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RESEARCH ARTICLE

Heat waves and health risks in the northern part of Senegal: analysing the distribution of temperature-related diseases and associated risk factors

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Abstract
The Sahelian zone of Senegal experienced heat waves in the previous decades, such as 2013, 2016 and 2018 that were characterised by temperatures exceeding 45°C for up to 3 successive days. The health impacts of these heat waves are not yet analysed in Senegal although their negative effects have been shown in many countries. This study analyses the health impacts of observed extreme temperatures in the Sahelian zone of the country, focusing on morbidity and mortality by combining data from station observation, climate model projections, and household survey to investigate heat wave detection, occurrence of climate-sensitive diseases and risk factors for exposure. To do this, a set of climatic (temperatures) and health (morbidity, mortality) data were collected for the months of April, May and June from 2009 to 2019. These data have been completed with 1246 households' surveys on risk factor exposure. Statistical methods were used to carry out univariate and bivariate analyses while cartographic techniques allowed mapping of the main climatic and health indicators. The results show an increase in temperatures compared to seasonal normal for the 1971–2000 reference period with threshold exceedances of the 90th percentiles (42°C) for the maxima and (27°C) the minima and higher temperatures during the months of May and June. From health perspective, it was noted an increase in cases of consultation in health facilities as well as a rise in declared morbidity by households especially in the departments of Kanel (17.7%), Ranérou (16.1 %), Matam (13.7%) and Bakel (13.7%). The heat waves of May 2013 were also associated with cases of death with a reported mortality (observed by medical staff) of 12.4% unequally distributed according to the departments with a higher number of deaths in Matam (25, 2%) and in Bakel (23.5%) than in Podor (8.4%) and Kanel (0.8%). The morbidity and mortality distribution according to gender shows that women (57%) were more affected than men (43%). These health risks have been associated with a number of factors including age, access to drinkable water, type of fuel, type of housing and construction materials, existence of fan and an air conditioner, and health history.The heat wave recurrence has led to a frequency in certain diseases sensitive to rising temperatures, which is increasingly a public health issue in the Sahelian zone of Senegal.

Keywords Climate · Temperature · Heat waves · Diseases · Health risks · Senegal

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Introduction

In the context of global climate warming, with a predicted rise in global temperature from 1 to 6°C by 2100, the risk of extreme weather events such as heat waves will increase and greatly affect Sahel territories (Kovats & Kristie 2006; Fouillet et al. 2006; Christensen et al. 2007; Smith et al. 2014; OMM 2015). In the African Sahel belt, reported heat wave events date back to 2000 with high temperatures reaching 50°C around 19 April in Niamey, with an almost similar situation in Senegal, Mali, Burkina-Faso and Chad during the same period. Other parts of the African continent are also affected by extreme temperature events with 51.3°C in Ouargla and 49.6°C in Touggour in Algerian Sahara and 49.2°C in Tozeur and 48.3°C Kairouan in Tunisia during July 2018 (Carlton et al. 2016; Guo et al. 2018). In particular, in the northern part of Senegal, temperatures are expected to rise between 1.1°C (RCP 4.5) and 1.3°C (RCP 8.5) in 2015, while climate projections indicate an increase of 2°C by 2040 and 3°C by 2100. The most pessimistic scenarios indicate a temperature increase about 4°C by 2050 (IPCC 2014; IPCC 2022).

On the other hand, heat wave events are becoming a serious public health threat particularly in the Sahel with the absence of effective adaptation measures (Huang et al. 2010; Benmarhnia et al. 2014; Murari et al. 2015; Guo et al. 2016; Baaghideh & Mayvaneh 2017). Indeed, heat wave events have been associated with excess of mortality and morbidity which often affect young children, people suffering from chronic diseases and the ageing population (Armstrong 2006; Corobov et al. 2013; Elliot et al. 2014; Zacharias et al. 2014; Auger et al. 2015; Chen et al. 2016). A historical review of some past events provides a good context of health risks associated with heat waves. In the city of Chicago in the USA, a large part of the ageing population was affected by rising temperatures, with 365 deaths recorded during the summer of 1995 (Naumova et al. 2007). In France, the heat wave recorded during the summer of 1983 led to the death of several elderly people, with more than 300 deaths reported in the city of Marseille (Cadot 2006; Fouillet et al. 2006). The terrible heat wave of 2003 was particularly lethal with more than 15,000 deaths reported in France (Besancenot 2005; Vandentorren et al. 2004). The occurrence of heat waves in July 2018 in the northern hemisphere, which lasted 7 days, was marked by excess of mortality with 70 deaths in Canada and 35,000 people hospitalised and 80 deaths in Japan (IPCC 2022).

In contrast to developed countries, heat wave episodes and their impacts on population health are still poorly documented in Sahelian territories where the number of hot days and nights is constantly increasing (Basu & Samet 2002; Johnson et al. 2005; New et al. 2006; IPCC 2014; Smith et al. 2015; Li et al. 2015). In Africa, the health impact of heat waves is still little known due to the lack of scientific work on this phenomenon, although in some geographical areas such as the Sahel high rates of extreme temperatures are often recorded (OMM 2015: Musengimana et al. 2016). For instance, in 2013, the Sahelian region located between Senegal, Mauritania and Mali experienced an exceptional heat wave with a temperature which exceeded 45°C and lasted from May 23 to 27 (i.e. 5 days). This event had a considerable impact on the population health. During this heat wave episode, localities in northern Senegal recorded 27 cases of deaths reported and confirmed by the health districts. In Senegal, in particular, except for some non-exhaustive data from the ACASIS project for example, the occurrence of heat wave episodes and their impacts on health are poorly documented and not well known or analysed. The ACASIS project—a research project of Sahelian Heatwaves Alert and Health Impacts (ACASIS)—allowed to carry out between 2016 and 2018 a series of field surveys in the departments of the northern part of Senegal, i.e. located on the Sahelian belt which is more affected by heat wave episodes.

This lack of knowledge about the impact of heat wave events on the population's health could account for their low level of consideration in public health policies and programs.

Using the Sahelian zone of Senegal as a case study, the objective of this paper is to analyse the occurrence of heat wave episodes and their health impacts in Senegal. Specifically, this study aimed to document the effects of the extreme temperature recurrence on communities' health in this part of the country, with a particular emphasis on the detection of heat wave indices, the analyses of the evolution of linked climate diseases and climate vulnerability factors such as the practices and behaviours of populations facing abnormally high temperatures during the months of April-May-June and the socio-economic, environmental and cultural characteristics of households. This allows, on the one hand, to strengthen the knowledge about the impacts of heat waves on the population's health in Senegal and, on the other hand, to sensitise the decision-makers for a better consideration of these phenomena in the policies and programs of public health in Senegal.

Thus, assuming that the rising temperatures are a major driver of health status deterioration of communities, the relationships between (i) the recurrence of heat wave episodes, (ii) the excess of morbidity/mortality and (iii) the exposure factors involved in modulating the vulnerability of populations against this type of health risk were analysed in the present study.

