Pneumonia Occurrence in Relation to Population and Thermal Environment in Ondo State, Nigeria

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This study investigated the occurrence of pneumonia in relation to human population and meteorological/ bio-meteorological variables in Ondo State, Nigeria, over the period 1998–2008 to better understand the spatial and temporal dimensions of variability in pneumonia occurrence with an emphasis on the role of the environmental factors. The statistical relationship between monthly pneumonia case count data series and monthly mean value of meteorological/ bio-meteorological parameters series were analyzed over the study period. The lag period between pneumonia and each meteorological/ bio-meteorological parameter was determined by cross-correlation analysis along with stepwise regression analysis in order to determine the parameters that are statistically significant to the reported cases of pneumonia. The logarithm of reported cases of pneumonia in relation to population of each local government area (LGA) showed that 5, 8 and 5 LGAs belongs to high, middle and low classes, respectively. There was a significant correlation ($P<0.01$) between monthly cases of pneumonia and thermal environmental factors. High transmission of pneumonia occurred in the months of June to October with peak period in July during high rainfall and regular surface wetness. A combination of rainfall, air temperature, relative humidity and solar radiation accounted for 87.6% of pneumonia occurrence in humid forest zone of Ondo State. For derived savannah, combinations of air temperature, rainfall, solar radiation and wind speed accounted for 86.8% variation in the occurrence of pneumonia. The statistical model of this study would be valuable tool for early warning system for predicting the magnitude of occurrence of pneumonia up to one month lead-time if the total monthly rainfall, mean air temperature and relative humidity for the future month can be predicted with high certainty.

1. Introduction

Climate and weather events play a role in determining the incidence and geographic range of infectious diseases. The scientific interest in the role of the environment, including weather and climate, in the dynamics of infectious disease has been further stimulated by the growing problems of emergence and re-emergence of infectious diseases despite series of intervention policies worldwide [1].

Pneumonia is inflammation of the lung that is often caused by infection with bacteria, viruses, fungi and other agents. There are different types of pneumonia and it's usually classified according to its location in the lung. Pneumonia-causing agents reach the lungs through multiple routes: in most cases, a person breathes in the infectious organism, which then travels through the airways to the lungs. Sometimes, the normally harmless bacteria in the mouth, or on items placed in the mouth, can enter the lungs and cause ailments. This usually happens if the body's "gag reflex", an extreme throat contraction that keeps substance out of the lungs, is not working properly. Infections could also spread through the bloodstream from other organs to the lungs [2].

Multiple studies have found a relationship between environmental factors and pneumonia incidence; among them are the study of Bull and Morton [3], which revealed that there is positive correlation between air temperature and lobar pneumonia. According to them, high air temperature causes profound physiologic changes such as an increase blood viscosity and cardiac output leading to dehydration, and even endothelial cell damage. The air temperature at which the lowest lobar pneumonia occurred in this study was around 27°C. In other areas of the globe, the most favourable air temperature varies, from 26°C – 29°C in Taiwan, 22°C in Sao Paulo, Brazil and 16°C in the Netherlands [4]. Such variation may be explained by differences in housing conditions and by a process of acclimatization to the local climate. Thus, this study emphasizes the importance of thermal comfort, as well as outdoor weather

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protection for disease prevention. The study of Tromp [5] demonstrated that maximum air temperature combined with relative humidity influence occurrence of pneumonia.

The aim of this paper is to analyse the occurrence pneumonia transmission with respect to thermal environment based on human-bio-meteorological approaches in order to ascertain the significant role of human-bio-meterological variables in the transmission of the disease because of its seasonal pattern.

2. Data and Methods

Ondo State (5° 45′ N–8° 15′ N, 4° 45′ E– 6° 00′ E) is situated in the South-western part of Nigeria (Figs. 1, 2). The state has 18 local government areas (LGAs) with a population of about 3,441,024 according to the 2006 population census and a land area of about 14,606 km2 [6]. It has a tropical wet-and-dry climate. Ondo State has a mean annual rainfall of about 1,500 mm and 2,000 mm in the derived savannah and humid forest zones [7].

