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Research Article

Impact of Climate Variability on Hydroelectric Power Production in Guinea: Case of the Kinkon Dam

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Abstract

In Guinea, analysis of the hydrological balance of recent years shows the severity of the impact of climate variability on the hydrological regimes of rivers. This would impact the productivity of hydroelectric dams. The illustrative case is that of the power plant located upstream of the Kinkon waterfall, on the Kokoulo River in Pita prefecture, built between 1963 and 1966. With an initial production capacity of 3.4 megawatts, Kinkon now produces only 1.6 megawatts, mainly due to the gradual reduction in water flow. The present work, which focuses on the impact of climate variability on the production of hydroelectric energy at the Kinkon power plant, aims to assess the main causes of the drop in energy productivity at this Kinkon power plant. The main data used are the rainfall in the area, the energy production of the power plant, and Landsat satellite images. The method used consists of calculating the monthly rainfall balance of the area as well as the energy productivity to determine the interannual variability. The calculation of anomalies made it possible to visualize the trend and the analysis of the correlation showed the linear dependence of the two variables (rainfall and energy productivity). A supervised classification of Landsat satellite images leading to the extraction of land cover made it possible to better understand the anthropogenic pressure on the area concerned. The results obtained show a downward trend in rainfall in the area, which in turn has led to a decrease in the plant's productivity. This decrease in rainfall is believed to be due to the strong anthropogenic pressure exerted on the environment in the area concerned.

Keywords

Climate Variability, Hydroelectric Power Production, Kinkon Power Plant, Anthropogenic Pressure

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1. Introduction

Guinea is among the least electrified countries in Africa. Even in the West African subregion, most of our neighbors surpass us in terms of their countries' electricity coverage. Despite significant efforts by the government over the past ten years to improve electricity supply, Guinean cities are still plagued by a lack of electricity. The multiple untimely power cuts observed in recent years have had direct consequences, the proliferation of demonstrations in affected neighborhoods, the disruption of administrative, professional and even informal activities. It should be noted that the main sources of electrical energy are hydroelectric power plants such as Kaleta, Kinkon, Garafiri, Souapiti, Koukoutamba, Tamara. These dams are currently far from meeting the real need in terms of energy because of their underproduction [1].

Since the late 1980s, the Republic of Guinea has been facing a significant rainfall deficit, both in terms of intensity and duration. This phenomenon has major repercussions on the available water resources in the region. Preliminary studies have hypothesized that climate change could lead to a decrease in river flows and levels in Guinea. The work of Hartmann and Croley in the 1990s notably suggested that these changes could result in a drop in river water levels, with a climate stabilized at CO_2 concentrations twice those of historical levels. Thus, the increase in temperatures, induced by the rise in greenhouse gas concentrations in the atmosphere, risks accentuating evaporation and evapotranspiration in the Great Rivers, without necessarily compensating for the expected increase in precipitation. This combination of factors could lead to a decrease in flows, thus reducing the production capacity of hydroelectric power plants located in the Great Rivers of the St Lawrence system [2].

To fully understand the impact of climate variability on hydroelectric production, it is essential to understand the hydroelectric production process. Hydroelectricity is generated by converting the kinetic energy of water into electrical energy using hydraulic turbines coupled with alternators. The amount of hydroelectric energy available depends closely on the volume of water available, natural inflows and outflows over the period considered, and the head, defined as the vertical distance between the water inlet and outlet of the pipe [3].

Although some studies in the 1990s predicted increases in precipitation, most predicted an increase in evaporation, thus leading to decreases in net inflows. As part of the major regional studies initiated by Natural Resources Canada, Ouranos was commissioned to carry out, in collaboration with the Mowat Center, an economic study of the impacts of climate variables on hydroelectric production and their repercussions on the different uses of this resource, as well as on possible adaptation measures [4, 1].

The main question that comes back to us repeatedly is why these significant investments for so little results?

Several causes could appear to justify this underproduction, but we will address in this present work, those linked to the strong climatic variability caused by the anthropogenic pressure of the zones concerned thus leading to the random variations of the flow of the rivers due to the strong disturbance of the rainfall in the region. The main objective of this work is to contribute to the understanding of some environmental causes that regulate the energy production of the Kinkon dam, located in the Pita prefecture in Middle Guinea (Figure 1). Specifically, it will be a question of: Analyze flow variability as a function of rainfall variability; Identify the main anthropogenic causes on the environment of the power plant and perform cross-analysis to aid decision-making.

