

THE EFFECT OF TEMPERATURE AND RAINFALL ON ROAD TRAFFIC CRASHES IN THE GREATER KUMASI METROPOLITAN AREA OF GHANA: A SPATIOTEMPORAL APPROACH

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ABSTRACT

Introduction: Road traffic crashes are a significant public health concern worldwide, causing numerous injuries and fatalities. While various factors contribute to these crashes, the influence of weather and climate conditions has emerged as an important area of research. This study aimed to access the influence of temperature and rainfall on road traffic crashes in the Greater Kumasi Metropolitan Area (GKMA) of Ghana using a Bayesian spatiotemporal modeling approach.

Method: Monthly road traffic crash data from 2010 to 2021, along with monthly temperature and rainfall, were analyzed. A Bayesian geo-spatiotemporal model was self-developed to quantify the effects of climate variables on road crashes while accounting for spatial and temporal dependencies.

Results: The findings revealed that a one-degree Celsius decrease in monthly average temperature was associated with a 0.049 increase in the risk of road crashes. On the other hand, one-millimeter increase in monthly average rainfall was associated with a 0.008 increase in crash risk. Significant spatial and temporal patterns were observed, with districts traversed by major highways exhibiting consistently higher relative risks of crashes.

Conclusion: This study revealed a significant relationship between monthly average rainfall and monthly road traffic crashes in the Greater Kumasi Metropolitan Area. This finding informs the need for targeted infrastructure improvements and enhancing public awareness campaigns to promote safe driving practices during rainy seasons.

Keywords: Road crashes, temperature, rainfall, climate.

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INTRODUCTION

Road traffic crashes are a major public health concern worldwide, causing significant loss of life, injuries, and economic burdens (WHO, 2023). According to the World Health Organization (WHO), approximately 118,000 people die annually due to road traffic crashes (WHO, 2024), making it the eighth leading cause of death globally (WHO, 2023). In addition to the tragic loss of life, road traffic crashes result in millions of non-fatal injuries, often leading to long-term disabilities and substantial healthcare costs (WHO, 2023). The impact of road traffic crashes is particularly severe in low- and middle-income countries, where over 90% of road traffic deaths occur (WHO, 2024). In Ghana, statistics from coroner’s autopsies performed at the Cape Coast Teaching Hospital between 2011 and 2016 confirm road traffic crashes as the primary cause of death (Akakpo et al., 2020) and the most harmed were those who were in their third decade of life (Blankson et al., 2019). Most Ghanaians depend on roads for daily transportation as well as for the movement of food and raw resources. Roads are hence the nation’s main means of transportation (Mends–Brew et al., 2018) and often car crashes occur causing injuries and, in the worst cases, fatalities (WHO, 2024).

Various factors contribute to the occurrence of road traffic crashes, including the influence of weather and climate conditions (Islam, Alharthi and Alam, 2019).

Climatic variables such as temperature and rainfall effect on the potential increasing risk of crashes (Islam, Alharthi and Alam, 2019; Park, Choi and Chae, 2021) hasn’t been investigated in Ghana. Understanding the relationship between climate variables and road traffic crashes is crucial for developing effective prevention strategies and informing decision-making processes related to road safety. In this study, a Bayesian spatiotemporal modeling approach was used to investigate the influence of available monthly average temperature and rainfall on road traffic crash relationships in the Greater Kumasi Metropolitan Area (GKMA) of Ghana.

MATERIALS AND METHODS

Study Design

This study adopted a longitudinal research design, allowing for the collection of data at a single point over time.

Study Area

The study was conducted within the Greater Kumasi Metropolitan Assembly (GKMA) in Ghana, which comprises seven distinct municipal districts: Asokore Mampong Municipal, Asokwa Municipal, Kumasi Metropolitan, Kwadaso Municipal, Oforikrom Municipal, Old Tafo Municipal, and Suame Municipal (see figure 1).

