Original Research Article

Relationship of Hydroclimate Variables and Power Generation in Jebba Dam, North Central Nigeria

Abstract

This study aims to determine a relationship between power generation and hydroclimate elements.The Mann-Kendall test, Sen's slope tests, Pearson's correlation and linear regression have been used for data analysis. The results of monthly hydroclimate elements showedmixed increasing and decreasing trends. The annual rainfall, maximum and minimum temperature showed an increasing trend,while evaporation showed decreasing trends. The annual inflow and outflow showed significantly increasing trends, while reservoir elevation showed a significant decreasing trend. The annual hydropower generation showed a non-significant increasing trend implying power generation has risen over the years. The Pearson's correlation results showed a positive relationship between rainfall, hydropower generation whileother climate elements showed a weak negative relationship.This relationship implies that climate factors play an insignificant role in power generation at Jebba dam. However, the consistently increased temperature trends inthe Jebba damcould indicate climate variability and change. Contrary to other studies, we concluded that climatemight not significantly influence hydropower generation at Jebba dam, Nigeria. Although continuing climate studies are encouraged, we recommended that authorities focus more on other factors for optimum power generation.

Keywords: Hydropower, climate change, Hydro Dam, Trends, Jebba Dam, Nigeria

1. Introduction

The world is witnessing an increasing population and industrial development. The rise in world population and industrial development has increased energy demands (Sanhueza et al., 2019). Hydropower is viewed as thecheapest and cleanest energy source to meet the electricity world's increasing needs. Khaniya et al. (2020) opine that hydropower is the most reliable, leading renewable source for global electricity generation for the world's electricity demand. However, water resource that drives hydropower is affected by climate change worldwide (Mtilatila et al., 2020).

Similarly, Gaudard et al. (2013) suggest that hydropower's significant impact as the electric system is likely to be affected by climate change. Climate change and variability impacted precipitation and runoff in many parts of the world, which served as the inflows to surface reservoirs at hydropower plants (Tarroja et al., 2016). Besides, Van Vliet et al. (2016) established statistically significant impacts of drought years on hydropower. Furthermore,Spalding-fecher et al. (2017) established that hydropower production in the

Zambezi could decline under a drying climate. Furthermore, Mtilatila et al. (2020) opine that climate change's hydrological effects vary from region to region. The previous studies are, therefore, in consensus that climate change impacts hydropower generation. Finally,Sanhueza et al. (2019) suggest that achieving sustainable development of hydroelectric resources is hinged on understanding availability, variability, and the expected impacts of climate change.

The quest for economic development and a rise in urban population has increased the need for power in Africa (Kabo-bah et al., 2016). Like other developing countries, hydropower is the dominant energy source in Africa (Kabo-bah et al., 2016). However, climate change has affected water availability that influences hydropower generation in Africa (IHA, 2020). One of the surest ways of achieving energy sufficiency in Africa and other developing countries will depend on those countries' ability to utilise the available water resources (Antwi & Sedegah, 2018). Therefore, understanding the effects of climate change on hydropower generation is vital for nations' economic development in Africa.

Previous studies agree that climate change hasimpacted hydropower generation (Hamududu & Killingtveit, 2012; Solaun & Cerdá, 2017; Chilkoti et al., 2017; Khaniya et al., 2018; Tiezzi et al., 2018). However, researchers have rarely studied hydroelectric generation responses to climate elementsafter eliminating other factors in Jebba dam, North-Central Nigeria. Many studies focused on climate variability and the Kainji dam (Salami et al., 2011; Machina & Sharma, 2017; Olanrewaju et al., 2018). Some studies focused on the hydropower dam and resettlement communities (Olawepo, 2006; Dukiya, 2013). Other studies focused on the relationship between power generation and reservoir inflow (Emoabino et al., 2007; Ifabiyi, 2011; Olukanni et al., 2016). Generally, the impactsof climate changes on hydropower generation in Jebba dam, North Central Nigeria, is rarely studied. Therefore, this study analysed the trends and quantified hydropower generation fluctuation to key climate indicators in Jebba dam, North Central Nigeria. The implication of findings in this study could be appliedto areas in West African sub-regions that share similar climatic characteristics.

In this study, possible effects of climate change on hydropower generation in the

2. Methods

2.1 *The study area*

The construction of the Jabba dam in North-Central Nigeria was in the year 1984. The dam construction led to the evacuation and resettlement of 6,000 rural dwellers (Ifabiyi, 2011). Jebba dam range from latitude 9^{o} 35` and 9$^{o}$ 50`N and longitude 4^{o} 30` and 5$^{o}$ 00` E (Figure 1). The dam is about 550 miles (885km) from the sea. It is located on the south bank and at the natural head of navigation in the Niger State. It has an estimated surface area of 303km^{2}. The dam was constructed as a tailwater dam to harness Kainji Dam's outflow for additional power generation.

The latitudinal location of the Jebba dam supported a humid climate. The climate alternate between wet and dry season in response to changes in maritime and continental air masses' patterns. The onset of rainfall in the Jebba watershed is from May. From May to July, the annual rainfall varies from 280–300mm. The rainy season peak between August to September (400mm) within the Jebba dam and its environs. The creation of the dam has modified the relative temperature of the catchments areas. The dam makes the temperature different further away from the dam. The climate pattern made agriculture a significant prevailing economic activity of rural inhabitants around the dam.

