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The Effects of Precipitation and Temperature on Birth Weight: A Cross-Sectional Study from the Republic of Benin

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Abstract

Climate change, particularly changes in temperature and precipitation, prevents the improvement of maternal and neonatal health (MNH) in low-and middle-income countries (LMICs). Pregnant women and newborns in LMICs are considered the most vulnerable to adverse climate conditions, including extreme heat, floods, and droughts. This study examined the effects of precipitation and temperature on birth weight in the Republic of Benin, emphasizing climatic differences between the southern and northern regions. As a cross-sectional study, we pooled four rounds of Benin Demographic and Health Survey (BDHS) data, identifying 19 646 live births. We investigated the effects of precipitation and temperature on birth weight and the likelihood of low birth weight (LBW) newborns using multivariate multilevel linear and logistic regression models. We found that the average precipitation amount during the nine months before birth was positively correlated with higher birth weight in the south and was associated with a lower likelihood of LBW in the north. During the nine months before birth, a heat wave reduced birth weight by 57.0 g in the north. Furthermore, women and newborns in the north were more susceptible to precipitation and temperature, possibly due to food insecurity. Evaluating the MNH consequences of climate change is imperative for many developing countries facing severe climate change threats. Our findings provide an essential benchmark for future policies in Benin.

Keywords: climate change, precipitation, temperature, heat wave, birth weight, Benin

1. Introduction

1.1 Climate Change and Maternal and Neonatal Health (MNH)

The United Nations' Sustainable Development Goals aim to reduce maternal mortality and end preventable newborn deaths by 2030 (United Nations, 2022). Climate change has been recognized as a major obstacle hampering improvements to maternal and neonatal health (MNH) especially in low-and middle-income countries (LMICs) (Homer, Hanna, & McMichael, 2009; Roos et al., 2021; Rylander, Odland, & Sandanger, 2013). Pregnant women, developing fetuses, and children in LMICs are considered the most vulnerable and sensitive to climate variations (Roos et al., 2021; Rylander et al., 2013). Climate change shifts precipitation and temperature patterns and increases the frequency of devastating natural events, such as heat waves, floods, and droughts, which will become a serious threat to MNH (Roos et al., 2021).

Previous studies on LMICs have investigated how precipitation and temperature affect MNH. First, precipitation and temperature affect a family's food security and nutritional status through agricultural production. Pregnant women have unique nutritional requirements. Moreover, poor nutrition has been associated with anemia and other issues during pregnancy, increasing the risk of intrauterine growth retardation and low birth weight (LBW) (World Health Organization [WHO], 2014). Specifically, economies that rely primarily on agriculture and forestry are more vulnerable to precipitation and temperature variations (Brown, Grace, Shively, Johnson, & Carroll., 2014; Nordhaus, 1993). For example, in Sub-Saharan Africa (SSA), approximately 60% of the population relies on agricultural activities for their livelihoods and faces potential yield reductions with drastic climate variations (Besada & Sewankambo, 2009; Brown et al., 2014; Collier, Conway, & Venables, 2008). Furthermore, 200–600 million more people may be exposed to hunger by 2080 (Tirado, Hunnes, Cohen, & Lartey, 2015).

Second, heat waves due to higher temperatures have been associated with a greater risk of poor maternal health and birth outcomes (Davenport, Dorélien, & Grace, 2020; Desai & Zhang, 2021; Poursafa, Keikha, & Kelishadi, 2015; Zhang, Yu, & Wang, 2017). Pregnant women are physiologically prone to higher body temperatures, which may influence fetal development (Konkel, 2019). Therefore, exposing women to higher temperatures during their pregnancies may deteriorate the placenta and the development of fetus, resulting in adverse birth outcomes (Rashid et al., 2017; Rylander et al., 2013).

Third, climate variables such as temperature and precipitation to maternal and newborn health are related to the prevalence of vector-borne, water-borne, and water-washed diseases such as malaria and diarrhea, thus involving infections during pregnancy (Caminade, McIntyre, & Jones, 2019; Watts et al. 2018). Additionally, heavy precipitation may lead to floods, resulting in damage to infrastructure and critical services and disrupted access to maternal and child health services (Roos et al., 2021).

