Iranian (Iranica) Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

An Investigation on Interdependence Between Rainfall and Temperature in Ekpoma, Edo State, Nigeria

I. U. Siloko[1]*, E. A. Siloko[2]

[1] Department of Mathematics and Computer Science, Edo State University Uzairue, Nigeria
[2] Department of Statistics, University of Benin, Benin City, Edo State, Nigeria

P A P E R I N F O

Paper history:
Received 26 December 2022
Accepted in revised form 17 February 2023

Keywords:
Asymptotic mean integrated squared error
Bandwidth
Climate
Kernel
Rainfall
Temperature

A B S T R A C T

This paper focuses on the interdependence between rainfall and temperature and their joint effect. Rainfall and temperature are vital climatic variables for agricultural productivity and other human activities. Despite the importance of rainfall and temperature, there are difficulties associated with accurate analysis of their joint distribution due to the possibility of interrelationship between the variables. Several studies have been conducted by researchers on the interaction between climatic variables in order to ascertain their effects on the environment because temperatures were observed to be undergoing changes regularly. The analysis of rainfall and temperature for exploratory and visualization purposes is investigated because underlying structures and patterns do form the basis of decisions by government and regulatory agencies. This study employs the statistical approach in investigating the interdependence between rainfall and temperature in Ekpoma, Edo State, Nigeria for a period of five consecutive years from 2016 to 2020 using Gaussian kernel estimator. The results of the investigations using some statistical indicators established that there is irregular pattern of rainfall which is occasioned by changes in temperature. The variability of rainfall is mostly prominent in two years which are 2017 and 2019 with 29.43mm and 27.74mm as maximum amount of rainfall, respectively. The results also demonstrate that the performance of years with high standard deviations are better than that of low standard deviations. Again, the performance of years with high negative correlation coefficients and high negative covariance of rainfall and temperature is better than years with weak correlations and low covariance.

doi: *10.5829/ijee.2023.14.03.01*

INTRODUCTION

Rainfall and temperature are among the most relevant weather variables with large effects on the environment because weather is one of the vital sources of uncertainty affecting agricultural productivity particularly with respect to climate change. Global warming that is responsible for changes in the intensity of rainfall and temperature is being experienced in several countries of the world and thereby resulting in serious environmental hazards such as floods and droughts [1, 2]. Several authors have investigated the sensitivity of crops production to the variability of these weather variables with emphasis on the examination of low rainfall and high temperatures and vice-versa [3-5]. The sensitivity of crops production to high rainfall was examined by Lesk et al. [6] with the conclusion that the intensity of rainfall is of immerse beneficial effects on crop production, however; the benefits did not counter the losses associated with higher temperatures.

The variability in the amount of rainfall has resulted in floods and drought and hence creating serious challenges in water supply since the availability of water for different purposes is dependent on rainfall. A study on the role of temperature on elderly patients was conducted in United States of America within twelve cities and the results of the investigation revealed that the number of patients admitted on cases of heart related diseases are positively related with temperature [7]. It has been reported that high temperatures can induce social vices such as criminality and also capable of affecting the household income [8].

*Corresponding Author Email: *siloko.israel@edouniversity.edu.ng* (I. U. Siloko)

Please cite this article as: I. U. Siloko , E. A. Siloko, 2023. An Investigation on Interdependence Between Rainfall and Temperature in Ekpoma, Edo State, Nigeria, Iranian (Iranica) Journal of Energy and Environment, 14(3), pp. 197-204. Doi: 10.5829/ijee.2023.14.03.01

The best meteorological explanation of the inter-connectivity between rainfall and temperature is usually in terms of sea surface temperatures (SSTs) and El Nino Southern Oscillation (ENSO), respectively. Researchers have shown that the variability of rainfall in Africa particularly in the southern countries is connected with the Indo-Pacific sea surface temperature [9, 10]. Temperature is one of the vital weather variables that influences the amount of rainfall. Temperature changes could result in serious hydrological problems such as low soil moisture and evaporation due to the fact that a rise in temperature may reduce soil moisture which contains important nutrients for plants. Temperature affects rainfall in numerous ways because increase in temperature usually give rise to extraordinarily lofty rates of evaporation with an exiguous precipitation. Again, increase in temperatures lead to high rate of evaporation which gives rise to condensation that ultimately leads to high rainfall. The importance of rainfall can not be overemphasized because rain gives shape to the vegetation with the natural environment. Hence rainfall is an essential meteorological variable and also the most important ecological variable.

Temperature influences the intensity of rainfall seriously because with a warm air, there is the tendency of producing excess moisture which result in rainfall. The amount of rainfall depends heavily on the amount of the vapour available in the atmosphere [11]. Agricultural activities rely on rainfall and food security can only be guaranteed when there is adequate amount of rainfall which also translates to economic growth and development. Several research investigations on rainfall across the globe depicts that agricultural activities are often affected by the pattern and amount of rainfall. The effects of the variability of rainfall and changes in temperature has become a critical subject by researchers because rainfall variability is occasioned by variation in temperature [12-16]. The significance of rainfall and temperatures as essential climatic factors that are critical for the existence of plants and animals in the ecosystem is vividly established, hence it is imperative to study their interdependence or correlation. This paper investigates the relationship between rainfall and temperature statistically in Ekpoma, Edo State, Nigeria using the nonparametric kernel estimator.

