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RESEARCH ARTICLE

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Malaria and meningitis under climate change: initial assessment of climate information service in Nigeria

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Abstract
It is often difficult to define the relationship and the influence of climate on the occurrence and distribution of disease. To examine this issue, the effects of climate indices on the distributions of malaria and meningitis in Nigeria were assessed over space and time. The main purpose of the study was to evaluate the relationships between climatic variables and the prevalence of malaria and meningitis, and develop an early warning system for predicting the prevalence of malaria and meningitis as the climate varies. An early warning system was developed to predetermine the months in a year that people are vulnerable to malaria and meningitis. The results revealed a significant positive relationship between rainfall and malaria, especially during the wet season with correlation coefficient $R^2 \geq 60.0$ in almost all the ecological zones. In the Sahel, Sudan and Guinea, there appears to be a strong relationship between temperature and meningitis with $R^2 > 60.0$. In all, the results further reveal that temperatures and aerosols have a strong relationship with meningitis. The assessment of these initial data seems to support the finding that the occurrence of meningitis is higher in the northern region, especially the Sahel and Sudan. In contrast, malaria occurrence is higher in the southern part of the study area. We suggest that a thorough investigation of climate parameters is critical for the reallocation of clinical resources and infrastructures in economically underprivileged regions.

KEYWORDS
aerosol, climatic indices, malaria, meningitis, tropical ecological zones

1 | INTRODUCTION

The climate–health relationship is now an issue of concern for health policies in many countries because of the total number of people at risk, the age structure of the population and the density of the settlements. Interannual climate variability has been known to be the primary cause of the annual changes in the occurrences of malaria in Africa (Afrane *et al.*, 2004; Omumbo *et al.*, 2011; Chirombo *et al.*, 2020). Malaria and meningitis are among the most important causes of morbidity and mortality, especially in African countries. Understanding the climate conditions that drive malaria and meningitis occurrence, future patterns and transmission determines the efficient control programmes and contingency plans to be put in place before a major outbreak.

Potentially 400 million people are exposed to meningitis within the West Africa belt, resulting in 25,000 to 250,000 victims every year; the occurrence of meningitis epidemics occurs in the local dry season, when there is a substantial amount of dust in the atmosphere. Environmental change increases the risk of meningitis in Africa, especially in the Sahel region of West Africa which is immediately after the Sahara desert (Molesworth *et al.*, 2003; Sultan *et al.*, 2005; De Longueville *et al.*, 2013).

In recent years, several studies on the interaction between climate and human health have greatly emphasized the role of climate change in determining the rise in malaria occurrence in the highland areas in Africa where temperature in place of rainfall is the dominant parameter in the study. Some of these studies have suggested that climate can affect infectious disease patterns because disease agents (viruses, bacteria and other parasites) and their vectors are highly sensitive to temperature, moisture and other ambient environmental conditions (Ameneshewa, 1995; Appawu *et al.*, 2004; Boakye *et al.*, 2004). Malaria and meningitis are distributed mainly throughout the warmer regions of the world, and Nigeria is one of the countries in which they are holoendemic. The yearly economic loss due to malaria in Nigeria has been put as 12 billion Naira due to cost of treatment, loss of working hours, absenteeism from school and other indirect costs not only on the country's income but on the rate of economic growth and invariably on its level of economic development. Thus, malaria places a staggering economic burden on the already strained national economics. It has been hypothesized that variations in climatic conditions could be the critical factor that influences the geographical range and intensity of malaria transmission in endemic areas. Other risk factors such as climate changes were implicated for a possible role in the Nigeria malaria mortality rate. Notwithstanding in recent times, not much has been done on the impact of climatic indices on both malaria and meningitis in Nigeria. While some studies have focused on the socio-economic impact of man on the prevalence of these diseases in both Nigeria and other African countries, none has provided a model that will serve as an early warning system in endemic locations (Siamudaala, 2006; Sindato *et al.*, 2011).

Despite the effort in achieving these results, the relationship between climatic indices and epidemics remains unclear. For this reason, this study aims at examining the intimate relationship between variability in climatic indices (precipitation, temperature and aerosol) and the occurrences of malaria and meningitis across the different tropical ecological zones in Nigeria. Since Nigeria is one of the fastest growing countries in Africa in terms of population and economic development, the social implications of this study may be paramount. The motivation of the study is based on three research questions: (a) What are the indicators of climate variability in the study area? (b) What are the drivers of malaria and meningitis spatiotemporal distributions in the study area? (c) Also, are there relationships between climatic variables and the prevalence of meningitis and malaria? Hence, the study investigates the prevalence of malaria and meningitis with regard to the changes in the distribution of precipitation, temperature and aerosol, alongside creating a model that will serve as an early warning system.

2 | DATA AND METHODS

Both satellite climatology data and epidemic (malaria and meningitis) data were used in this study. Satellite climatology data, including precipitation, minimum and maximum temperature from January 2000 to December 2018, and aerosol optical depth (AOD) from January 2000 to December 2018, were retrieved from satellite observations. These data scale from January to December, showing the variability in each month. The dataset covers the ecological zones in Nigeria (Figure 1), the Sahel savannah, Sudan savannah, Guinea savannah, rainforest, freshwater and the mangrove swamp. The mangrove is located in the coastal regions, in the southern part of Nigeria, especially in the Niger Delta. It is also found in the low swampy land that is associated with rivers and lagoons under the influence of the sea; this type of ecological zone is the type that nurtures the breeding of mosquitoes since the soils are poorly aerated. The freshwater forest is mainly found in the inland region; the plant types here are palm and fibre plants. The tropical forest is an ecological zone characterized by biodiversity; it stretches from the western border of Nigeria to the Benin Republic and along the Niger–Benue river system. Guinea savannah is found in the middle of the country, the west and north. The Sahel savannah is found in the northeastern states and is affected by extreme weather. The montane zone is found in the mountainous areas, while Sudan savannah is located in the northwestern region.