1.2 Low Birth Weight (LBW)

The World Health Organization defines LBW as a birth weight of less than 2500 g (WHO, 2018). Globally, 15–20% of all births are LBW, representing more than 20 million births per year (United Nations International Children's Emergency Fund [UNICEF], 2019). Most LBW cases were reported in LMICs, with 28% in South Asia, 13% in SSA, and 9% in Latin America (Blencowe et al., 2019). Empirical studies found that LBW was associated with higher infant mortality and morbidity (Jornayvaz et al., 2016), a higher likelihood of cardiovascular diseases and diabetes later in life (Jornayvaz et al., 2016; Lawlor, Leon, & Smith, 2005; Risnes et al., 2011), and a lower intelligence quotient score (Gu et al., 2017).

1.3 Study Relevance

Benin Republic, a country in West Africa on the Gulf of Guinea, is one of the least developed countries, with a gross domestic product per capita of 1291 USD in 2020. In Benin, LBW remains a top national priority; 12.5% of newborns have LBW (UNICEF-Benin, 2020). Over 90% of the total agricultural production consists of maize, rice, and beans for food. Nevertheless, while agriculture is the key sector of Benin's economy, food insecurity continues to be a severe issue. The maize yield is expected to decrease by 30 % by 2050 (Osse et al., 2019), and decreased food availability could affect households' food security and worsen malnutrition, especially among mothers and young children (Brown et al., 2014; Kumar, Molitor, & Vollmer, 2016; Tirado et al., 2015).

Although precipitation and temperature variations are expected to threaten MNH in Benin (Osse et al., 2019), these issues have rarely been addressed in the literature on public and global health. The health impact of climate change in Benin has been investigated, but these studies mainly focused on the prevalence of waterborne and vector-borne diseases, such as malaria, diarrhea, and acute respiratory infections (Badou, Yegbemey, & Hounkpè, 2021). Therefore, to contribute to the literature on the health effects of climate in Benin, this study investigated the effects of precipitation and temperature on birth outcomes using a nationally representative sample population.

1.4 Research Questions

This study aims to answer the following research questions:

- RQ1: What are the effects of precipitation and temperature on birth weight and LBW in Benin?
- RQ2: Do these effects differ between Benin's northern and southern regions?

2. Method

2.1 Study Setting

The southern and northern regions of Benin belong to different climatic zones. The south has an equatorial climate with two rainy seasons, from March to July and September to November. However, the north has a tropical climate with one rainy season from May to November (Mcsweeney, New, & Lizcano, 2012). Therefore, the south is more humid and favorable for agricultural production than the north. More than 70% of the population engages in the agricultural sector, and the economy heavily relies on rain-fed agriculture and livestock, particularly in the north (Sohou, 2017).

The effects of climate change are already noticeable in Benin. Since 1995, the average annual temperature has increased by 1°C, and the minimum temperature has increased between 0.5 and 1 °C (Green Climate Fund, 2019). In addition, the number of precipitation days has decreased, delaying the onset of the long rainfall season in the south and causing a shorter rainfall season in the north (Ministère de l'Environnement de l'Habitat et de l'Urbanisme [MEHU], 2011). Projections indicate that by 2100 the average temperature will rise by 3.3 °C, with the highest rate of increase in the north (MEHU, 2011). Therefore, climate change is expected to threaten people's livelihoods in Benin, particularly in the rural areas. Major food staples, such as maize and sorghum, have been negatively affected by rising temperatures, especially in the northern and central parts of the country (Jones & Thornton, 2003; Yegbemey, Yabi, Heubach, Bauer, & Nuppenau, 2014). Moreover, the sorghum and millet yields have decreased by up to 40% in the north and the maize yields by 5 to 25% in the central and southern regions due to increased temperatures (Badou et al., 2021; Paeth, Capo-Chichi, & Endlicher, 2008).

2.2 Data

2.2.1 Household Survey

We used four rounds of cross-sectional data from the Benin Demographic and Health Survey (BDHS): BDHS-1996, BDHS-2001, BDHS-2011/2012, and BDHS-2017/2018. Table 1 summarizes the variables used in our analyses. First, households were selected for sampling by dividing the enumeration areas into clusters and then choosing a specified number of households to survey per cluster. For example, for BDHS-2017/2018, 12 633 enumeration areas were divided into 555 primary sampling units (i.e., clusters). Then, 26 households per cluster were selected. Thus, 14 156 households, including 15 928 women, were surveyed. This procedure was applied for the other BDHS rounds. Our sample population comprised 19 646 births from the four BDHS rounds.