MATERIALS AND METHODS

The data used in this study is the daily temperature and rainfall obtained from the archives of the Nigerian Meteorological Agency (NiMet) Edo State (Ekpoma) for a period of five consecutive years (2016 to 2020) from January 1st to December 31st of each year. The univariate and bivariate probability density function employed in the analysis of rainfall and temperature is the Gaussian kernel function. The Gaussian kernel function is very prominent and of numerous applications in several fields of studies because many real life situations can be modeled after the Gaussian distribution. The correlation coefficient of the variables was used to establish the level of the interdependence between the variables. The univariate form of the kernel estimator is given below:

$$\hat{f}(\mathrm{x}) = \frac{1}{nh_{\mathrm{x}}}\sum_{i=1}^{n} K\left(\frac{\mathrm{x}-\mathrm{X}_i}{h_{\mathrm{x}}}\right) \tag{1}$$

here, $K(\cdot)$ is a kernel function, h_{x} is the smoothing parameter that regulates the smoothness of the estimate, n is the number of observations, x is the range of the observations while X_i is the set of data [17]. The kernel estimator rely greatly on the smoothing parameter for its implementation and several selectors have been propounded by Siloko et al. [18]. The univariate smoothing parameter is given as follows:

$$h_{\mathrm{x}} = \left\{\frac{R(K)}{\mu_2(K)^2 R(f'')}\right\}^{1/5} \times n^{-1/5} \tag{2}$$

where $R(K) = \int K^2(\mathrm{x})d\mathrm{x}$ is the kernel roughness while $\mu_2(K)^2$ is kernel variance and $R(f'') = \int f''(\mathrm{x})^2 d\mathrm{x}$ is the roughness of the unknown distribution which is the Gaussian kernel in this study. All kernel functions are usually probability density function and therefore must satisfy the following conditions:

$$\int K(\mathrm{x})d\mathrm{x} = 1, \int \mathrm{x}K(\mathrm{x})d\mathrm{x} = 0 \text{ and } \int \mathrm{x}^2 K(\mathrm{x})d\mathrm{x} \neq 0 \tag{3}$$

The implications of the conditions in Equation (3) is that kernel functions are probability density functions whose integral is one but with the mean zero and a variance that is not equal to zero. Similarly, the bivariate kernel density estimator is given by the following expression:

$$\begin{aligned}\hat{f}(\mathrm{x},\mathrm{y}) &= \frac{1}{nh_{\mathrm{x}}h_{\mathrm{y}}}\sum_{i=1}^{n} K\left(\frac{\mathrm{x}-\mathrm{X}_i}{h_{\mathrm{x}}},\frac{\mathrm{y}-\mathrm{Y}_i}{h_{\mathrm{y}}}\right) \\ &= \frac{1}{nh_{\mathrm{x}}h_{\mathrm{y}}}\sum_{i=1}^{n} K\left(\frac{\mathrm{x}-\mathrm{X}_i}{h_{\mathrm{x}}}\right)K\left(\frac{\mathrm{y}-\mathrm{Y}_i}{h_{\mathrm{y}}}\right)\end{aligned} \tag{4}$$

where $h_{\mathrm{x}} > 0$ and $h_{\mathrm{y}} > 0$ are the smoothing parameters of variables X and Y, respectively while x and y are ranges of the variables in the different directions [19]. Again, $K(\mathrm{x},\mathrm{y})$ is the bivariate kernel which in this study is the Gaussian kernel estimator. The smoothing parameter of the bivariate kernel estimator using the Gaussian kernel function for the x-axis and y-axis are stated below:

$$h_{\mathrm{x}} = \left\{\frac{\int\left(\frac{\partial^2 f}{\partial \mathrm{x}^2}\right)^2}{4n\pi}\right\}^{1/6} \times \left\{\frac{\int\left(\frac{\partial^2 f}{\partial \mathrm{x}^2}\right)^2}{\int\left(\frac{\partial^2 f}{\partial \mathrm{y}^2}\right)^2}\right\}^{2/3} \tag{5}$$

$$h_{y} = \left\{\frac{\int\left(\frac{\partial^2 f}{\partial \mathrm{y}^2}\right)^2}{4n\pi}\right\}^{1/6} \times \left\{\frac{\int\left(\frac{\partial^2 f}{\partial \mathrm{y}^2}\right)^2}{\int\left(\frac{\partial^2 f}{\partial \mathrm{x}^2}\right)^2}\right\}^{2/3} \tag{6}$$

The bivariate kernel is often use to investigate the joint distribution of two random variables numerically and graphically. The asymptotic mean integrated squared error (AMISE) is one of the popular error criteria function in kernel density estimation. The AMISE of the bivariate Gaussian kernel function for data that are correlated is given below:

$$\text{AMISE}\left(\hat{f}(\text{x},\text{y})\right) = \frac{3}{8\pi\sigma_{\text{x}}\sigma_y(1-\rho^2)^{5/6}}\left(1-\frac{\rho^2}{2}\right)^{-1/3} n^{-2/3} \quad (7)$$

where ρ is the correlation coefficient which is obtained from the Person product moment correlation technique [20, 21]. The AMISE of Equation (7) depends on the data size, standard deviations and correlation coefficient of the data.

