

Climate And Water Resources Dynamics In Kinshasa (DRC) From 1980 To 2024: Multi-Parameter Analysis And Projections To 2050

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Summary

This study analyzes the evolution of the main climatic and water parameters in the city of Kinshasa (Democratic Republic of Congo) over the period 1980–2024. The approach adopted is based on the temporal and spatial analysis of climate and environmental data, including air temperature, precipitation, soil temperature, surface runoff, and groundwater, aggregated at the level of administrative districts. The results highlight a gradual increase in maximum and minimum temperatures, a marked inter-annual variability in precipitation, an intensification of surface runoff, and a general downward trend in piezometric levels. Projections to 2050, based on the extrapolation of observed trends, suggest a continuation of global warming, an increase in rainfall variability and a potential decrease in groundwater resources. This study thus provides an objective inventory of climate and water evolution in Kinshasa, constituting a scientific basis for future analyses and strategies for the management of water resources.

Keywords : *climate change, air temperature, precipitation, surface runoff, and groundwater.*

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I. Introduction

African cities are experiencing rapid population growth combined with often unplanned urbanization, which increases pressures on urban climate and water resources. In Kinshasa, these dynamics are reflected in an intensification of urban heat islands, a modification of rainfall regimes and a gradual deterioration of

groundwater. Although several studies have addressed these phenomena separately, few studies simultaneously integrate climate parameters, runoff, and groundwater over a long period of time. The present work aims to fill this gap by proposing a - multi-parameter analysis covering the period 1980—2024, supplemented by projections to 2050.

II. Study Environment

The city of Kinshasa is located in the west of the Democratic Republic of Congo, on the south bank of the Congo River. It has a humid tropical climate characterized by a rainy season from October to May and a dry season from June to September. Administratively, the city is subdivided into four major districts: Lukunga, Funa, Mount Amba and Tshangu. - The geological substratum is dominated by sandy sedimentary formations, favorable to the existence of shallow groundwater but vulnerable to anthropogenic pressures.

III. Materials And Methods

Climate and environmental data

The data used comes from the **GIOVANNI** platform (NASA GES DISC), which offers access to reanalyzed satellite and climate products. Parameters analyzed include air temperature, precipitation, soil temperature, and surface runoff for the period 1980—2024.

Spatial and temporal resolution

The data has a monthly temporal resolution and a spatial resolution of between 0.25° and 0.5° depending on the products. The monthly series were aggregated on an annual scale in order to identify long-term climate trends.

Data processing and analysis

The data, extracted in netCDF and CSV formats, was checked for missing values. Statistical analyses (averages, maxima, minima and anomalies) made it possible to produce temporal graphs and spatial maps illustrating the evolution of the parameters studied.

Data limitations

Satellite data have some limitations, in particular related to their spatial resolution, the imperfect representation of urban microclimates, and the dependence on reanalysis models. However, they remain suitable for the study of long-term climate trends in regions with low instrumentation.

Projection methods to 2050

Climate and hydrological projections are based on statistical extrapolation of trends observed between 1980 and 2024, combined with hypotheses of demographic change and urbanization. Two scenarios were considered: (i) the continuity of current trends and (ii) increased anthropogenic pressure characterized by increased urbanization and soil sealing.

IV. Results

Air temperature

Air temperature is one of the most sensitive indicators of climate change in urban areas, especially in large agglomerations subject to rapid and poorly planned urbanization. In Kinshasa, the increase in built density, the waterproofing of soils and the reduction of vegetated areas contribute to the intensification of urban heat islands, modifying both day and night temperatures. The analysis of the evolution of maximum and minimum temperatures over the period 1980—2024 thus makes it possible to identify warming trends, seasonal variability and spatial contrasts between the different districts of the city. This section looks successively at the dynamics of maximum temperatures, minimum temperatures, as well as their joint evolution, in order to characterize the extent and implications of global warming at the urban scale of Kinshasa.

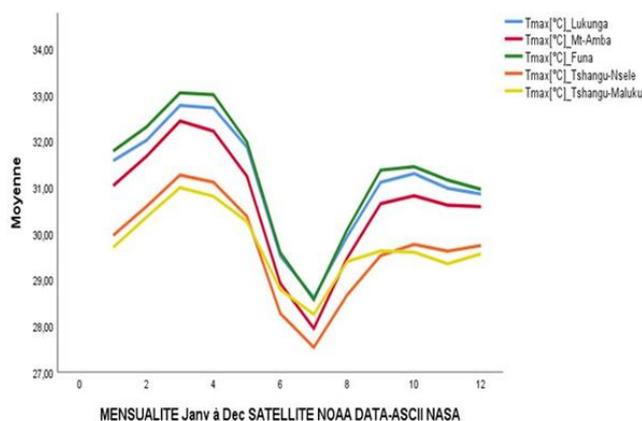


Figure 1 : Monthly variability of maximum temperatures in the city Kinshasa Province

This figure highlights a marked seasonal variability in maximum temperatures in Kinshasa. The highest values are observed between March and April, corresponding to the end of the main rainy season, while the lowest maximum temperatures are around the month of July, in the middle of the dry season. This monthly distribution reflects a regular thermal dynamic controlled by the regional seasonal cycle, with a clear alternation between hot and relatively cooler periods.