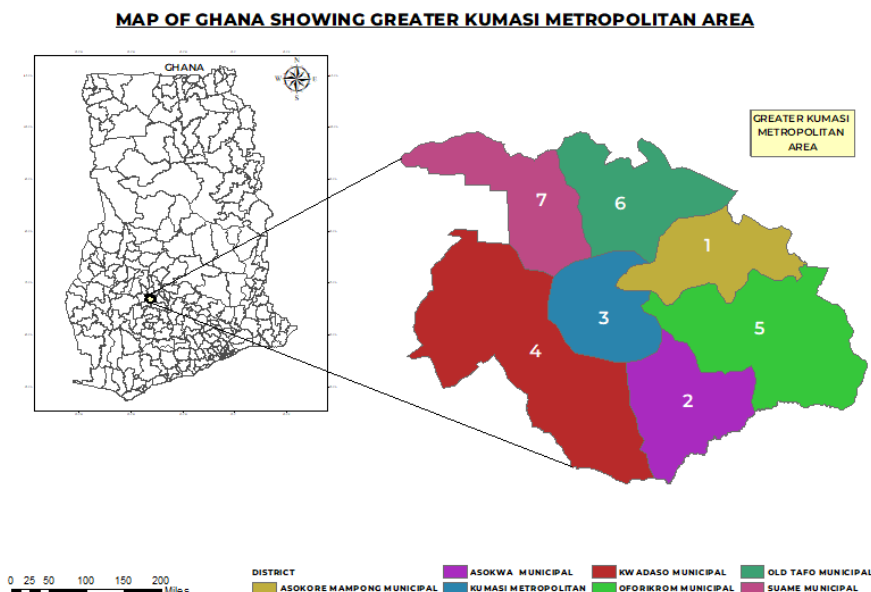


Figure 1: Map of Ghana showing Greater Kumasi Metropolitan Area

The GKMA encompasses several major highways, including the Kumasi-Bibiiani/Sunyani, Kumasi-Techiman, Kumasi-Mampong, Kumasi-Accra, Kumasi-Bosomtwe, and Kumasi-Obuasi/Cape Coast highway

Data Sources

Road traffic crash data were obtained from Building and Road Research Institute (BRRI) for the period of 2010 to 2021. Likewise, the climate data including monthly temperature and rainfall was obtained from the Ghana Meteorological Agency (GMet) on 17th April 2023 for the period of 2010 to 2021. Additional information on population density was obtained from the Ghana Statistical Population Census Report.

Data Preprocessing and Variable Selection

The road traffic crash and climate data were preprocessed to ensure data quality and consistency. This involved checking for missing

values, outlier detection, and data cleaning procedures. Due to the monthly aggregated nature of both crash and climate variables, daily observations with missing values were omitted rather than imputed, maintaining the integrity of the observed data. Relevant variables were selected based on prior knowledge, literature review, and exploratory data analysis. The outcome variable of interest was the monthly count of road traffic crashes within the study area. Predictor variables included climatic factors that is monthly average temperature and monthly average rainfall and potential confounders such as population density.

Data Analysis and Modeling

Descriptive statistics was used to summarize monthly road traffic crash counts, temperature, and rainfall in this study. Additionally, Spearman’s rank correlation test was used to examine associations between monthly average temperature, rainfall and road traffic crashes in the GKMA. Spatial trends

were analyzed by calculating standardized incidence ratios (SIRs) for road traffic crashes across districts, while temporal patterns were visualized using time-series plots. To quantify the impact of monthly average temperature

and rainfall on road traffic crashes, a Bayesian spatiotemporal model with integrated nested Laplace approximation (INLA) was fitted. Assuming a Poisson distribution, the model specification was as follows:

$$y_i \sim \text{Poisson}(\mu_i) + \epsilon_i \tag{eqn 1}$$

$$\text{MTC} = \alpha + \beta_1[\text{MAT}] + \beta_2[\text{MAR}] + v_i + u_i + w_t + z_i + \epsilon_i \tag{eqn 2}$$

where α is the intercept, MTC is the monthly road traffic crashes, MAT is the monthly average temperature, MAR is the monthly average rainfall, u_i is the spatial effect, w_t is the temporal effect, z_i is the spatiotemporal interaction effect, ϵ_i is the error term.

The model incorporated both spatial and temporal random effects to account for unobserved heterogeneity and dependencies across geographic areas and periods, respectively. The correlation matrix is an autoregressive matrix of order 1 (Hannan and Kavalieris, 1986). This is relevant because of road traffic policies introduced over the study period to deal with the menace of road traffic crashes. The function also uses a spatial model called Besag-York-Mollié (BYM) (Besag, York and Mollié, 1991) that can separate the effect of space from other random effects that are not explained. The BYM model assumes a linear combination of an identity matrix and a spatial adjacency matrix.

Appropriate prior distributions were assigned to the model parameters, reflecting available prior knowledge or expert opinions. The INLA algorithm was used to approximate the marginal posterior distributions of the model parameters and hyperparameters. Posterior means and credible intervals, were obtained for the effects of climate variables on road traffic crashes.