In the study area, the daily temperature is sometimes above 35–38°C depending on the location; the monthly mean value falls to around 27°C. The intertropical convergence zone includes the warm, tropical-maritime air mass that originates from the Atlantic Ocean over the southern part of Nigeria and the dry, dusty, tropical-continental air mass which originates from the Sahara desert over northern Nigeria. The Sahara desert is a

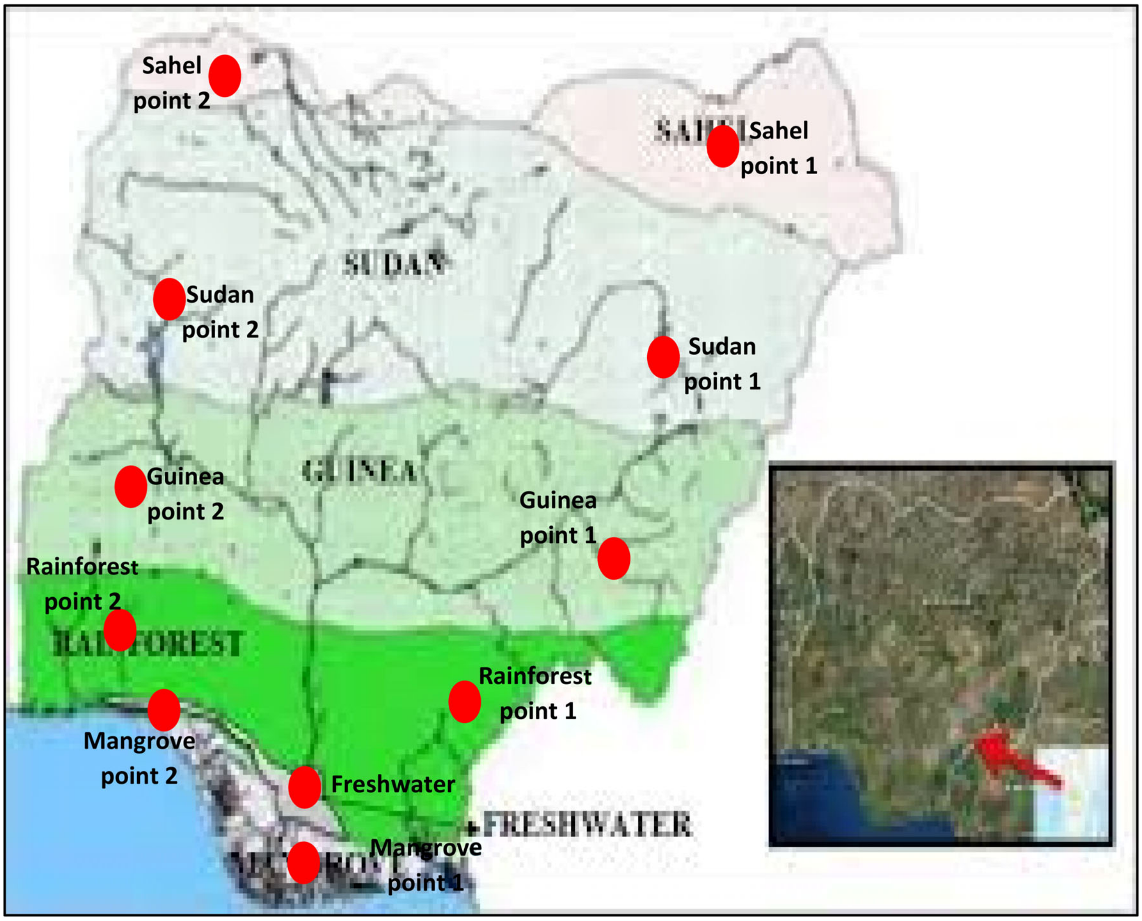

FIGURE 1 Map of the study area, showing distinct ecological zones with the specific locations of data collection (the red points)

significant indicator of climatic variability in Nigeria: temperature increases around March–April moving northward, after a low period in January, while the inter-tropical convergence zone (rainfall) causes a low temperature in the north in August when the sun migrates southward (Ayanlade *et al.*, 2019). Climate datasets of the Moderate Radiometer Imaging Spectroradiometer and Tropical Rainfall Measuring Mission (TRMM) for these ecological zones were assessed from the National Oceanic and Atmospheric Administration (NOAA). The principal climate variables considered are rainfall, temperature and aerosol (Table 1).

The analysis of climate indices (Table 1) was carried out using precipitation and precipitation estimate percentages. The calculation of percentage occurrence of climate conditions suitable for the transmission of malaria and meningitis was initiated based on climate indices. Numerous climate indices have been projected for climate change and its effect. The principal climate variables usually considered are with respect to rainfall, temperature and humidity (Dale *et al.*, 2001; Caminade *et al.*, 2014). Since Nigeria is a tropical country, it follows that these indices will be mainly peculiar to the tropics. These are discussed in Table 1. Descriptive statistical techniques were adopted; maps and charts were developed to show the estimate and trend of climatic indices, which include precipitation, AOD and maximum and minimum temperature. The pattern of the climatic index (Table 1) was compared with the malaria and meningitis dataset to show the relationship between the diseases and climatic indices. An early warning system model was developed to project the possibility of malaria and meningitis occurring at specific periods of climatic extremes. Numerous climate indices have been projected for climate change and its impacts on health (Jessel *et al.*, 2019).

3 | CLIMATE VARIABILITY AND OCCURRENCE OF MALARIA AND MENINGITIS

In each ecological zone, the results show variations in both rainfall and temperature for each season. The two seasons in Nigeria are the wet and dry seasons. The climate of an area can be best understood through annual

TABLE 1 Climate indices estimated to be responsible for the prevalence of malaria and meningitis

Climate indices		Prevalence of malaria and meningitis	
Rainfall indices	Heavy precipitation days: number of days with precipitation ≥1 mm Highest effective precipitation during a consecutive 7 day period Highest effective precipitation during a consecutive 14 day period Highest effective precipitation during a consecutive 30 day period	Climate indices estimated to be responsible for the outbreak and prevalence of malaria at a particular location are: Average precipitation greater than 80 mm Temperature ranging from 180°C < T < 32°C Relatively humidity (>60%)	The outbreak and prevalence of meningitis at a particular location is estimated to be due to various indices such as: Temperature— meningitis thrives during warm seasons Wind that carries dust and aerosols When the threshold of dryness reaches 40%
Temperature indices	Mean daily maximum temperature in °C Mean daily minimum temperature in °C Maximum consecutive days with daily maximum temperature above 15°C in days Warm night/hot night frequency: percentage of days when daily minimum temperature (TN) 90th percentile		
Aerosols	The relative amount of aerosols—solid and liquid particles suspended in the atmosphere influenced by the action of wind and precipitation/ITCZ were estimated		

Abbreviations: ITCZ, intertropical convergence zone.

