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Study of the Effect of Climate Variability on Hydroelectric Power Generation Capacity: The Case of the Garafiri Dam in Guinea

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Abstract: Hydroelectric power production from Garafiri dam and rainfall are essential elements with the observation of hydroelectric power production in West African power system, particularly in Guinea. This article focuses on the study and the influence of climate variability on hydroelectric power production at Garafiri dam over 16-year period (2008-2023). The aim of this work is to show the correlation between rainfall anomalies and hydroelectric power production at Garafiri dam. The method used consists of calculating precipitation anomalies at Garafiri site and those for the production of hydroelectric power from Garafiri dam over the study period. This approach led us to calculate the anomalies, leading to the study on climatic variability, in order to establish correlation between rainfall and hydroelectric power dam's production. The trend with the correlation found made it possible to carry out a significance test between these two variables. These results clearly show that rainfall in Garafiri site increases hydroelectric power production and vice versa, which explains the interdependence between these two parameters, i.e. climatic variability and hydroelectric power production.

Key words: Dam, Garafiri, energy production, rainfall, hydroelectricity.

1. Introduction

Towards the end of 1980s, the Republic of Guinea has experienced a significant rainfall deficit, both in terms of intensity and duration. This phenomenon has had major repercussions on water resources available in region [1]. Preliminary studies have suggested that climate change could lead to a reduction in river flows and the water table levels in Guinea. The work of Hartmann and Crowley in 1990s [2, 3] suggested in particular that these changes could result in a drop in river water table levels, with climate stabilized at CO_2 concentrations twice as high as historical levels.

Rising in temperatures, induced by increased concentrations of greenhouse gases in atmosphere, is likely to increase evaporation and evapotranspiration in the major rivers, without necessarily offsetting the expected increase in precipitation. This combination of factors could lead to a drop in flows, thereby reducing production capacity of hydroelectric power plants located in major St. Lawrence river system [4]. This article focuses on assessing the impact of climate variability on hydroelectric production in Guinea from 2008 to 2023, particularly at Garafiri site. The analysis is based on the assumption that no major changes will

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occur in the production equipment of hydroelectric power stations over this period. It should be stressed, however, that this study is limited to a partial analysis from the impact of climate variability on hydroelectric power production in Guinea.

To fully understand the impact of climate variability on hydroelectric power production, it is essential to understand the hydroelectric power production process. Hydroelectricity is generated by converting kinetic energy from water into electrical energy using hydraulic turbines coupled with alternators. The amount of hydroelectric power available depends closely on the volume of water available, the natural inflows and outflows over the period in question, and the head, defined as vertical distance between water entering pipes and water leaving it.

Although some studies in 1990s predicted increases in precipitation, most predicted an increase in evaporation, leading to reductions in net inputs [5]. As part of major regional studies initiated by Natural Resources Canada, Ouranos has been asked, in collaboration with Mowat Centre, to carry out an economic study on the impact of climate variability on hydroelectric power production and its repercussions on various uses of this resource, as well as on possible adaptive measures.

This article focuses specifically on the impact of climate change on hydroelectric power production in Guinea. From this perspective, six areas of activity are considered, including maritime transport, municipal waters, ecosystems and fisheries, tourism and yachting, hydroelectric power production and land values. The main objective is to assess how climate variations could influence hydroelectric power production in the region during study period.

2. Data and Research Methodology

2.1 Presentation of Study Area

Garafiri hydroelectric power dam facility is located in Guinea (Fig. 1), in Konkouré River. The power station was built between 1995 and 1999. The dam, was commissioned in 1999, holds back 1.3 billion cubic metres of water in a 91 km^2 lake. Its hydroelectric power station is equipped with three groups capable of supplying a total of 80 MW. Since it was commissioned, the plant has produced an average of 270 GWh of energy per year, but this is not enough to supply the capital alone.

2.2 Data Used

The first step is to collect historical rainfall data for Guinea region, using reliable meteorological records over a significant period, preferably several decades from 2008 to 2023. In addition, it is essential to collect data on energy production of hydroelectric power dam concerned over the same period, which has been obtained through EDG (Guinea Electricity Cooperation).