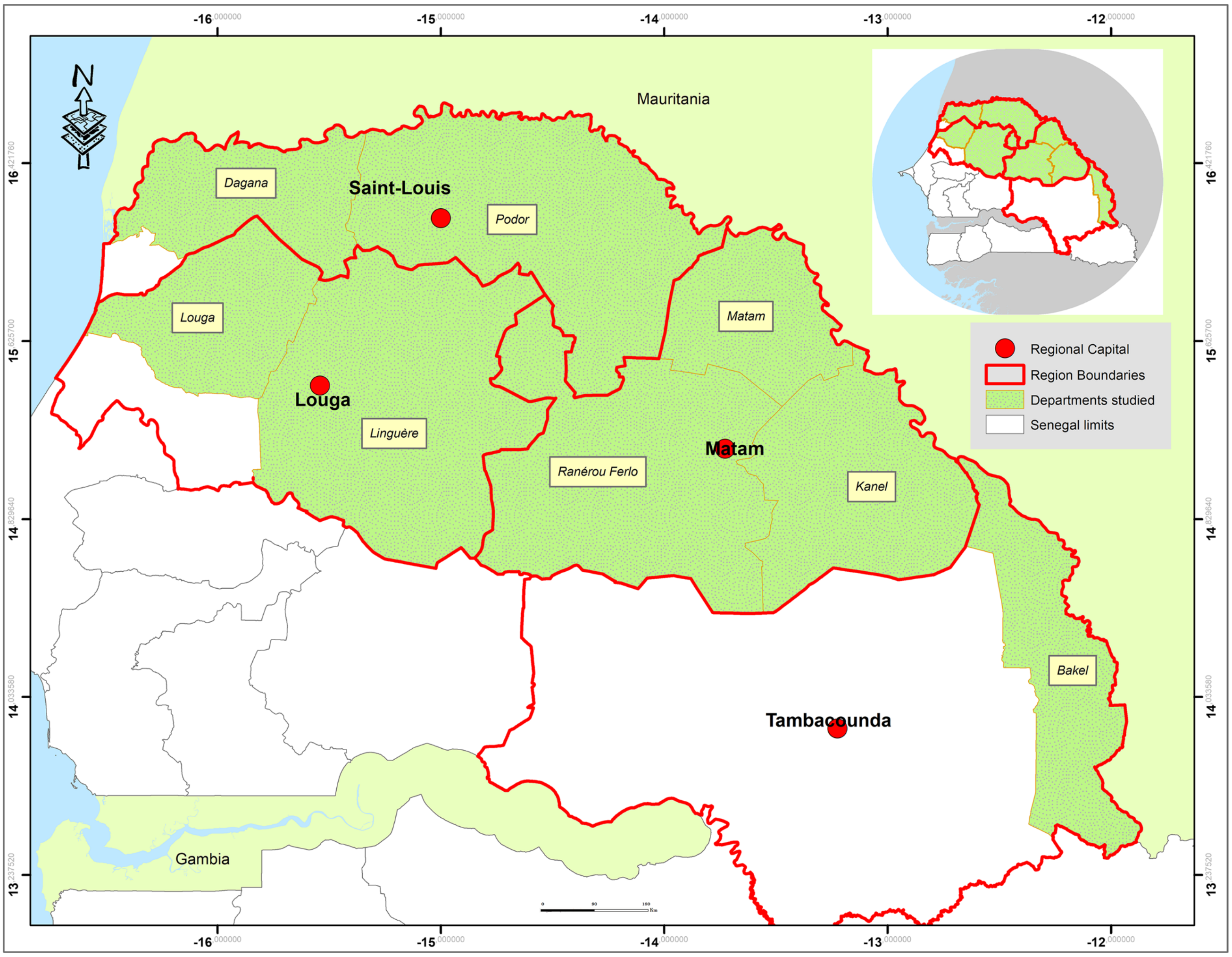

Fig. 1 Location of the study area

Data and methods

Study area

The study focusses on the Northern and North-Eastern part of Senegal and covers the departments of Dagana, Podor, Louga, Linguère, Matam, Ranérou, Kanel and Bakel located in the regions of Saint-Louis, Louga, Matam and Tambacounda (Fig. 1). This area regularly experiences hot extremes exceeding 46 °C and covers a large population of around 2 million people in 2013 (ANSD 2013). The population has specific demographic characteristics with a very low population density, which is about 30 inhabitants per km^2 due to a strong migration towards coastal urban centres. The majority of the resident rural population are often elderly peoples, women and children.

The climate characteristic is continental Sahelian type with two seasons: a rainy season (July-September) and a dry season (October-June). After three decades of drought from 1970 to 1990, wet periods are back in this area since the early 2000s, even if rainfall total is generally low, varying between 200 and 400 mm per year. Temperatures in this area are among the highest in Senegal, with annual averages around 30°C and maxima sometimes exceeding 45°C (MEDD-GCF 2020). These particular climatic conditions that characterise the study area do not enable the development of dense vegetation and the presence of permanent watercourses which can lead to a micro-climate condition.

Data collection

Temperature data

The temperature data were obtained from ANACIM (Agence Nationale de l'Aviation Civile et de la Météorologie) weather stations in the departments of Louga, Linguère, Podor, Matam and Bakel. These are ambient temperatures in the areas polarised by health facilities in the study area. These data were supplemented by data from climate model outputs (ERA database) for the departments of Dagana, Ranérou and Kanel without meteorological stations. The variables used to analyse the impact of heat wave episodes on population health are relative to the maximum, average and minimum temperatures during the hottest months of April, May and June for the period 2009 to 2019. The choice of these parameters for the correlation analysis between temperature increase and health risks was motivated by the scientific need to document and analyse the relationship between heat wave episodes and health risks in terms of excess of morbidity and mortality.

Epidemiological data from health facilities

Health data were collected according to the prior definition of a list of diseases considered linked to climate variability (i.e. arterial hypertension, diarrhoea, asthma, colds and coughs, acute respiratory infection, diabetes, kidney problems, heart problems, joint pain and skin irritations). This list was defined through the precise and clear identification of clinical signs and symptoms (fevers, headaches, body pain, heat stroke, exhaustion, dehydration, syncope and hyperthermia) associated with the physiological state of the patients in consultation during periods of rising temperatures.

The health data collection was carried out for the hottest months (April-May-June) from 2009 to 2019.

The collected data comes from two sources: (i) the National Health Information System “SNIS” via the DHSI2 (District Health Information Software) platform of the Ministry of Health and Social Action and (ii) the use of information from patient consultation registers through a collection form validated by the health centres of the departments of Louga, Linguère, Dagana, Podor, Ranérou, Matam, Kanel and Bakel. The variables recorded were the date of consultation, age, sex, place of residence, clinical signs or symptoms, the pathology diagnosed, the treatment prescribed, etc. These information were then used to determine the patient’s health status and the cause of consultation.

