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Research Article

Study of the Climate Vulnerability of Water Resources in the Milo River in the Department of Kankan (Guinea)

Amadou 2 Condé[1, 2, *], Amadou Lamarana Bah[2, 3], Simon Pierre Lamah[2, 3], Idrissa Diaby[2, 3], Cellou Kanté[2, 3]

[1] Department of Environmental Education, National Center for Environmental Documentation (CNDE), Kankan, Republic of Guinea

[2] Department of Physics, Gamal Abdel Nasser University, Conakry, Republic of Guinea

[3] Department of Physics, Laboratory for Teaching and Research in Applied Energy (LEREA), Conakry, Republic of Guinea

Abstract

Climate change affects the availability, quality, and quantity of water needed to meet the basic needs of the billions of people inhabiting the planet. This study assessed the climate vulnerability of water resources in the Milo River watershed, located in the Kankan prefecture. It focused specifically on the impacts of climate change on water availability and quality in this watershed. The main objective of this work was to evaluate the vulnerability of the Milo River's water resources and the variability influencing rainfall and hydrological patterns in the study area. This work also helped determine the risks associated with the socio-economic activities of the Kankan population. To achieve this, we combined the analysis of historical climate data and future projections with field hydrological measurements. The use of hydrological models to simulate the effects of future climate scenarios allowed us to analyze data from 2000 to 2020, covering both dry and wet seasons, to obtain a comprehensive view of hydrological variations. The analysis reveals a high impact of water resource vulnerability, on the order of 0.91, or 91%, reaching the conventional threshold of 0.6 to 1. This result indicates that the Milo River basin is particularly vulnerable to climate change. A marked decrease in flow is observed during dry seasons, accompanied by an increase in significant flooding during periods of heavy rainfall. Water quality is also affected, with higher concentrations of pollutants during floods. These changes in the hydrological regime have direct repercussions on associated aquatic and terrestrial ecosystems, as well as on the human communities that depend on this resource.

Keywords

Study, Climate Vulnerability, Precipitation, Potential Impacts

1. Introduction

Climate change is affecting the availability, quality, and quantity of water needed to meet the basic needs of billions of people. The hydrological changes it is causing will complicate the sustainable management of water resources (Drinking -

*Correspondence: Amadou 2 Condé (amadoubinko@gmail.com)

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December 16, 2010) [1, 2].

Food security, human health, urban and rural settlements, energy production, industrial development, economic growth and ecosystems all depend on water and are therefore vulnerable to the effects of climate change (Florence Habets, 2011) [2, 3].

Guinea is distinguished by the great diversity of its landscapes, linked to their specific physical conditions. This varied topography allows for the distinction of four natural regions with distinct physical and climatic characteristics: Lower Guinea, Upper Guinea, Forest Guinea, and Middle Guinea. A country with a tropical climate, Guinea experiences a growing demand for water, both for drinking water supply and for agriculture and industry. This demand increases year after year and is therefore becoming increasingly difficult to meet due to the combined challenges posed by these multiple needs and the vulnerability of the resource to climate change.

At the same time, water resources are becoming scarce for multiple reasons: poor management of existing resources; waste due to excessive water use; and climate variations and changes (FEINDOUNO, S, 2022), [3-9].

However, studies on the vulnerability of water resources in Upper Guinea and Kankan in particular (see sectoral study) show that, beyond the natural and usual alternation of dry and wet periods, the various basins will suffer direct and indirect impacts from climate change. Among the regions most affected by this phenomenon, if the necessary measures are not taken to combat it… this change will have serious consequences for the lives of the populations of the Guinean savanna [9-14].

The vulnerability of water resources to climate change has become a major concern due to the increasing impact of these changes on water availability and quality.

From south to north, the Milo River, as it flows through the various localities, is composed of a series of streams which are: Fonerenko, Kansanko, Kooba , Koba, Djessé, Bangkalan , Lambo, Sikoba , … Since 1931, data on temperatures, rainfall and flow rates of the Milo River have been collected throughout the territory and archived by the National Meteorological Agency (ANM) and the National Directorate of Hydraulics (DNH) [14-18].

hydroclimatic. Faced with this situation, it is important to adopt an approach that takes into account both the dynamics of the physical environment and human activities.