2.3 Methodological Approach

2.3.1 Monthly Climatology of Precipitation and Hydroelectric Power Production

Monthly climatology consists of calculating the average climatic data for each month of the year over a given period, which provides a better understanding of seasonal variations in rainfall and energy production from Garafiri dam in a given region. To calculate the monthly average of rainfall, we can use the following formula:

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

where: P_{moy} is the monthly average rainfall of hydroelectric power production;

P_i is the amount of precipitation observed from day one of the month;

n is the total number of days in the month.

2.3.2 Annual Climatology of Precipitation and Hydroelectric Power Production

We can use the same Eq. (1) to calculate the annual climatology. To do this, we add up all rainfall data for

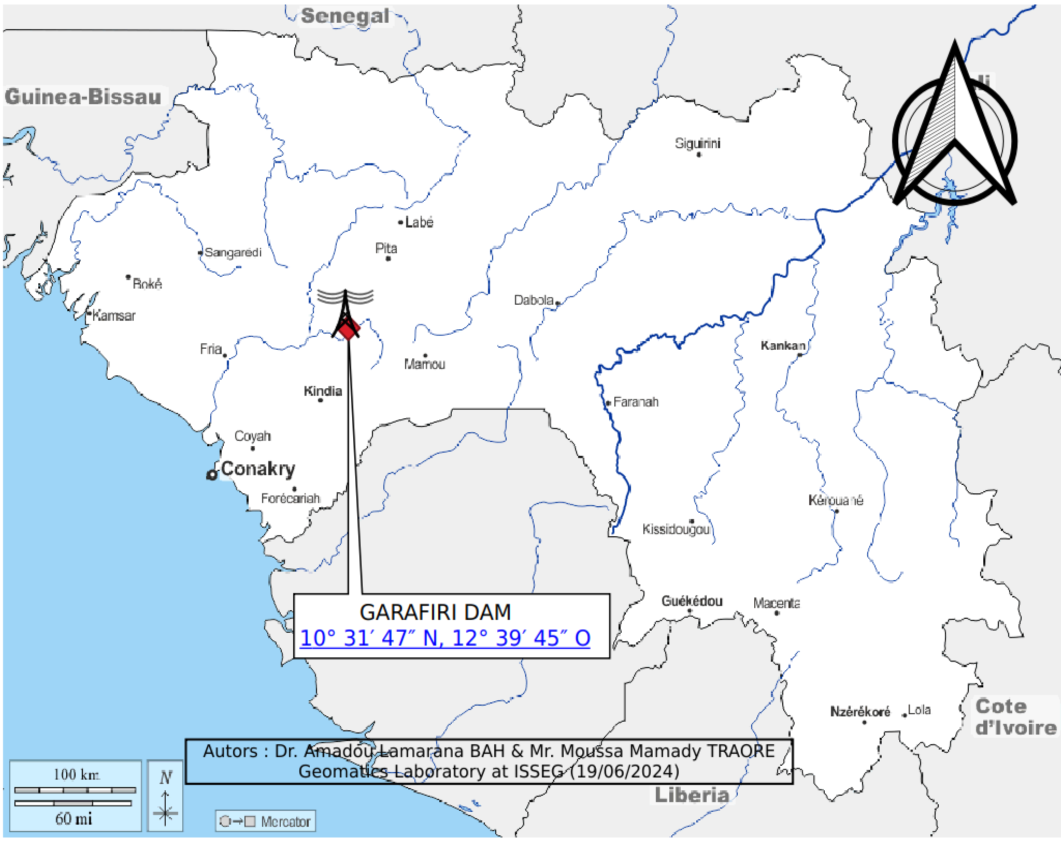

Fig. 1 Hydrology map of Guinea and the Garafiri dam.

each year of study period, then divide the sum by the total number of years to obtain the average annual rainfall.

2.3.3 Anomalies in Inter-annual Variability of Precipitation of Hydroelectric Power Production

By monitoring anomalies in precipitation and hydropower production over time, the impacts of climate change on water resources and hydroelectric power can be assessed. This can help in an inform adaptation and mitigation policies to meet future climate-related challenges.

$$Ano_i = \frac{P_i - \overline{P}}{\sigma} \quad (2)$$

where: $\overline{P}$ is calculated as the average of all the values in data set P of variable under consideration into precipitation or hydroelectric energy production;

P_i is the annual value of variable X considered for a given year i;

σ is the sample standard deviation.