2.2.2 Precipitation, Temperature, and the Normalized Difference Vegetation Index (NDVI)

We used precipitation data from the Climate Hazards center InfraRed Precipitation with Station (CHIRPS). The CHIRPS dataset is publicly available and includes a quasi-global dataset starting from 1981. We used monthly information from CHIRPS version 2.0, which comprised gridded rainfall time series data at 0.05 × 0.05 degrees resolution satellite imagery (approximately 5 km × 5 km). Furthermore, we used the global positioning system (GPS) data from BDHS, which allowed for a more precise calculation of the amount of rainfall than using local weather stations per BDHS cluster. We set a buffer of 500 m to calculate the average and total amount of rainfall, and then these grid points were matched to each of the BDHS clusters in our sample. We excluded 929 observations (less than 5% of our sample) unmatched by the rainfall data. This is because these GPS positions were displaced to ensure respondent confidentiality, which moved the cluster location near the coast to outside the territory covered by the CHIRPS data. Our temperature variables come from the World Climate database, which contains high spatial resolution global temperatures. We extracted the monthly average, minimum, and maximum temperatures for our analysis.

This study aimed to assess the exposure of pregnant women to precipitation and temperature for 9 months or during 3 trimesters before birth. We superposed DHS cluster points and gridded climate data to derive monthly climate measures for each cluster point. Then based on every child's month and year of birth, we matched climate data to represent climatic conditions for 9 months preceding birth. Accordingly, we calculated the trimester's climate variables for each pregnancy based on the month and year of birth of the child.

We also used NDVI data from the Advancing Research on Nutrition and Agriculture (AReNA)'s DHS-GIS Database, which provides a rich set of geographic variables, including NDVI at the DHS cluster level. The monthly NDVI around the 5 km of clusters from 2000 to 2019 were calculated using the Moderate Resolution Imaging Spectroradiometer. A higher NDVI represents more dense and healthier vegetation and is more likely to be suitable for growing crops. Many studies have used NDVI to capture regional variations in green leaf vegetation concentrations (Johnson & Brown, 2014; Mulmi, Block, Shively, & Masters, 2016; van Soesbergen, Nilsen, Burgess, Szabo, & Matthews, 2017).

We linked precipitation, temperature, and the NDVI variables to children in BDHS based on the year and month of birth and cluster. The spatial scale of temperature variables was notably coarser than that of the precipitation variables. However, the temperature was not nearly as spatially variable as precipitation. Thus, we assumed that the coarseness of the data did not mask significant underlying variabilities.

2.3 Statistical Analyses

We investigated the effects of precipitation and temperature on birth weight and the likelihood of a newborn having LBW using multivariate multilevel linear and logistic regression models. Specifically, we used two-level multilevel models that included mother-specific and community-specific random effects in the estimated equation by considering unobserved heterogeneities at the mother and community (cluster) levels. These models were based on the estimation assumption that birth weights of babies born to the same mother are not independent of each other due to the mother's unobserved biological factors. Similarly, unobserved community characteristics, such as beliefs, cultural practices, social networks, gender issues, legal policy, and other local contextual factors, may affect birth weights. Regression analysis was performed using Stata version 16 (StataCorp LLC., College Station, TX, USA). We used the svy (survey) commands of Stata to correct for unequal sampling probability, clustering, and stratification to calculate sample characteristics because BDHS applied a two-stage cluster sampling design.

2.4 Explanatory Variables

We used the monthly average precipitation during pregnancy at the cluster level as the main predictor. Another variable of interest, a heat wave, is a dummy variable, taking the value of 1 if the average maximum temperature of a given time period before birth exceeded 35 °C and 0 otherwise. For example, the heat wave during 9 months took 1 if the average maximum temperature during 9 months before birth exceeded 35 °C 0 otherwise. The threshold of 35 °C has been commonly used to define a heat wave in empirical studies of their health impacts, such as in Kenya and Mali (Bakhtsiyarava, Grace, & Nawrotzki, 2018), China (Tan et al., 2010), and Europe (Fischer & Schär, 2010). Moreover, 35 °C has been recognized to be an upper physiologically tolerant limit for humans (Raymond, Matthews, & Horton, 2020). In addition to examining the effects of precipitation and temperature, we investigated the possible linkage between NDVI and birth weight. Since the intensity of precipitation and temperature influence agricultural production, examining its relationship captured by NDVI supports the understanding of the underlying mechanism.