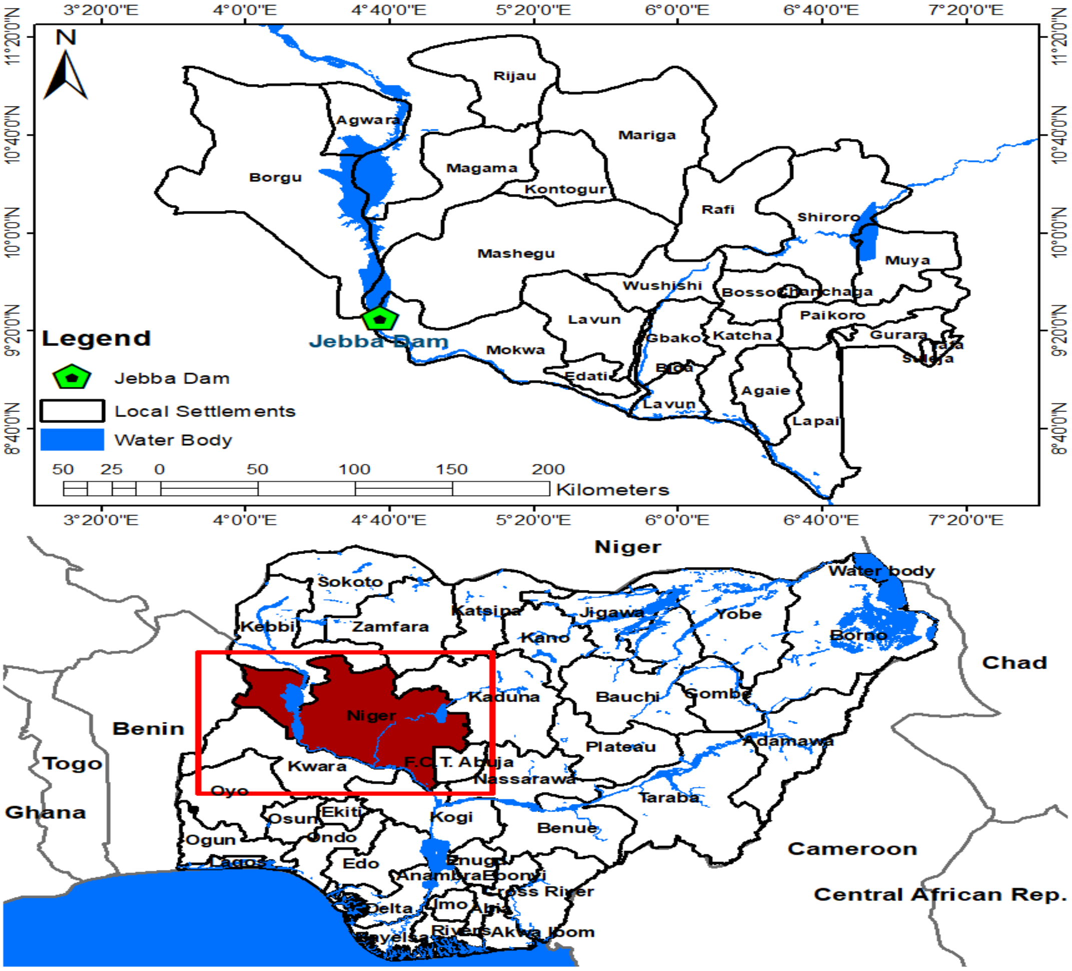

Figure 1: The Jebba Hydrological Dam in Nigeria

2.2 *Data Used*

Monthly rainfall data, evaporation, temperature, reservoir inflow, outflow, and reservoir elevation, for 30 years (1988-2017) were acquired from the hydrological unit of Jebba Dam. The monthly energy generated was acquired for 20 years (1998-2017) from the power generation unit Jebba Dam.The data were checked for quality control, and a single climate data was missing

2.3 Data Analysis

2.3.1 Trend Analysis

We subject the climate elements and the inflow/outflow data to the Mann-Kendall test (Mann, 1945; Kendall, 1975). The Confidence levels of α= 0.001, 0.01, 0.05, and 0.1 were taken as a starting point to classify the significance of upward and downward trends. Several studies have adopted the Mann-Kendall (MK) test as a standard in climate data trends analysis (for example, Sushant *et al.*, 2015; Soro *et al.*, 2016; Katsanos *et al.*, 2017; Abatan et al., 2018; Ibrahim et al., 2020; Khaniya et al., 2020). We computed the MK as hereunder:

$$W = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sign}\left(x_J - x_k\right) \tag{1}$$

$$\text{Where: } \mathrm{sign}\left(x_J - x_k\right) = \begin{Bmatrix} 1 \text{ if } (x_J - x_k) > 0 \\ 0 \text{ if } (x_J - x_k) = 0 \\ -1 \text{ if } (x_J - x_k) < 0 \end{Bmatrix} \tag{2}$$

$$\mathrm{VAR(S)} = \frac{[\mathrm{n(n-1)(2n+5)} - \sum_{\mathrm{i=1}}^{\mathrm{m}} \mathrm{t_i(t_i-1)(2t_i+5)}}{18} \tag{3}$$

Where:

n is the number of data points

t_i is the number of ties for the i value and

m is the number of tied values (a tied group is a set of sample data having the same value)

Then Equation 1 and 2 is used to compute the test statistic Z from the following equation:

$$Z = \begin{Bmatrix} \frac{W-1}{\sqrt{VAR(S)}} \text{ if S} > 0 \\ 0 \qquad \text{ if S} = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \text{ if S} < 0 \end{Bmatrix} \tag{4}$$

A positive value of Z is classified as an upward trend and a negative value as a downward trend, while zero value indicates no trends.

