Journal of Interventional Epidemiology and Public Health
eISSN: 2664-2824

Spatiotemporal dynamics and drivers of Rift Valley fever outbreaks in Madagascar: A systematic review

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Article history: **Received:** 30 March 2026 **Accepted:** 17 July 2026 **Published:** 19 August 2026

Abstract

Introduction: Rift Valley fever (RVF) is a reemerging viral zoonosis in Madagascar that causes significant economic losses to the livestock sector. Outbreak occurrence and spread are influenced by a complex interplay of environmental variables and animal trading channels. This study examined the spatiotemporal dynamics of RVF outbreaks across the island to guide surveillance and control strategies.

Methods: A systematic review was conducted following PRISMA guidelines, encompassing literature published in English or French from 1979 to 2026. Major databases, including PubMed, Google Scholar, and ScienceDirect, were queried using search algorithms focused on RVF, Madagascar, and spatiotemporal patterns.

Results: Twenty-four studies were included in the final analysis. Since the first reported case in 1979, three major epidemic waves occurred in 1990–1991, 2008–2009, and 2021. The East Coast, Central Highlands, Northwest, and Southwest regions were identified as high-risk zones. Outbreaks peaked between January and April, coinciding with the rainy season. While climatic factors trigger initial transmission, the synthesised evidence suggests that livestock movement along trade corridors is a key anthropogenic factor in viral propagation, although the relative contribution of this driver requires further quantitative validation.

Conclusions: Rift Valley fever (RVF) dynamics in Madagascar are uniquely determined by regional environmental conditions and human activities. These findings underscore the urgent need for region-specific surveillance and the implementation of an integrated "One Health" approach for effective outbreak management.

Keywords: Rift Valley Fever, Madagascar, spatio-temporal dynamics, livestock trade, outbreaks

Citation

Suggested citation: Alain F, Miraimila B, Randriananahirana ZA, Rakotondrasoa SR, Ratsiambakaina D, Randriatsarafara FM, Ravaoharisoa L, Andrianasolo RL, Rakotonirina J. Spatiotemporal dynamics and drivers of Rift Valley fever outbreaks in Madagascar: A systematic review [Systematic Review]. J. Interv. Epidemiol. Public Health. 2026 Aug 19;9(3) 137. doi: 10.37432/jieph-d-26-00101

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Introduction

Rift Valley fever (RVF) is an acute viral zoonosis caused by a Phlebovirus, family Phenuiviridae, and order Bunyavirales [1]. It was first identified in Kenya in 1930 [1]. It represents a major threat to public and veterinary health, especially in sub-Saharan Africa and Madagascar [1,2]. Recent research highlights the evolving global threat of RVF and underscores the critical need for advanced mathematical modelling, including the use of singular and non-singular kernels, to better predict and manage its emergence [3,4].

The disease primarily affects domestic ruminants, such as cattle, sheep, and goats [1]. Among these animals, RVF causes massive abortions and high mortality rates, particularly among young animals [1]. While most human cases are mild or asymptomatic, approximately 1% to 3% can develop severe complications [1]. These severe forms include encephalitis, haemorrhagic fevers, or ocular lesions that may result in blindness [1].

In Madagascar, RVF was first detected in 1979 and has since become endemic [5]. Significant outbreaks were recorded in 1990-1991, 2008-2009, and most recently in 2021 [5–10]. Persistence of RVF in Madagascar is influenced by the convergence of several factors: the island's unique ecological environment, the presence of effective mosquito vectors (notably Aedes spp.), and intensive human activities, particularly livestock trade [11,12]. These epidemics are closely linked to extreme climatic conditions, such as heavy rainfall and flooding, which promote the proliferation of mosquito vectors [11,12]. While climatic factors trigger initial transmission, livestock movement along trade corridors appears to be a major anthropogenic contributor to viral propagation, although its relative weight compared to climatic factors warrants further quantitative study. This observation distinguishes the island's dynamics from East Africa where extreme climate events like El Niño play a more singular role[2].

Rift Valley fever (RVF) presents unique challenges that warrant a deeper investigation in Madagascar [12]. There is a crucial need to better understand the spatio-temporal dynamics of the disease, particularly how human activities like livestock trading influence its spread [13]. Despite the sanitary, economic, and ecological importance of RVF, there is currently no exhaustive synthesis of data concerning its spatio-temporal dynamics in Madagascar [14].

The disease in Madagascar presents particular epidemiological characteristics that merit specific attention [2]. Epidemics are irregular and seem more linked to human activities than to extreme climatic events [2]. The virus also appears to persist between outbreaks, suggesting mechanisms of ecological and vectorial persistence that are still poorly understood [2]. Furthermore, current surveillance and response systems are often judged insufficient or inadequate, which limits the effectiveness of sanitary interventions [14]. It underscores the urgency of a global analysis of environmental, climatic, and human factors to better understand the spread and recurrence of RVF on the island [12].

The diversity and dispersion of available literature, characterised by heterogeneous methodologies, have previously hindered a unified vision of Rift Valley fever dynamics in Madagascar [15,16]. Consequently, this systematic review provides the first 47-year longitudinal synthesis (1979–2026), filling a critical regional knowledge gap by integrating disparate data into a cohesive, scientifically rigorous epidemiological framework [15–17].

The main research question of this study is: What are the spatio-temporal, climatic, environmental, and anthropogenic factors that influence the emergence and propagation of RVF in Madagascar? The general objective of this systematic review is to consolidate available knowledge on the spatio-temporal, climatic, and anthropogenic drivers of RVF in Madagascar to guide 'One Health' prevention and control strategies.

Methods

Study framework

This research is based on a systematic review of relevant publications on RVF in Madagascar aimed at consolidating knowledge on spatio-temporal dynamics between 1979 and 2026. While not formally pre-registered, the review followed a rigorous internal protocol in strict accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure a structured, transparent, and reproducible selection process. A PRISMA flow diagram (Figure 1) was utilised to visualise all stages of the selection process: initial identification, screening, eligibility assessment, and final inclusion of studies.

The scope of the study focused on high-risk endemic regions, such as the East Coast, Central Highlands, Northwest, and Southwest. These areas are characterised by specific factors that favour disease transmission, which were analysed from three main angles: (i) climatic: evaluating the effect of rainfall, temperature, and seasonal flooding; (ii) ecological and environmental: examining habitats such as irrigated rice fields and marshes that allow vector mosquitoes, notably species of the genera Aedes and Culex, to proliferate; and (iii) anthropogenic: analysing agricultural practices, livestock movement, and strategies implemented for health control.

Study period and duration

This systematic review encompassed a comprehensive analysis of literature published over a 47-year period, beginning with the first identification of RVF in Madagascar in 1979 and extending through February 28, 2026. This

extensive temporal scope was adopted to account for the evolution of scientific knowledge, long-term epidemiological dynamics, and the shifting impact of climate change on viral emergence on the island. The active research phase was updated and extended to include literature published through February 2026 to ensure the review provides the most current overview of RVF dynamics in the Malagasy context.

Study population and eligibility criteria

The target population included studies focusing on RVF in domestic ruminants (cattle, sheep, goats) and human populations located in endemic areas of Madagascar. We specifically searched for studies exploring the prevalence, lethality, and spatio-temporal dynamics of the disease. The PICO (Population, Intervention, Comparison, Outcome) framework was applied to identify studies focusing on RVF in domestic ruminants and humans in Madagascar to evaluate risk factors and outcomes.

Inclusion criteria: study type: quantitative studies, including cross-sectional, cohort, and observational studies; accessibility: articles available in full text; publication period: published between 1979 and 2026. The search was restricted to English and French, as these are the primary scientific and official languages of Madagascar, where the vast majority of primary field research and official health reports on Malagasy RVF are published.

Exclusion criteria: studies were excluded if they lacked specific information on endemic areas in Madagascar, or contained no usable quantitative or qualitative data. A comprehensive recruitment (exhaustive sampling) of relevant literature meeting these criteria was conducted for the review.

Data collection and search strategy

To ensure broad and rigorous coverage of relevant articles, data were extracted from major electronic databases, including MEDLINE/PubMed, Scopus/ScienceDirect, and Google Scholar. Grey literature, such as official reports and publications from international organisations (WHO, FAO, WOAH) and health ministry documents, was also consulted to enrich the analysis with unpublished data.

A systematic and exhaustive search strategy was implemented using a combination of keywords and Medical Subject Headings (MeSH), linked by Boolean operators (AND, OR, NOT), to refine results and include all pertinent studies on RVF prevalence and risk factors in Madagascar. The full search string used was: ("Rift Valley Fever" OR "Rift Valley Fever Virus") AND ("cattle" OR "sheep" OR "goats" OR "ruminants" OR "humans" OR "livestock") AND ("prevalence" OR "lethality" OR "incidence" OR "spatio-temporal dynamics") AND ("environmental factors" OR "climatic" OR "transmission dynamics") AND Madagascar. An updated, comprehensive search strategy was implemented across major databases and grey literature through February 2026 to minimise bias and ensure the validity of the synthesised findings. To restrict the results according to the inclusion criteria (language, publication period, and research article type), filters were applied. We used ZOTERO software to manage the references.

Study selection and data extraction

The selection process followed defined steps: (i) initial filtering: review of titles and abstracts to identify potentially relevant articles; (ii) in-depth evaluation: full-text analysis of pre-selected articles to confirm eligibility; (iii) double examination: independent evaluation by two researchers, with a third researcher arbitrating any disagreements, ensuring rigorous and transparent selection. Data were recorded using a standardised data extraction form to ensure consistency across the independent reviews. Extracted information included study characteristics (authors, publication year, country, study type), methodological data (sample size, data collection methods), spatio-temporal analysis findings, and statistical measures (estimates of RVF evolution over time and space, with confidence intervals).

Study quality assessment and bias management

The methodological quality of each study was quantitatively assessed using a 45-point evaluation grid. This tool was constructed by adapting the Newcastle-Ottawa Scale to include 15 specific criteria tailored to the spatio-temporal epidemiology of RVF in Madagascar. Validity was established through expert review, and inter-rater reliability was ensured via a pilot assessment of a subset of studies by two independent reviewers to ensure consistency, with discrepancies resolved by consensus. Total scores were categorised as low (15–25), moderate (26–35), or high (36–45) quality. For each included study, bias management was a key component, ensuring that potential biases (selection, information, and confounding biases) were checked and evaluated. Furthermore, a formal risk-of-bias assessment was conducted for all included studies, and a comprehensive risk-of-bias table was integrated into the analysis to evaluate internal validity and facilitate the cautious weighting of evidence during the synthesis of results. This rigorous approach ensured the validity of conclusions, especially regarding the spatio-temporal dynamics and influential factors of RVF in Madagascar.

