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Research Article

Impact of Climate Factors in Modeling and Predicting the Transmission of Meningitis in Africa: The Case of Burkina Faso

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Abstract

Background: Meningitis is a major cause of morbidity in the world. Previous studies showed that weather factors influence the occurrence of meningitis. A multiple linear regression model was developed to forecast meningitis cases in Burkina Faso using weather factors. However, the multivariate linear regression model based on times series data may produce fallacious results given the autocorrelation of errors.

Aims: The aim of the study is to develop a model to quantify the effect of weather factors on meningitis cases, and then predict the expected weekly incidences of meningitis for each district.

Data and Methods: The weekly cases of meningitis come from the Ministry of Health and covers the period 2005-2017. Weather data were collected daily in 10 meteorological stations from 2005 to 2017 and were provided by the national meteorological Agency of Burkina Faso. An ARIMAX and a multivariate linear regression models were estimated separately for each district.

Results: The multivariate linear model is inappropriate to model the number of meningitis cases due to autocorrelation of errors. With the ARIMAX Model, relative humidity is significantly associated with a decrease of meningitis cases in all of the 10 districts while temperature is significantly associated with an increase of meningitis cases in 6 of 10 districts. The effects of wind speed and rainfall are not significant at the 5% level in all 10 districts. Prediction errors reveal that ARIMAX model has better predictive power than multiple linear model.

Conclusion: The ARIMAX model is more appropriate than the multivariate linear model to analyze the dynamics of meningitis cases. Weather factors such as temperature and relative humidity have a significant influence on the occurrence of meningitis in Burkina Faso; the temperature influences it positively and the relative humidity influences it negatively.

Keywords: ARIMAX; Modeling; Meningitis; Seasonality; Weather factors

Introduction

According to the World Health Organization (WHO), meningitis is a serious infection of the thin membranes that surround the brain and spinal cord. It is most often caused by an infection (bacterial, viral or fungal). Different bacteria can cause meningitis. Neisseria meningitidis is most likely to cause major epidemics. Twelve serogroups of *Neisseria meningitidis* have been identified, and six of them are known to cause epidemics

(A, B, C, W135, X and Y). The geographical distribution and the epidemic potential vary from one serogroup to another. This bacterial infection is a major cause of morbidity and mortality in the world: about 500,000 cases are reported each year, with a fatality rate of about 10 % [1]. Half of the cases occur in sub-Saharan Africa during the dry season, in an area called the "meningitis belt” where meningococcal meningitis is endemic and "epidemic" [2]. Studies carried out in epidemiology and climatology since the mid-twentieth century have demonstrated the existence of a spatial and temporal concordance of meningitis epidemics with the dry season [2-6]. Meningitis epidemics generally begin in February and disappear in May. The Sudano-Sahelian part of Africa is subject to the alternation of a dry season in winter, dominated by harmattan winds, and a wet season that starts in the spring to reach its peak in summer with the establishment of the monsoon. The typical climatic context of winter in subtropical latitudes provides favorable conditions for the development of meningitis: whereas drought and strong, dust-laden winds can stimulate meningococcal invasion by directly damaging the mucosal barrier or inhibiting surface immune defenses, spring moisture and Guinean latitudes significantly reduce the incidence of meningitis [7]. The work of Sultan et al. (2005) in Mali have statistically shown ($r = 0.92$) that the start of meningitis epidemics coincided with maximum winter in the middle of February. This period is characterized by a strongest harmattan and a lowest humidity. The launch of the African Monsoon Multidisciplinary Analysis Program (AMMA) in 2002 [8] has led to unprecedented progress in understanding the climate-meningitis relationship. Around a multidisciplinary approach led by the Climatology Research Center (CRC), pilot of the group climate-health at the French level of the program, and since recently in collaboration with the World Health Organization (WHO), new ways of investigation to better understand the climate - environment - meningitis relationship have been updated. More recently, [9] used weekly WHO censuses of meningitis-related cases and deaths in Niger, Mali and Burkina Faso for the period 2004-2009 as well as moisture data from AERONET, the network of photometric measurements. The results of this study in Niger show that the increase in humidity is associated with a reduction in the number of cases over the same period, and then signs the cessation of the seasonal cycle of meningitis (whether the years are epidemic or not). The results obtained in Burkina Faso and Mali are also similar. However, the mechanisms responsible for the start, cessation and intensity of these outbreaks are not accurately identified yet. Many studies have shown the relationship between climatic factors and the occurrence of meningitis, but few have established predictive models for meningitis cases. It is in this context that this study will focus on providing predictions of meningitis cases to address a possible failure of the surveillance system and consequently to plan the stock of vaccines for controlling the disease. We suggest the use of the ARIMAX model [10] or Auto Regressive Integrated Moving Average with eXegenous variables, to evaluate the impact of weather factors on the occurrence of meningitis. ARIMAX is an extension of the ARIMA model [11], popular in econometric analysis [12], which includes independent variables as explanatory variables and combines regression and ARIMA model [13]. Pascal Yaka et al. (2008) [14] developed a forecasting model using weather factors, but this multivariate linear regression model can produce misleading or fallacious/invalid results given the auto-correlation inherent in time series (fallacious regression / spurious regression). The main difference between the formal ARIMAX modeling and the Yaka’s multiple regression model is that the ARIMAX modeling rigorously meets six statistical assumptions underlying the multiple regression model. Since the ARIMAX modeling process is much more complex than that of the multiple regression, it discourages model builders to use it. One of the assumptions related to that of a multiple linear regression requires, inter alia, that the residuals are not auto-correlated (The auto-correlation is the correlation of a time series with its lags. When the residuals are auto-correlated, this means that the current value depends on the previous ones). Violation of these assumptions generates inefficient results. In this paper, we fit an ARIMAX as well as linear multiple regression models for 1o districts in Burkina Faso. We compare the two types of models in order to assess the performance of each type of these two models.