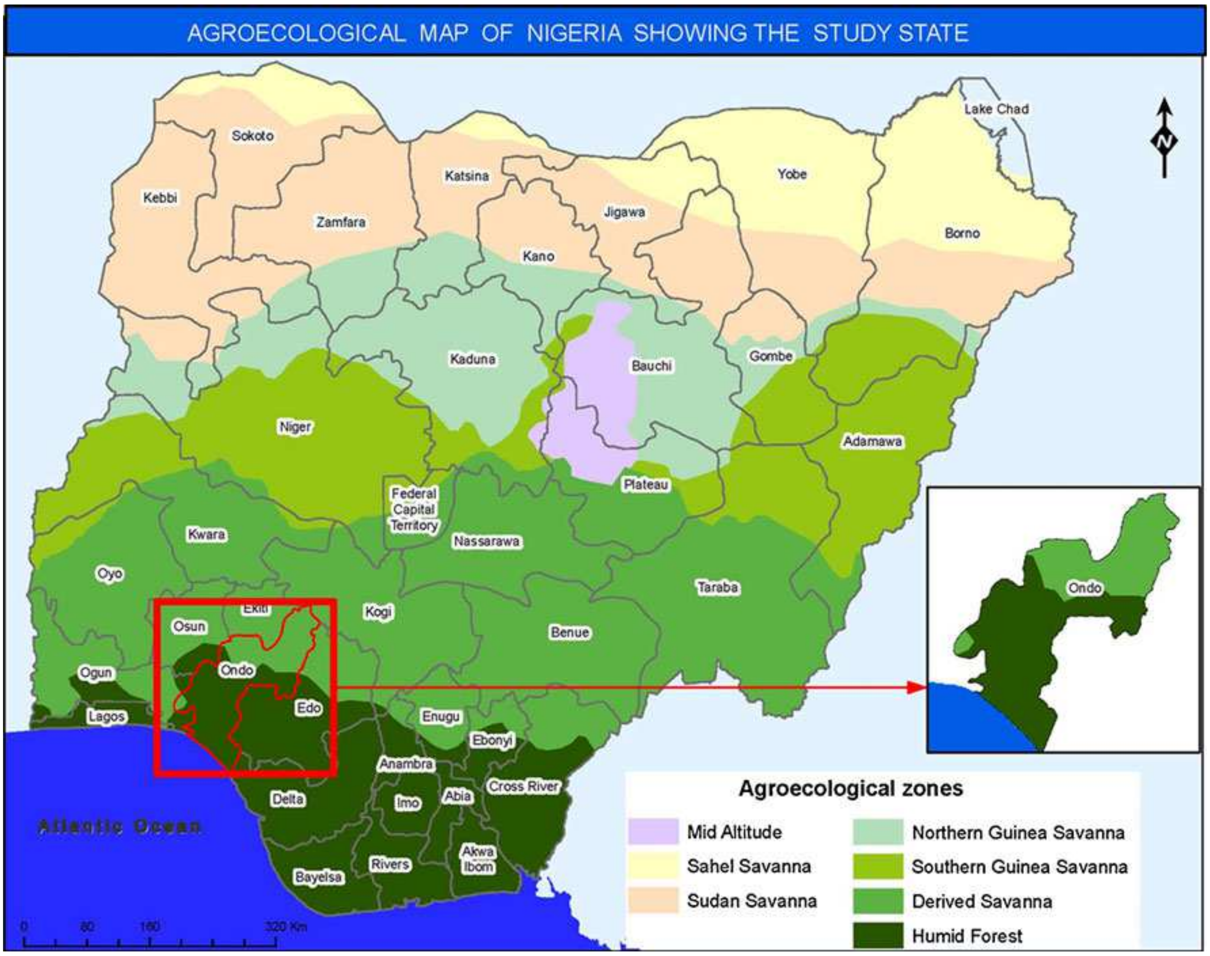

Fig.1: Map of Nigeria showing the study area (Ondo State)

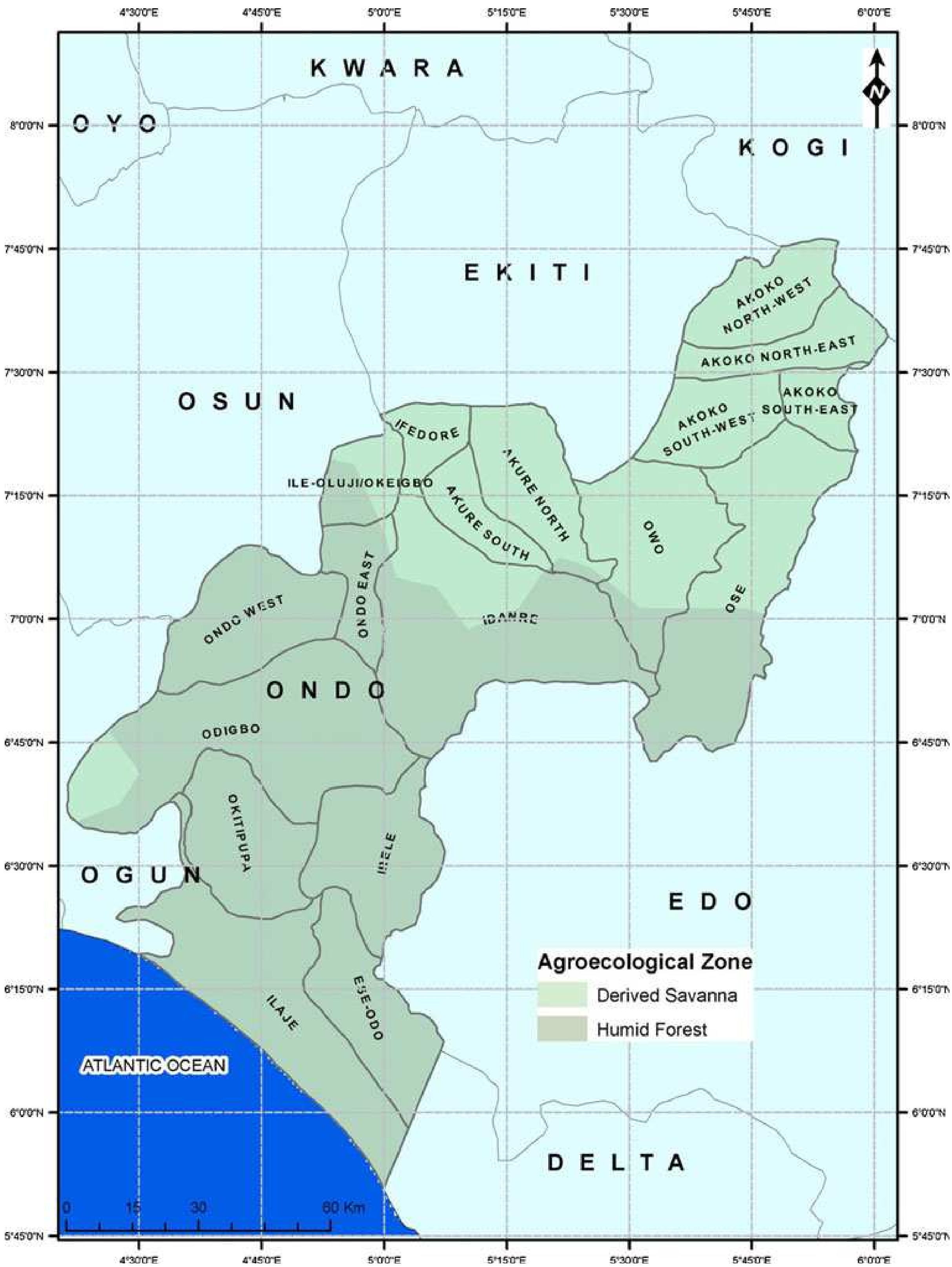

Fig.2: Map of Ondo State (study area) showing the two eco-climatic zones and local government areas (LGAs)

