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Full Length Research Article

INFLUENCE OF EXTREME TEMPERATURE ON ADVERSE PREGNANCY OUTCOMES IN KADUNA STATE, NIGERIA

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ABSTRACT
Temperature extremes have been linked to adverse pregnancy outcomes globally. This study investigated the influence of extreme temperature on adverse pregnancy outcomes in Kaduna State, Nigeria. Daily minimum and maximum temperature data of Kaduna State (2015-2023) were downloaded from NASA Power Access. Monthly records of three adverse pregnancy outcomes which include Pre-Term (PT), Low Birth Weight (LBW) and Still Birth (SB) for the period 2015 to 2023 were retrieved from the database of Barau Dikko Specialist Teaching Hospital, Kaduna State. RClimdex was employed to compute four percentile-based extreme temperature indices (TX10p; TX90p; TN10p; and TN90p). Pearson correlation coefficient and linear regression were used to examine the association and extent of the relationship between extreme temperature indices and adverse pregnancy outcomes in Kaduna State, Nigeria. Results of the correlation analysis revealed that correlation coefficient between TN10p and LBW, PT and SB were 0.237, 0.142 and -0.006, among which only LBW had a significant relationship. The correlation coefficient between TN90p and LBW, PT and SB were -0.190, -0.301, and -0.335, with PT and SB exhibiting significant relationship. The correlation coefficient between TX10p and PT, LBW and SB were 0.491, 0.440 and 0.361 respectively. All the correlation were statistically significant. Lastly, TX90p had moderate negative relationship with PT and SB, but a weak negative significant relationship with LBW, with correlation coefficients of -0.408, -0.449 and -0.397 respectively. From the regression analysis, it can be concluded that both cold and warm temperature extremes significantly influence adverse pregnancy outcomes in the study area. Also, daytime extremes exhibit stronger influence on adverse pregnancy outcomes compared to nighttime extremes. Therefore, this study recommends that pregnant women should be educated on the significance of avoiding extreme temperatures, as well as how to avoid health problems caused by heat or cold.

Keywords: Low Birth Weight, Stillbirth, Preterm Birth, Extreme Temperature Indices, Kaduna State.

INTRODUCTION
The climate system has unquestionably changed significantly as a result of human activity and the use of fossil fuels (IPCC, 2021). Climate change is the long-term alteration of the typical weather patterns that define local, regional, and global climates (Ha et al., 2022). Throughout human history, the global climate has been changing with numerous short- and long-term health impacts linked to it, including heatstroke, dehydration, respiratory disorders, infectious infections, mental health issues, cardiovascular disease, and even death (Watts et al., 2021). Low-income nations are especially susceptible to climate change due to endemic poverty, inadequate sanitation, severe malnutrition rates, infections, non-communicable diseases, detrimental living conditions, and unstable, insufficient healthcare systems (Roos et al., 2021).
Every year, over 19 million women worldwide experience adverse pregnancy outcomes (McElroy et al., 2021); The World Health Organization (WHO) reports that the annual count of these cases is increasing (Chawanpaiboon et al., 2019). Due to several factors, such as limited healthcare access and a dearth of information and resources about pregnancy health (Ngandu et al., 2020), developing countries, including Nigeria, account for a large share of the world's adverse pregnancy outcomes (McElroy et al., 2021). Women are particularly vulnerable to the harmful consequences of climate change due to their unique health requirements, such as the need for additional nourishment during pregnancy (Sorensen et al., 2018). The effects of climate change on pregnancy health can be characterized in three ways: (a) directly through isolated environmental disasters; (b) indirectly through changes in the natural environment; and (c) indirectly through changes in society (Ha et al. 2022). This is shown in Figure 4.1.
Stillbirth (SB), low birth weight (LBW), and preterm birth (PT) are serious pregnancy complications that are very common in developing countries such as Nigeria. SB is defined as fetal death after 28 weeks gestation or at least 1000 grams at birth, and there are an estimated 2.6 million SBs every year (McElroy et al., 2022). The consequences of LBW (defined as live births less than 2500g) include subsequent disadvantages in educational attainment, health and income in adulthood, and mortality risks (Aizer & Currie, 2014). PT, which is defined as a live birth before 37 weeks gestation, causes an enormous burden on healthcare systems by increasing the risk of several poor health outcomes later in life, including respiratory conditions, neurodevelopment and growth abnormalities, and other morbidities (Undela et al., 2019).
High ambient temperatures are linked to pregnancy outcomes and challenges, such as SB and LBW (Chersich et al., 2020). Due to changes in placental blood flow, heat might raise the risk of hypertensive crises and stillbirth by increasing the production of vasoactive chemicals, blood viscosity, and endothelial cell activity (Sorensen et al., 2018). Temperatures above 20°C increase the risk of adverse birth outcomes for expectant mothers, and this risk rises with rising temperatures and peaks above 30°C (McElroy et al., 2022). There is strong evidence that vector-borne illnesses like malaria, which are impacted by climatic factors, may increase the risk of SB and LBW delivery for expectant mothers (Sorensen et al., 2018).
According to Ruan et al. (2023), expectant mothers exposed to exceptionally low ambient temperatures are more likely to have a negative pregnancy outcome, especially in late pregnancy.