In the following steps, we will calculate standardized anomalies in inter-annual variability of precipitation and hydroelectric power production, in enabling a more in-depth analysis and a better understanding of climate variations and their impacts.

2.3.4 The Correlation between Precipitation and Hydroelectric Production

Once rainfall trends have been established, an analysis is carried out to examine the correlation between rainfall levels and energy production from hydroelectric dam. This can be achieved by calculating correlation coefficients defined as follows:

$$r = \frac{1}{N}\sum_{i=1}^{n} \frac{(X_i - \overline{X})}{\sigma_X} \frac{(Y_i - \overline{Y})}{\sigma_Y} \quad (3)$$

X_i: The cumulative total of the entire series of the first variable;

Y_i: the cumulative total of the entire series of the second variable;

$\bar{X}$: with the calculated average of all values in data set x_1 for the first variable;

$\bar{Y}$: with the calculated mean of all values in data set y_1 for the second variable;

σ_X: The sample standard deviation of all the first *x* variables;

σ_Y: The sample standard deviation of all the second variable *y*;

r: correlation coefficient, $-1 < r < 1$;

N: The total number of values with *x* and *y* matched data set.

This methodology enabled us to obtain the results described in the following section.

3. Results and Discussions

3.1 Monthly Climatology of Rainfall and Hydroelectric Power Production at Garafiri

In this scientific article, Fig. 2 shows the monthly climatology of rainfall, shown in blue. The figure shows that rainfall changes significantly between May and October. This explains why rainy season extends from May to October in this locality, with a peak recorded in August, corresponding to an amount of rainfall of around 500 mm for the month, over the period from 2008 to 2023. Also in Fig. 2, the red curve represents hydroelectric power production from Garafiri dam. We can see that the peak in energy production is recorded between November and April. However, this corresponds to the minimum rainfall recorded at Garafiri dam.

3.2 Inter-annual Variability of Rainfall and Hydroelectric Power Production at Garafiri

In this scientific article, Fig. 3, shown in blue, illustrates the inter-annual variability of precipitation, with numerous fluctuations. This variability shows that, the amount of precipitation varies between around 160 mm and 300 mm per year over the period 2008 to 2020. However, the years 2008, 2014, 2018 and 2023 recorded the fewest rainfall peaks. On the other hand, 2009 and 2010 recorded the most peaks, with rainfall amounts varying between 280 mm and 300 mm per year.

