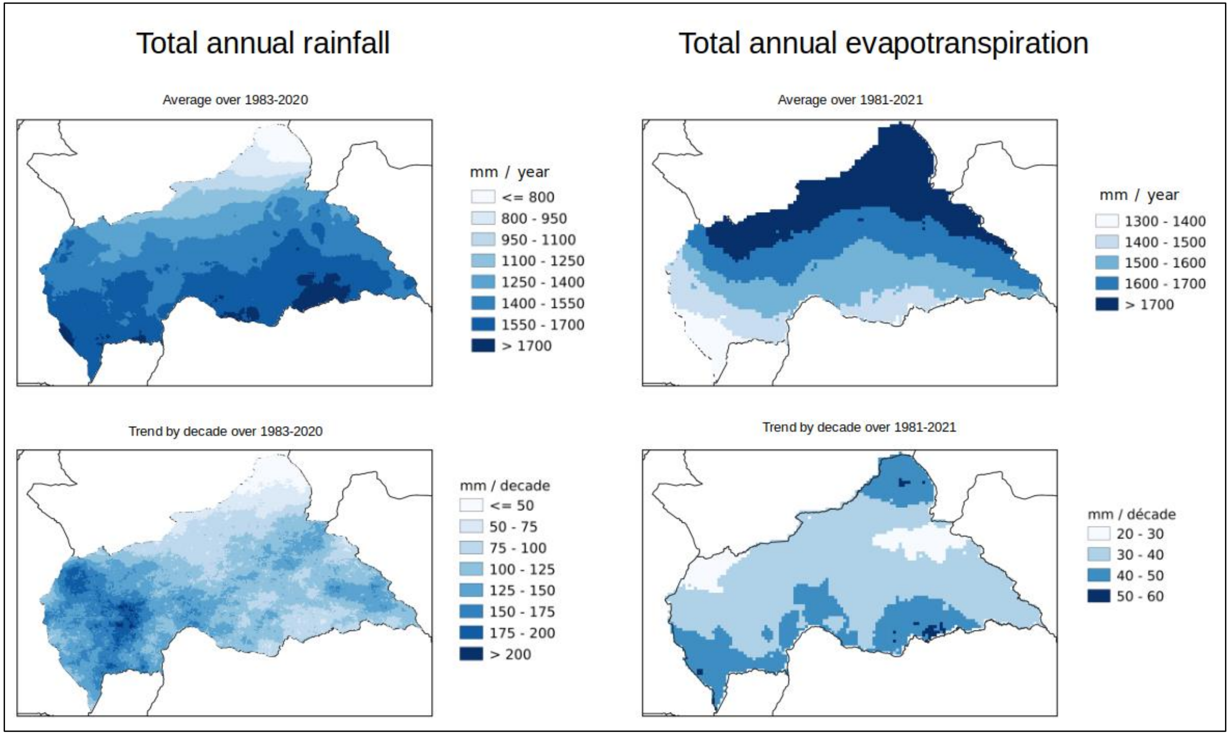
The study used a multi-model approach that captures the full range of possible future impacts of climate change. A mapping of the multi-model median, as well as a reliability indicator, have been produced, in order to provide more robust information than that of an individual climate model. The reliability indicator has been incorporated into the analysis, defined as the ratio of the interquartile range to the median of the set of indicators computed with each of the 22 climate models. The associated reliability scale is “Good” if the dispersion of the set of indicators values is smaller than its median value; “Weak” if the dispersion is one to two times that of the median and “Poor” if the dispersion is greater than twice the median of the set of indicators.

RESULTS AND DISCUSSION

Recent climate trends

The Central African climate is humid tropical and comprises four variants from south to north: Guinean-Forest, Sudano-Obanguinean, Sudano-Guinean and Sudano-Sahelian. It is characterized by two seasons per year: a dry season (October to March) and a rainy season (April to September). The spatial precipitation pattern is characterized by a decrease in rainfall along a south-north gradient (identified from TAMSAT data over the period 1983 to 2020, Maidment et al., 2017), ranging from an annual average of 1600 mm in the south to approximately 800 mm in the north (Figure 2, top left).