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According to several studies (Bruckner et al., 2014; Cox et al., 2016; Elter et al., 2004; Xiong et al., 2020), low ambient temperature can limit foetal growth, raise the risk of preterm birth, as well as increase the probability of severe birth complications. Ruan et al. (2023) conducted a systematic meta-analysis and review on the association between low ambient temperature during pregnancy and adverse birth outcomes. The results revealed that pregnant women exposed to low ambient temperatures were more likely to experience PT births and LBW. The meta-analysis also revealed that pregnant women who were exposed to low ambient temperatures during their pregnancy were more likely to develop SB (Ruan et al., 2023).

Variable rainfall significantly impacts the availability of food, water, and economic resources. These effects can be reflected in a variety of adverse pregnancy outcomes, including SB, abortion, and miscarriage (Rayco-Solon et al., 2005). Due to water scarcity, women are forced to walk great distances to harvest from sources that might be contaminated both biologically and toxicologically (Sorensen et al., 2018). Long distances travelled in search of water can also result in increased heat exposure. On the other hand, food insecurity and undernutrition result in macro and micronutrient deficiencies in expectant mothers, which can have an impact on the development of their pregnancy, nursing, and delivery of their child. It can also result in low birth weights, miscarriages, and perinatal mortality (Sorensen et al., 2018).

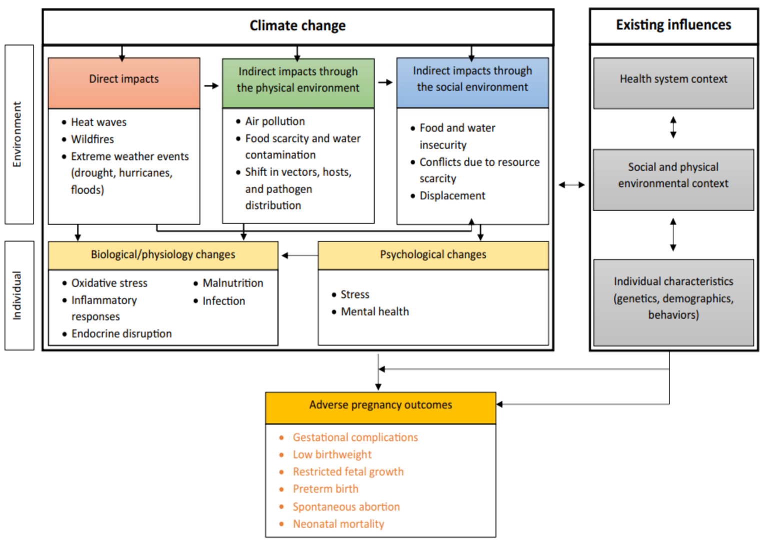

Figure 1: Impacts of climate change on pregnancy outcomes
Source: Ha (2022)