2.3.2 *Magnitude of Changes*

Sen's slope estimator developed by Sen (1968)analysed the magnitude of climate change and generated energy variables. Sen's slope method is considered robust in estimating a trend's magnitude (Yue and Hashino, 2003). Therefore, the method has been preferred above other regression slope methods in climate and hydrologic studies (Maggioni *et al.*, 2017; Zhang *et al.*, 2017). We computed the magnitude of trend following the study of (Oguntunde *et al.*, 2017):

$$\beta = Median\left(\frac{x_j - x_k}{j - k}\right) \quad \forall\ k < j \tag{5}$$

Where:

$\beta$is the slope between data points x_j and x_k

$x_j, x_k$is the data values at times j and k, j>k, respectively.

MAKESENS 1.0 software developed by the Finnish Meteorological Institute was used to analysethe trends and theirmagnitude of changes.

2.3.3 *Relationship of power generation and hydroclimate variables*

Lobell & Burke (2010) developed a method for analysing the crops-climate relationship. The method assumed that crop yields have a confounding influence onnon-climatic factors such as management practices. The authors suggested using a first-difference time series to eliminate the influence of non-climatic factors such as crop management on crop climate relationship (the difference in values from one year to the next). Power generation is influencedby both climate and non-climatic factors (change in management practices). This study adopted Lobell & Burke (2010) to analyse the relationship between energy generated and climate variables. We calculated the first-difference time series (the difference in values from one year to the next) for energy generated (Δy) and one type of climate variable (Δx). Then, the relationships between Δy and Δx were evaluated using Pearson's correlation coefficient and simple linear regression. The regression model is formed as:

$$\Delta y = a\Delta x + b \tag{6}$$

Where:

Δy is the firstdifference of energy generated at the dam

Δx represents climate and hydrological elements.

Manystudies have used the adopted method (El-Maayar & Lange, 2013; Huang et al., 2018, 2019, 2020; Tao et al., 2012) as a standard in climate-crop yields relationship. This method departs from previous studies (Perera & Rathnayake, 2019; Salami et al., 2011), using raw climate data for correlation analysis.

3. Results and Discussion

3.1 The Trend and Magnitude of Change in Climate Variables

Table 1 represents the trend and magnitude of change in climate variables. Each year, the monthly rainfall was taken from March to October, representing the study area's rainy season. The results showed non-significant positive trends in rainfall in July, September, and October. Findings also showed a non-significant negative trend in March, May and June. Kachaje et al. (2016) also reported a mixed trend in monthly rainfall in the Lujeri micro hydropower scheme, Malawi. Tiezzi et al. (2018)suggested that rainfall's negative trends could lead to a loss of generation capacity as rainfall directly influences river flow, a fundamental factor in hydropower generation. The trend in April showed no change. Generally, the annual rainfall showed a non-significant positive trend. The general positive trends indicate that those months with negative trends were counter by months of positive trends. The general trends in rainfall could indicate running water availability for increased hydropower generation. However, Mulumba et al. (2012) suggested that such a positive trend could mean more extreme climate events, raising the probability of seeing the dramatically affected hydropower system.The rate of change in annual rainfall showed 3.45mm per year. The positive trend in rainfall is contrary to the finding of Machina & Sharma (2017)Jong et al. (2018), that reported a declining rainfall in Kainji dam Nigeria and Brazil's São Francisco River. The inconsistency in the findings worldwide could suggest an influence of the local climate in the rainfall system.

The maximum temperature showed general positive trends in all months except August, where a negative trend was detected. The study detected significant positive trends in January, July, November and December. The general pattern in monthly maximum temperature indicates that those months with significant trends coincided with months in the dry season except for July. The annual maximum temperature showed a significant trend. The trend indicates that the maximum temperature has changed at 0.45^{0}C per year in the reservoir. This rate of change is a pointer to climate change. The minimum temperature showed general significant positive trends from January to December. The annual temperature also indicates a significant positive trend with 1.17^{0}C as the rate of change per year. The rate of temperature change is a pointer to climate change. According to Wang et al. (2013), this could increase hydropower generation vulnerability. The findings of positive change in the maximum and minimum temperature are consistent with the findings of Machina & Sharma, 2017), Nepal (2016) and Bunyasi (2012). Their studies found an increase in maximum and minimum temperature in the Kainji dam in Nigeria, the Koshi river basin in the Himalayan region and Masinga Reservoir, Kenya. Miguel et al. (2017), on their part, found a significant increase in temperature between October-March for hydropower generation in Mozambique

The evaporation results showed negative trends across all the months in the reservoir. February, June, July, August, October and November indicated significant negative trends while other months showed non-significant negative trends. The annual trend of evaporation showed a significant trend with -0.81 as the rate of change per year. The negatives trends imply that more water is available in the reservoir for power generation. However, this finding was unexpected as an increasecould ordinarily have resulted in higher evaporation.

Table 1 Mann–Kendall and Sen's slope results for monthly and annual climate elements

	Rainfall		Maximum Temperature		Minimum Temperature		Evaporation	
	Z	**β**	**Z**	**β**	**Z**	**β**	**Z**	**β**
Jan			1.82+	0.05	2.43*	0.06	-1.12	-0.04
Feb			1.50	0.00	3.29***	0.13	-2.36*	-0.09
Mar	-0.88	0.00	1.63	0.00	4.06***	0.10	-0.04	0.00
Apr	0.00	0.00	0.97	0.00	3.22**	0.08	-0.21	-0.02
May	-1.14	-1.55	0.63	0.00	4.36***	0.09	-1.32	-0.06
Jun	-1.03	-1.51	0.63	0.00	2.98**	0.06	-1.78+	-0.05
Jul	0.93	1.39	2.06*	0.00	4.43***	0.08	-1.71+	-0.06
Aug	1.86+	3.97	-1.27	0.00	3.91***	0.05	-3.21**	-0.13
Sep	0.75	0.96	0.37	0.00	4.36***	0.10	-0.75	-0.02
Oct	0.36	0.50	2.00	0.00	4.85***	0.09	-2.09*	-0.09
Nov			1.85*	0.00	3.85***	0.13	-2.00*	-0.05
Dec			1.43+	0.00	2.37*	0.06	-0.27	0.00
Total	1.39	3.45	2.11*	0.45	4.50***	1.17	-2.53*	-0.81