2. Materials and Methods

2.1. Presentation of the Study Area

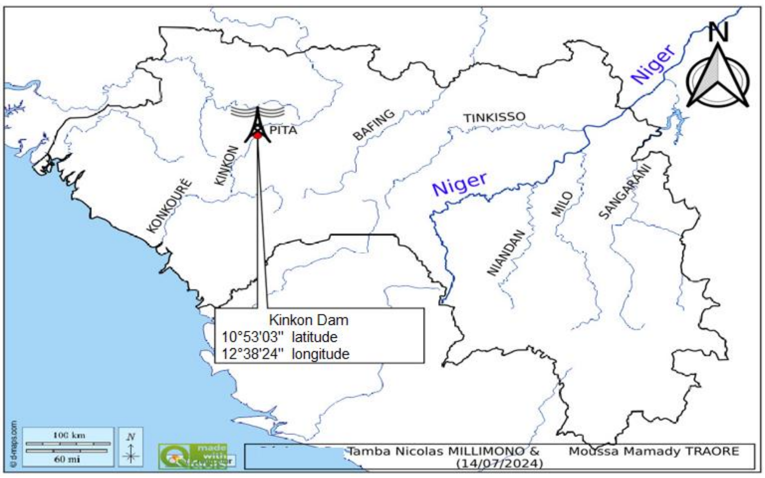

Figure 1. Geographical position of the Kinkon power plant.

Kinkon is located approximately 9 kilometers from the urban commune of Pita. This locality is home to one of the very first hydroelectric dams in Guinea. This product of the first Guinean regime built after independence was intended to provide electricity to the towns of Labé-Pita-Dalaba and Mamou.

2.2. Data

The data used in this study are of three categories: Rainfall data from synoptic stations available for the study area at the National Directorate of Metrology (DNM) in Guinea. These rainfall data used result from the annual rainfall averages over a period of 13 years (2008-2020) for the four (4) synoptic stations covering the dam site andhistributaries, these data have been processed to reduce distortions; Data on the hydroelectric dam's energy production over a significant period, preferably around a decade from 2008 to 2020. They were provided by the General Directorate of the Water and Electricity Company of Guinea (EDG) and Landsat satellite images for assessing anthropogenic pressure in the affected area have been downloaded free of charge online.

2.3. Methods

2.3.1. Calculation of Monthly Precipitation Climatology and Hydroelectric Power Production

Monthly climatology involves calculating the average of climate data for each month of the year over a given period, which provides a better understanding of seasonal variations in precipitation and the energy production of the Garafiri Dam in a given region. To calculate the monthly average precipitation, we used the following relationship [3, 5].

$$P_{moy} = \frac{1}{n}\sum_{i=1}^{n} P_i$$

Where P_{moy} is the monthly average precipitation or hydroelectric power generation; P_i is the amount of precipitation observed for day (i) of the month; n is the total number of days in the month.

2.3.2. Calculation of Annual Precipitation Climatology and Hydroelectric Power Production

To calculate the annual climatology, Precipitation data were summed for each year of the study period and then divided by the total number of years to obtain the annual mean precipitation.

$$P_{moy} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

Where P_{moy} is the annual average precipitation, P_i is the amount of precipitation observed for year (i), and N is the total number of years in the study period.

2.3.3. Calculation of Anomalies in Interannual Variability of Precipitation and Hydroelectric Power Production

By monitoring anomalies in precipitation and hydropower generation over time, the impacts of climate change on water resources and hydropower can be assessed. This can help inform adaptation and mitigation policies to address future climate-related challenges [6].

$$A_{noi} = \frac{P_i - \bar{P}}{\sigma}$$

Or: $\overline{P}$ is the calculated average of all values in the data set P of the variable under consideration: precipitation or hydroelectric power generation; Pi is the annual value of the variable X considered for a given year I; σ is the sample standard deviation.

By following these steps, we will calculate standardized anomalies of interannual variability in precipitation and hydroelectric power generation, which allows for a more in-depth analysis and a better understanding of climate variations and their impacts.