Socio-economic, environmental and health surveys among households

These quantitative and qualitative cross-sectional surveys were carried out with the support of the Health Districts professionals in the target departments between 2015 and 2017. These household surveys were conducted to highlight the factors of exposure and vulnerability to the health impacts of heat waves. They involved households in the departments that agreed to participate by signing the informed consent form. The information collected by questionnaire covered the following headings: demographic and socio-economic characteristics, knowledge of climate change risks, identification of clinical signs or symptoms associated with climate-sensitive diseases, morbidity and mortality of the target pathologies, access to health care, factors of exposure and vulnerability to the health impacts of heat waves, adaptation behaviours and practices.

The sample size was determined using the National Agency for Statistics and Demography (ANSD) database, which provides estimates of 13,306 households in the study area. Applying a confidence level of 90% and an error margin of 5%, a sample size of 1,331 households was surveyed in the entire target area. For the sample spatial distribution, a two-stage stratified survey was carried out based on a stratification of the different departments according to specific demographic, socio-economic and environmental characteristics. In each stratum of departments, five settlements were selected, three of which were in urban areas and two in rural areas. In the selected localities, the proportion of households interviewed in the overall sample was calculated according to the number of households represented in the settlement. The method used to select the households surveyed was done randomly with a time step of ten concessions. The questionnaire was administrated to the head of household or persons delegated by him to answer the questions. With an initial planned sample of 1,331 households targeted for the study, only 1,246 were surveyed due to different reasons such as difficulty to access to villages and unavailability of respondents.

Data processing and analysis

The temperature data (maximum, minimum and average) were analysed based on ANACIM 1971–2000 normal, the 3-day temperature threshold exceedance of the 90th percentiles and the definition of heat wave indices as part of ACASIS project (IPCC 2014). Daily maxima observation and daily mean maxima temperatures were considered to define a heat wave period that takes into account the threshold of the 97.5 and 81th percentile of the maximum temperature distribution (OMM 2015). These indices of heat waves and temperature threshold exceedances (maximum, minimum and average) compared to the seasonal normal were used to identify trends in temperature anomalies and highlight the years during which the months of April, May and June are the warmest for the period 2009–2019 in this part of Senegal. These analyses provided a series of temperature curves and maps that enabled to select 3 years during which the months of April, May and June were warmer.

Epidemiological data on climate-sensitive diseases (consultation register) were analysed by applying descriptive statistical methods (dynamic cross-tabulation) to determine their prevalence in overall morbidity and mortality but also their distribution according to the different departments, age

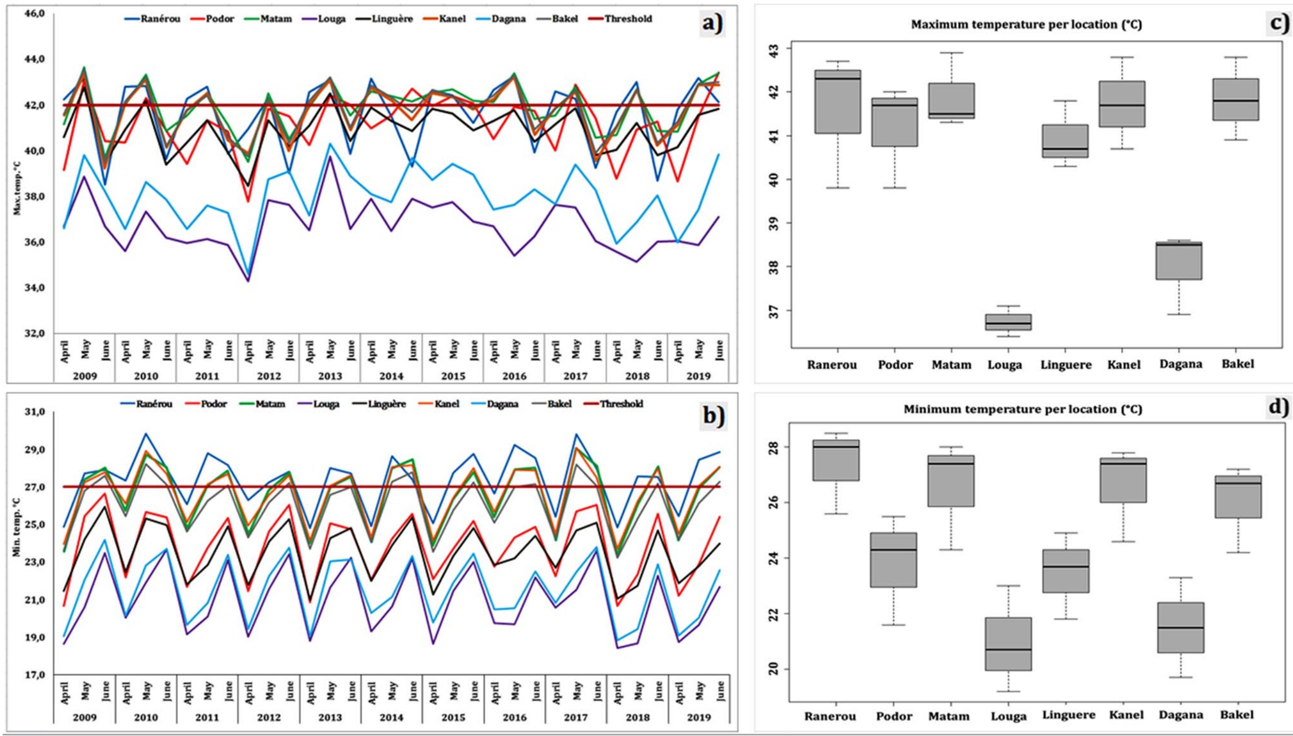

Fig. 2 Variation of monthly maximum (**a**) and minimum (**b**) temperatures and corresponding boxplots (**c**, **d**) in April, May and June between 2009 and 2019

and sex of patients affected by the pathologies concerned for the months of April, May and June of the period 2009–2019. Cross-analyses in the term of correlative evolution curves between the temperature variables (maxima, minima, averages) for April, May and June months and the evolution of the number of consultations and deaths for climate-sensitive diseases were carried out to highlight the association between heat waves and health risks. The results of these analyses are presented using graphs and maps.

Data on the perceived morbidity and mortality of temperature-related diseases from household surveys[1] were first analysed using descriptive statistical methods (dynamic cross-tabulation) to determine their prevalence in overall burden rate but also their distribution according to different departments, age and sex of patients affected by the diseases investigated. Factorial and correlative statistical analyses were then carried out between the prevalence of perceived morbidity and the various risk factors identified (socio-demographic, economic, environmental and cultural variables) by carrying out χ^2 (Fisher/Pearson) tests, logistic regression with odds ratios (ORs) and 95% confidence intervals and a correlation matrix between different dependent variables. A logit model has been developed in the search for correlation between variables. This logistic regression model is used when the dependent variable *Y* is a dichotomous variable with two modalities (0 or 1 for example). This characteristic prevents the usual method of estimating it from being used, as the disturbance would follow a discrete distribution, which is not compatible with the assumptions of continuity and normality of the residuals. A logit model assumes that the observed responses are the manifestation of a latent variable *Z* which is continuous. The hypothesis of simultaneous nullity of the coefficients must be rejected if the value of the statistic exceeds the critical threshold (i.e. the χ^2 value at q degrees of freedom). In other words, this test compares the full model with the one containing just the constant. The lower the significance level, the greater the difference between these two models, and the more valid the model presented is overall.