TABLE 2 Annual and seasonal variations in climatic indices in ecological zone seasons

Ecological zone Annual variation	Maximum temperature (°C) 2002–2018		Minimum temperature (°C) 2002–2018		Average rainfall (mm) 2002–2018		Average aerosol 2000–2018	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sahel	32.74	2.17	21.06	2.85	435	23.45	0.55	0.04
Sudan	31.61	2.76	20.06	2.13	498	31.21	0.51	0.05
Guinea	30.86	2.30	20.76	1.97	503	41.08	0.41	0.08
Rainforest	29.56	1.43	20.46	1.08	698	87.01	0.34	0.03
Freshwater	27.42	1.23	19.33	1.91	1,002	92.12	0.19	0.08
Mangrove	27.62	1.09	18.34	3.02	1987	103.13	0.18	0.05
Seasonal variation								
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Sahel	33.68	31.87	29.36	21.25	54.18	676	0.54	0.49
Sudan	33.13	31.25	29.32	29.71	61.02	749	0.51	0.42
Guinea	32.57	29.43	28.85	27.08	73.37	896	0.40	0.20
Rainforest	31.87	28.63	28.72	27.57	110.65	932	0.26	0.18
Freshwater	30.47	26.32	27.92	26.15	198.58	1,343	0.21	0.15
Mangrove	30.68	25.57	27.59	26.49	219.57	2,708	0.21	0.14

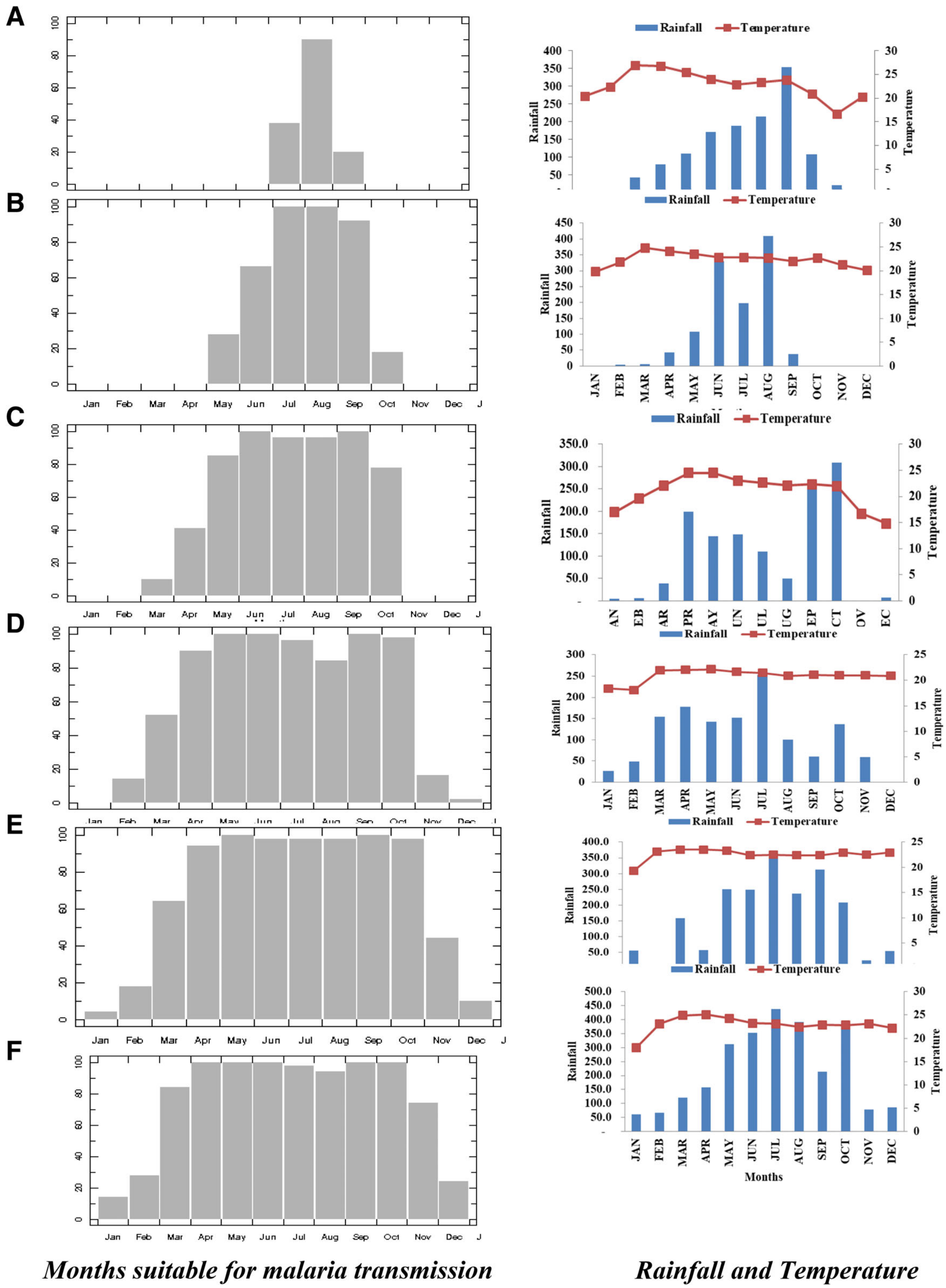

FIGURE 2 Rainfall and temperature monthly frequency and malaria occurrences: A, Sahel; B, Sudan; C, Guinea; D, rainforest; E, freshwater; F, mangrove

or seasonal averages of rainfall and precipitation (Table 2). The average aerosol is more significant in the Sahel and Sudan zones, compared to the freshwater and mangrove zones (Table 2). The mean annual rainfall is generally higher in the rainforest, freshwater and mangrove zones compared with Sahel and Sudan (Table 2). In contrast, the Sahel and Sudan ecological zones experience higher temperatures than other ecological zones.