Research Objectives and Hypothesis

Aim

Estimate the expected incidences of meningitis by epidemiological week and by district, using known or predicted weather factors.

Objectives

i. Determine the correlation between weather factors and the transmission dynamics of meningitis;

ii. Modeling the transmission dynamics of meningitis taking into account weather factors;

iii. Recommend the best model to explain and predict the transmission dynamics of meningitis;

iv. Estimate the number of expected meningitis cases in the case the surveillance system fails;

v. Predict possible epidemics of meningitis.

Research Hypotheses

i. The transmission dynamics of meningitis is correlated with weather factors;

ii. There is over-dispersion and auto-correlation for the series of cases of meningitis;

iii. The ARIMAX model is better than the multiple linear regression model to establish the relationship and predictions of the incidence of meningitis.

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Materials and methods

Study Design

This is a retrospective study based on data from meningitis and weather registered in 10 health districts out of the 70 that exist in Burkina Faso. These districts are: Bobo-Dioulasso, Bogandé, Boromo, Dédougou, Dori, Fada N'Gourma, Gaoua, Ouagadougou, Ouahigouya and Po (Figure 1). Data are collected weekly and cover the period 2005-2017. These districts were included in the study because they host weather stations that report weather parameters each day.

Meningitis Data

The meningitis weekly data are surveillance data obtained from the Ministry of Health. These data come from the different health facilities of the country, and are centralized at district level before being transmitted to central database. An official request was sent to the Ministry of Health to obtain these data and permission to use them for the study.

Weather Data

The Weather data were collected daily through weather stations in the ten health districts of the study. The data were obtained from the National Agency of Meteorology and covers the same period as the meningitis data (2005-2017). Weather variables are: temperature, relative humidity, rainfall, and wind speed.

Data Processing

The daily weather data were aggregated on a weekly basis using the mean function for all variables except for rainfall where total function was used. The weeks of aggregation are consistent with epidemiological weeks used for meningitis surveillance. The series of meningitis cases and weather parameters were merged to obtain a database containing both meningitis cases and weather variables by district. We used log-transformation of variables (log(count+1)) to take into account high skewness and non-gaussian structure that may appear.

ARIMAX Modeling Methods

The ARIMAX model is an extension of the ARIMA (Auto Regressive Integrated-Moving Average) that takes into account exogenous variables when the past values of the series are insufficient to explain its present and future values. The estimation of the ARIMAX model is implemented in two phases: (1) An estimation of the ARIMA model using the Box-Jenkins approach, then (2) a multiple regression taking into account the exogenous variables.

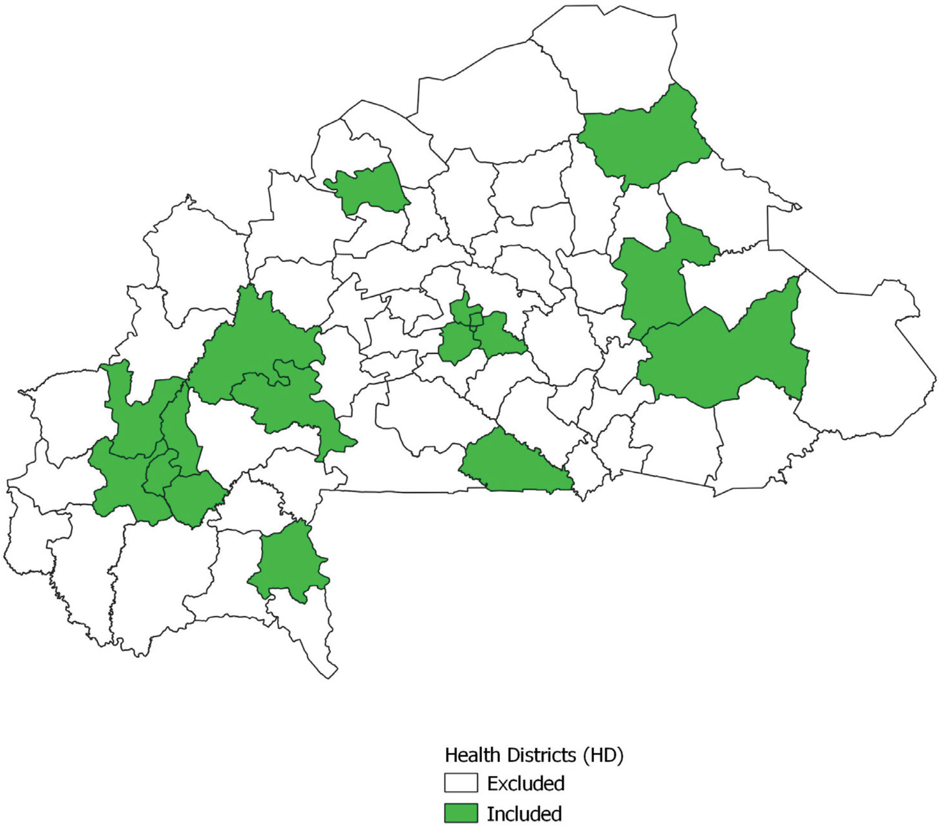

Figure 1: Study area.