1) How can we develop adaptation measures to mitigate the vulnerability of the river's water resources?
2) How to assess the vulnerability of water resources in the Milo River catchment area?

2. Tools and methods

Presentation of the study area

The prefecture of Kankan is located in eastern Guinea, between 8 °20' 08" and -8 °67' 32" north latitude and 9 °18'20" and 9 °18'20" west longitude, with an average altitude of 381 m. It covers an estimated area of 11,564 km^2 and had a population of 3,704,508 inhabitants according to the RGHP (2021), which represents a density of 44 inhabitants per km^2.

It is bordered to the north by the prefectures of Kouroussa and Mandiana; to the east by the prefecture of Mandiana and the Republic of Côte d'Ivoire; to the west by the prefecture of Kouroussa; and to the south by the prefectures of Beyla, Kérouané, and Kissidougou. The prefecture includes 16 sub-prefectures and one urban commune (the location of Kankan is yet to be confirmed).

Administratively, Cincinnati is the second largest city in the Republic of Guinea after the capital, Conakry. It is part of the Upper Guinea region, of which it is the capital and administrative center, as well as the capital of the Kankan department.

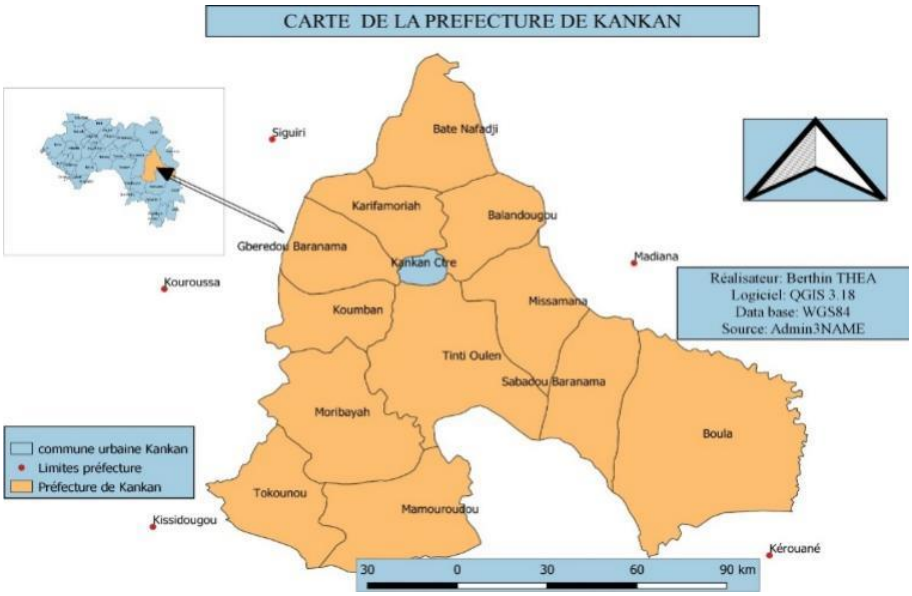

Figure 1. *Map of Kankan.*

Data used

The data used in this research are qualitative and quantitative hydrometeorological data (see Tables 1 and 2) .

Table 1. *Measurable indicators of climate vulnerability .*

Determining factors (water)	Measurement indicator	Data sought	Equipment used
Exposure			
	Temperature (Max, Min, Average)	Yes	ANM database
	Rainfall	Yes	ANM database
	Air humidity	Yes	ANM database
	river flow	Yes	DNH database
	The drought	Yes	Documentation
	soil typology	Yes	Documentation
	The Flood	Yes	Documentation
Sensitivity			
	Population explosion	Yes	ANS database
	Number of water points	Yes	SNAPE database
	Number of waterways	Yes	DNH database
	drinking water quality	Yes	Survey form

The data includes precipitation, temperature, and humidity for the period from 2000 to 2020, a period of 20 years. This data was collected at the Kankan synoptic station.