Data analysis

Data extracted from the included studies were analysed using a descriptive and exploratory approach, combining quantitative and qualitative tools. Analysis covered three main components: characteristics of the included studies, spatio-temporal distribution of epidemics, and factors associated with RVF emergence. A formal meta-analysis was not performed due to the significant heterogeneity in study designs, sampling methods, and reporting standards across the 47-year study period, which precluded a reliable

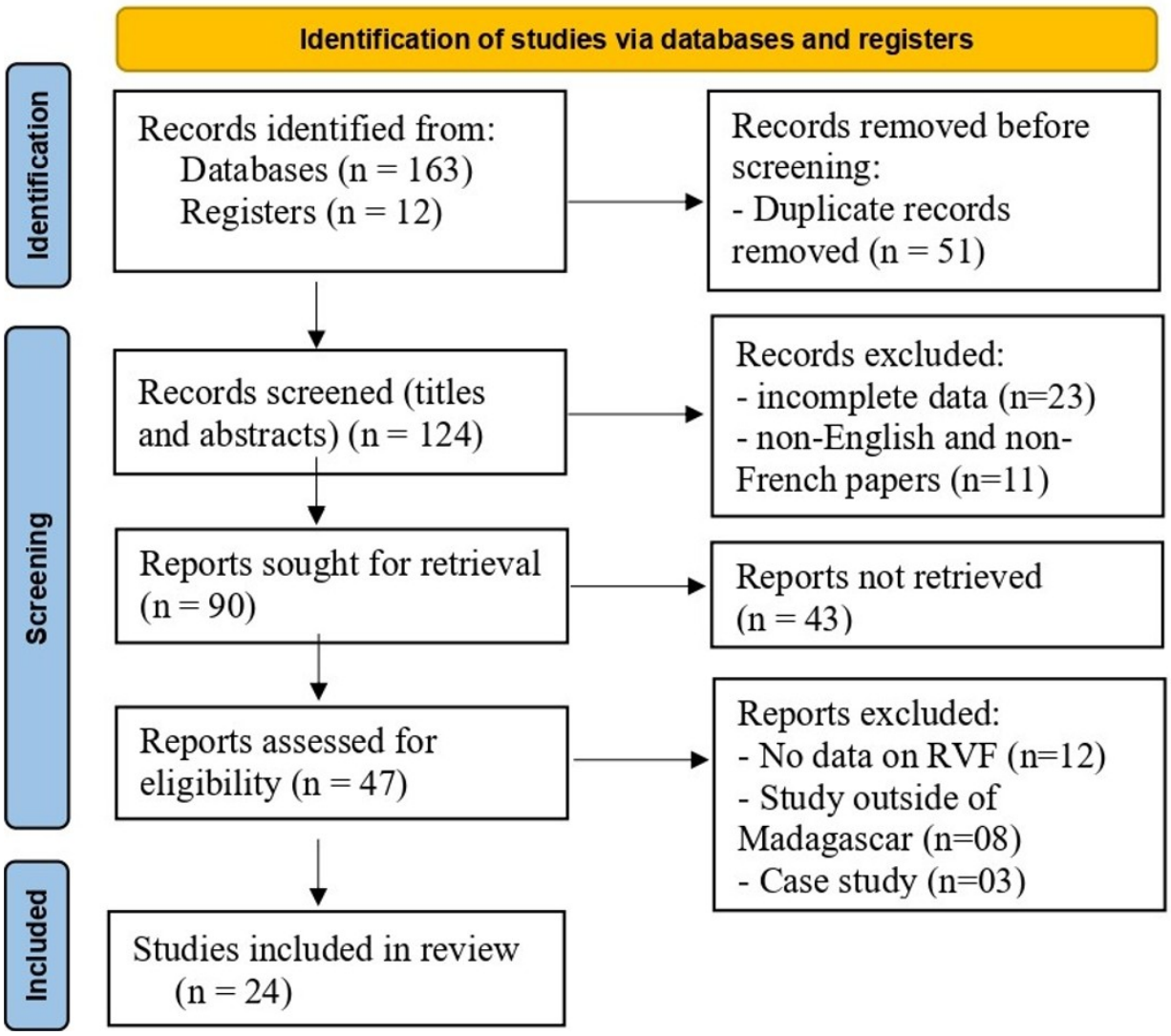


Figure 1. PRISMA 2020 flow diagram illustrating the systematic selection process of 24 studies on Rift Valley Fever in Madagascar, covering identification, screening, eligibility, and final inclusion

quantitative pooling of effects.

Specific analytical tools included:

Visualisation: R and RStudio software were used for generating all graphical visualisations, ensuring reproducible analysis; Mapping: Interactive maps produced via R Markdown (RMD) illustrated the geographic distribution and temporal variations of outbreak foci; Quantitative scoring: An impact scale ranging from 1 (low) to 5 (high) was applied to identified factors. This scale was validated by triangulating the frequency of reporting across studies with the strength of association reported in primary quantitative analyses to minimise subjectivity;

Frequency analysis: A heatmap represented the frequency of studied variables, using a simple colour code (Very frequent: dark purple, Frequent: blue, Moderate: green); and Modelling: To supplement the descriptive synthesis, an exploratory Binomial GLM with a logit link function was employed to generate hypotheses regarding environmental drivers. Monthly precipitation data were retrieved from the Tropical Rainfall Measuring Mission (TRMM), and land surface temperature (LST) was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS). These datasets were spatially aggregated to the district level and averaged over the study period to ensure temporal alignment with reported outbreak occurrences. Given the reliance on secondary ecological data, this model is presented as supportive evidence to guide future primary research rather than a confirmatory analysis of risk factors. We tested for multicollinearity (VIF < 3) and validated model fit via the Akaike Information Criterion (AIC) and residual spatial autocorrelation checks (Moran's I) to ensure statistical validity.

Ethical considerations

This is a systematic review of secondary data; ethical approval was not required, as no individual participant data

Table 1. Summary characteristics of the 24 studies included in the systematic review

Study reference	Study type	Data collection methods	Key finding / result
Clerc et al. (1982) [24]	Surveillance	Mosquito collection, viral analysis	Detection of the virus in the Andasibe-Périnet forest
Fontenille et al. (1988) [25]	Surveillance	Mosquito capture, virological tests	The first isolation of the virus was recorded in 1979
Morvan et al. (1991) [7]	Epidemic	Clinical and epidemiological surveys	Documentation of the first major epizootic
Morvan et al. (1992) [26]	Epidemic	Serology (IgM, IgG), mosquito collection	High IgM levels in cattle and human cases
Morvan et al. (1992) [36]	Surveillance	Analysis of past outbreaks, climate	Suggested a potential link to El Niño events, later clarified as an indirect influence compared to East African dynamics
Nicolas et al. (2010)* [54]	Association	Farmer surveys, commercial network	Link between cattle trade and seroconversion
Andriamandimby et al. (2010) [6]	Surveillance	ELISA IgG/IgM, blood samples	Evidence of active vector transmission
Jeanmaire et al. (2011) [27]	Surveillance	Blood samples, ELISA	Post-epizootic prevalence in ruminants
Chevalier et al. (2011) [22]	Association	Longitudinal serological monitoring	Factors affecting transmission in cattle
Ratovonjato et al. (2011) [55]	Epidemic	Mosquito capture, genetic tests	Virus detected in vectors (Haute Matsiatra)
Olive et al. (2013) [5]	Surveillance	Serological and virological monitoring	Identification of high-risk geographic zones
Nicolas et al. (2013) [21]	Association	Seroprevalence, livestock movements	Key role of livestock trade in virus spread
Nicolas et al. (2014) [13]	Spatial Modelling	Spatially explicit modelling	Key determinants for recurrent circulation
Olive et al. (2016) [19]	Surveillance / Association	Seroprevalence, environmental, and socio-economic data	Behavioural and environmental links to infection
Lancelot et al. (2017) [12]	Epidemic	Environmental and climatic data	Climatic drivers identified in past outbreaks
Olive et al. (2017) [56]	Bayesian Modelling	Seroprevalence, FOI modelling	Identification of peak transmission periods
Nepomichene et al. (2018) [18]	Entomological	Experimental infection	Vector competence of *Culex* and *Anopheles*
Morvan et al. (2021)* [20]	Epidemic	Surveillance, laboratory tests	Viral persistence during inter-epidemic periods
SEGA One Health (2021)* [2]	Epidemic	Description of response actions	Evaluation of response strategies and training
Razafindraibe et al. (2023) [8]	Epidemic	Surveillance data	Description of 2021 epidemic and response
Tantely et al. (2024) [9]	Epidemic	Clinical surveys, data collection	Findings from multisite epidemic monitoring
Tantely et al. (2024) [57]	Entomological	Longitudinal multi-host survey	Insights into mosquito dynamics in peri-urban Antananarivo
Harimanana et al. (2024) [28]	Epidemic	Outbreak investigation, surveillance data	Documentation of the 2021 re-emergence in Mananjary

*Grey literature

were collected. Adherence to ethical standards was a prerequisite for inclusion. We explicitly verified that each primary study involving animal or human subjects reported oversight by a recognised institutional ethics committee or followed national Malagasy guidelines for veterinary research.

Results

Introduction to included studies and variables

The selection process for studies adhered to the PRISMA flow diagram (Figure 1). Initial identification yielded 175 records from databases (PubMed and ScienceDirect, n=163) and registers (n=12). After removing 51 duplicates, 124 records were screened (titles and abstracts). Thirty-four

