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ARTÍCULOS / *ARTICLES*

TERRITORIALITY OF EBOLA EPIDEMICS IN AFRICA (1976 - APRIL 2025): *STORYMAPS* VISUALIZING TOOL

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Abstract: This work is situated within the field of health geography. It investigates epidemics caused by the Ebola virus from the identification of the disease in 1976 through April 2025. It is focused on those originating *in situ* from a primary zoonotic case and classified by the causative *Orthoebolavirus*. The aim is to examine their relationships with climate and average altitude as physical and environmental factors influencing their emergence. The study includes a temporal ordering of epidemics and an analysis of the historical evolution of fatality rates, using a mixed quantitative and qualitative methodology. The results reveal gaps and inconsistencies in the understanding of the disease, which could serve as a starting point for future research. The ESRI® StoryMaps tool has been utilized to visualize the employed cartography, facilitate the dissemination of results in affected countries, and fulfil an educational purpose.

Keywords: Health geography, geographic factors, physical environment, environmental determinants, territory, fatality rate, Ebola, sub-Saharan Africa.

TERRITORIALIDAD DE LAS EPIDEMIAS DE ÉBOLA EN ÁFRICA (1976 – ABRIL 2025): VISUALIZACIÓN CON LA HERRAMIENTA *STORYMAPS*

Resumen: El presente trabajo se enmarca en el campo de la geografía de la salud. Se investigan las epidemias producidas por el virus del Ébola desde la identificación de la enfermedad en 1976 hasta abril de 2025. Se han considerado las originadas *in situ* a partir de un caso primario zoonótico y en función del *Orthoebolavirus* causante, con el fin de observar sus relaciones con el clima y la altitud media en cuanto factores físicos y ambientales que influyen en su aparición. Se completa con una ordenación temporal de las epidemias y un estudio de la evolución histórica de las tasas de letalidad utilizando una metodología mixta, cuantitativa y cualitativa. Los resultados identifican lagunas e incongruencias en el conocimiento de la enfermedad que servirán de punto de partida para futuras investigaciones. Se ha utilizado la herramienta *StoryMaps* de ESRI ®para visualizar la cartografía empleada, facilitar la difusión de los resultados en los países donde se producen las epidemias y cumplir una función didáctica.

Palabras Clave: Geografía de la salud, factores geográficos, medio físico, condicionantes ambientales, territorio, tasa de letalidad, ébola, África subsahariana.

1. INTRODUCTION AND OBJECTIVES

Geographical science is a discipline that studies the spatial, socioeconomic, and geopolitical consequences of the relationships between humans and the environment in which they live. Health geography, which focuses on the relationships between the environment and human health, is essential at a time when infectious diseases tend to globalize. Zika, chikungunya, dengue, mpox, and COVID-19 serve as examples of the emergence, re-emergence, and new geographic distributions of infectious diseases. Health geography is also concerned with the relationship between disease, human activity, and inequality (Jori, 2013), and therefore studies the evolution and trends of diseases such as cholera.

The hemorrhagic fever caused by the Ebola virus was first identified simultaneously in 1976 in Nzara (South Sudan) and Yambuku (Democratic Republic of the Congo [DRC]). It is an infectious disease that is naturally transmitted from animals to humans, representing a specific case of zoonosis, a term used for diseases transmitted among various species, including humans (*Real Academia Nacional de Medicina de España*, 2023). Once humans are infected, the disease spreads through direct contact with patients, their secretions, or contaminated fomites, with unsafe burials and caregiving being the main sources of infection.

It is caused by viruses of the Filoviridae family, genus *Orthoebolavirus*, which includes the species *taïense* (TAFV), *sudanense* (SUDV), *zairense* (EBOV), *restonense* (RESTV), *bundibugyoense* (BDBV), and *bombaliense* (BOMV) (World Health Organization [WHO], 2023; Centers for Disease Control and Prevention [CDC], 2025a). The RESTV and TAFV species are not dangerous to humans, and BOMV, recently discovered and with no known epidemics, also appears not to be (Bodmer *et al.*, 2023). In contrast, EBOV, BDBV, and SUDV cause severe disease in humans. Some bat species are being studied as potential natural reservoirs (Pourrut *et al.*, 2009), although it is not ruled out that these animals may be secondary reservoirs infected through contact with amoebas living in water stored in tree holes (Kollars *et al.*, 2018).