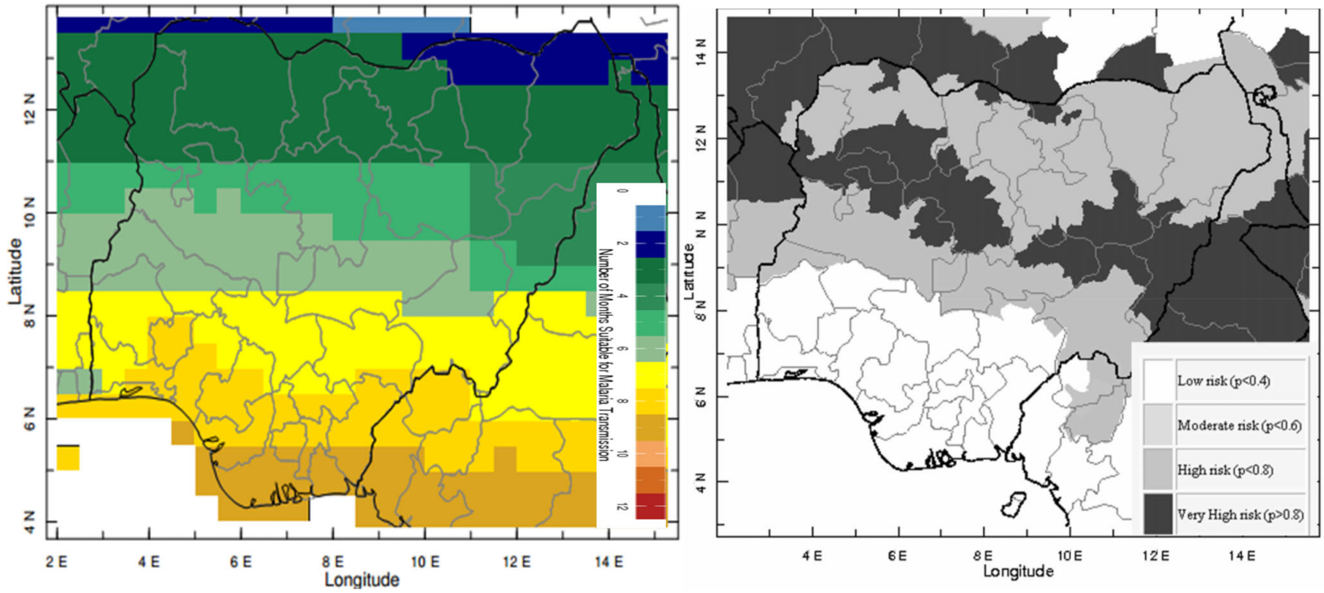

FIGURE 3 The number of months suitable for malaria and meningitis transmission

The results in Table 2 reveal the seasonal climate variability with many variations from dry to wet seasons. Both freshwater and mangrove ecological zones experience higher annual (seasonal) rainfall, with rainfall >1,000 mm during the wet season. However, the Sahel, Sudan and Guinea ecological zones experience deficient precipitation, mostly rain during 3–6 months, with annual rainfall ranging between 100 mm and 1,000 mm. In the Sahel and Sudan, the temperature is at its highest (≥30°C) during the dry seasons, with maximal temperatures rising as high as 40°C in some years.

Variations in monthly rainfall and temperature are visible in all the ecological zones. The temperature distribution appears relatively high across the environmental zones with temperature >20°C throughout the year (Figure 2). Precipitation increases from the northern part of Nigeria to the south, while temperature varies over the ecological zones. On the other hand, rainfall appears highly variable in all ecological zones. (Figure 2). In rainforest, freshwater and mangrove zones, for example, the annual precipitation in some years is greater than 1,041 mm with temperature ranging from 19°C to 30°C and these climatic indices are suitable for malaria prevalence. Generally, in the various ecological zones, the rate of precipitation is high because Nigeria is a tropical region of the world. For meningitis, the climatic index is the aerosol. The Sahel has an aerosol that ranges from 0.4 to 0.57, which is the highest density of aerosol; the rate of meningitis in this ecological zone will be the highest (Table 2, Figure 3). The Sudan zone aerosol ranges from 0.42 to 0.25, while the aerosol falls within 0.47 to 0.35 in the Guinea zone. Rainforest has an average aerosol of 0.17 to 0.30. In freshwater and mangrove zones the aerosol ranges from 0.15 to 0.21 (Table 2). Aerosol density in the north is higher, and it declines towards the south. This is a result of the northeastern trade wind, originating from the Sahara desert and flowing into Nigeria from the north.

Each ecological zone shows a distinct rate of malaria transmission. The monthly malaria occurrence is an indication of the monthly variation in rainfall (Figure 2). The malaria transmission in the ecological zones are indicators of the corresponding amount of rainfall variability as presented in Figure 2. The months with the highest risk of malaria occurrence are July to September in the Sahel zone, while May to October have the highest risk of malaria occurrence in the Sudan zone. Figure 2 further reveals that the months with the highest risk of malaria occurrence are March to October for the Guinea zone; February to November for the rainforest zone; January to December for the freshwater and mangrove ecological zones.

Figure 3 shows the pattern of malaria transmission throughout the ecological zones. From Sahel to Guinea savannah, between 1 and 5 months are ideal malaria the transfer of malaria, but between 5 and 9 months for the southern ecological zones. This distribution is in line with the spatial and temporal variability in precipitation. Precipitation is higher in the southern region of Nigeria than in the north (Figure 3). The results of the climate indicator and suitability for meningitis transmission also revealed further variations for each ecological location (Figure 4).