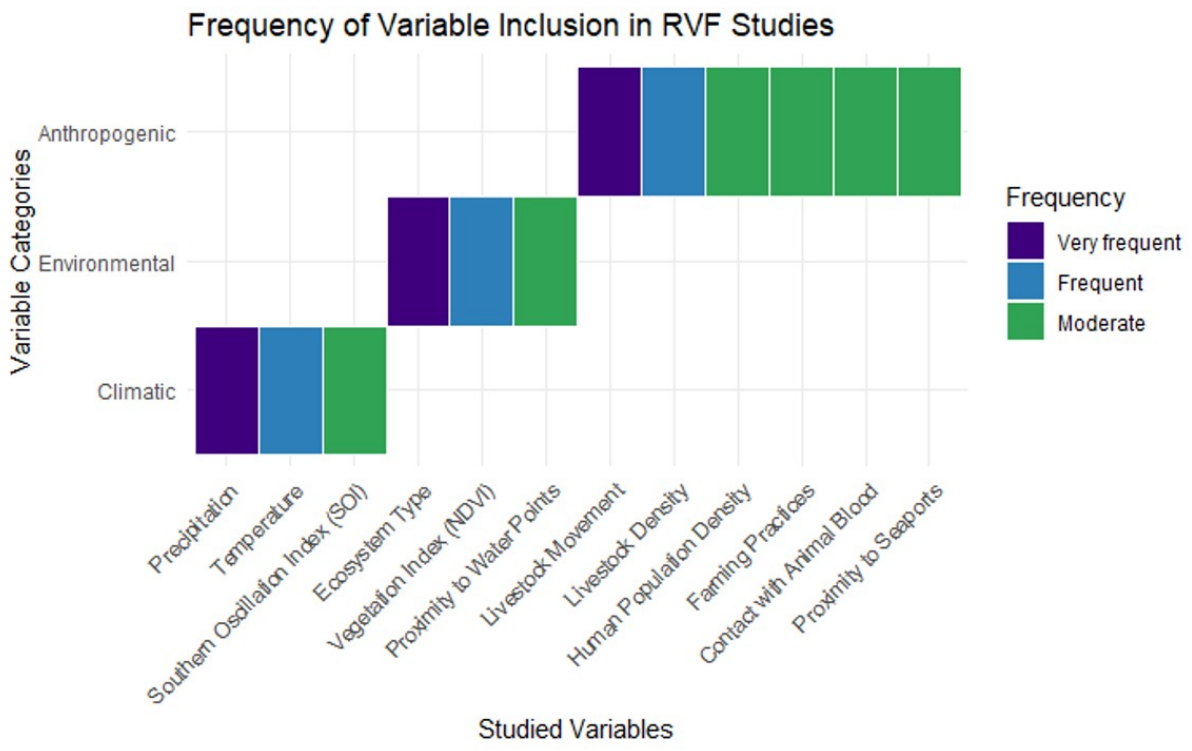


Figure 2. Heatmap illustrating the reporting frequency of climatic, environmental, and anthropogenic variables across the 24 included studies (Very frequent: dark purple, Frequent: blue, Moderate: green)

records were subsequently excluded, mainly due to the absence of data on RVF or geographical irrelevance (studies outside Madagascar). Of the 90 reports sought for retrieval, 43 were not accessible. After the eligibility assessment of 47 reports, 23 more were excluded. A total of 24 studies were included in this systematic review, consisting of 21 articles from peer-reviewed databases and 3 from grey literature. The key characteristics of the 24 studies included in this systematic review are summarised in Table 1.

The variables analysed across the included studies were categorised into climatic, environmental, and anthropogenic drivers, with their research prominence illustrated through frequency analysis (Figure 2). This visual hierarchy is further detailed in a thematic synthesis, which maps each specific factor to its corresponding peer-reviewed evidence (Table 2). Precipitation, specific ecosystem types (wetlands, rice fields), and livestock movement were the most frequently included variables. Concerning anthropogenic variables, livestock movement (very frequent) is a key driver for spreading the virus along trade corridors. These factors are essential triggers for vector proliferation and viral spread across the island [6,13,18]. Temperature, cattle density, and the Normalised Difference Vegetation Index (NDVI) were also frequently studied to identify critical habitats and acceleration rates of the mosquito life cycle [12,19]. Additionally, moderate-frequency variables such as human population density, altitude, and the Southern Oscillation Index (SOI) were incorporated to assess regional risks and human exposure [5,12]. Finally, certain studies examined high-risk human behaviours, such as contact with infected animal fluids, as a key factor in transmission to human populations [19].

Spatio-temporal distribution and trend

The disease has been endemic in Madagascar since its first isolation in 1979. The island has experienced three major waves of outbreaks (Figure 3): 1990–1991, 2008–2009, and 2021 [6–8]. Inter-epizootic periods are characterised by silent viral circulation, where the virus persists in animal reservoirs or through transovarial transmission in vectors without causing major reported outbreaks, necessitating improved surveillance during these ‘quiet’ intervals [20,21]. Chronological evolution is summarised and visually represented in Figure 3.

Spatial clusters and high-risk zones

Geographical distribution demonstrates an expansion of the virus, although previous hotspots often experience recurrence [6,8]. High-risk areas are primarily concentrated in the Central Highlands, where high human and animal density, coupled with major livestock markets, contribute to risk [21–23]. The Northwest is identified as a potential zone for silent, enzootic circulation due to its warm, humid climate [19]. The East Coast is frequently impacted, likely due to climatic conditions favouring vector proliferation, often exacerbated by cyclones [7,12]. Peri-urban centres like Antananarivo are also hotspots due to population and

Table 2. Thematic synthesis of drivers and factors influencing RVF dynamics in Madagascar

Category	Specific Driver / Factor	Citations (Author, Year)
Climatic	Heavy and abundant rainfall	Andriamandimby et al. (2010), Tantely et al. (2024)
Climatic	Elevated temperatures	Lancelot et al. (2017), Olive et al. (2016)
Climatic	Cyclones and exceptional flooding	Morvan et al. (1991), Morvan et al. (1992), Jeanmaire et al. (2011)
Anthropogenic	Livestock trade along commercial corridors	Nicolas et al. (2010), Nicolas et al. (2013), Nicolas et al. (2014), Olive et al. (2016)
Anthropogenic	Transhumance and seasonal pastoral routes	Lancelot et al. (2017), Nicolas et al. (2013)
Anthropogenic	Irrigation of rice fields	Nicolas et al. (2014), Nepomichene et al. (2018)
Anthropogenic	Deforestation and land-use changes	Lancelot et al. (2017)
Ecological	Flood zones (Marshes and temporary pools)	Lancelot et al. (2017), Nicolas et al. (2014), Nepomichene et al. (2018)
Ecological	Dense vegetation (NDVI)	Lancelot et al. (2017), Olive et al. (2016)
Human Behaviours	Occupational exposure (slaughterhouse, vets)	Zeller et al. (1998), Olive et al. (2016)
Human Behaviours	Consumption of raw, unpasteurised milk	Olive et al. (2016)
Human Behaviours	Handling aborted products and fluids	Nicolas et al. (2013), Zeller et al. (1998)
Demographic	High animal and human population density	Lancelot et al. (2017), Olive et al. (2016)

commercial activities [23]. These studies emphasise a key region for surveillance and understanding the dynamics of the disease: Alaotra Mangoro, Analamanga, Analanjorofo, Atsimo Andrefana, Atsimo Atsinanana, Atsinanana, Bongolava, Diana, Haute Matsiatra, Itasy, Sava, Vakinankaratra and Vatovavy Fitovinany. Overall, the endemic distribution of RVF is mapped in Figure 4.

Temporal trends and seasonality

Temporal trends of RVF in Madagascar reveal cyclic increases in outbreak frequency and intensity, which are typically separated by prolonged periods of low-level circulation. Prior to 1979, the frequency of outbreaks was considered indeterminate as no data were available for that period. The first isolation of the RVF virus on the island occurred in 1979 from mosquitoes captured in the Perinet forest [6,24,25]. Between 1980 and 1989, information remained limited, and the frequency of outbreaks was again indeterminate.

The first major epizootic was recorded during 1990–1991, significantly affecting the East Coast and Central Highlands [7,23,26]. Following this major event, a period of possible low-level circulation occurred between 1992 and 2007; serological studies during this timeframe suggested diffuse viral circulation from 1990 to 1992 and low-level circulation between 1996 and 1998 [21].

Renewed outbreak activity emerged during the rainy seasons of 2008 and 2009, with reported cases in both human and animal populations [6,27]. This was followed by another decade (2010–2020) characterised by probable persistent viral circulation, although no major outbreaks were officially reported. In 2021, a significant outbreak resulted in over 100 human cases reported across several regions [2,8,9,20,28]. Currently, for the period between 2022 and 2025, data on outbreak frequency remain limited and are classified as indeterminate.

Rift Valley fever (RVF) outbreaks demonstrate a pronounced seasonality closely linked to the precipitation cycle, as shown in Figure 5. The period of highest risk is from January to April, coinciding with the rainy season and peak mosquito vector activity. Outbreaks are frequent in January and February, often peaking in March due to optimal conditions for mosquito multiplication [6,7,28]. Conversely, the dry season, spanning from June to October, limits mosquito reproduction and results in low vector activity and infrequent outbreaks. The risk gradually increases again in November and December with the return of seasonal rains [6].

Climatic drivers

The determinant role of precipitation is demonstrated in Figure 6. Abundant precipitation significantly increases the risk of epidemics by creating favourable stagnant water habitats for mosquito reproduction [6,12,13]. Above-average precipitation in certain years is associated with increased frequency and intensity of outbreaks [11]. The influence of temperature is illustrated in Figure 6. High

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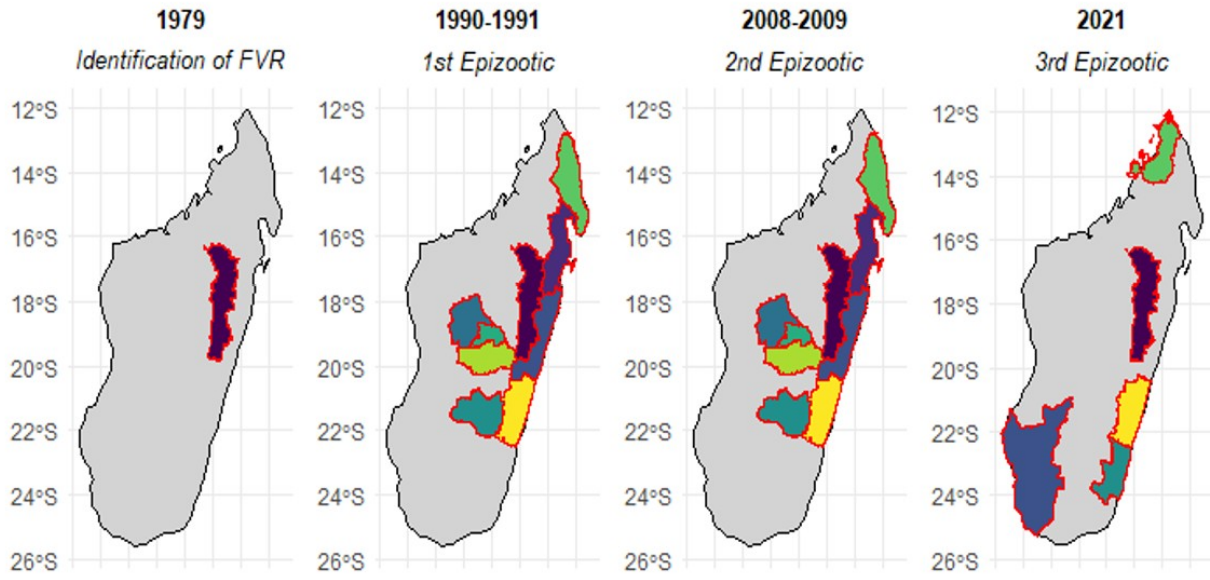


Figure 3. Spatio-temporal Map of RVF outbreaks in Madagascar. Data derived from peer-reviewed reports and Ministry of Health records (1979-2026). Areas in red indicate recurrent hotspots

temperatures accelerate mosquito development and increase the rate of viral transmission, making outbreaks more probable [12,19]. While low temperatures during the dry season slow vector transmission, the virus may persist through residual vectors or other mechanisms [13].

