Modeling the relationship between temperature and mortality: a case study in SENEGAL

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Abstract. In this paper, we have used the Generalized Additive Model (GAM) to investigate the relationships between high temperature and daily number of deaths in Niakhar, a Sahelian-Sudanese climate in central Senegal. Daily data on number of deaths and meteorological variables over the period of 1983-2013 were considered. (To be continued in page 1474).

Key words: Temperature; mortality; GAM; relative risk.

AMS 2010 Mathematics Subject Classification Objects : 62F10; 62Q05.

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In this paper, we have used the Generalized Additive Model (GAM) to investigate the relationships between high temperature and daily number of deaths in Niakhar, a Sahelian-Sudanese climate in central Senegal. Daily data on number of deaths and meteorological variables over the period of 1983-2013 were considered. Descriptive statistics show that, over the study period, the total number of non-accidental deaths were 12,798, among which we notice that 490 persons (3.83%) died of cardiovascular disease, 1,015 persons (7.93%) died of respiratory disease, 3,970 persons (31.02%) died of certain infectious and parasitic diseases, and 224 persons (1.75%) died of nervous system disease. From the GAM model, we observe that high temperature significantly increased the relative risk (RR). Indeed, relative risk of deaths due to cardiovascular disease is 1.034 with a 95% confidence intervals [CI] 1.025 to 1.044, while it is 1.030 with a 95% CI 1.026 to 1.033 for certain infectious and parasitic disease. For respiratory disease, the RR is 1.012 with a 95% CI 1.007 to 1.017, and for nervous system disease, the relative risk is 1.034 with 95% CI 1.026 to 1.043. In addition, we obtain that: (a) during heat exposure, the elderly as well as the female are more vulnerable; (b) the presence of lagged effect of temperature on mortality with an optimum temperature of 25°C; (c) the effect of high temperatures on mortality is predominantly within the current and lag 1 day and is more pronounced at a lag of 9 days.

(Résumé. (Abstract in French) Dans cet article, nous avons utilisé le modèle additif généralisé (GAM) permettant de décrire la relation entre la température élevée et la mortalité à Niakhar situé au centre du Sénégal dont le climat est du type Soudano-Sahélien. Les données journalières de mortalité et les conditions météorologiques journalières étaient disponibles au cours de la période 1983-2013. L’analyse descriptive montre que, sur la période d’étude, le nombre total de décès non accidentels enregistré est de 12,798, parmi lesquels on note 490 personnes (soit 3.83%) sont décédées des maladies cardiovasculaires, 1,015 personnes (soit 7.93%) de maladies respiratoires, 3,970 personnes (soit 31.02%) de certaines maladies infectieuses et parasitaires, et 224 personnes (soit 1.75%) des maladies du système nerveux. Le modèle GAM nous permet d’observer l’augmentation significative de la température avec le risque relatif (RR). En effet, le risque relatif de décès dus aux maladies cardiovasculaires est de 1.034 avec un intervalle de confiance (IC) à 95% de 1.025 à 1.044, alors qu’il est de 1.030 avec un IC à 95% de 1.026 à 1.033 pour certaines maladies infectieuses et parasitaires. Pour les maladies respiratoires, le RR est de 1.012 avec un IC à 95% de 1.007 à 1.017, et pour les maladies du système nerveux, le risque relatif est de 1.034 avec un IC à 95% de 1.026 à 1.043. De plus, on obtient: (a) lors de l’exposition à la chaleur, les personnes âgées ainsi que les femmes sont plus vulnérables; (b) la présence d’un effet retardé de la température sur la mortalité avec une température optimale de 25°C; (c) l’effet des températures élevées sur la mortalité est prédominant le même jour et pour le décalage de 1 jour et est plus prononcé avec un décalage de 9 jours.
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1. Introduction
Climate change and its rapid emergence in the last decades are a major challenge to public health together with health inequity and weakening of health systems particularly in Africa. With the current concern for global warming it is reasonable to oppose that heat waves which are a major cause of weather-related deaths may increase in frequency, severity and duration in Africa. Thus, to predict the consequences of global warming and dangerous weather conditions, the relation temperature-mortality become a challenging modeling exercise which is considered, among a large other things, by a large and growing body of research literature and government reports (IPCC (1990); IPCC (2001); IPCC (2007a); IPCC (2007b)). However, while there is abundant literature of the effect of temperature on mortality (Laaïdi et al. (2006); Rocklov et al. (2011); Bobb et al. (2014); Curriero et al. (2002); Gouveia et al. (2013); Kalkstein and Davis (1989); Braga et al. (2002)), a very few have been conducted in Africa. For example, Diboulo et al. (2012), using distributed lag non-linear model (DLNM), considered daily temperature and mortality data in Nouna, Burkina Faso, Bettaieb et al. (2010) used Tunisian data, Scovronick and Armstrong (2012) treated the Eastern Cape and Western Cape provinces of south Africa as a case study, Sewe et al. (2016) studied the association between remote sensing variables like day LST (Land Surface Temperature), precipitation and NDVI (Normalized Difference Vegetation Index) on malaria mortality over time in three malaria endemic regions in western Kenya, while Wiru et al. (2020) explored an association between apparent temperature and mortality in the Kintampo Health and Demographic Surveillance area of Ghana’s middle belt. All these studies found some significant impacts of temperature on the health effects.