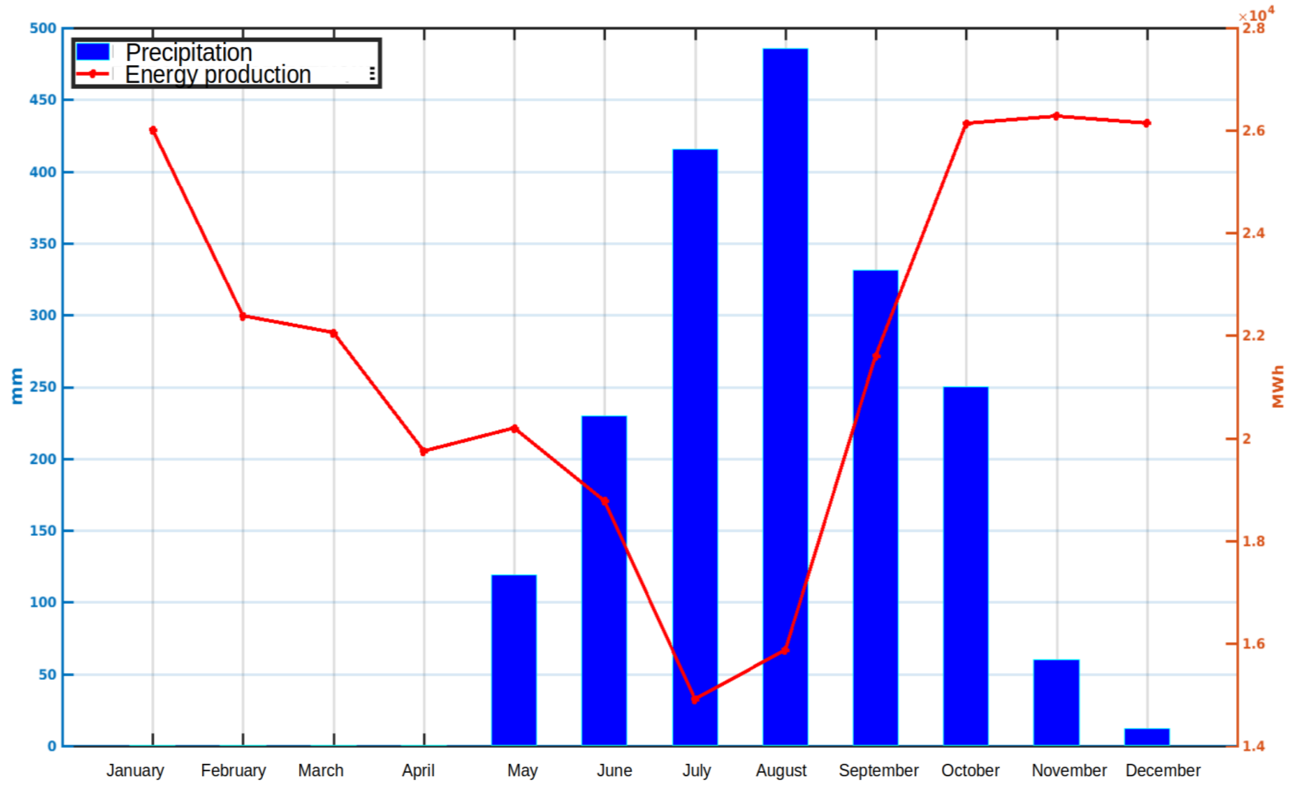

Fig. 2 Monthly climatology of rainfall and hydroelectric power production at Garafiri.