Data Tools

The Bayesian geospatiotemporal modeling and associated analyses were implemented using the R statistical computing environment (RStudio Team, 2023) and the "INLA" package. Additional R packages, such as "dplyr" package (Hadley et al., 2023), "ggplot2" package (Wickham, Chang and Wickham, 2016), "lubridate" package (Spinu, Golemund and Wickham, 2010) and "sf" (Pebesma, 2016), were utilized for spatial data handling and visualization. Also, the study employed statistical tools such as ArcGIS software version 10.7.1 (ESRI, 2019).

Ethics Statement

Approval for the study was obtained from the Committee on Human Research, Publication, and Ethics of Kwame Nkrumah University of Science and Technology, reference CHRPE/AP/181/23. Written informed consent was obtained from study participants prior data collection. Rigorous measures were implemented to safeguard participants' privacy and confidentiality, and accurate presentation of results was maintained throughout the study. Authors had no access to information that could identify individual participants during or after data collection.

Consent for Publication

Not applicable

Availability of Data and Materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors declare that they have no competing interests.

Funding

Not applicable

Authors' Contributions

J.S.I. conceived the study, conducted in study design, data collection, data analysis, results interpretation and drafted the manuscript.

E.N. participated in the study design and supervised and reviewed the manuscript.

D.B. participated in the study design, results interpretation and reviewed the manuscript.

T.P.A. participated in the study conception and reviewed the manuscript.

A.M. participated in the study conception and reviewed the manuscript

S.M. participated in the study conception and reviewed the manuscript.

EAB supervised and reviewed the manuscript.

All authors read and approved the final manuscript.

RESULTS

Descriptive Statistics

The study analyzed road traffic crash data spanning 2010 to 2021 in the GKMA. During this period, a total of 9022 road traffic crashes were recorded. The average monthly temperature in the study area 95% confidence interval ranged from 22.74 to 26.90 °C, with a mean of 26.82 °C. The average monthly precipitation varied between 2 and 6.6 mm, with a median of 3.95 mm. Monthly average temperature and monthly average rainfall were significantly, negatively and positively correlated with monthly road crashes respectively.

Table 1: Summary Statistics of Study Variables

Variable	Frequency (Over study period)	Median	Standard Deviation	Interquartile Range/95% CI	Spearman's rho Correlation
Monthly Road Traffic crashes	9022	8.00		5.00-11.00	
Monthly Average Minimum Temperature (°c)		22.23 ⁺	0.93	22.18-22.29*	
Monthly Average Maximum Temperature (°c)		31.41 ⁺	1.92	31.29-31.53*	
Monthly Average Rainfall (mm)		3.95		2.00-6.60	0.11*
Monthly Average Temperature (°c)		26.82 ⁺	1.25	26.74-26.90*	-0.11*

+: mean; *: 95% confidence interval (CI)

Spatial and Temporal Patterns

The spatial distribution of road traffic crashes exhibited distinct patterns across the study area. Kwadaso, Asokwa, and Suame districts consistently recorded higher standardized incidences (ranging from 2 to 6) compared to the other four municipal districts, as depicted in Figure 2. Conversely, the Kumasi and Old Tafo districts consistently recorded the lowest

standardized incidences (ranging from 0 to 2) over the study period. In 2013, all districts reported lower standardized incidences of road crashes, ranging from 0 to 3. Kwadaso lacked available data in 2014; however, the district exhibited a consistent increase in the standardized incidence of monthly road crashes from 2019 to 2021.

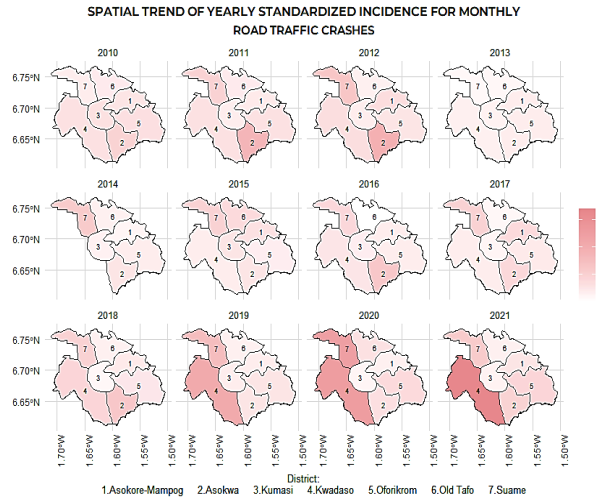


Figure 2: Spatial Trend of Yearly Standardized Incidence Road Traffic Crashes in GKMA from 2010 – 2021

The study observed temporal variations in road crashes, with higher incidences from second quarter of 2010 to December 2012 and second quarter of 2020 to the end of 2021. After 2012, there was a consistent yearly increase in crashes. Within a year, crashes generally peaked in May and November, with lows in September and February. During periods of increased crash incidence, average temperature remained relatively constant, while average rainfall showed sharp fluctuations.