Location of study area

Epkoma is the administrative headquarters of Esan West Local Government Area, Edo State, Nigeria. Edo State is one of the States located in the rain forest of the Southern part of Nigeria in the oil rich region called Niger Delta and it lies between longitude 5°E and 6°42''E and latitude 5°45''N and 35''N [22].

The state is bounded by three states; Kogi State towards the North with Delta and Ondo States in the South and West, respectively while towards the East is the River Niger [23]. Geographically, Ekpoma is situated at Edo Central and it lies between latitude 6°44′34.80″N and longitude 6°08′25.04″E. The inhabitants of Ekpoma are predominantly farmers and the National Population Census of 2006 placed the population of Ekpoma to be 125,842 of which 63,785 are males while 62,057 are females with the present population of over two hundred fifty thousand people [23, 24]. The map of Nigeria showing the location of Ekpoma in Edo State is depicted in Figure 1.

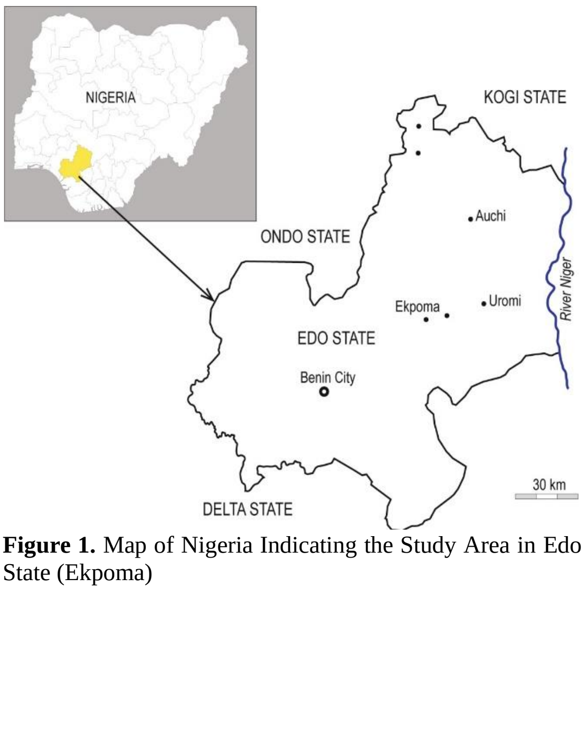


Figure 1. Map of Nigeria Indicating the Study Area in Edo State (Ekpoma)

Ekpoma possesses a tropical Savannah vegetation with an average annual temperature of 30.5°C and annual rainfall of about 19.23mm (7.57 inches)**.** Rainfall in Ekpoma is usually heavily experienced in two months; the first month is July with a monthly total of about 344.7mm while the second month is September with a total of approximately 457.2mm. The highest amount of rainfall is recorded in these two months while the least amount of rainfall is usually in the month of December (7mm). The highest yearly recorded temperature in Ekpoma is between 36°C and 38°C which is usually in the month of March [22-25].

RESULTS AND DISCUSSION

The interdependence between rainfall and temperature is statistically investigated using the kernel method. Rainfall and temperature are vital weather variables due to the significance of water for human existence. Temperature influences the amount of rainfall. The numerical and statistical analysis of the data is done by Mathematica version 12 software. The statistical relationship between two variables can be well established by the value of their correlation coefficient denoted by ρ which lies between 1 and -1, that is $-1 \leq \rho \leq 1$. As a measure of relationship, for values of ρ closer to 1 and -1, the variables are either highly positively or highly negatively correlated otherwise the variables are weakly related. However; for the correlation value being zero, that is $\rho = 0$, then the variables are said to be uncorrelated.

The correlation coefficient values of rainfall and temperature, smoothing parameter and the AMISE with other descriptive statistics are summarized in Tables 1, 2 and 3, respectively. The univariate and bivariate kernel estimates of the data are shown in Figures 2, 3, 4, 5 and 6. In this study, temperature and rainfall will be denoted by X and Y, respectively. The kernel estimates of temperature in most cases display two modes that lies between 26°C and 32°C which depicts the region of the average annual temperature of Ekpoma. The kernel estimates of rainfall are skewed to the right with a long tail which is a demonstration of the fact that rainfall is not evenly distributed within a year because certain months do record sparsely amount of rainfall. Again, the long tail of the kernel estimates displayed by the rainfall data affirms that the pattern of rainfall in Ekpoma is irregular, which means that rainfall has no specific pattern but varies greatly with different years. Rainfall is a vital variable for agricultural activities in Ekpoma but the variability of the amount of rainfall affects productivity as shown in Table 3 particularly for the years with large AMISE values. The AMISE which is the measure of performance of the kernel estimator is based on the principle that the years with the smallest AMISE values are with better yields than the years with larger AMISE [26]. The bivariate kernel estimation requires the standardization of the data to ensure that the differences in the range of the data are eliminated. The inherent statistical features of the data set are not eliminated due to standardization because data standardization is usually employed in multivariate analysis [27]. Therefore, the rainfall and temperature data for the bivariate kernel estimate is standardized to ensure the removal of the differences that exist in the variables but the statistical properties such as bimodality of the data is retained.