The symptoms of the disease are nonspecific, making early diagnosis difficult. Contagion only occurs from patients with clear symptoms, with fever being one of the main indicators. Therefore, taking temperatures at critical points, such as home, work, shops, and roads, is essential for detecting possible cases. If someone has a fever, they are provisionally isolated at home or in a Transit Center (TC) while tests are conducted. If positive, they are admitted to one Ebola Treatment Center (ETC), which is always the best option. In confirmed cases, contact tracing is conducted, creating a list of people who can continue their normal lives without isolation but must have their temperature checked twice daily (WHO, 2023).

Regarding treatments (WHO, 2022a), and specifically for epidemics caused by the *Zaire Orthoebolavirus*, two Randomized Controlled Trials (RCTs) have been conducted. PREVAIL II, carried out in 2015 during the West Africa epidemic, highlighted the efficacy of ZMapp (PREVAIL, 2016), while PALM, conducted in 2018 during the Kivu-Ituri epidemic, ruled out ZMapp and Remdesivir, recommending the use, though never simultaneously, of the monoclonal antibodies mAb114 and REGN-EB3 (PALM, 2019), commercially known as EBANGA and INMAZEB (Sivanandy *et al.*, 2022). Also, for the *Zaire* species, and only for it, two vaccines are available (WHO, 2020): Ervebo, administered in a single dose for ring vaccination during ongoing epidemics, and Zabdeno/Mvabea, which requires two doses six weeks apart and is therefore not useful once an area has been reached by the epidemic. It is used only for mass vaccination when there is a risk of the epidemic spreading, for example, to a large city. For the disease caused by the *Sudan Orthoebolavirus*, several vaccines are under study but not yet approved. One of them, rVSV SUDV, was tested during the 2025 Uganda epidemic, though results are still pending (*Comité Asesor de Vacunas de la Asociación Española de Pediatría*, 2023; WHO, 2025a). Future challenges include: i) developing treatments effective against any *Orthoebolavirus* species; ii) providing early care, as it has been shown that each day of delay in treatment after symptom onset reduces survival chances by 12%; iii) ensuring adequate resources in ETCs, such as dialysis, blood banks, or oxygen therapy; and iv) supporting survivors, as social stigmatization is believed to persist for an average of eight years after recovery (Rojek, Fieggen, Apiyo *et al.*, 2025; Rojek, Fieggen, Paterson *et al.*, 2025).

Orthoebolaviruses jump from their natural reservoirs to humans due to human interaction with forests in contexts of poverty and weak healthcare systems (Metidieri and Pelozo, 2021). Notable among these are the studies by Olivero (2020) on rainforests, where, as confirmed in this work, primary cases occur; Snowden (2019), who explained how the 2013–2016 West Africa Ebola epidemic originated from hundreds of bats

living in trees in Meliandou (Guinea), an area deforested for agriculture; and Laporta (2014), who proposed that the overlap between anthropogenic landscapes and forest patches may be a factor influencing the emergence of the disease.

To explore these and other studies linking Ebola and geography, a literature search was conducted in the databases listed in Table 1. These include African Journals Online (AJOL), specializing in African scientific output; BIOLINE, which compiles health publications from developing countries; and PROSPERO, where protocols for Cochrane systematic reviews in progress are registered. The search expression ((Geography AND Ebola) OR (Geografía AND Ébola)) was used in any field, limiting results to open-access, peer-reviewed online resources published between 2014 and April 2025, yielding 361 results distributed as shown in the same table.

Table 1.
NUMBER OF ARTICLES FOUND IN EACH DATABASE

Database	Search results
PUBMED	73
Biblioteca Virtual de Salud (BVS)	60
UNED search engine (WOS, SCOPUS, SCIELO and up to 72 databases)	166
EMBASE	Access was not possible
African Journals Online (AJOL)	57
BIOLINE	1
PROSPERO	4
TOTAL	*361*

Source: Own elaboration using the databases mentioned.

After screening, 60 articles were identified within the field of health geography that link the disease to the territory and address four thematic groups (Table 2).

Table 2.
RELEVANT STUDY TOPICS FOR OUR WORK FOUND IN THE SEARCH "GEOGRAPHY AND EBOLA," INDICATING THE NUMBER OF ARTICLES THAT ADDRESS THEM

Topic	No. of articles
Spatial distribution of the virus and study of its natural reservoirs	21
Internal expansion of epidemics	25
Critical epidemiology	10
Specific cartography as support for controlling ongoing epidemics	4
TOTAL	60

Source: Own elaboration.

It is observed that the main topic of study is the spatial distribution of the virus and its natural reservoirs. This is followed by the internal spread of epidemics and critical epidemiology, which links epidemics to the weakness of the State, the healthcare system infrastructure, economic activity, poverty levels, and violence. Finally, cartography appears as a fundamental tool for controlling active epidemics.