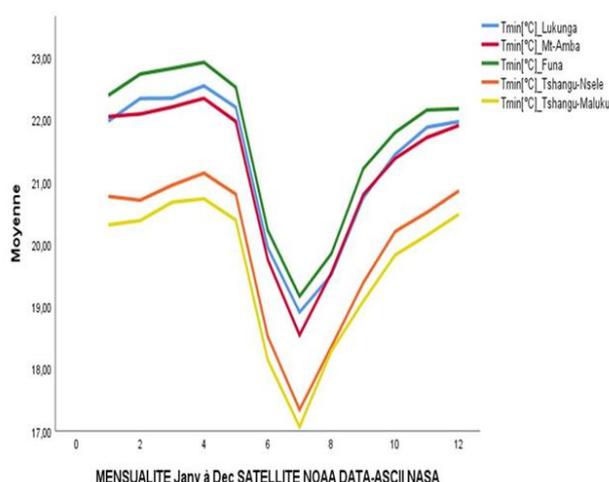


Figure 2: Monthly variability of minimum temperatures in the city Province of Kinshasa

Minimum temperatures have a smaller seasonal range than maximum temperatures, with values generally between 17 and 23°C. The highest minimum temperatures are recorded during the months of March and April, while the lowest temperatures appear in July. This relative stability of nighttime temperatures reflects the thermal inertia of the local climate system, with nevertheless a perceptible seasonal modulation.

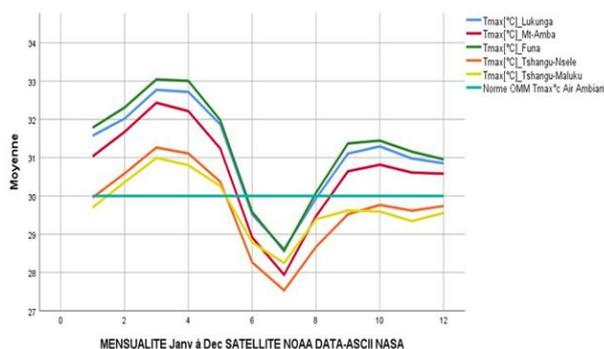


Figure 3: Monthly variability of maximum temperatures in the city Province of Kinshasa compared to the WMO Standard

The comparison between the maximum temperatures observed and the World Meteorological Organization standard (30°C) shows that, over a large part of the year, the monthly values exceed this reference. Only June, July, and August have temperatures that meet or fall below the norm in the majority of districts. This situation highlights a high frequency of thermal conditions that exceed the reference climate standards.

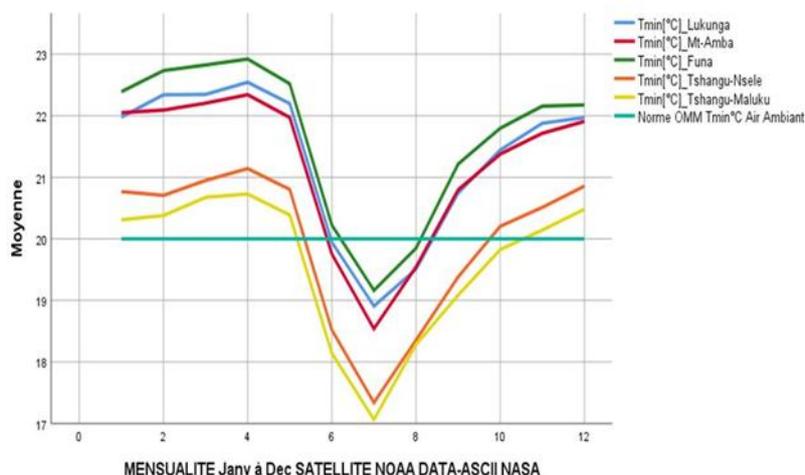


Figure 4: Monthly variability of minimum temperatures in the city Province of Kinshasa compared to the WMO Standard

Monthly minimum temperatures are generally in line with the WMO standard of 20°C during the cool period, mainly between June and August for the districts of Lukunga, Mont-Amba and Funa. The Tshangu district has extended compliance until October. This spatial variability highlights nocturnal thermal contrasts between districts, while indicating partial compliance with international climate standards.