In Table 1, temperature is negatively Skewed while in Table 2, rainfall is positively Skewed and this is clearly demonstrated in the univariate kernel estimates of temperature and rainfall. The season of heavy rainfall in Ekpoma is mainly between the months of April and October with little amount of rainfall in some other months of the year [25]. As observed in Table 2, the minimum amount of rainfall of every year is 0.00mm and this is due to the fact that in most days of some months of the year there was no rainfall. Again in Table 2, the amount of rainfall of the period investigated tend to have a heavy tail distribution as depicted by the value of their their Kurtosis and this is also supported by the kernel estimates of rainfall. The covariance of rainfall and temperature revealed the usual inverse relationship between rainfall and temperature. This inverse relationship is also demonstrated by the values of the correlation coefficient of rainfall and temperature as noticed in Table 3 where the negative correlation values also produce a negative covariance due to the fact that correlation coefficient is statistically a function of covariance. The AMISE which is the performance measure in kernel density estimation has shown that activities that are rainfall reliant did very well in 2018 and 2020 and this is due to their production of the least AMISE values as presented in Table 3.

The correlation coefficient values and covariances of 2018 and 2020 are high in comparison with the other years and this support the claim that years with highly negatively correlated values, human activities tend to be more productive. The bivariate kernel estimates of temperature and rainfall in Figures 2 to 6 displayed that the observations are bimodal and the bimodality is attributed to the climatic differences of the means of

Table 1. Descriptive statistics of temperature for the five years period

Years	n	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
2016	366	25.22	34.68	30.2215	1.89335	−0.407509	2.91412
2017	365	24.17	34.68	30.5922	2.19473	−0.209339	2.26617
2018	365	24.17	34.67	30.4658	2.32031	−0.425694	2.42956
2019	365	24.17	35.73	30.0337	2.33306	−0.236261	2.24132
2020	366	24.15	37.83	29.9897	3.18039	0.1817970	2.03949

Table 2. Descriptive statistics of rainfall for the five years period

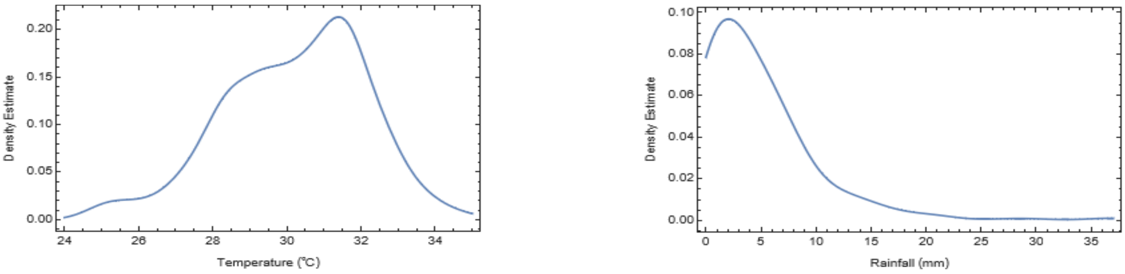
Years	n	Minimum	Maximum	Mean	SD	Skewness	Kurtosis
2016	366	0.00	36.89	4.86104	6.78509	2.48933	12.6397
2017	365	0.00	29.43	4.17661	4.54721	1.77161	7.05817
2018	365	0.00	62.42	6.77784	8.47992	2.02245	8.30520
2019	365	0.00	27.74	3.29707	4.09564	1.94772	8.97001
2020	366	0.00	53.18	10.1361	10.5692	1.06680	3.55095

Table 3. Bandwidths, ρ, covariance and AMISE of temperature and rainfall for the five years period

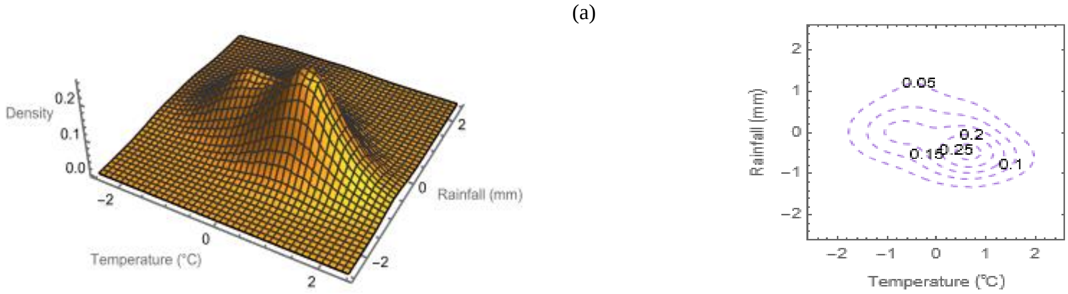
Years	n	h_x	h_y	σ_x	σ_y	ρ	Covariance	AMISE
2016	366	0.40529	0.40386	1.89335	6.78509	−0.441708	−4.35086	0.000224457
2017	365	0.40389	0.40335	2.19473	4.54721	−0.369895	−3.69151	0.000270638
2018	365	0.40723	0.40366	2.32031	8.47992	−0.666095	−12.3044	0.000210925
2019	365	0.40343	0.40332	2.33306	4.09564	−0.652540	−6.23526	0.000414159
2020	366	0.40575	0.40343	3.18039	10.5692	−0.703268	−23.6399	0.000132164

rainfall and temperature, respectively. The joint probability distribution of the occurrence of the two variables is at its peak with probability value of 0.3 as indicated in the bivariate kernel estimate of Figure 4b which is higher than other bivariate estimates and the individual kernel probabilities values as shown in the univariate kernel estimates of the observations.