Table 2. *Hydrometeorological data of the Milo river through Kankan.*

Years	Humidity (%)	Temperature (℃)	Rainfall (mm)	Speed (m^3/s)
2000	65.21	26.50	1,450.80	220.52459
2001	67.21	26.61	1,381.88	197,118,852
2002	66.75	26.80	1,292.49	167 157 104
2003	65.88	26.54	1,601.29	92.0478142
2004	66.79	26.53	1,543.72	196,710,383
2005	66.33	26.82	1,467.68	159,968,839
2006	66.50	26.36	1,548.66	191,646,175
2007	64.08	26.40	1,388.96	179.060109
2008	59.79	25.85	1,678.69	194,980,609
2009	62.58	26.19	1,451.61	196,733,607
2010	63.71	26.62	1,724.66	191 508 197
2011	61.54	25.97	1,446.33	163,189,891
2012	61.75	25.82	1,526.30	181,005,464
2013	60.54	26.31	1,590.45	177,646,175
2014	62.08	26.50	1,440.28	181,170,765

Years	Humidity (%)	Temperature (℃)	Rainfall (mm)	Speed (m $^{3/}$ s)
2015	64.00	26.57	1,555.55	206,188,525
2016	67.08	26.79	1,532.85	201,693,989
2017	62.13	26.80	1,295.50	184,434,426
2018	62.13	26.63	1,589.74	220.086066
2019	61.05	26.68	1,550.19	220.52459
2020	62.92	26.50	1,519.66	197,118,852

The climate data used in this study are temperature, precipitation, and humidity, on a monthly and annual scale. This data comes from the National Directorates of Meteorology and Hydrology and was collected from meteorological stations in Kankan over the period 2000-2020.

Method

The rainfall index method allows us to assess the variation in precipitation over a given observation period. This method has the advantage of highlighting periods of rainfall surplus and deficit. Thus, for each station, based on the selected rainfall data, an interannual rainfall index was determined and defined as a standardized variable, expressed by equation (1) below.

$$I_i = \frac{P_i - P}{\sigma}$$

Where II - Precipitation index (Nicholson index)

Pi - value of the average annual rainfall of year i;

P- Average annual rainfall over the period studied; σ- Average annual standard deviation of rainfall over the period studied

Aridity

Aridity can be expressed quantitatively by various conventional and empirical aridity indices, as well as by hydrothermal ratios based primarily on average precipitation and temperature values, used to define degrees of aridity and stream flow conditions. These indices have been proposed by climatologists, geomorphologists, geographers, and botanists. The best known are those of De Martonne (1926), Emberger (1932), Thornthwaite (1948), and Bagnouls and Gaussen H. (1953). At the beginning of the last century, E. de Martonne developed an aridity index:

$$I_{DM} = \frac{P}{T+10}$$

Where P represents the average annual rainfall (in mm) and T the average annual temperature (in ℃).

Table 3. *Annual evolution of temperature, relative humidity and devotion in Kankan (2000-2020).*

1	index values	$0 < I_{DM} < 5$	$5 < I_{DM} < 10$	$10 < I_{DM} < 20$	$20 < I\ am_{diabetic} < 30$	$30 < I_{DM} < 55$
2	Climate types	Hyperarid	arid	semi-arid	semi-moist	humid

3. Methodology

For data processing, we used the following software:

1) Microsoft Office (for processing, projection, calculations, analysis, and graphs),
2) QGIS (for mapping),

Results and interpretation

Meteorological and hydrological data from the Kankan prefecture were used to study the climate vulnerability of water resources over the period 2000-2020 (20 years). The analysis of water resource variability in the Milo watershed, up to the Kankan bridge hydrometric station, is based on measurements of precipitation, humidity, temperature, and flow rate.

interannual (2000-2020)

Graphical analysis of annual temperature data allowed for the assessment of climate behavior from a thermal perspective. The interannual and monthly average air temperature values for the 20-year period (2000-2020) are presented in Figures 2 and 3.

Table 4. Annual evolution of temperature, relative humidity and devotion in Kankan (2000-2020).

Years	Humidity (%)	Temperature (℃)	Precipitation (mm)	Flow rate (m^3/s)
2000	65.21	26.50	1,450.80	72146
2001	67.21	26.61	1,381.88	61180
2002	66.75	26.80	1,292.49	33690
2003	65.88	26.54	1,601.29	71996
2004	66.79	26.53	1,543.72	56469
2005	66.33	26.82	1,467.68	70143
2006	66.50	26.36	1,548.66	65536
2007	64.08	26.40	1,388.96	70388
2008	59.79	25.85	1,678.69	72005
2009	62.58	26.19	1,451.61	70092
2010	63.71	26.62	1,724.66	59728
2011	61.54	25.97	1,446.33	66248
2012	61.75	25.82	1,526.30	65019
2013	60.54	26.31	1,590.45	66309
2014	62.08	26.50	1,440.28	75465
2015	64.00	26.57	1,555.55	73820
2016	67.08	26.79	1,532.85	67503
2017	62.13	26.80	1,295.50	80552
2018	62.13	26.63	1,589.74	68552
2019	61.05	26.68	1,550.19	73618
2020	62.92	26.50	1,519.66	66860