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The estimation of the ARIMAX model is based on the following assumptions:

H1: The series y_t is stationary;

H2: Errors ε_t are not auto-correlated;

- H3: The coefficient associated with the exogenous variable x_t is significant;
- H4: There is no significant multi-collinearity between exogenous variables x_t;
- H5: There is a causal relationship (in the sense of Granger) between y_t and x_t;

The estimation algorithm of the ARIMAX model follows 8 (eight) steps:

i. Test the stationarity of the series y_t and exogenous variables x_t, then eventually differentiate the series to make them stationary. Augmented Dickey-Fuller and Philip Perron's Tests are appropriate to test the stationarity of series;

ii. Test the causality between the variable y_t and the exogenous variables x_t using Granger‘s causality test;

iii. Determine the sign of the effect of the exogenous variables x_t on the dependent variable y_t using an analysis of the correlation matrix ;

iv. Determine the number of lags p and q of the AR and MA components using the correlograms (ACF and PACF);

v. Estimate the ARIMAX regression using lags p and q, then add the exogenous variables;

vi. Test residual auto correlation using the LJung-Box test;

vii. Repeat steps iv, v, and vi until the residuals are non-auto correlated and the exogenous variables are significant;

viii. Keep the final model that meets basic assumptions and with the smallest information criterion such as AIC and BIC.

The model was implemented independently in each of the 10 districts where dependent variable y_t is the weekly meningitis cases and exogenous variables x_t are temperature, relative humidity, rainfall and wind speed. Seasonal movement in a series is simply the tendency of that series to repeat a certain behavior at regular intervals in time called "season". The number of moments in a season is an integer called period and noted "s". An ARIMAX model that incorporates seasonality is noted SARIMAX. The variables were visualized to identify missing values, outliers and the possible presence of seasonality and trend. Missing values were imputed using the average of the neighboring points. All weekly meningitis cases from 2017 were used as test data to assess the predictive power of the models. The models were estimated using the forecast package in R software.

Results

Summary of Variables

The distribution and quality of the data were assessed by calculating the minimum, the median, the maximum (Table 1) and the number of missing values for each variable. A total of 676 weekly observations were collected for each district over the period 2005 to 2017, giving a total of 6,760 observations for the 10 districts. The maximum temperature varies from 23.8 to 44.8, with an average of 35.43. The average wind speed is 3.9 km/h, and the average relative humidity is 49.7%. Wind speed has 7% missing values and a complete observations in only 3 of the 10 districts.

Evolution of the Number of Meningitis Cases by District

The data were visualized to detect possible outliers, seasonality and trend. The weekly meningitis cases fluctuated over the period 2005-2017 for each district with peaks observed for some weeks. The district of Ouagadougou recorded 1,828 cases of meningitis in March 2007. For the district of Bobo-Dioulasso, the peak was recorded in March 2006 with 407 cases of meningitis (Figure 2a, Figure 2b). The figures indicate a variation in the evolution of meningitis cases by district and no clear trend over the period of the study. Also, the increases in the number of meningitis cases are observed in the months of March and April of each year.

Granger Causality between Variables

The Granger causality test indicates whether past and present weather factors predict the number of meningitis cases significantly. The last column of Table 2 shows statistical test and the associated p-value with the null hypothesis (no Granger causality). Temperature and wind speed are causal factors of meningitis cases in 3 of the 10 districts ($P<0.05$); the relative humidity and rainfall are other causal factors in all of the 10 districts. Temperature and wind speed are positively correlated with the number of meningitis cases, while rainfall and relative humidity are negatively correlated to this variable. These 4 weather factors have a Granger causal effect on the number of meningitis cases in at least one health district. Simultaneous consideration of these factors in ARIMAX modeling will provide the adjusted effect of each factor.

Seasonality

The Webel-Ollech overall seasonality test applied for seasonality reveals the presence of seasonality in 4 of the 10 districts. These four districts are Bobo-Dioulasso, Dori, Ouahigouya and Po. The absence of seasonality in certain districts can be explained by the multiple germs (Nm, Sp, Hi) being responsible for the occurrence of meningitis, the number of cases often varies from year to year in the periods considered (December-June) as the period of

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Table 1: Descriptive statistics of variables of interest by health district.