[1] 1,119 questionnaires for which information on the symptoms described by the respondents corresponded to the clinical signs of climate-sensitive diseases

Results

Evolution of temperatures and heat waves in the northern part of Senegal

In temperature data analysis for the months of April, May and June from 2009 to 2019, the occurrence of heat waves was considered when there is a 90th percentile threshold exceedance of 42°C for maximum temperatures and 27°C for minimum temperatures. Overall, it was observed a global increase trend in maximum and minimum temperatures compared to the seasonal normal of the reference period 1971–2000. Exceedances of the 90th percentile threshold (42°C) for maximum and minimum temperatures (27°C) were recorded in several departments except Louga (38.5°C) and Dagana (38.8°C). For both maximum and minimum temperatures, the months of May and June were considered the hottest periods of the year affecting more the departments of the continental Sahel (Bakel, Matam, Kanel, Ranérou, Linguère and Podor) (Fig. 2). The monthly heat wave distribution shows that May appears as the hottest with variations of more than 6.6°C in 2009 in Podor compared to the period 1971–2000 and record heat waves in 2010 and 2013 for maximum temperatures. Compared to the seasonal normal, the year 2010 was considered the hottest with more than 250 heat wave events recorded with a higher frequency in the departments of Ranérou, Matam, Kanel and Bakel. Since 2016, there has been an increase trend in heat wave events often exceeding the threshold of 100 events in the year, especially in 2016, 2017 and 2019 (Fig. 2a). However, the different heat wave events recorded from 2009 to 2019 do not have the same intensity in localities with regard to the lower maximum and minimum temperatures observed (between 30 and 39°C) in Louga, which certainly benefits from the effect of the maritime and oceanic domain (Fig. 3).

Distribution of morbidity and mortality of heat wave–sensitive diseases

The spatial distribution of diagnosed morbidity of diseases sensitive to the rise in temperatures for the months of April, May and June from 2009 to 2019 shows a higher number of consultation cases in the departments of Matam (44,514 cases), Kanel (41,655 cases) and Bakel (41,204 cases) while this proportion is lower in Linguère (10,588 cases), Louga (21,527 cases) and Dagana (23,476 consultation cases) with a predominance of the female gender (Fig. 4). For the 3 months considered, the distribution according to

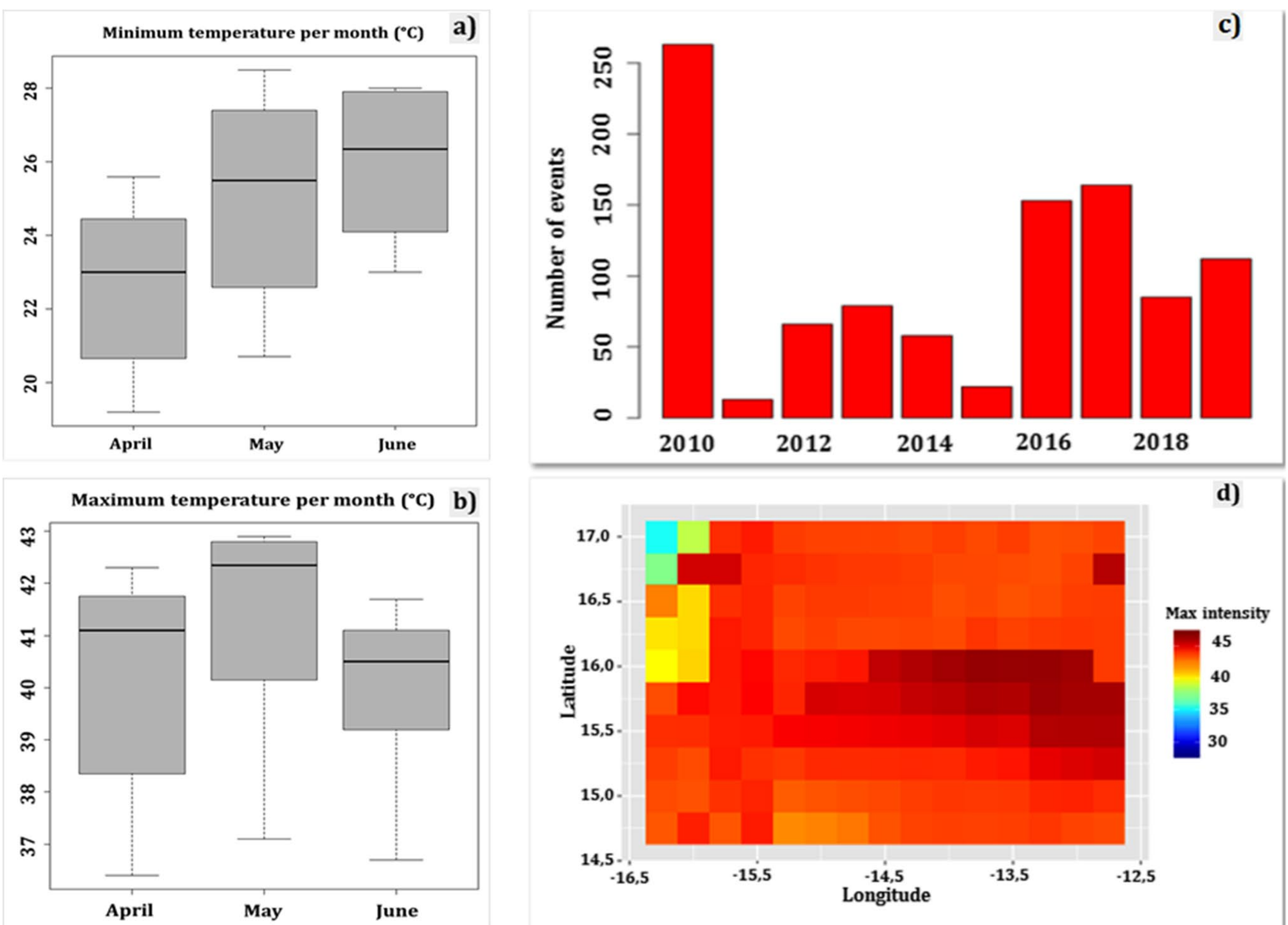

Fig. 3 Heat waves events during the period 2009 to 2019: **a** number of events and **b** their locations in terms of intensity; **c**, **d** relative exposure level of localities and detection of the most exposed localities

type of disease shows that diarrhoea is the most represented in global pathology. The global distribution of the morbidity diagnosed nearly follows the same dynamic as that reported for 2013, with more than 12.5% of the households surveyed declaring morbid episodes (769 cases) during the heat wave period (Fig. 5). Indeed, households that declared cases of morbidity are more represented in the departments of Kanel (17.7%), Ranérou (16.1%), Matam (13.7%) and Bakel (13.7%), while this proportion is relatively lower in Linguère (7.8%) and Podor (8.5%). The gender distribution of affected population during the May 2013 heat wave shows that women (57%) were more affected than men (43%). The occurrence of heat waves in May 2013 was associated with cases of death reported by the households surveyed, and had particularly affected elderly women (Fig. 6). However, reported mortality (confirmed by health professional) of 12.4% (119 cases) is also unevenly distributed across the departments with more households reporting deaths noted in Matam (25.2%), Bakel (23.5%), Dagana (22.7%) and Louga (10%) than in Linguère (9.2%), Podor (8.4%) and Kanel (0.8%). The spatial distribution of reported morbidity is almost proportional to the distribution of recorded mortality according to the departments except for Dagana where the rate of households that registered occurrence of morbid episodes is lower than the number of reported deaths.