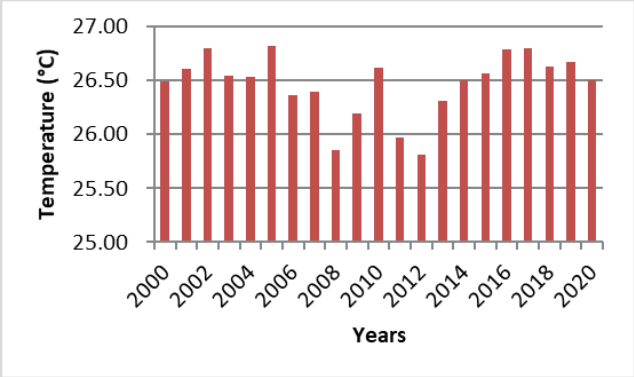

Figure 2. Variability of the average annual temperature in Kankan.

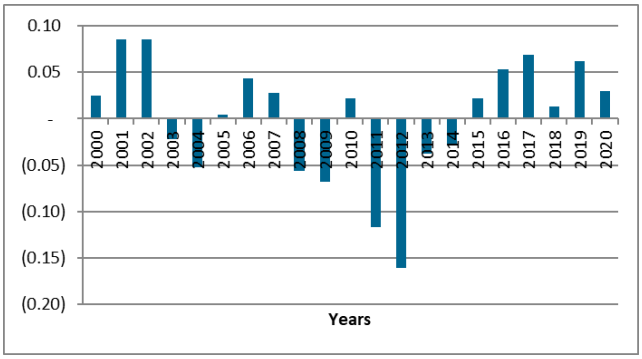

Figure 3. Average annual thermal index of Kankan 2000-2022.

In Figure 2, average annual temperatures vary between 26.82 ℃ in 2005, 2016 and 2017 and 25.82 ℃ in 2012 and 2008. The trend curve tends towards a slight decrease.

Kankan thermal indices

Figure 3 shows the years in which a moderation of thermal indices was observed: 2005 (0.001), 2018 (0.01), 2000 (0.02); high thermal indices were observed in 2012 (0.16) and 2011 (0.12).

Air humidity variability along the Milo Kankan River

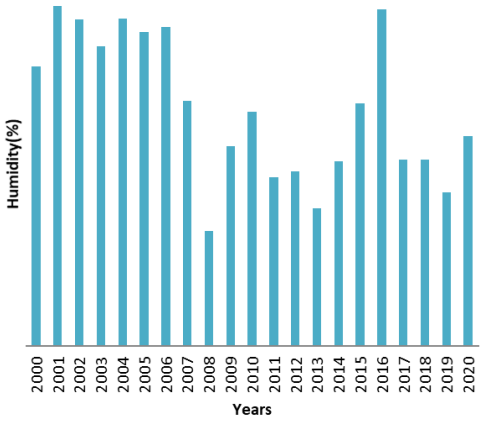

Figure 4. *Variation in air humidity in Kankan.*

Figure 4 shows two periods of variability in air humidity: the first, with slight variation, extends from 2000 to 2006, and the second, with more pronounced variation, extends from 2007 to 2020. It is important to remember that the highest humidity was observed in 2016 with 68.8% and the lowest in 2008 with 59.79%.