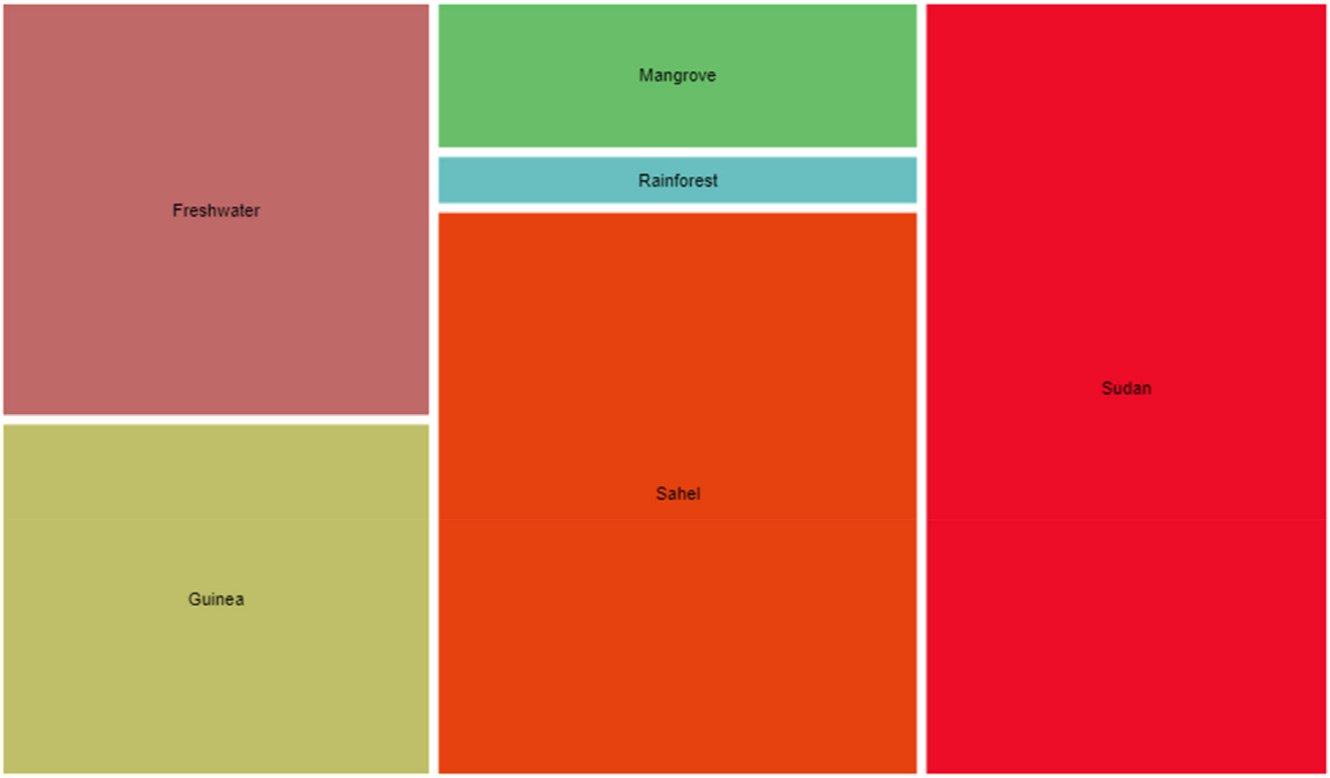

FIGURE 4 Chart showing the correlation between dust/temperature and the prevalence of meningitis

The amount of AOD in a particular location influences the transmission of meningitis in such places (Figure 4). The monthly distribution of aerosol in Sahel savannah peaks in February and extends to April, $2 \geq \text{AOD} \geq -1$. The Sudan savannah shows a similar trend to Sahel savannah, $2 \geq \text{AOD} \geq -1$. The disparity in AOD between Guinea and Sudan slight increase in April but May to December apears considerable varied with, $2 \geq \text{AOD} \geq -1$ in Figure 4. For the rainforest zone, the highest AOD is in April, followed by February, while the lowest amount is in June $2.5 \geq \text{AOD} \geq -1$ (Figure 4). The freshwater has a similar occurrence of AOD with the rainforest green zone (Figure 4). For all the locations, the months with the highest AOD experiences show the highest rate of meningitis for the period of the study.

4 | INFLUENCE OF CLIMATIC INDICES ON MALARIA AND MENINGITIS DISTRIBUTION

Table 3 shows the correlation coefficient for all the ecological zones. The correlation coefficient signifies the degree to which the rainfall, dust and temperature affects malaria and meningitis distributions over different seasons. All the ecological zones show a positive correlation between climate variables and malaria distribution within a year. The results reveal a significant positive relationship between rainfall and malaria, especially during the wet season with correlation coefficient $R^2 \geq 60.0$, in almost all the ecological zones. However, meningitis rainfall has less influence on the spread of meningitis with correlation coefficient $R^2 < 35.0$ during both dry and wet seasons in all the ecological zones. A strong positive relationship between rainfall and malaria was noted, for example, in freshwater and mangrove zones, with a correlation coefficient $R^2 = 72.13$ and 70.09 respectively during the wet season. Still, the relationship between rainfall and meningitis in all ecological zones appears weak (Table 3).