2.3.4. Correlation Between Precipitation and Hydroelectric Production

Once the rainfall trends are established, an analysis is conducted to examine the correlation between rainfall levels and the hydroelectric dam's power output. This can be done by calculating correlation coefficients defined as below [7].

$$r = \frac{1}{N}\sum_{i=1}^{n} \frac{(X_i - \bar{X})}{\sigma X} \frac{(Y_i - \bar{Y})}{\sigma Y}$$

X_i: accumulation of the entire series of the first variable; Y_i: accumulation of the entire series of the second variable; $\bar{X}$: calculated mean of all values in the data set X_i for the first variable; $\bar{Y}$, calculated mean of all values in the data set yi for the second variable; σX: Sample standard deviation of all first variables x; σY: Sample standard deviation of all second variable y; r: correlation coefficient, -1<r<1. N: the total number of values in the paired data set x and y.

Then, to test the significance of the Spearman correlation coefficient between the two variables, a transformation into a t-statistic is often used under certain null hypothesis conditions (no correlation). The t-statistic can be calculated as follows:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

Or: r is the Spearman correlation coefficient; n is the number of value pairs; this t-statistic approximately follows the student distribution with n-2 degrees of freedom. The resulting t-value is then compared to a critical value in the student's t-distribution table for a given significance level (e.g., 0.05 for a 95% confidence interval). If the absolute value of t is greater than the critical value, the correlation is considered statistically significant.

2.3.5. Analysis of Anthropogenic Pressure by Diachronic Development of Land Use Maps

In this section, the spatio-temporal assessment of the landscape of the sub-prefecture of Pita around thebThe survey was carried out on the basis of collecting, processing and analyzing satellite data covering the boundaries of the sub-prefecture. The images used are Landsat 5 and 8. These types of images have the advantage of being available to the general public on the internet. The high spatial resolution of these data is 30 m [8]. For the processing and analysis of satellite data, different types of software were used in this study. These are the satellite image processing software QGIS 3.22 through the Orfeo Toolbox (OTB) tools for all image processing, classification and change detection up to the digitization of occupation units and cartographic works [9].

By processing Landsat satellite images (images with a resolution of 30 meters), we produced dynamic land use maps between 1990 and 2024 using the Orfeo Toolbox plugin of QGIS software version 3.22. This mapping was done on the basis of five land use classes namely: Urban fabric, Vegetation, Waterway, Cultivation zone and Bare soils, Savannah. We used Excel for the workstructuring andproduction of graphs. The data concerning the Areas listed in an Excel table and this file is converted into XLS format. This methodology allowed us to obtain the results described in the following section [10].

3. Results and Discussions

3.1. Monthly Climatology

Figure 2 shows the monthly precipitation climatology, indicated in blue. We observe that precipitation varies significantly between the months of May and October. This indicates that the rainy season extends from May to October in this locality, with a peak in August reaching approximately 400 mm of rain for this month, over the period from 2008 to 2020. Furthermore, still in Figure 2, the red curve represents the hydroelectric power generation of the Kinkon Dam. We note that the peak of energy production is between the months of November and April, corresponding to the minimum rainfall recorded at the Kinkon Dam.