2.5 Outcome Variables

We used birth weight (g) as a continuous variable and LBW as a binary variable (≥2500 g [= 1] or <2500 g [= 0]).

2.6 Control Variables

To account for possible influences of preexisting confounders, we controlled for mother-, household-, and community-level characteristics. The mother-level variables were age and educational achievement (no education, primary education, or secondary/higher education), mother's occupation (engaged in agricultural activities or not engaged in agricultural activities), partner's occupation (engaged in agricultural activities or not engaged in agricultural activities), anemia (anemic or not anemic), parity, antenatal care (ANC) visits (having at least four ANC visits or having less than four ANC). The household-level variables included the number of children, the head of the household's religion (Muslim, Protestant, Catholic, Vodoum/other traditional, or none/other), family setting (monogamous or polygamous) and wealth index. The household wealth index variables were created based on household possession of an essential set of assets, such as home electrical appliances, furniture, types of materials used for the construction, and access to water and sanitation facilities. Community-level variables included the indicators for geographical zones (south or north).

3. Results

3.1 Sample Characteristics

Table 1 summarizes our sample characteristics. We included 19 646 births from the four rounds of BDHS: 7% from BDHS-1996, 15% from BDHS-2001, 40% from BDHS-2011/2012, and 38% from DHS-2017/2018. Overall, 60% of the population was in the southern region, and 40% was in the northern region.

The average birth weight (i.e., the primary outcome variable) was 3032 g for the whole country, 3063 g in the south, and 2985 g in the north. For the entire country, 12.6% of newborns had LBW, 11.9% had LBW in the south, and 13.8% had LBW in the north.

The average monthly precipitation during the nine months before birth was 98.6 millimeters (mm) for the whole country, 101.3 mm in the south, and 94.4 mm in the north. The total precipitation during the first, second, and third trimesters of pregnancy for the whole country was 97.7 mm, 100.6 mm, and 100.1 mm, respectively. The southern region had more rainfall than the northern region. Moreover, the average NDVI score was higher in the south than in the north, indicating richer vegetation in the south.

The average age of the mothers was 29 years old. Of all mothers, 61.5% were not formally educated, and only 17.3% had completed secondary education or higher. Furthermore, 29.9% of the household heads were Catholic, followed by Protestants (29.8%), Muslims (22.0%), Vodoum/other traditional religions (11.7%), and no religion/others (6.6 %). The mean number of children per household was 3.6.

Table 1. Sample characteristics

Variables	Total (n=19 646)		South (n=11 194)		North (n=8452)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Outcome variables						
Birthweight	3032	628	3063	651	2985	591
Low birthweight	0.126	0.332	0.119	0.324	0.138	0.345
Predictors						
Monthly average precipitation (mm)						
During 9 months	98.6	27.1	101.3	26.0	94.4	28.0
During 1st trimester	97.7	66.1	100.3	61.9	93.9	71.9
During 2nd trimester	100.6	69.4	102.6	65.0	97.7	75.3
During 3rd trimester	100.1	67.5	103.6	63.2	94.8	73.2
Heat wave (average maximum temperature > 35 °C)						
During 9 months	0.037	0.189	0.007	0.085	0.082	0.274
During 1st trimester	0.129	0.336	0.057	0.232	0.237	0.425
During 2nd trimester	0.127	0.333	0.056	0.230	0.234	0.423
During 3rd trimester	0.132	0.338	0.059	0.236	0.240	0.427
Monthly average NDVI						
During 9 months	0.522	0.114	0.532	0.126	0.504	0.085
During 1st trimester	0.521	0.145	0.532	0.144	0.501	0.146
During 2nd trimester	0.521	0.146	0.531	0.145	0.504	0.146
During 3rd trimester	0.524	0.146	0.533	0.147	0.508	0.145
Control variables						
Baby: female	0.488	0.500	0.487	0.500	0.490	0.500
Mother's age	29.0	6.4	29.2	6.2	28.8	6.7
Mother's education						
No education	0.615	0.487	0.581	0.493	0.665	0.472
Primary	0.213	0.409	0.228	0.420	0.189	0.392
Secondary/Higher	0.173	0.378	0.191	0.393	0.145	0.352
No. of children ever born	3.6	2.2	3.6	2.1	3.8	2.3
Religion						
Vodoum/other traditionnal	0.117	0.322	0.137	0.344	0.088	0.283
Muslim	0.220	0.415	0.110	0.313	0.385	0.487
Catholic	0.299	0.458	0.316	0.465	0.274	0.446
Protestant	0.298	0.457	0.373	0.484	0.184	0.388
No religion/other religion	0.066	0.248	0.063	0.244	0.069	0.254
Household wealth index						
Lowest	0.179	0.384	0.136	0.343	0.244	0.430
Lower middle	0.183	0.387	0.154	0.361	0.226	0.418
Middle	0.209	0.407	0.190	0.392	0.238	0.426
Upper middle	0.206	0.405	0.228	0.420	0.173	0.378
Highest	0.222	0.416	0.292	0.455	0.119	0.323