Inferential modelling of outbreak probability

To quantify these climatic influences, a Binomial Generalised Linear Model (GLM) was employed with the probability of outbreak occurrence as the dependent variable. The independent variables, precipitation (TRMM) and temperature (MODIS), were integrated at the district level. While the exploratory model identified positive associations between outbreak probability and precipitation (OR: 1.001; 95% CI: 0.988–1.014; $p = 0.805$) and temperature (OR: 1.549; 95% CI: 0.444–8.512; $p = 0.515$), neither variable reached statistical significance ($p > 0.05$). Consequently, these findings are presented as indicative trends rather than confirmatory evidence of causality.

Regarding modelling assumptions, the model demonstrated a fit with an Akaike Information Criterion (AIC) of 22.2. Multicollinearity tests confirmed the independence of variables (VIF < 3), and residual analysis was conducted to ensure the model successfully captured the spatial distribution of RVF across the identified high-risk districts. Identification of critical thresholds.

The risk of an RVF outbreak in Madagascar is fundamentally driven by the convergence of competent vectors, high densities of susceptible livestock, and human practices that either facilitate or restrict viral spread [9,22]. According to the sources, specific climatic thresholds serve as primary triggers for viral activity; notably, excessive rainfall and the flooding of dambos (temporary pools) trigger a massive emergence of infected Aedes mosquitoes, which initiates an active transmission cycle [9]. Furthermore, irregular rainfall patterns and subsequent variations in pond water levels promote the successive hatching of multiple mosquito generations during a single rainy season, effectively amplifying viral transmission [22]. High temperatures during the rainy season further exacerbate the risk by accelerating larval development, shortening the mosquito's gonotrophic cycle, and increasing vector survival, which ensures faster transmission of the virus [5,12]. In contrast, while low temperatures during the dry and cold seasons generally slow down vector-mediated transmission, the virus may still persist through direct transmission, residual vectors, or other underlying ecological mechanisms [21].

Relation with extreme climatic events

The influence of El Niño episodes, characterised by the warming of equatorial Pacific surface waters that alter global climatic conditions, is observed to be less pronounced in triggering RVF outbreaks in Madagascar than in East Africa [7,12]. While these events are associated with abundant rainfall in certain regions of the island, the correlation with outbreaks remains less clear compared to the strong links documented on the African continent [12,26]. Conversely, El Niño episodes, which involve the cooling of these surface waters, have variable effects on local rainfall and may correlate with periods of low outbreak activity, although further data are required to confirm this trend.

Floods resulting from exceptional submersions are frequent during the rainy season and are often exacerbated by cyclones that regularly affect Madagascar between November and April [6,27]. These flooding events create

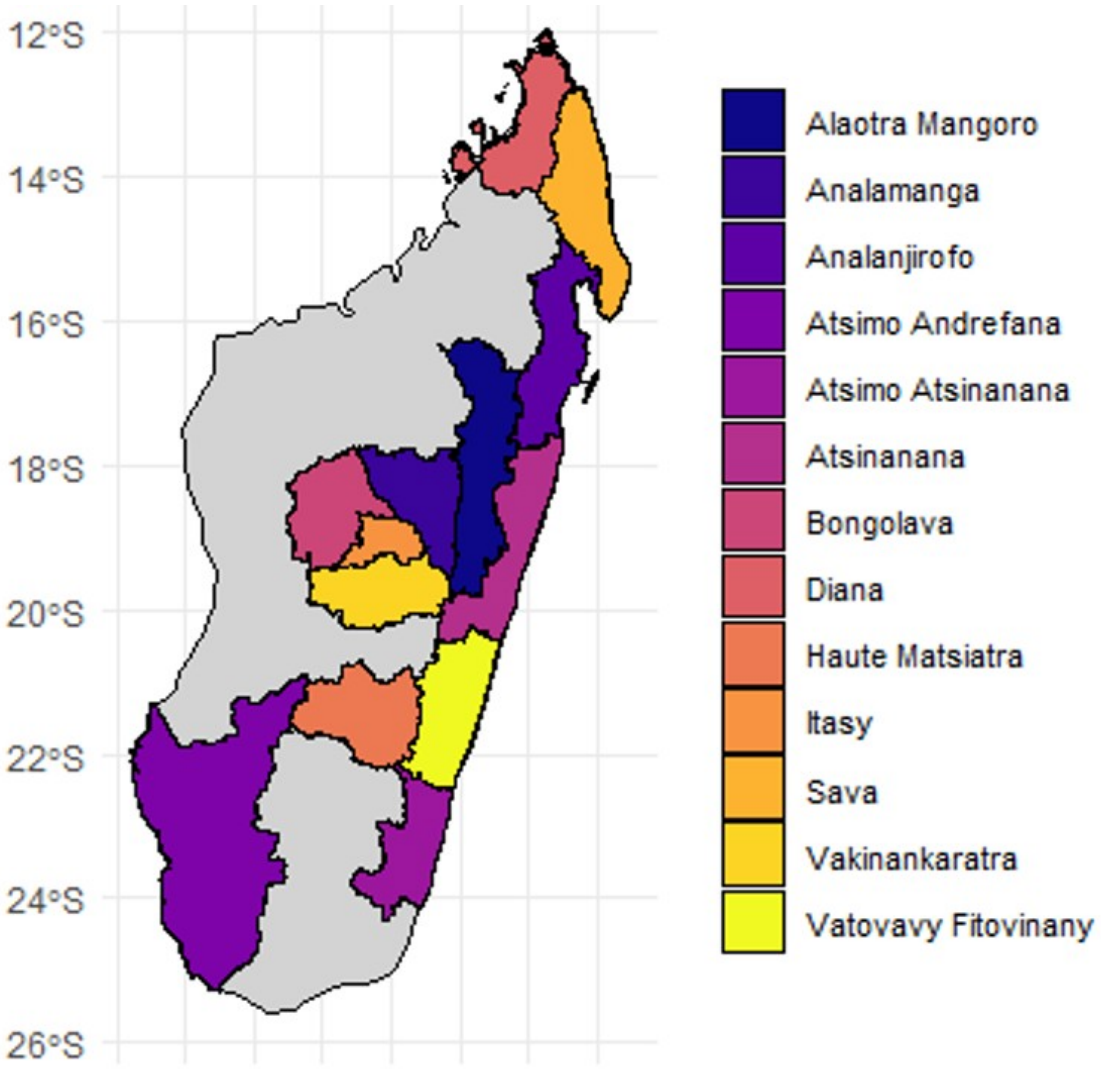


Figure 4. Geographic distribution of RVF endemic regions in Madagascar. The map identifies high-risk clusters in the Central Highlands, East Coast, Northwest, and Southwest based on cumulative seroprevalence and historical outbreak data

favourable conditions for mosquito proliferation by providing essential larval habitats for RVF vectors, thereby significantly increasing the risk of virus transmission [6,27]. Finally, the heavy rains and violent atmospheric disturbances associated with cyclones may further elevate outbreak risks by favouring the abundance and geographic dispersion of vectors across the island.

Specificities of Madagascar

Rift Valley Fever (RVF) dynamics in Madagascar are uniquely shaped by the island's distinct ecological and social landscapes [12,19]. Wide ecological diversity leads to significant regional variations in how the virus emerges and persists [12,19]. While precipitation is a primary driver of epidemic dynamics, the specific thresholds for rainfall vary across different Malagasy ecosystems and vector species, necessitating localised studies to identify precise regional risks [22].

Furthermore, the wide variety of ecosystems on the island creates significant fluctuations in temperature, rainfall, and vector abundance, causing RVF dynamics to differ markedly from one region to another [12,19]. One of the most critical specificities is the role of long-distance livestock trade, where movements along commercial corridors introduce the virus into new areas regardless of local climatic triggers [13,21]. As a result, the rigorous monitoring of livestock movements is deemed essential for effective outbreak prevention and control [13,21]. Finally, the current lack of sufficient data concerning climatic events, mosquito vectors, and historical outbreaks makes it difficult for researchers to develop robust and precise predictive models for the island.

Ecological and environmental factors

Flood zones, including irrigated rice fields, marshes, and temporary pools, are critical habitats for vector mosquito reproduction, contributing to viral persistence. These areas enhance larval habitats for mosquitoes, particularly Aedes

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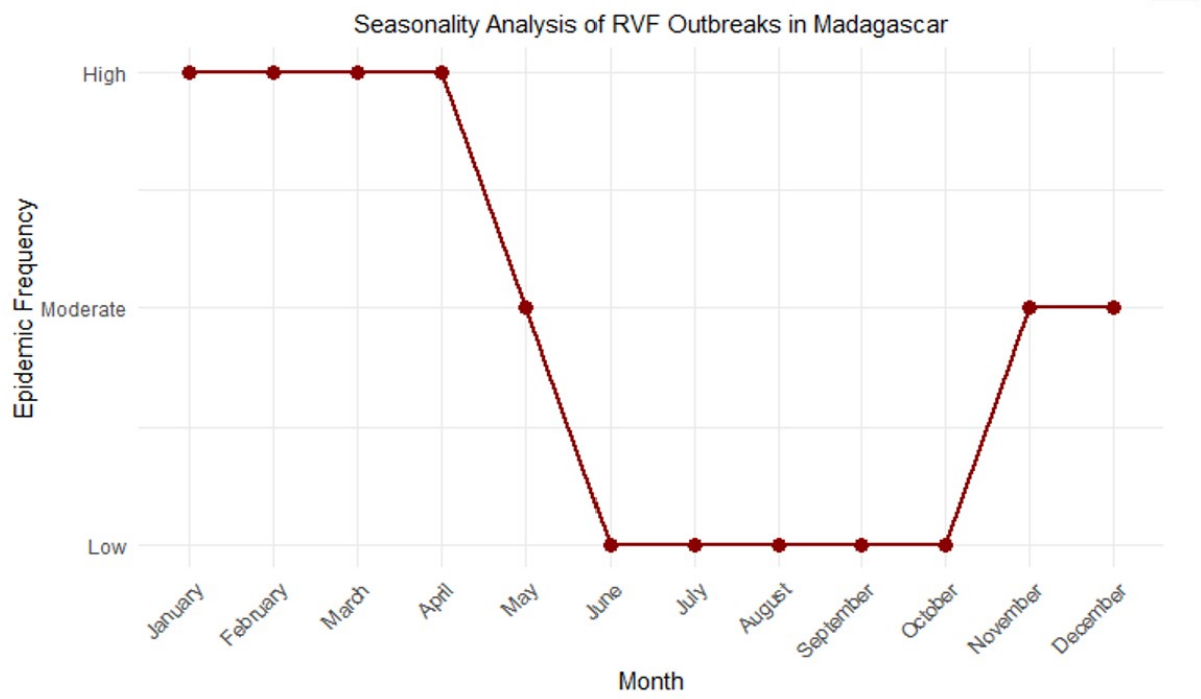


Figure 5. Seasonal and interannual variations of RVF outbreak frequency. The line graph highlights the peak transmission period between January and April, coinciding with the rainy season and peak vector activity

and Culex, which utilise these sites to reproduce [12,13,18,19]. For example, irrigated rice fields in the Central Highlands are conducive to the development of Culex and Anopheles, demonstrating how agricultural water management influences vector abundance [13,19]. Furthermore, dense vegetation offers refuge to adult mosquitoes, creating favourable micro-habitats [19].