Figure 2 Total annual rainfall over 1983-2020 in average (top/left) and trend by decade (bottom/left) in TAMSAT data. Total annual potential evapotranspiration over 1981-2021 in average (top/right) and trend by decade (bottom/right) in PET Bristol data.



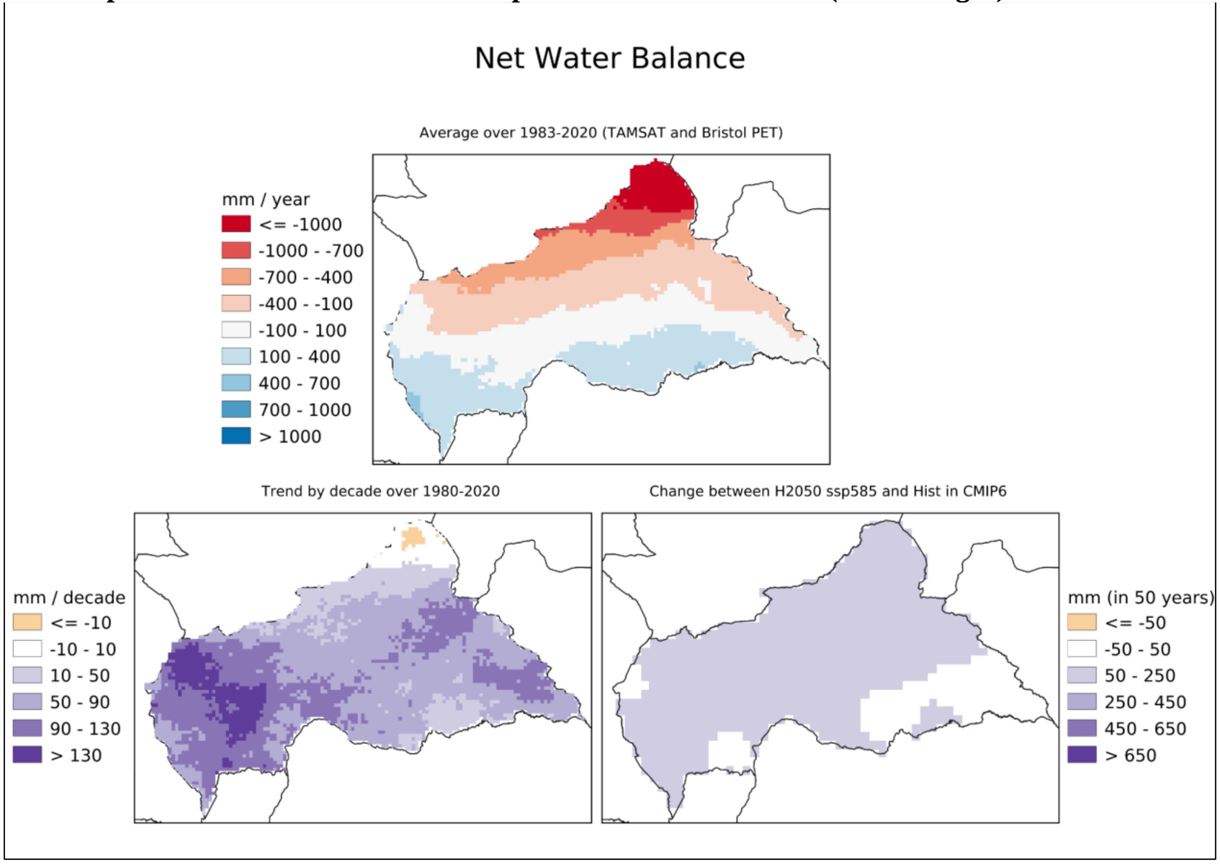
The temporal trend observed over this period is an increase in cumulative annual rainfall across the country, with the rate of increase ranging from 50 mm/decade in the upper Chari basin in the northeast to more than 150 mm/decade in the Yadé massif in the west (where over 40 years there has been a 20% increase in cumulative annual rainfall). This trend is supported by the World Bank's Climate Risk Profile (World Bank Group, 2021) for CAR, which shows an average 8% increase in cumulative annual rainfall over the country's last 30 years.