***Significant trend at α = 0.001, ** Significant trend at α= 0.01,
* Significant trend at α= 0.05, + Significant trend at α= 0.1

3.2 The Trend and Magnitude of Change in Hydrological Variables

Table 2 representsthe trend and magnitude of change in hydrological variables and energy generation. The inflow showed a general consistent significant positive trend across all months. The inflow increase is inconsistent with Bunyasi (2012) and Vicuña et al. (2011) finding that reported an inflow decline in Masinga Reservoir, Kenya and the Upper Colorado

River Basin, California.The annual inflow also showed a significant positive trend with 211.41as the rate of change per year. The outflow showed general positive trends across all months in the study periods. Except for June, July and August that indicated non-significant trends, other months showed significant trends. The annual outflow showed a significant positive trend with 216.52 as the rate of change per year. This result implies that for any rate inflow of water from rain and other tributaries into the dam, there is an equivalent of water discharged from the dam. A consistent significant negatives trend were detected from the reservoir elevation for all months, except for October, where the non-significant negative trend was detected. The annual rate of change in reservoir elevation was -0.50 per year. The reservoir elevation trend is unusual as the increasing water inflow could have meant a higher reservoir elevation. The possible interpretation could mean that the rate of outflow has been greater than the rate of inflow.

The hydropower generation showed mixed monthly trends of positive and negative. January, August and September showed non-significant negative trends.At the same time, other months showed non-significant positive trends except for November, where a significant positive trend was detected. The general annual trend showed an increasing power generation over the study periods. The trend in power generation is contrary to Khaniya et al. (2020), who found a decreasing trend in power generation at Denawaka Ganga mini-hydropower, Ratnapura district, Sri Lanka.

Table 2 Mann–Kendall and Sen's slope results for monthly and annual hydrological elements

	Inflow		Outflow		Elevation		Energy	
	Z	**β**	**Z**	**β**	**Z**	**β**	**Z**	**β**
Jan	2.68**	19.89	2.71**	17.30	-3.37***	-0.07	-0.29	-454.33
Feb	3.02**	20.83	2.89**	21.44	-2.07*	-0.06	0.00	8.00
Mar	3.59***	22.14	3.62***	22.06	-2.82**	-0.06	1.14	2042.11
Apr	3.44***	16.84	3.71***	18.29	-1.94+	-0.04	0.68	1576.00
May	2.84**	15.80	2.75**	18.50	-2.27*	-0.06	1.20	2509.24
Jun	1.68+	11.86	1.62	11.32	-2.05*	-0.05	0.36	896.72
Jul	1.78+	11.62	1.57	10.25	-2.91**	-0.07	0.23	658.29
Aug	1.71+	16.25	1.39	12.31	-1.68+	-0.04	-0.68	-2600.67
Sep	2.03*	34.72	1.82+	30.75	-1.23	-0.02	-0.49	-886.67
Oct	2.00*	29.43	1.86+	28.95	0.16	0.00	0.16	676.49
Nov	2.78**	18.83	3.00**	19.54	-0.39**	-0.01	2.04*	4697.69
Dec	2.00*	10.72	2.62**	12.92	-3.12**	-0.06	0.23	623.94
Total	3.14**	211.41	3.14**	216.52	-2.78	-0.50	0.16	2751.89

***Significant trend at α = 0.001, ** Significant trend at α= 0.01,
* Significant trend at α= 0.05, + Significant trend at α= 0.1

3.3 Relationship Between Hydroclimatic Variables and Power Generation

Table 3 represents the Pearson’s correlation coefficients (PCC) of hydroclimatic variables and power generation time series based on the first-difference operation. The correlation range from negative to positive. Except for rainfall,whichshows a positive relationship with power generation, the maximum temperature (Max Temp), minimum temperature (Min Temp) and evaporation (Evap) showed a negative association with power generation. The P-Values of climate variables are greater than the Alpha values of 0.05, implying the non-significant relationship. On the other hand, the hydrological variables of inflow, outflow and reservoir elevation showed a positive relationship with power generation. The findings are consistent withJoseph et al. (2016) and Kachaje et al. (2016), which found positive correlations between the reservoir inflow, outflow and the power generation in Jebba dam and Lujeri hydropower scheme in Malawi. The similarity in correlation results is an indication that the hydropower generation in Jebba dam has had a long term relationship with the hydrological variables. Except for the inflow P-Value that is less than Alpha value implying a significant relationship, other hydrologic variables showed a non-significant positive relationship.

Table 3 Pearson’s correlation coefficients (PCC) of hydroclimatic variables and power generation time series

Variables	PCC	P-Value	Alpha
Rainfall	0.124	0.612	0.05
Max Temp	-0.129	0.599	0.05
Min Temp	-0.272	0.26	0.05
Evap	-0.328	0.171	0.05
inflow	0.464	0.045	0.05
Outflow	0.452	0.052	0.05
elevation	0.234	0.335	0.05

Figure 2 represents a scattergram of how power generation varies with climatic variables. Figure 2(a) indicates that rainfall increases power generation increases. Figure 2(b, c & d) show an inverse relationship between power generation with maximum temperature, minimum temperature and evaporation. The previous study by Tiezzi et al. (2018) suggests a loss of power generation attributed to negative rainfall anomalies. They argued that rainfall has a direct relationship with inflow, which is fundamental to hydropower generation. In addition, temperature and evaporation are understood to have a direct positive relationship. The finding implies that more water from the reservoir will escape into the atmosphere as the temperature rises, affecting power generation.