The maximum temperature of the period investigated is 37. 83°C while the minimum is 24.15°C as recorded in Table 1 for the year 2020. The highest temperature in Ekpoma is usually recorded in the month of March and it is between 36°C and 38°C. The maximum amount of rainfall for the study period as presented in Table 2 is 62.42mm and that is in the year 2018. The analysis in Table 3 clearly shows that the years with higher amount of rainfall yields better results as affirmed by the AMISE. The variability of rainfall in the period investigated is mostly prominent in two years which are 2017 and 2019 with 29.43mm and 27.74mm as the maximum amount of rainfall, respectively with the largest AMISE values.

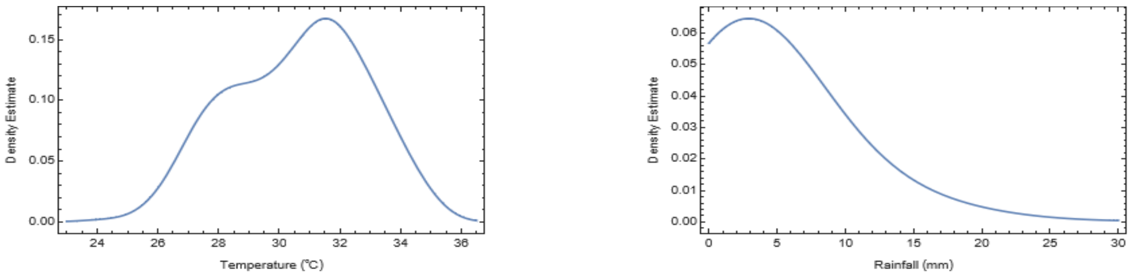


(a)

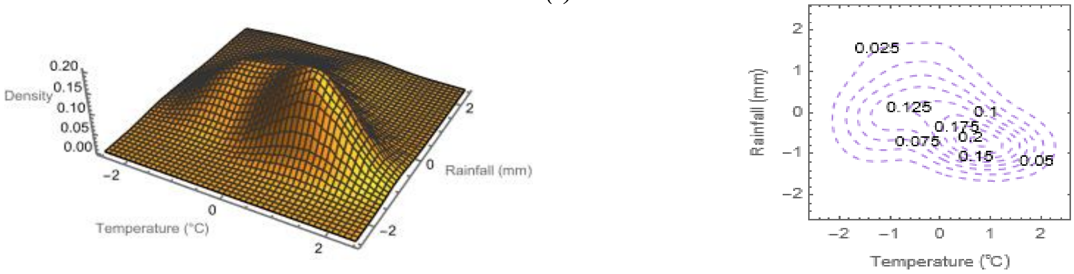


(b)

Figure 2. Estimated temperatures (°C) and rainfalls (mm) of 2016 data by (a) Univariate kernel and (b) Bivariate kernel

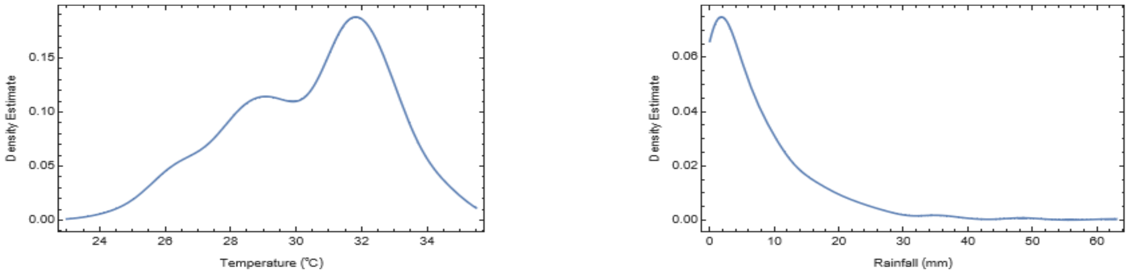


(a)

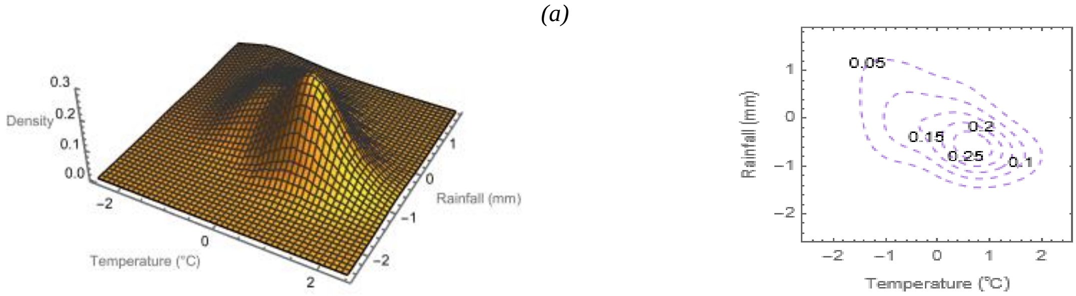


(b)

Figure 3. Estimated temperatures (°C) and rainfalls (mm) of 2017 data by (a) Univariate kernel and (b) Bivariate kernel