Health District	Maximum temperature (°C)			Relative humidity (%)			Wind speed (km.h-1)			Rainfall (mm)			Number of meningitis cases		
	Minimum	Median	Maximum	Minimum	Mediane	Maximum	Minimum	Mediane	Maximum	Minimum	Mediane	Maximum	Minimum	Mediane	Maximum
Bobo Dioulasso	23.80	33.80	40.30	10.10	60.20	86.40	3.20	6.00	9.80	0.00	2.70	187.90	0.00	3.00	407.00
Bogande	27.20	35.70	42.40	9.10	40.80	83.10	1.50	4.60	9.30	0.00	0.00	156.30	0.00	0.00	199.00
Boromo	28.30	35.70	42.50	13.60	52.40	84.40	0.50	2.10	5.10	0.00	0.95	193.90	0.00	1.00	80.00
Dedougou	28.50	36.30	43.60	11.60	47.60	84.90	1.50	4.60	9.40	0.00	0.30	201.10	0.00	1.00	71.00
Dori	27.50	37.30	44.80	11.70	37.50	79.70	0.00	1.90	5.70	0.00	0.00	118.40	0.00	1.00	62.00
Fada Ngourma	28.30	35.75	42.60	12.90	52.00	86.90	0.60	3.10	7.00	0.00	0.35	190.00	0.00	1.00	192.00
Gaoua	28.30	34.50	40.20	16.60	64.20	86.00	0.60	3.40	7.90	0.00	7.25	134.60	0.00	1.00	106.00
Ouagadougou	27.70	35.70	42.70	15.60	47.95	81.70	2.00	5.10	8.50	0.00	0.20	264.10	0.00	3.00	1828.00
Ouahigouya	26.80	36.20	43.00	9.30	37.30	83.10	0.50	4.10	9.30	0.00	0.00	195.70	0.00	1.00	65.00
Po	28.50	35.00	41.50	10.60	57.65	86.70	1.00	3.10	7.10	0.00	2.70	187.00	0.00	1.00	22.00
Total	23.80	35.50	44.80	9.10	49.60	86.90	0.00	3.80	9.80	0.00	0.30	264.10	0.00	1.00	1828.00

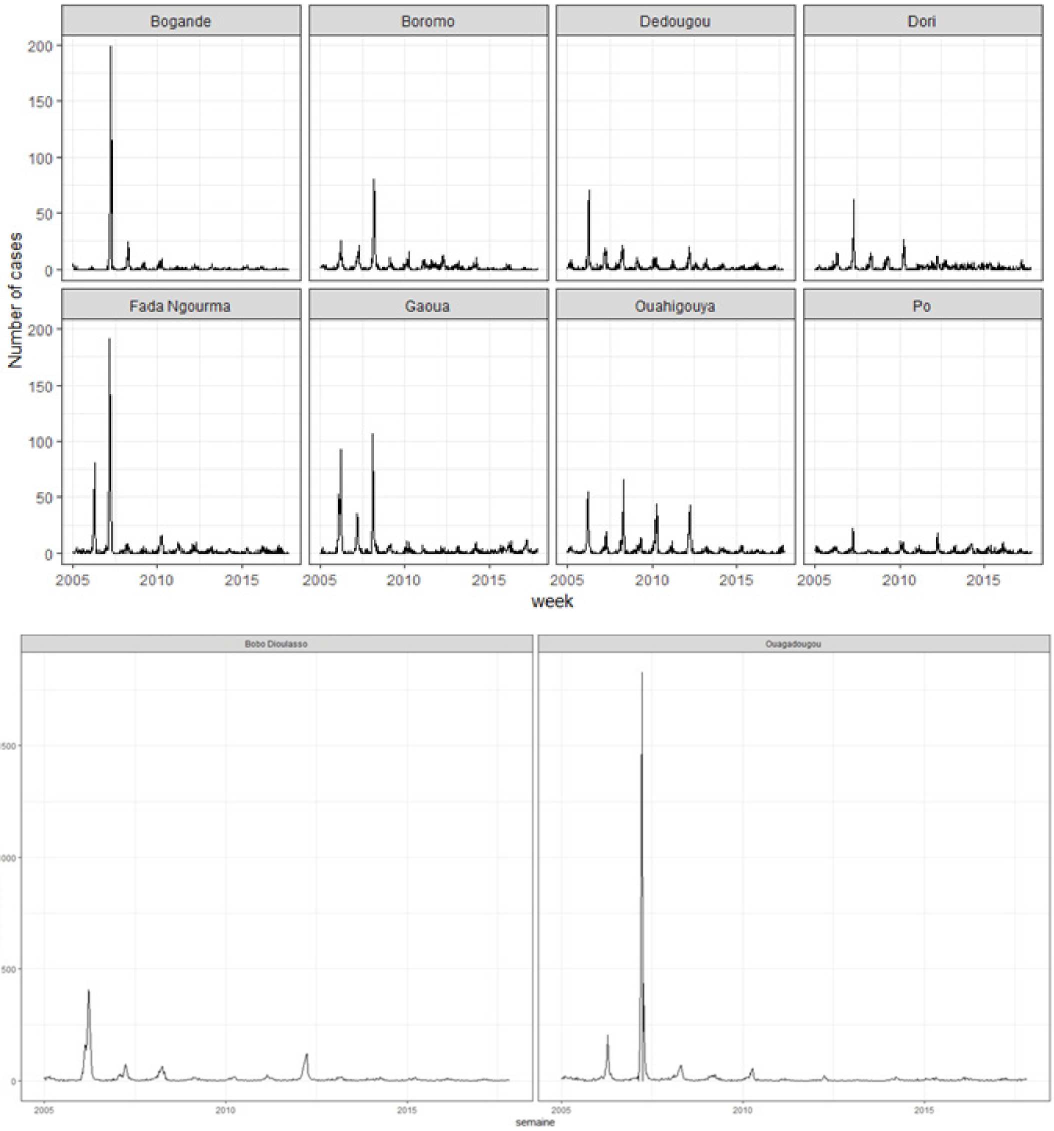

Figure 2a and 2b: Number of meningitis cases reported between 2005 and 2007.