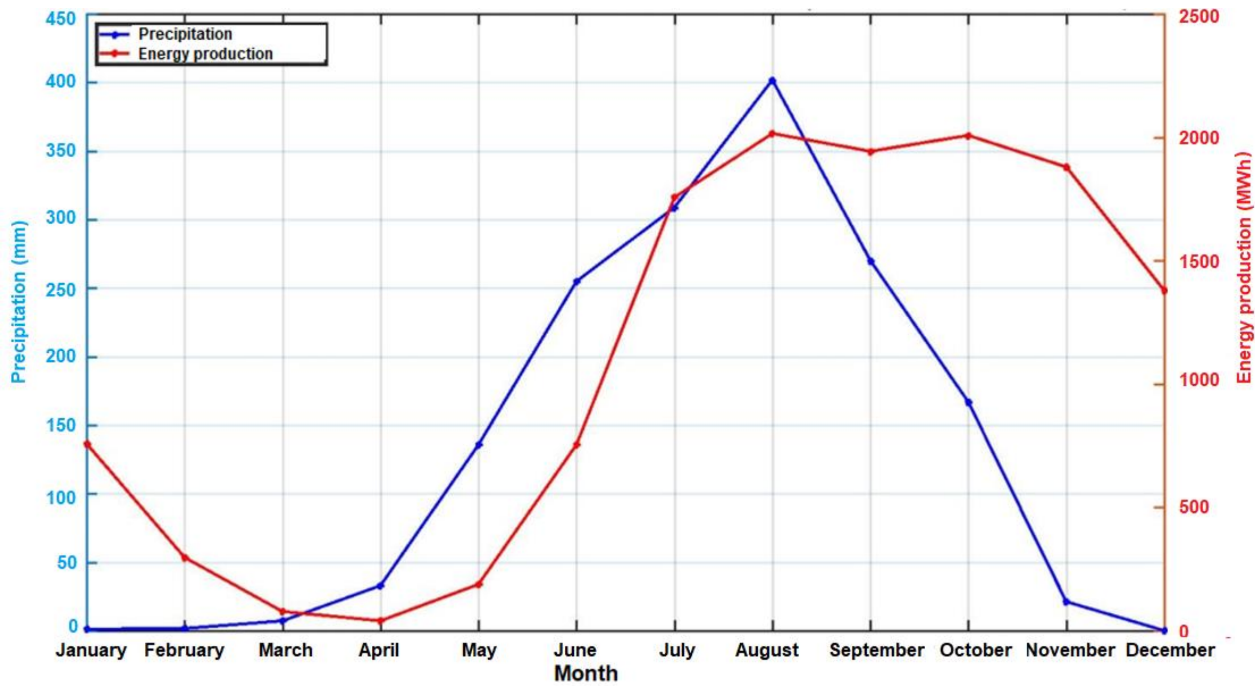

Figure 2. *Monthly climatology of rainfall and electrical productivity of the Kinkon site (2008 - 2020).*

3.2. Interannual Variability of Precipitation and Energy Production

In the same Figure 4, the yellow curve also shows the interannual variability of the dam's hydroelectric power generation, characterized by strong fluctuations. This variability reveals that hydroelectric power generation varies between approximately -150 MWh and 150 MWh per year over the same period. Notably, the years 2008 and 2020 recorded the lowest production levels, while the years 2013 and 2014 reached maximum production peaks, with approximately 75 MWh per year.

In general, we observe that increased precipitation leads to increased hydroelectric power generation at the Kinkon Dam during the period 2008 - 2020. Interestingly, this correlation confirms the direct impact of weather conditions, particularly precipitation, on hydroelectric power generation [11]. Periods of abundant precipitation correspond to an increase in power generation, while periods of drought are associated with a decrease in this production (Figure 3).

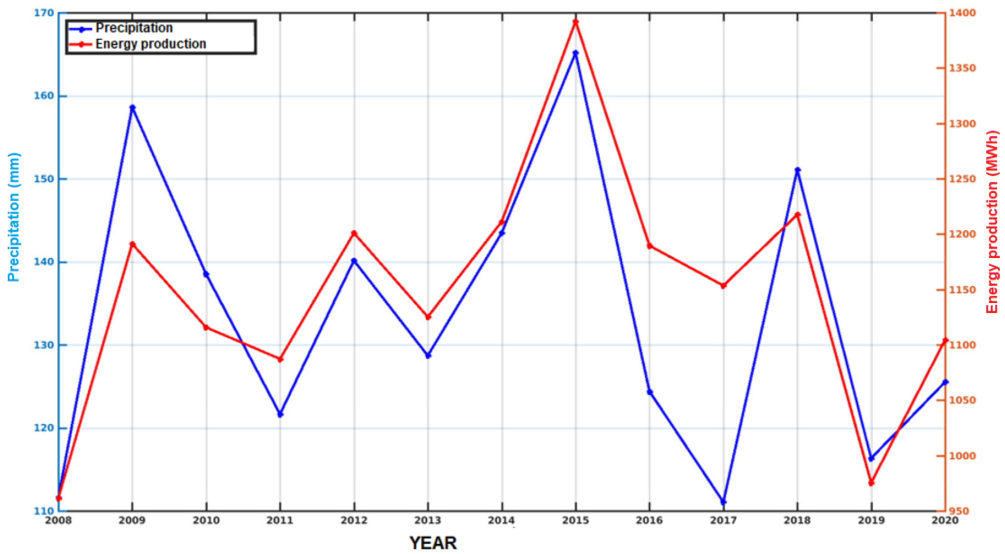

Figure 3. *Annual climatology of precipitation, water flow and hydroelectric power generation of Kinkon in 2008 to 2020.*