The source of the pneumonia data for the period 1998 to 2008 used in this study is the Monitoring and Evaluation Unit, Ministry of Health, Akure, Ondo state. The pneumonia data were collected after approval was given by the ethical committee of the Ministry of Health. The following limitations in this data are recognized: (1) not everyone visit hospital for medical care/treatment, (2) there is no separation between suspected and confirmed pneumonia cases. The information therefore may not represent the true number of cases of pneumonia in each local government areas across the state. However, the data present a general picture of the occurrence of pneumonia in the study area. Meteorological data—air temperature, relative humidity, wind speed, solar radiation and rainfall—used in this study were provided by the Agro-climatological and Ecological Monitoring Unit, Akure, Ondo State; other meteorological data used were the vapor pressure calculated by RayMan model. The weather stations were located in all the 18 LGA areas headquarter of Ondo State (Fig. 3). Measurements were taken at 0900 daily; the daily data were aggregated into monthly data by finding the average of daily data over a month. SPSS was used to interpolate the missing data. The sea surface temperatures (SSTs) over the area 5°N–5°S, 150°–90°W, known as the Niño3 region in the equatorial Pacific Ocean, obtained from the website http://www.esrl.noaa.gov/psd/data/gridded/ were also included in this study. SSTs over the Niño3 region have been linked to weather patterns over Nigeria, most especially rainfall pattern as noted by Adedoyin [8]; Wassila and Kingtse [9]; Giannini et al. [10]. In addition, since some studies [11-14] have linked effects of El Niño to different diseases in several regions of the world, it will be necessary to attempt to assess the role of this ENSO indicator (SSTs) in the occurrence of pneumonia because its seasonal occurrence usually coincides with periods of rainy season and surface wetness in the study area.

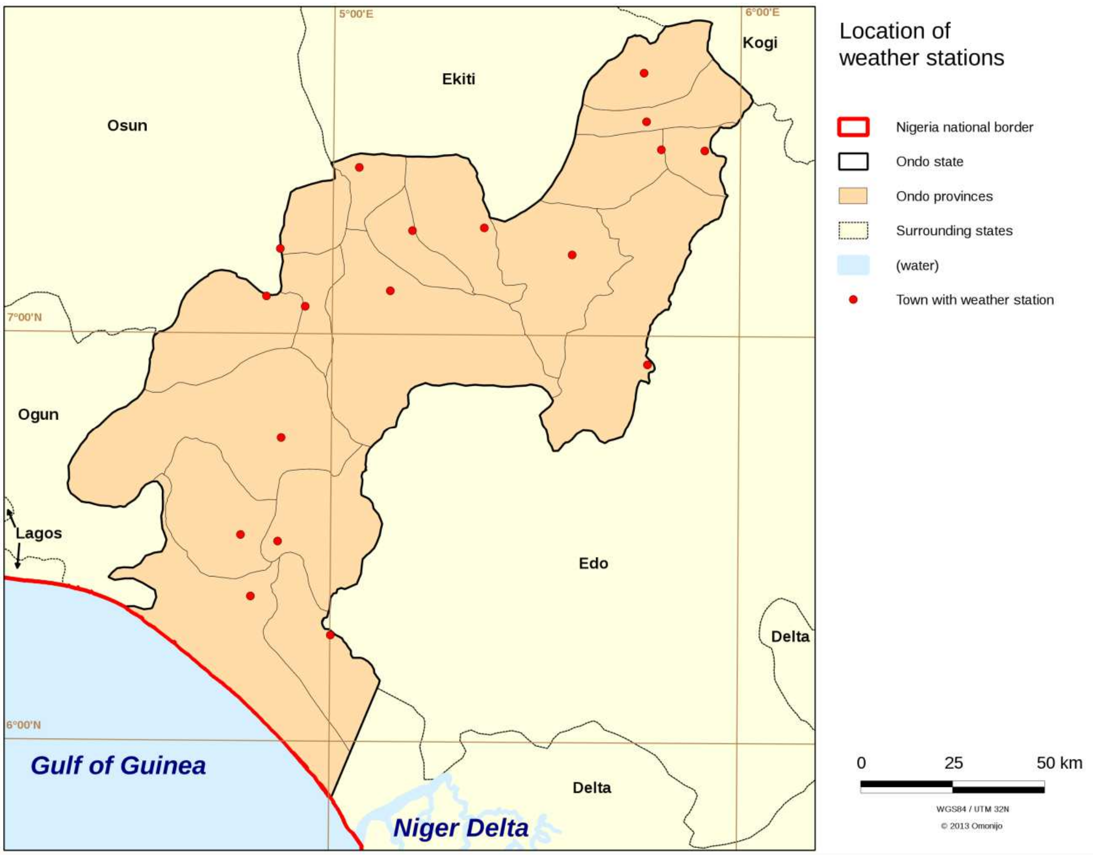

Fig.3: Map of Ondo State showing location of weather stations

The bio-meteorological parameters are the mean radiant temperature (Tmrt) [15,16], physiologically equivalent temperature (PET) [17-19] and Universal Thermal Climate Index (UTCI) [20] were calculated using the RayMan model [16,21]. The advantage of bio-meteorological parameters that are indicators of human thermal comfort in an environment using just meteorological variables is the inclusion of both meteorological components of the thermal environment and physiological components of the human body, e.g., activity level, age, and clothing, in their calculation. Therefore, in this study, bio-meteorological parameters are used because these indices capture human physiological comfort better than any of the single weather variables.

3. Spatial Analysis Based on Human Population

A population factor (*Pf*) and the logarithm of reported pneumonia cases in relation to population (*Ncp*) [22,23] were also determined for objective comparison between the 18 LGAs in the state.

$$Pf = \frac{Population\ of\ LGA,\ Px}{PN}$$

$$Ncp = \frac{\ln N_m}{Pf} = \frac{log_{e\ N_m}}{Pf}$$

Where, *x* varies from LGA to LGA as shown in Table 1, *PN* is the population of the least populated LGA (Ondo East), *Nm* is the approximate number of cases of pneumonia in the respective LGAs over the study period. In addition, a demographic analysis of pneumonia' patients was carried out. For further analysis, the 18 LGAs were divided along the two eco-climatic zones in the state (Fig. 2) for simplicity and easy handling of the data.