The potential association between adverse pregnancy outcomes and exposure to climatic factors during pregnancy are major public health concern (Wu et al., 2023). Studies have shown that climate variables such as temperature (Chersich et al., 2020), severe heat (McElroy et al., 2021 & Zhang et al., 2017), relative humidity (Wu et al., 2023), and variability in rainfall (Chacon-Montalvan et al., 2021) have an impact on adverse pregnancy outcomes. However, Zhang et al. (2017) conducted a systematic review of temperature exposure during pregnancy and birth outcomes, identifying 36 epidemiological studies investigating adverse birth outcomes, the vast majority of which were from Europe, North America, Asia (Israel, China, and Japan), and Australia, with only one study conducted in Africa (Ghana). Similarly, Chersich et al. (2020) did a systematic evaluation of 48 papers on the correlation between high temperatures and adverse birth outcomes in upper-middle- and high-income countries. Ruan et al. (2023) conducted a systematic review and meta-analysis of 34 research on the correlation between low ambient temperature during pregnancy and adverse birth outcomes. Among the 34 studies, none were conducted in Africa.

The majority of studies investigating the correlation between climate factors and adverse pregnancy outcomes are based in it is essential to understand that the correlation varies with country, population size, and pregnancy stage (Wu et al., 2023), preventing results from being generalized. In addition, pregnant women lack uniform standards for climate impact adaptation and mitigation (Ha et al., 2022). This requires local-level studies on the impact of the climate and weather on adverse pregnancy outcomes.

industrialized countries, with very few in Africa, particularly Nigeria. Considering the social, demographic, and climatic settings that women in developing countries face are significantly different, it is inappropriate to take conclusions from this research and extend them to women in underdeveloped nations like Nigeria (McElroy et al., 2021). In reality, investigations on the correlation between adverse pregnancy outcomes and weather factors should focus more on developing countries, which bear the greatest burden of adverse pregnancy outcomes while also being most vulnerable to weather and climatic change.

There is limited information on how extreme temperatures impact adverse pregnancy outcomes in Kaduna State particularly, and Nigeria at large. The purpose of this study is to investigate the impact of extreme temperature on three adverse pregnancy outcomes (SB, LBW, and PT) in Kaduna State, Nigeria. The goal

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is to provide valuable insights that can enhance our understanding of how extreme temperatures contribute to adverse pregnancy outcomes in Kaduna State, and Nigeria as a whole. The findings can assist public health professionals, policymakers, community leaders, and other stakeholders in designing effective strategies and interventions to promote reproductive health and prevent adverse pregnancy outcomes.

MATERIALS AND METHODS

Study Area

Kaduna is located between Latitudes 8°57’12” and 11°34’1” north of the equator and between Longitudes 6°3’25” and 8°50’13” east of the Greenwich meridian (Figure 2). The state has a tropical savanna climate (*Aw*) under Köppen climate classification, which is characterized by wet and dry seasons (Abdussalam, 2020). With an average rainfall of about 1400 mm, the rainy season lasts for roughly six to seven months, primarily from April to October, with a peak in August. The Harmattan dry season is characterised by strong dust clouds and winds coming from the desert to the north (Abubakar et al., 2024). The hottest months in Kaduna North are March, April, and May, with maximum temperatures that can reach well over 35°C. Depending on the month of the year, the relative humidity normally varies from 25% to 90%, with December and February having the lowest humidity.

Figure 2: Kaduna State Showing Local Government Areas

Source: Adapted from GRID[3] - Nigeria, 2022

Materials

This study made use of weather data and adverse pregnancy outcomes which were both collected from secondary sources.

Adverse Pregnancy Outcomes

Three measurements of adverse pregnancy outcomes were considered in this study (SB, LBW & PT) due to their high prevalence in the study area. After being given ethical and full approval by Barau Dikko Teaching Hospital Kaduna Health Research and Ethics Committee, the three chosen metrics of adverse pregnancy outcomes were retrieved from the database of Barau Dikko Specialist Hospital (BDSH). BDSH formerly known as Nursing Home is the major tertiary health (non-specialty) institution in Kaduna Town. The hospital has a long history dating back to

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1930 when it served as a colonial administration hospital. Following accreditation by the Medical and Dental Council of Nigeria (MDCN) and the National University Commission (NUC), the hospital commenced functional operations as a teaching hospital in March 2016.