Potential evapotranspiration is strongly linked to temperature, and equally demonstrates a spatial south-north gradient, the inverse to that of rainfall (Figure 2, top right) over the evaluation period of 1981 to 2020 in the Bristol data (Singer et al., 2020).

Potential evapotranspiration increases from south to north, with an annual average accumulation of 1300 mm/year in the south, rising to over 1700 mm/year on the northern plains. The temporal trend over the evaluation period has also been towards an increase across the country, with higher intensity in the north-east and south of CAR, where it reaches 40 mm/decade. When assessed over the past 40 years, this increase in potential evapotranspiration (of the order of 2.5% to 5%) remains lower than that of rainfall.

The net water balance, estimated as cumulative annual precipitation minus potential evapotranspiration, is a potentially important factor affecting water resource availability. Over the evaluation period, the net balance is negative across northern CAR and positive across southern CAR, in line with the type of climate and vegetation observed: from equatorial forests in the south to savannah in the north (top map on Figure 3). It is noted that the potential evapotranspiration is likely to overestimate the actual evapotranspiration during the dry season, giving on an annual scale a positive net water balance across most of the country.

Figure 3 Net water balance over 1983-2020 (top) and trend by decade (bottom left) computed with TAMSAT rainfall data and PET Bristol data. Change in net water balance between the 2050 horizon in the ssp585 scenario and the historical period in CMIP6 models (bottom right).



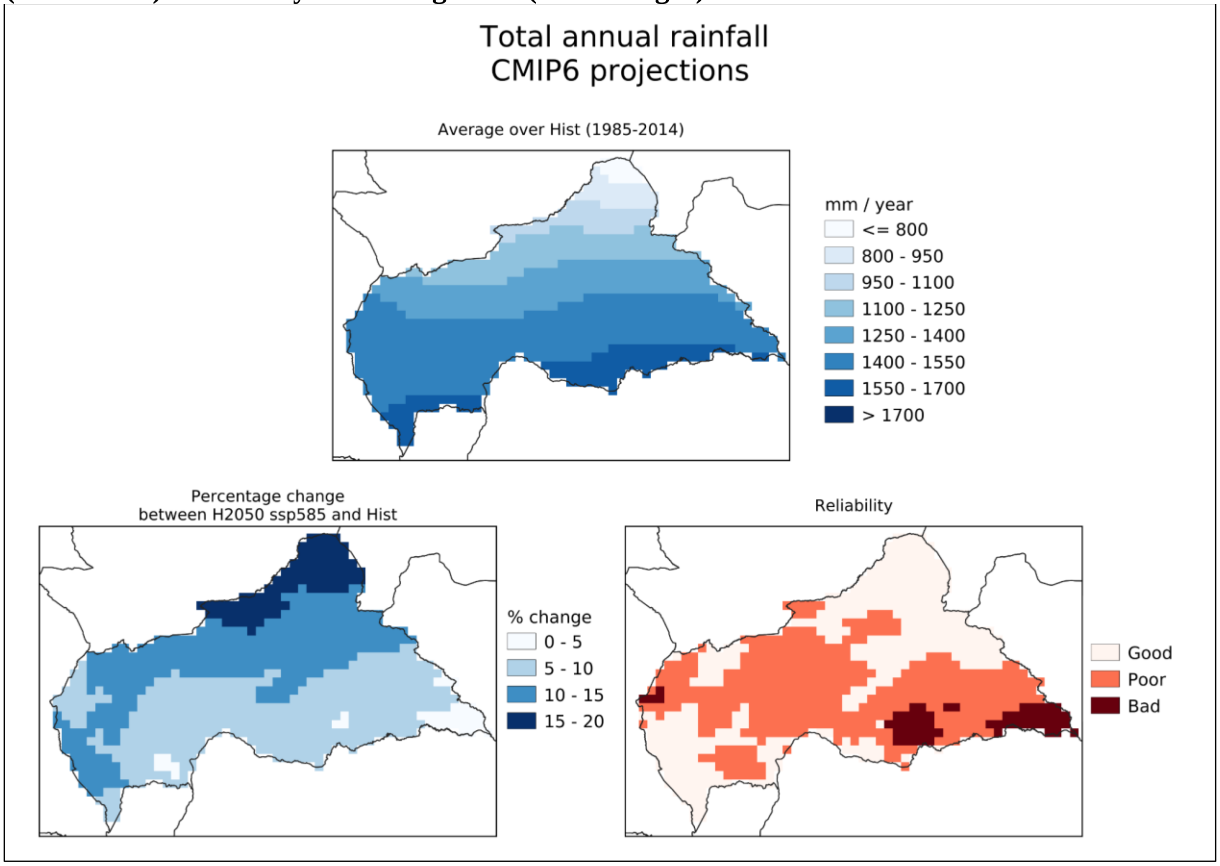
Over the last 40 years, the net water balance has globally increased over CAR, ranging from an increase of less than 10 mm/decade in the northeast of CAR to more than 130 mm/decade in the north-western mountain range.