Table 1: Logarithm of reported pneumonia cases in relation to population of each local government areas (LGAs) in Ondo state, Nigeria

LGA	*Population*	*Population factor (Pf)*	*Average reported pneumonia cases for the period 1998 to 2008 (Nm)*	*Logarithm of pneumonia cases in relation to population of each LGA (Ncp)*	*Rank*
Akoko North West*	213,792	2.86	151	1.75	15
Akoko North East**	175,409	2.35	275	2.39	10
Akoko South East**	82,426	1.10	57	2.05	13
Akoko South West*	229,486	3.07	195	1.72	16
Ose**	144,901	1.94	120	2.47	8
Owo*	218,886	2.93	206	1.82	14
Akure North**	131,587	1.76	133	2.78	6
Akure South*	353,211	4.72	551	1.34	18
Ifedore**	176,327	2.36	232	2.31	12
Ile-Oluji/Okeigbo**	172,870	2.31	211	2.31	11
Ondo West*	283,672	3.79	484	1.63	17
Ondo East***	74,758	1.00	110	4.70	1
Idanre***	129,024	1.73	279	3.26	5
Odigbo**	230,351	3.08	2900	2.59	7
Okitipupa**	233,565	3.12	1877	2.41	9
Irele***	145,166	1.94	1455	3.75	3
Ese-Odo***	154,978	2.07	2478	3.77	2
Ilaje***	290,615	3.89	2899	3.67	4

*** $N_{cp} \geq 3.00$; ** N_{cp}: (2.00 – 2.99); * N_{cp}: (1 – 1.99)

*** N_{cp} (5 LGAs) = 41.0%; ** N_{cp} (8 LGAs) = 41.3%; * N_{cp} (5 LGAs) = 17.7%

3.1. Lag associations: Cross correlation analysis

Cross correlation is used to compare two different time series, covering the same time span and with equal and even sampling frequency with the aim of finding possible time delay between the correlations of the two series [24].

For two series *x* and *y*, the cross correlation value at lag time *m* is

$$r_m = \frac{\sum(x_i - \bar{x})\sum(y_{i-m} - \bar{y})}{\sqrt{\sum(xi - \bar{x})^2 \sum(y_{i-m} - \bar{y})}}$$

The above equation shows that for positive lags, *x* (meteorological/bio-meteorological parameters in Table 2) is compared to a *y* (pneumonia value), that has been delayed by *m* samples. A high correlation value at positive lags thus means that features in *y* are leading, while *x* lags behind. For negative lags, features in *x* are leading.

Table 2: Correlations coefficient between pneumonia and meteorological/ bio-meteorological parameters in humid forest zone of Ondo State

Variables	Pneumonia (Derived savannah)	Pneumonia (Humid forest)
Air temperature, Ta (ºC)	-0.884**	-0.898**
Physiologically equivalent temperature, PET (ºC)	-0.842**	-0.885**
Mean radiant temperature, T_{mrt} (ºC)	-0.809**	-0.807**
Sea surface temperature, SST (ºC)	-0.216*	-0.209*
Solar radiation, SR (Wm^{-2})	-0.626**	-0.628**
Rainfall, Rfall (mm)	0.875**	0.880**
Relative humidity, RH (%)	0.872**	0.920**
Wind speed, u (ms^{-1})	0.192*	0.198*

** - Correlation is significant at the 0.01 level
* - Correlation is significant at the 0.05 level

3.2. Temporal analysis: Stepwise multiple regression

The temporal pattern of the monthly clinical reported pneumonia cases was then examined and a regression analysis performed. The relationship between each of the meteorological/bio-meteorological parameters and monthly clinical reported pneumonia cases was examined by finding the correlation between the two categories of data sets. In order to identify specific meteorological/bio-meteorological parameters, or their combination, that explains the temporal pattern of pneumonia disease, a stepwise multiple regression analysis was conducted.

A multiple regression scheme is most often used in cases in which the response variable depends on more than one explanatory variable, sometimes called an extended linear model. The multiple regression equation where there are more than two explanatory factors is given below as

$$\mathrm{Y} = \mathrm{b}_0 + \mathrm{b}_1\mathrm{X}_1 + \mathrm{b}_2\mathrm{X}_2 + \mathrm{b}_3\mathrm{X}_3 + \mathrm{b}_4\mathrm{X}_4 + \mathrm{b}_5\mathrm{X}_5$$

In order to incorporate the lag period *n* (monthly interval between meteorological/bio-meteorological parameters and number of monthly reported cases of pneumonia) and time *t* (month to be predicted for pneumonia); the above equation becomes

$$\mathrm{Y} = \mathrm{b}_0 + \mathrm{b}_1\mathrm{X}_{1(t-n)} + \mathrm{b}_2\mathrm{X}_{2(t-n)} + \mathrm{b}_3\mathrm{X}_{3(t-n)} + \mathrm{b}_4\mathrm{X}_{4(t-n)} + \mathrm{b}_5\mathrm{X}_{5(t-n)}$$

The dependent variable, Y (monthly pneumonia value) and independent variables X_1, X_2, X_3, X_4, X_5, …….n, (meteorological/bio-meteorological parameters in Table 2) were regressed using the above equation; b_0 is the interception coefficient; b_1, b_2, b_3, b_4, b_5 are linear effect parameters or coefficients. Coefficients of this equation were estimated from the experimental results with SPSS 13.0 (SPSS, Chicago, IL). A regression model is considered to be statistically significant if the calculated F value is larger than the F distribution value at a probability of α.

Analysis of variance (ANOVA), including F-test, P-value of the models and determination coefficient R^2, which measures the goodness-of-fit of regression model at a confidence limit of 95%, was performed. The larger the magnitude of the t-values and the smaller the magnitude of the P-values, the more significant is the corresponding coefficient [24-26].

4. Results

The reporting patterns of pneumonia cases (Table 1) are categorized into high (****Ncp* ≥ 3.00); medium [***Ncp*: (2.00 – 2.99)]; and low [**Ncp*: (1 – 1.99)] classes. This classification was based on the value of the logarithm of reported pneumonia cases in relation to the population of each LGA (Table 1). In this study, five LGAs each fall into the higher and lower classes of reported pneumonia cases while the middle class have eight LGAs.

The pattern of pneumonia disease reporting (Fig. 4) in relation to patient age shows that 35.7% of the 54,586 cases were found among patients in the age group of '< 1 year', while the lowest number of cases occurred among patients '5 – 14 years' (15%). The percentage of reporting varies from one local government to another. For example, in the age group < 1 year, the percentage of occurrence varies from 27.0% to 45.6%. Overall, about 79% of the reported pneumonia cases in the study area were recorded in the age group ≤ 14 years. This result shows that there is a significant variation in the occurrence of pneumonia disease among age groups at the 0.01 probability level ($P<0.01$).