In the present study, we analyze the association of temperature and mortality in Niakhar a rural community in the west of Senegal from 1983 to 2013 using generalized additive model (GAM). Particularly, we investigate the impact of temperature changes on age, sex and cause-specific mortality.

The paper is organized as follows. Section 2 presents the materials and methods, and describes the study site, the data used as well as the data analysis. In Section 3, we present the different results while Section 4 is dedicated to the discussion. Finally, Section 5 contained the conclusion.
2. Materials and Methods

2.1. Study site

The Niakhar Health and Demographic Surveillance System (HDSS) of the Institute of Research for Development (IRD), (see Figure 1), is located in the region of Fatick in central Senegal, 120 km from the capital, Dakar. Its geographical extent is 14° 28’60” North to 16° 24’ West. This area covers 30 villages and has a Sahalian-Sudanese climate with two distinct seasons: a dry season for a period of 7 to 8 months (from November to May or June), and a rainy season for a period of 4 to 5 months (from June or July to October). Niakhar covers 203 km² and has a population of 23,000 to 44,000 between 1983 and 2013 which provide an interesting opportunity to examine the relationships between temperature and mortality.

![Fig. 1. Map of the study area of Niakhar covering 30 villages](https://id.erudit.org/iderudit/014935ar)

2.2. Data Collection

2.2.1. Mortality data

Daily death data for Niakhar were obtained from the Health and Demographic Surveillance System (HDSS) for 1983 to 2013 periods. The data included original source information on 14,975 death persons with date of birth, date of death, sex, age, and cause of death. The underlying causes of death were coded according to International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10). The mortality data were stratified into four cause-specific categories: mortality due to cardiovascular diseases (I00 – I99), mortality due to...
respiratory diseases ($J00 - J99$), mortality due to certain infectious and parasitic diseases ($A00 - B99$), and mortality due to nervous system diseases ($G00 - G99$). In addition, the mortality data were also classified according to gender and three age groups: 0-5, 6-54, and $\geq$ 55 years old.

2.2.2. Meteorological data

Meteorological data covering the same period was obtained from Diourbel's station including daily minimum temperature ($t_{\text{min}}$), daily maximum temperature ($t_{\text{max}}$), daily mean temperature ($t_{\text{m}}$), dew point temperature ($\text{dew}$), wind speed ($\text{ws}$), and rainfall ($r$). Notice that the unit of measurement of these temperatures was $^\circ F$ and converted to $^\circ C$ with the formula:

$$^\circ C = \frac{5}{9} \times (^\circ F - 32).$$

Diourbel, where a synoptic station of National Weather Service is located, is a region in central Senegal situated at 31 km of Niakhar, so close to this site than well reproduce the main features of its climatology.

2.2.3. Data Analysis

The relationships between temperature and mortality is studied using a generalized additive models (GAMs) Hastie and Tibshirani (1999). GAMs were performed using R software version 3.2.2, with the mgcv package. The association between temperature and mortality was analyzed by two steps. In the first step, the empirical distribution of the daily mortality was plotted to determine its distribution. In Figure 2, we observe that the distribution of the number of death seems to be Negative Binomial.

Fig. 2. Empirical and theoretical distributions

Moreover, using the two-sample Kolmogorov-Smirnov test (see Table 1), we find that the daily death data can be approximated by Poisson or Negative Binomial distribution.
Modeling the relationship between temperature and mortality: a case study in SENEGAL.

Table 1. Two-sample Kolmogorov-Smirnov test.

<table>
<thead>
<tr>
<th></th>
<th>Poisson</th>
<th>Quasi Poisson</th>
<th>Negative Binomial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistics</td>
<td>0.08</td>
<td>0.34</td>
<td>0.18</td>
</tr>
<tr>
<td>P-value</td>
<td>0.9972</td>
<td>0.006177</td>
<td>0.3927</td>
</tr>
</tbody>
</table>

In the second step, we used the GAM, as follows, with uncorrelated errors to estimate temperature-mortality associations:

\[ Y_i \sim D(\lambda_i) \]

with

\[
\log[\mathbb{E}(Y_i)] = \alpha + S(time, df.time) + S(tmin_i, df.tmin) + S(dew_i, df.dew) \\
+ S(ws_i, df.ws) + S(r_i, df.r) + \varepsilon_i,
\]

where \( D \) is the considered distribution (Poisson or Negative Binomial); \( Y_i \) represents the observed daily death count on day \( i \); \( \mathbb{E}(Y_i) \) is the expected daily death number on day \( i \); \( \alpha \) denotes the intercept term; \( S(.) \) denotes the cubic smoothing splines function with \( df.time = 8 \), \( df.tmin = 5 \), \( df.dew = 8 \), \( df.ws = 2 \), and \( df.r = 2 \) are the degree of freedom in the spline smoothing function of time trend, daily minimum temperature, dew point temperature, wind speed, and rainfall respectively; and \( \varepsilon_i \) is the residual.