Relationships between heat waves and morbidity of temperature-sensitive diseases

The analysis results of the association between the heat wave rise and frequency during the months of April, May and June and the cumulative of temperature-related pathologies show a growing increase in consultations in health facilities from the years during which heat waves become more recurrent. The care use due to temperature-sensitive diseases was very high during the years 2013, 2015, 2017 and 2018 in the departments of Ranérou, Bakel, Podor and Louga in correlation with the occurrence of heat wave episodes, particularly during the month of May (Fig. 7). In the department of Bakel where 2015 was considered the hottest year, there was an increase in consultations for the six diseases considered to be sensitive to temperature changes. Similarly, in both Louga and Podor, there was a significant increase in the

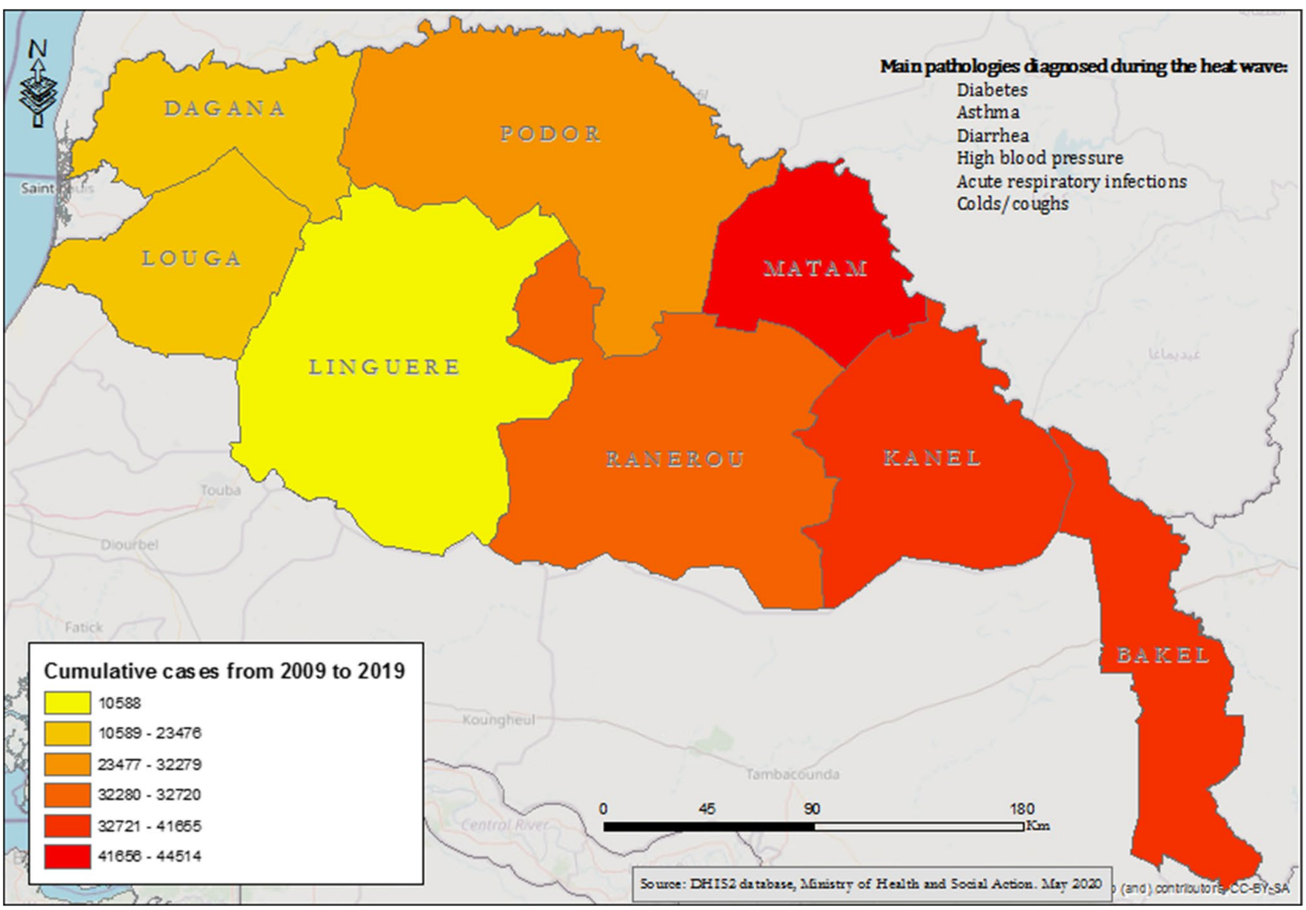

Fig. 4 Cumulative cases of diagnosed morbidity from 2009 to 2019 and prevalence of six temperature-related diseases

consultations number in health facilities during 2016 and 2017, considered to be the hottest years. In the district of Ranérou, episode of heat waves were correlated with a very high number of health facilities visits from 2014 to 2018, a period during which there was a significant increase in temperatures, particularly the maxima. Overall, the upward trend in the frequency of heat waves and the evolution of consultations number for the six climate-sensitive diseases highlight the impact of temperatures on health facility visits.