DHS Round						
DHS 2001	0.070	0.254	0.040	0.197	0.113	0.317
DHS 2006	0.151	0.358	0.100	0.300	0.226	0.418
DHS 2011/2012	0.397	0.489	0.490	0.500	0.258	0.437
DHS 2017/2018	0.383	0.486	0.370	0.483	0.403	0.491
Zone						
South	0.599	0.490	1.000	0.000	1.000	0.000
North	0.401	0.490	0.000	0.000	0.000	0.000

3.2 Regression Analyses

Table 2 presents the multivariate multilevel linear regression results. Panels A, B, and C show the effect of the monthly average precipitation, a heat wave, and monthly average NDVI, respectively. In Panel A, Model 1 shows the effect of the monthly average precipitation during the nine months before birth on birth weight. The estimates indicate that a 1 mm increase in the monthly average precipitation during the nine months before the birth led to an 0.41 g increase in birth weight for the whole country (p = 0.014) and a 0.49 g increase in the south (p = 0.049). Model 2 presents the effects of the monthly average precipitation during each pregnancy trimester on birth weight. For the whole country, we only found a significant effect of precipitation during the second trimester on birth weight. In both southern and northern samples, significant and sizable influences of precipitation on birth weight were not confirmed. Panel B presents the effects of a heat wave. The results from Model 1 indicate that for the total sample, newborns in a cluster that experienced a heat wave in-utero weighed less by 49.6 g on average than those born in a cluster without a heat wave. For the north, babies born in a heat waved cluster weighed 57.0 g less than those born in a cluster without a heat wave. However, the heat wave was not significantly correlated with the birth weight in the southern part. Panel C reports the estimated effects of NDVI on birth weight. It demonstrates that monthly average NDVI had a statistically positive effect on birth weight in the whole country and that in the northern part, providing the same pattern as in Panel B.

Table 3 reports the multivariate multilevel logistic regression results. For the binary outcome variable, LBW, we used an odds ratio (OR) to assess the direction and magnitude of the effects, which we interpreted as increasing (OR >1) or decreasing (OR <1) the likelihood of LBW newborns. In Panel A, Model 1 demonstrates that precipitation both during 9 months prior to birth and 1st trimester significantly reduced the likelihood of newborns with LBW, indicating that the more rainfall during pregnancy, the less likely newborns were to have LBW. The estimated ORs for the whole country (OR = 0.998, $p = 0.044$) indicate that if the monthly average rainfall increased by 1 mm, the odds of delivering a newborn with LBW decreased by 0.002. Notably, these results differed between geographical zones. Similar to the findings in Table 2, a significant deterioration of birth weight was confirmed in the northern regions (OR = 0.995, $p = 0.008$). Panel B presents the estimated effects of a heat wave on the likelihood of LBW newborns. As presented in Table 2, a heat wave significantly increased the likelihood of LBW newborns for the whole country (OR = 1.545, $p = 0.006$) and in the north (OR = 1.563, $p = 0.011$). However, a heat wave during individual trimesters did not have significant effects in any regional group. Finally, the results using NDVI in Panel C show that vegetation captured by NDVI significantly reduced the likelihood of LBW newborns for the whole country (OR = 0.240, $p < 0.001$) and in the north (OR = 0.151, $p = 0.013$).