In this work, two cases will be studied:

a) the GAM with uncorrelated errors; and

b) the GAM with correlated errors where we consider ARMA\((p, q)\) model with \( p \leq 10 \) and \( q \leq 10 \) and use auto.arima command in \( R \) to find the best model.

The different models were compared with the generalized likelihood ratio test in the ANOVA approach using \( lme \) command in \( R \). Moreover, some results were presented as changes in excess risks (ER) with 95\% CI in mortality for every 1°C increase in temperature. The ER was calculated using the following equation:

\[
ER = (RR - 1) \times 100%,
\]

where \( RR \) is relative risk of temperature on the mortality.

3. Results

During the study period (1983-2013), there were 12,798 non-accidental deaths in total; 490 persons (3.83\%) died from cardiovascular disease, 1,015 persons (7.93\%) died from respiratory disease, 3,970 persons (31.02\%) died from certain infectious and parasitic diseases, and 224 persons (1.75\%) died from nervous system disease (see, Table 2). An average of 0.00, 0.00, 0.20, and 0.00 cases per day is observed for
cardiovascular, respiratory, infectious and parasitic, and nervous system mortality, respectively. The average daily maximum, mean, and minimum temperature were 36.37°C (range: 19.61°C, 50°C), 28.85°C (range: 18°C, 38.94°C), and 20.78°C (7.50°C, 34.78°C), respectively. The daily average dew point temperature was 16.35°C and ranged from 6.44°C to 28.11°C, while the daily average of wind speed, rainfall, and visibility were 3.034 m/s, 1.059 mm, and 6.18 m, respectively.

Table 2. Descriptive statistics of daily temperatures, weather conditions and category-specific mortality in Niakhar, Senegal during 1983 to 2013.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Q_1</th>
<th>Q_2</th>
<th>Q_3</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>36.37</td>
<td>3.24</td>
<td>19.61</td>
<td>34.21</td>
<td>36.39</td>
<td>38.60</td>
<td>50</td>
</tr>
<tr>
<td>Mean</td>
<td>28.85</td>
<td>2.62</td>
<td>18</td>
<td>27.28</td>
<td>29.15</td>
<td>30.61</td>
<td>38.94</td>
</tr>
<tr>
<td>Minimum</td>
<td>20.78</td>
<td>3.54</td>
<td>7.50</td>
<td>18.11</td>
<td>21</td>
<td>23.62</td>
<td>34.78</td>
</tr>
<tr>
<td>Dew Point</td>
<td>16.35</td>
<td>7.11</td>
<td>6.44</td>
<td>11.22</td>
<td>17.06</td>
<td>22.94</td>
<td>28.11</td>
</tr>
<tr>
<td>Weather conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>3.034</td>
<td>1.81</td>
<td>0.00</td>
<td>1.79</td>
<td>2.83</td>
<td>4.00</td>
<td>24.00</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>1.059</td>
<td>9.19</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>99.99</td>
</tr>
<tr>
<td>Visibility (m)</td>
<td>6.18</td>
<td>0.72</td>
<td>0.10</td>
<td>6.20</td>
<td>6.20</td>
<td>6.40</td>
<td>14.20</td>
</tr>
<tr>
<td>Sex-specific mortality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>0.4</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
<td>29.0</td>
</tr>
<tr>
<td>Female</td>
<td>0.4</td>
<td>1.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
<td>28.0</td>
</tr>
<tr>
<td>Age-specific mortality</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-5 years</td>
<td>0.4</td>
<td>1.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
<td>28.0</td>
</tr>
<tr>
<td>6-54 years</td>
<td>0.1</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>11.0</td>
</tr>
<tr>
<td>≥ 55 years</td>
<td>0.2</td>
<td>0.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>18.0</td>
</tr>
</tbody>
</table>

µ: mean; Q_1 : is the first quartile; Q_2 : is the median; Q_3 : is the third quartile.

3.1. Poisson GAM Model

To take into account the serial correlation structure in the GAM model, criteria such as AIC and BIC as well as ANOVA have been calculated and appeared in Table 3. We observe that the p-values are very small indicating that the GAM with AR is significantly better than the model GAM with uncorrelated residual. However, with respect to the BIC criteria, GAM with AR(1) model is favored to better describe the data.