Air humidity variability index in Kankan

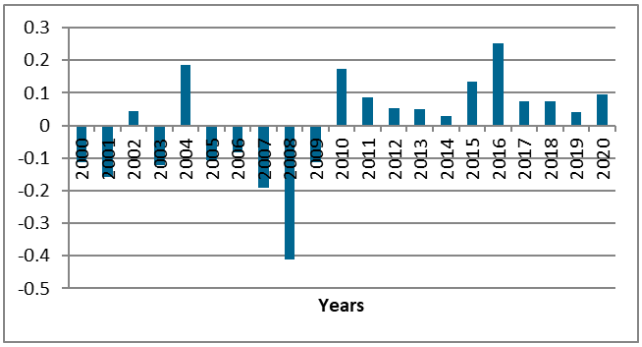

Figure 5. *Average annual thermal index of Kankan 2000-2022.*

Figure 5 shows that from 2000 (-0.11) to 2006 (-0.10), we observed moderate aridity and high aridity in 2007 (-0.19), with moderate humidity in 2001 (-0.15) and 2009 (-0.11), and high humidity in 2004 (0.18), 2010 (0.17) and 2016 (0.25); from 2011 to 2014 (0.3), moderate humidity was observed; from 2002 (0.4), from 2012 to 2014 (0.030) and from 2017 to 2019 (0.041), we observed moderate humidity, with high humidity in 2011 (0.041) and 2015 (0.13); extreme humidity in 2008 (-0.41).

Rainfall in Kankan between 2000 and 2020

Rainfall variability is the most important climatic factor for populations and ecosystems. This explains the exceptional impact of anomalies affecting this parameter.

variability along the Milo Kankan river

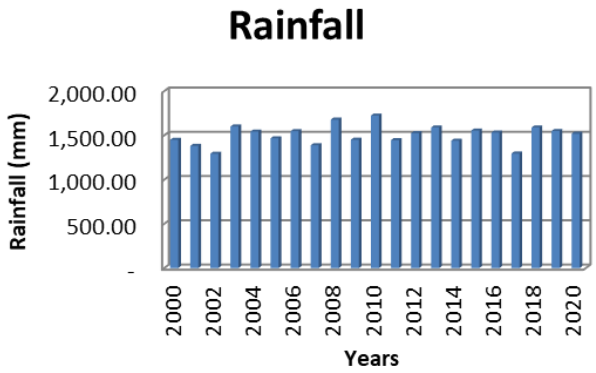

Figure 6. *Variation in precipitation a kqnkqn between 2010 and 2021.*

The analysis of rainfall data from the synoptic observation station of Kankan is illustrated in Figure 6. An alternation between periods is observed.

Deficits from 2001 to 2002 and from 2016 to 2017 with some surpluses in 2003, 2008, 2010, 2013 and 2018 then an upward trend.

Average annual variation in rainfall indices in Kankan between 2000 and 2020

Air and its influence on wind dynamics and precipitation.

The 2023 data show slight but regular pressure fluctuations throughout the year, reflecting seasonal variability linked to the transition between the dry and wet seasons.

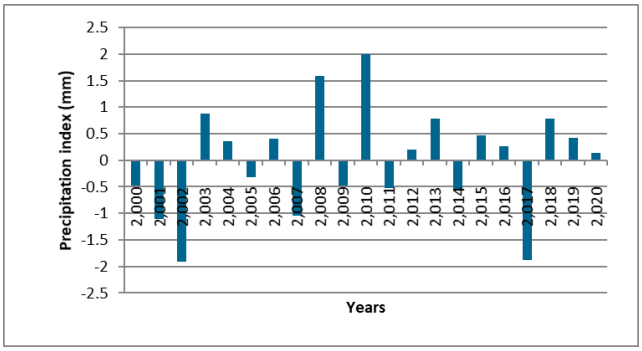

Figure 7. *Average annual variation of precipitation indices in Kankan.*

Figure 7 shows that in 2000, 2005 and 2009 (-0.41), aridity was moderate; from 2008 (1.58) to 2010 (2), humidity was extreme; high humidity in 2003 (0.88), 2013 (0.78) and 2018 (0.77); moderate humidity in 2004 (0.36), 2006 (0.40), 2012 (0.20) with a few years of moderate aridity in 2011 (-0.51) and 2014 (0.57) and high aridity in 2001 and 2007 (-1.03).

Variability of the annual flow of the Milo catchment

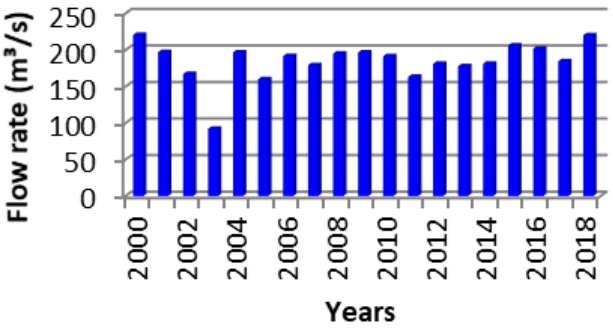

Figure 8. *Variability of the annual flow of the Milo catchment.*

Figure 8 shows the maximum average flow recorded in 2002 and 2017 for a value of 220 m ^{3} /s with a minimum of 92.04 m^3 /s in 2003.