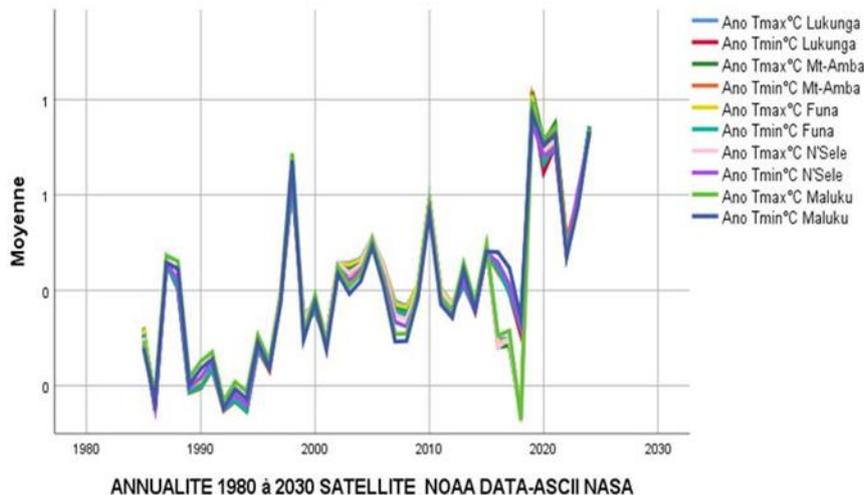


Figure 4: Annual temperature trend curve for districts in the city of Kinshasa

The annual trend curve reveals a gradual increase in temperatures during the period 1980—2024 in all the districts studied. This evolution reflects a general warming trend at the scale of the city of Kinshasa, affecting the various districts in a relatively homogeneous manner, although differences in amplitude can be observed.

Rainfall

Rainfall is the main factor controlling the hydrological cycle in humid tropical environments and directly affects the availability of surface and groundwater. In Kinshasa, the spatial and temporal variability of rains plays a decisive role in the dynamics of urban runoff, the infiltration and recharge of groundwater. The analysis of precipitation over the period 1980—2024 makes it possible to highlight inter-annual trends, rainfall anomalies and contrasts between districts, while identifying a possible intensification of extreme events. This

section looks at the evolution of rainfall regimes in Kinshasa and their hydrological implications in a context of rapid urbanization.

Table 1: Descriptive analysis of parameters

	Nombre DATA PPmm	PPmm Mensuelle Minimum	PPmm Mensuelle Maximum	Somme PPmm sur 116 ans	Moyenne PPmm	Ecart type
PPmm(mm)_Lukunga	1392	,1	588,3	295722,1	212,444	182,4857
PPmm(mm)_Mt-Amba	1392	,1	595,6	303129,7	217,766	183,9924
PPmm(mm)_Funa	1392	,1	604,1	313330,0	225,093	185,1906
PPmm(mm)_Tshangu-Nsele	1392	,2	595,1	307179,2	220,675	182,3865
PPmm(mm)_Tshangu-Maluku	1392	,2	595,1	307179,2	220,675	182,3865
N valide (liste)	1392					

Système d'Alerte Précoce SAP Prévision Saisonnière Mensuelle à Géorisque Inondation en Novembre et en Avril sur Kinshasa

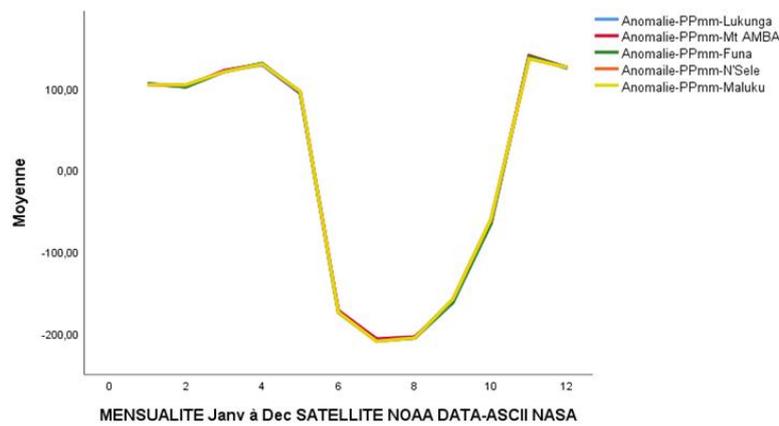


Figure 5: Monthly rainfall trend curve for districts in the city of Kinshasa

The monthly distribution of precipitation highlights two distinct rainfall maxima, observed in April and November respectively. This configuration corresponds to the bimodal rainfall regime characteristic of the region, marked by two rainy seasons separated by relatively drier periods.

Système d'Alerte Précoce Géorisque Précipitations PPmm Mensuelles sur Kinshasa

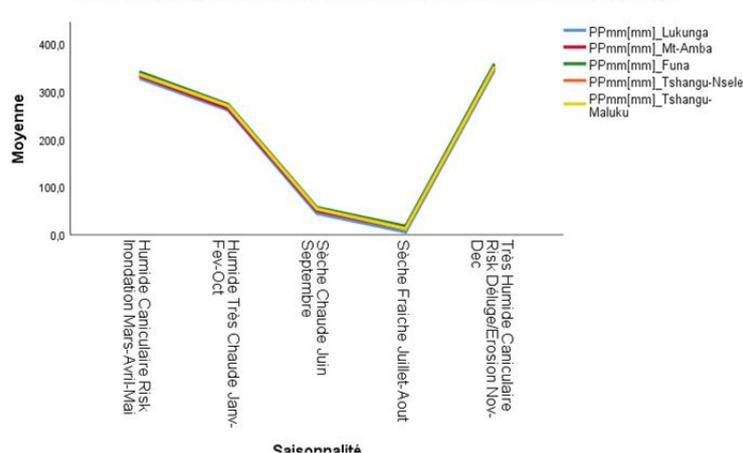


Figure 6: Monthly trend curve of precipitation by seasonality of districts in the city of Kinshasa