Table 3. Model selection with Poisson GAM

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>BIC</th>
<th>Test</th>
<th>L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>62357.35</td>
<td>62448.72</td>
<td></td>
<td>9.702</td>
<td>0.0018</td>
</tr>
<tr>
<td>Model 2</td>
<td>62349.65</td>
<td>62448.63</td>
<td>1 vs 2</td>
<td>9.702</td>
<td>0.0018</td>
</tr>
<tr>
<td>Model 3</td>
<td>62346.42</td>
<td>62453.02</td>
<td>2 vs 3</td>
<td>5.229</td>
<td>0.0222</td>
</tr>
</tbody>
</table>

Model 1: Poisson GAM with uncorrelated residuals; Model 2: Poisson GAM with AR(1) residuals; Model 3: GAM with AR(2) residuals. L.Ratio: Likelihood Ratio Test.
In Figure 3, we plotted the relationships curve between the relative risk and the minimum temperature of the current day (lag 0), lags 0-1, and lags 0-9.

For lag 0, the cumulative relative risk on specific cause of death was decreased quickly, when the temperature was greater than 29°C.

For lags 0-1, an W-shaped association curve for nervous system and cardiovascular mortality is obtained with two temperature thresholds: hot (25°C) and cold (13°C) for nervous system mortality and hot (25°C) and cold (15°C) for cardiovascular mortality. For low temperatures (below 12°C or 15°C) and high temperatures (above 25°C), the relative risk for cardiovascular and nervous system mortality increased approximately linearly along with decreases (and increases) in temperature. The risk curve is relatively flat when the temperature is between 15°C and 25°C for cardiovascular mortality. No clear effect for minimum temperature in respiratory and certain infectious diseases is noticed.

For lags 0-9, the association between temperature and cause-specific mortality was non-linear except nervous system mortality.

Figure 4 shows the effects of high temperature (34.8°C, 99th percentile) relative to the 75th percentile of temperature (30.6°C), and the effects of low temperature (22.1°C, 1st percentile) relative to the 25th percentile of temperature (27.2°C) on cause-specific mortality over 25 days of lag. We find that high temperature effect is observed after a few days except for cardiovascular mortality which an immediate effect was observed with a strongest effect at lag 0 and lasted six days. Low temperature effect appeared after a few days except for infectious which no clear short-term effect and acute were observed, and for nervous system (no effect) mortality. The death risk of cause-specific mortality decreased at high temperature.

Figure 5 shows the effects of high temperature (34.8°C, 99th percentile) relative to the 75th percentile of temperature (30.6°C), and the effects of low temperature (22.1°C, 1st percentile) relative to the 25th percentile of temperature (27.2°C) on age- and sex-specific mortality over 25 days of lag. We observed immediate effects of hot temperature on mortality among those ≥ 55 years of age on the current day (lag 0). For low temperature, an immediate effect and statistically significant were observed on mortality for males at lag 0 days.

Figure 6 shows the cumulative effects of temperature on cause-specific mortality at lag 0 (current day), lags 0-1, and lags 0-9. For both current day (lag 0) and lags 0-1, we note that the mortality risk decreased rapidly with both the low and high temperatures. We found that at lags 0-9, which reflects long-term effects of the temperature on mortality rate, the curve of their relationships had a W shape. We remark that, as lags time increased, the relative risk associated with high temperatures increased, while the risks associated with low temperatures decreased. In the city of Niakhar, we observe an association of high and low temperatures with increased mortality, with the effect of high temperatures on mortality was higher.
Fig. 3. The association between cause-specific daily mortality and daily minimum temperature at lag 0 (left), lags 0-1 (middle), and lags 0-9 (right) with Poisson GAM. The black lines are relative risks of mortality and the dotted lines represent the 95% confidence interval regions within 9 days. This findings is consistent with some studies (Bao et al.(2016); Jong et al.(2017)).

Table 4 shows the relative risk of minimum temperature effect on cause-specific mortality at lag 0 (current day), lags 0-1, and lags 0-9 with Poisson GAM model.

For the current day, our age-specific analysis showed that the effects of minimum temperature are greater among the elderly ≥ 55 years old. Similar evidence that the elderly population is among the most vulnerable groups is provided in the literature. For instance, one can refer to Guo et al.(2012a); Guo et al.(2012b); Astrom et al.(2011); Rocklov et al.(2011); Baiden et al.(2006); and Hajat et al.(2014). In addition, we observe that the minimum temperature

Fig. 4. The lag structure of high and low temperature effects on cause-specific mortality along lag days with Poisson GAM Model. The cyan lines are relative risks of mortality and grey bands represent the 95% confidence intervals.

Effects are more pronounced among females compared to males. For cause-specific mortality, we notice that the relative risks are significant, and higher for cardiovascular diseases ($ER = 0.034\%$ (95% CI: 0.025%, 0.044%)) and nervous system diseases ($ER = 0.034\%$ (95% CI: 0.026%, 0.043%)). Overall, there was significant association between the minimum temperature and cause-, age- and sex-specific mortality.

