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ORIGINAL RESEARCH

Assessing the Impact of Climate Change on Rift Valley Fever Outbreak Risk in the Sahel Region

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Abstract

Background: Rift Valley fever (RVF) is a zoonotic arboviral disease that causes significant livestock and human health impacts across Africa, with outbreaks often linked to climatic anomalies. The Sahel region is particularly vulnerable due to its reliance on pastoralism and limited adaptive capacity. Understanding how climate change may alter RVF outbreak risk is critical for early warning and preparedness.

Methods: We developed a spatially explicit risk model integrating historical RVF outbreak data (1998–2022), satellite-derived environmental variables (rainfall, temperature, vegetation indices), and future climate projections under Representative Concentration Pathways (RCPs) 4.5 and 8.5 for the 2050s and 2080s. Logistic regression and random forest models were used to identify key climatic drivers and map current and future risk across six Sahelian countries.

Results: Rainfall anomalies and vegetation greenness were the strongest predictors of outbreaks. Under RCP 8.5, the area at high risk for RVF is projected to expand by 34% by 2080, with increased risk in northern latitudes where transmission was historically limited. The model achieved an area under the receiver operating characteristic curve (AUC) of 0.89 during validation.

Conclusions: Climate change is likely to increase RVF outbreak risk in the Sahel, particularly in regions undergoing ecological transition. These findings underscore the need for climate-adaptive surveillance and vaccination strategies tailored to changing risk landscapes.

Keywords: Rift Valley fever, climate change, Sahel, risk mapping, vector-borne disease, pastoralism, early warning

Introduction

Rift Valley fever (RVF) is a mosquito-borne viral disease that primarily affects livestock but can also cause severe human illness, including hemorrhagic fever and encephalitis [1,2]. Outbreaks of RVF have historically been associated with periods of heavy rainfall and flooding, which create ideal breeding sites for the primary mosquito vectors, particularly *Aedes* and *Culex* species [3,4]. The disease is endemic in sub-Saharan Africa, with major outbreaks reported in Kenya (1997–1998), Saudi Arabia (2000), Sudan (2007), and Mauritania (2022) [5-7,20].

The Sahel region, a semi-arid belt stretching across Africa from the Atlantic Ocean to the Red Sea, is characterized by high interannual rainfall variability and a strong dependence on pastoral livestock production [8]. Pastoralists in the Sahel are particularly vulnerable to RVF outbreaks, which can decimate herds and threaten food security and livelihoods [3,17]. Climate change is expected to alter rainfall patterns, increase the frequency of extreme weather events, and raise temperatures across the Sahel, potentially expanding the geographic range and intensity of RVF transmission [13,24].

Despite the recognized link between climate and RVF, few studies have quantitatively assessed how future climate scenarios may affect outbreak risk in the Sahel. Previous risk mapping efforts have focused on East Africa [4,30] or used static climatic averages [9]. Here, we aim to fill this gap by developing a dynamic risk model that integrates historical outbreak data, high-resolution climate projections, and ecological covariates to map current and future RVF risk across six Sahelian countries: Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal.

Literature Review

RVF epidemiology is tightly coupled with climate and environmental factors. Heavy rainfall and flooding trigger the hatching of transovarially infected *Aedes* mosquito eggs, leading to epizootics [1,3]. Subsequent amplification by *Culex* mosquitoes sustains transmission [13]. El Niño–Southern Oscillation (ENSO) events have been linked to increased RVF activity in East Africa [24,25], and similar teleconnections may influence the Sahel [28].

Several studies have developed risk models for RVF using climate and satellite data. Hightower et al. (2012) identified rainfall, elevation, and soil type as key predictors in Kenya [30]. Gikungu et al. (2016) built a dynamic risk model for Kenya using rainfall and temperature anomalies [4]. In Sudan, Abdelgadir et al. (2010) found that proximity to water bodies and livestock density increased outbreak risk [21]. However, these models were region-specific and did not incorporate future climate projections.

Climate change is projected to alter rainfall patterns in the Sahel, with some models predicting increased rainfall in the central Sahel and decreased rainfall in the west [16,28]. Higher temperatures may also affect vector survival and viral replication [13]. Mesfin et al. (2020) assessed household adaptive capacity to climate change in the Ethiopian Rift Valley, highlighting the importance of socio-economic factors [11]. Mburu et al. (2022) documented pastoralist perceptions of RVF impacts in Kenya, emphasizing the need for early warning systems [17].

Despite these advances, a comprehensive assessment of future RVF risk under climate change in the Sahel remains lacking. Our study addresses this gap by combining historical outbreak data, high-resolution climate projections, and machine learning methods to produce spatially explicit risk maps for the 2050s and 2080s.

Methodology

Study area

The study area comprises six Sahelian countries: Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal. This region is characterized by a steep north–south rainfall gradient, with annual precipitation ranging from 600 mm in the south. Livestock populations are high, with cattle, sheep, goats, and camels forming the backbone of pastoral livelihoods [8,29].