In Figure 3, the blue curve represents the interannual variability of precipitation, highlighting numerous fluctuations. This variability indicates that the amount of precipitation fluctuates between approximately 40 mm and 80 mm per year over the period from 2008 to 2020. However, 2017 recorded the lowest level of precipitation. In contrast, the years from 2009 to 2015 show variations in precipitation of approximately 20 mm per year. The red curve shows the interannual variability of the energy produced at the Kinkon dam, also marked by strong fluctuations. The energy produced varies between approximately 800 and 1400 MWh per year during the period from 2008 to 2020. The year 2019 recorded the flowthe mostlow production, while 2015 recorded the maximum energy value, with approximately 1400 MWh [12].

3.3. Anomalies of Precipitation and Energy Production

Built in 1966 with a capacity of 3.4 megawatts, the Kinkon hydroelectric dam, once a jewel that was the pride of the populations of several towns in Middle Guinea, is slowly dying. Today, it is only a shadow of its former self. This dam can no longer ensure a normal supply of electricity, even during the rainy season. Its capacity is limited to 3.4 megawatts. The Kinkon Dam is filled with mud. Its immediate surroundings require imminent reforestation to save what little remains. In towns like Labé that are supplied with electricity, complaints about the local EDG agency are continuing. A look inside this dam located in the heart of Fouta. Kinkon is located approximately 9 kilometers from the urban commune of Pita. This town is home to one of the very first hydroelectric dams in Guinea. This product of the first Guinean regime, built after independence, aimed to provide electricity to the towns of Labé-Pita-Dalaba and Mamou. The work carried out shows that the hydroelectric energy production of the dam is a function of the immediate rainfall in the area. The calculation of standardized anomalies shows a total dependence between the two parameters (rainfall, energy) (Figure 4).

Flow rate is the key factor in the performance of a hydroelectric dam in good condition. Sudden fluctuations in this flow rate cause major disruptions in energy production. The climatic variability observed in recent times is one of the main causes of the disruption of Guinea's rainfall regime.

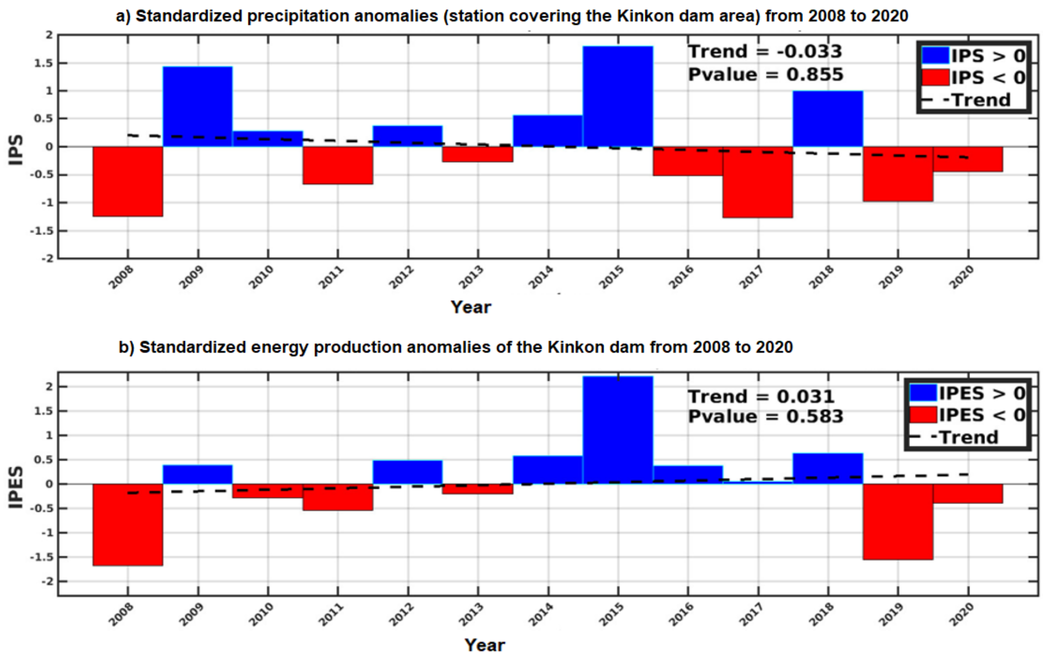

Figure 4. Standardized anomalies of rainfall and energy production at the Kinkon dam from 2008 to 2020.