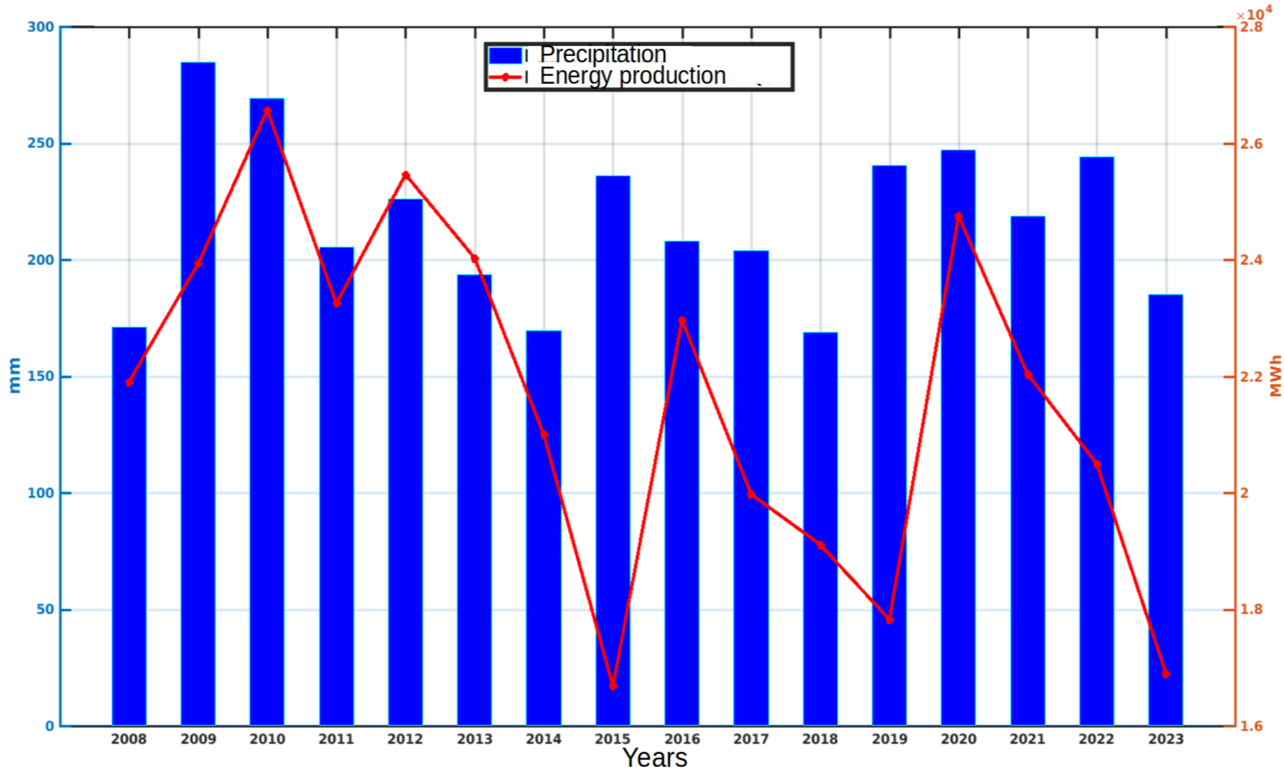

Fig. 3 Annual climatology of rainfall and hydroelectric power production at Garafiri.

Fig. 3, shown in red, shows the inter-annual variability of hydroelectric energy production, also with strong fluctuations. This variability shows that the amount of hydroelectric power generated varies between or around 1.6×10^4 MWh and 2.8×10^4 MWh per year over the period from 2008 to 2020. However, the years 2015 and 2019 show fewest production peaks. On the other hand, 2010, 2012 and 2020 recorded the highest peaks, with production quantities varying between 2.4×10^4 MWh and 2.8×10^4 MWh per year.

In general, we observe that the increase in rainfall leads to an increase in production of hydroelectric power at The Garafiri dam over the period from 2008 to 2020.

3.3 The Anomalies in Inter-annual Variability of Rainfall and Hydroelectric Power Production at Garafiri

Fig. 4a shows the standardized precipitation anomalies, indicating that the years 2009, 2010, 2012, 2015, 2017, 2020 up to 2022 experienced a precipitation surplus, corresponding to very wet years. However, the years 2008, 2011, 2013-2014, 2016, 2018-2019 and 2023 were deficient, corresponding to drought years. So, over the entire study period from 2008 to 2023, we can see a decrease in the trend, which explains the drop in precipitation over the years.

The standardized anomalies in Garafiri's hydroelectric power generation, presented in Fig. 4b, show that the years 2008 to 2014 saw a surplus in Garafiri's hydroelectric power generation, also corresponding to very wet years. However, the years 2015 to 2023 were in deficit, corresponding to years of drought. As a result, over the entire study period from 2008 to 2023, we observe a decreasing trend, which explains the decline in Garafiri's hydroelectric energy production over the years.

In general, a decrease in total precipitation trend is observed, leading to a decline in Garafiri's hydroelectric power generation over the period from 2008 to 2023.