Extreme Temperature

This study's meteorological data includes daily maximum and minimum temperature which was retrieved from the NASA Power Data Site (https://power.larc.nasa.gov/data-access-viewer/). NASA's Global Modelling and Assimilation Office (GMAO) has released the contemporary Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2), the most recent atmospheric reanalysis of the contemporary satellite era. MERRA-2 comprises observation types not accessible in its predecessor, MERRA, as well as changes to the GEOS model and analysis scheme, resulting in an advanced product suite appropriate for weather and climate applications. NASA Power meteorological characteristics are based on NASA's GMAO MERRA-2 assimilation model and Goddard Earth Observing System (GEOS) 5.12.4 FP-IT data. MERRA-2 is an updated version of NASA's GEOS Data Assimilation System. MERRA-2 has a resolution of 0.5º x 0.625º.

Methods

Extreme Temperature Indices Computation

Four percentile-based extreme temperature indices were computed using RClimdex as well using the daily temperature (maximum and minimum) data downloaded from the NASA Power Data Site. The methodology used in computing extremes with RClimDex is shown in Figure 3.

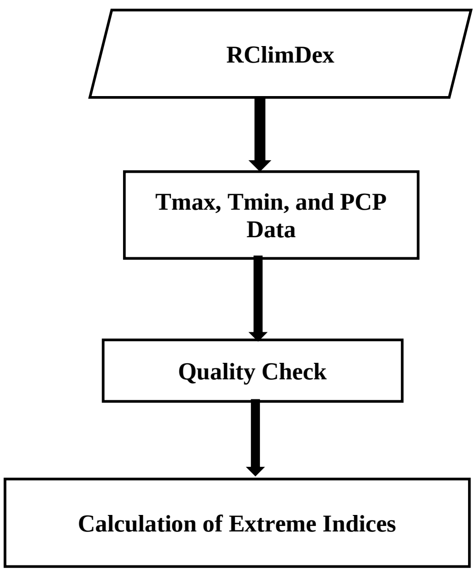

Figure 3: Adopted Methodology in Computation of Extremes using RClimDex.
Source: Zang and Yang, 2004.

RClimDex software is an R-based software package developed by ETCCDI that computes extreme climate indices using a user-friendly interface. The indices used in this study are shown in Table 1.

Table 1: List of four extremes computed using RClimDex

ID	Indicator name	Definition	Units
TN10p	Cool Nights	Percentage of days when TN<10th percentile	Days
TX10p	Cool Days	Percentage of days when TX<10th percentile	Days
TN90p	Warm Nights	Percentage of days when TN>90th percentile	Days
TX90p	Warm Days	Percentage of days when TX>90th percentile	Days

TX=Daily Maximum Temperature, TN=Daily Minimum Temperature

Correlation

To examine the influence of extreme temperature on adverse pregnancy outcomes in Kaduna, monthly pregnancy outcome records were used as dependent variables, while four of the computed temperature extremes (TN10p, TN90p, TX10p, and TX90p) served as independent variables. Pearson correlation was applied to determine the type and extent of the relationship between the dependent and independent variables. Pearson's correlation coefficient is a metric that measures the strength of a linear relationship between two sets of data. In a sample, it is indicated by r and is design-constrained as follows: (1) Positive values represent positive linear correlation; (2) Negative values indicate negative linear correlation; and (3) A value of 0 indicates no linear correlation; Evans (1996) suggest that the absolute value

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of r: (1) .00-.19 "very weak" (2).20-.39 "weak", (3) .40-.59, "moderate" (4).60.79 "strong", and (5).80-1.0 "Very strong". The formula for Pearson correlation is shown in equation (i):

$$r = \frac{\sum(xi - x)(yi - y)}{\sqrt{\sum(xi-x)2 \sum(yi-y)2}} \quad \text{(i)}$$