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high transmission. In addition, the impact of vaccination against certain germs, considerably reduces the number of cases the years after vaccination. We can mention the massive vaccination campaign with MenAfrivac against Neisseria Meningitis A (NmA) serotype in 2010 and some introductions of new vaccines in the routine Expanded Program on Immunization (EPI). The data being weekly, it is therefore not easy to find a particular week of the year where the number of cases varies regularly.

Results of Linear Models and ARIMAX

The stationarity tests of Augmented Dickey-Fuller and Philip Perron on the series were significant for 7 of the 10 districts. The series with a unit root have been differentiated to make them stationary. Table 3 shows a comparison between the linear and ARIMAX models for each district. The results suggest that ARIMAX models are valid whereas the linear models are not. Indeed, the null hypotheses of the Portementeau residuals autocorrelation test (white noise) are all rejected for the linear models, but are not rejected for the ARIMAX models. Therefore, residuals of ARIMAX models are not auto correlated. In addition, the AIC and BIC criteria derived from the models of each district are lower for the ARIMAX models compared to those of the linear models. This results in higher performances of ARIMAX models compared to linear models. Table 4 shows the estimated coefficients of the ARIMAX model associated with the autoregressive (AR) components, Moving Average (MA) and exogenous variables. The best model selected for the Bobo-Dioulasso district is a SARIMA $(2,1,1)(1,0,0)_{52}$ model where humidity is the only significant exogenous variable. Residuals auto-correlation test (LJung-Box) shown in the last column of the table validates the model. The parameters of the ARIMAX model vary by district and the only significant exogenous variables are temperature and relative humidity. Temperature is significant in 6 of the 10 districts $(P < 0.05)$ and the relative humidity is significant in all of the 10 districts. The observed values of meningitis cases for all 52 weeks of 2017 and those predicted by the models in each district are presented in Table 5. ARIMAX models show the best predictions in 3 districts such as Bobo-Dioulasso (7.2%) and Dori (4.9%). For district of Bobo-Dioulasso, the cumulative observed cases in 2017 is 94, while predicted cases are 87.2 for ARIMAX model and 70.6 for linear model. For district of Dori, the cumulative observed cases in 2017 is 65, while predicted cases are 61.8 for ARIMAX model and 40.4 for linear model. Thus, relative prediction error are respectively 4.9% and 37.9% for ARIMAX and linear models. We observe a weak prediction capacity of the two models, but we note that the prediction capacity of the ARIMAX model is better than that of the linear model.

Table 2: Granger causality by district.

District	Weather variables	Granger Test (p-value)
Bobo-Dioulasso	maximum temperature	0.922 (0.512)
	Relative humidity	8.722 (<0.001)
	rainfall	5.357 (<0.001)
	Wind speed	3.325 (<0.001)
Bogandé	maximum temperature	1.263 (0.248)
	Relative humidity	2.819 (0.002)
	rainfall	2.022 (0.029)
Boromo	maximum temperature	1.552 (0.117)
	Relative humidity	2.073 (0.0246)
	rainfall	2.039 (0.0277)
Dédougou	maximum temperature	1.298 (0.228)
	Relative humidity	5.851 (<0.001)
	rainfall	2.420 (0.008)
Dori	maximum temperature	3.237 (<0.001)
	Relative humidity	3.903 (<0.001)
	rainfall	2.103 (0.022)
Fada N'Gourma	maximum temperature	1.503 (0.134)
	Relative humidity	4.516(<0.001)
	rainfall	2.438 (0.007)
Gaoua	maximum temperature	1.793(0.058)
	Relative humidity	8.700 (<0.001)
	rainfall	4.409(<0.001)
Ouagadougou	maximum temperature	2.068(0.025)
	Relative humidity	7.8285(<0.001)
	rainfall	4.3581(<0.001)
	Wind speed	2.296 (0.011)
Ouahigouya	maximum temperature	1.198 (0.289)
	Relative humidity	5.467(<0.001)
	rainfall	2.709(0.003)
	Wind speed	1.931 (0.038)
Po	maximum temperature	2.534 (0.005)
	Relative humidity	7.907 (<0.001)
	rainfall	5.815 (<0.001)

Discussion

In this study, we modeled the occurrence of meningitis cases taking into account weather factors using an ARIMAX model and a multivariate linear model. The residuals auto-correlation in the series suggests that the multivariate linear model may produce fallacious results regarding the effect of weather factors on the occurrence of meningitis. It is therefore, inappropriate to model the effect of weather factors on the occurrence of meningitis. ARIMAX models for the districts of Bobo-Dioulasso, Bogande, Boromo and Dedougou have humidity as significant weather factors, whereas the districts of Dori, Fada, Gaoua, Ouagadougou,

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Table 3: Parameters of linear multivariate and ARIMAX models of weekly meningitis cases and their performance.

