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Bioclimatic stress, heat perception and asthma attacks in young adults in Natitingou (Benin, West Africa)

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Abstract

Climate variability and the intensification of bioclimatic discomfort are major environmental factors influencing respiratory health in tropical cities. In Natitingou, a municipality in northwestern Benin characterized by a marked alternation between dry and rainy seasons, the population is regularly exposed to challenging bioclimatic conditions, exacerbated by the harmattan wind, high temperatures, and humidity fluctuations. This study analyzes the influence of bioclimatic discomfort on the frequency of asthma attacks in young adults aged 18 to 35 years.

The methodological approach relies on the use of climatological data covering the period 1993–2024, obtained from the National Meteorological Directorate of Benin and NOAA, combined with perception data collected through surveys. Bioclimatic conditions were characterized using the UTCI (Universal Thermal Climate Index), calculated from air temperature, relative humidity, wind speed, and radiation, at monthly and three-hourly timescales. Perceived discomfort and the frequency of asthma attacks were assessed using self-reported data on a five-level ordinal scale.

The results highlight a marked seasonality in UTCI, with average monthly values ranging from 26.2°C in January and December to a maximum of 34.5°C in April. The March–May period sees the highest levels of heat stress, with values exceeding 32°C, corresponding to the high heat stress class, while a second peak is observed in October at 32.2°C. On a three-hour scale, UTCI varies from 23.9°C at 6:00 a.m. to a maximum of 34.4°C at 2:00 p.m., identifying the 12:00 p.m.–4:00 p.m. period as the period of maximum stress. These high levels coincide with a significant deterioration in bioclimatic perception, with the proportion of negative perceptions reaching 62% in April and up to 65% at 2:00 p.m. This correlation suggests a potential increase in the frequency of asthma attacks during the most stressful periods and time slots.

This study highlights the importance of integrating bioclimatic environments into asthma prevention strategies in tropical urban settings, in order to anticipate periods of risk and guide public health actions.

Keywords: Bioclimatic environments; UTCI; Asthma; Heat stress; Natitingou

1. Introduction

Climate variability and the intensification of bioclimatic discomfort are now major environmental determinants of human health (G. D'Amato et al., 2020, p. 2223), particularly in tropical cities of West Africa. Several studies have shown that climate change, through increased temperatures, altered wind patterns, and degraded air quality, has a significant impact on respiratory health and can contribute to the worsening of chronic conditions such as asthma (PJ Beggs and HJ Bambrick, 2005, p. 918). In Natitingou, a municipality in northwestern Benin characterized by a marked alternation of hot, wet, and dry seasons, the population is regularly exposed to challenging bioclimatic conditions, exacerbated by

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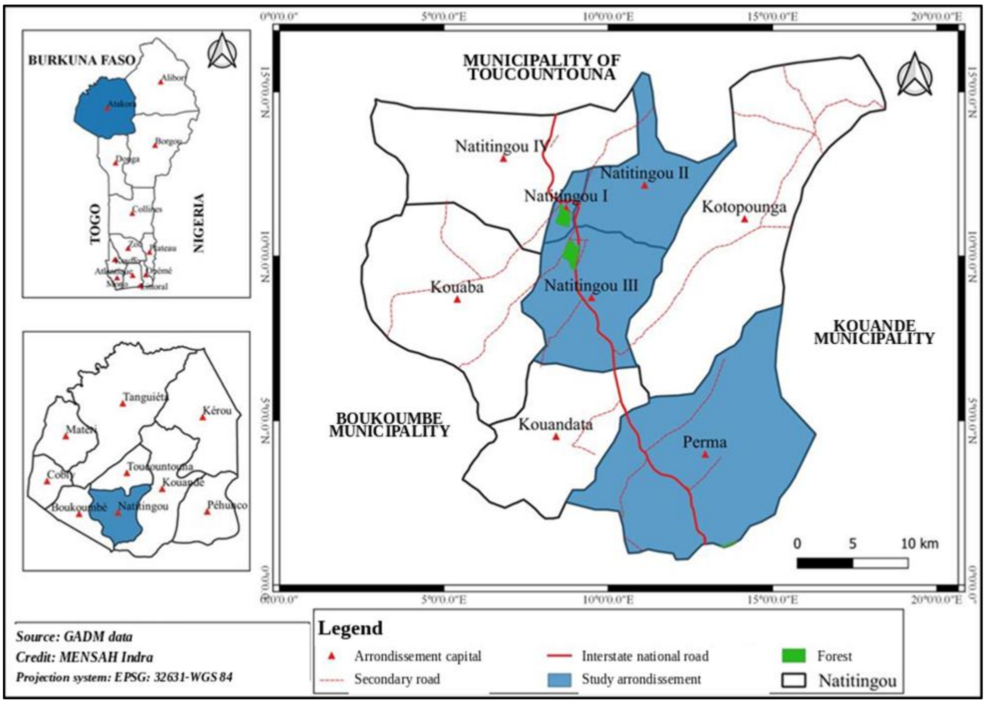
Harmattan winds, intense heat, and periods of high humidity. These conditions can affect the functioning of the respiratory system and promote the exacerbation of chronic diseases such as asthma (G. D'Amato et al., 2015, p. 960), a pathology whose frequency and severity seem to be increasing in urban African environments.