Seasonal analysis confirms a concentration of precipitation during rainy seasons, with a significant decrease in accumulations during the dry season. The differences observed between districts reflect moderate spatial variability in precipitation at the city level.

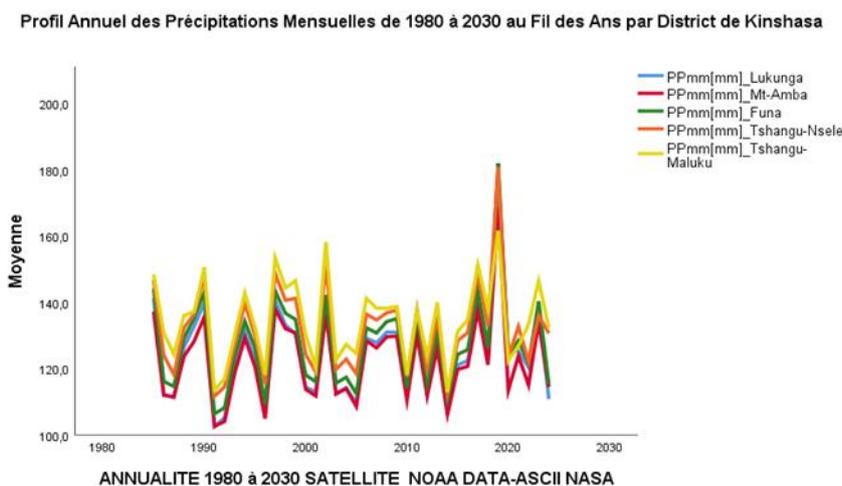


Figure 7 : Annual precipitation trend curve for districts in the city of Kinshasa

The annual precipitation trend shows marked inter-annual variability, without a strictly monotonous evolution. This fluctuation reflects the alternation of relatively humid and dry periods during the period studied, characteristic of tropical climates subject to high climate variability.

Flow

Surface runoff is an essential indicator of the hydrological functioning of watersheds, reflecting the response of continental surfaces to rainfall inputs. In Kinshasa, the evolution of runoff reflects the interactions between the variability of precipitation and the physical characteristics of the environment. The analysis of surface runoff over the period 1980—2024 makes it possible to highlight temporal trends, inter-annual fluctuations and their relationship with observed rainfall regimes. These results provide elements of understanding on the hydrological dynamics of urban watersheds and on the evolution of source flow at the city scale.

Table 2: Descriptive Analysis of Source Water Flows
Reserves en DEBITS D' EAU DES SOURCES SOUTERRAINES en Litre/Sec sur la Ville de Kinshasa de 1980 à 2030 par Disctict

	N	Minimum	Maximum	Somme	Moyenne	Ecart type
Debit_Source C/Bumbu Q/Dipiya Av. Kinzozi7 (Litre/Sec) GPS Long15, 2930 Lat-4,3811	480	1,2073	1,5500	667,0083	1,389601	,1296866
Debit_Eau_Source_Bumbu_Dipiya_Kingungu (Litre/Sec) GPS Long15, 2927 Lat-4,3815	480	1,2113	1,5540	668,9283	1,393601	,1296866
Debit_Source_MontNgafu la_DonBosco (Litre/Sec) GPS Long15,2126 Lat-4,3774	480	1,1985	1,6319	691,0598	1,439708	,1759755
Debit_Source_Centroide_Lukunga (Litre/Sec)	480	1,2025	1,6359	692,9798	1,443708	,1759755
Debit_Source_Centroide_Mt_Amba (Litre/Sec)	480	1,2043	1,6778	701,0875	1,460599	,2032244
Debit_Eau_Source_Centroide_Funa (Litre/Sec)	480	1,2113	1,6848	704,4475	1,467599	,2032244
Debit_Source_Centroide_Nsele (Litre/Sec)	480	1,2003	1,6738	699,1675	1,456599	,2032244
Debit_Source_Centroide_GPS_Maluku (Litre/Sec)	480	1,2023	1,6758	700,1275	1,458599	,2032244
N valide (liste)	480					