High-risk regions for RVF emergence in Madagascar are primarily identified as the East Coast, the Central Highlands, the Northwest, and the Southwest (notably Atsimo Andrefana) [12,19]. The East Coast is characterised by warm and wet conditions, high livestock density, and proximity to seaports, which have resulted in frequent epidemic foci and elevated seroprevalence rates in local livestock [12,19]. In the Central Highlands, the management of irrigated rice fields and significant livestock movements create ideal habitats for Culex and Anopheles vectors, facilitating recurrent viral circulation as evidenced by major epidemics during 1990–1991 and 2008–2009 [19,21,26]. Finally, the Northwest region remains highly vulnerable due to its warm and humid climate, the presence of extensive flood zones, and high cattle density, all of which favour mosquito proliferation and increase the risk of inter-epizootic transmission [12,19].

The proliferation of RVF vectors in Madagascar is significantly influenced by specific environmental conditions. The combination of geographical and climatic factors sustains vector populations and facilitates virus transmission [12,19]. High humidity is a key determinant, as warm and humid areas receiving abundant rainfall establish ideal conditions for mosquito development by providing abundant larval habitats [12,19]. These conditions make high-risk zones, including the East Coast, the Northwest, and the Central Highlands, particularly vulnerable during the rainy season [12,19]. Furthermore, moderate temperatures are observed to favour mosquito development and survival, contributing to the risk in the Central Highlands and temperate coastal regions [19].

The presence of flood zones significantly enhances mosquito reproduction by creating larval habitats. These zones include both natural areas, such as alluvial plains, and artificial environments, such as irrigated rice fields [19,21]. Consequently, alluvial plains, irrigated rice fields, and low coastal areas are identified as high-risk environments.

Vector survival, particularly during the dry season, is sustained by the proximity to permanent water bodies [19]. Lakes, rivers, and marshes create stable habitats that allow certain mosquito species to persist in river valleys, lake areas, and coastal regions [19]. Finally, dense vegetation offers crucial shelter to adult mosquitoes and creates humid micro-habitats favourable for reproduction, a condition common in forests, wooded savannas, and rice fields [19].

Anthropogenic and demographic factors

Anthropogenic activities are key drivers of RVF spread in Madagascar. The assessed impact of these factors is illustrated in Figure 7. Livestock trade is the key anthropogenic factor, facilitating viral introduction into non-endemic areas [19,21]. Transhumance facilitates long-distance spread along seasonal movement routes

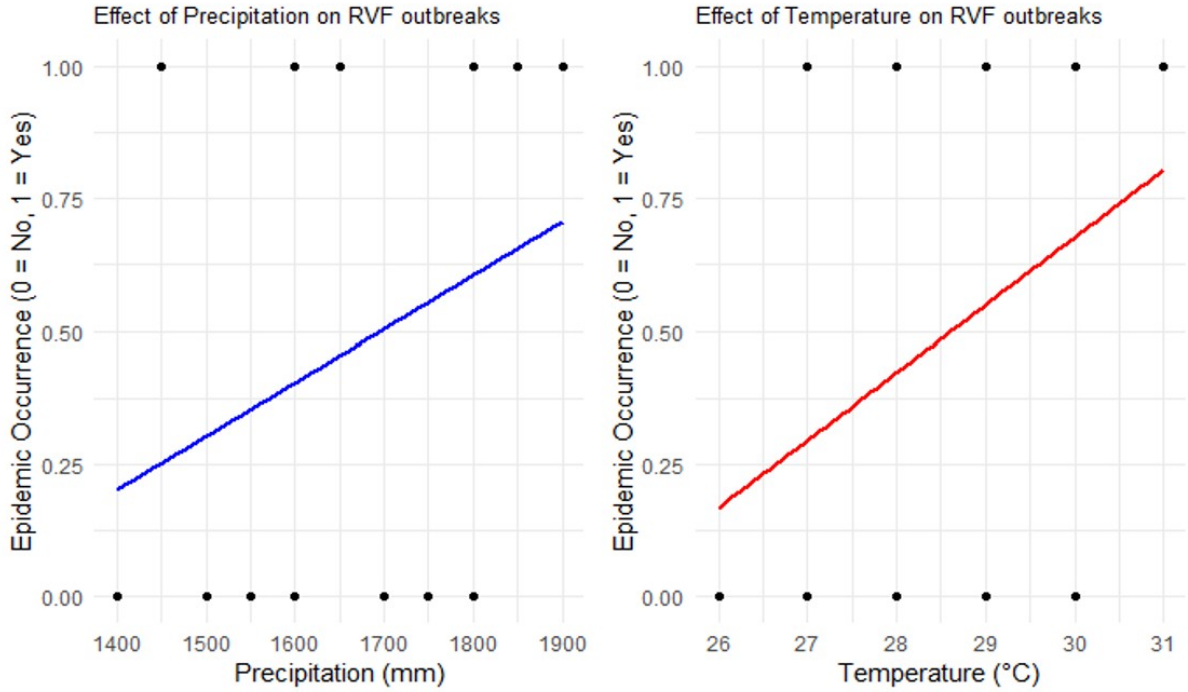


Figure 6. Correlation between seasonal climatic variables (precipitation and temperature) and Rift Valley Fever outbreak occurrence. Statistical modelling demonstrates an increased probability of outbreaks following above-average rainfall and high temperatures

[12,21]. Rice field irrigation creates ideal habitats for vector proliferation, increasing transmission risk [10,21]. Deforestation modifies vector habitats, increasing their proximity to human and livestock populations [12].

As a result, human behaviours significantly influence the transmission of RVF to humans. The impact of high-risk human behaviours is detailed in Figure 7. Professional exposure among slaughterhouse workers, veterinarians, and livestock farmers constitutes a significant risk due to frequent contact with infected animals and fluids [19,23]. The consumption of raw milk from infected animals is an effective transmission route, particularly in rural areas [19]. Handling of aborted products and body fluids (placenta, blood) without adequate protection significantly increases the risk of direct viral exposure [21]. Furthermore, a lack of awareness and insufficient hygiene practices during animal handling worsen the risk of exposure and disease spread [2].

Demographic factors

Demographic factors, including animal and human density, play a crucial role in RVF extension and transmission. This influence is shown in Figure 7. High animal population density in regions like the East Coast favours the emergence and propagation of epizootics by increasing contact between hosts and vectors [19]. High human population density, especially where raw animal product consumption is common, increases the risk of human exposure [12]. Epidemic foci cluster in zones where favourable environmental conditions converge with high livestock density and human activities such as pastoralism and agriculture [12,21].

Discussion

Analysis of spatio-temporal dynamics and international perspective

The cyclical emergence of RVF in Madagascar, characterised by three major waves since 1979 [6–8,25], suggests enduring viral persistence during inter-epizootic intervals. This maintenance, potentially through transovarial transmission or silent circulation in animal reservoirs, mirrors patterns observed in other endemic African regions [20,21,29–31].

Geographically, the expansion of high-risk clusters in the Central Highlands, Northwest, and East Coast reflects distinct regional drivers. The Highlands represent a critical hotspot where converging livestock markets and irrigated rice cultivation facilitate transmission, a dynamic analogous to focal points in Nigeria and Ethiopia [19,21–23,31,32]. Furthermore, the environmental conditions of the humid Northwest and the cyclone-driven vulnerability of the East Coast mirror the weather-driven outbreak patterns observed in East and Southern Africa, respectively.

Influence of climatic and environmental factors and vector habitat interpretation The strictly seasonal nature of RVF in Madagascar aligns with broader patterns observed in East and West Africa, where vector explosions are fundamentally

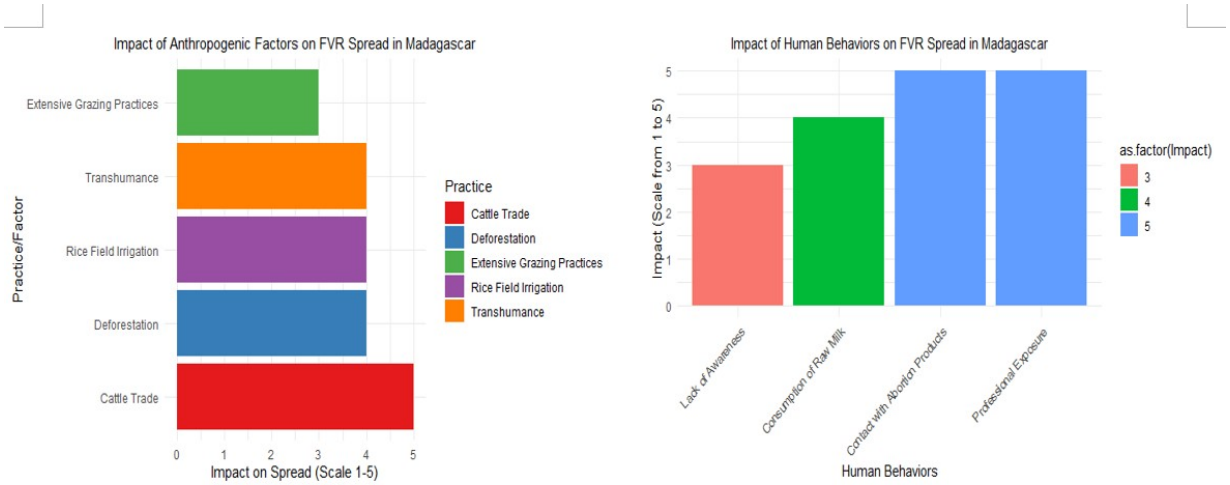


Figure 7. Impact of anthropogenic drivers and high-risk human behavioural practices on Rift Valley Fever transmission dynamics, based on an impact scale of 1 (low) to 5 (high)

driven by seasonal rains and temporary backwaters [33–35]. While the primary triggers on the island, such as the flooding of dambos and irregular rainfall patterns, are mechanistically similar to continental dynamics, our findings highlight a critical regional divergence regarding extreme events [9,22].