Despite the growing importance of climate-related health issues, few local studies have examined the direct influence of bioclimatic conditions on the occurrence of asthma attacks, particularly using indicators that integrate heat stress and human comfort (F. Makrufardi et al., 2023, p. 7). The lack of detailed data linking bioclimatic conditions to the clinical manifestations of asthma limits the ability of health and urban planning professionals to anticipate periods of risk and implement appropriate prevention strategies. In this context, analyzing bioclimatic discomfort as an explanatory factor for asthma attacks appears both scientifically relevant and socially necessary.

The hypothesis of this study is that periods characterized by significant bioclimatic discomfort are associated with a substantial increase in the frequency of asthma attacks in Natitingou. The objective is to analyze the relationship between bioclimatic conditions and the frequency of asthma attacks in order to better understand climate-health interactions in this tropical urban context and to contribute to the development of decision-support tools for public health prevention.

2. Presentation of the study environment

The commune of Natitingou is located in the Atacora department. It is the capital of this department. Triangular in shape, the commune of Natitingou covers an area of 3,045 km². Administratively, the commune of Natitingou comprises 9 districts and 65 villages and urban neighborhoods since January 15, 1999. These are: Kotopounga (9 villages); Kouaba (11 villages) ; Kouandata (5 villages); Perma (9 villages); Tchoumi-Tchoumi (5 villages); Natitingou I (6 neighborhoods); Natitingou II (6 neighborhoods); Natitingou III (7 neighborhoods); and Natitingou IV (7 neighborhoods). Figure 1 shows the geographical location of Natitingou.



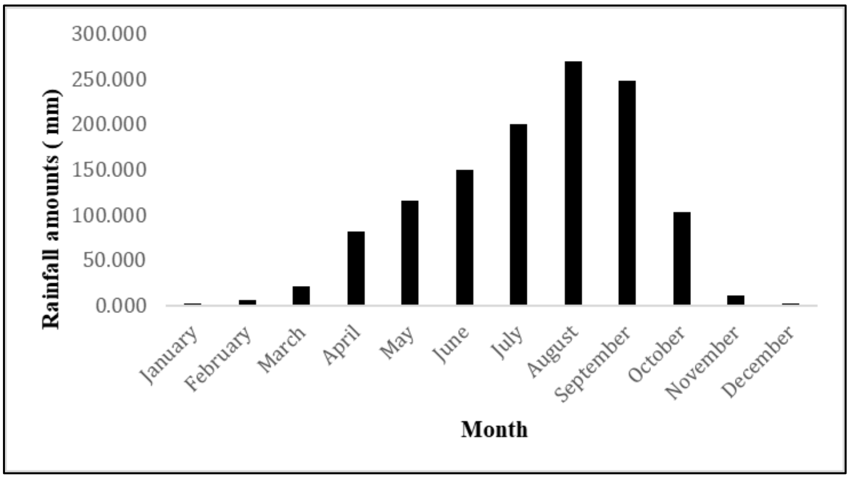
(Source: GADM data; Credits: Nouvêwa Patrice Maximilien Boko, October 2020; Projection: EPSG: 32631-WGS 84)

Figure 1 Geographical location of Natitingou

According to Figure 1, the Commune of Natitingou is located between 9° 40' and 10° 34' North latitude and between 1° 04' and 1° 45' longitude. It is bordered to the North by the Commune of Toucountouna, to the South by the Commune of Copargo, to the West by the Commune of Boukoumbé, and to the East by the Commune of Kouandé.

This commune is located in the middle of the Atacora Mountains, at an altitude of approximately 500 m and is characterized by a rugged and compartmentalized terrain in terms of morphology and socio-cultural aspects.

The municipality of Natitingou is characterized by a Sudanese-type climate with two seasons: a rainy season and a dry season marked by the harmattan, a dry, cool wind from the Sahara. Figure 2 illustrates the rainfall pattern of Natitingou.