Figure 4 clearly shows the gaps between years of good production and those of deficit. Only 2015 was the most productive year in terms of energy.

3.4. Correlation Between Precipitation and Energy Production

This strong significance of the correlation between rainfall and energy productivity in the Kinkon area confirms that this dam has a purely seasonal yield regardless of the renovation investments that would be required. This allows us to show that climate variability will have a major impact on hydroelectric power plants. Climate change will increase temperature, thereby increasing the rate of evaporation from water sources and reducing the amount of water available for electricity generation [13]. Such an analysis would allow resources to be better directed towards other strategies aimed at optimizing energy supply in the Republic of Guinea.

Figure 4 clearly shows this seasonal regime of the dam. We can therefore note that the yield is satisfactory from July to November, that is, just 5 months out of 12 and the January-May interval which corresponds to the dry period in the area shows a drastic underproduction. A significant correlation was observed (Figure 5) thus showing the close link between the two variables.

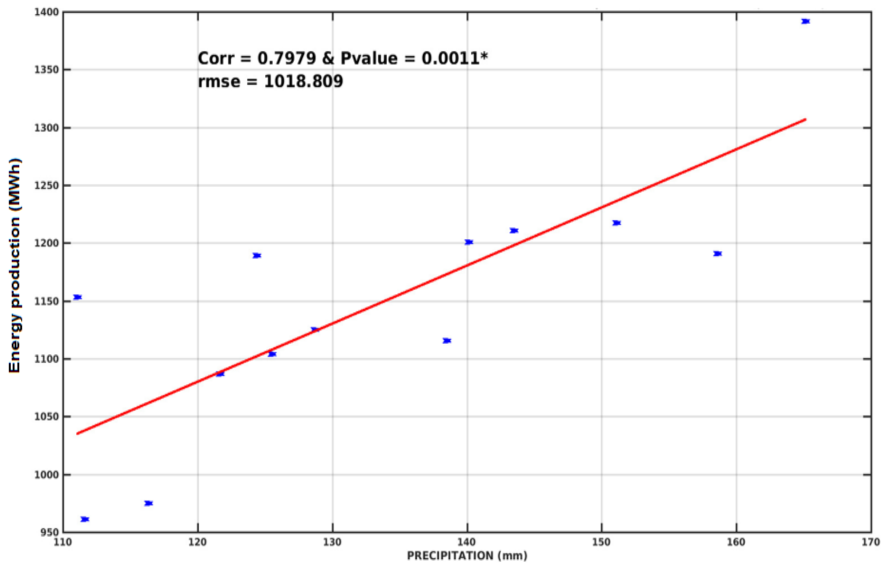

Figure 5. Correlation between rainfall and energy production of the Kinkon dam (2008 - 2020).

There is a very strong and highly significant correlation between precipitation and energy production, with a p-value less than 0.05, confirmed by the Supermann significance test at a 95% confidence level.

3.5. Land Use in the Kinkon Area

For a more in-depth analysis of this under-productivity of the dam, we looked at other parameters influencing the rainfall in the area. Our findings show that there is a correlation between poverty and environmental degradation. In the absence of income-generating activities, people exploit natural resources in an anarchic manner to survive. Figures 6 and 7 show anthropic pressure on the landscape of the Kinkon area, justified by the proliferation of the urban fabric between 1990 and 2024 and the reduction of waterways. Although there is a decrease in agricultural activities which would also be due to the strong rural exodus of the active class, there is an increase in buildings with these consequences.