Specifically, while El Niño is the dominant driver of major outbreaks in East Africa, its influence in Madagascar is less direct [12,36]. Instead, the island's risk is more significantly amplified by tropical cyclones and heavy late-season rains, which create the vast larval habitats necessary for large-scale transmission [6,11,27]. This dynamic mirrors weather-driven outbreaks observed in South Africa and Mozambique, distinguishing the island's risk profile from the El Niño-dependent patterns of the African Horn [12,29].

Environmental modelling further confirms that anthropogenic water management, such as rice field irrigation in the Highlands, provides stable breeding grounds for Culex and Anopheles species [19,21]. This ecological synergy between agricultural practices and seasonal rainfall is a well-documented driver of vector abundance globally, notably mirroring dynamics in the Senegal River Valley where a strong correlation exists between rice cultivation and viral emergence [37].

By integrating vegetation indices (NDVI) to identify micro-habitats for vector survival, these results provide a framework for region-specific predictive models [12,19]. Such models are essential for shifting from reactive outbreak management to proactive anticipation, as successfully demonstrated by satellite-based global models used in other parts of sub-Saharan Africa [29,38,39].

Impact of livestock movements, trade, and anthropogenic factors

Anthropogenic activities are primary drivers of RVF spread across Madagascar, often outweighing local climatic triggers in terms of geographic propagation [2,13]. Livestock trade along established commercial corridors is the key anthropogenic factor, facilitating the introduction of the virus into previously unaffected or non-endemic regions independently of local weather conditions [13,19,21]. Trade networks connecting the Central Highlands to the East Coast explain the recurrent viral circulation observed in areas with otherwise low vector density [19]. This dynamic mirrors trade patterns in West African countries like Mali and Niger, where livestock mobility is a known focal point for viral dissemination [40]. Similarly, transhumance facilitates the long-distance spread of RVF along seasonal pastoral routes, a phenomenon also observed in East Africa where proximity between livestock and vectors in grazing areas increases transmission risk [12,19].

Land-use changes further exacerbate these risks; irrigation for rice cultivation creates stable breeding grounds for Culex and Anopheles mosquitoes, effectively sustaining vector populations through artificial water management [10,21]. This link between rice paddies and increased vector-borne disease epidemics is well-documented globally, particularly in Asia and other parts of Africa [41,42]. Additionally, deforestation in Madagascar modifies natural habitats, increasing the contact between human-animal populations and forest-dwelling vectors [12]. The first isolation of the virus in the Perinet Forest in 1979, prior to any documented outbreaks, suggests a potential sylvatic origin involving wild animal reservoirs [20,25]. This parallels findings in Central and West Africa, where wildlife such as buffalo and antelope in forested or flooded wetlands play a role in viral persistence [43,44].

Demographic factors, risk behaviours, and socio-economic impacts

The transmission of RVF to humans in Madagascar is closely tied to occupational exposure and demographic density. High-risk groups include slaughterhouse workers, veterinarians, and livestock farmers who have frequent contact with infected animal fluids [19,23]. Studies in Tanzania have shown that slaughterhouse workers are 1.8 times more likely to be exposed to the virus through direct blood contact or aerosols [45]. Furthermore, handling aborted foetal materials without personal protective equipment (PPE) is a universal transmission mechanism, often identifying the first human cases during an epidemic, as seen in Kenya during the 2006–2007 wave [21,46]. Foodborne transmission is another critical factor; the consumption of raw, unpasteurised milk is a major risk in Malagasy rural areas, a finding corroborated by outbreaks in Mauritania and Egypt [19,35].

The socio-economic consequences of RVF are devastating for Madagascar's rural economy. Outbreaks lead to significant economic losses due to trade restrictions, market closures, and international embargoes, with estimated impacts in East Africa ranging from 470 million [47]. In Madagascar, the physical disabilities observed in infected animals exacerbate consumer mistrust of meat and milk products, fuelling food crises in affected regions [48,49]. Moreover, the rapid spread of the virus often overwhelms local health infrastructures, particularly in rural areas where access to care is already limited [31,50]. Veterinary services also face immense strain, as they must manage mass slaughters and the biosecure destruction of carcasses during peak epizootic periods [51].

Surveillance systems, predictive modelling, and "One Health" Strategies

Current surveillance and response systems in Madagascar have historically been judged insufficient or inadequate [14]. To address these gaps, a "One Health" approach is essential, requiring the joint mobilisation of human, animal, and environmental health sectors [1,2]. The involvement of veterinarians, health authorities (DSV, DVSSER), and community animal health agents (APPSA) is crucial for improving early detection and managing high-risk trade corridors [6,28]. Strengthening surveillance during silent inter-epizootic periods is particularly important for identifying low-level viral circulation before it escalates into a major outbreak [20,21].

The development of local predictive models incorporating climatic data (rainfall, temperature) and environmental indices (NDVI) is a priority for intervention planning [13,38]. Global models using satellite data have successfully predicted outbreaks in sub-Saharan Africa, providing a template for Madagascar to target its resources more effectively [29]. Furthermore, participatory epidemiology, which integrates local communities and livestock owners into data collection, has proven successful in Kenya and Ethiopia for improving risk management [32,52]. Ultimately, a resilient strategy for Madagascar must include preventive livestock vaccination, vector control programs (such as larviciding in rice fields), and intensive public health education to reduce the long-term impact of RVF on the island's population and economy [2,10,53].

Limitations

Limitations include potential publication bias toward major outbreaks, significant methodological heterogeneity across the 47-year period. The varying frequency of reported outbreaks must be contextualised within the evolution of Madagascar's health infrastructure. The transition from classical entomological surveillance in 1979 to the implementation of molecular diagnostics (RT-PCR) and community-based surveillance networks in 2021 has significantly enhanced detection sensitivity, potentially biasing longitudinal comparisons across the 47-year study period. Furthermore, we acknowledge the inherent challenges of inferring causality from secondary ecological data, particularly concerning geospatial accuracy and standardisation of collection methods. The restricted number of studies available on this specific topic and potential publication bias in accessible literature were noted, alongside challenges in generalising findings due to the ecological and epidemiological diversity across Madagascar.

Conclusion

Rift Valley Fever (RVF) represents a major public health and veterinary threat in Madagascar, resulting in significant morbidity and socio-economic burdens for both human populations and the livestock sector. Since its initial detection in 1979, the island has experienced three distinct epidemic waves: 1990–1991, 2008–2009, and 2021, with evidence of silent viral circulation during inter-epizootic intervals. The emergence and propagation of the virus are driven by a complex interplay of environmental conditions, seasonal climatic fluctuations, and anthropogenic dynamics, most notably livestock movements along trade corridors. High-risk zones, including the East Coast, Central Highlands, Northwest, and Southwest, require targeted surveillance due to their high animal densities and favourable wetland habitats. To mitigate future outbreaks, Madagascar must adopt an integrated "One Health" strategy that strengthens early warning systems, enhances biosecurity in livestock trade, and facilitates cross-sectoral coordination between human, animal, and environmental health authorities.

What is already known about this topic

- Rift Valley Fever (RVF) is a re-emerging zoonosis in Madagascar, causing major economic losses and severe human complications, including encephalitis and haemorrhagic fever;
- Since its 1979 detection, the island has experienced three major epidemic waves (1990–1991, 2008–2009, and 2021) separated by "silent" inter-epidemic viral circulation;
- Outbreaks are triggered by seasonal rainfall and flooding favouring mosquito vectors, while human infection primarily occurs through occupational exposure or raw milk consumption.

What This Study Adds

- This research offers the first comprehensive 47-year longitudinal synthesis (1979–2026) of Rift Valley Fever in Madagascar, filling a significant gap in regional epidemiological data;
- It establishes a clear distinction between Malagasy dynamics, highly influenced by anthropogenic factors like livestock trade corridors, and the climate-dependent El Niño patterns typical of East Africa;
- Furthermore, the study provides newly synthesised regional risk maps and actionable "One Health" recommendations to modernise and strengthen existing surveillance systems.

Conflict of Interest

The authors of this work declare no competing interests.

Funding

The authors did not receive any specific funding for this work.

Acknowledgments

The research team would like to thank the following individuals and institutions for their critical support in the realisation of this systematic review. Faculty of Medicine of Antananarivo, for his leadership and commitment to academic excellence. Director of Training and Research at the National Institute of Public and Community Health (INSPC), and all superiors and colleagues at the Institute, for their professional support. All professors and teachers at the Faculty of Medicine of Antananarivo for the knowledge generously transmitted. The administrative and technical staff of the Faculty of Medicine of Antananarivo for their essential logistical support.

List of abbreviations and acronyms

AIC: Akaike Information Criterion
APPSA: Local animal production and health agents (or Community Animal Health Workers/Agents)
DSV: Directorate of Veterinary Services (Direction des Services Vétérinaires)
DVSSER: Directorate of Health Monitoring, Epidemiological Surveillance, and Response (Direction de la Veille Sanitaire, de la Surveillance Épidémiologique et de la Riposte)
GLM: Generalised Linear Models (specifically Binomial Generalised Linear Models)
INSPC: National Institute of Public and Community Health (Institut National de la Santé Publique et Communautaire)
MODIS: Moderate Resolution Imaging Spectroradiometer
NDVI: Normalised Difference Vegetation Index
PICO: Population, Intervention, Comparison, Outcome (a framework applied to the systematic review)
PPE: Personal Protective Equipment
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Guidelines for reporting systematic reviews)
RVF: Rift Valley Fever (the subject of the review)
RVFV: Rift Valley Fever Virus
SOI: Southern Oscillation Index
TRMM: Tropical Rainfall Measuring Mission
VIF: Variance Inflation Factor

Authors' contributions

FA: Conceptualisation, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualisation, Writing – original draft, and Writing – review editing. BM: Conceptualisation, Validation, and Writing – review editing. ZAR: Conceptualisation, Methodology, and Validation. SRR: Writing – review editing. DR: Supervision and Validation. FMR: Supervision and Validation. LR: Supervision, Validation, and Writing – review editing. RLA: Validation. JR: Supervision and Validation. All authors have read and approved the final version of the manuscript.