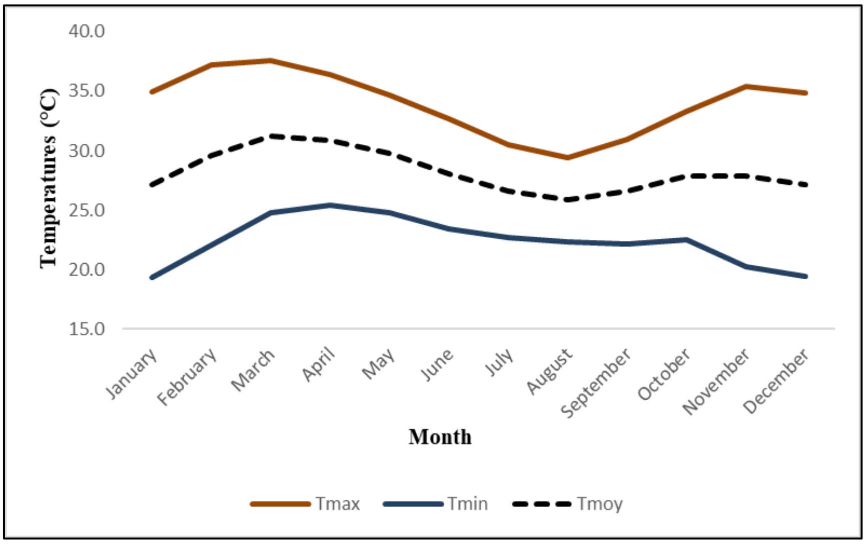
Data source : Météo-Benin, 2024

Figure 2 Rainfall regime of Natitingou (1965-2020)

Figure 2 shows that the rainy season begins in April with a rainfall of 81.7 mm (monthly average) in the commune of Natitingou. From May onwards, rainfall becomes abundant, reaching its maximum in August (269.4 mm). The period from November to March is the least rainy (10.3 mm to 20.4 mm) and corresponds to the dry season.

It follows, therefore, that the year is divided into two distinct seasons: a dry season from November to March and a rainy season from April to October. It should also be noted that the months of December, January, and February represent the Harmattan period, during which there is a general absence of rain.

Figure 3 shows the evolution of maximum, minimum and average temperatures in the municipality of Natitingou from 1965 to 2020.



Data source : Météo-Benin, 2024

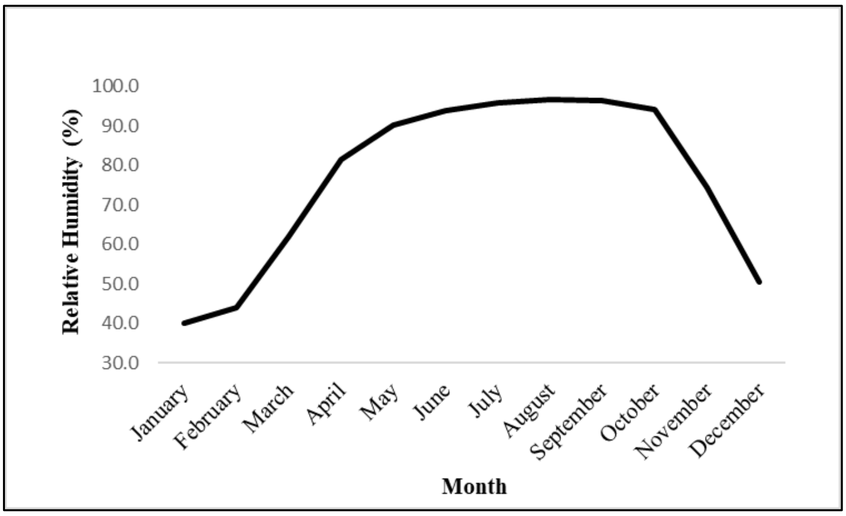
Figure 3 Natitingou Thermal Regime

Figure 3 shows the variations in maximum, minimum, and average temperatures. The maximum temperature follows a bimodal pattern with two peaks. It gradually increases, reaching its first peak in March (37.6 °C), and decreases in August (29.4 °C), where it reaches its second peak.

As for the minimum temperature, it also follows a bimodal pattern with two peaks. It gradually increases and reaches a first peak in April at a value of 23.9 °C; and decreases to a value of 19.4 °C in December.

Compared to these two temperatures (maximum and minimum), the average temperature varies around 31.2 °C and 25.8 °C respectively in March and August.

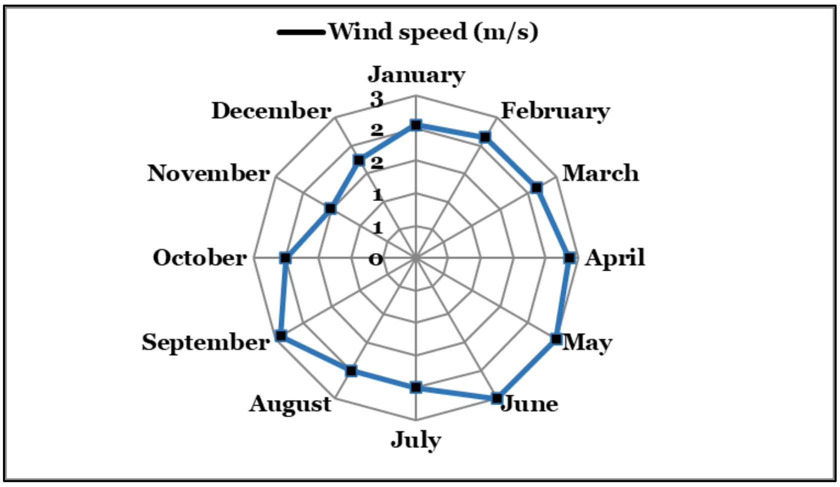
Figure 4 shows the evolution of relative humidity from 1965 to 2020 in Natitingou.