The results imply that rainfall does not have a significant influence on meningitis transmission. In the Sahel, Sudan and Guinea, there appears to be a strong relationship between temperature and meningitis with $R^2 > 60.0$. The influence of temperature on malaria is prominent in the Sahel zone with a correlation coefficient $R^2 = 65.23$ (Table 3). These results imply that temperature has a more substantial impact on meningitis than malaria. On the other hand, meningitis is most affected by aerosol, especially in the Sahel, Sudan and Guinea savannah compared to different ecological zones. What is evident from these results is that meningitis exhibits the strongest

TABLE 3 The relationship and influence of climatic indices on the occurrence of malaria and meningitis in different ecological zones in the study area

		Rainfall		Temperature		Dust	
Ecological zone	**SS**	**Malaria**	**Meningitis**	**Malaria**	**Meningitis**	**Malaria**	**Meningitis**
Sahel	DS	17.34	34.54	21.43	72.01	11.71	71.67
	WS	68.12	16.29	65.23	32.01	09.98	31.03
Sudan	DS	12.02	21.87	12.56	70.12	10.66	70.01
	WS	60.51	14.72	32.45	33.87	11.43	29.51
Guinea	DS	15.21	11.69	10.01	64.22	19.55	61.34
	WS	61.78	10.09	29.69	35.89	12.05	23.78
Rainforest	DS	45.03	10.34	12.77	40.01	12.90	24.05
	WS	70.01	09.04	23.78	15.44	14.34	34.13
Freshwater	DS	58.92	09.03	14.06	07.18	08.06	19.56
	WS	72.13	05.31	55.78	06.05	01.18	15.47
Mangrove	DS	60.45	10.07	13.56	15.67	06.67	10.88
	WS	70.09	04.07	58.56	02.07	04.91	08.98

Abbreviations: DS, dry season; SS, season; WS, wet season.

TABLE 4 Predicted probability of malaria and meningitis epidemic

	Predicted probability of malaria				Predicted probability of meningitis			
	West		**East**		**West**		**East**	
Ecological zone	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**
Sahel	0.12	0.24	0.11	0.22	0.51	0.38	0.48	0.28
Sudan	0.14	0.36	0.10	0.27	0.42	0.32	0.54	0.23
Guinea	0.13	0.38	0.11	0.23	0.23	0.19	0.10	0.13
Rainforest	0,23	0.48	0,19	0.47	0.03	0.04	0.03	0.07
Freshwater	0.21	0.48	0.20	0.46	0.03	0.02	0.17	0.05
Mangrove	0.22	0.51	0.32	0.49	0.02	0.01	0.09	0.08

Abbreviations: DS, dry season; WS, wet season.

correlation with temperature and aerosol, while malaria has a strong relationship with precipitation (Table 3).

These results are a reflection of the predicted probability of malaria, which is much more during the wet season, but the predicted probability of meningitis is much more during the dry season, especially in the Sahel and Sudan ecological zones (Table 4). Some studies have reported that malaria transmission was highly seasonal due to climatic conditions; these occurrences are much more frequent in recent times due to climate change (Asadullah *et al.*, 2008; Samdi *et al.*, 2012; Ayanlade *et al.*, 2013; Maggioni *et al.*, 2016; Nandargi, 2016; Guofeng *et al.*, 2017; Sergi *et al.*, 2019). Meningitis is predominant during the dry season. This suggests that variability in climatic elements such as low precipitation, high temperature and aerosol are responsible for this (Frederick, 2013; Ayanlade *et al.*, 2015). Ayanlade *et al.* (2015) has earlier noted that the northern part of Nigeria is the most affected by meningitis. The difference between their study and the present study is the extent of the present study which covers the whole country and considers impacts of climate change not only on meningitis but also on malaria. The present study further develops climatic indices for both malaria and meningitis and predicts the probability of a malaria and meningitis epidemic. The major findings are that meningitis is greatly influenced by the northeast trade wind which moves dust, as the wind blowing from the northern part Sahara through Niger (Middleton and Goudie, 2006; Ayanlade *et al.*, 2015).

It has been reported in the literature also that knowledge of climate variability over some time with records is essential to understand the nature of some illnesses (Henne *et al*., 2018). While meningitis occurs in every part of the world, the highest rate is recorded in Sub-Saharan Africa (Besancenot *et al*., 1997; Mohammed *et al*., 2017; Novak *et al*., 2019; Greene *et al*., 2020). This area spreads from the Gambia to Ethiopia, known as the "meningitis belt." Meningitis occurs mostly during the warmer months between February and April, with a significant effect on a large number of people in cycles of 8–12 years (Goldsmith, 2007). Climate not only defines the seasonal and spatial distribution of disease, but also influences the inter-annual variability of epidemics. In long term trends, climate variability is now an issue of concern for health policy in many countries because the total number of people at risk, the age structure of the population and the density of settlements are important variables determining the socio-economic development of any country (Meehl *et al*., 2007; Portier *et al*., 2017; Hathaway and Maibach, 2018).

5 | CONCLUSION

In this study, the influence of temperature, precipitation and aerosol on the seasonal distribution of malaria and meningitis across six ecological zones in Nigeria from 2000 to 2017 were assessed using NOAA satellite data. The satellite data were analysed using the *Z* test, and the correlation coefficient was used to evaluate the degree of influence of climatic indices on the monthly distribution of malaria and meningitis. There are three significant findings in this study: (a) the climatic indices vary across ecological zones; (b) the climatic index with the most significant influence on the event and spread of malaria is precipitation; (c) while for meningitis temperature and aerosol are the most significant climate indices. The harmattan season experiences the highest mean AOD. Sahel, Sudan and Guinea savannah have the highest AOD during the dry season, while the rainforest, freshwater and mangrove zones have the lowest AOD during the wet season in Nigeria. Therefore, meningitis is higher in the north than in the south of Nigeria, and aerosol is highest during the dry season from November through February. In contrast to meningitis, malaria occurrence is higher in the south than in the north of Nigeria, and precipitation is higher in the south than the north. During the wet and dry season, precipitation is higher from June to September; this is the wet season of Nigeria. Temperature is relatively high within the year because in Nigeria, a tropical country, the relationship between temperature and meningitis is higher than the relationship between malaria and temperature.

Meningitis appeared higher during the dry season, because aerosol has a significant influence on meningitis, while malaria is higher during the wet season because precipitation has a substantial influence on malaria. Malaria and meningitis are affected by variables other than the climatic indices, and factors like urbanization, irrigation and agricultural practices affect malaria (Lindblade *et al*., 2000; Kibret *et al*., 2010). In contrast, meningitis is affected by available medical facilities, feeding habits and many more. Because of the nature of its variability or precipitation in amount and intensity in different ecological zones, rainfall is considered to be one of the significant factors influencing variability in malaria transmission (Onyango *et al*., 2016), only because it provides a breeding site for mosquitoes (malaria vector) to lay their eggs and ensures a suitable humid condition to prolong mosquito survival. The temperature determines the ability of mosquitoes to survive as they cannot survive under extreme temperature conditions. Aerosols, which consist of dust, gases and water vapour, determine meningitis prevalence to no small extent.