Where $r = correlation\ coefficient$

$xi = values\ of\ the\ x - variable\ in\ a\ sample$
$x = mean\ of\ the\ values\ of\ the\ x - variable$
$yi = values\ of\ the\ y - variable\ in\ a\ sample$
$y = mean\ of\ the\ values\ of\ the\ y - variable$

Regression

Regression analysis involves finding the extent of relationship between a dependent variable and one or more variables that are independent. The dependent variable (predictand) is the variable whose value is to be predicted, whereas the independent variables (predictors) are those whose known values are used for prediction. In regression, the coefficient indicates how much the dependent variable is projected to rise (if positive) or decrease (if negative) as the independent variable increases by one. The sign indicates the direction of effect. The regression formula is in equation (ii):

$$Yi = f(Xi, \beta) + \text{e}i \quad \text{(ii)}$$

Where $Yi = dependent\ variable$

$f = function$
$Xi = independent\ variable$
$\beta = unknown\ parameters$
$\text{e}i = error\ terms$

RESULTS

Between 2015 and 2023, BDSH recorded 19,831 births, with 28.23% of these resulting in adverse outcomes such as low birth weight, stillbirths, and premature birth. The study revealed that the SB rate at BDSH was higher, at 60.41, as opposed to Nigeria's national average of 36.7 which was reported by UNICEF in 2023. However, the LBW rate (16.53%) was lower than the West African average but at the same time higher than the Sub-Saharan African average in 2023 according to data from UNICEF/WHO. Finally, the PT birth rate (6.04%) was much lower than Nigeria's national average of 15.7% (Chawanpaiboon et al., 2019).

Correlation Analysis

This study assessed the relationship between extreme temperature indices and adverse pregnancy outcomes using Pearson correlation coefficient. The result is shown in Table 2.

Table 2: Correlation Matrix

VARIABLES	PT	LBW	SB
TN10p	0.142	**0.237**	-0.006
TN90p	**-0.301**	-0.190	**-0.335**
TX10p	**0.491**	**0.440**	**0.361**
TX90p	**-0.408**	**-0.397**	**-0.449**

Values in bold are different from 0 with a significance level of alpha=0.05

Results from Table 2 revealed that TN10p has a very weak positive correlation with PT, but is inversely correlated with SB although these correlations were insignificant. However, TN10p has a moderate correlation with LBW, which is significant at 0.05. Additionally, TN90p is inversely correlated with PT, LBW and SB having a correlation coefficients of -0.301, -0.190 and -0.335. The correlation between TN90p, PT and SB were significant at 0.05, while the correlation between TN90p and LBW is insignificant. TX10p is moderately correlated with PT and LBW, but revealed a weak correlation with SB. All the correlations are significant at 0.05 significance level. Lastly, TX90p is inversely correlation with PT, LBW and SB. All the correlations are significant at 0.05 significance level. The correlation matrix is depicted in Figure 3.

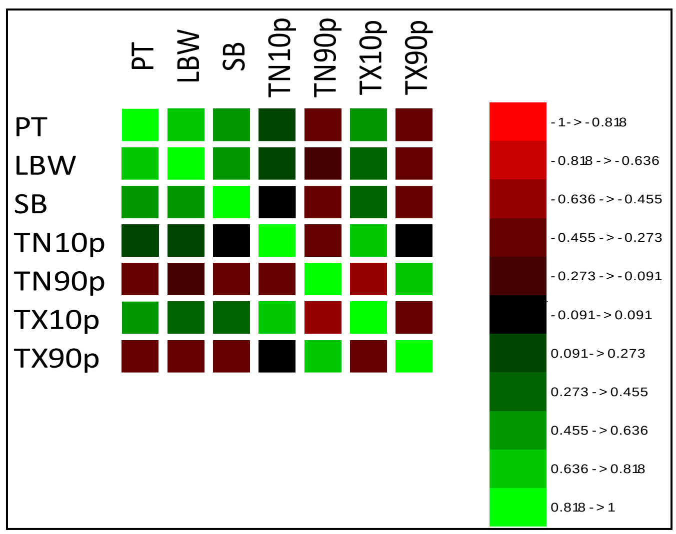

Figure 3: Image of the Correlation Matrix

3.1 Regression Analysis

This study examined the extent of relationship between the various extreme temperature indices and adverse pregnancy outcomes using linear regression. The results are shown in Tables 3, 4 and 5, and Figure 4.