Data source : Météo-Benin, 2024

Figure 4 Humidity regime of Natitingou

Analysis of Figure 4 shows that relative humidity follows a unimodal pattern, with a maximum during the rainy season and a minimum during the dry season. Maximums are reached from April to October, and minimums are observed from November to March. It fluctuates around 96.6% and 40% in August and January, respectively. The figure 5 shows the evolution of wind speed from 1965 to 2020 in Natitingou.



Data source : Météo-bénin, 2024

Figure 5 Monthly wind speed pattern in Natitingou

Analysis of Figure 5 shows that wind speeds are low (1.9 m/s) during July, August, and November, and high (2.3 m/s) during May, June, and September. These winds are likely to carry dust, causing respiratory problems for the population.

Furthermore, this climate is evidenced by the presence of a savanna dotted with a few shea and néré trees. Associated with this climate are other elements of the natural environment, resulting in a landscape structured around the

Atakorian mountain range, composed of quartzites and schists, oriented NNE/SSW, which extends into Togo, Ghana, and Niger.

The landscape is characterized by tropical ferruginous soils with concretions, supporting a wooded savanna dominated by Butyrospermum parkii (shea) and Parkia biglobosa (African locust bean). This beautiful, rugged terrain offers proximity to the Pendjari National Park, as well as cultural significance, which also constitutes a major tourist attraction. This mountain range in the Atacora has a gentle topography (640 m altitude) with two parallel ridges separated by a depression through which flows the upper reaches of the Pendjari River. This depression is the water tower from which the major rivers of Benin and Togo originate (Ouémé, Mono, Mékrou, Pendjari, and Oti). Mineral resources, such as a gold mine and ornamental stone quarries, represent considerable potential for the economic development of the municipality (Natitingou Town Hall, 2008).

3. Data and methods

3.1. Data used

The study is based on an observational approach that examines the perceptions of young adults aged 18 to 35, combined with an analysis of local bioclimatic conditions. Two categories of data were used: climatological and health data. The climatological data included air temperature, relative humidity, wind speed and direction, and monthly sunshine duration. This data covers a 30-year period, from 1993 to 2024. It was extracted from the database of the National Meteorological Directorate (DNM) of Benin and supplemented with data from the National Oceanic and Atmospheric Administration (NOAA) to ensure the continuity and consistency of the time series.

The data focusing on the perceptions of young adults (18-35 years) relate exclusively to cases of asthma attacks. The frequency of asthma attacks is assessed through self-reported data collected via surveys, concerning the recent occurrence of respiratory symptoms consistent with asthma exacerbations, such as dyspnea, wheezing, chest tightness, or increased use of bronchodilators.

3.2. Processing and analysis methods

3.2.1. Determination of bioclimatic environments

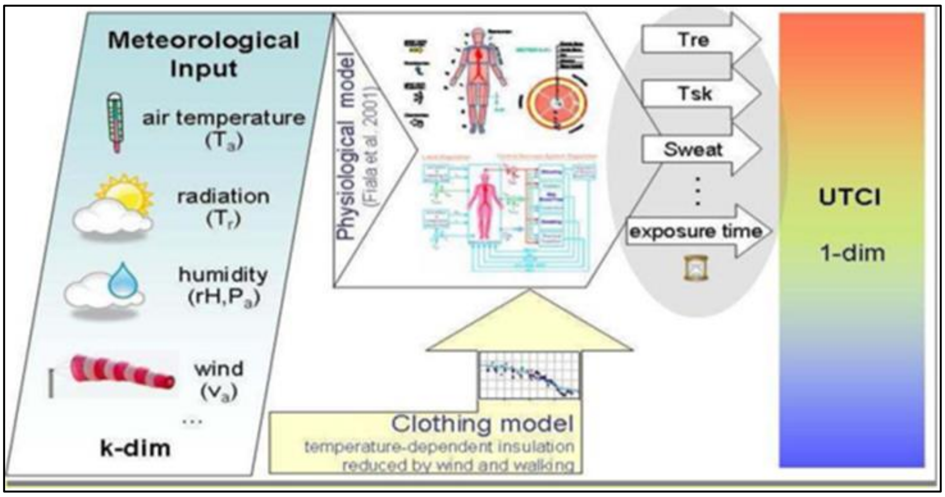
The analysis of bioclimatic environments was determined using the UTCI (Universal Thermal Climate Index). The mathematical formula for the universal thermal climate index is as follows (equation 1).

$$UTCI = 3.21 + 0.872t + 0.2459Mrt - 2.5078v - 0.0176HR$$

With : t: air temperature (in °C); Mrt: mean radiant temperature (in °C);

v: wind speed at 10 m above ground level (in ms-1); HR: Relative humidity of the air (in %).