Meningitis is more predominant in January, February, April and December throughout the year. The reason for this is that these periods belong to the dry season in Nigeria. Meningitis is higher in the north than in the south; the influence of dry wind blowing over the north from the Sahara is the primary reason for this. The climatic variable that has the most substantial impact on meningitis is aerosol. Malaria is more predominant during the wet season from June to September than for most of the year. Precipitation has the most significant influence on malaria; moisture increases breeding sites for mosquitoes. The prevalence of malaria is higher in the south than in the north; the reason for this is that there is more precipitation in the south than in the north of Nigeria.

The factors affecting malaria and meningitis epidemics or distribution cannot be limited to climate alone. There are non-climatic factors, whether directly or indirectly, that have a significant relationship with the occurrence of these epidemics. The factors that affect malaria include irrigation and agricultural practices. The migration of non-immune people creates an environment for the epidemic. These areas are unplanned, and poor people live in unsanitary conditions. This creates the right environment for getting malaria. Urbanization increases both malaria and meningitis. It leads to overpopulation in urban centres, which causes a rapid transmission of the diseases; aerosols are generated more in urban centres. There is a higher probability of having water-logged areas, especially in unplanned urban centres, that will increase the breeding of mosquitoes. Also, urbanization is heavily connected with industrialization, at least in some geographical areas, which leads to the emission of greenhouse gases which cause an increase in temperature of the environment.

The rise in temperature increases the number of days for a mosquito's lifecycle; high temperature is also suitable for the transmission of meningitis. Irrigation is created by building large numbers of dams and canals, which often cause seepage from canals and a rise in the water table, thus creating a source of still water in which malaria vectors can breed (Kelly-Hope and Thomson, 2008). Irrigation can increase the transmission season of malaria. Dry regions require moisture to carry out agricultural practices, so pipes and drains are created to move water to the farm sites. Leaks in the pipes and tube rupture create artificial water bodies that serve as a breeding ground for mosquitoes; this seems to be contradictory to meningitis occurrence because meningitis is predominant in dry regions due to the presence of aerosols. Mosquitoes are also known to feed on maize pollen, and a 2005 study reported an association between intensified maize cultivation and higher malaria transmission in an area of Ethiopia. Previously maize, a marginal garden crop, became intensely cultivated close to homes, with correspondingly high levels of pollen. This aspect does not mean maize causes malaria, but it shows how specific agro-ecological changes can accelerate it, perhaps in an unforeseen way. The accessibility of healthcare facilities is another fundamental determinant. With regard to the prevalence of both epidemics, when there is adequate health provision, the sustainability and prevalence of the outbreaks will be minimal.

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REFERENCES

Afrane, Y.A., Klinkenberg, E., Drechsel, P., Owusu-Daaku, K., Garms, R. and Kruppa, T. (2004) Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi, Ghana? *Acta Tropica*, 89, 125–134.

Ameneshewa B (1995) The Behaviour and Bioloy of Anopheles Arabiensis in Relation to Epidemiology and Control of Malaria in Ethiopia. Doctoral dissertation, University of Liverpool.

Appawu, M., Owusu-Agyei, S., Dadzie, S., Asoala, V., Anto, F., Koram, K., Rogers, W., Nkrumah, F., Hoffman, S.L. and Fryauff, D.J. (2004) Malaria transmission dynamics at a site in northern Ghana proposed for testing malaria vaccines. *Tropical Medicine and International Health*, 9, 164–170.

Asadullah, A., McIntyre, N. and Kigobe, M. (2008) Evaluation of five satellite products for estimation of rainfall over Uganda/Evaluation de cinq produits satellitaires pour l'estimation des précipitations en Ouganda. *Hydrological Sciences Journal*, 53, 1137–1150.

Ayanlade, A., Adeoye, N.O. and Babatimehin, O. (2013) Intra-annual climate variability and malaria transmission in Nigeria. *Bulletin of Geography Socio-Economic Series*, 21, 7–19.

Ayanlade, O.S., Baloye, D.O., Jegede, M.O. and Ayanlade, A. (2015) A geo-informatics technique for the management of meningitis epidemic distributions in northern Nigeria. *Information Resources Management Journal (IRMJ)*, 28, 15–28.

Ayanlade, A., Atai, G. and Jegede, M.O. (2019) Spatial and seasonal variations in atmospheric aerosols over Nigeria: assessment of influence of intertropical discontinuity movement. *Journal of Ocean and Climate*, 9, 1759313118820306.

Besancenot, J., Boko, M. and Oke, P. (1997) Weather conditions and cerebrospinal meningitis in Benin (Gulf of Guinea, West Africa). *European Journal of Epidemiology*, 13, 807–815.

Boakye, D., Wilson, M., Appawu, M. and Gyapong, J. (2004) Vector competence, for *Wuchereria bancrofti*, of the Anopheles populations in the Bongo district of Ghana. *Annals of Tropical Medicine and Parasitology*, 98, 501–508.

Caminade, C., Kovats, S., Rocklov, J., Tompkins, A.M., Morse, A.P., Colón-González, F.J., Stenlund, H., Martens, P. and Lloyd, S.J. (2014) Impact of climate change on global malaria distribution. *Proceedings of the National Academy of Sciences*, 111, 3286–3291.

Chirombo, J., Ceccato, P., Lowe, R., Terlouw, D.J., Thomson, M.C., Gumbo, A., Diggle, P.J. and Read, J.M. (2020) Childhood malaria case incidence in Malawi between 2004 and 2017: spatio-temporal modelling of climate and non-climate factors. *Malaria Journal*, 19, 1–13.