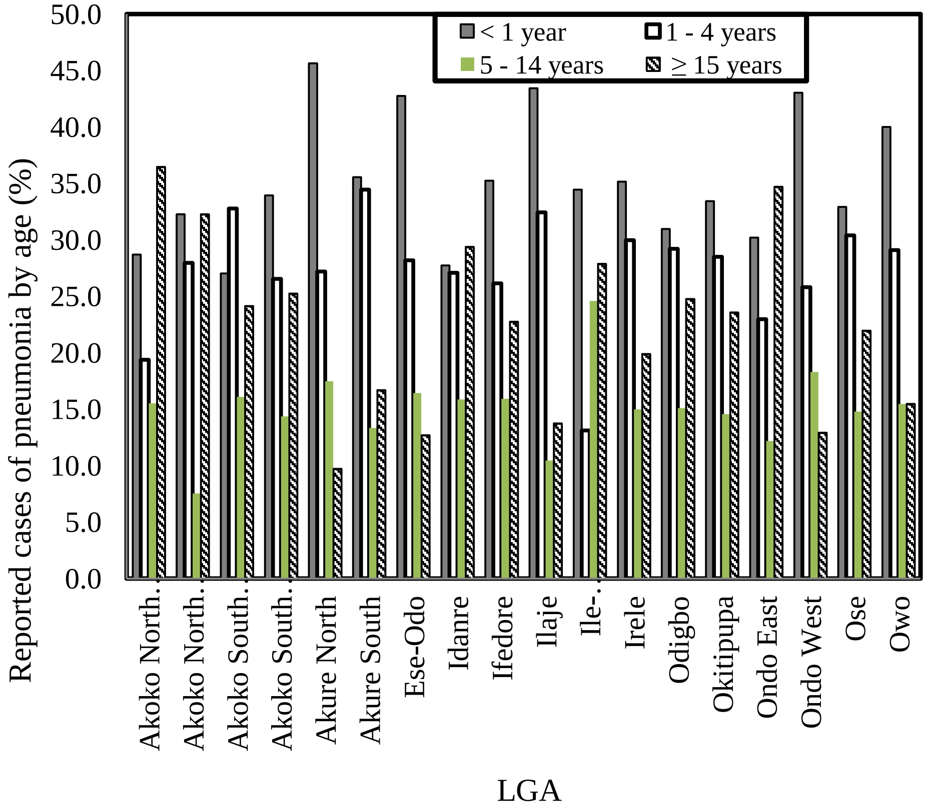

Fig.4: Pattern of age characteristics of pneumonia' patients in the 18 LGAs of Ondo State, Nigeria

Fig. 5 shows the distribution of reported clinical pneumonia disease according to patient gender in all 18 LGAs of Ondo State. Out of the 54,586 cases recorded within the 11-year (1998–2008) study period, 51% were males and 49% females. T-test shows no significant variation in the reported cases of the pneumonia disease between the two gender groups at "$p < 0.05$" in the study area within the study period.

Fig. 6 shows that the period of high manifestation of pneumonia, which accounted for about 67% of the reported cases of pneumonia within the study period occurred in the months of June to October, reaching a peak in the month of July, while the least number of reported cases occurred in the month of February. The pattern of trend shown in Fig. 7 (derived savannah) is similar to that of Fig. 6 (humid forest), except for differences in the magnitude of occurrence of the disease. Generally, the reported cases of pneumonia were higher in humid forest eco-climatic zone than derived savannah eco-climatic zone. The difference in the rate of pneumonia cases in the two zones is statistically significant at 0.01 ($p < 0.01$) probability level.

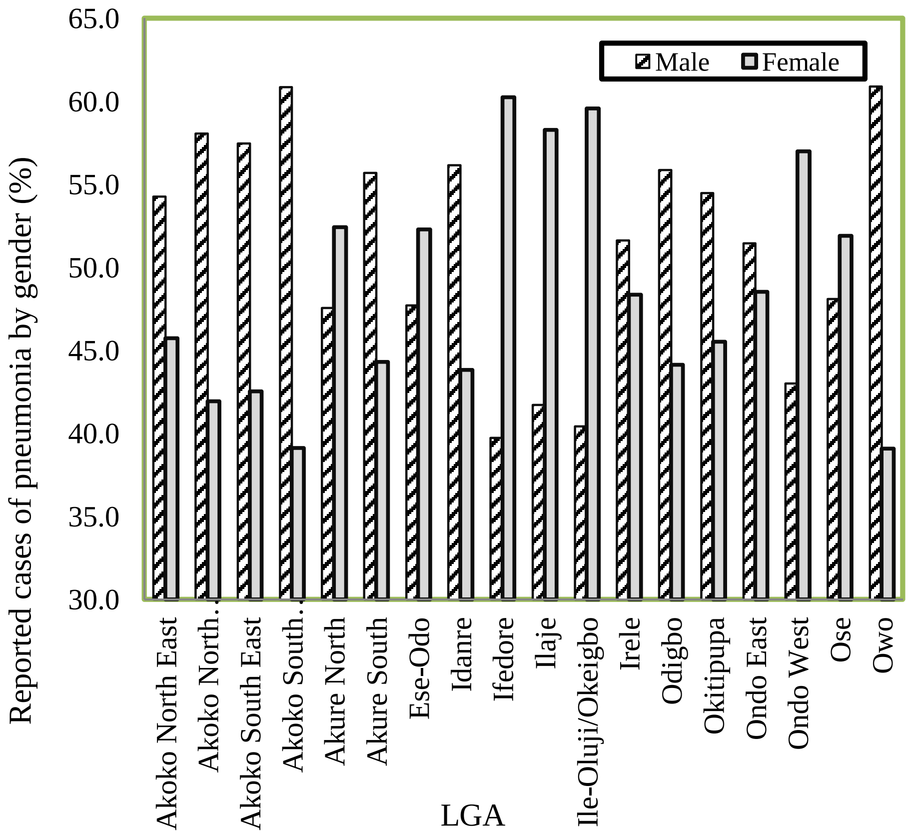

Fig.5: Trend of gender characteristics of pneumonia patients in the 18 LGAs of Ondo State, Nigeria