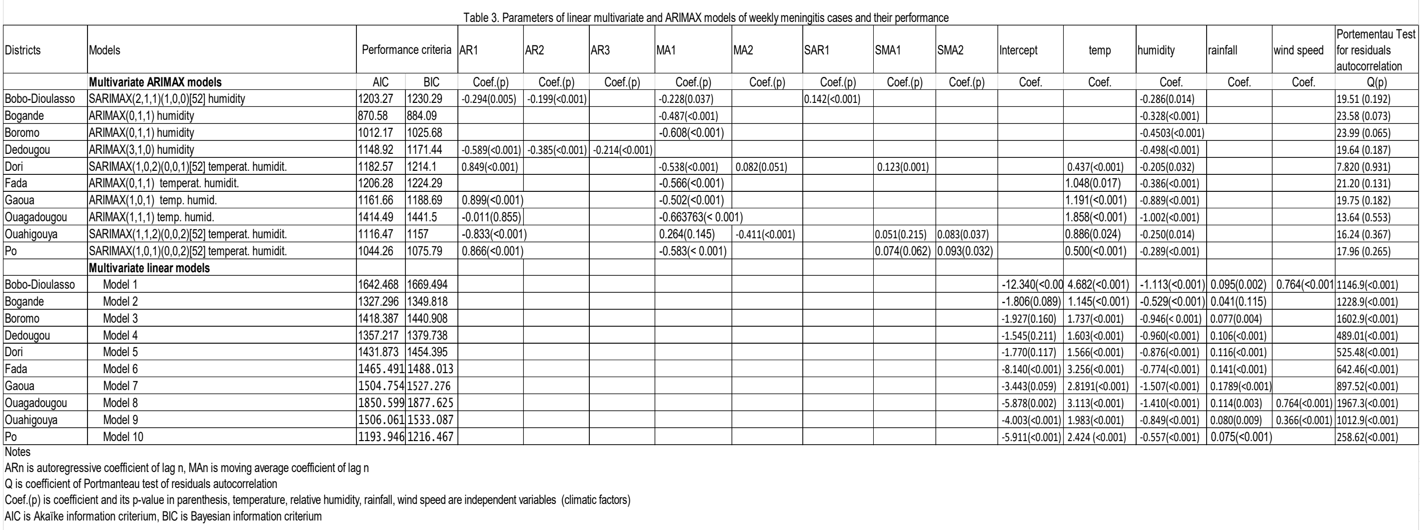

Table 3. Parameters of linear multivariate and ARIMAX models of weekly meningitis cases and their performance

Districts	Models	Performance criteria		AR1	AR2	AR3	MA1	MA2	SAR1	SMA1	SMA2	Intercept	temp	humidity	rainfall	wind speed	Portementau Test for residuals autocorrelation
	Multivariate ARIMAX models	AIC	BIC	Coef.(p)	Coef.(p)	Coef.(p)	Coef.(p)	Coef.(p)	Coef.(p)	Coef.(p)	Coef.(p)	Coef.	Coef.	Coef.	Coef.	Coef.	Q(p)
Bobo-Dioulasso	SARIMAX(2,1,1)(1,0,0)[52] humidity	1203.27	1230.29	-0.294(0.005)	-0.199(<0.001)		-0.228(0.037)		0.142(<0.001)					-0.286(0.014)			19.51 (0.192)
Bogande	ARIMAX(0,1,1) humidity	870.58	884.09				-0.487(<0.001)							-0.328(<0.001)			23.58 (0.073)
Boromo	ARIMAX(0,1,1) humidity	1012.17	1025.68				-0.608(<0.001)							-0.4503(<0.001)			23.99 (0.065)
Dedougou	ARIMAX(3,1,0) humidity	1148.92	1171.44	-0.589(<0.001)	-0.385(<0.001)	-0.214(<0.001)								-0.498(<0.001)			19.64 (0.187)
Dori	SARIMAX(1,0,2)(0,0,1)[52] temperat. humidit.	1182.57	1214.1	0.849(<0.001)			-0.538(<0.001)	0.082(0.051)		0.123(0.001)			0.437(<0.001)	-0.205(0.032)			7.820 (0.931)
Fada	ARIMAX(0,1,1) temperat. humidit.	1206.28	1224.29				-0.566(<0.001)						1.048(0.017)	-0.386(<0.001)			21.20 (0.131)
Gaoua	ARIMAX(1,0,1) temp. humid.	1161.66	1188.69	0.899(<0.001)			-0.502(<0.001)						1.191(<0.001)	-0.889(<0.001)			19.75 (0.182)
Ouagadougou	ARIMAX(1,1,1) temp. humid.	1414.49	1441.5	-0.011(0.855)			-0.663763(< 0.001)						1.858(<0.001)	-1.002(<0.001)			13.64 (0.553)
Ouahigouya	SARIMAX(1,1,2)(0,0,2)[52] temperat. humidit.	1116.47	1157	-0.833(<0.001)			0.264(0.145)	-0.411(<0.001)		0.051(0.215)	0.083(0.037)		0.886(0.024)	-0.250(0.014)			16.24 (0.367)
Po	SARIMAX(1,0,1)(0,0,2)[52] temperat. humidit.	1044.26	1075.79	0.866(<0.001)			-0.583(< 0.001)			0.074(0.062)	0.093(0.032)		0.500(<0.001)	-0.289(<0.001)			17.96 (0.265)
	Multivariate linear models																
Bobo-Dioulasso	Model 1	1642.468	1669.494									-12.340(<0.00	4.682(<0.001)	-1.113(<0.001)	0.095(0.002)	0.764(<0.001	1146.9(<0.001)
Bogande	Model 2	1327.296	1349.818									-1.806(0.089)	1.145(<0.001)	-0.529(<0.001)	0.041(0.115)		1228.9(<0.001)
Boromo	Model 3	1418.387	1440.908									-1.927(0.160)	1.737(<0.001)	-0.946(< 0.001)	0.077(0.004)		1602.9(<0.001)
Dedougou	Model 4	1357.217	1379.738									-1.545(0.211)	1.603(<0.001)	-0.960(<0.001)	0.106(<0.001)		489.01(<0.001)
Dori	Model 5	1431.873	1454.395									-1.770(0.117)	1.566(<0.001)	-0.876(<0.001)	0.116(<0.001)		525.48(<0.001)
Fada	Model 6	1465.491	1488.013									-8.140(<0.001)	3.256(<0.001)	-0.774(<0.001)	0.141(<0.001)		642.46(<0.001)
Gaoua	Model 7	1504.754	1527.276									-3.443(0.059)	2.8191(<0.001)	-1.507(<0.001)	0.1789(<0.001)		897.52(<0.001)
Ouagadougou	Model 8	1850.599	1877.625									-5.878(0.002)	3.113(<0.001)	-1.410(<0.001)	0.114(0.003)	0.764(<0.001)	1967.3(<0.001)
Ouahigouya	Model 9	1506.061	1533.087									-4.003(<0.001)	1.983(<0.001)	-0.849(<0.001)	0.080(0.009)	0.366(<0.001)	1012.9(<0.001)
Po	Model 10	1193.946	1216.467									-5.911(<0.001)	2.424 (<0.001)	-0.557(<0.001)	0.075(<0.001)		258.62(<0.001)