UTCI is a simulated model based on several input variables (Figure 6).



Source: Błażejczyk et al. (2010) and Havenith et al. (2012)

Figure 6 Main UTCI modeling parameters

The UTCI was calculated using BioKlima software (© version 2.6), supplemented by processing in Microsoft Excel for data organization, aggregation, and statistical analysis. The resulting UTCI values were interpreted according to the rating scale presented in Table I.

Table 1 UTCI Assessment Grid (Source: Blazejczyk et al. 2010)

UTCI (°C)	Stress level	Thermal sensation
Above 46	extreme thermal stress	Torrid
+38 to +46	Very high heat stress	Very hot
+32 to +38	High thermal stress	Very hot
+26 to +32	Moderate thermal stress	Hot
+9 to +26	No thermal constraints	Comfortable
+9 to 0	Slight stress due to the cold	Slightly cool
0 to -13	Moderate stress due to cold	Cool
-13 to -27	Severe stress due to the cold	Cold
-27 to -40	Very high stress due to the cold	Extremely cold
Below -40	Extreme stress due to the cold	Very cold

Analysis of the data in Table I indicates that bioclimatic environments have been classified into classes of thermal comfort and discomfort, in accordance with the thresholds recommended in the scientific literature.

3.2.2. Method for analyzing the perceptions of young adults

The approach is based on a face-to-face questionnaire survey administered to young adults aged 18 to 35 residing in the municipality of Natitingou. Field investigations are conducted at locations with high foot traffic and significant exposure to external environments in order to maximize the variability of experienced bioclimatic conditions and the likelihood of observing reported discomfort. For example, sites may include the main market and its surroundings, the bus station, intersections and busy roads, as well as densely populated residential areas where ventilation and dust can influence respiratory problems. The choice of locations is justified by the concentration of young working adults and students, high daily mobility, and direct exposure to sun, heat, the dry Harmattan wind, and dust—factors likely to interact with respiratory symptoms.

In the absence of a comprehensive database on the target population, the minimum sample size is estimated using the Cochran formula.

$$n0 = (Z^2 \times p \times (1 - p)) / e^2$$

With n0 = Minimum sample size (before adjustment for a finite population)

Z = Confidence score (1.96 for a 95% confidence interval)

p = Estimated proportion of the target population having the characteristic being studied (if unknown, we take 0.5 to maximize the sample size)

e = Tolerable margin of error (often 5% or 0.05)

The resulting size constitutes the minimum sample size to be investigated. In order to improve comparability between exposure contexts, the sample is distributed by quotas according to sex, activity status, neighborhood of residence and level of daily exposure to outdoor environments, ensuring that it covers both subjects with a known history of asthma and subjects reporting compatible symptoms, without requiring clinical proof.

The surveys are conducted at fixed times representing the main phases of daily bioclimatic constraints in Natitingou, as shown in the following table:

Table 2 Survey time slots and their relevance to asthma-bioclimatic analysis.

Hour	Representation	Why this is useful for asthma-bioclimatic studies
6am	Morning freshness, air often more stable	Reference point for comparing the evolution of symptoms throughout the day, identification of a baseline respiratory state before high exposures
9am	The temperature rise begins, and activity and mobility increase.	Active exposure begins in young adults, with discomfort developing gradually and respiratory distress possible in sensitive individuals.
12pm	Peak solar energy, more pronounced heat	Increased heat stress and dehydration of the mucous membranes, a period conducive to a worsening of respiratory symptoms in certain profiles
2 p.m.	Heat stress is often at its maximum, with air being drier or heavier depending on the season.	This is a critical moment to link bioclimatic discomfort classes to the reported frequency of crises, cumulative exposure, and potential respiratory fatigue.
4 p.m.	Transition phase, resumption of activities and circulation	Combined exposure to residual heat and dust related to travel is a relevant period for capturing delayed effects and triggers related to the urban environment.
6 p.m.	Gradual drop in temperatures, return to calm	Assessment of bioclimatic recovery and cumulative effects, identification of any persistent symptoms at the end of the day

These ranges allow for the capture of the daily thermal gradient, the period of maximum stress, and recovery effects, while associating each response with a realistic exposure context. Perceived comfort levels are collected on a five-category ordinal scale ranging from very uncomfortable to very comfortable, coded from -2 to +2, suitable for Givoni-type bioclimatic approaches and subjective comfort assessments.

The results are interpreted as perception-based associations, useful for identifying periods and bioclimatic situations at risk and for guiding targeted prevention actions among young adults.