2050 climate projections

In CMIP6 simulations, cumulative annual rainfall is well represented for the historical period both in terms of actual rainfall and spatial patterns (top map in Figure 4). It correlates well with the TAMSAT historical satellite observations (top left map in Figure 2).

By 2050 in the ssp585 scenario, an increase in annual precipitation of 5% to 20% is projected, with a relatively larger increase across the north of CAR compared to the south of the country. The reliability of this is estimated from the changes calculated for each CMIP6's climate models; it is Good in the north, where the rainfall increase is maximum, Poor in the centre of the country and Bad in the localized areas where the rainfall change is predicted to be the lowest. This projected increase in annual rainfall across the country is already observed in past trends as described in Section 3.1 and presented in Figure 2 (bottom left) and also confirmed by various publications (such as Haensler et al., 2013; World Bank Group 2021). However, the projected rate of change varies according to the projections used. CMIP6 is more reliable than CMIP5 or CORDEX-Africa for this parameter. As presented in Figure 2 and Figure 4, the CMIP6 projected increase in annual precipitation follows a comparable rate of increase as that observed over the last 40 years, namely a sustained 5 to 20% increase over the next 40 to 50 years. The potential evapotranspiration is not provided directly by climate models but is calculated following Hargreaves et al. (1985) using the daily minimum and maximum temperatures.

Figure 4 Total annual rainfall in CMIP6 projections. Average over the historical period 1985-2014 (top) and percentage change between the 2050 horizon in the ssp585 scenario and the historical period (bottom left). Reliability of the diagnostic (bottom right).