In this context, our work is framed, focusing on the analysis of the relationships between epidemics and the territory in which they occur, considering the species of *Orthoebolavirus* responsible, aiming for a comprehensive spatiotemporal overview and providing visualization through a Digital Storytelling Map (DSM),

as explained in the methodology. None of the articles found in the literature search combine all these elements: Ebola disease, its relationship with the territory depending on the *Orthoebolavirus* species, and explanation through DSM.

This study investigates documented Ebola epidemics that originated in situ from a primary zoonotic case and have occurred since the disease was identified in 1976 until the end of April 2025, when the last epidemic before the writing of this paper concluded. Epidemics caused by travellers, those occurring in laboratories, and relapses caused by former patients have been excluded.

The specific objectives are: i) to relate the emergence of epidemics, depending on the species of *Orthoebolavirus* causing them, to the physical territory and climate; ii) to observe the evolution of fatality rates from 1976 to 2025, study their variations according to the causative *Orthoebolavirus*, and analyse internal differences in the two most severe known epidemics; iii) to disseminate the results on the ArcGIS StoryMaps platform through a digital storytelling map (DSM) narrative, demonstrating that this tool is suitable for sharing information, especially in impoverished environments, and for doing so in an educational manner using ArcGIS Online maps and the cartography created using other tools; and iv) to identify gaps in the knowledge of the disease to be addressed in future research.

The paper is organized as follows: an introduction providing an overview of Ebola disease in the context of health geography, a literature review of studies on the disease, and a description of the objectives; followed by methodology and sources, presentation of results, discussion, conclusions, and references.

Demographic, social, economic, cultural, or historical aspects related to human geography and the disease, due to space limitations in this article and the need to streamline the work, will be addressed in other research, two of which are already underway: one entitled "Consequences of Ebola epidemics in Africa on the human and economic dimensions of local development in affected areas," and another that will examine their impact on the structure and spatial distribution of the population.

2. METHODOLOGY AND SOURCES

A mixed methodology was used, employing both qualitative and quantitative techniques. The qualitative component consisted of a literature review in specialized databases to understand the current state of research, and the identification, for each epidemic, of the location where the primary case occurred. According to the *Real Academia Nacional de Medicina de España* (2023), this is the case that introduced the disease into a community. The quantitative component involved collecting the following data for each epidemic: i) geographic coordinates of the location of the primary case; ii) start and end dates; iii) average monthly temperature and precipitation, annual average temperature, total annual precipitation, and altitude above sea level of the location of the primary case; iv) number of cases and deaths.

This information made it possible to situate the epidemics in both space and time, relate them to the physical environment and climate, and identify patterns. It also allowed for the analysis of their case fatality rates, defined as the percentage of deaths relative to the total number of people who contracted the disease. These rates were calculated by including confirmed, suspected, and probable cases. According to the World Health Organization, suspected cases are those that meet all symptoms and have had contact with another case but have not been assessed by a physician; if a physician identifies it as Ebola, it is considered a probable case; confirmed cases are those with laboratory confirmation (WHO, 2014). Suspected and probable cases are generally deceased individuals who were buried without laboratory testing. Including all three types of cases was considered the most accurate way to reflect reality, which may lead to differences with other studies that only consider confirmed cases.

Information on the epidemics was obtained from the WHO Institutional Repository for Information Sharing (IRIS), which includes documents such as External Situation Reports (SITREPs), Disease Outbreak News (DONs), Weekly Epidemiological Records (WERs), and the Weekly Bulletin on Outbreaks and Other Emergencies. Data were also sourced from the U.S. CDC. Temperature, precipitation, biomes, ecoregions, and elevation data, necessary to relate the origin of epidemics to the physical environment, were obtained through ArcGIS StoryMaps from layers integrated into the DSM.

The level of disaggregation achieved was generally provincial, depending on data availability. In the case of the Democratic Republic of the Congo (DRC), it was possible to reach the level of Health Zones. The DRC's healthcare system is organized into three levels: central (national), intermediate (provincial), and peripheral. The peripheral system consists of 515 Health Zones (HZs), which are "the operational units for planning and implementing the country's health policy." Each HZ serves an average of 150,000 people, has a General Referral Hospital, and is composed of Health Areas, basic units with a Health Center serving between 5,000 and 10,000 people (Republique Democratique du Congo [RDC], 2011). In the provinces of North Kivu and Ituri, data were handled at the HZ level. North Kivu, with 59,483 km², had in 2019 (when the epidemic occurred) 7,574,000 inhabitants distributed across 34 HZs, each covering an average of 1,750 km² and serving 223,000 people. Ituri, with 4,008,000 inhabitants and 65,658 km², was organized into 31 HZs, each serving an average of 129,000 people and 2,118 km² (RDC, 2019; *Institut National de la Statistique de la RDC*, 2021).