Crashes tended to increase following at least two successive increases in average rainfall in preceding months. Crashes typically peaked in second quarter and third quarter, and were lowest from the last month of the year to first quarter of the succeeding year, except in the later study period where they remained relatively high (see Figure 3).

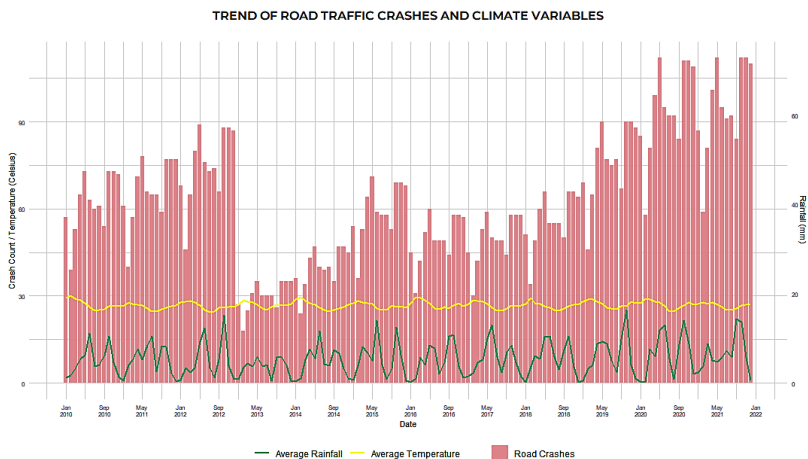


Figure 3: Temporal Trend of Road Traffic Crashes and Climate Variables from 2010-2021

Impact of Climate Variables

The Bayesian geo-spatiotemporal model revealed significant associations between climate variables and road traffic crashes (see Table 2).

Table 2: Summary table of spatiotemporal regression model for monthly road traffic crashes

Variable	Model 1 [E=Monthly Road Traffic Crashes]	Lower Credible Interval (C.I)	Upper Credible Interval (C.I)
Fixed Effect			
Constant	1.079	-0.006	2.187
Monthly Average Temperature	-0.049	-0.086	-0.012
Monthly Average Rainfall	0.008	-0.002	0.017
Random Effect			
Spatial Effect	1.92e+03	1.29 e+02	6.94e+03
Temporal Effect	14.0	6.94	23.5
Spatiotemporal Effect	5.12	1.55	11.6
Marginal log-Likelihood:	-2601.88	Average CPO = 0.1019	
Residual Deviance =	-0.00044	Df= 9021	

E: Mean estimate

Specifically, a decrease of one degree Celsius in the monthly average temperature was significantly associated with a factor of 0.049 percent increase in the risk of road traffic crashes (posterior mean: -0.049, 95% credible interval: -0.086 to -0.012). Regarding precipitation, a one-millimeter increase in the monthly average rainfall was associated with a 0.008 increase in the risk of road traffic crashes (posterior mean: 0.008, 95% credible interval: -0.002 to 0.017).

Spatial and Temporal Random Effects

The model incorporated spatial and temporal random effects to account for unobserved heterogeneity and dependencies across geographic areas and time periods,

respectively. The spatial random effects exhibited significant variability. Similarly, the temporal random effects captured significant temporal trends and patterns, highlighting the significant role of time on the impact of climate on road traffic crashes. Comparing the relative risks between the dry (December to March) and rainy (April to November) seasons, a seasonal prediction analysis (refer to Figure 3) revealed that the Suame, Kwadaso and Asokwa districts significantly showed higher relative risk of 1.6 (95% credible interval:1.4-2.0), 1.7 (95% credible interval: 1.4-2.0) and 1.5 (95% credible interval:1.2-1.8) respectively for monthly road traffic crashes in the dry season.