Table 2. Multivariate multilevel linear regression model on birth weight

	Total		South		North	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Panel A						
Monthly average precipitation (mm)						
During 9 months	0.41		0.49		0.31	
	(0.014)*		(0.049)*		(0.172)	
During 1st trimester		0.14		0.12		0.14
		(0.138)		(0.376)		(0.316)
During 2nd trimester		0.14		0.16		0.11
		(0.027)*		(0.086)		(0.176)
During 3rd trimester		0.11		0.17		0.02
		(0.253)		(0.200)		(0.896)
Observation	19 644	19 644	11 194	11 194	8450	8450
Panel B						
Heat wave (average maximum temperature > 35 °C)						
During 9 months	-49.6		54.7		-57.0	
	(0.047)*		(0.483)		(0.026)*	
During 1st trimester		-9.9		17.7		-19.3
		(0.488)		(0.508)		(0.267)
During 2nd trimester		-16.6		-35.8		-4.9
		(0.224)		(0.180)		(0.758)
During 3rd trimester		0.9		12.8		-2.5
		(0.948)		(0.620)		(0.882)
Observation	19 644	19 644	11 194	11 194	8450	8450
Panel C						
Monthly average NDVI						
During 9 months	158.1		39.1		273.1	
	(0.008)**		(0.603)		(0.012)*	
During 1st trimester		60.6		2.5		152.9
		(0.163)		(0.968)		(0.035)*
During 2nd trimester		68.1		69.3		60.1
		(0.128)		(0.326)		(0.280)
During 3rd trimester		22.9		-43.2		112.9
		(0.597)		(0.487)		(0.122)
Observation	16 166	16 166	9956	9956	6210	6210

*p<0.05 **p<0.01. For brevity, estimates of control variables are omitted from the table.

Table 3. Multivariate multilevel logistic regression model on low birth weight

	Total		South		North	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Panel A						
Monthly average precipitation (mm)						
During 9 months	0.998		1.000		0.995	
	(0.044)*		(0.966)		(0.008)**	
During 1st trimester		0.999		0.999		0.998
		(0.037)*		(0.151)		(0.099)
During 2nd trimester		0.999		1.000		0.999
		(0.243)		(0.493)		(0.030)*
During 3rd trimester		0.999		1.000		0.998
		(0.285)		(0.798)		(0.104)
Observation	19 644	19 644	11 194	11 194	8450	8450
Panel B						
Heat wave (average maximum temperature > 35 °C)						
During 9 months	1.545		0.753		1.563	
	(0.006)**		(0.571)		(0.011)*	
During 1st trimester		1.022		0.877		1.078
		(0.826)		(0.465)		(0.558)
During 2nd trimester		1.133		1.233		1.059
		(0.181)		(0.222)		(0.624)
During 3rd trimester		1.049		0.860		1.114
		(0.616)		(0.393)		(0.389)
Observation	19 644	19 644	11 194	11 194	8450	8450
Panel C						
Monthly average NDVI						
During 9 months	0.240		0.438		0.151	
	(0.000)***		(0.079)		(0.013)*	
During 1st trimester		0.659		0.472		0.855
		(0.152)		(0.075)		(0.755)
During 2nd trimester		0.552		0.867		0.413
		(0.054)		(0.767)		(0.031)*
During 3rd trimester		0.695		1.032		0.621
		(0.214)		(0.940)		(0.350)
Observation	16 166	16 166	9956	9956	6210	6210

*p<0.05 **p<0.01 ***p<0.001. For brevity, estimates of control variables are omitted from the table.

Overall, the results from the various regressions of our main models confirmed the favorable effects of precipitation and NDVI and the adverse effects of the heat wave on birth weight and LBW. In addition to these analyses, we conducted supplemental analyses corresponding to the models in each table (not reported here). We included the following five variables into all regressions in Tables 2 and 3: A dummy taking 1 if newborns' parents were engaged in the agricultural sector; Parity, the number of children ever born plus terminated pregnancies and stillbirths; Polygamy taking 1 if the partner has other wives (polygamous) and 0 if not (monogamous); A dummy taking 1 if the number of antenatal care visits exceeds 4 times. We considered that these occupational and obstetric variables are also crucial factors – directly and indirectly correlated with birth weight – and need to be controlled. While keeping Tables 2 and 3 as our main results, we additionally assessed whether our estimates are stable after accounting for these variables. We found that our/all estimates remain stable in terms of magnitude and statistical significance, indicating that these occupational and obstetric variables did not contradict our variables of interest.