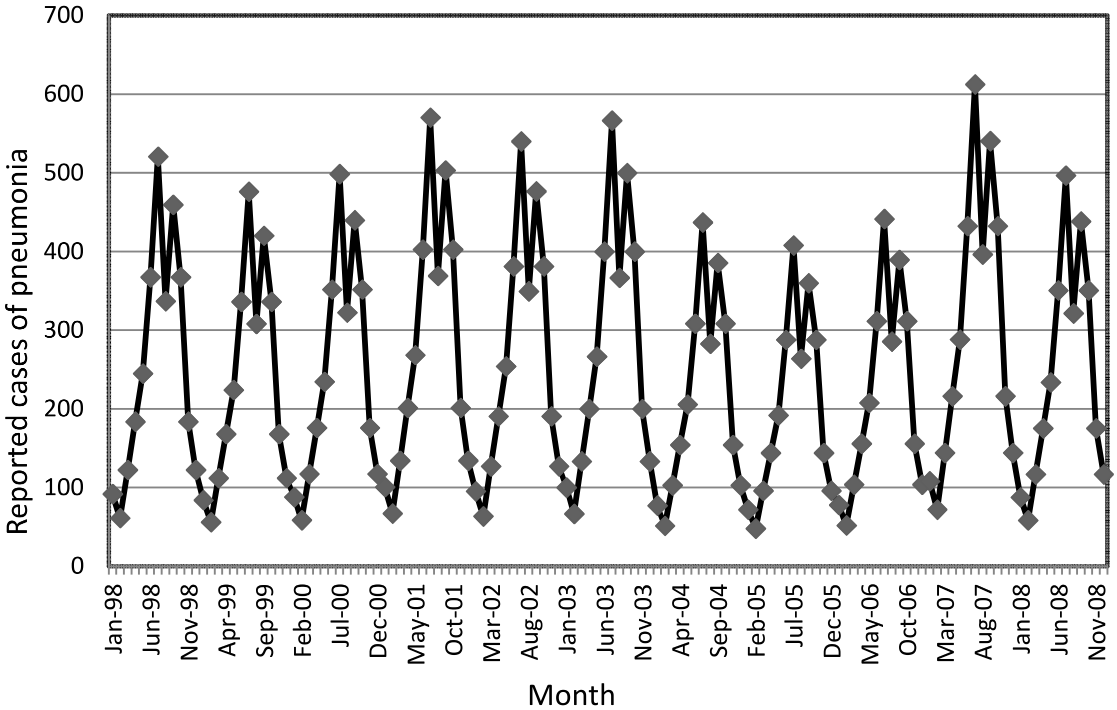

Fig.6: Monthly time series of reported cases of pneumonia in humid forest eco-climatic zone of Ondo State (1998–2008)

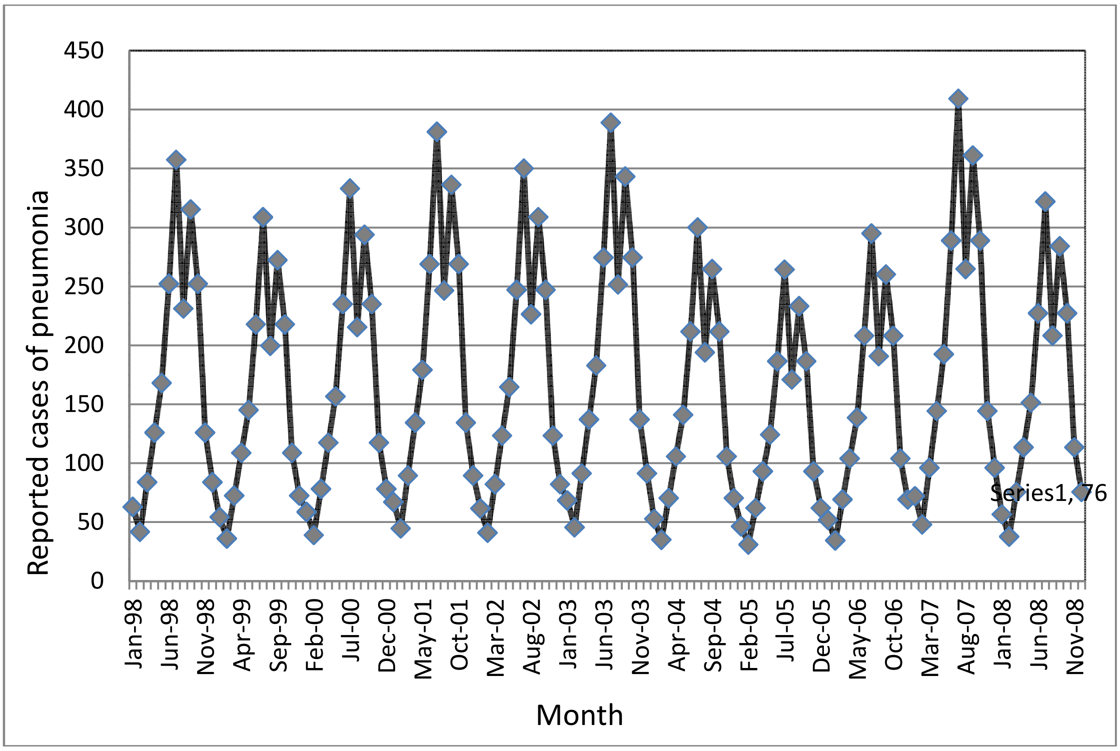

Fig.7: Monthly time series of reported cases of pneumonia in derived savannah eco-climatic zone of Ondo State (1998–2008)

The findings presented in Table 2 show the negative correlation between pneumonia and solar radiation, air temperature, mean radiant temperature and physiologically equivalent temperature at the 0.01 probability level and SST ($p<0.05$) while rainfall and relative humidity show positive correlation at 0.01 probability level and wind speed ($p<0.05$) for both humid forest and derived savannah.

The results of the cross-correlation analysis that determined the lags period between pneumonia and meteorological/bio-meteorological variables in humid forest and derived savanna eco-climatic zone of Ondo State showed is shown in Table 3. In humid forest, the meteorological/bio-meteorological variables preceded pneumonia by zero to two months. The lag period for each of relative humidity, air temperature and rainfall was zero months, while the lag period for solar radiation was one month and the lag period for wind speed and sea surface temperature was two months each. The lag period for bio-meteorological parameters– PET was zero months while T_{mrt} was one month. In derived savannah, the lag period for each of air temperature and rainfall was zero months, while the lag period for relative humidity and solar radiation was one month each and the lag period for wind speed and sea surface temperature was two months each. The lag period for bio-meteorological parameters– PET was zero months and T_{mrt} was one month.