This study has certain limitations inherent to the use of self-reported data. The absence of clinical or hospital data prevents medical confirmation of the reported asthma attacks or the establishment of a strict causal relationship between bioclimatic conditions and asthma exacerbations. The results should therefore be interpreted as associations based on individual perception, which may be influenced by memory bias or subjectivity. However, this approach remains relevant for exploring climate-health interactions in a tropical urban context and provides a useful basis for guiding future research incorporating objective medical data.

4. Results

4.1. Bioclimatic environments of the municipality of Natitingou

4.1.1. Monthly bioclimatic environments in the municipality of Natitingou

This figure shows the monthly variation of the UTCI index in Natitingou, allowing us to understand the seasonal dynamics of bioclimatic conditions throughout the year. It highlights periods of heat stress likely to influence the occurrence and intensity of asthma attacks in the population.

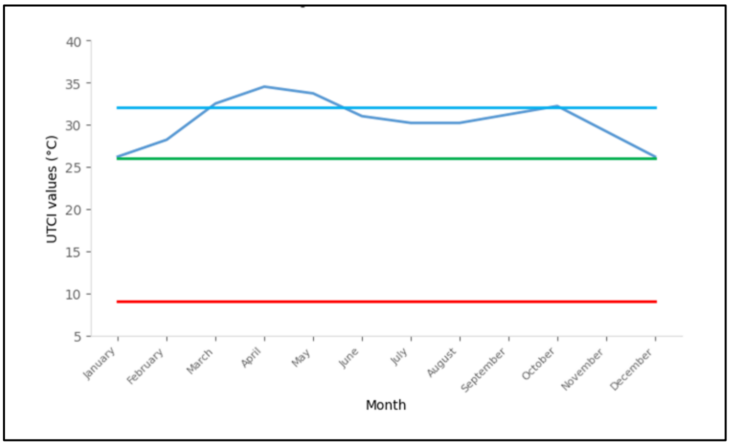


Figure 7 Monthly change in the UTCI index in Natitingou

Examination of this figure highlights a marked seasonality in the bioclimatic conditions in Natitingou, as measured by the monthly UTCI. Values are moderate in January and December at 26.2, increase to 28.2 in February, and then reach a significantly more challenging level of 32.5 starting in March. The peak occurs in April at 34.5, followed by a sustained high of 33.7 in May, corresponding to the most bioclimatic stressful period of the year. From June onward, the UTCI decreases to around 31.0 and then stabilizes around 30.2 in July and August, before a slight increase in September (31.2) and October (32.2), followed by a decrease in November (29.2). This dynamic suggests a critical window centered on March to May, and a second phase of stress in October. In the context of asthma, these periods of bioclimatic stress may coincide with an increase in the prevalence of symptoms and attacks, either through increased thermal discomfort or through interaction with seasonal drought and dust, factors known to exacerbate bronchial hyperreactivity.

4.1.2. Three-hour bioclimatic environments in the municipality of Natitingou

This figure highlights a very marked daily evolution of average values, reflecting a diurnal cycle typical of bioclimatic environments in Natitingou.

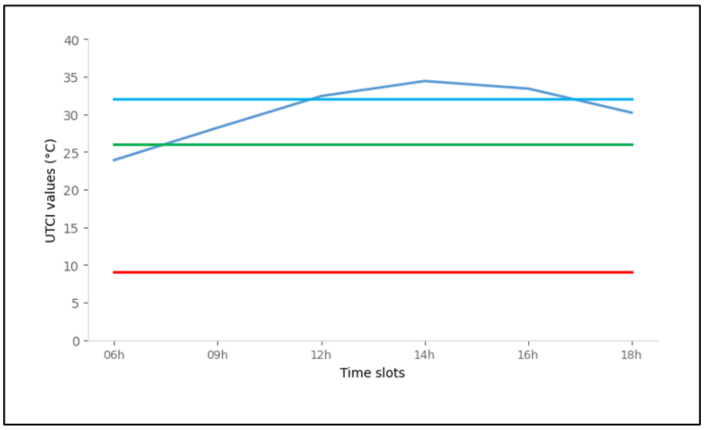


Figure 8 Three-hourly variation of the UTCI index at Natitingou

Observation of this figure shows a clear three-hourly variation in UTCI, reflecting the progressive intensification of bioclimatic stress throughout the day in Natitingou. The lowest value is recorded at 6:00 AM at 23.9, corresponding to a relatively milder atmosphere in the early morning. At 9:00 AM, UTCI reaches 28.2, indicating the onset of a phase of rapid warming. The stress becomes more pronounced at 12:00 PM with 32.4, then peaks at 2:00 PM with 34.4, identifying the afternoon as the period of greatest bioclimatic load.

At 4 p.m., the value remains very high at 33.4, suggesting prolonged exposure to heat stress, before a partial decrease at 6 p.m. when the UTCI drops to 30.2. In the context of asthma, this daily range is important because it allows for the anticipation of potential exacerbation windows. The peak between noon and 4 p.m. can promote respiratory distress due to heat fatigue and airway irritation, while the morning and evening transitions can be accompanied by changes in ventilation and resuspended dust, which may increase the frequency of attacks in susceptible individuals.