For lags 0-1, we can find that the excess risk for respiratory system ($ER = 0.535\%$, 95% CI: 0.151%, 0.557%) and cardiovascular mortality ($ER = 0.273\%$, 95% CI: 0.001%, 0.457%).
Fig. 5. The lag structure of high and low temperature effects on age- and sex-specific mortality along lag days with Poisson GAM Model. The cyan lines are relative risks of mortality and grey bands represent the 95% confidence intervals.
0.243%, 0.308%) were higher than those for nervous system (ER = 0.248%, 95% CI: 0.199%, 0.297%) and infectious mortality (ER = 0.0104%, 95% CI: −0.002%, 0.022%). A significant excess risk was observed for cause-specific mortality except infectious mortality. By the three age groups, the highest excess risk (ER = 0.248%, 95% CI: 0.199%, 0.297%) was found in the 6-54 years of age, and was not significant. Among sex-specific risk, both the excess risk for male and females were statistically significant.

For the lag of 9 days, the people aged ≥ 55 years presented higher excess risk (ER = 1.683%, 95% CI: 1.694%, 1.694%), compared with those 0-5 years old (ER = 0.934%, 95% CI: 0.925%, 0.942%) for 0-5 years old and (ER = 1.031%, 95% CI: 1.017%, 1.046%) for 6-54 years old, and for males (ER = 0.801%, 95% CI: 0.792%, 0.810%) with compared females (ER = 0.570%, 95% CI: 0.561%, 0.579%). However, the excess risks were statistically significant for sex-, and age-specific mortality, but not significant for cause-specific mortality.

### Table 4. Relative Risk (95% confidence interval) for cause-, age- and sex-specific mortality for minimum temperature at lag 0, lags 0-1, and lags 0-9, with Poisson GAM Model.

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Lag 0</th>
<th></th>
<th>Lag 0-1</th>
<th></th>
<th>Lag 0-9</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>RR</td>
<td>95%CI</td>
<td>RR</td>
<td>95%CI</td>
<td>RR</td>
<td>95%CI</td>
</tr>
<tr>
<td>Cause of deaths</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>1.034</td>
<td>(1.025-1.044)</td>
<td>1.275</td>
<td>(1.243-1.308)</td>
<td>1.016</td>
<td>(0.519-1.512)</td>
</tr>
<tr>
<td>Infectious</td>
<td>1.030</td>
<td>(1.026-1.033)</td>
<td>1.010</td>
<td>(0.998-1.022)</td>
<td>1.005</td>
<td>(0.993-1.917)</td>
</tr>
<tr>
<td>Respiratory</td>
<td>1.012</td>
<td>(1.007-1.017)</td>
<td>1.535</td>
<td>(1.151-1.557)</td>
<td>1.011</td>
<td>(0.866-1.153)</td>
</tr>
<tr>
<td>Nervous system</td>
<td>1.034</td>
<td>(1.026-1.043)</td>
<td>1.248</td>
<td>(1.199-1.297)</td>
<td>1.011</td>
<td>(0.587-1.434)</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-5</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>0-5</td>
<td>1.030</td>
<td>(1.010-1.121)</td>
<td>1.004</td>
<td>(1.000-1.005)</td>
<td>1.934</td>
<td>(1.925-1.942)</td>
</tr>
<tr>
<td>6-54</td>
<td>1.036</td>
<td>(1.067-1.065)</td>
<td>1.007</td>
<td>(0.987-1.027)</td>
<td>2.031</td>
<td>(2.017-2.046)</td>
</tr>
<tr>
<td>≥55</td>
<td>1.098</td>
<td>(1.085-1.111)</td>
<td>1.005</td>
<td>(0.991-1.019)</td>
<td>2.683</td>
<td>(2.672-2.694)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.079</td>
<td>(1.061-1.097)</td>
<td>1.004</td>
<td>(1.004-1.004)</td>
<td>1.801</td>
<td>(1.792-1.810)</td>
</tr>
<tr>
<td>Female</td>
<td>1.106</td>
<td>(1.092-1.121)</td>
<td>1.004</td>
<td>(1.003-1.005)</td>
<td>1.570</td>
<td>(1.561-1.579)</td>
</tr>
</tbody>
</table>

*Journal home websites: [www.jafristatap.net](http://www.jafristatap.net), [www.projecteuclid.org/euclid.ajas](http://www.projecteuclid.org/euclid.ajas)*
Figure 7 shows the effects of minimum temperature on age-, sex-specific mortality at lag 0, lags 0-1, and lags 0-9. For both current day (lag 0) and lags 0-1, the risk of death due to age-, sex-specific decreased rapidly with both the low and high temperatures, except those among 6-54 years at lags 0-1.

For lags 0-9, the relationships between minimum temperature and age-specific mortality were non-linear, which a clear U-shaped curve was observed, except the subgroup of 6-54 years old. The effects of minimum temperature on sex-specific mortality were similar both the males and females. We find that slight increase in males and females mortality at low temperature and rapid increase at high temperature.