Exposure and vulnerability risk factors to health impacts of heat waves

Exposure and vulnerability to the health impacts of heat waves are influenced by a number of risk factors (Table 1). The age of persons has been identified as an exposure risk factor to the effects of heat waves, which affect more people over 61 years old and children and adolescents under 20 years old. This risk factor is often aggravated by having a medical background including chronic diseases such as high blood pressure, epilepsy, diabetes, heart disease or asthma which more affect the elderly. The majority of those affected had symptoms associated with the onset of heat waves such as hyperthermia, headaches, tiredness body, fainting or dizziness. Access problem to safe drinking water was also analysed as an exposure factor to health impacts of heat waves. Households with a tap at home are less exposed to the effects of increasing temperature than those who move to get water from standpipes (91%) or wells (86%) (Fig. 8). The type of fuel used is also an exposure risk factor to temperature-sensitive diseases. The results of the analyses show that people living in households using wood (85%) or charcoal (85%) are more affected than those using butane gas (Fig. 4b). The kitchen location was also an exposure factor to health risk related to heat waves. Indeed, women cooking open air are much more at exposure risk to effects of heat waves than those whose kitchen is located in housing inside (Fig. 8). The types of housing and building materials were identified as risk factors for diseases related to heat waves. People living in huts and straw huts are less exposed to the temperature effects than those living in low-rise (76%) or multi-storey (80%) houses (Fig. 8). For building materials, people living in straw or wooden houses are less exposed than

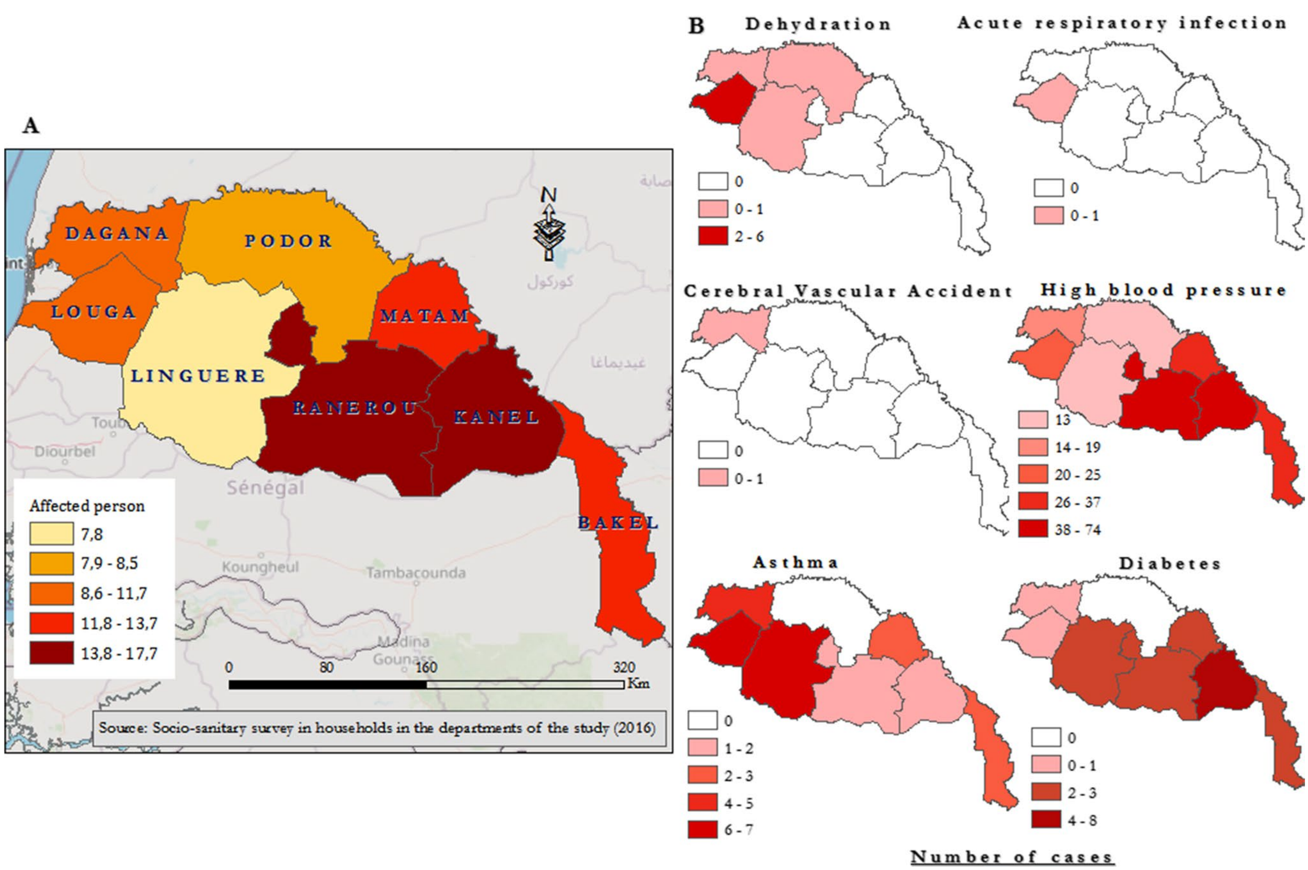

Fig. 5 Morbidity and main diseases reported by households during heat wave episodes

those living in solid or banco-built housings (Fig. 8). The availability of household equipment such as a fan or air conditioner was analysed as a mitigation factor of heat wave effects. The analyses demonstrated that people living in households with a fan or air conditioner are less exposed to heat effects compared to those without such equipment (Fig. 8).

Discussion

Like the countries located in temperate latitudes, which are increasingly affected by recurrent heat wave phenomena, the Sahelian tropical areas are frequently affected by a generalised trend of warming temperatures (Green et al. 2010; Guo et al. 2018). In Senegal, the north-eastern part of the country is particularly affected by the recurrence of heat waves, with significant variations of temperatures compared to the 1971–2000 normal ranging from −2 to +3°C. The ratio between the inter-annual variability and the normal of 1971–2000 shows a considerable increase in maximum and minimum temperatures with a very significant positive variation of 2.5°C for 2013 in the Northern localities of Senegal. Very high maximum temperatures exceeding the threshold of 46°C and a variation of more than 7°C for some days during the month of May 2013 have been reached compared to the normal of 1971–2000 (MEDD-GCF 2020).

Thus, the occurrence frequency of heat waves is increasingly becoming a major public health issue in the Senegalese context, in particular since the results of the study showed that the gradual increase in temperatures up to around 39°C resulted in a surplus of 45 patients in health centres and an excess mortality of nearly 25 people during hot days, in particular in the departments of Matam, Bakel, Dagana and Louga (Diboulo et al. 2012; Petkova et al. 2013; Zhang et al. 2014). According to clinical examinations during the heat wave periods, the symptoms presented by the patients were hyperthermia, headaches, tiredness, fainting or dizziness, while the pathologies diagnosed were mainly chronic diseases such as high blood pressure, epilepsy, diabetes, cardiovascular diseases, respiratory infections, diarrhoea and asthma (Semenza et al. 1995; Pascal et al. 2013; Smith et al. 2016; Sanderson et al. 2017; Joshi et al. 2020).