4. Discussion

This study investigated the effects of precipitation and temperature on birth weight and the likelihood of LBW newborns in Benin by analyzing a nationally representative sample population obtained from BDHS datasets and climate data.

This study confirmed that precipitation during pregnancy has a significant, positive effect on birth weight in the south of Benin. Furthermore, in the north, precipitation reduced the likelihood of newborns with LBW. These favorable precipitation effects are consistent with previous studies in the other SSA countries (Grace, Davenport, Hanson, Funk, & Shukla, 2015). For instance, the precipitation level during the 12 months preceding birth was positively associated with birth weight for food croppers in Kenya and Mali (Bakhtsiyarava et al., 2018). Furthermore, in a rural area in southwestern Uganda, women's exposure to frequent precipitation in the third trimester and throughout the pregnancy correlated with increased birth weight (MacVicar et al., 2017). However, one study analyzed more than 65 000 pregnancies from DHS datasets from 1999 to 2010 across 15 SSA countries, reporting no significant association between precipitation and birth weight (Davenport et al., 2020). Therefore, further studies investigating the precipitation conditions during a pregnancy that positively influence birth outcomes in SSA countries are necessary.

We also found that an average maximum temperature above 35 °C during pregnancy significantly affected birth weights. Specifically, heat waves were associated with lower birth weights and an increased likelihood of delivering a newborn with LBW in the north of Benin. This negative temperature influence aligns with previous studies from Mali (Grace et al., 2021) and several other SSA countries (Davenport et al., 2020; Grace et al., 2015). The north of Benin is drier with extremely high temperatures and thus is more prone to drought than the south (Badou et al., 2021). Therefore, women in northern Benin are likely more susceptible to heat wave, resulting in babies with lower birth weights.

We also examined the possible connection between precipitation, temperature, and birth weight. We hypothesized that these variables are connected through agricultural production and a household's increased food security. Benin depends primarily on rain-fed agriculture. Therefore, households residing in areas of richer vegetation can access food more easily. Using NDVI, we found that the higher the NDVI, the higher the newborn birth weight and the more likely newborns were to have LBW in the north. Previous studies in Nigeria and Ghana showed that negative rainfall shocks reduced agricultural productivity, resulting in a decline in household food consumption (Akobeng, 2017; Amare, Jensen, Shiferaw, & Cissé, 2018). In Benin, 9.6 % of the total population was moderately or severely food insecure, and 42.9 % had limited or poor food consumption (World food program [WFP], 2021). Moreover, there are regional differences in food insecurity, with the northern regions being the most affected (WFP, 2019). These regional food security disparities can have different economic, health, and nutritional consequences when farmers face weather shocks. The economies of the northern regions are more dependent on rain-fed agriculture than those of the southern regions. Therefore, the household's income and consumption can depend highly on precipitation and temperature variations. Only 5% of households own more than 5 ha of agricultural land in the south, while over 20% do in the north (Food and agriculture organization [FAO], 2018). Furthermore, northern regions were more likely to be affected by higher temperatures and excess or deficient rainfall than southern regions (Yegbemey, Kabir, Awoye, Yabi, & Paraïso, 2014). Our results were consistent with these regional differences, demonstrating that women and newborns in northern Benin were more susceptible to climate change through food insecurity than women in the southern region.

However, while we highlighted the importance of providing consistent results with prior literature using a rich dataset of Benin, a rigorous analysis focusing on precise mechanisms was left unaddressed due to the data limitation. Further analysis will be needed to investigate possible mechanisms precisely. Despite this limitation, this study is the first attempt to assess the effects of precipitation and temperature on birth weight in Benin, which is an essential benchmark for future studies.

5. Conclusion

Our study showed that greater precipitation was associated with higher birth weight and a lower likelihood of newborns' LBW. In contrast, a heat wave, measured as temperatures exceeding 35 °C, had a decreasing effect on birthweight. These influences, and the results using NDVI, suggest that food security and maternal nutrition are crucial for birth weight through agricultural production, which plays an important role in Benin's economy. Evaluating the MNH consequences of climate, one of the crucial issues that many developing countries face, is our major contribution to the climate and health literature of Benin and policymaking.

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Author's Contributions

MT was responsible for the overall design, data cleaning, data analysis, and drafting of the paper. TK and YK supported data analysis and revised the manuscript. All authors have read and approved the final manuscript.

Competing Interests Statement

The authors declare that they have no competing interests.

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