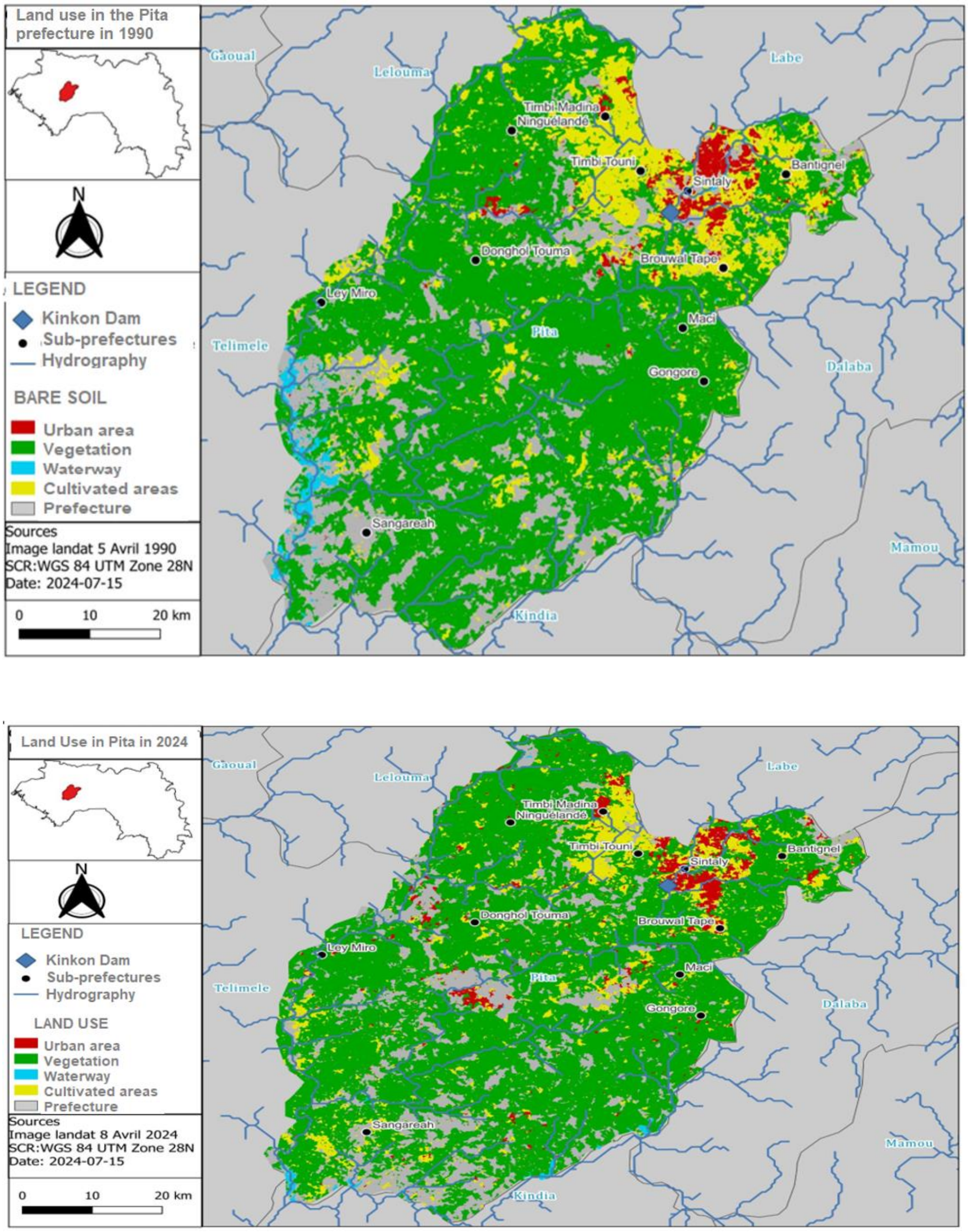

Figure 6. Land use maps of the Kinkon area 2008 and 2024 with a significant increase in the urban fabric.