The model summary for the extent of relationship between temperature extremes and PT using linear regression. The result is

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shown in Table 3.

Table 3: Model summary for PT

Extreme Temp.	Obs.	DF	R^2	Adjusted R^2	Pr > F	Standard error
TN90p	101.000	99	0.090	0.081	0.002	0.680
TX10p	101.000	99	0.241	0.233	< 0.0001	0.609
TX90P	101.000	99	0.166	0.158	< 0.0001	0.448

Results from Table 3 revealed that TN90p is responsible for 9% of the variation in PT, whereas TX10p and TX90p are responsible for 24.1% and 16.6% of the variation in PT, respectively.

The linear regression analysis between temperature extremes and LBW is shown in Table 4.

Table 4: Model summary for LBW

Extreme Temp.	Obs.	DF	R^2	Adjusted R^2	Pr > F	Standard error
TN10p	101.000	99	0.056	0.046	0.017	1.450
TX10p	101.000	99	0.194	0.186	< 0.0001	1.282
TX90p	101.000	99	0.158	0.149	< 0.0001	0.921

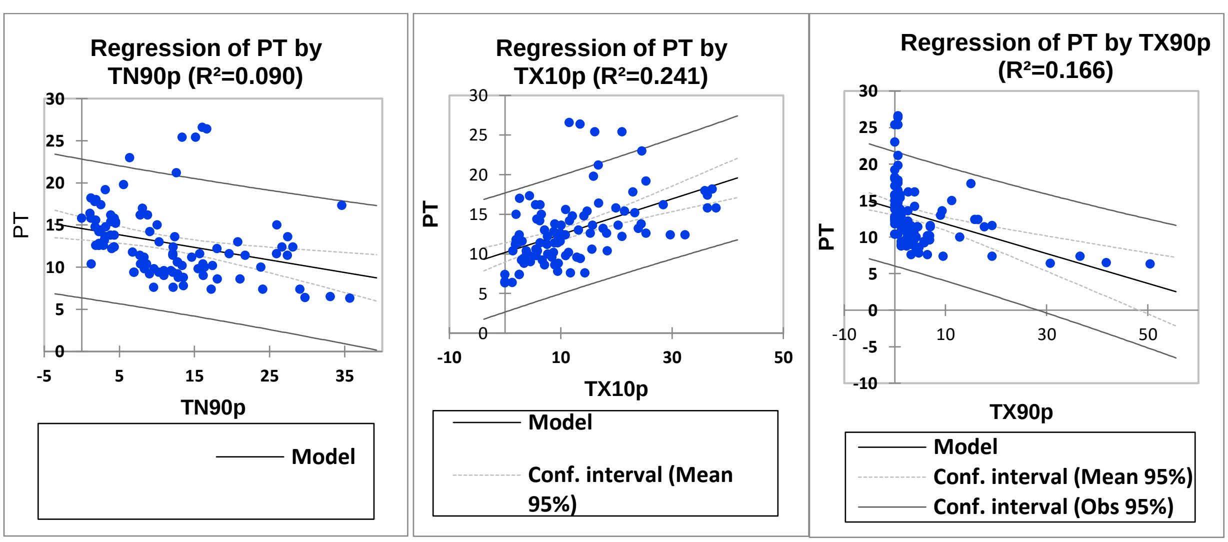
From Table 4, the linear regression model summary for LWB, revealed that TN10p constitutes just 5.6% of the variation in LBW, whereas TX10p and TX90p contribute 19.4% and 15.8%, respectively.

Lastly, the model summary for linear regression between extreme temperature indices and SB is shown in Table 5.

Table 5: Model summary for SB

Extreme Temp.	Obs.	DF	R^2	Adjusted R^2	Pr > F	Standard error
TN90p	101.000	99	0.112	0.103	0.001	0.465
TX10p	101.000	99	0.130	0.122	0.001	0.451
TX90p	101.000	99	0.201	0.193	< 0.0001	0.304

Findings from Table 5 revealed that TN90p constitutes 11.2% of the variation in SB, whereas TX10p and TX90p constitute 13.0% and 20.1% of the variation, respectively.