References

[1] World Health Organization. Rift Valley fever [Internet]. 2024 Dec 20, cited 2026 Aug 19. [about 4 screens]. Available from:https://www.who.int/fr/news-room/fact-sheets/detail/rift-valley-fever

[2] SEGA One Health. Riposte contre la fièvre de la Vallée du Rift à Madagascar (FVR) Response to Rift Valley Fever in Madagascar (RVF) [Internet]. Ebène (Mauritius): SEGA One Health; 2021 Aug 30, cited 2026 Aug 19. [about 1 screen]. Available from: https://segaonehealth.org/riposte-contre-la-fievre-de-la-vallee-du-rift-a-madagascar-fvr/

[3] Farman M, Ahmad A, Atta U, Nisar KS, Ghaffar A. Hyers Ulam stability and bifurcation control of leptospirosis disease dynamics and preventations: Modeling with singular and non-singular kernels. PLOS ONE [Internet]. 2025 Mar 31, cited 2026 Aug 19;20(3):e0314095. doi: 10.1371/journal.pone.0314095

[4] Ahmad A, Atta U, Farman M, Nisar KS, Ahmad H, Hincal E. Investigation of lassa fever with relapse and saturated incidence rate: mathematical modeling and control. Model Earth Syst Environ [Internet]. 2025 Jun 1, cited 2026 Aug 19;11:202 doi: 10.1007/s40808-025-02370-7

[5] Olive MM, Razafindralambo N, Barivelo TA, Rafisandratantsoa JT, Soarimalala V, Goodman SM, Rollin PE, Heraud JM, Reynes JM. Absence of Rift Valley Fever Virus in Wild Small Mammals, Madagascar. Emerg Infect Dis [Internet]. 2013 Jun, cited 2026 Aug 19;19(6):1025–7. doi: 10.3201/eid1906.121074

[6] Andriamandimby SF, Randrianarivo-Solofoniaina AE, Jeanmaire EM, Ravololomanana L, Razafimanantsoa LT, Rakotojoelinandrasana T, Razainirina J, Hoffmann J, Ravalohery JP, Rafisandratantsoa JT, Rollin PE, Reynes JM. Rift Valley fever during rainy seasons, Madagascar, 2008 and 2009. Emerg Infect Dis [Internet]. 2010 Jun, cited 2026 Aug 19;16(6):963–70. doi: 10.3201/eid1606.091266

[7] Morvan J, Saluzzo JF, Fontenille D, Rollin PE, Coulanges P. Rift Valley fever on the east coast of Madagascar. Res Virol [Internet]. 1991 Nov-Dec, cited 2026 Aug 19;142(6):475–82. doi: 10.1016/0923-2516(91)90070-j

[8] Razafindraibe NP, Ranoaritiana DB, Andriamandimby SF, Vololoniaina MC, Ndjakani YD, Rasamoelina AH. Description de l'épidémie de Fièvre de la Vallée du Rift chez les humains et les animaux, Madagascar, 2021 [Description of the Rift Valley fever outbreak in humans and animals, Madagascar, 2021]. Revue d'Épidémiologie et de Santé Publique [Internet]. 2023 Sep, cited 2026 Aug 19;71:102004. doi: 10.1016/j.respe.2023.102004 French

[9] Tantely LM, Andriamandimby SF, Ambinintsoa MF, Raharinirina MR, Rafisandratantsoa JT, Ravalohery JP, Harimanana A, Ranoelison NN, Irinantenaina J, Ankasitrahana MF, Ranoaritiana DB, Randrianasolo L, Randremanana RV, Lacoste V, Dussart P, Girod R. An Entomological Investigation during a Recent Rift Valley Fever Epizootic/Epidemic Reveals New Aspects of the Vectorial Transmission of the Virus in Madagascar. Pathogens [Internet]. 2024 Mar 16, cited 2026 Aug 19;13(3):258. doi: 10.3390/pathogens13030258

[10] Tantely LM, Boyer S, Fontenille D. A Review of Mosquitoes Associated with Rift Valley Fever Virus in Madagascar. Am J Trop Med Hyg [Internet]. 2015 Apr 1, cited 2026 Aug 19;92(4):722–9. doi: 10.4269/ajtmh.14-0421

[11] Chemison A, Ramstein G, Jones A, Morse A, Caminade C. Ability of a dynamical climate sensitive disease model to reproduce historical Rift Valley Fever outbreaks over Africa. Sci Rep [Internet]. 2024 Feb 16, cited 2026 Aug 19;14(1):3904. doi: 10.1038/s41598-024-53774-x

[12] Lancelot R, Béral M, Rakotoharinome VM, Andriamandimby SF, Héraud JM, Coste C, Apolloni A, Squarzoni-Diaw C, de La Rocque S, Formenty PB, Bouyer J, Wint GR, Cardinale E. Drivers of Rift Valley fever epidemics in Madagascar. Proc Natl Acad Sci U S A [Internet]. 2017 Jan 31, cited 2026 Aug 19;114(5):938-943. doi: 10.1073/pnas.1607948114

[13] Nicolas G, Chevalier V, Tantely LM, Fontenille D, Durand B. A Spatially Explicit Metapopulation Model and Cattle Trade Analysis Suggests Key Determinants for the Recurrent Circulation of Rift Valley Fever Virus in a Pilot Area of Madagascar Highlands. PLoS Negl Trop Dis [Internet]. 2014 Dec 4, cited 2026 Aug 19;8(12):e3346 doi: 10.1371/journal.pntd.0003346

[14] World Organisation for Animal Health. Rift Valley fever [Internet]. Paris (France): World Organisation for Animal Health; 2025, cited 2026 Aug 19. [about 3 screens]. Available from: https://www.woah.org/en/disease/rift-valley-fever/

[15] Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JP, Clarke M, Devereaux PJ, Kleijnen J, Moher D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. BMJ [Internet]. 2009 Jul 21, cited 2026 Aug 19;339:b2700. doi: 10.1136/bmj.b2700

[16] Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA; PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev [Internet]. 2015 Jan 1, cited 2026 Aug 19;4(1):1. doi: 10.1186/2046-4053-4-1

[17] Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA; PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ [Internet]. 2015 Jan 2, cited 2026 Aug 19;350:g7647. doi: 10.1136/bmj.g7647 Erratum in: BMJ [Internet]. 2016 Jul 21, cited 2026 Aug 19;354:i4086. doi: 10.1136/bmj.i4086

[18] Nepomichene TNJJ, Raharimalala FN, Andriamandimby SF, Ravalohery JP, Failloux AB, Heraud JM, Boyer S. Vector competence of Culex antennatus and Anopheles coustani mosquitoes for Rift Valley fever virus in Madagascar. Med Vet Entomol [Internet]. 2018 Jun, cited 2026 Aug 19;32(2):259-262. doi: 10.1111/mve.12291

[19] Olive MM, Chevalier V, Grosbois V, Tran A, Andriamandimby SF, Durand B, Ravalohery JP, Andriamamonjy S, Rakotomanana F, Rogier C, Heraud JM. Integrated Analysis of Environment, Cattle and Human Serological Data: Risks and Mechanisms of Transmission of Rift Valley Fever in Madagascar. PLoS Negl Trop Dis [Internet]. 2016 Jul 14, cited 2026 Aug 19;10(7):e0004827. doi: 10.1371/journal.pntd.0004827 Erratum in: PLoS Negl Trop Dis [Internet]. 2016 Aug 24, cited 2026 Aug 19;10(8):e0004976. doi: 10.1371/journal.pntd.0004976

[20] Morvan J. Plus de 100 cas humains de fièvre de la vallée du Rift signalés à Madagascar [More than 100 human cases of Rift Valley fever reported in Madagascar]. MesVaccins [Internet]. 2025 Nov 26, cited 2026 Aug 19. [about 1 screen]. Available from: https://www.mesvaccins.net/web/news/17535-plus-de-100-cas-humains-de-fievre-de-la-vallee-du-rift-signales-a-madagascar French

[21] Nicolas G, Chevalier V, Durand B, Fontenille D. Diffusion de la fièvre de la Vallée du Rift par les mouvements de bovins : modélisation de la circulation virale dans un écosystème tempéré et montagneux, l'exemple de Madagascar [Rift Valley

fever spreading by cattle movements: modelling of the viral circulation in a temperate and mountainous ecosystem of Madagascar] [Thesis on the Internet]. Montpelier (France): Université Montpellier II; 2013 Dec 16, cited 2026 Aug 19. 163 p. Available from: https://agritrop.cirad.fr/577698/1/NICOLAS_2013_archivage.pdf French

[22] Chevalier V, Rakotondrafara T, Jourdan M, Heraud JM, Andriamanivo HR, Durand B, Ravaomanana J, Rollin PE, Rakotondravao R. An unexpected recurrent transmission of Rift Valley fever virus in cattle in a temperate and mountainous area of Madagascar. PLoS Negl Trop Dis [Internet]. 2011 Dec [cited 2026 Aug 19;5(12):e1423. doi: 10.1371/journal.pntd.0001423

[23] Zeller HG, Rakotoharinadrasana HT, Rakoto Andrianarivelo M. La fièvre de la vallée du Rift à Madagascar : risques d'infection pour le personnel d'abattoir à Antananarivo [Rift Valley fever in Madagascar: infection risks for slaughterhouse workers in Antananarivo]. Rev Elev Med Vet Pays Trop [Internet]. 1998 Jan 1, cited 2026 Aug 19;51(1):17–20. doi: 10.19182/remvt.9646

[24] Clerc Y, Rodhain F, Digoutte JP, Tesh R, Heme G, Coulanges P. Le virus Périnet, rhabdoviridae, du genre vésiculovirus isolé à Madagascar de Culicidés [The Perinet virus, rhabdoviridae, of the vesiculovirus type isolated in Madagascar from Culicidae]. Arch Inst Pasteur Madagascar [Internet]. 1982, cited 2026 Aug 19;49(1):119-29. French

[25] Fontenille D, Mathiot C, Rodhain F, Coulanges P. Les arboviroses dans la région de Nosy-Bé, Madagascar. Données sérologiques et entomologiques [Arboviroses in the region of Nosy-Bé, Madagascar. Serologic and entomologic data]. Bull Soc Pathol Exot Filiales [Internet]. 1988, cited 2026 Aug 19;81(1):58-70. French

[26] Morvan J, Rollin PE, Laventure S, Rakotoarivony I, Roux J. Rift Valley fever epizootic in the central highlands of Madagascar. Res Virol [Internet]. 1992 Nov-Dec, cited 2026 Aug 19;143(6):407-15. doi: 10.1016/s0923-2516(06)80134-2

[27] Jeanmaire EM, Rabenarivahiny R, Biarmann M, Rabibisoa L, Ravaomanana F, Randriamparany T, Fy Andriamandimby S, Diaw CS, Fenozara P, De La Rocque S, Reynes JM. Prevalence of Rift Valley Fever Infection in Ruminants in Madagascar After the 2008 Outbreak. Vector-Borne and Zoonotic Diseases [Internet]. 2011 Apr, cited 2026 Aug 19;11(4):395–402. doi: 10.1089/vbz.2009.0249

[28] Harimanana AN, Andriamandimby SF, Ranoaritiana DB, Randrianasolo L, Irinantenaina J, Ranoelison NN, Rafisandrantatsoa JT, Ankasitrahana MF, Raherinandrasana AH, Andriamahatana MV, Tantely ML, Girod R, Dussart P, Lacoste V, Randremanana RV. The Re-Emergence of Rift Valley Fever in Mananjary District, Madagascar in 2021: A Call for Action. Pathogens [Internet]. 2024 Mar 16, cited 2026 Aug 19;13(3):257. doi: 10.3390/pathogens13030257