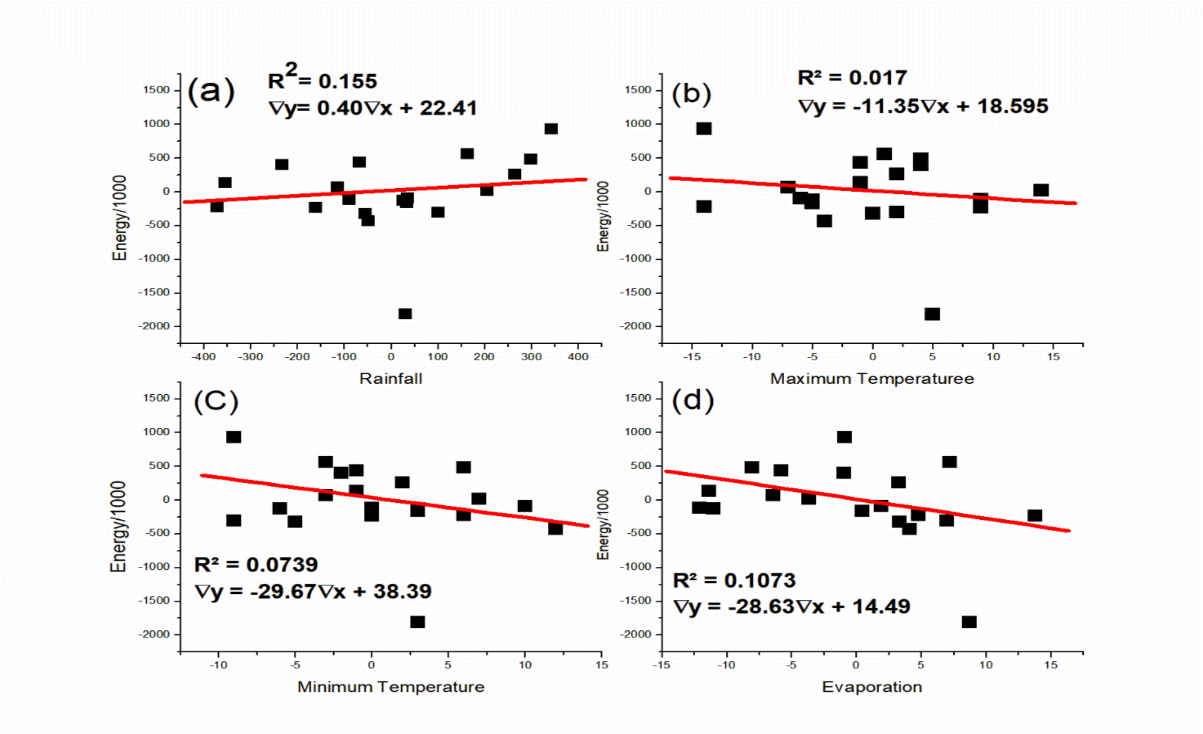

Figure 2: (a) linear relationship between the rainfall and energy generation, (b) linear relationship between the maximum temperature and energy generation, (c) linear relationship between the minimum temperature and energy generation, (d) linear relationship between the evaporation and energy generation.

Figure 3 represents a scattergram of how power generation varies with hydrologic variables. Figure 3 indicates that as all the three hydrologic variables (inflow, outflow and reservoir elevation) increase, the power generation increases. However, of the three hydrologic variables, inflow shows a more direct relationship.