A point layer in shapefile format (ESRI) was created using the free GIS software gvSIG, projected in WGS84, with coordinates of the primary case locations obtained from GeoNames, OpenStreetMap (OSM), and Google Earth. When the exact location was unknown, an arbitrary point within the area where the epidemic began was chosen. These points were overlaid in the cloud-based GIS ArcGIS Online (AGOL) with other data sources containing physical and climate information in shapefile or raster formats. This allowed the correlation of primary cases with physical conditions of the territory, enabling the creation of maps or extraction of data for graphs and climographs. Climographs were drawn for each point to identify the climate according to the Köppen classification. The y-axes were designed to easily visualize dry months as defined by the Gaussen index, those where the precipitation curve falls below the average monthly temperature curve. The x-axis starts in January for locations in the Northern Hemisphere and in July for those in the Southern Hemisphere, facilitating comparison between climographs. Box plots were used to study variables based on the causative *Orthoebolavirus*.

To visualize the results, a Digital Storytelling Map (DSM), was created using the ArcGIS StoryMaps tool from the Environmental Systems Research Institute (ESRI®) demonstrate that this is a suitable tool for disseminating scientific information in impoverished environments where access is often via mobile phones. A DSM is a web-based narrative that integrates various types of data and resources from different sources (texts, tables, graphs, maps, podcasts, photos, videos, other images, and web links), accessible anytime and anywhere via an internet-connected mobile device. A long-scroll format design was chosen for the StoryMaps (Roth, 2021), where the narrative is displayed vertically with indefinite length, allowing continuous scrolling that is especially suitable for such devices. It includes interactive maps with the same vector and raster layers used in this study, enabling users to explore the research further or apply the methodology, thus fulfilling an educational function and promoting access to scientific information, which is not always easy in developing countries (Sánchez, 2007). It also includes supplementary information not typically included in an article, such as tables, photographs, timelines, or texts that help contextualize the studied epidemics. It is available online at: https://storymaps.arcgis.com/stories/43f5c07c4f7a4cfc841936372ffdfb48 (Barra, 2025).

3. RESULTS

3.1. Documented Epidemics in the Period 1976 – April 2025

3.1.1. Classification by the Causative *Orthoebolavirus*

The 46 documented Ebola epidemics have been classified according to the *Orthoebolavirus* responsible (Table 3). Of these, 39 were caused by the Zaire, Sudan, and Bundibugyo *Orthoebolaviruses*, the species known to cause severe disease in humans.

These 39 epidemics can, in turn, be classified according to how the primary case occurred, allowing us to select those that originated *in situ* through zoonosis. After excluding those caused by travellers, those that occurred in laboratories, and relapses, 32 epidemics remain (Table 4). These 32 epidemics are the focus of this study.

TABLE 3.
DOCUMENTED EBOLA EPIDEMICS (1976 - APRIL 2025) BY *ORTHOEBOLAVIRUS* SPECIES RESPONSIBLE AND THEIR SEVERITY FOR HUMANS

Severity for humans	Orthoebolavirus species	No. of epidemics	Subtotal
Do not cause severe disease in humans	Taï Forest	1	7
	Reston	6	
Severely affect humans	Zaire	28	39
	Sudan	9	
	Bundibugyo	2	
Effect on humans unknown	Bombali	0	0
TOTAL		46	46

Source: Own elaboration based on the existing documentation for each epidemic in the WHO Institutional Repository (IRIS) (WHO, n.d.) and the U.S. Centres for Disease Control and Prevention (CDC, 2023).