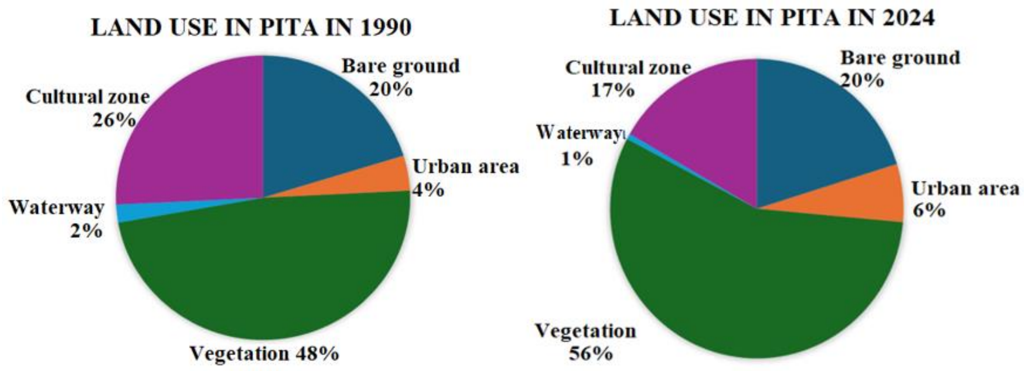

Figure 7. *Land use rate of the Kinkon area between 1990 and 2024.*

From 4% in 1990 to 6% in 2024, this increase in human habitats in an area of common interest would be one of the causes of environmental degradation in the locality, thus leading to a disruption of the microclimate. Similarly, there is a significant decrease in waterways from 2% in 1990 to 1% in 2024 (Figure 7), which would be explained by the occupation of the places by the inhabitants of the locality [14]. According to the National Council of the Environment report dated July 2007, the rise in temperature will be accompanied by changes in the distribution and volume of precipitation across the country. These changes could reach 36.4% of the current normal from 2050 and 40.4% in 2100. This drastic drop in precipitation will have significant impacts on water resources (surface and groundwater) and the country's main socioeconomic sectors. The results presented in our study reveal a positive correlation between rainfall and hydroelectric power generation at the Kinkon Dam. This correlation, although less statistically significant, nevertheless suggests a relationship between these two parameters.

Interestingly, this correlation confirms the direct impact of weather conditions, particularly precipitation, on hydroelectric power generation. Periods of abundant precipitation correspond to an increase in energy production, while periods of drought are associated with a decrease in this production. This relationship is consistent with the operating principles of hydroelectric power plants, which harness the energy of water to generate electricity in accordance with the work of [15].

Furthermore, our study shows an interdependence between rainfall and hydropower generation in the Kinkon Dam. This is in full agreement with the work of Al Anfaf, MMM, (2016). And highlights the importance of taking into account climate variations in the planning and management of energy resources. Seasonal and interannual fluctuations in rainfall can have a significant impact on the availability and reliability of hydropower generation. Therefore, a thorough understanding of this relationship is essential for sustainable management of water and energy resources in the Kinkon region.

4. Conclusion

This study showed that the Kinkon hydroelectric dam is highly dependent on rainfall in the area. The low productivity observed in recent years would therefore be due to the sharp drop in the water level in the bed. The increase in residential areas has significantly contributed to environmental degradation, thus leading to negative consequences for the survival of the dam.

The main contribution of this present work was to show that although Guinea is rich in water resources, but the exploitation of these resources for energy production will have to take into account the realities of climate variability and anthropogenic pressure that control the rainfall regime, an essential factor for the good performance of hydroelectric dams. This could avoid large unnecessary expenses to the State for the construction of almost useless dams and direct funds towards other alternatives for efficient energy production.

Abbreviations

P_{moy}	Monthly Average Precipitation or Hydroelectric Power Generation / Annual Average Precipitation
P_i	Amount of Precipitation Observed for Day (i) of the Month
n	Total Number of Days in the Month
N	Total Number of Years in the Study Period
$\overline{P}$	Calculated Average of All Values in the Data Set *P* of the Variable Under Consideration
σ	Sample Standard Deviation
X_i	Accumulation of the Entire Series of the First Variable
Y_i	Accumulation of the Entire Series of the Second Variable
$\bar{Y}$	Calculated Mean of All Values in the Data Set yi for the Second Variable
$\bar{x}$	Calculated Mean of All Values in the Data set X_i
σX	Sample Standard Deviation of All First Variables x
σY	Sample Standard Deviation of All Second Variable y

r	Correlation Coefficient
EDG	Electricity Company of Guinea
QGIS	Quantum Geographic Information System
MWh	Megawatt-saat
OTB	Through the Orfeo Toolbox
DNM	National Directorate of Metrology

Author Contributions

Tamba Nicolas Millimono: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Moussa Mamady Traore: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

Ansoumane Sakouvogui: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Software, Supervision, Visualization, Writing – review & editing

Yacouba Camara: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Writing – review & editing

Diakaria Diallo: Formal Analysis, Investigation, Project administration, Resources, Software, Supervision, Visualization, Writing – review & editing

Amara Kourouma: Formal Analysis, Investigation, Project administration, Resources, Software, Supervision, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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