Table 3: Lagging time between pneumonia disease and meteorological/ bio-meteorological parameters in humid forest and derived savannah eco-climatic zones of Ondo State

Meteorological/ bio-meteorological parameters	Humid forest eco-climatic zone	Derived savanna eco-climatic zone
	Pneumonia	*Pneumonia*
Air temperature (Ta)	0 month	0 month
Solar radiation (SR)	1 month	1 month
Rainfall (Rfall)	0 month	0 month
Relative Humidity (RH)	0 month	1 month
Wind speed (u)	2 months	2 months
Sea surface temperature (SST)	2 months	2 months
Physiologically equivalent temperature (PET)	0 month	0 month
Mean radiant temperature (T_{mrt})	1 month	1 month

The results of regression analysis in Table 4 (humid forest) showed that all the regression models (pAH, pBH, pCH) are significant ($P<0.001$). The coefficient of determination R^2 from the regression analysis indicates that combinations of different meteorological/ biometeorological parameters accounted for 87%, 88.2% and 87% variation in the occurrence of pneumonia in models pAH, pBH and pCH respectively.

In Table 5, the regression models (pAS, pBS and pCS) are significant ($P<0.001$) like models in Table 4. The coefficient of determination R^2 in Table 5 shows that meteorological/ biometeorological parameters account for 86.4%, 87% and 85% of variation in the occurrence of pneumonia disease in model pAS, pBS and pCS in the derived savannah zone of Ondo State, Nigeria.

To identify the specific meteorological-biometeorological parameters, or combination thereof, that are statistically significant, the regression modelling results in Table 4 and 5 were adjusted by applying stepwise regression analysis. This step filters out those variables that are not statistically significant in the models in Tables 4 and 5 to leave the following final form for humid forest (Table 6) and derived savannah (Table 7) zones of Ondo State. Out of the three models (pAH*, pBH* and pCH*) in the Table 6, pBH* model has the highest percentage, which explained 87.6% of the monthly reported cases of pneumonia, while model pBS* accounted for 86.8% in the occurrence of monthly reported cases of pneumonia in Table 7.

Table 4: Linear regression of pneumonia on combinations of meteorological/ bio-meteorological parameters for humid forest zone of Ondo State

	Model terms	Regression coefficients	95% CI	p-value	R^2
	Constant	1113.536	821.460 to 1405.611		
pAH	PET	-32.429	-39.179 to -25.679	0.000	
	Rfall	0.618	0.502 to 0.734	0.000	86.9%
	SST	2.949	-4.246 to 10.144	0.419	
pBH	Constant	975.921	440.040 to 1511.801		
	SR	-1.276	-1.814 to -0.737	0.000	
	RH	2.602	-0.202 to 5.405	0.069	88.2%
	Ta	-35.295	-49.579 to -21.012	0.000	
	Rfall	0.470	0.311 to 0.629	0.000	
	SST	6.357	-0.745 to 13.460	0.079	
	U	74.871	-0.732 to 150.475	0.052	
pCH	Constant	141.337	-105.656 to 388.329		
	RH	4.814	2.292 to 7.335	0.000	
	Rfall	0.535	0.372 to 0.698	0.000	87%
	SST	9.244	1.682 to 16.807	0.017	
	u	56.972	-21.898 to 135.842	0.155	
	Tmrt	-17.300	-21.358 to -13.242	0.000	

95% CI: Confidence interval at 95% level for estimated regression coefficient
pAH, pBH, pCH: Identification term for pneumonia models in humid forest zone

Table 5: Linear regression of pneumonia on combinations of meteorological/ bio-meteorological parameters for derived savannah zone of Ondo State

	Model terms	Regression coefficients	95% CI	p-value	R^2
pAS	Constant	815.339	626.693 to 1003.985		
	PET	-20.908	-24.878 to -16.938	0.000	
	Rfall	0.583	0.481 to 0.685	0.000	86.4%
	SST	0.371	-4.647 to 5.390	0.884	
pBS	Constant	918.415	552.458 to 1284.372		
	SR	-0.594	-0.970 to -0.218	0.002	
	RH	-0.118	-1.021 to 0.786	0.797	86.9%
	Ta	-27.007	-36.915 to -17.099	0.000	
	Rfall	0.500	0.378 to 0.623	0.000	
	SST	2.554	-2.547 to 7.655	0.324	
	U	72.225	11.699 to 132.752	0.020	
pCS	Constant	204.655	20.717 to 388.593		
	RH	0.989	0.203 to 1.775	0.014	85%
	Rfall	0.608	0.487 to 0.730	0.000	
	SST	5.995	0.456 to 11.534	0.034	
	u	41.477	-21.340 to 104.295	0.194	
	Tmrt	-9.543	-12.988 to -6.098	0.000	

95% CI: Confidence interval at 95% level for estimated regression coefficient
pAS, pBS, pCS: Identification term for pneumonia models in derived savannah zone

Table 6: Stepwise linear regression of pneumonia on combinations of meteorological/ bio-meteorological parameters for humid forest zone of Ondo State

	Model terms	Regression coefficients	95% CI	p-value	R^2
pAH*	Constant	1187.935	959.429 to 1416.440		
	Rfall	0.632	0.521 to 0.743	0.000	77.4%
	PET	-32.425	-39.165 to -25.684	0.000	9.4%
pBH*	Constant	1101.262	576.887 to 1625.637		
	Rfall	0.492	0.332 to 0.653	0.000	77.4%
	Ta	-34.652	-49.173 to -20.130	0.000	8.2%
	SR	-1.191	-1.733 to -0.650	0.000	1.3%
	RH	3.625	0.908 to 6.342	0.009	0.7%
pCH*	Constant	159.039	-87.740 to 405.817		
	Rfall	0.537	0.374 to 0.701	0.000	77.4%
	Tmrt	-17.222	-21.295 to -13.149	0.000	6.4%
	RH	5.400	3.003 to 7.797	0.000	2.4%
	SST	8.836	1.264 to 16.408	0.023	0.6%