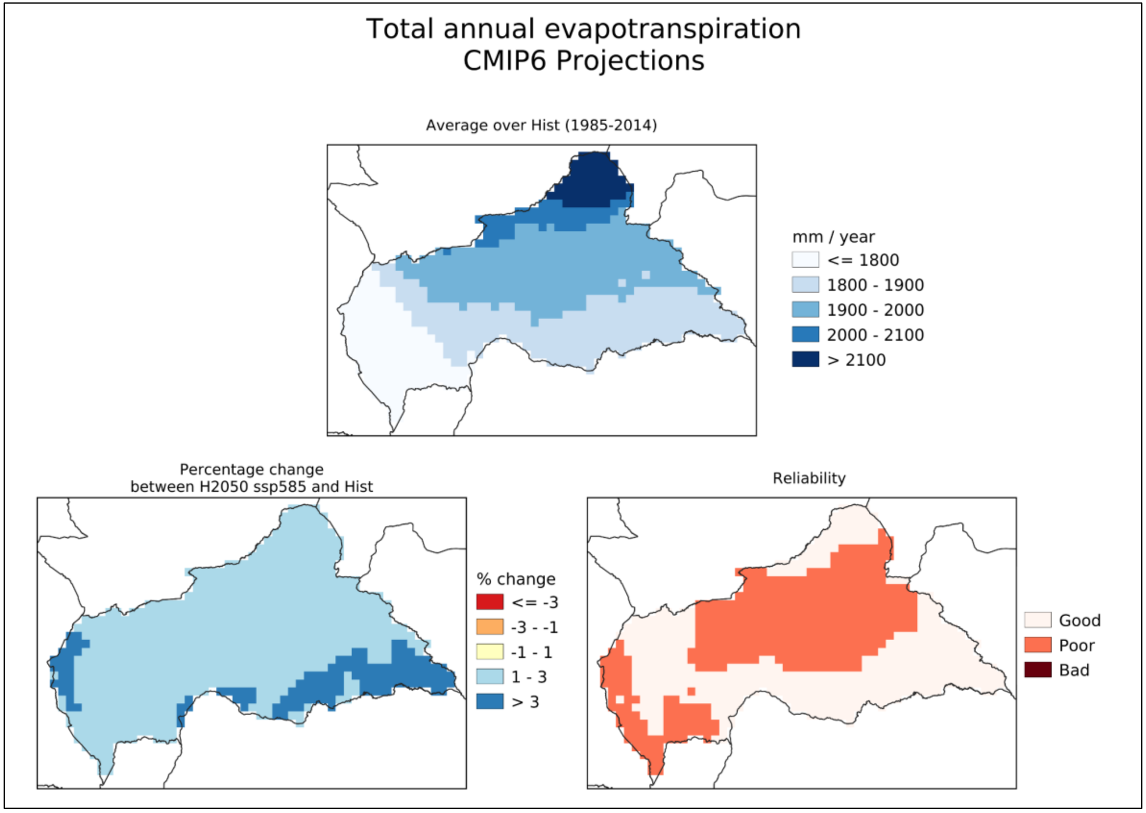


The PET spatial variations observed over the past 40 years (as presented in Figure 2, top right) are well replicated by the CMIP6 simulations (top map in Figure 5), although an overestimation of about 400 mm/year is noted compared to the Bristol climatology data. This model bias, quite significant, is also present in future projections. Therefore, relative changes in evapotranspiration between present and future are applied to historical observations to build the projections of net water balance change.

By 2050 in the ssp585 scenario, a slight increase in evapotranspiration (of the order of 3%) is projected over the whole country, with a slightly higher increase in the south-eastern and western regions of CAR (Figure 5, bottom left). The reliability of the projections is good in the northeast and the south of the country and poor in the centre and the west of CAR.

By 2050 in the ssp585 scenario, CMIP6 climate projections show an increase in cumulative annual rainfall, combined with a smaller increase in potential evapotranspiration (linked to rising temperatures). This results in a positive net water balance change projection between 2050 and the historical period across the entire country, with higher values in the north and central regions of CAR, as shown in Figure 3 (bottom right map). In a localized region in the south-east of the country, the change in net water balance is close to zero. A study by Karam et al. (2022) on the Congo Basin identified comparable trends in the south of CAR, namely: a slight decrease in the net water balance by 2050 under the RCP8.5 scenario. These projections are in line with the trends observed over the last few decades (bottom left in Figure 3), which indicate an overall increase in the quantity of water resources.

Figure 5 Total annual PET in CMIP6 projections. Average over the historical period 1985-2014 (top) and percentage change between the 2050 horizon in the ssp585 scenario and the historical period (bottom left). Reliability of the diagnostic (bottom right).