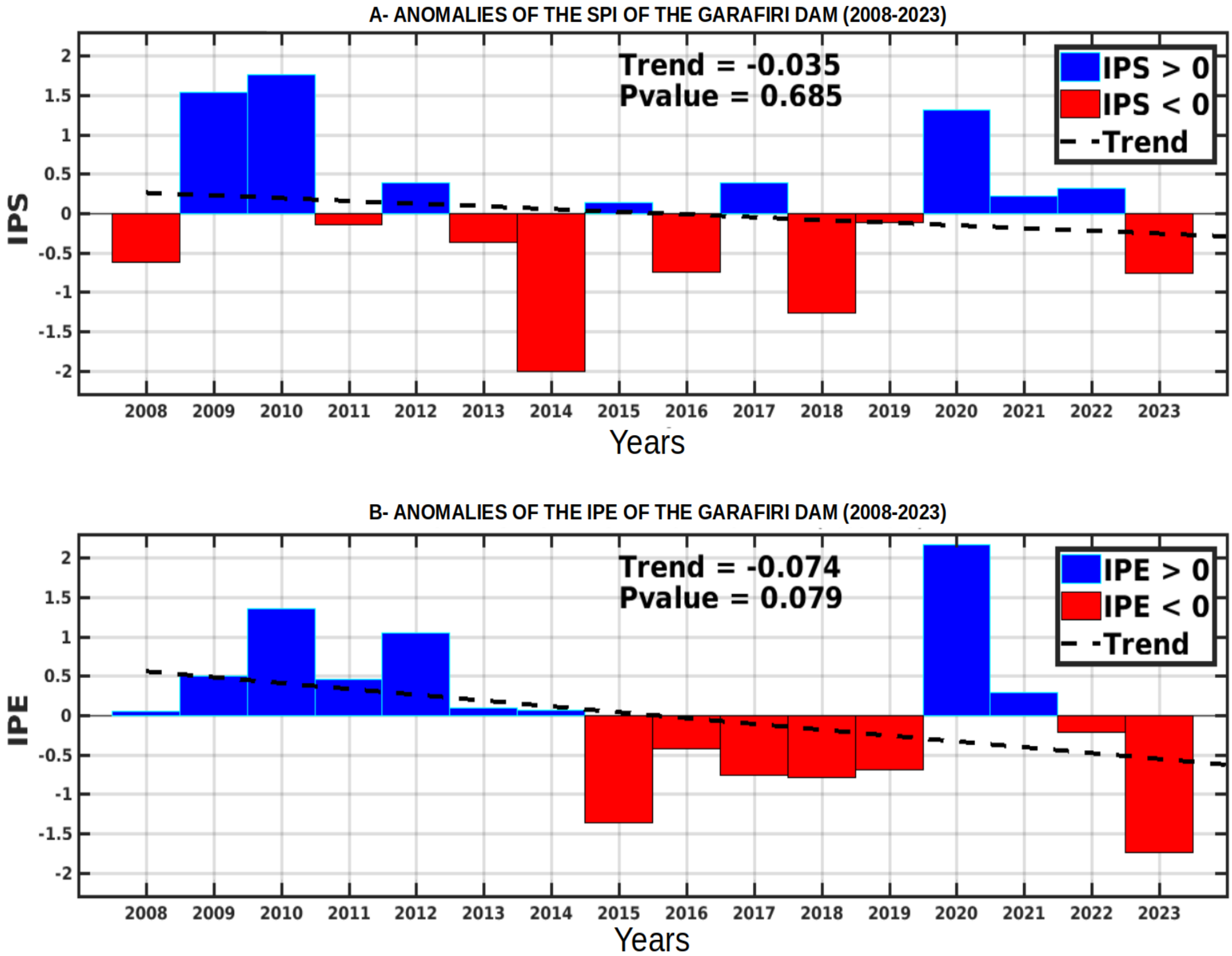

Fig. 4 The annual anomalies rainfall and hydroelectric power production at Garafiri.

3.4 The Correlation between Rainfall and Hydroelectric Power Production at Garafiri

Fig. 5 shows the correlation between the rainfall indices for Garafiri dam, recorded on site, and those for Garafiri's hydroelectric power production. It shows a positive correlation between rainfall and hydroelectric power production at Garafiri, with a correlation coefficient r = 0.3478 and a p-value = 0.1869 (less significant correlation). In fact, this correlation value indicates that rainfall at the Garafiri site increases with hydroelectric power production at Garafiri, and vice versa, which means that these two parameters are interdependent.

3.5 Discussions

The results presented in our study reveal a positive correlation between rainfall and hydroelectric power production at Garafiri dam. Although less statistically significant, this correlation nevertheless suggests a relationship between these two parameters.

Interestingly, this correlation confirms the direct impact of weather conditions, particularly rainfall, on hydroelectric power generation. The periods of abundant rainfall are associated with 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 energy of water to generate electricity [6].

Moreover, the interdependence between precipitation and hydropower generation highlights the importance of taking climate variations into account in planning