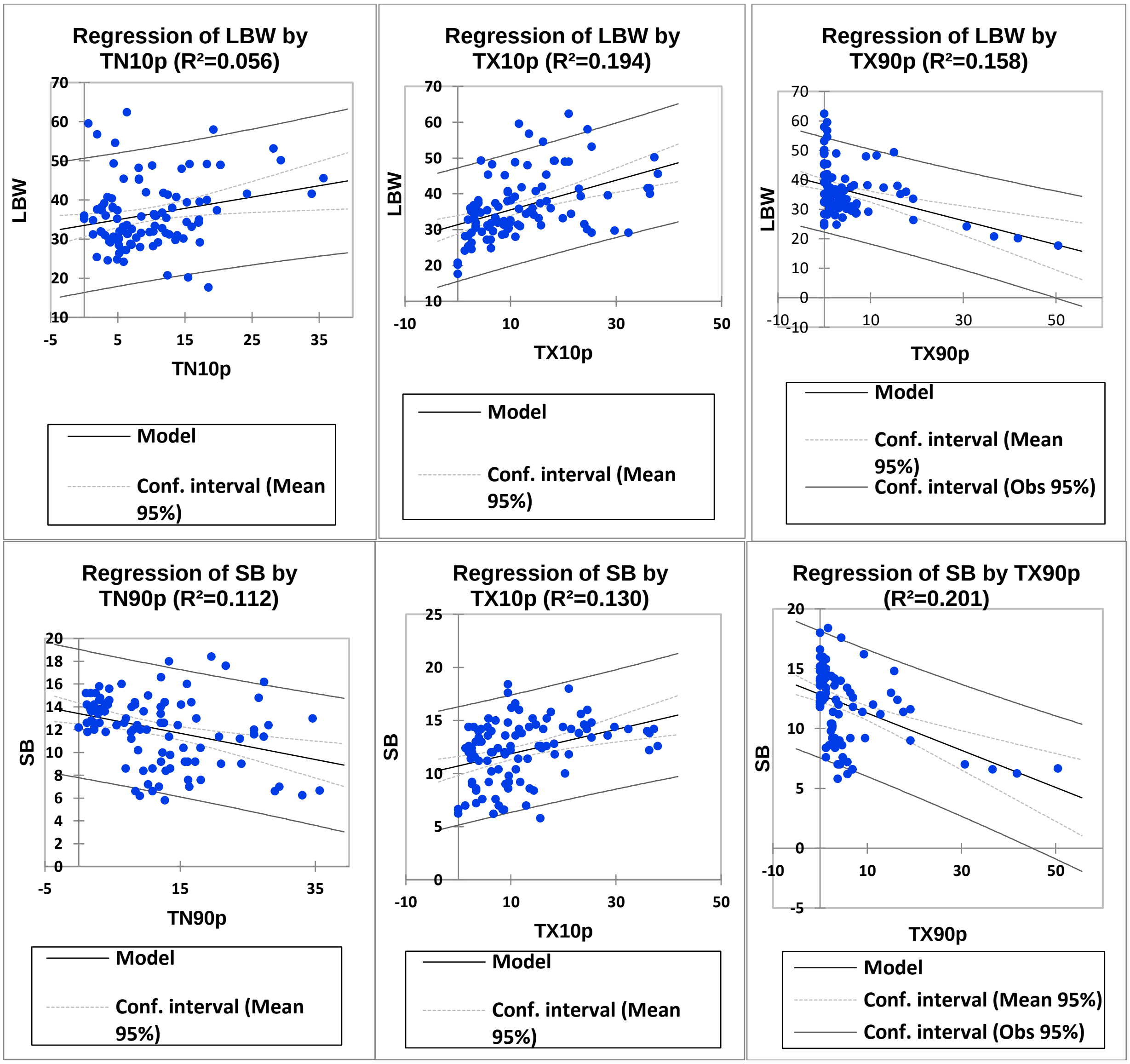


Figure 4: Regression plot of extreme temperature and adverse pregnancy outcomes

DISCUSSION

The regression analysis revealed that cold temperature extremes significantly increase adverse pregnancy outcomes, while in contrast, warm temperature extremes significantly reduce adverse pregnancy outcomes in Kaduna. These findings are consistent with the results of previous studies conducted worldwide. For instance, Qiu et al. (2023) have reported that exposure to either very low or very high temperatures during pregnancy can increase the risk of preterm birth in China. Similarly, Dastoorpoor et al. (2021) reported that both cold and hot thermal stress may be associated with an increased risk of low birth weight and stillbirths in Iran. Bruckner et al. (2014) found that cold temperatures increase the risk of stillbirth and premature birth in Sweden. It is worth noting that excessively low temperatures can harm foetal development (Cox et al., 2016), increasing the chance of adverse pregnancy outcomes.

Although the study revealed that extreme temperature indices are linked to adverse pregnancy outcomes, other factors such as poor health and growth, intellectual and mental disabilities, the early onset of chronic diseases, and other short- and long-term effects are linked to postpartum haemorrhage (PT) (Ramaswamy et al., 2021: Sarda et al., 2021). According to Aizer & Currie (2014) and Wan et al. (2014), LBW has repercussions that include mortality risks, health and income in adults, and eventual disadvantages in educational attainment. Because of the immaturity of multiple organ functions and changes in pharmacokinetic and pharmacodynamic qualities, LBW newborns are more likely to experience adverse medication responses. This implies that extreme caution is required while exposing such neonates to various medications (Undela et al., 2019).

Although the foetal temperature remains generally constant when ambient temperature varies, thermoregulatory responses to cold may include increased blood viscosity and vascular constriction

(Keatinge & Donaldson, 2004). The placenta, which provides essential nutrients and oxygen to the developing foetus, may experience altered blood flow when a mother has certain physiological reactions. As a result of the decreased blood flow, the fetus's growth and development could be affected.