[29] Anyamba A, Chretien JP, Small J, Tucker CJ, Formenty PB, Richardson JH, Britch SC, Schnabel DC, Erickson RL, Linthicum KJ. Prediction of a Rift Valley fever outbreak. Proc Natl Acad Sci USA [Internet]. 2009 Jan 20, cited 2026 Aug 19;106(3):955–9. doi: 10.1073/pnas.0806490106

[30] Kimble JB, Noronha L, Trujillo JD, Mitzel D, Richt JA, Wilson WC. Rift Valley Fever. Vet Clin North Am Food Anim Pract [Internet]. 2024 Jul, cited 2026 Aug 19;40(2):293–304. doi: 10.1016/j.cvfa.2024.01.004

[31] Tariku F, Rebuma T. A Review of Rift Valley Fever: Its Epidemiology and Economic Impact on Livestock. Open Access J Vet Sci Res [Internet]. 2024 Jul 24, cited 2026 Aug 19;9(2):0–0. doi: 10.23880/oajvsr-16000267

[32] Gibson S, Noronha LE, Tubbs H, Cohnstaedt LW, Wilson WC, Mire C, et al. The increasing threat of Rift Valley fever virus globalization: strategic guidance for protection and preparation. J Med Entomol [Internet]. 2023 Nov 14, cited 2026 Aug 19;60(6):1197–213. doi: 10.1093/jme/tjad113

[33] Anyamba A, Chretien JP, Britch SC, Soebiyanto RP, Small JL, Jepsen R, Forshey BM, Sanchez JL, Smith RD, Harris R, Tucker CJ, Karesh WB, Linthicum KJ. Global Disease Outbreaks Associated with the 2015–2016 El Niño Event. Sci Rep [Internet]. 2019 Feb 13, cited 2026 Aug 19;9(1):1930. doi:

[34] Mohapatra RK, Kutikuppala LVS, Kandi V, Mishra S, Rabaan AA, Costa S, et al. Rift valley fever (RVF) viral zoonotic disease steadily circulates in the Mauritanian animals and humans: A narrative review. Health Sci Rep [Internet]. 2023 Jul 2, cited 2026 Aug 19;6(7):e1384. doi: 10.1002/hsr2.1384

[35] Morvan J, Rollin PE, Roux J. Situation de la fièvre de la vallée du Rift à Madagascar en 1991. Enquêtes séro-épidémiologiques chez les bovins [Status of Rift Valley fever in Madagascar in 1991. Sero-epidemiological surveys in cattle]. Rev Elev Med Vet Pays Trop [Internet]. 1992 Feb 1, cited 2026 Aug 19;45(2):121–7. doi: 10.19182/remvt.8935

[36] Sow A, Faye O, Ba Y, Diallo D, Fall G, Faye O, Bob NS, Loucoubar C, Richard V, Dia AT, Diallo M, Malvy D, Sall AA. Widespread Rift Valley Fever Emergence in Senegal in 2013–2014. Open Forum Infectious Diseases [Internet]. 2016 May 1, cited 2026 Aug 19;3(3):ofw149. doi: 10.1093/ofid/ofw149

[37] Anyamba A, Damoah R, Kemp A, Small JL, Rostal MK, Bagge W, Cordel C, Brand R, Karesh WB, Paweska JT. Climate Conditions During a Rift Valley Fever Post-epizootic Period in Free State, South Africa, 2014-2019. Front Vet Sci [Internet]. 2022 Jan 31, cited 2026 Aug 19;8:730424. doi: 10.3389/fvets.2021.730424

[38] Leedale J, Jones AE, Caminade C, Morse AP. A dynamic, climate-driven model of Rift Valley fever. Geospatial Health [Internet]. 2016 Mar 31, cited 2026 Aug 19;11(1 Suppl):394. doi: 10.4081/gh.2016.394

[39] Rich KM, Wanyoike F. An Assessment of the Regional and National Socio-Economic Impacts of the 2007 Rift Valley Fever Outbreak in Kenya. Am J Trop Med Hyg [Internet]. 2010 Aug 5, cited 2026 Aug 19;83(2 Suppl):52–7. doi: 10.4269/ajtmh.2010.09-0291

[40] Gerdes GH. Rift Valley fever. Rev Sci Tech Int Off Epizoot [Internet]. 2004 Aug, cited 2026 Aug 19;23(2):613–23. doi: [10.20506/rst.23.2.1500]

[41] Soti V, Tran A, Degenne P, Chevalier V, Lo Seen D, Thiongane Y, Diallo M, Guégan JF, Fontenille D. Combining Hydrology and Mosquito Population Models to Identify the Drivers of Rift Valley Fever Emergence in Semi-Arid Regions of West Africa. PLoS Negl Trop Dis [Internet]. 2012 Aug 21, cited 2026 Aug 19;6(8):e1795. doi: 10.1371/journal.pntd.0001795

[42] Bird BH, Ksiazek TG, Nichol ST, MacLachlan NJ. Rift Valley fever virus [Internet]. 2009 Apr 1, cited 2026 Aug 19. doi: 10.2460/javma.234.7.883

[43] Nabeth P, Kane Y, Abdalahi MO, Diallo M, Ndiaye K, Ba K, Schneegans F, Sall AA, Mathiot C. Rift Valley fever outbreak, Mauritania, 1998: seroepidemiologic, virologic, entomologic, and zoologic investigations. Emerg Infect Dis [Internet]. 2001 Nov-Dec, cited 2026 Aug 19;7(6):1052-4. doi: 10.3201/eid0706.010627

[44] Nanyingi MO, Munyua P, Kiama SG, Muchemi GM, Thumbi SM, Bitek AO, Bett B, Muriithi RM, Njenga MK. A systematic review of Rift Valley Fever epidemiology 1931–2014. Infection Ecology Epidemiology [Internet]. 2015 Jan 31, cited 2026 Aug 19;5(1):28024. doi: 10.3402/iee.v5.28024

[45] LaBeaud AD, Muchiri EM, Ndzovu M, Mwanje MT, Muiruri S, Peters CJ, et al. Interepidemic Rift Valley Fever Virus Seropositivity, Northeastern Kenya. Emerg Infect Dis [Internet]. 2008 Aug, cited 2026 Aug 19;14(8):1240–6. doi: 10.3201/eid1408.080082

[46] Peyre M, Chevalier V, Abdo-Salem S, Velthuis A, Antoine-Moussiaux N, Thiry E, Roger F. A Systematic Scoping Study of the Socio-Economic Impact of Rift Valley Fever: Research Gaps and Needs. Zoonoses and Public Health [Internet]. 2015 Aug, cited 2026 Aug 19;62(5):309–25. doi: 10.1111/zph.12153

[47] Alders R. Preventing pandemics, improving food security: sustainable control of vaccine preventable animal disease in resource-limited settings [Internet]. 2024, cited 2026 Aug 19. Available from: https://www.cambridge.org/engage/coe/article-details/65ff92209138d23161267cec doi: 10.33774/coe-2024-nb74q

[48] Bett B, Randolph D, McDermott J. Africa's growing risk of diseases that spread from animals to people [Internet]. Washington, DC: International Food Policy Research Institute; 2020 Jun 1, cited 2026 Aug 19. Available from: https://hdl.handle.net/10568/108990 doi: 10.2499/p15738coll2.133762$_2$8

[49] Evans MV, Rajaonarifara E, Garchitorena A, Ralaivavikoa FA, Rahajatiana PE, Finnegan KE, Cordier L, Rakotonirina L, Razafinjato B, Randrianjatovo TM, Révillion C, Mbimbisoa MJ, Bonds MH. Designing and Evaluating a Health System Resilient to Extreme Weather Events in Rural Madagascar. Ann Glob Health [Internet]. 2025 Jul 22, cited 2026 Aug 19;91(1):40. doi: 10.5334/aogh.4759

[50] Sindato C, Karimuribo E, Mboera LEG. The epidemiology and socio-economic impact of rift valley fever epidemics in Tanzania: a review. Tanzan J Health Res [Internet]. 2011 Dec, cited 2026 Aug 19;13(5 Suppl 1):305–18. doi: 10.4314/thrb.v13i5.1

[51] Gachohi JM, Bett B, Njogu G, Mariner JC, Jost CC. The 2006-2007 Rift Valley fever outbreak in Kenya: sources of early warning messages and response measures implemented by the Department of Veterinary Services. Rev Sci Tech Int Off Epizoot [Internet]. 2012 Dec, cited 2026 Aug 19;31(3):877–87. Available from: doi: 10.20506/rst.31.3.2163

[52] FAO. Principaux défis du point de vue de la sécurité alimentaire et de l'agriculture [Key challenges from the perspective of food security and agriculture] [Internet]. Rome (Italy): FAO; 2011, cited 2026 Aug 19. Available from: https://www.fao.org/4/i2307f/i2307f01.pdf French

[53] Nicolas G, Chevalier V, Duboz R. Description et analyse des mouvements commerciaux des bovins sur les Hautes Terres de Madagascar et leur rôle potentiel dans la dissémination de la FVR [Description and analysis of cattle trade movements in the Highlands of Madagascar and their potential role in the spread of RVF] [Internet]. Montpellier (France): Université Montpellier II; 2010, cited 2026 Aug 19. 63 p. Available from:https://agritrop.cirad.fr/561535/1/document_561535.pdf French

[54] Ratovonjato J, Olive MM, Tantely LM, Andrianaivolambo L, Tata E, Razainirina J, Jeanmaire E, Reynes JM, Elissa N. Detection, Isolation, and Genetic Characterization of Rift Valley Fever Virus from Anopheles (Anopheles) coustani, Anopheles (Anopheles) squamosus, and Culex (Culex) antennatus of the Haute Matsiatra Region, Madagascar. Vector-Borne and Zoonotic Diseases [Internet]. 2011 Jun, cited 2026 Aug 19;11(6):753–9. doi: 10.1089/vbz.2010.0031

[55] Olive MM, Grosbois V, Tran A, Nomenjanahary LA, Rakotoarinoro M, Andriamandimby SF, Rogier C, Heraud JM, Chevalier V. Reconstruction of Rift Valley fever transmission dynamics in Madagascar: estimation of force of infection from seroprevalence surveys using Bayesian modelling. Sci Rep [Internet]. 2017 Jan 4, cited 2026 Aug 19;7(1):39870. doi: 10.1038/srep39870

[56] Tantely ML, Guis H, Raharinirina MR, Ambinintsoa MF, Randriananjantenaina I, Velonirina HJ, Revillion C, Herbreteau V, Tran A, Girod R. Mosquito dynamics and their drivers in peri-urban Antananarivo, Madagascar: insights from a longitudinal multi-host single-site survey. Parasites Vectors [Internet]. 2024 Sep 10, cited 2026 Aug 19;17(1):383. doi: 10.1186/s13071-024-06393-4