95% CI: Confidence interval at 95% level for estimated regression coefficient

pAH*, pBH*, pCH*: Identification term for pneumonia stepwise models in humid forest zone

Table 7: Stepwise linear regression of pneumonia on combinations of meteorological/ bio-meteorological parameters for derived savannah zone of Ondo State

	Model terms	Regression coefficients	95% CI	p-value	R^2
pAS*	Constant	824.287	680.096 to 968.477		
	Rfall	0.586	0.491 to 0.681	0.000	74.6%
	PET	-20.897	-24.848 to -16.945	0.000	11.8%
pBS*	Constant	952.965	723.344 to 1182.585		
	Ta	-26.303	-33.567 to -19.039	0.000	75.8%
	Rfall	0.517	0.402 to 0.631	0.000	9.6%
	SR	-0.552	-0.918 to -0.186	0.003	0.7%
	u	66.138	15.692 to 116.584	0.011	0.7%
pCS*	Constant	212.295	28.217 to 396.374		
	Rfall	0.611	0.489 to 0.733	0.000	74.6%
	Tmrt	-8.818	-12.092 to -5.544	0.000	8%
	RH	1.262	0.591 to 1.933	0.000	1.7%
	SST	5.737	0.197 to 11.277	0.043	0.5%

95% CI: Confidence interval at 95% level for estimated regression coefficient

pAS*, pBS*, pCS*: Identification term for pneumonia stepwise models in derived savannah zone

5. Discussion

An examination of the occurrence of pneumonia in 18 LGAs of Ondo State, Nigeria, shows that the gender distribution was not statistically significant. Meanwhile, the study showed that children under the age of 1 year were more susceptible to pneumonia. High rate of pneumonia among the children under the age of 1 year could be attributed to their low immune system. This might have contributed to the statistically different in the age group differentials in the reported cases of pneumonia. This result conforms to the findings of Ye et al. [27] which reported that pneumoniarelated mortality rates are common among the children below the age of 5 years.

The study further revealed that reported cases of pneumonia in both humid forest and derived savannah eco-climatic zones of Ondo State depicted a similar pattern but varied in magnitude. Higher number of pneumonia cases was reported in humid forest eco-climatic zone than derived savannah zone of the State within the study period. The differences noticed in the reported clinical cases of pneumonia in the two zones could be linked to variation in the ecological and weather conditions. For example, the five local government areas with high value of logarithm of pneumonia cases in relation to population were located in the humid forest eco-climatic zone of the study area. Ilaje, Ese-Odo and Irele local government areas are closer to Gulf of Guinea over Atlantic Ocean while Ondo East and Idanre are densely forested areas; all the aforementioned local government areas have annual mean rainfall of more than 2000mm, which amount to regular surface wetness during rainy season that favors the spread of pneumonia [28,29]. Another explanation for the spatial variation in the reported pneumonia cases could be poor housing and overcrowding condition that facilitate transmission of the pneumonia-causing agents. Since pneumonia is one of the airborne diseases, indoor crowding during winter or rainy seasons will lead to transmission of pneumonia pathogen from affected person(s) to individual without the disease. This transmission will be aided by wind. In addition, indoor air pollution could be another contributory factor, due to its role in the causation/ aetiology of acute upper and lower respiratory tract infections, especially among children below the age of 5 years [30-32]. In this study area, majority of households use fire-wood and kerosene stoves for cooking. The particulate matter and carbon dioxide emitted by burning kerosene and fire-wood are inflammatory agents that lead to breaches in the epithelial lining of the respiratory tract, hence increasing the risk of respiratory tract infections [33,34].

The seasonal pattern of reported pneumonia cases corresponds to rainfall pattern throughout the study period, which concurs with some studies [14,28,35] that high number of pneumonia morbidity was observed during wet season in a tropical climate region. This could be that during surface wetness as a result of heavy rainfall people tend to stay indoor during this period, which led to overcrowding in a poor housing condition. This situation facilitates the transmission of pneumonia-causing agents among people with health conditions.

The interaction effects of weather parameters on monthly reported cases of pneumonia in both humid forest and derived savannah eco-climatic zones shows that rainfall was the leading contributor to the occurrence of reported cases of pneumonia, followed by air temperature. Going by findings of laboratory–based studies, the survival of airborne pneumonia was found to be a function of both temperature and relative humidity. However, the temperature response was mediated by humidity in that the effect of temperature was observed when some water vapor was present [36,37].

6. Conclusion

Based on the findings of this study, there is high seasonal variation in the occurrence of pneumonia in the two eco-climatic zones of Ondo State. The transmission peak was in the rainy season. The study also revealed that highest number of cases of pneumonia was recorded in the children below 5 years. There is no significant difference in the number of cases of pneumonia occurrence among male and female within the study period in both humid forest and derived savannah eco-climatic zones of the study area.

The pneumonia infection is modulated by both meteorological and bio-meteorological parameters which impacts on the transmission of *mycoplasma pneumoniae*. The individual meteorological and bio-meteorological parameters with different lag periods influence pneumonia infection; rainfall is the best predictor and the main driving force.

Conclusively, cases of pneumonia occurrence were higher in humid forest eco-climatic zone of Ondo State within the study period. In addition, the study confirmed the roles of seasons in the occurrence of pneumonia in Ondo State.

This study stresses the need for further investigation to explore the role played by meteorological/bio-meteorological factors on a day-to-day basis in order to actually determine the weather transition period that has the most significant effect on pneumonia in the study area and also to know the lead-time for predicting the magnitude of pneumonia occurrence, which will assist in preparedness and early warning intervention for pneumonia disease. Such studies are all the more necessary given that the aim of reducing pneumonia case fatality to near zero has not been realized.

Finally, the implications of these results for the government and health policy decisions are numerous. First, close monitoring of the atmospheric environment should be incorporated into health management schemes; this will give health practitioners timely awareness of the prevailing atmospheric conditions that are favourable to the transmission of certain infectious diseases so that they can act in time. Second, since there are certain parts of the study area that record higher numbers of pneumonia cases. It is necessary, therefore, to prioritize health problems according to areas, and to direct health investments to areas most in need; a human-biometeorological approach will be of great help in achieving this. Third, there is need to protect our environment in order not to be affected adversely by the impact of climate change.

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