Notes
ARn is autoregressive coefficient of lag n, MAn is moving average coefficient of lag n
Q is coefficient of Portmanteau test of residuals autocorrelation
Coef.(p) is coefficient and its p-value in parenthesis, temperature, relative humidity, rainfall, wind speed are independent variables (climatic factors)
AIC is Akaïke information criterium, BIC is Bayesian information criterium

Ouahigouya and Po have temperature and humidity as weather factors significantly associated with occurrence of meningitis cases. Indeed, an increase in temperature is associated with an increase in meningitis cases for Dori, Fada, Gaoua, Ouagadougou, Ouahigouya and Po, while an increase in relative humidity is associated with a decrease in meningitis cases for all 10 districts. Results about effect of humidity are similar to those of other studies mentioned in the introduction. Indeed, "the humidity of spring and Guinean latitudes considerably reduces the incidence of meningitis [7]. The results of Martin's and Chiapello's (2012) Nigerian study, which used weekly WHO data, also showed that the increase in humidity is associated with a decrease in the number of meningitis cases. Other studies like that of Sultan B et al (2004) on Mali showed a relationship between meningitis cases and wind speed. However, the effect of wind speed was not significant in this study. In addition, this variable contained several missing values and was therefore taken into account in the modeling of 3 of the 10 districts (Bobo-Dioulasso, Ouagadougou and Ouahigouya). Few studies have pointed temperature as a risk factor for meningitis even though our study has shown it. However, the fact that its effect is significantly positive in 7 of the 10 districts provides strong evidence to conclude that temperature is a risk factor for the increase in the number of meningitis cases. The quality of prediction based on the ARIMAX model is better than that of linear model. However, ARIMAX have good predictions for only 3 districts because relative prediction error is less than 17%. The poor quality of the prediction can be potentially explained by the high frequency of zero cases of meningitis in the data (40%) and failure to predict peaks cases. Note, however, that the available data both clinical and weather does not allow a precise analysis of correlations because other weather parameters (such as vegetation index normalized difference, the wind direction, Carlos data: concentration of surface dust) are potential explanatory factors for the occurrence of meningitis. In fact, the occurrence and spread of meningitis epidemics is multifactorial [15-17]. It would then be appropriate to use a systematic approach which, beyond climate, would take into account the virulent strain, the receptive population, the environment and the living conditions. The absence of these parameters in the modeling reduce explanatory and predictive power of the model. Future studies may take these parameters into account if they are available to better refine the effect of weather factors on the occurrence of meningitis, and thus, build more robust predictive models. It should also be noted that the meningitis surveillance data used in this study are data from suspected and unconfirmed cases of meningitis, and this could therefore have an effect on the quality of the models, especially the lack of control over the case definitions by some health workers due to a lack of training on Integrated Disease Surveillance and Response (IDSR) can lead them to diagnose false suspected cases of meningitis like other diseases. For the specific case of the cities of Ouagadougou and Bobo-Dioulasso, which are not limited to a single district, the cumulation of data from all the districts of each of these two cities has been made because the weather factors were calculated for each city and not for a given district. Elsewhere each city corresponded to a district. In addition to this, it should be emphasized that the aggregate meningitis data does not give indications on the districts of origin of the patients but on the reporting districts, which can also impact the quality of the models when one knows that there are movements of people from one district to another. These different aspects may have influenced the quality of our models and the results we have obtained. Although the stepwise approach we used for the variables selection in our models may be useful in finding relationships that have not been tested before, it may also have limitations for our models because the biases and shortcomings of stepwise multiple regression are well established within the statistical literature. Another limitation of our model is that we did not use surface

Table 4: ARIMAX parameters of weekly meningitis cases and their performance.