However, the distribution of heat wave–related diseases varies widely by location, age, gender and risk factors. Indeed, the departments located in the North-Eastern part of the country, which are Matam, Ranérou, Kanel and Bakel, concentrate on the populations that are most exposed to the health risks related to heat wave occurrence. As demonstrated in other countries in Europe, Asia and America, people over 61 years and

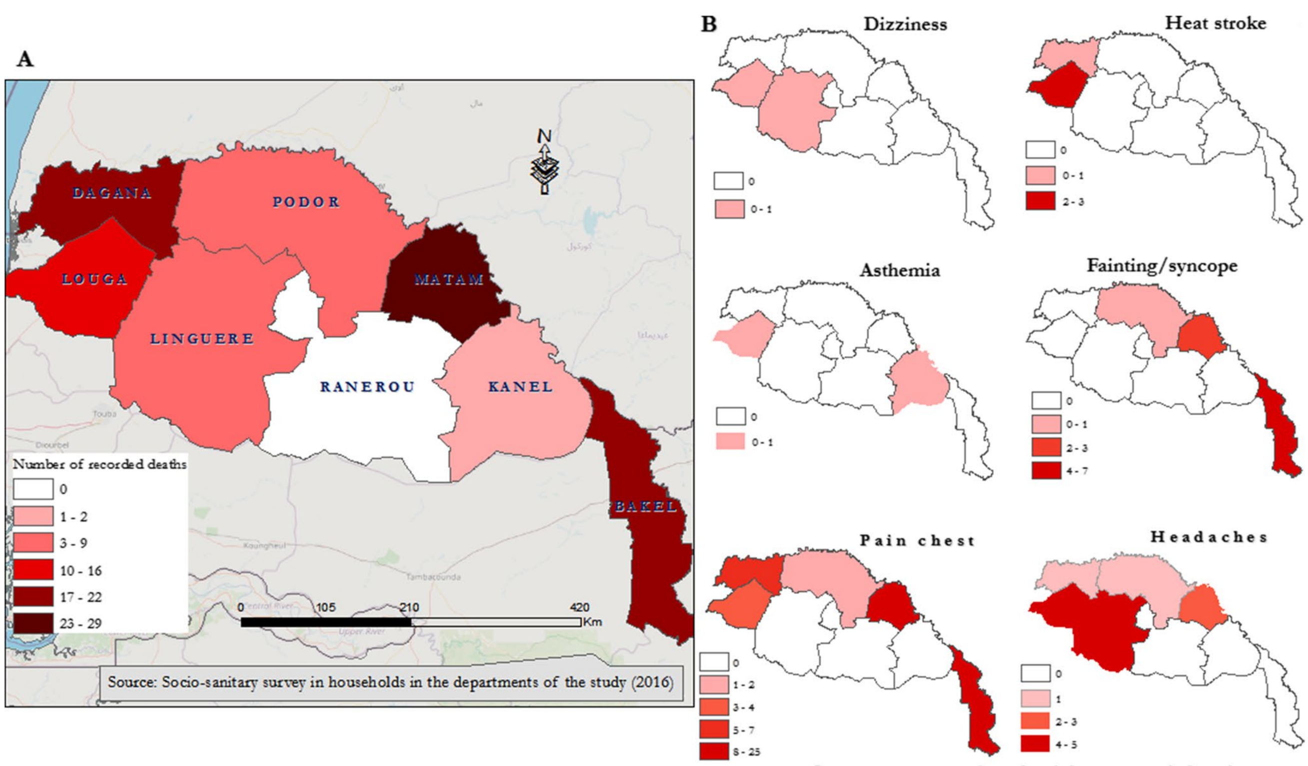

Fig. 6 Distribution of deaths and major complaints

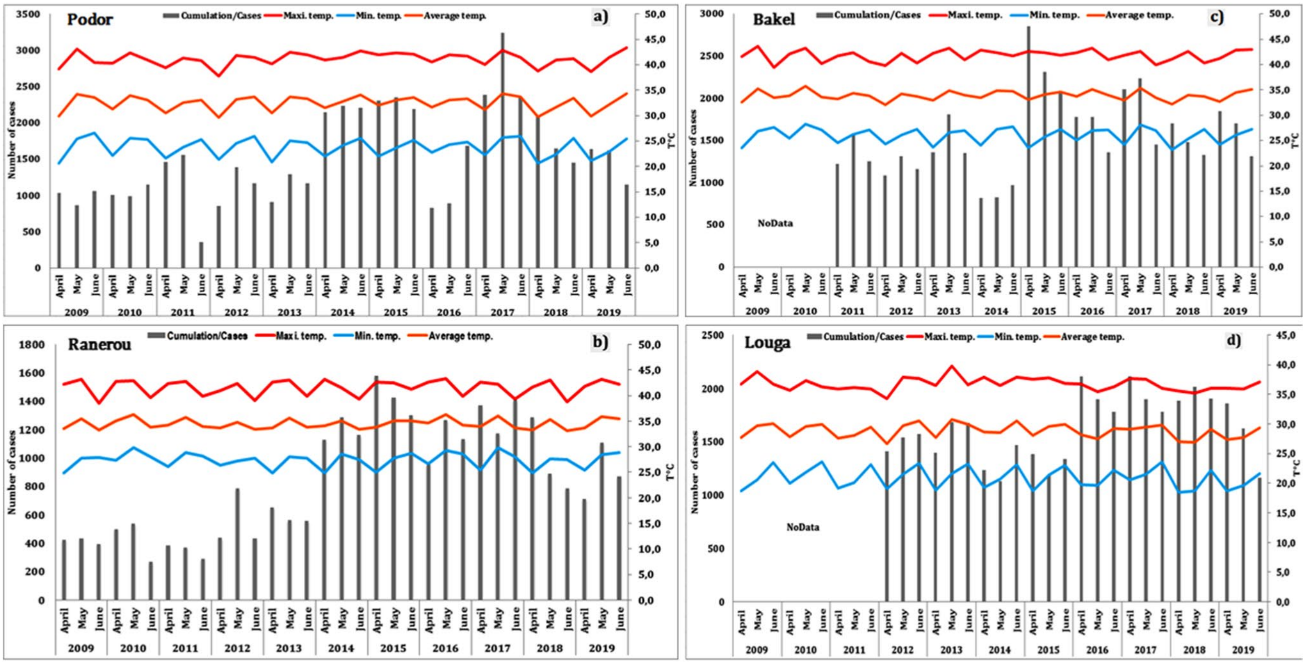

Fig. 7 Relationship between cumulative pathology and temperature (°C): example of **a** Podor, **b** Ranerou, **c** Bakel and **d** Louga

the infant and child fringe are the most vulnerable to the health impacts related to the rise in temperatures in the most affected departments (Jones et al. 1982; Semenza et al. 1996; Hémon and Jougla 2003; Pascal et al. 2013). Older people are exposed through the prism of comorbidity to chronic diseases considered the aggravating health background of heat wave effects (Nitschke et al. 2013). Regarding children, increasing temperatures amplify the spread of childhood illnesses, especially those that cause dehydration, in a group consisting mainly of schoolchildren who, in these localities, walk long distances to reach their schools, whose descent (12 to 13 h) and recovery (14 to 15 h) times correspond to period of extreme heat peaks (Xu et al. 2012). According to gender, women engaged in extra-domestic activities, such as fetching water, searching firewood and agro-pastoral activities that require them to travel long distances under the sun, are the most exposed to heat wave effects, especially since there are no early warning systems to prevent risks associated with increasing temperatures (Xu et al. 2016).