Climate change is largely regarded as the cause of more frequent and severe extreme weather events around the world. Several studies (e.g., Bruckner et al., 2014; Zhang et al., 2017; Chersich et al., 2020; Chacon-Montalvan et al., 2021; McElroy et al., 2021; Ruan et al., 2023; Qiu et al., 2023; Wu et al., 2023) have also found a concerning link between prenatal exposure to these events and adverse pregnancy outcomes. Nigeria in general, and Kaduna State, is regarded as one of the hotspots of climate change. According to Abdussalam (2020), this is due to its geographical location and limited capacity to deal with the effects of catastrophic weather events. Unfortunately, the burden of adverse pregnancy outcomes, which can result from these climate-induced stressors, is already high in Nigeria, and this only adds to the strain on the country's already fragile healthcare system.

Conclusion

According to the study's findings, it can be concluded that both cold and warm temperature extremes have a detrimental impact on pregnancy outcomes. Particularly, daytime temperature extremes, both cool and warm, have a stronger correlation with adverse pregnancy outcomes than nighttime extremes, both cool as well as warm. Furthermore, of the three adverse pregnancy outcomes examined, PT exhibited the strongest association with temperature extremes in the study area. These findings hold relevance for other areas in Northern Nigerian with similar climatic and socio-economic conditions.

Limitations

Although this study had some limitations, it still provided valuable insights regarding the association between extreme temperature and adverse pregnancy outcomes in an area where evidence is scarce. Other factors such as previous birth history, maternal living habits, and nutritional status were unavailable and could not be included in this study. Nonetheless, this research is among the first to examine the impact of extreme temperature exposure on the risk of PT, LBW, and SB in Nigeria generally, and in Kaduna State specifically.

Recommendations

Based on the findings of this study, we recommend that pregnant women should be educated on the significance of avoiding extreme temperatures, as well as how to avoid health problems caused by heat or cold. Additionally, future studies incorporating other confounding factors such as previous birth history, maternal living habits, and nutritional status are recommended. Lastly, more study is needed to fully understand how temperature extremes impact pregnancy outcomes and also to identify important exposure periods.

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