Milo River Flow Index

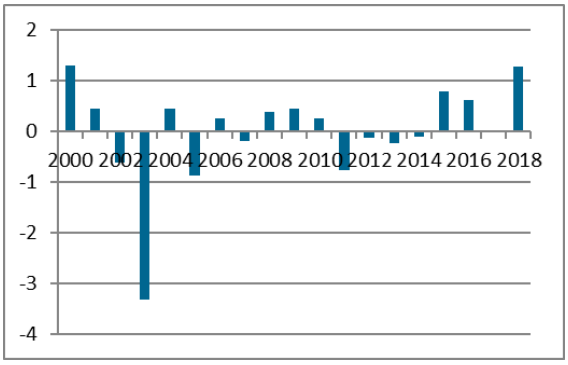

Figure 9. *Milo River flow indices.*

Figure 9 shows that from 2004 to 2014 (-0.11), aridity was moderate; from 2000 (1.29) to 2018 (1.21), humidity was extreme; high humidity in 2015 (0.78) and 2016 (0.62); moderate humidity in 2001 (0.41), with a few years of moderate aridity in 2002 (-0.61), 2005 (-0.87) and 2011 (0.75) and high aridity in 2003 (-3.30).

Aridity Index

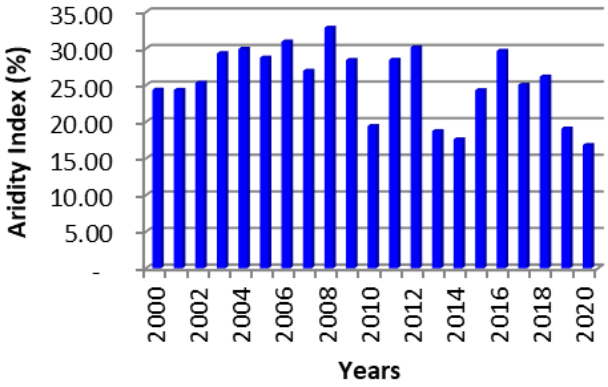

Figure 10. *Variability of the Aridity Index in the Milo catchment.*

To better quantitatively assess the degree of aridity in the Milo basin, we calculated the De Martonne index. The hydrological conditions of the Milo are influenced by two factors. In recent decades, the region has experienced alternating semi-humid and semi-arid climates, with a high recurrence of semi-arid periods. Conversely, south of the Milo basin, in the Macenta region, rainfall is affected by climate change due to the increased frequency of extreme weather events (heat waves).

Table 5. *Average annual values of the aridity indices of the river at Kankan.*

Years	Temperature (℃)	Rainfall (mm)	Aridity index	Climate type
2000	39.47	1450.80	24.40	Semi-moist
2001	36.70	1381.88	24.37	Semi-moist
2002	31.00	1292.49	25.34	Semi-moist
2003	34.50	1601.29	29.38	Semi-moist
2004	31.50	1543.72	29.98	Semi-moist
2005	30.99	1467.68	28.78	Semi-moist
2006	30.00	1548.66	30.97	Humid
2007	31.48	1388.96	26.98	Semi-moist
2008	31.07	1678.69	32.87	Humid
2009	31.01	1451.61	28.46	Semi-moist
2010	31.45	1000.00	19.44	Semi-arid
2011	30.77	1446.33	28.49	Semi-moist

Years	Temperature (℃)	Rainfall (mm)	Aridity index	Climate type
2012	30.55	1526.30	30.19	Humid
2013	33.15	996.00	18.74	Semi-arid
2014	36.20	990.28	17.62	Semi-arid
2015	33.45	1300.55	24.33	Semi-moist
2016	31.61	1532.85	29.70	Semi-moist
2017	31.68	1295.50	25.07	Semi-moist
2018	37.30	1500.74	26.19	Semi-moist
2019	38.65	1119.89	19.09	Semi-arid
2020	39.40	1000.66	16.85	Semi-arid

4. Discussion

Studies on the vulnerability of water resources in the Milo River, located in the Kankan prefecture in Guinea, reveal several critical problems related to the management of this vital resource.