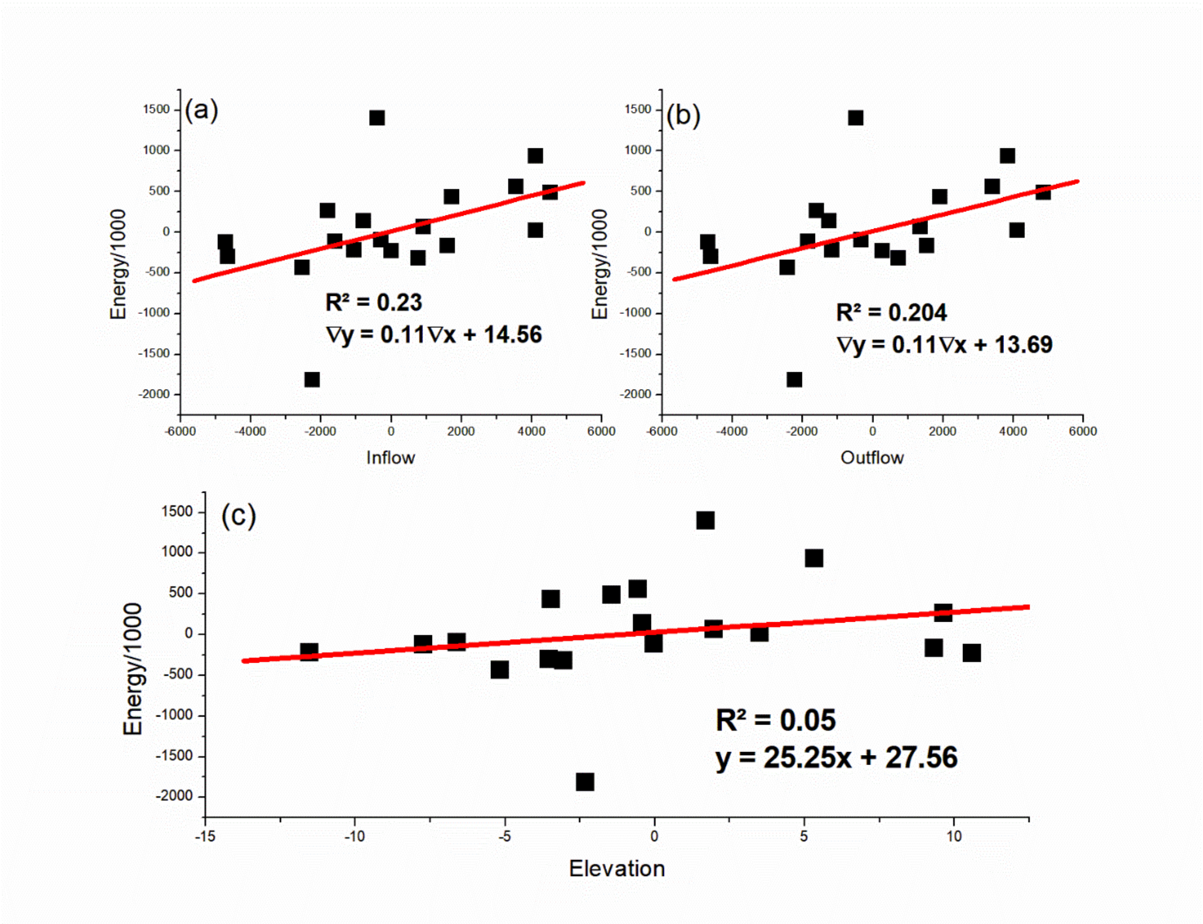

Figure 3: (a) linear relationship between the inflow and energy generation, (b) linear relationship between the outflow and energy generation, (c) linear relationship between the reservoir elevation and energy generation

4. Conclusion

We carried out the Mann-Kendall test and Sen's slope estimator tests to find the trends and relationship in hydroclimatic elements and the hydropower generation at Jebba dam. In addition, we carried out the firstdifference to eliminate the influence of non-climatic factors (change in management practices) on hydropower generation. Some conclusions are as follows:The monthly hydroclimatic elements showed mixed increasing and decreasing trends. The annual rainfall, maximum and minimum temperature showed an increasing trend, while the annual evaporation values surprisingly showed decreased trends. The annual inflow and outflow showed significantly increased trends. In contrast, reservoir elevation showed a significantly decreased trend, implying the outflow rate was greater than the inflow. The annual hydropower generation showed a non-significant increasing trend over the study periods. There has been a consistent increase in temperature over the study periods implying the Jebba dam is under climate change. Except for rainfall which shows a positive relationship, the climate elements showed a weak negative relationship while all the hydrological elements showed a positive relationship with hydropower generation. The climate elementsand power generation relationship indicate that climate plays an insignificant role in power generation at Jebba dam.

References

Antwi, M., & Sedegah, D. D. (2018). Climate Change and Societal Change — Impact on Hydropower Energy Generation. In *Sustainable Hydropower in West Africa* (pp. 63–73). Elsevier Inc. https://doi.org/10.1016/B978-0-12-813016-2.00005-8

Bunyasi, M. M. (2012). Vulnerability of Hydro-Electric Energy Resources in Kenya Due to Climate Change Effects : The Case of the Seven Forks Project. *Journal of Agriculture and Environmental Sciences*, *1*(1), 36–49.

Chilkoti, V., Bolisetti, T., & Balachandar, R. (2017). Climate change impact assessment on hydropower generation using multi-model climate ensemble. *Renewable Energy*, *109*, 510–517. https://doi.org/10.1016/j.renene.2017.02.041

Deka, R. L., Mahanta, C., Nath, K. K., & Dutta, M. K. (2015). Spatio-temporal variability of rainfall regime in the Brahmaputra valley of North East India. *Theoretical and Applied Climatology*, *70*, 342–360. https://doi.org/10.1007/s00704-015-1452-8

Dukiya, J. J. (2013). Spatial Analysis of the Impacts of Kainji Hydropower Dam on the Down Stream Communities. *Geoinformatics & Geostatistics: An Overview*, *7*, 1–5.

El-Maayar, M., & Lange, M. A. (2013). A methodology to infer crop yield response to climate variability and change using long-term observations. *Atmosphere*, *4*(4), 365–382. https://doi.org/10.3390/atmos4040365

Emoabino, I. U., Waheed, A. A., & Bamgboye, O. A. (2007). Tail Water Recycling for Higher Efficiency in Hydropower–Case Study of Kainji–Jebba Hydropower Dams in Nigeria. *International Conference on Small Hydropower - Hydro Sri Lanka*, 22–24.

Gaudard, L., Romerio, F., Dalla, F., Gorret, R., Maran, S., Ravazzani, G., Stoffel, M., & Volonterio, M. (2013). Science of the Total Environment Climate change impacts on hydropower in the Swiss and Italian Alps. *Science of the Total Environment, The*, *25*, 1–17. https://doi.org/10.1016/j.scitotenv.2013.10.012

Hamududu, B., & Killingtveit, A. (2012). Assessing Climate Change Impacts on Global Hydropower. *Energies*, *5*, 305–322. https://doi.org/10.3390/en5020305

Hoscilo, A., Balzter, H., Bartholomé, E., Boschetti, M., Brivio, P. A., Brink, A., & Clerici, M. (2015). A conceptual model for assessing rainfall and vegetation trends in sub-Saharan +Africa from satellite data. *International Journal of Climatology*, *3592*, 3582–3592. https://doi.org/10.1002/joc.4231