Furthermore, analyses have shown that the degree of vulnerability to heat wave-related health risks is the result of a range of risk factors including the type of housing, building materials, human density in households, access to water, type of used fuel, location of kitchen, access to ventilation or air conditioning, existence of relaxation areas and health history. In numerous studies carried out in similar heat wave situations, such risk factors were highlighted in the occurrence of pathologies linked to rising temperatures

Table 1 Vulnerability risk factors of households to heat waves

Risk factors	Coef.	Std. err.	*z*	*P*>*z*	[95%]	Conf.	Significance
Gender person	−.6504591	.1605448	−4.05	0.000	−.965121	−.3357972	***
Household population density	.1103047	.0490329	2.25	0.024	.014202	.2064075	*
Type of housing used	−.6888186	.1745533	−3.95	0.001	−1.030937	−.3467005	***
Housing material construction	.3784948	.1907388	1.98	0.003	.0046536	.752336	***
Type of energy used	.5459268	.2305418	2.37	0.018	.0940732	.9977804	*
Household water availability	.046807	.2048986	0.23	0.010	−.3547868	.4484008	*
Fan or air conditioner availability	−.3625368	.1803599	−2.01	0.000	−.7160357	−.0090378	***
Type of fuel used in household	.7673144	.1763332	4.35	0.000	.4217077	1.112921	***
Previous and chronic health problems	1.685009	.217815	7.74	0.006	1.2581	2.111919	**

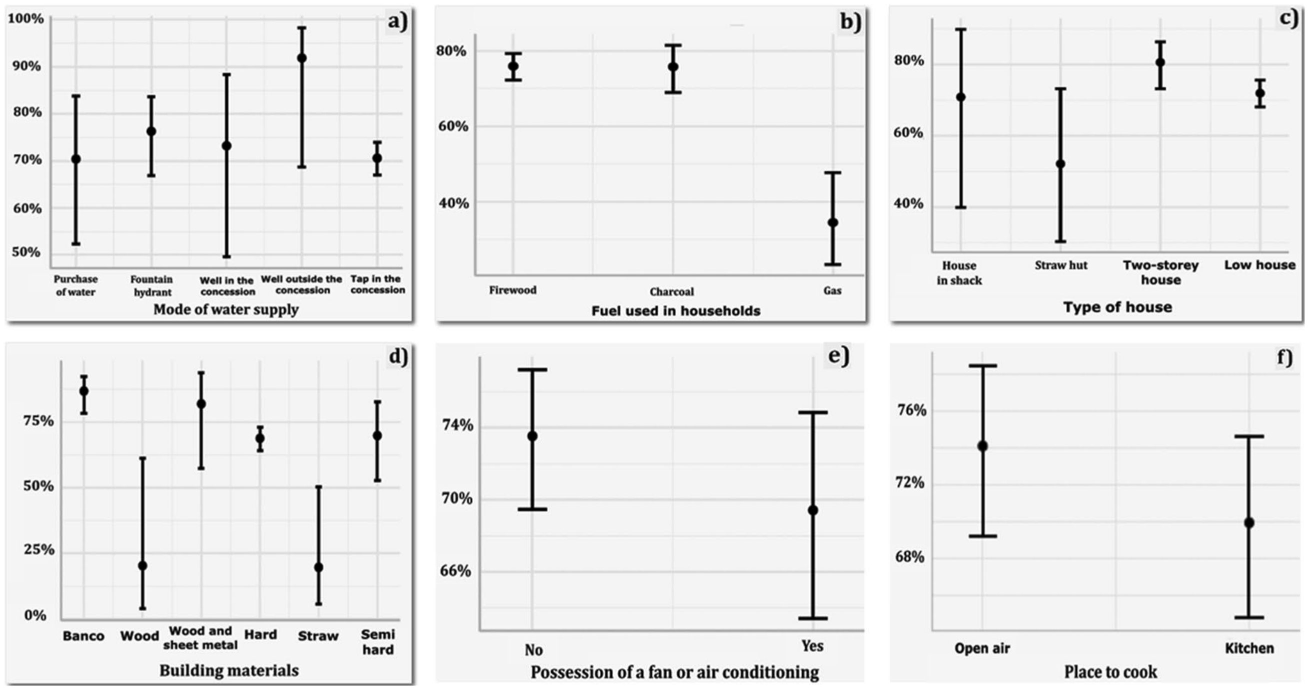

Fig. 8 **a–e** Predicted values of the data subject in relation to social and environmental determinants

(Michelozzi et al. 2010; Cheng et al. 2014; Anderson et al. 2016). However, heat waves cannot be considered direct causes of morbidity or mortality, but as aggravating factors in temperature-sensitive diseases development for vulnerable populations with a health background (Xu et al. 2012; Zeng et al. 2016).

Conclusion

Minimum and maximum temperatures are on an increasing trend in the northern part of Senegal with the years 2010, 2013, 2017 and 2018 considered very hot with a large number of days with heat waves recorded. This temperature upward combined with the rise in relative humidity tends to increase the heat felt sensation and the heat wave effect on populations' health.

The frequency of heat wave recurrence resulted in a resurgence of certain diseases sensitive to the temperature increase leading to excess of morbidity and mortality with high frequentation of health facilities in the North and North-East departments of Senegal. The diseases concerned are mainly chronic diseases such as heart disease, diabetes, arterial hypertension, asthma, respiratory affections, hyperthermia and rheumatism, which affect more people over 60 years and children under 14 years. The highest morbidity and mortality rates were recorded especially among elderly women during the severe heat wave episodes experienced especially in May 2013.

While there are many risk factors associated with morbidity and mortality related to the impact of heat waves, including housing conditions, lifestyles, socio-economic comfort level and types of activities, populations with a health background are mainly most exposed and vulnerable to rising temperatures.

However, the high vulnerability of the populations noted in these localities is not just related to the occurrence of extreme temperatures but also related to other factors such as adaptation strategies or the responses of communities to the health impact of heat waves. Thus, the prevention of health problems related to rising temperatures requires the development of an early warning system for heat waves in order to strengthen the resilience of populations and the health system to the impacts of climate change.

In the end, this study has the merit of laying the foundations for a scientific reflection on the health impact of rising temperatures in a Sahelian country where the issue of heat waves is not yet anchored in public health debates.

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Data availability The data and materials from household surveys are available and could be uploaded.

Author contribution IS, BC, BN, AAD, MT and JAN designed the study. IS, BC and BN coordinated the field data collection. BC, MT and BN did the statistical and geospatial analysis. IS wrote the first draft of the manuscript. ON, MAS, BC, BN, AAD, YN, MT, DB, RL, SJ and JAN reviewed the manuscript. All authors read and approved the final version of the manuscript prior to submission.

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Declarations

Ethical approval This study obtained the approval of the National Health Research Ethical Committee of Senegal, which made it possible to collect health data from health centres and households.

Consent to participate An informed consent form was submitted to the selected households before the administration of the questionnaire and all the participants in the household survey signed the ethical clearance.

Consent to publish The authors consent to publish their paper in the journal of Environmental Sciences and Pollution Research.

Competing interests The authors declare no competing interests.

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