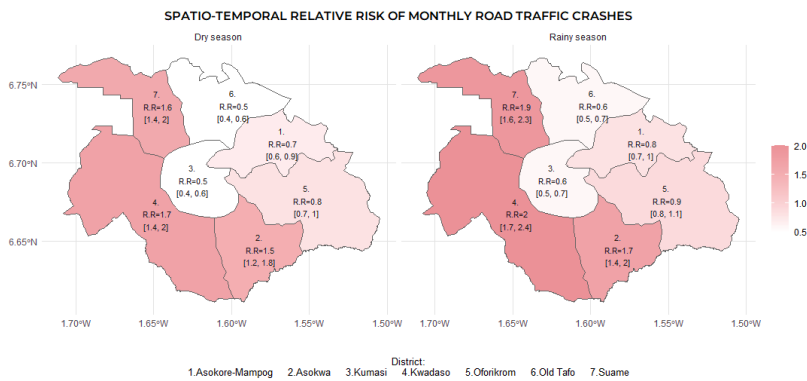


Figure 3: Spatial-Temporal Seasonal Relative Risk of Monthly Road Traffic

During the rainy season, these same districts significantly showed a relatively higher risk of road crashes by a factor of 1.9 (95% credible interval:1.6-2.3), 2.0 (95% credible interval: 1.7-2.4) and 1.7 (95% credible interval:1.4-2.0) respectively. On the other hand, the Old Tafo and Kumasi districts consistently showed a significant lower risk of road traffic crash among the exposed in a month during the dry (0.5 [95% credible interval: 0.4-0.6]; 0.5 [95% credible interval: 0.4-0.6]) and rainy (0.6 [95% credible interval: 0.5-0.7]; 0.6 [95% credible interval: 0.5,0.7]) seasons respectively.

DISCUSSION

Road traffic crashes are a significant public health concern, contributing to numerous injuries and fatalities worldwide. In this study, we analyzed a dataset comprising 996 monthly observations over an 11-year period to explore the impact of temperature and rainfall on road crash occurrences in the Greater Kumasi Metropolitan Area (GKMA). Specifically, the study revealed that a one-degree Celsius decrease in monthly average temperature was significantly associated with a 0.049 times

increase in the risk of road crashes. This finding can be attributed to the potential influence of temperature on road surface conditions, vehicle performance, and driver behaviour. Lower temperatures may lead to reduced tire grip and increased stopping distances, while also affecting driver vigilance and reaction times (Basagaña *et al.*, 2015; Zhai *et al.*, 2019). Similarly, a study conducted in Saudi Arabia revealed that temperature and rainfall have a statistically significant impact on road traffic accidents (Ali, Yaseen and Khan, 2020).

Furthermore, this study identified a moderate range of 5.0 to 11.0 road traffic crash occurrences in most months with distinct periods of higher crash incidence, particularly from the second quarter of 2010 to December 2012 and experienced a relatively higher incidence from the second quarter of 2020 to the end of 2021. On a year-to-year comparison, road crashes increased generally from 2013 to the end of 2021. Possible reasons for this outcome may include factors such as changes in road infrastructure, increased vehicular traffic due to population growth, inadequate enforcement of road safety regulations, and behavioral factors among road users, including speeding, reckless driving, and impaired driving (Ali, Yaseen and Khan, 2020; Blankson and Lartey, 2020; Damsere-Derry *et al.*, 2021) affecting societies and individuals in different facets. Despite the prominence of Covid-19 disease in the current public health space, road crashes remain an important contributor to mortality. It is estimated that some 1.4 million people die from road crashes globally, with most of these being the youth, and people from developing countries.¹ In Ghana, 72 persons out of every 100 000 population, suffered from grievous bodily injury, and close to 8 of the same population died from Road Traffic Accidents (RTAs). The National Road Safety report of Ghana (National Road Safety Authority, 2021) and the 2021 Kumasi annual road safety report (Kumasi Metropolitan Assembly and Bloomberg Philanthropies

Initiative for Global Road Safety, 2021) confirm the finding of this study of increased crashes in the recent year compared to previous years. Also in Ghana, victims of road crashes are the most attendants at the accident and emergency department of Komfe Anokye Teaching Hospital (Oteng *et al.*, 2019) and likewise in the Korle-Bu (Blankson *et al.*, 2019) and Cape Coast (Akakpo *et al.*, 2020) teaching hospitals in Ghana.