3.2. Binomial Negative GAM Model

In this section, we present the different results obtained from the Negative Binomial model. Table 5 shows both AIC and BIC, a model selection with negative binomial distribution. According to BIC, a GAM with uncorrelated residual model is favored to better describe the data.

Table 5. Model selection with Negative Binomial GAM

<table>
<thead>
<tr>
<th>Model</th>
<th>AIC</th>
<th>BIC</th>
<th>Test</th>
<th>L.Ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>67979.23</td>
<td>68009.69</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td>68134.16</td>
<td>68172.23</td>
<td>1 vs 2</td>
<td>6.077</td>
<td>0.00312</td>
</tr>
<tr>
<td>Model 3</td>
<td>68036.76</td>
<td>68082.45</td>
<td>2 vs 3</td>
<td>7.99</td>
<td>0.00471</td>
</tr>
</tbody>
</table>

Model 1: Negative Binomial GAM with uncorrelated residuals; Model 2: Negative Binomial GAM with AR(2) residuals; Model 3: Negative Binomial GAM with AR(2); L.Ratio: Likelihood Ratio Test.

Figure 8 shows the effects of minimum temperature on cause-specific mortality at lag 0, lags 0-1, and lags 0-9.

For lag 0, the association between temperature and the risk for deaths due to cause-specific was non-linear except the mortality due to nervous system.

For lags 0-1 days, the relationships between temperature and mortality was W or U-shaped (Figure 8), with largest effects (steeper slopes) for mortality due to specific causes.

For lags 0-9 days, the association between temperature and cause-specific mortality was linear except the mortality due to cardiovascular.

Table 6 shows the relative risk of minimum temperature effect on cause-specific mortality at lag 0, lags 0-1, and lags 0-9 with Binomial Negative. For lag 0, our cause-specific analyses show that the excess risk of mortality \( ER = 1.04\% \), 95%
Fig. 7. Relationship between age-, and sex-specific daily mortality and daily minimum temperature at lag 0 (left), lags 0-1 (middle), and lags 0-9 (right), with Poisson GAM Model. The black lines are relative risks of mortality and the dotted lines represent the 95% confidence interval regions.

CI: 0.93%, 1.15%) was higher for nervous system and overall the risks were statistically significant. Our sex-specific analyses, the excess risk of mortality among females (ER = 0.00096%, 95% CI: -0.01%, 0.021%) was higher than those males (ER = 0.00087%; 95% CI: -0.02%, 0.012%), these excess risks were not significant. With to respect age, the highest ER was found among individuals ≥ 55 years old and was

Modeling the relationship between temperature and mortality: a case study in SENEGAL.

Fig. 8. The association between cause-specific daily mortality and daily minimum temperature at lag 0 (left), lags 0-1 (middle), and lags 0-9 (right), with Negative Binomial GAM. The black lines are relative risks of mortality and the dotted lines represent the 95% confidence interval regions.

statistically significant (ER = 0.097%; 95% CI: 0.082%, 0.11%) but not on other group. For lags 0-1, the strongest excess risk was observed for cardiovascular mortality (0.078% (95% CI: –0.01%, 0.078%)). The excess risks were not significantly significant for age-, sex-, and cause-specific except for infectious mortality (0.035% (95% CI: 0.019%, 0.050%)). For lags 0-9, the temperature was significantly associated with the excess risk of age-, sex-specific, but not significant for cause-specific. The highest excess risk was seen in the age group of 6-54 years old (ER = 0.044%, 95% CI: 0.017%, 0.044%).

Figure 9 shows the effects of high temperatures (34.8°C, 99th percentile) relative to the 75th percentile of temperature (30.6°C) and the effects of low temperature (22.1°C, 1st percentile) relative to the 25th percentile of temperature (27.2°C) on cause-specific mortality along the lags up to 25 days with Negative Binomial GAM.
Modeling the relationship between temperature and mortality: a case study in SENEGAL.

Table 6. Relative Risk (95% confidence interval) for cause-, age- and sex-specific mortality for minimum temperature at lag 0, lags 0-1, and lags 0-9, with Negative Binomial GAM Model.

<table>
<thead>
<tr>
<th>Mortality</th>
<th>Lag 0</th>
<th>Lag 0-1</th>
<th>Lag 0-9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RR</td>
<td>95% CI</td>
<td>RR</td>
</tr>
<tr>
<td>Cause of deaths</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>1.68</td>
<td>(1.63-1.74)</td>
<td>1.078</td>
</tr>
<tr>
<td>Infectious</td>
<td>1.20</td>
<td>(1.18-1.22)</td>
<td>1.035</td>
</tr>
<tr>
<td>Respiratory</td>
<td>1.010</td>
<td>(0.975-1.045)</td>
<td>1.010</td>
</tr>
<tr>
<td>Nervous system</td>
<td>1.93</td>
<td>(1.88-1.97)</td>
<td>1.006</td>
</tr>
<tr>
<td>Age (years)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-5</td>
<td>1.0011</td>
<td>(0.98-1.013)</td>
<td>1.006</td>
</tr>
<tr>
<td>6-54</td>
<td>1.0054</td>
<td>(0.98-1.022)</td>
<td>1.008</td>
</tr>
<tr>
<td>≥55</td>
<td>1.097</td>
<td>(1.082-1.11)</td>
<td>1.007</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>1.00087</td>
<td>(0.98-1.012)</td>
<td>1.006</td>
</tr>
<tr>
<td>Female</td>
<td>1.097</td>
<td>(1.082-1.11)</td>
<td>1.006</td>
</tr>
</tbody>
</table>