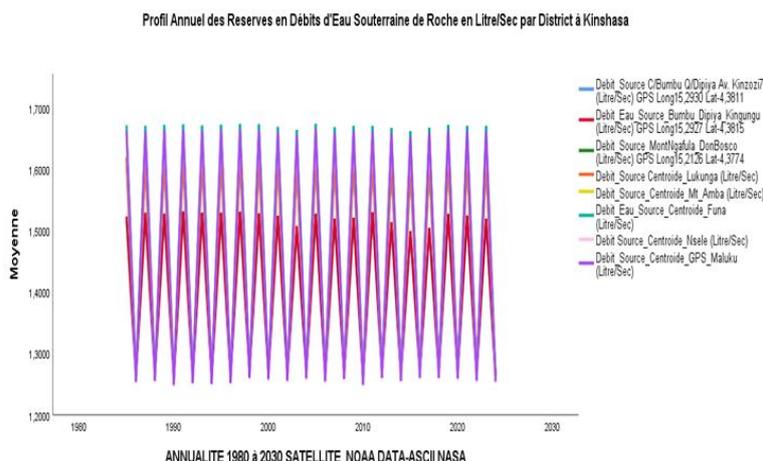


Figure 8: Annual Profile of Roche Groundwater Flow Reserves of districts in the city of Kinshasa

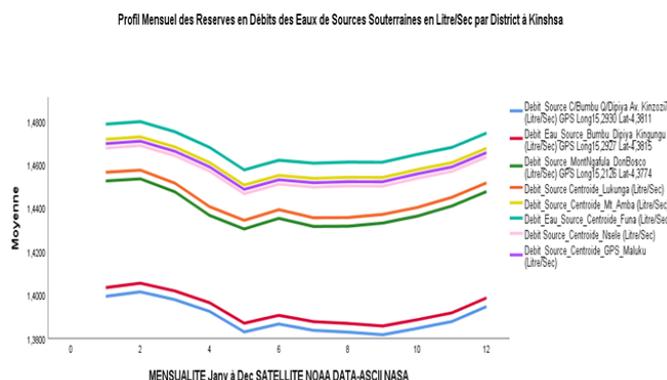


Figure 9: Monthly Profile of Roche Groundwater Flow Reserves of districts in the city of Kinshasa

The annual and monthly profiles of groundwater flow reserves show significant fluctuations during the year, with higher values during periods corresponding to maximum rainfall. This dynamic suggests a close relationship between the variability of precipitation and the evolution of observed flows.

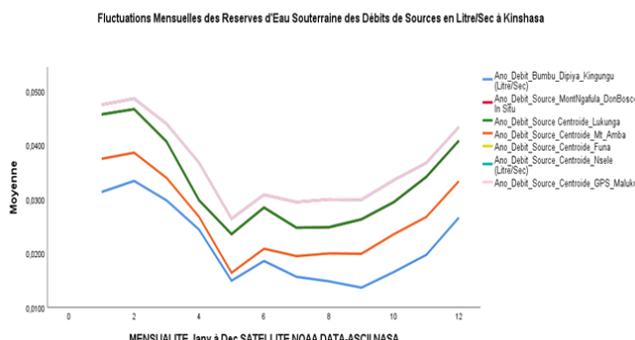


Figure 10: Monthly Fluctuations in Groundwater Flow Reserves in districts in the city of Kinshasa

Monthly fluctuations highlight a marked intra-annual variability in flow, reflecting the sensitivity of the hydrological system to rainfall inputs and seasonal climatic conditions. The differences observed between districts reflect contrasting hydrological responses at the local level.

Soil temperature

Soil temperature is an essential parameter for understanding energy exchanges between the land surface and the atmosphere, especially in highly anthropized urban environments. In Kinshasa, the increase in mineralized surfaces and the decrease in plant cover modify the thermal balance of the soil, contributing to the intensification of urban heat islands and to the alteration of superficial hydrological processes. The study of the evolution of ground temperature between 1980 and 2024 makes it possible to identify thermal trends, spatial contrasts between districts and links with urbanization and local climate dynamics.

Table 3: Descriptive Analysis of Subsoil Temperatures at 2m Depth by District

Valeurs des Températures du Sous-Sol 2m par District à Kinshasa

	N	Minimum	Maximum	Moyenne	Ecart type
Temperature_2mSous_Sol_Tshiangu_Villages en °C	480	1,036800	22,629000	11,96555208	9,154983685
Temperature_2mSous_Sol_Cités_Villages_LUKUNGA en °C	480	,77760	21,40100	11,2041117	8,65254938
Temperature_2mSous_Sol_Villes_Cités_FUNA_MONT_AMBA en °C	480	1,29600	20,24600	10,8008646	7,93289477
N valide (liste)	480				