4.2. Perceptions of young adults in the municipality of Natitingou

4.2.1. Monthly perception of young adults in the municipality of Natitingou

This figure presents the monthly distribution of young adults' bioclimatic perceptions according to different levels of comfort and discomfort. It allows us to compare the objective evolution of bioclimatic environments with subjective feelings, essential elements for understanding respiratory vulnerability and the prevalence of asthma.

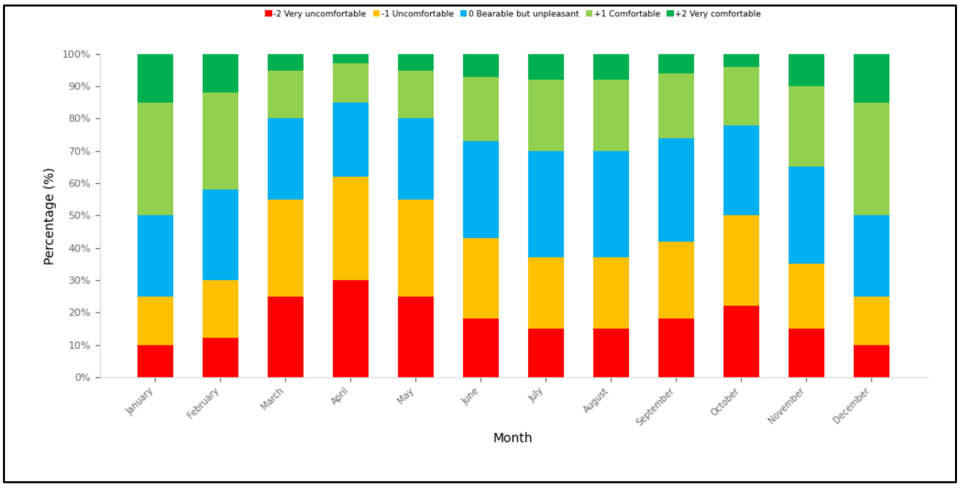


Figure 9 Monthly perception of young adults in Natitingou

The analysis of this figure highlights a strong seasonality in the bioclimatic perception of young adults in Natitingou, with a marked shift between periods considered comfortable and those considered uncomfortable.

In January and December, positive ratings predominate, with 35 percent describing comfort and 15 percent describing comfort as very comfortable, while negative ratings remain limited. Conversely, the period from March to May sees the highest levels of discomfort, particularly in April where the combined perception of discomfort as very uncomfortable and uncomfortable reaches 62 percent, reflecting widespread unease. June to September corresponds to a phase of relative improvement where the 'bearable but unpleasant' category becomes the majority, at around 30 to 32 percent, indicating moderate but persistent discomfort. October marks a further decline, consistent with an increase in bioclimatic stress, before an improvement in November and then December.

In the context of asthma, these seasonal shifts are important because months dominated by discomfort may coincide with an increase in attacks due to airway irritation, heat fatigue, and increased exposure to dust in the dry season, thus contributing to the prevalence of respiratory symptoms.

4.2.2. Three-hourly perception of young adults in the municipality of Natitingou

This figure highlights the three-hourly variation in young adults' bioclimatic perception throughout the day. It sheds light on the times when perceived discomfort is greatest, which may coincide with an increased risk of triggering asthma attacks.

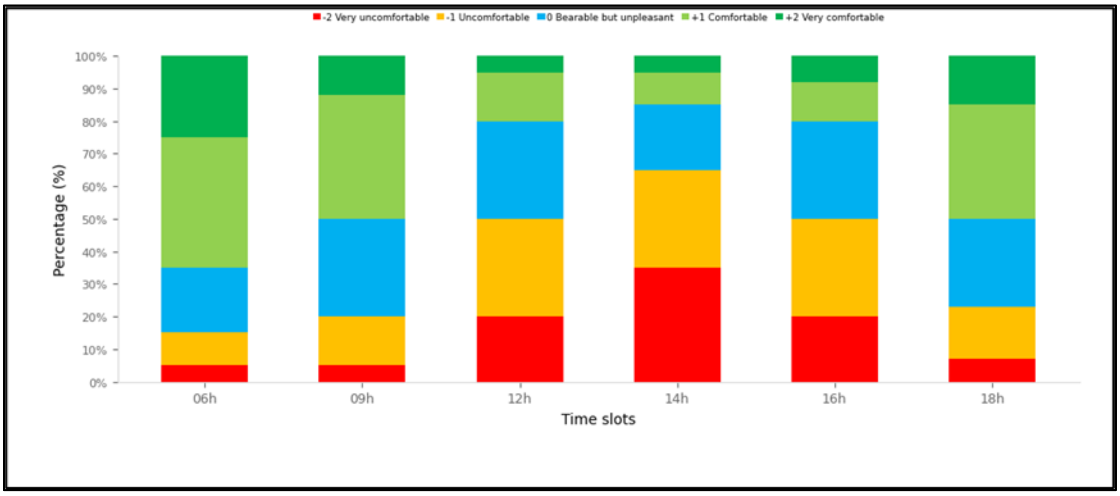


Figure 10 Three-hour perception of bioclimatic environments by young adults in Natitingou

Examination of this figure highlights a strong three-hourly variability in the bioclimatic perception of young adults in Natitingou, reflecting the direct influence of the daily cycle of thermal stress on their experience. At 6:00 a.m., positive perceptions largely dominate, with 40 percent reporting comfort and 25 percent reporting very comfort, while levels of discomfort remain marginal.