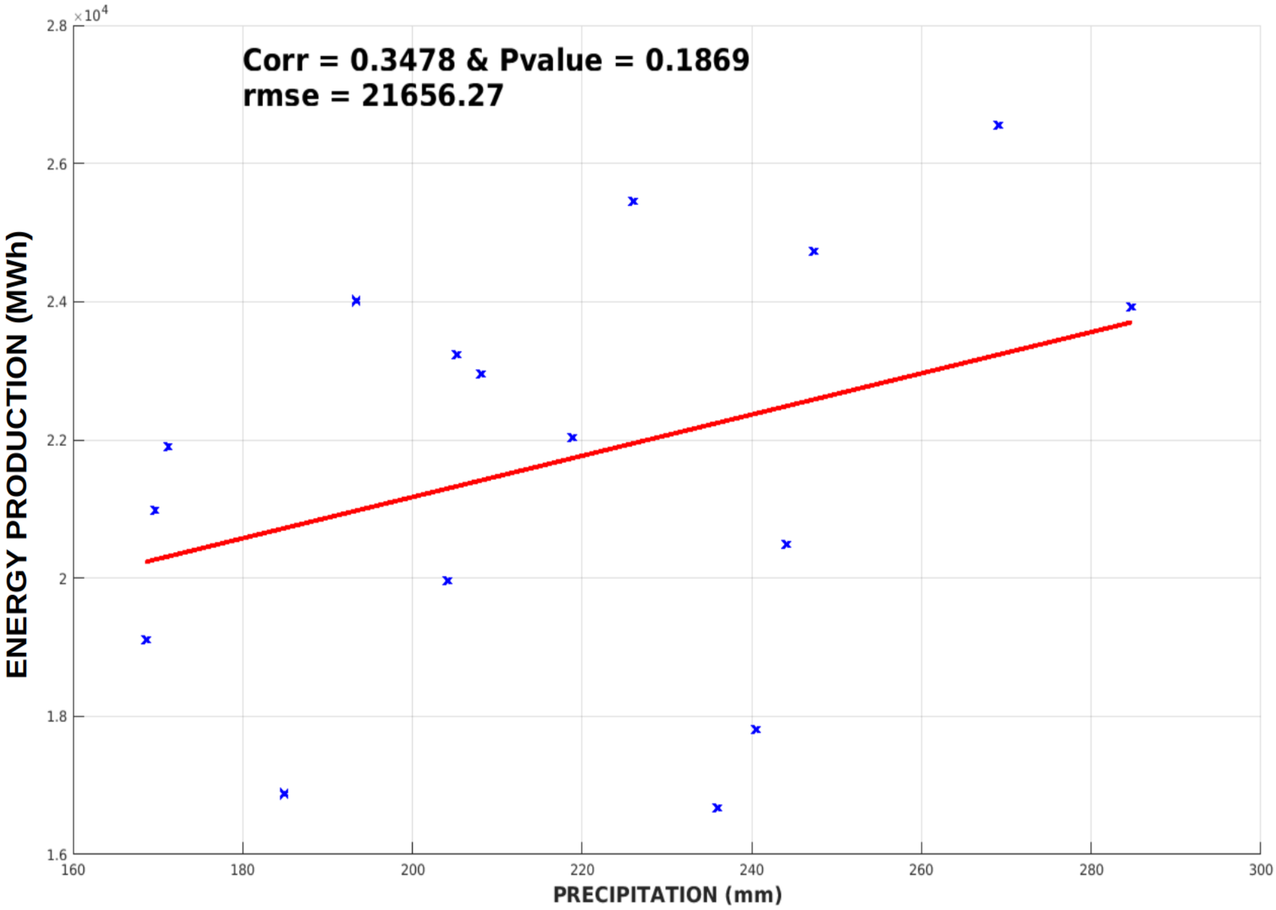

Fig. 5 Correlation between rainfall and hydroelectric power production at Garafiri.

and management of energy resources [7]. Seasonal and inter-annual fluctuations in precipitation can have a significant impact on the availability and reliability of hydroelectrical power generation. Therefore, a thorough understanding of this relationship is essential for sustainable management of water and energy resources in Garafiri region.

4. Conclusion

This study focused on the climate variability on hydroelectric power production capacity of Garafiri dam in Guinea that has shed significant light on historical trends and current impacts. Examination of hydroelectric power production data identified correlations between rainfall variations and the dam's production capacity. The analyses highlighted the direct impact of climate change on the availability of water resources and, consequently, on the production of hydroelectric power.

It is clear that Garafiri dam is facing increasing challenges due to fluctuations in hydrological regime, directly linked to observed climate change. Our results show that an increase in precipitation at the dam site leads to an increase in hydroelectric power production over from the period 2008 to 2023, while a decrease in precipitation leads to a decrease in production. Although a positive correlation (r = 0.3478) between precipitation and energy production was observed, it was not significant (p-value = 0.1869), highlighting an interdependence between these two parameters.

This study provides a solid basis for future recommendations on water resource management, energy planning and adaptation to climate change. It is imperative that decision-makers use this information to implement robust strategies to ensure sustainability and resilience of Garafiri dam for the challenges of climate change.

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