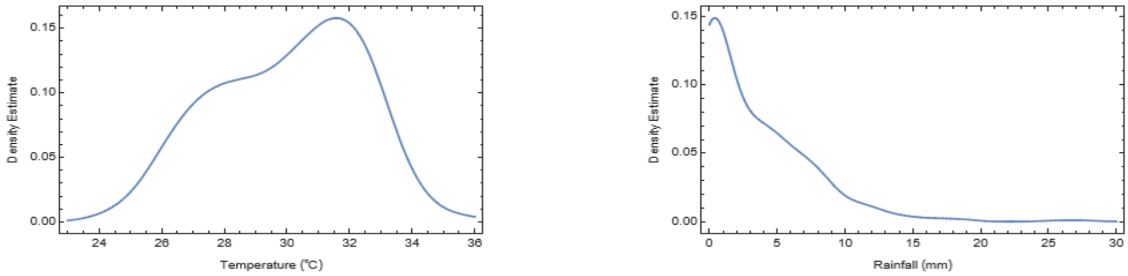


(a)

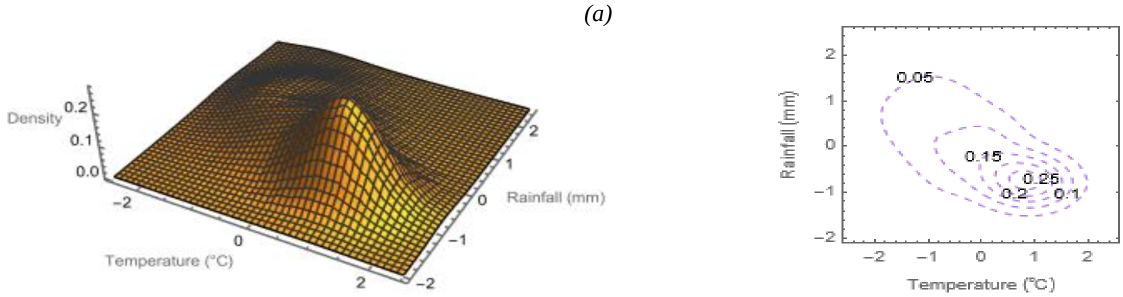


(b)

Figure 4. Estimated temperatures (°C) and rainfalls (mm) of 2018 data by (a) Univariate kernel and (b) Bivariate kernel



(a)

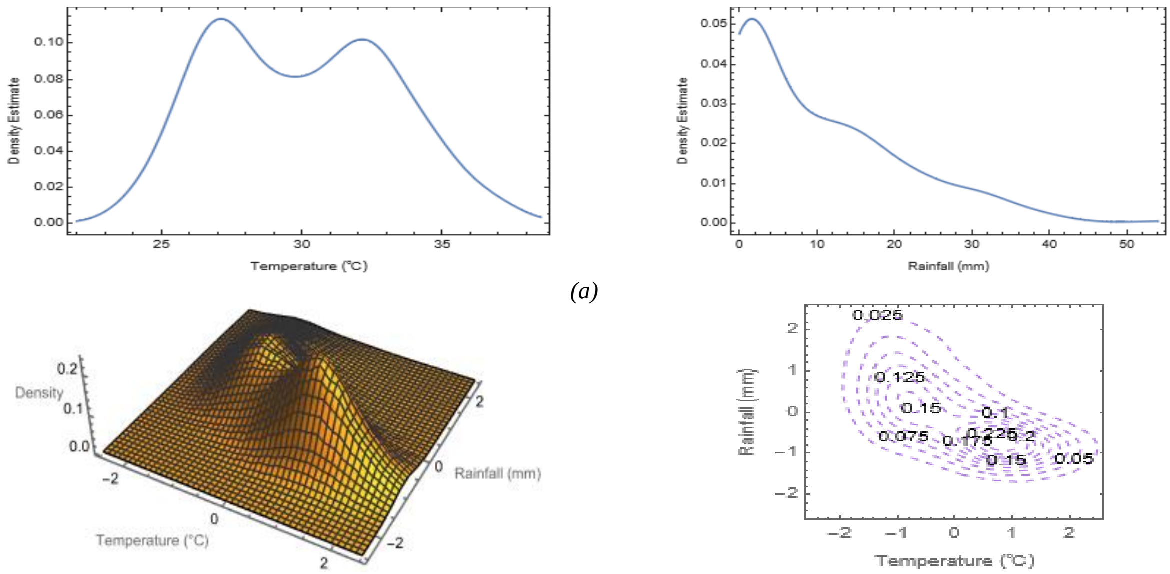


(b)

Figure 5. Estimated temperatures (°C) and rainfalls (mm) of 2019 data by (a) Univariate kernel and (b) Bivariate kernel

One of the main determinants of performance in Equation (7) is the standard deviation because it shows how well distributed the observations are with respect to the mean. A high standard deviation is an indication that the data are well spread out while a low standard deviation implies that the data are clustered around the mean. As stated in Table 3, the distribution of rainfall and temperature varies considering their standard deviations in the period been examined. In the case of years where the standard deviation high for both variables, the performance is better in comparison with years of low standard deviation as vividly noticed in Table 3. The performance of 2016, 2018 and 2020 are better than the performance of 2017 and 2019 and this is attributed to the magnitude of their standard deviations.