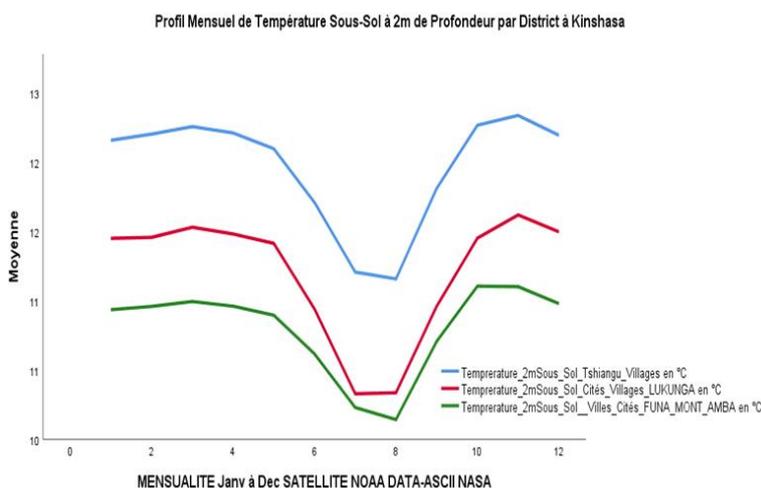


Figure 11: Monthly Basement Temperature Profile at 2 m from districts in the city of Kinshasa

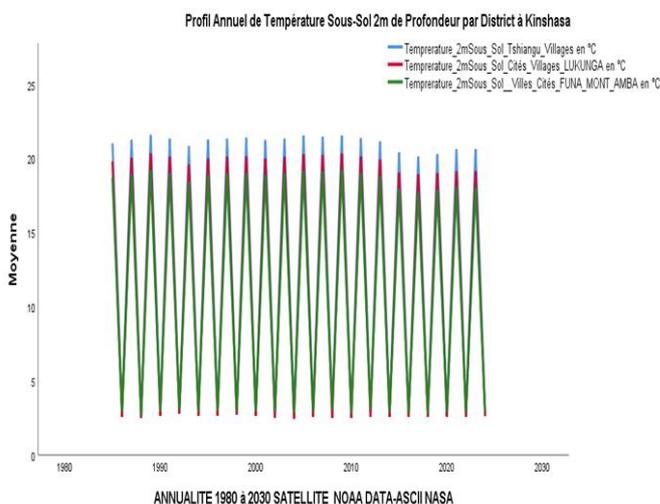


Figure 12: Annual Basement Temperature Profile at 2 m from districts in the city of Kinshasa

The monthly and annual profiles of soil temperature at 2 m depth show a more attenuated variation than that in air temperature, reflecting the thermal inertia of the soil. The highest values are observed during hot periods, while the lows appear during the dry season, with relative homogeneity between years.

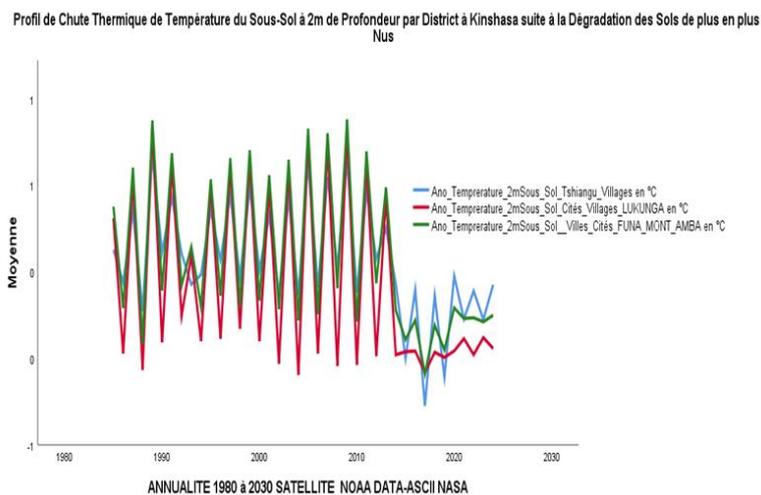


Figure 13: Profile of temperature drop in basement to 2m deep by districts in the city of Kinshasa

The figure depicting the fall in ground temperature highlights gradual seasonal decreases, suggesting a delayed response of the soil to surface climate variations. This dynamic confirms the role of the ground as a thermal reservoir.

Groundwater/water stock

Groundwater is a strategic resource for the supply of drinking water to urban populations, especially in cities where distribution networks are inadequate. In Kinshasa, groundwater recharge is strongly influenced by climate variability, increased runoff and anthropogenic pressure linked to rapid urbanization. The analysis of the evolution of piezometric levels and groundwater stock over the period 1980—2024 makes it possible to assess the response of aquifers to climate change and land use transformations, as well as to identify areas of hydrogeological vulnerability at the scale of urban districts.

Descriptive analysis of groundwater stocks.