This study noticed crash rates exhibited a seasonal trend, with a general increase from March to May and a subsequent decline until September. A subsequent increase occurred, reaching a maximum in November, remaining high in December and then decreasing until February. The seasonal pattern of road crashes reflects the variation in culture, travel demand, and road maintenance activities in GKMA (Basagaña *et al.*, 2015). Festive seasons such as Christmas, New Year, and Easter, which are celebrated during these specific months, lead to increased travel demand and traffic volume (Blankson *et al.*, 2019; Hesse, Boyetey and Ashiagbor, 2022) accounting for 9% of all deaths worldwide. While knowledge of the pattern of injuries is essential to plan health interventions to reduce the incidence of injuries, these are not thoroughly described in Ghana. The aim of this study was to describe the epidemiology of injuries seen at the Accident centre of the Korle-Bu Teaching Hospital, Ghana's main referral hospital. Method: A retrospective review of two-year records of all patients who attended the Accident centre of the Korle-Bu Teaching Hospital from January 2016 to December 2017 was done. Data on the cause of injuries was the main focus of this review. Results: A total of 17,860 patients' records were included in the study. There were 12,116 (67.8%).

The spatial and temporal random effects captured in the model highlighted the significance of localized factors and time-varying patterns influencing road traffic

crashes. Consistently, over the study period, higher relative risks was observed in districts like Kwadaso, Suame, and Asokwa. This may be attributed to factors such as road infrastructure quality, traffic volume, driver behavior and enforcement of road safety policies (Ali, Yaseen and Khan, 2020; Blankson and Lartey, 2020; Damsere-Derry *et al.*, 2021) affecting societies and individuals in different facets. Despite the prominence of Covid-19 disease in the current public health space, road crashes remain an important contributor to mortality. It is estimated that some 1.4 million people die from road crashes globally, with most of these being the youth, and people from developing countries.¹ In Ghana, 72 persons out of every 100 000 population, suffered from grievous bodily injury, and close to 8 of the same population died from Road Traffic Accidents (RTAs. Additionally, the Kwadaso district is traversed by two major highways, which may further explain the increased risk (Kumasi Metropolitan Assembly and Bloomberg Philanthropies Initiative for Global Road Safety, 2021). Moreover, the seasonal patterns revealed in this analysis underscore the importance of cultural factors, travel demand, and road maintenance activities in shaping road safety dynamics (Basagaña *et al.*, 2015; Sangkharat *et al.*, 2021).

CONCLUSION

This study provides an analysis of the relationship between key climate variables (temperature and rainfall) and road traffic crashes in the GKMA, employing a Bayesian spatiotemporal modeling approach. This study revealed a significant relationship between monthly average rainfall and monthly road traffic crashes in the Greater Kumasi Metropolitan Area. Additionally, significant spatial and temporal patterns were observed, with districts traversed by major highways exhibiting consistently higher relative risks of crashes.

Policy Recommendation

Based on the findings of this study, seasonal road safety awareness campaigns should be implemented, particularly targeting the rainy season. These campaigns should emphasize visibility concerns, reduced traction, and increased stopping distances associated with wet conditions. Infrastructure improvements are also critically needed, especially in high-risk districts like Kwadaso, Suame, and Asokwa, with particular focus on enhanced drainage systems to reduce standing water during rainfall events. Additionally, targeted enforcement efforts should be concentrated in these identified high-risk areas, with increased monitoring during periods of adverse weather conditions. Furthermore, climate-responsive traffic management strategies should be developed, including variable speed limits during rainfall events and early warning systems based on weather forecasts.

Limitation

The strengths of this study lies in the use of a robust Bayesian geospatiotemporal modeling approach, which allowed us to account for spatial and temporal dependencies while quantifying the effects of climate variables. Additionally, the incorporation of prior knowledge and uncertainty quantification through Bayesian inference enhances the reliability and interpretability of the findings of this study.

However, it is important to acknowledge the limitations of the study. Firstly, the analysis focused primarily on temperature and rainfall, while behavioral, socio-demographics and other climate variables, such as wind speed and humidity, were not considered. Future research should integrate these other climate, human and vehicular factors through mixed-methods approaches. Additionally, predictive models that can function as early warning systems based on weather forecasts should be investigated. Finally, future research

should evaluate the effectiveness of climate-responsive road safety interventions through rigorous before-and-after studies, thereby generating evidence-based strategies for reducing weather-related crash risks across similar urban environments in sub-Saharan Africa.

Acknowledgments

N/A

Declaration of Conflict of interest

The authors declare that they have no conflict of interests.

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