As observed from the kernel estimates of rainfall and temperature, the hotter the temperature, the more evaporation is likely to occur which will ultimately lead to high amount of rainfall and vice-versa. Rainfall is a vital weather variable due to the importance of water in Ekpoma especially for consumption and agricultural activities. Ekpoma is known for lack of water due to its location until the recent drilling of bore holes for water supply by private individuals who are well placed financ-



(b)

Figure 6. Estimated temperature (°C) and rainfall (mm) of 2020 data by (a) Univariate kernel and (b) Bivariate kernel

ially for consumption and industrial purposes. Prior to this development, the major source of water has been rainfall since there are no water bodies such as streams and rivers around Ekpoma.

CONCLUSION

This study reveals that there is an irregular pattern of distribution of rainfall in the period been investigated which is attributed to the effect of temperature. The variability of the amount of rainfall in the study period is more noticeable in 2017 and 2019 with maximum amount of rainfall being 29.43mm and 27.74mm, respectively. The performance of years with low amount of rainfall is clearly indicated by the large AMISE values. The study also revealed that smaller amount of rainfall will result in large AMISE values and vice-versa. The low amount of rainfall could lead to drought which is capable of affecting agricultural activities in the area. The decrease in the amount of rainfall may be occasioned by human activities such as deforestation, bush burning and the use of chemicals which are capable of increasing the yearly temperature. Bush burning by farmers and other outdated farming techniques that are not environmentally friendly should be prohibited. Hence, efforts should be made by government and other regulatory bodies to promulgate laws that are environmentally friendly and also to punish erring citizens.

CONFLICT OF INTEREST

The authors declared that they have no conflict of interest.

REFERENCES

1. Cong, R.-G. and Brady, M., 2012. The interdependence between rainfall and temperature: copula analyses, *The Scientific World Journal*, 2012. Doi:10.1100/2012/405675
2. Islam, M. T. and Zakaria, M., 2019. Interdependency between rainfall and temperature using correlation analysis in the Barishal district of Bangladesh, *IOSR Journal of Applied Mathematics*, 15(5), pp. 49-55. Doi:10.9790/5728-1505034955
3. Li, Y., Guan, K., Schnitkey, G. D., DeLucia, E. and Peng, B., 2019. Excessive rainfall leads to maize yield loss of a comparable magnitude to extreme drought in the United States, *Global Change Biology*, 25(7), pp. 2325-2337. Doi:10.1111/gcb.14628
4. Siloko, I., Ukhurebor, K., Siloko, E., Enoyoze, E., Bobadoye, A., Ishiekwene, C., Uddin, O. and Nwankwo, W., 2021. Effects of some meteorological variables on cassava production in Edo State, Nigeria via density estimation, *Scientific African*, 13, pp. e00852. Doi:10.1016/j.sciaf.2021.e00852
5. Urban, D. W., Roberts, M. J., Schlenker, W. and Lobell, D. B., 2015. The effects of extremely wet planting conditions on maize and soybean yields, *Climatic Change*, 130, pp. 247-260. Doi:10.1007/s10584-015-1362-x
6. Lesk, C., Coffel, E. and Horton, R., 2020. Net benefits to US soy and maize yields from intensifying hourly rainfall, *Nature Climate Change*, 10(9), pp. 819-822. Doi:10.1038/s41558-020-0830-0
7. Dell, M., Jones, B. F. and Olken, B. A., 2014. What do we learn from the weather? The new climate-economy literature, *Journal of Economic Literature*, 52(3), pp. 740-798. Doi:10.1257/jel.52.3.740
8. Abrignani, M. G., Corrao, S., Biondo, G. B., Lombardo, R. M., Di Girolamo, P., Braschi, A., Di Girolamo, A. and Novo, S., 2012. Effects of ambient temperature, humidity, and other meteorological variables on hospital admissions for angina pectoris, *European Journal of Preventive Cardiology*, 19(3), pp. 342-348. Doi:10.1177/1741826711402741
9. Manatsa, D. and Matarira, C., 2009. Changing dependence of Zimbabwean rainfall variability on ENSO and the Indian Ocean dipole/zonal mode, *Theoretical and Applied Climatology*, 98, pp. 375-396. Doi:10.1007/s00704-009-0114-0

10. Nkuna, T. R. and Odiyo, J. O., 2016. The relationship between temperature and rainfall variability in the Levubu sub-catchment, South Africa, *International Journal of Education and Learning Systems*, 1. Available at: http://www.iaras.org/iaras/filedownloads/ijes/2016/008-0011.pdf

11. Pumo, D., Carlino, G., Arnone, E. and Noto, L. V., 2018. Relationship between extreme rainfall and surface temperature in Sicily (Italy), *EPiC Series in Engineering*, 3, pp. 1718-1726. Doi:10.29007/rtts

12. Aweda, F. and Samson, T., 2022. Relationship between Air Temperature and Rainfall Variability of Selected Stations in Sub-Sahara Africa, *Iranian (Iranica) Journal of Energy & Environment*, 13(3), pp. 248-257. Doi:10.5829/ijee.2022.13.03.05

13. Oloruntade, A. J., Mogaji, K. and Imoukhuede, O., 2018. Rainfall trends and variability over Onitsha, Nigeria, *Ruhuna Journal of Science*, 9(2). Doi:10.4038/rjs.v9i2.40

14. Siloko, I. U., Ukhurebor, K. E., Siloko, E. A., Enoyoze, E. and Ikpotokin, O., 2022. The interactions between temperature and relative humidity: results for Benin City, Nigeria using statistical analysis, *Current Applied Science and Technology*, 22(1), pp. 1-15. Doi:10.55003/cast.2022.01.22.009