Implications for long-Long-term Water Resource availability and management

The climate analysis presented here has identified that overall at a national scale, water resources are not expected to decrease in the next 40 years but rather marginally increase. However, a number of significant potential risks to water resource availability exist at the local level, notably due to likely increasing rainfall intensity, increasing demographic pressures and local scale climatic variations. Such risks include decreased groundwater levels (associated with potential over-abstraction and reduced aquifer recharge), increased local scale water demand associated with population growth and a deterioration in surface and groundwater quality associated with increased anthropogenic activities.

Climate change projections also indicate an expected rise in temperature, implying a likely associated increase in human and livestock water consumption, and a risk of overexploitation of the already insufficient number of water points (and the risk of increased tensions around these points in the context of already high social tension).

Increased risks of damage to infrastructure due to climate change and extreme related events such as flooding and storms also present a significant long-term risk. Although flood risk evaluations across CAR are limited in terms of both availability and detail, the limited available studies (such as REACH, 2020) indicate that flood risk will continue to increase, in terms of both frequency and severity. This increase is likely to accentuate the flooding episodes already affecting the country, particularly in the prefectures of Vakaga, Ouham, Ombella M'Poko (including Bangui) and Basse-Kotto (REACH, 2020).

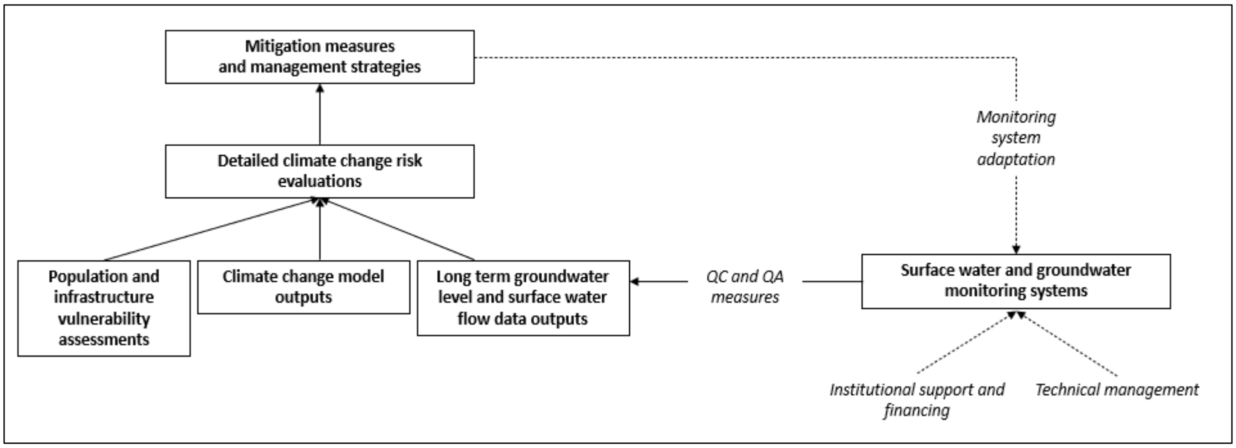
A lack of long-term monitoring data (groundwater level, surface water flows as well as meteorological data) currently prevents more detailed assessment of these risks at local levels across the country. As a result, more detailed local scale assessments, particularly across the most populated regions are needed to better characterize these risks, taking into account the state of infrastructure and the collection of information from more informal observations and experiences from local actors and the local population.

The need to implement long-term meteorological and water resource monitoring systems

It is essential to identify and characterize the expected effects of climate change and the anthropogenic exploitation of water resources so that appropriate management systems and mitigation measures can be proactively developed and implemented to minimize risks (such as overexploitation). This requires the systematic and robust collection of long-term data, tailored to focus on the most vulnerable areas.