Model. The effect of high temperature were appeared immediately with greatest effects on the same day as event (lag 0) and lasted usually only one or few days for cause-specific mortality except for infectious mortality. Statistically significant effects were observed for high temperature. However, the effects of low temperature were delayed by few days with statistically significant effects for cause-specific mortality except for nervous system mortality.

Figure 10 shows the effects of high temperature (34.8°C, 99th percentile) relative to the 75th percentile of temperature (30.6°C), and the effects of low temperature (22.1°C, 1st percentile) relative to the 25th percentile of temperature (27.2°C) on age- and sex-specific mortality over 25 days of lag. The law temperature effects on age- and sex-specific mortality were observed immediately and acute at lag of 0-1 days. Both the law and high temperature effects, no statistically significant effect was observed.

The relative risk of minimum temperature on all-cause, and -age mortality at lag 0, lags 0-1, and lags 0-9 with Negative Binomial GAM Model are as shown Figure 11. Based on the GAM with Negative Binomial the results demonstrate the same conclusion as for the GAM with Poisson distribution (Figure 6).

Figure 12 shows the effects of minimum temperature on age-, sex-specific mortality at lag 0, lags 0-1, and lags 0-9 with Negative Binomial GAM.

For lag 0, a clear U-shaped curve was observed among the people aged between 6 and 54 years old.

For lags 0-1, the curve of the relationship between age-specific mortality among those aged ≥ 55 years showed an W-shaped.

For lags 0-9, a steeper U-shaped relation was observed in the 0-5 year old groups, males and females with a stronger effect of both low and high temperatures on mortality, with respect to other age groups the curve assumes a linear trend.

Modeling the relationship between temperature and mortality: a case study in SENEGAL.

4. Discussion

In epidemiological studies, the meteorological influences on human health indicators are often investigated in a modeling approach. Notice that, the GLM and GAM are the well used models. In this work, different GAM models are considered to examine the temperature-mortality relationships in Niakhar HDSS, Senegal. During the study period 1983 to 2003, Niakhar experienced hot summers (May to October) with an average daily temperature 23.7°C and daily maximum temperature larger than 37°C occurred per summer. Therefore, in this study we have the opportunity
Modeling the relationship between temperature and mortality: a case study in SENEGAL.

We investigated the temperature-mortality relationships in an extremely hot area. A non-linear and W-shaped relationship was found between temperature and all cause-specific mortality categories, specifically for nervous system disease and cardiovascular disease, which revealed that both low and high temperature were associated with increased mortality risk (see Figure 3). This result is consistent with previous studies conducted in sub-Saharan Africa (Diboulo et al., 2012) or near this region (Ballester et al., 1997; Saez et al., 2000). Moreover, the study indicated that the effects of low temperatures on mortality were much larger than that of high temperatures. These findings may have important implications for public health policies in Niakhar, Senegal. For long lags, low temperature effects were significant (see Figure 4). This finding concurs with a number of previous studies in other tropical cities (McMichael et al., 2006; Yu et al., 2012).

When analyzing by cause of death (Tables 4, 6, Figures 3 and 8), effect estimates were markedly higher for cardiovascular and nervous deaths compared to respiratory and infectious deaths, consistent with previous studies mainly conducted in Europe (Huynen et al., 2001; Eurowinter, 1997; Chung et al., 2009). In addition, as stated in Onozuka and Hagihara (2015), Yang et al. (2015), and Huang et al. (2012), we found that gender and age of the study population modify the relationships between temperature and mortality. The findings are compatible with other previous literatures (Gao et al., 2017; Medina et al., 2006; Analitis et al., 2018). Indeed, regarding the age-specific analysis, temperature effects were observed for the elderly (≥ 55 years old) which was the most affected (Table 4). At lags 0-9, the effects of both high and low temperature were greater among the 0-5 years old compared to the 6-54 years old and the elderly (see Figure 12 and Table 6); these results seem to be similar those found by Ballester et al. (1997) and Saez et al. (2000) in Spain. Numerous studies have provided similar evidence that the children and elderly are among the most vulnerable group (Hajat et al., 2007; Conti et al., 2005; Empereur, 2004; Donaldson et al., 2003; Huynen et al., 2001).

We found also that at a long lag, females were more susceptible to low temperature, while the high temperature effects were not significantly different in females compared to males (Figure 12). These findings are in line with other study like Dang et al. (2016).