Data sources

We compiled a database of RVF outbreaks reported between 1998 and 2022 from published literature, World Health Organization (WHO) reports, and ProMED-mail archives [2,5-7,10,20]. Outbreak locations were georeferenced to the nearest settlement or coordinate. Only confirmed outbreaks (by laboratory diagnosis) were included, yielding 47 outbreak events.

Environmental covariates were derived from satellite and reanalysis datasets at a 0.1° spatial resolution. Monthly rainfall and temperature data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and ERA5-Land, respectively. The Normalized Difference Vegetation Index (NDVI) was sourced from MODIS (MOD13A2). Future climate projections for the 2050s (2041–2060) and 2080s (2071–2090) under RCP 4.5 and RCP 8.5 were obtained from the Coupled Model Intercomparison Project Phase 5 (CMIP5) ensemble, downscaled and bias-corrected to match historical observations.

Model development

We used a two-step modeling approach. First, we identified the most important climatic predictors of RVF outbreaks using logistic regression with backward selection. Second, we applied a random forest classifier to map outbreak probability across the study area. The random forest model was trained on 70% of the outbreak locations and an equal number of pseudo-absence points randomly sampled from areas without reported outbreaks. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC) on the remaining 30% of data. Variable importance was assessed using mean decrease in Gini impurity.

Future risk maps were generated by projecting the random forest model onto the climate projections for each scenario and time period. Risk was classified into three categories: low (probability 0.6).

Results

Descriptive statistics

Table 1 summarizes the environmental conditions at outbreak locations compared to non-outbreak locations. Outbreaks occurred in areas with significantly higher rainfall anomalies (p0.6) cover approximately 18% of the region, concentrated in the southern Sahel where rainfall is higher and livestock density is greatest.

Future risk projections

Under RCP 8.5, the area classified as high risk expands to 24% by the 2050s and 34% by the 2080s. Table 2 shows the percentage change in high-risk area relative to the current baseline.

Figure 2. Bar chart comparing the proportion of high-risk area under current, RCP 4.5, and RCP 8.5 scenarios for the 2050s and 2080s

Figure 3. Map of future RVF risk under RCP 8.5 for the 2080s, showing northward expansion into northern Mali and Niger

Figure 3 illustrates the projected northward expansion of high-risk areas, particularly into northern Mali, Niger, and Chad, regions that currently have low risk but are expected to experience increased rainfall and vegetation greenness.

Regional variation

Table 3 presents the country-level changes in high-risk area under RCP 8.5 for the 2080s.

Discussion

Our results demonstrate that climate change is likely to significantly increase RVF outbreak risk in the Sahel, with the most pronounced effects under the high-emission scenario (RCP 8.5). The expansion of high-risk areas into northern latitudes, where livestock populations are growing and pastoralist communities are concentrated, poses a serious threat to animal and human health [8,29]. The projected increase in rainfall and NDVI in these regions aligns with climate model predictions of a wetter Sahel [16,28].

The strong predictive power of rainfall anomalies and NDVI confirms previous findings that RVF outbreaks are driven by wet conditions [3,4,30]. Our model's high AUC (0.89) suggests that environmental variables alone can accurately predict outbreak risk, supporting the use of satellite-based early warning systems. However, socio-economic factors such as livestock movement, vaccination coverage, and public health infrastructure also influence outbreak occurrence and severity [11,17]. Integrating these factors into future models could improve risk assessment.

Our findings are consistent with studies projecting increased vector-borne disease risk under climate change [22,27,28]. For example, Diouf et al. (2021) projected an expansion of malaria transmission in West Africa [28], and Hamlet et al. (2018) found that yellow fever risk may increase in parts of Africa due to climate change [27]. RVF, like these diseases, is sensitive to temperature and precipitation, but its epizootic nature and reliance on flooding events make it particularly responsive to extreme rainfall [24,25].

Limitations of this study include the reliance on reported outbreak data, which may underrepresent true incidence due to underreporting in remote areas [23]. Pseudo-absence sampling may introduce bias, though we attempted to minimize it by using a large number of random points. Additionally, climate projections from CMIP5 have inherent uncertainties, particularly for rainfall in the Sahel [16]. Future work should use CMIP6 projections and incorporate dynamic vegetation models.

Despite these limitations, our study provides robust evidence that climate change will expand the geographic area at risk for RVF in the Sahel. This has important implications for surveillance, vaccination, and preparedness. Early warning systems that integrate rainfall forecasts and satellite-derived vegetation indices can help trigger preemptive livestock vaccination and vector control [4,9]. Strengthening veterinary services and community-based surveillance in high-risk areas is essential, especially in regions projected to become newly suitable for transmission.

Conclusion

Climate change is projected to increase Rift Valley fever outbreak risk in the Sahel, with high-risk areas expanding northward by up to 89% under the high-emission scenario by the 2080s. The strong association between rainfall anomalies and outbreak occurrence underscores the potential for climate-based early warning systems. Our risk maps provide a valuable tool for targeting surveillance and control efforts to areas of greatest future risk. To mitigate the impact of RVF on pastoralist livelihoods and public health, adaptation strategies must be developed and implemented in collaboration with local communities and veterinary services.