The existing water resource monitoring network across CAR is extremely weak. Surface water: ORSTOM's old hydrometric network is largely non-functional. This lack of data across most of the country means that there is a significant data gap, and consequently a lack of visibility on long-term trends in watercourse evolution. The only monitoring systems identified to measure long-term surface water quality are those managed by SODECA to monitor quality at water intakes for its drinking water distribution networks. The absence of a more extensive monitoring network again prevents the development of visibility on hydrological dynamics to understand trends, including potential pollution associated with anthropogenic activities such as urbanization and industry (e.g. mining). Figure 6 presents a schematic illustrating the key need for long-term monitoring data in the management of climate change risks.

Figure 6 Key need for long-term monitoring data in the management of climate change risks



Regarding groundwater monitoring, despite the frequent practice of recording water table levels and taking samples for water quality analysis at the drilling installation stage, there is an absolute lack of long-term systematic monitoring systems (existing and past) to assess variations in long-term groundwater levels and groundwater quality. These significant gaps result in i) a lack of visibility of groundwater level dynamics linked to climatic variations and anthropogenic exploitation, ii) an inability to identify trends in groundwater quality, including pollution associated with anthropogenic activities such as urbanization and industry and iii) a lack of ability to make informed decisions regarding groundwater resource operations and long-term investments.

Institutional structure

Although the implementation of monitoring systems presents a challenge in a fragile state such as CAR, the identification and implementation of appropriate technical solutions is achievable assuming that appropriate financial and technical resources are made available. However, the long-term operationalization of such monitoring systems presents a significant challenge requiring i) adequate local technical capacity to be able to maintain and operate the monitoring equipment, ii) long-term national and regional level institutional management capacity to ensure the above tasks can be appropriately managed and financed while conforming with quality control and quality assurance requirements. Furthermore, the cooperation between stakeholders (government institutions, water users, NGOs) is essential to ensure that the data is effectively capitalized upon (for example flood and drought prediction, incorporation into early warning systems, and the effective management of operational water supplies).

Such long-term measures in CAR are extremely challenging to implement given the unstable security, institutional and financial contexts. The current institutional instability and lack of technical and management capacities mean that the successful implementation of such measures would require significant external support, likely via the humanitarian and development sectors. Such interventions could be possible using financing such as the Green Climate Funds although any such programmes would require long-term commitments of at least 10 years in close partnership with the state actors.

CONCLUSION

This study showed that climate change across CAR is projected to increase the cumulative annual rainfall and the annual potential evapotranspiration, due to an increase in temperature through to 2050 and beyond. However, since the increase in annual PET is projected to be smaller than the increase in annual rainfall, the net water balance is projected to globally increase across the country by 2050 under the ssp585 scenario. These projections are in line with the trends observed over the last few decades, which indicate an overall increase in the regional water balance.

However, these global increases in water resource availability will be complicated by the rapid population growth and urbanization which is occurring across the country and will continue to put increased pressure on water resources at local levels.

The lack of long-term spatial and temporal monitoring coverage of river flows, groundwater levels and water quality reduces the capacity of institutions to make informed decisions regarding long-term trends in water resource availability. The investment in appropriately designed and managed monitoring infrastructure, in conjunction with centralized data management systems, is essential now to enable future trends to be identified and mitigation measures to be implemented to help protect the vulnerable populations across CAR.

The development of technical solutions for the implementation of long-term monitoring systems is relatively straightforward. However, the implementation of such measures is extremely challenging due to the chronic lack of institutional functionality and lack of technical capacity across CAR. As such the development of long-term monitoring systems equally requires investment to develop and establish reliable, long-term institutional systems to support the monitoring and associated data management systems. Such an approach will require long-term (10 years plus) investments to provide suitable institutional platforms and the required long-term technical support.

The absence of long-term hydrological and hydrogeological monitoring systems leaves CAR exposed to high risks due to a severe lack of reliable data to inform climate change mitigation measure planning. Much of the current GCF investments, development and humanitarian interventions are relatively short-term measures (less than 10 years) which results in a significant gap related to these critical long-term monitoring systems. These gaps will ultimately impact the population due to a lack of reliable data to inform appropriately designed or scaled interventions. Although this study has focused on CAR as a case study, it is highly important that the establishment of reliable long-term monitoring systems is urgently deployed across other similar contexts, particularly where drought risks are elevated (e.g. South Sudan).