15. Ukhurebor, K. E. and Siloko, I. U., 2020. Temperature and rainfall variability studies within South-South region of Nigeria, *AU eJournal of Interdisciplinary Research*, 5(2), pp. 1-19. Available at:http://www.assumptionjournal.au.edu/index.php/eJIR/article/view/4791

16. Wang, D., Hejazi, M., Cai, X. and Valocchi, A. J., 2011. Climate change impact on meteorological, agricultural, and hydrological drought in central Illinois, *Water Resources Research*, 47(9). Doi:10.1029/2010WR009845

17. Silverman, B. W., 2018. Density estimation for statistics and data analysis. New York: Routledge. ISSN:1315140918.

18. Siloko, I. U., Nwankwo, W. and Umezuruike, C., 2020. A discourse on smoothing parameterizations using hypothetical dataset, *Journal of Applied Sciences*, 1(1), pp. 80-88. Available at: https://jasic.kiu.ac.ug/assets/articles/1593455804_a-discourse-on-smoothing-parameterizations-using-hypothetical-dataset.pdf

19. Siloko, I. and Siloko, E., Year.Density estimation and data analysis using the kernel method, Proceedings of 56th National Conference of Mathematical Association of Nigeria, pp. 218-226,

20. Scott, D. W., 2015. Multivariate density estimation: theory, practice, and visualization. Second edn. New Jersey: John Wiley & Sons. ISSN:0471697559.

21. Siloko, I., Ishiekwene, C. and Oyegue, F., 2018. New gradient methods for bandwidth selection in bivariate kernel density estimation, *Mathematics and Statistics*, 6(1), pp. 1-8. Doi:10.13189/ms.2018.060101

22. Nwaopara, A. and Blackies, H., 2014. The incidence of human induced community road dilapidation: A case study of Ekpoma, Edo-Nigeria, *International Journal of Community Research*, 3(3), pp. 80-85. Avaiable at: https://www.ajol.info/index.php/ijcr/article/view/107686

23. Odjugo, P., Enaruvbe, G. and Isibor, H., 2015. Geospatial approach to spatio-temporal pattern of urban growth in Benin City, Nigeria, *African Journal of Environmental Science and Technology*, 9(3), pp. 166-175. Doi:10.5897/AJEST2014.1715

24. Commission, N. P., 2006. Housing and population census result: Edo State National population office, Benin City.

25. Ehisuoria, S. E., 2014. Strategies for rural poverty reduction in Ekpoma region of Edo State, Nigeria, *Strategies*, 4(9), pp. 100-108. Available at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=ae44aeea5c49fb45c256e8e1038c08ac154d4c73

26. Jarnicka, J., 2009. Multivariate kernel density estimation with a parametric support, *Opuscula Mathematica*, 29(1), pp. 41-55. Available at: https://bibliotekanauki.pl/articles/255530.pdf

27. Cula, S. G. and Toktamis, O., 2012. Estimation of multivariate probability density function with kernel functions, *Journal of the Turkish Statistical Association*, 3(1-2), pp. 29-39. Available at: http://jtsa.ieu.edu.tr/Archives/Volume3No12/4.pdf

Persian Abstract

چکیده

این مقاله بر وابستگی متقابل بین بارندگی و دما و اثر مشترک آنها تمرکز دارد. بارندگی و دما متغیرهای آب و هوایی حیاتی برای بهره‌وری کشاورزی و سایر فعالیت‌های انسانی هستند. علی‌رغم اهمیت بارندگی و دما، به دلیل امکان ارتباط متقابل بین متغیرها مشکلاتی در تحلیل دقیق توزیع مشترک آنها وجود دارد. مطالعات متعددی توسط محققان بر روی تعامل بین متغیرهای آب و هوایی به منظور تعیین اثرات آنها بر محیط زیست انجام شده است زیرا دماها به طور منظم در حال تغییر هستند. تجزیه و تحلیل بارندگی و دما برای اهداف اکتشافی و تجسمی مورد بررسی قرار می‌گیرد زیرا ساختارها و الگوهای زیربنایی اساس تصمیم‌گیری‌های دولت و سازمان‌های نظارتی را تشکیل می‌دهند. این مطالعه از رویکرد آماری در بررسی وابستگی متقابل بین بارندگی و دما در اکپوما، ایالت ادو، نیجریه برای مدت پنج سال متوالی از سال ۲۰۱۶ تا ۲۰۲۰ با استفاده از تخمین‌گر هسته گاوسی استفاده می‌کند. نتایج بررسی‌ها با استفاده از برخی شاخص‌های آماری نشان داد که الگوی بارندگی نامنظمی وجود دارد که ناشی از تغییرات دما است. تغییرپذیری بارندگی بیشتر در دو سال ۲۰۱۷ و ۲۰۱۹ به ترتیب با ۲۹/۴۳ میلی متر و ۲۷/۷۴ میلی متر به عنوان حداکثر میزان بارندگی قابل توجه می‌باشد. نتایج همچنین نشان می‌دهد که عملکرد سال‌های با انحراف استاندارد بالا بهتر از سال‌های با انحراف استاندارد پایین بوده و عملکرد سال‌های با ضرایب همبستگی منفی بالا و کوواریانس منفی بالای بارندگی و دما بهتر از سال‌های با همبستگی ضعیف و کوواریانس کم می‌باشد.