Stocks d'Eau Souterraine de Nappe Phréatique en Tonne H2O/ha par District à Kinshasa

	N	Minimum	Maximum	Somme	Moyenne	Ecart type
Stock_Eau_Souterraine_Maluku en TonneH2O/ha	1392	,35000	2710,28000	2276878,041	1635,688248	701,6566706
Stock_Eau_Souterraine_Nsele en TonneH2O/ha	1392	,25000	3508,66000	3143199,007	2258,045264	998,1818004
Stock_Eau_Souterraine_Funa en TonneH2O/ha	1392	,35000	4017,78000	3631734,468	2609,004647	1164,790208
Stock_Eau_deTerre_MTAmaba en TonneH2O/ha	1392	,23000	2294,86000	1639236,552	1177,612465	622,5216317
Stock_Eau_deTerre_Lukunga en TonneH2O/ha	1392	,23000	3065,37000	2718925,671	1953,251201	922,4898282
Stock_Eau_deTerre_Bumbu_Dipiya_Kinzozi7 en TonneH2O/ha	480	,20000	3569,51000	853185,2700	1777,469313	1699,481877
Stock_Eau_deTerre_Bumbu_Dipiya_Kingungu en TonneH2O/ha	480	,20	3569,51	853185,27	1777,4693	1699,48188
Stock_Eau_deTerre_MTNgafula_Don_Bosco en TonneH2O/ha	480	,23	3065,37	715889,07	1491,4356	1464,17594
N valide (liste)	480					

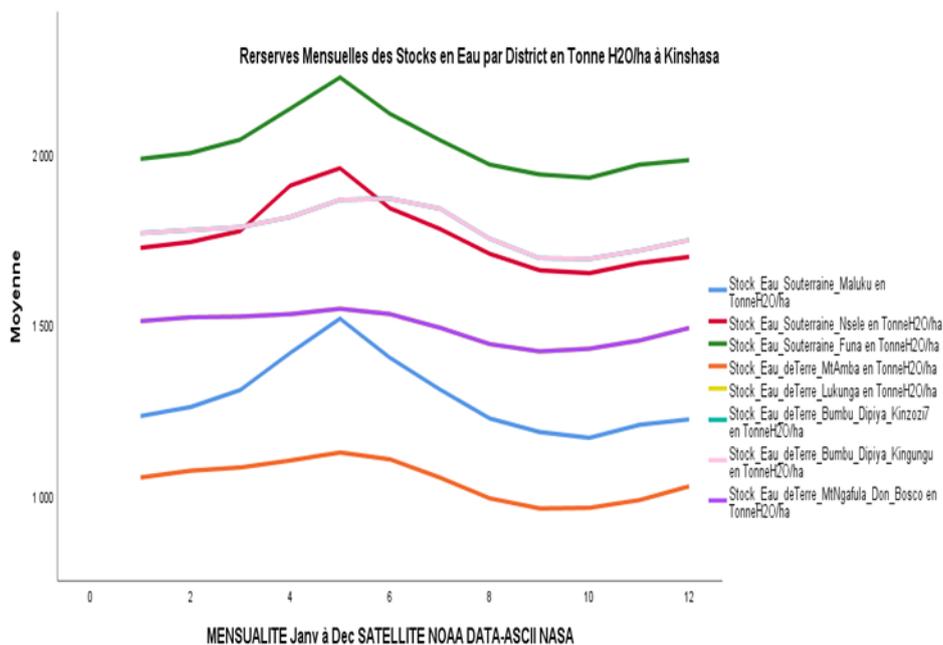


Figure 14: Monthly Groundwater Reserve of the Groundwater Table by districts in the city of Kinshasa

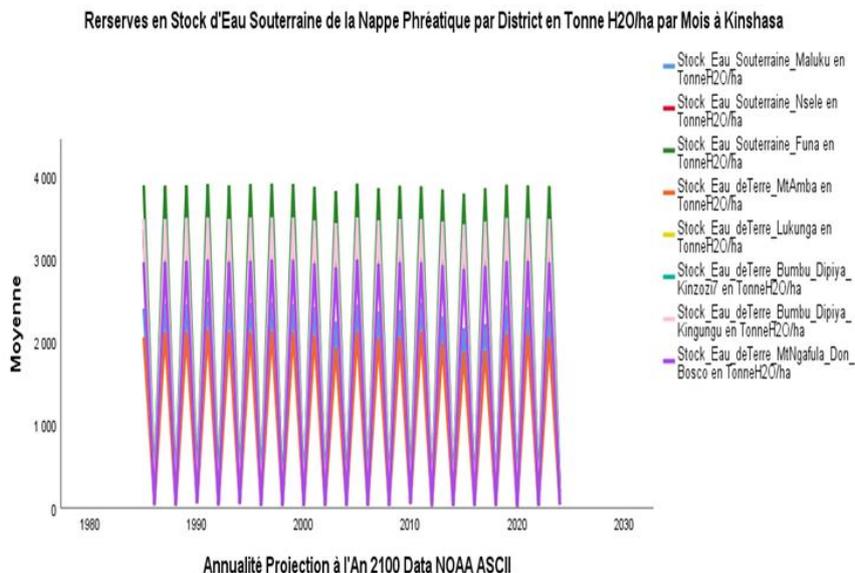


Figure 15: Annual groundwater reserve of the groundwater table by districts in the city of Kinshasa

Monthly and annual groundwater reserves show significant temporal variability, with phases of relative increase and decrease during the period studied. The general trend observed suggests a gradual decrease in groundwater stock in several districts, reflecting an unfavorable evolution of groundwater resources in the long term.