Study limitations

Only the change in the annual budget for rainfall, PET and net water balance has been studied. The IPCC highlights that the water cycle will be modified by climate change, with more occurrences of drought episodes and intense rainfall events leading to flooding. This modification of the water cycle increases surface runoff and decreases soil water storage.

REFERENCES

Boulvert, Y., and Buffard-Morel, J.-M. (1987). Oro-hydrographic map of the Central African Republic 1:1,000,000. ORSTOM.

Haensler, A., Saeed, F. and Jacob, D. (2013): Assessment of projected climate change signals over central Africa based on a multitude of global and regional climate projections. In: Climate Change Scenarios for the Congo Basin. [Haensler A., Jacob D., Kabat P., Ludwig F. (eds.)]. Climate Service Centre Report No. 11, Hamburg, Germany, ISSN: 2192-4058.

Hargreaves, G.H., and Samani, Z.A. (1985) Reference Crop Evapotranspiration from Temperature. *Applied Engineering in Agriculture*, *1*, 96-99. http://dx.doi.org/10.13031/2013.26773.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group

I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

Karam S., Seidou O., Nagabhatla N., Perera D., Tshimanga RM. (2022) Assessing the impacts of climate change on climatic extremes in the Congo River Basin. Clim Change. 2022;170(3-4):40. doi: 10.1007/s10584-022-03326-x.

Maidment, R. I., D. Grimes, E. Black, E. Tarnavsky, M. Young, H. Greatrex, R. P. Allan et al. (2017). A new, long-term daily satellite-based rainfall dataset for operational monitoring in Africa. Nature Scientific Data, 4: 170063. DOI: 10.1038/sdata.2017.63.

Practica Foundation, UNICEF and Enterprise Works/VITA. 2014. République Centrafricaine: Etude de faisabilité des forages manuels: identification des zones potentiellement favorables. Practica/Enterprise works/VITA/UNICEF.

Singer M., Dagmawi Asfaw, Rafael Rosolem, Mark O. Cuthbert, Diego G. Miralles, Edisson Quichimbo Miguitama, Dave MacLeod, Katerina Michaelides (2020): Hourly potential evapotranspiration (hPET) at 0.1degs grid resolution for the global land surface from 1981- present. https://doi.org/10.5523/bris.qb8ujazzda0s2aykkv0oq0ctp

REACH, 2020. Susceptibilité et risque d'inondations en République Centrafricaine - Méthodologie d'analyse.

SODECA provided estimated water supply volumes (personnel communication, February 2023).

Thornthwaite, C. (1948). An Approach toward a Rational Classification of Climate, Geogr. Rev., 38, 55–94, https://doi.org/10.2307/210739.

Thrasher, B., Wang, W., Michaelis, A. et al. NASA Global Daily Downscaled Projections, CMIP6. Sci Data 9, 262 (2022). https://doi.org/10.1038/s41597-022-01393-4.

UNICEF. 2010. Etude de faisabilité des forages manuels, identification des zones potentiellement favorables. DGH Bangui, 30p.

United Nations. 1988. United Nations Department of Technical Cooperation for Development and Economic Commission for Africa. Natural Resources/Water Series No.18, ST/TCD/5.

Upton K, Ó Dochartaigh BÉ and Bellwood-Howard, I. 2018. L'Atlas de l'eau souterraine en Afrique: Hydrogéologie de la République centrafricaine. British Geological Survey.

WHO, UNICEF, World Bank. 2022. State of the world's drinking water: an urgent call to action to accelerate progress on ensuring safe drinking water for all. Geneva: World Health Organization. Licence: CC BY-NC-SA 3.0 IGO

The World Bank Group (2021). Climate Risk Profile: Central African Republic.