This situation reflects a relatively mild morning atmosphere, often associated with less respiratory exertion. At 9:00 a.m., perception begins to gradually deteriorate, marked by a rise in the 'bearable but unpleasant' category to 30 percent, signaling the increase in heat stress. The deterioration becomes pronounced at noon, when negative perceptions reach 50 percent, indicating growing discomfort. The peak of discomfort is observed at 2:00 p.m., when the sum of 'very uncomfortable' and 'uncomfortable' perceptions reaches 65 percent, indicating a particularly unpleasant atmosphere. At 4:00 p.m., although discomfort remains high, a slight improvement begins, before a more marked decrease at 6:00 p.m., with a gradual return to comfortable perceptions.

In the context of asthma, these results suggest that attacks may be more frequent between 12pm and 4pm, a period when maximum bioclimatic stress can promote bronchial irritation, respiratory fatigue and exacerbation of symptoms in sensitive subjects.

5. Discussion

The results of this study show that periods of high bioclimatic stress, identified by high UTCI values, coincide with a decline in perceived comfort and a reported increase in asthma attacks among young adults in Natitingou. This observation is consistent with the work of Beggs and Bambrick (2005), who highlighted an early link between increased climatic stress and the resurgence of respiratory illnesses, particularly asthma. Similarly, D'Amato et al. (2015) emphasize that periods of intense heat and extreme weather conditions exacerbate asthma symptoms through airway irritation and increased physiological stress.

The importance of the fine time scale observed in this study, particularly the 12–4 p.m. time slot, confirms the findings of Makrufardi et al. (2023), according to which the effects of extreme weather conditions on asthma can manifest in the short term, sometimes within a few hours. This daily dynamic is also consistent with the work of Chung and Pavord (2008), who show that the perception of thermal discomfort often reflects a real physiological stress that can exacerbate respiratory symptoms.

Furthermore, the climatic context of Natitingou, characterized by the harmattan and dust-laden winds, reinforces the observed results. Studies conducted in other regions have demonstrated that episodes of atmospheric dust are associated with an increase in respiratory problems and asthma consultations, thus confirming the relevance of the results obtained (Chen et al., 2010). However, unlike some studies based on hospital data, this research relies on self-reported perceptions, which limits direct comparison but aligns with the approaches centered on lived experience and respiratory vulnerability highlighted by Poole et al. (2019) and Zhou et al. (2022). In the context of global climate change, these results are fully in line with current public health concerns and confirm the need to integrate bioclimatic indicators into asthma prevention strategies (Haines and Ebi, 2019; Wright, 2020).

6. Conclusion

This study aimed to analyze the relationships between bioclimatic stress, perceived temperature, and asthma attacks in young adults in the municipality of Natitingou. The approach adopted, combining the UTCI index and the analysis of individual perceptions at monthly and three-hourly scales, revealed a clear temporal structure in bioclimatic environments and their potential effects on respiratory health. The results show that periods characterized by high temperature stress, particularly between March and May and during certain times of day, coincide with a marked decline in perceived comfort and an increase in perceptions associated with asthma attacks.

Three-hour analysis reveals that the periods between noon and 4 p.m. are the most challenging from a bioclimatic perspective, reflecting prolonged exposure to heat that can contribute to bronchial irritation and respiratory fatigue. The observed correlation between high UTCI values and negative perceptions reinforces the importance of integrating subjective dimensions into climate-health analyses, particularly in tropical urban contexts where exposure conditions are highly variable.

Although based on self-reported data, this study provides relevant insights for identifying periods of risk and highlights the need to integrate bioclimatic indicators into asthma prevention strategies. It also opens avenues for future research combining objective clinical data and biometeorological approaches to better anticipate the local health impacts of climate change.

Compliance with ethical standards

Acknowledgments

The author expresses gratitude to the National Meteorological Directorate (DNM) of Benin and NOAA for providing the climatological datasets used in this research.

Disclosure of conflict of interest

The author declares that there are no financial or non-financial conflicts of interest regarding the publication of this article.

Statement of informed consent

The study methodology involving human participants (surveys on self-reported perceptions) adhered to ethical standards of non-invasive observational social research, maintaining total anonymity and informed consent of all participants.

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