Districts	Models	Temperature	Humidity	LJung-Box Test
	Multivariate ARIMAX models	Coef (SE)	Coef (SE)	Q(p) (pvalue)
Bobo-Dioulasso	SARIMA(2,1,1)(1,0,0)$_{52}$ humidity		-0.287	19.51 (0.192)
			-0.117	
Bogande	ARIMAX(0,1,1) humidity		-0.328	23.58 (0.073)
			-0.082	
Boromo	ARIMAX(0,1,1) humidity		-0.45	23.99 (0.065)
			-0.107	
Dédougou	ARIMAX(3,1,0) humidity		-0.498	19.64 (0.187)
			-0.105	
Dori	SARIMAX(1,0,2)(0,0,1)$_{52}$ temperat. humidit.	0.436	-0.205	7.820 (0.931)
		-0.103	-0.096	
Fada	ARIMAX(0,1,1) temperat. humidit.	1.049	-0.433	21.20 (0.131)
		-0.441	-0.119	
Gaoua	ARIMAX(1,0,1) temp. humid.	1.191	-1.002	19.75 (0.182)
		-0.173	-0.174	
Ouagadougou	ARIMAX(1,1,1) temp. humid.	1.859	-0.89	13.64 (0.553)
		-0.512	-0.155	
Ouahigouya	SARIMA(1,1,2)(0,0,2)$_{52}$ temperat. humidit.	0.886	-0.25	16.24 (0.367)
		-0.393	-0.102	
Po	SARIMA(1,0,1)(0,0,2)$_{52}$ temperat. humidit.	0.5	-0.289	17.96 (0.265)
		-0.096	-0.087	

Table 5: Actual and predicted cumulative meningitis cases of the 52 weeks of 2017.

District	Annual observed Cases	Annual predicted cases using ARIMAX	ARIMAX Prediction Prediction Error (%)	Annual predicted cases using linear model	Linear Model Prediction Error (%)
Bobo-Dioulasso	94	87,2	7	70,6	25
Bogande	11	6,5	41	25,6	133
Boromo	14	24,8	77	42,6	204
Dedougou	36	9,6	73	42,6	18
Dori	65	61,8	5	40,4	38
Fada N'Gourma	52	10,9	79	39,7	24
Gaoua	157	71,3	55	43,2	72
Ouagadougou	218	327	50	72,9	67
Ouahigouya	63	91,3	45	43,3	31
Po	39	45,4	16	32,8	16

wind speed along the northeast–southwest direction (WS_{NE}) variable as a predictor in the model which could have had a significant effect in the occurrence of meningitis cases as shown by the study of Nakazawa and Matsueda, 2016 [18]. Indeed, we did not obtain this variable by district with the national Meteorology Agency of Burkina Faso. This must have impacted the quality of the prediction of the ARIMAX model which is weak, however the model allowed us to establish the link between the occurrence of meningitis and our initial climatic variables and to compare its prediction capacity with that of the linear model.

Conclusion

The purpose of this study was to develop models to predict the meningitis weekly cases. We used an ARIMAX modeling approach that resulted in models with humidity for some

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districts (Bobo-Dioulasso, Bogande, Boromo and Dedougou) but relative humidity and temperature as exogenous variables for the other districts (Dori, Fada, Gaoua, Ouagadougou, Ouahigouya and Po. Results show that the decrease in relative humidity and the increase in temperatures are favorable conditions for the occurrence of meningitis epidemics in some cities in Burkina Faso. Strong correlations that are both negative (humidity) and positive (temperature) suggest that monitoring these parameters may contribute to the establishment of a warning system for meningitis epidemics at the local level. Taking weather variables into account improves the power of the model to predict the number of meningitis cases. Our results therefore suggest that the predictive power increases when adding weather variables in the model. We did our modeling with the ARIMAX model but another alternative could have been the use of the Time Series Susceptible-Infectious-Recovered (TS-SIR) models. Other approaches such as the time series regression model using the poison model with variants as highlighted by [13,19-24] in their paper are also possible. Apart from the multivariate linear regression model used by Pascal Yaka whose results we have compared, other multivariate linear models could have been used for comparison and may have given better results. These are the Generalized Linear Models (GLM) and the Generalized Additive Models (GAM). This first study in Burkina Faso in the field of meningitis pathology hopes to stimulate other interests for further studies. To do this, meningitis surveillance must continue and even be strengthened, in order to better participate in the international effort to fight against the pathology.

Declarations

Ethics Approval and Consent to Participate

This study did not require ethics committee approval because no individual data was used. Only district level aggregated data was used. We obtained the authorization of the Ministry of Health for the use of meningitis data as well as the meteorology department authorization for the use of weather data.

Consent for Publication

All authors consent for publication of the manuscript.

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests

None declared. No animals and human subjects involved in this study.

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Authors' Contributions

IY and LO collected surveillance and laboratory data. OO collected and cleaned weather data. BB cleaned and merged surveillance and weather data. SS and BB did the statistical analysis. HT supervised data management and drafted the manuscript.

SS designed the methodology and developed the protocol. AE, JM and RN assisted with funding acquisition. All authors contributed in manuscript review.

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Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Burkina Faso Ministry of Health, the CDC, or WHO.

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