V. Projections To 2050

The results show a gradual increase in maximum and minimum temperatures over the entire period studied, particularly marked in highly urbanized districts (Lukunga and Funa). Rainfall has increasing inter-annual variability, while urban runoff is increasing under the effect of soil sealing. Piezometric levels indicate a general downward trend, reflecting insufficient groundwater recharge.

VI. Discussion

Thermal trends and consistency with regional observations

The results highlight a gradual increase in maximum and minimum temperatures in Kinshasa between 1980 and 2024. This trend is in line with observations reported at the scale of Central Africa, where a significant increase in average annual temperatures has been documented over the past few decades (IPCC, 2021; New et al., 2006). Nicholson et al. (2018) point out that the warming observed in humid tropical regions is expressed relatively homogeneously at the regional scale, which is consistent with similar trends observed in the various districts of Kinshasa.

The evolution of ground temperature follows a dynamic comparable to that of air temperature, with a more attenuated seasonal amplitude. Similar results were reported by Zhou et al. (2019), which show that soil temperature is a robust indicator of long-term climate change due to its thermal inertia. The agreement between these two parameters suggests a gradual modification of the surface energy balance.

Rainfall Variability and Climate Instability

The analysis of precipitation reveals a high degree of inter-annual variability, marked by the alternation of wet and dry years, with no clear linear trend over the entire period studied. This characteristic has been extensively documented in equatorial Africa, where rainfall regimes are strongly influenced by the dynamics of the intertropical convergence zone (Nicholson, 2017; IPCC, 2021).

Studies conducted in the Congo Basin indicate that this increased variability in rainfall is one of the main signals of regional climate change (Washington et al., 2013). The results obtained in Kinshasa are thus part of a regional climate context marked by increasing instability in rainfall regimes.

Surface runoff and hydrological response of urban basins

Runoff graphs show an increase in surface flow volumes in relation to rainfall fluctuations. This direct relationship between precipitation and runoff is consistent with the work of Oudin et al. (2018), which highlights the sensitivity of tropical watersheds to climate variations, even in the absence of major changes in physical parameters.

In urban Africa, several studies have highlighted an intensification of runoff associated with climate variability and surface transformations (Du et al., 2019; Kabanda et al., 2020). The results observed in Kinshasa confirm that runoff is a relevant indicator of the evolution of urban hydrological functioning in the long term.

Evolution of groundwater and imbalance in the aquifer system

Piezometric trends indicate a gradual decline in groundwater levels in several districts. Similar developments have been reported in many African cities, where shallow groundwater is particularly sensitive to climate fluctuations and anthropogenic pressure (Taylor et al., 2013; MacDonald et al., 2013; MacDonald et al., 2012).

According to Taylor et al. (2013), climate change can affect groundwater recharge indirectly, through the variability of precipitation and the intensification of runoff, thus reducing effective infiltration. The results obtained in Kinshasa suggest a gradual imbalance between recharge and destocking of urban aquifers.

Intra-urban spatial variability

The differences observed between administrative districts reflect the spatial heterogeneity of climatic and hydrological functioning. Similar contrasts have been demonstrated in other major African cities, where the response to climate forcings varies according to the local characteristics of watersheds (Grimmond, 2007; Roth, 2007).

This heterogeneity highlights the importance of a spatial approach in the analysis of urban climate and hydrological dynamics, making it possible to better understand local vulnerabilities.

Implications for climate and hydrologic projections

The trends observed over the period 1980—2024 provide a coherent basis for projections to 2050. Regional climate scenarios indicate continued warming and increased rainfall variability in Central Africa (IPCC, 2021). In this context, the results suggest increasing pressure on water resources, especially groundwater, as observed in other tropical cities (MacDonald et al., 2012).

VII. Conclusion

This study made it possible to analyze the joint evolution of climatic and hydrological parameters in Kinshasa over the period 1980—2024, using satellite and climate data aggregated at the level of administrative districts. The results highlight a gradual increase in air and ground temperatures, associated with a high interannual variability in precipitation. These developments reflect a persistent climate signal, consistent with the trends observed at the regional level in Central Africa.

On the hydrological level, the analysis reveals a significant response of surface runoff to rainfall fluctuations, as well as a gradual decrease in groundwater levels in several districts. These trends suggest a growing imbalance between natural inputs and outputs from the urban hydrological system, indicating increased vulnerability of groundwater resources in the long term.

Projections to 2050, based on the extrapolation of observed trends, indicate a continuation of warming and increased pressure on urban hydrological functioning. In this context, the results obtained constitute a relevant scientific basis for the prediction of hydrological and climatic risks in Kinshasa.

This study highlights the value of an integrated approach combining climatic and hydrological parameters for the analysis of environmental dynamics in tropical urban areas. It also highlights the need to strengthen climate and hydrological monitoring systems in order to improve the understanding and sustainable management of water resources in the city of Kinshasa.

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