We found that, for lags 0-1, the excess risk was stronger for cardiovascular mortality (Table 6) than the others cause-specific mortality, these findings are consistent previous study (Ma et al., 2015).

From Figure 12, for lags 0-9, the shapes of the curve for age-, sex-specific were similar except the age group ≥ 55 years.

The relationships between age-specific mortality and minimum temperature over a lags of 0-9 days was linear positive except the people aged 0-5 years (Figure 12). From Figures 3 and 8, the shapes of the curve of the temperature-mortality relationships...
relationship among cause-specific seems to have been similar for cardiovascular and nervous system mortality compared to infectious and respiratory mortality.

The effects of high temperature on cardiovascular mortality typically lasted and statistically significant within the first five days (Figure 4), similar pattern was also found in previous study (Liu et al. 2011)). In addition, the pattern for respiratory mortality shows the strongest effect of high temperature and persisted over a lag of 3-11 days. We also found that the effects of low temperature on cardiovascular and respiratory mortality appeared after one day and lasted five days. We observe that high effects lasted longer than low effects. These findings are not consistent with Negative Binomial GAM (Figure 9). We found high temperature effect had mortality displacement (harvesting effect) both Figures 4 and 9, consistent with previous study (Yang et al. 2012); Iranpour et al. 2020)). For low temperature effect, the mortality displacement was observed for all cause-specific except nervous system mortality. From Figure 9, we found that the effect of low temperature was stronger on respiratory mortality, this result is compatible by a previous study (O’Neill et al. 2003) and we observed a harvesting effect for high temperature effect on respiratory mortality, similar result was found by a previous study (Braga et al. 2002)).

Compared with criteria such as AIC and BIC with Negative Binomial GAM (Table 5), the values of both AIC and BIC obtained with Poisson GAM (Table 3) were generally smaller. In addition, for Poisson GAM, the model 2 is the most suitable the data. By contrary, for Negative Binomial GAM, the model 1 (Negative Binomial GAM with uncorrelated residual) is the most representative.

Some limitations should be pointed out. Firstly, the data are only from one city, so it should be interesting to generalize the findings to other geographic areas and other climates in Senegal. Secondly, measurements of meteorological variables generally obtained from point-source weather stations that may be some distance from where mortality are recorded. In particular, meteorological parameters from national weather station at Diourbel, situated at 31 km of Niakhar, are used in this study. Thirdly, biometeorological indices such as the apparent temperature, heat stress index, may be considered for next studies. These indices are absolute so that they assume the weather has the same impact on the human body regardless of location or the time at which it occurs.

5. Conclusion

No study on the temperature-mortality relationship has yet been published in Senegal, so this paper fills a big gap and was possible thanks to ACASIS project (http://www.agence-nationale-recherche.fr/Projet-ANR-13-SENV-0007).

Significant relationships between temperature and heat-related mortality have been observed and modeled for Niakhar HDSS in Senegal. Threshold temperatures
were significantly associated to nervous system mortality and to cardiovascular mortality through non-monotonic "U-shaped" relationship in agreement with many studies in Europe and in Sub-Saharan Africa. As the direct effects of extreme temperature on health are not always immediate, this study founds a lag of 9 days between mortality and temperature by a "W-shaped" relationship, which reflects long-term effects of the temperature on mortality rate. The elderly, the 0-5 years old and those with existing diseases such as nervous disease and cardiovascular disease are most susceptible to extreme temperatures, which typically occur with different lags: high temperature effect appeared after a few days except for cardiovascular mortality. Low temperature effect occurred after a few days except for infectious and nervous system mortality.

There is evidence that climate change will affect temperature-related mortality heterogeneously, so inter-regional comparisons are a necessity in Sub-Saharan area where climate projections indicate that heat waves should increase in frequency and intensity in the coming decades. Our findings can contribute to reduce the ill effects of temperature on human health.

Acknowledgment:

We would like to thank to ACASIS project (http://www.agence-nationale-recherche.fr/Projet-ANR-13-SENV-0007).

References


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Modeling the relationship between temperature and mortality:
a case study in SENEGAL.

10.4178/epih.e2020053


Modeling the relationship between temperature and mortality: a case study in SENEGAL.


Fig. 10. The lag structure of high and low temperature effects on age- and sex-specific mortality along lag days with Negative Binomial GAM Model. The red lines are relative risks of mortality and grey bands represent the 95% confidence intervals.
Fig. 11. The relationship between daily minimum temperature and all-causes, and all-ages mortality at lag 0, lags 0-1, and lags 0-9 with Negative Binomial GAM Model. The black lines are relative risks of mortality and the dotted lines represent the 95% confidence interval regions.
Fig. 12. Relationship between age-, and sex-specific daily mortality and daily minimum temperature at lag 0 (left), lags 0-1 (middle), and lags 0-9 (right), with Negative Binomial GAM. The black lines are relative risks of mortality and the dotted lines represent the 95% confidence interval regions.