The 480-km-long Milo River is a major tributary of the Niger River and drains a catchment area of 13,810 km ². It plays a vital role for local communities, notably by providing them with the water necessary for their domestic and agricultural needs. However, the availability of this resource is threatened by factors such as the lengthening dry season and pollution.

Climate variability, particularly changes in temperature and rainfall patterns, also affects the water resources of the Milo River. Data Analyzes in the UNDP report indicate that the vulnerability of the Milo River's water resources was 0.751, or 75.1%, in 2015, and that a general downward trend in water flows of 0.30, or 30%, is projected by 2023.

While data analyzes from this study indicate that the vulnerability of the Milo River water resources is 0.91 or 91%, after observations we found a 15% increase in vulnerability between 2000 and 2020, with a downward trend in flow to 0.78 or 78%, which represents an increase in the decrease in flow to 48%.

This situation has direct consequences on water resources, biodiversity and the livelihoods of riverside communities.

Faced with these challenges, water resource management is essential. This involves implementing policies to conserve and protect wetlands, which are vital for maintaining water quality and preserving ecosystem balance. Improving water resource management and raising awareness among local communities about the importance of protecting the river is also crucial.

The vulnerability of the Milo River's water resources in Kankan Prefecture stems from environmental, climatic, and human-induced factors. An integrated and sustainable approach is essential to ensure the long-term viability of this vital resource for local communities.

5. Conclusion

The analysis of the climate vulnerability of the Milo River's water resources reveals the significant impact of climate change on the availability and quality of this vital resource. This study leads to several key measures.

The data collected and processed indicate that the river is already experiencing significant effects of climate change, including increased variability in rainfall and flow rates, more frequent droughts, and more intense flooding. These changes are altering flow dynamics and water quality, thereby increasing the river's vulnerability to extreme weather events.

Changes in the hydrological regime have direct repercussions on associated aquatic and terrestrial ecosystems, as well as on the human communities that depend on this resource. Reduced water resources during droughts and increased pollution risks during floods affect biodiversity and local economic activities such as agriculture and tourism.

Changes in the hydrological regime have direct repercussions on associated aquatic and terrestrial ecosystems, as well as on the human communities that depend on this resource. Reduced water resources during droughts and increased pollution risks during floods affect biodiversity and local economic activities such as agriculture and tourism.

To mitigate future impacts, it is essential to implement appropriate policies, including proactive water resource management, initiatives to strengthen ecosystem resilience, and programs to raise awareness among water users. Implementing integrated water resources management (IWRM) practices can help reconcile human and environmental needs in the face of climate uncertainties.

This study opens up several avenues for research, including the need to model climate impacts at a finer scale and to evaluate the effectiveness of different adaptation strategies. It is also important to pay particular attention to the participation of local communities in decision-making processes to ensure the relevance and sustainability of the measures implemented.

In summary, the Milo River basin faces increasing challenges in water resource management due to climate change. It is imperative that stakeholders collaborate to develop innovative and sustainable solutions to ensure the resilience of this river and its ecosystems for future generations.

Table 5. *Nomenclature.*

Symbol	Meaning	Unit
T	Average temperature	°C
HEY	Air humidity	%
P	river flow	M^3/s
I	Rainfall	mm
V	Aridity	%
r	Linear correlation coefficient	–
σ	Standard deviation	–
n	Number of observations	Year

Abbreviations

AEP	Drinking Water Supply
IRC	Climate Risk Indices
IVPCC	Indicator of Physical Vulnerability to Climate Change
ANM	National Meteorological Agency
ANH	National Hydraulics Agency
IPCC	Intergovernmental Panel on Climate Change
AR4	Risk analysis in the IPCC's 4th Assessment Report
RCMP	Risk and Disaster Management
GIR	Risk Index Management

Author Contributions

Amadou 2 Condé: Conceptualization, Drafting – first version, Drafting – revision and correction

Amadou Lamarana Bah: Methodology, Data Preservation

Simon Pierre Lamah: Formal Analysis, Investigation

Conflicts of Interest

The author declares that he has no conflict of interest.

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