Huang, J., Zhang, F., Zhou, L., Hu, Z., & Li, Y. (2018). Regional changes of climate extremes and its effect on rice yield in Jiangsu province, southeast China. *Environmental Earth Sciences*, *77*(3), 1–11. https://doi.org/10.1007/s12665-018-7295-8

Huang, J., Zhou, L., Zhang, F., Hu, Z., & Li, Y. (2019). Regional Climate–Yield Relationship for Winter Oilseed Rape in Jiangsu Province, Southeast China. *International Journal of P+66.lant Production*, *23*, 1–10. https://doi.org/10.1007/s42106-019-00038-8

Huang, J., Zhou, L., Zhang, F., & Li, Y. (2020). Responses of Yield Fluctuation of Winter Oilseed Rape to Climate Anomalies in South China at Provincial Scale. *International Journal of Plant Production*, *14*(3), 521–530. https://doi.org/10.1007/s42106-020-00102-8

Ifabiyi, I. P. (2011). Relationship between Power Generation and Reservoir Elements in the Jebba Hydroelectric Reservoir, Nigeria. *Global Journal of Science Frontier Research, 11*(8), 1–12.

IHA. (2020). *Hydropower Status Report*.

Jones, J. R., Schwartz, J. S., Ellis, K. N., Hathaway, J. M., & Jawdy, C. M. (2015). Temporal variability of precipitation in the Upper Tennessee Valley. *Journal of Hydrology: Regional Studies, 3*, 125–138. https://doi.org/10.1016/j.ejrh.2014.10.006

Jong, P. De, Tanajura, S. A. C., Sánchez, S. A., Dargaville, R., Kiperstok, A., & Torres, A. E. (2018). Hydroelectric production from Brazil's São Francisco River could cease due to climate change and inter-annual variability. *Science of the Total Environment*, *634*, 1540–1553. https://doi.org/10.1016/j.scitotenv.2018.03.256

Joseph, S. A., Fajoye, S. O., Odiba, O., Akinluwade, K. J., Oduola, M. O., & Adetunji, A. R. (2016). Generation Cycle of Jebba Hydro Power Plant and its effect on the National Power Grid Generation Cycle of Jebba Hydro Power Plant and its Effect on the National Power Grid. *Journal of Basic and Applied Research*, *2*(4), 432–436.

Kabo-bah, A. T., Diji, C. J., Nokoe, K., Mulugetta, Y., Obeng-ofori, D., & Akpoti, K. (2016). Multiyear Rainfall and Temperature Trends in the Volta River Basin and their Potential Impact on Hydropower Generation in Ghana. *Climate*, *4*(49), 1–17. https://doi.org/10.3390/cli4040049

Kachaje, O., Kasulo, V., & Chavula, G. (2016). The potential impacts of climate change on hydropower : An assessment of Lujeri micro hydropower scheme , Malawi. *African Journal of Environmental Science and Technology*, *10*(12), 476–484. https://doi.org/10.5897/AJEST2016.2209

Katsanos, D., Retalis, A., Tymvios, F., & Michaelides, S. (2017). Study of extreme wet and dry periods in Cyprus using climatic indices. *Atmospheric Research*, *33*, 367–384. https://doi.org/10.1016/j.atmosres.2017.09.002

Khaniya, B., Priyantha, H. G., Baduge, N., Azamathulla, H., & Rathnayake, U. (2018). Impact of climate variability on hydropower generation: A case study from Sri. *ISH Journal of Hydraulic Engineering*, *26*(3), 301–309. https://doi.org/10.1080/09715010.2018.1485516

Khaniya, B., Priyantha, H. G., Baduge, N., Azamathulla, H., & Rathnayake, U. (2020). Impact of climate variability on hydropower generation: A case study from Sri Lanka. *ISH Journal of Hydraulic Engineering*, *26*(3), 301–309. https://doi.org/10.1080/09715010.2018.1485516

Lobell, D. B., & Burke, M. B. (2010). On the use of statistical models to predict crop yield responses to climate change. *Agricultural and Forest Meteorology*, *150*(11), 1443–1452.

https://doi.org/10.1016/j.agrformet.2010.07.008

Machina, M. B., & Sharma, S. (2017). Assessment of Climate Change Impact on Hydropower Generation : A Case Study of Nigeria. *International Journal of Engineering Technology Science and Research*, *4*(8), 753–762.

Maggioni, G. M., Bosetti, L., dos Santos, E., & Mazzotti, M. (2017). Statistical Analysis of Series of Detection Time Measurements for the Estimation of Nucleation Rates. *Crystal Growth & Design*, *17*(10), 5488–5498. https://doi.org/10.1021/acs.cgd.7b01014

Miguel, M., Aljaradin, M., Nilsson, E., & Persson, K. M. (2017). Climate Change observations into Hydropower in Mozambique. *2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies 2017 AEDCEE, 25-26 May 2017, Bangkok, Thailand*, *138*, 592–597. https://doi.org/10.1016/j.egypro.2017.10.165

Mtilatila, L., Bronstert, A., Shrestha, P., Kadewere, P., & Vormoor, K. (2020). Susceptibility of Water Resources and Hydropower Production to Climate Change in the Tropics : The Case of Lake Malawi and Shire River Basins, SE Africa. *Hydrology*, *7*(54), 1–26.

Mulumba, J. P. M., Afullo, T. J. O., & Ijumba, N. (2012). Climate Change and Hydropower Challenges In Southern Africa. *Rwanda Journal*, *27*, 32–43.