Dale, V.H., Joyce, L.A., McNulty, S., Neilson, R.P., Ayres, M.P., Flannigan, M.D., Hanson, P.J., Irland, L.C., Lugo, A.E. and Peterson, C.J. (2001) Climate change and forest disturbances: climate change can affect forests by altering the frequency, intensity, duration, and timing of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. *AIBS Bulletin*, 51, 723–734.

De Longueville, F., Ozer, P., Doumbia, S. and Henry, S. (2013) Desert dust impacts on human health: an alarming worldwide reality and a need for studies in West Africa. *International Journal of Biometeorology*, 57, 1–19.

Frederick, A. (2013) *Patterns, Perceptions and Management of Cerebro-spinal Meningitis in the Kassena-Nankana East and West Districts*. Accra, Ghana: University of Ghana.

Goldsmith, C. Meningitis. Twenty-First Century Books; 2007 Jul 31.

Greene, G., Lawrence, D., Jordan, A., Chiller, T. and Jarvis, J.N. (2020) Cryptococcal meningitis: a review of cryptococcal antigen screening programs in Africa. *Expert Review of Anti-Infective Therapy*, 1–12.

Guofeng, Z., Dahe, Q., Yuanfeng, L., Fenli, C., Pengfei, H., Dongdong, C. and Kai, W. (2017) Accuracy of TRMM precipitation data in the southwest monsoon region of China. *Theoretical and Applied Climatology*, 129, 353–362.

Hathaway, J. and Maibach, E.W. (2018) Health implications of climate change: a review of the literature about the perception of the public and health professionals. *Current Environmental Health Reports*, 5, 197–204.

Henne, P.D., Bigalke, M., Büntgen, U., Colombaroli, D., Conedera, M., Feller, U., Frank, D., Fuhrer, J., Grosjean, M. and Heiri, O. (2018). An empirical perspective for understanding climate change impacts in Switzerland. *Regional environmental change*, 18(1), 205–221.

Jessel, S., Sawyer, S. and Hernández, D. (2019) Energy, poverty, and health in climate change: a comprehensive review of an emerging literature. *Frontiers in Public Health*, 7, 1–19.

Kelly-Hope, L. and Thomson, M.C. (2008) Climate and infectious diseases. In: *Seasonal Forecasts, Climatic Change and Human Health*. New York, NY: Springer.

Kibret, S., Alemu, Y., Boelee, E., Tekie, H., Alemu, D. and Petros, B. (2010) The impact of a small-scale irrigation scheme on malaria transmission in Ziway area, Central Ethiopia. *Tropical Medicine and International Health*, 15, 41–50.

Lindblade, K.A., Walker, E.D., Onapa, A.W., Katungu, J. and Wilson, M. L. (2000) Land use change alters malaria transmission parameters by modifying temperature in a highland area of Uganda. *Tropical Medicine and International Health*, 5, 263–274.

Maggioni, V., Meyers, P.C. and Robinson, M.D. (2016) A review of merged high-resolution satellite precipitation product accuracy during the Tropical Rainfall Measuring Mission (TRMM) era. *Journal of Hydrometeorology*, 17, 1101–1117.

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye T, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A (2007) Global climate projections.

Middleton, N. and Goudie, A. (2006) *Desert Dust in the Global System*. New York, NY: Springer.

Mohammed, I., Iliyasu, G. and Habib, A.G. (2017) Emergence and control of epidemic meningococcal meningitis in sub-Saharan Africa. *Pathogens and Global Health*, 111, 1–6.

Molesworth, A.M., Cuevas, L.E., Connor, S.J., Morse, A.P. and Thomson, M.C. (2003) Environmental risk and meningitis epidemics in Africa. *Emerging Infectious Diseases*, 9, 1287–1293.

Nandargi, S.S. (2016) Assessment of TRMM rainfall data (2001–2015) over the Indian region. *Focus On Medical Sciences Journal*, 2, 1–10.

Novak, R.T., Ronveaux, O., Bita, A.F., Aké, H.F., Lessa, F.C., Wang, X., Bwaka, A.M. and Fox, L.M. (2019) Future directions for meningitis surveillance and vaccine evaluation in the meningitis belt of sub-Saharan Africa. *The Journal of Infectious Diseases*, 220, S279–S285.

Omumbo, J.A., Lyon, B., Waweru, S.M., Connor, S.J. and Thomson, M.C. (2011) Raised temperatures over the Kericho tea estates: revisiting the climate in the East African highlands malaria debate. *Malaria Journal*, 10, 12.

Onyango, E.A., Sahin, O., Awiti, A., Chu, C. and Mackey, B. (2016) An integrated risk and vulnerability assessment framework for climate change and malaria transmission in East Africa. *Malaria Journal*, 15, 551.

Portier, C.J., Thigpen, T.K., Carter, S.R., Dilworth, C.H., Grambsch, A. E., Gohlke, J., Hess, J., Howard, S.N., Luber, G. and Lutz, J.T. (2017) *A Human Health Perspective on Climate Change: A Report Outlining the Research Needs on the Human Health Effects of Climate Change*. Quezon City, Philippines: National Institute of Environmental Health Sciences.

Samdi, L., Ajayi, J., Oguche, S. and Ayanlade, A. (2012) Seasonal variation of malaria parasite density in paediatric population of north eastern Nigeria. *Global Journal of Health Science*, 4, 103.

Sergi, C., Serra, N., Colomba, C., Ayanlade, A. and Di Carlo, P. (2019) Tuberculosis evolution and climate change: how much work is ahead? *Acta Tropica*, 190, 157–158.

Siamudaala, V.M. (2006) *A Study of the Epidemiology and Socio-Economic Impact of Anthrax in Luangwa Valley in Zambia*. Pretoria, South Africa: University of Pretoria.

Sindato, C., Karimuribo, E. and Mboera, L.E. (2011) The epidemiology and socio-economic impact of Rift Valley fever in Tanzania: a review. *Tanzania Journal of Health Research*, 13(5). http://dx.doi.org/10.4314/thrb.v13i5.1.

Sultan, B., Labadi, K., Guégan, J.-F. and Janicot, S. (2005) Climate drives the meningitis epidemics onset in West Africa. *PLoS Medicine*, 2, e6.

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