Oguntunde, P. G., Abiodun, B. J., & Lischeid, G. (2017). Impacts of climate change on hydro-meteorological drought over the Volta Basin, West Africa. *Global and Planetary Change*, *155*, 121–132. https://doi.org/10.1016/j.gloplacha.2017.07.003

Olanrewaju, R. M., Olatunji, O. W., & Akpan, G. P. (2018). Iranian Journal of Energy & Environment Impacts of Climate Variability on Hydroelectric Power Generation in Shiroro Station, Nigeria. *Iranian Journal of Energy & Environment*, *9*(3), 197–203.

Olawepo, R. A. (2006). Resettlement and Agricultural Change in a Rural Nigerian Environment: The Jebba Scheme Example. *International Journal of Rural Management*, *2*(1), 57–66. https://doi.org/10.1177/097300520500200103

Olukanni, D. O., Adejumo, T. A., & Salami, A. W. (2016). Assessment of Jebba Hydropower Dam Operation for Improved Energy Production and Flood Management. *Journal of Engineering and Applied Sciences*, *11*(13), 8450–8467.

Perera, A., & Rathnayake, U. (2019). Impact of climate variability on hydropower generation in an un‐ gauged catchment: Erathna run‐ of‐ the‐ river hydropower plant, Sri Lanka. *Applied Water Science*, *9*(57), 1–11. https://doi.org/10.1007/s13201-019-0925-9

Salami, A. W., Sule, B. F., & Okeola, O. (2011). Assessment of Climate Variability on Kainji hydropower reservoir. *Hydrology for Sustainable Development and Management of Water Resources in the Tropic*, 1–10.

Sanhueza, P. A., Dieppois, B., Sidibe, M., & Link, O. (2019). Impacts of Climate Change and Climate Variability on Hydropower Potential in Data-Scarce Regions Subjected to Multi-Decadal Variability. *Energies*, *12*, 1–20. https://doi.org/10.3390/en12142747

Sen, P. K. (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association*, *63*(324), 1379–1389.

Solaun, K., & Cerdá, E. (2017). The Impact of Climate Change on the Generation of Hydroelectric Power—A Case Study in Southern Spain. *Energies*, *10*, 1–19.

https://doi.org/10.3390/en10091343

Spalding-fecher, R., Joyce, B., & Winkler, H. (2017). Climate change and hydropower in the Southern African Power Pool and Zambezi River Basin : System-wide impacts and policy implications. *Energy Policy*, *103*, 84–97. https://doi.org/10.1016/j.enpol.2016.12.009

Sushant, S., Balasubramani, K., & Kumaraswamy, K. (2015). Spatio-temporal Analysis of Rainfall Distribution and Variability in the Twentieth Century, Over the Cauvery Basin, South India. *Theoretical and Applied Climatology*, *54*, 21–42. https://doi.org/10.1007/978-3-319-13425-3

Tabari, H., & Hosseinzadeh, P. (2011). Recent trends of mean maximum and minimum air temperatures in the western half of Iran. *Meteorology and Atmospheric Physics*, *111*, 121–131. https://doi.org/10.1007/s00703-011-0125-0

Tao, F., Zhang, Z., Zhang, S., Zhu, Z., & Shi, W. (2012). Response of crop yields to climate trends since 1980 in China. *Climate Research*, *54*(3), 233–247. https://doi.org/10.3354/cr01131

Tarroja, B., Aghakouchak, A., & Samuelsen, S. (2016). Quantifying climate change impacts on hydropower generation and implications on electric grid greenhouse gas emissions and operation. *Energy*, *111*, 295–305. https://doi.org/10.1016/j.energy.2016.05.131

Tiezzi, R. D. O., Vieira, N. D. B., Simões, A. F., Filho, H. F., Viana, E., Mouette, D., & Domingues, M. S. (2018). Impacts of Climate Change on Hydroelectric Power Generation – A Case Study Focused in the Paranapanema Basin , Brazil. *Journal of Sustainable Development*, *11*(1), 140–149. https://doi.org/10.5539/jsd.v11n1p140

Van Vliet, M. T. H., Sheffield, J., Wiberg, D., & Wood, E. F. (2016). Impacts of recent drought and warm years on water resources and electricity supply worldwide. *Environmental Research Letters*, *11*, 124021. https://doi.org/10.1088/1748-9326/11/12/124021

Vicuña, S., Dracup, J. A., & Dale, L. (2011). Climate change impacts on two high-elevation hydropower systems in California. *Climate Change*, *109*, 151–169. https://doi.org/10.1007/s10584-011-0301-8

Wang, B., Liang, X., Zhang, H., Wang, L., & Wei, Y. (2013). Vulnerability of hydropower generation to climate change in China : Results based on Grey forecasting model. *Energy Policy*, *22*, 1–7. https://doi.org/10.1016/j.enpol.2013.10.002

Yue, S., & Hashino, M. (2003). Lond Term Trends of Annual and Monthly Precipitation in Japan. *Journal of the American Water Resources Association*, *39*(3), 587–596.

Yue, S., Pilon, P., Phinney, B., Cavadias, G., Herath, S., Ratnayake, U., N, T. N., Caloiero, T., Coscarelli, R., Mancini, M., Omonijo, T. O., Okogbue, E. C., Akinsanola, A. A., Ogunjobi, K. O., Xu, L., Zhou, H., Liang, C., Du, L., Li, H., … Tabari, H. (2012). Spatiotemporal trends and change point of precipitation in Iran. *Atmospheric Research*, *113*, 1–12. https://doi.org/10.1016/j.atmosres.2012.04.016

Zhang, W., Brandt, M., Guichard, F., Tian, Q., & Fensholt, R. (2017). Using long-term daily satellite based rainfall data (1983 –2015) to analyze spatio-temporal changes in the sahelian rainfall regime. *Journal of Hydrology*, *550*, 427–440. https://doi.org/10.1016/j.jhydrol.2017.05.033