TABLE 4.
CLASSIFICATION, BASED ON THEIR ORIGIN, OF EBOLA EPIDEMICS CAUSED BY THE ZAIRE, SUDAN, AND BUNDIBUGYO *ORTHOEBOLAVIRUSES* (1976 – APRIL 2025)

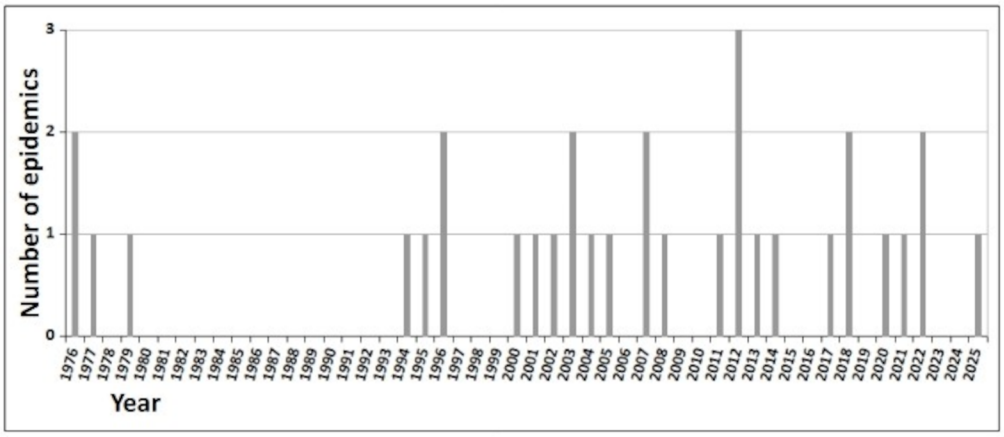
Place of Origin	Type of Transmission	No.
Originated in situ (primary case)	Zoonotic origin	32
	Recurrences	3
Imported	By travellers	1
	In laboratories, from biological material samples	3
TOTAL		39

Source: Own elaboration based on the existing documentation for each epidemic in the IRIS (WHO, n.d.) and the U.S. CDC (2023).

3.1.2. Evolution by Year

The temporal distribution of these 32 zoonotic-origin epidemics reveals a long 14-year period between 1980 and 1993 with no outbreaks (Fig. 1). After that, the disease began to appear with some regularity: 28 epidemics in 32 years, with more than one outbreak occurring in 1996, 2003, 2007, 2012, 2018, and 2022.

FIGURE 1.
TEMPORAL DISTRIBUTION OF ZOONOTIC-ORIGIN EBOLA EPIDEMICS FROM 1976 TO APRIL 2025 (NUMBER OF EPIDEMICS PER YEAR)



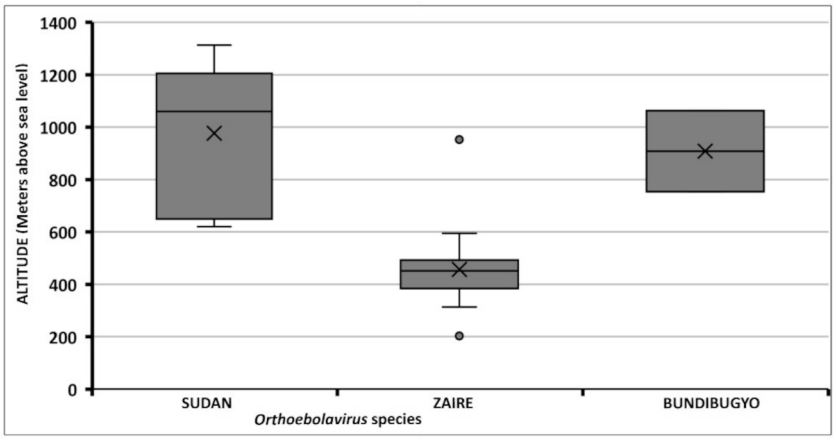
Source: Own elaboration based on data from IRIS (WHO, n.d.).

3.2. Relationship of the 32 Epidemics with Various Physical Environmental Elements Based on the Causative Orthoebolavirus

3.2.1. Relief and Altitude Above Sea Level

The point layer of primary cases was cross-referenced with the Terrain: Elevation Tinted Hillshade layer (ESRI, 2023a) in ArcGIS Online to obtain the altitude above sea level of the locations where those cases occurred. Based on the data obtained, a box plot was created (Fig. 2). It shows that the eight epidemics caused by the Sudan *Orthoebolavirus* occurred at elevations between 620 and 1,313 meters, with 50% of them falling between 649 and 1,205 meters, which correspond to the first and third quartiles of the diagram. The two epidemics caused by the Bundibugyo *Orthoebolavirus* occurred at 754 and 1,063 meters, respectively, while the epidemics caused by the Zaire *Orthoebolavirus* occurred at lower altitudes, around 400 meters, except for two outliers: one at 952 meters (Mabalako, in North Kivu) and another at 203 meters (Booué, in Gabon).

Figure 2.
ALTITUDE ABOVE SEA LEVEL OF LOCATIONS WHERE PRIMARY CASES OCCURRED, ACCORDING TO THE CAUSATIVE *ORTHOEBOLAVIRUS* SPECIES



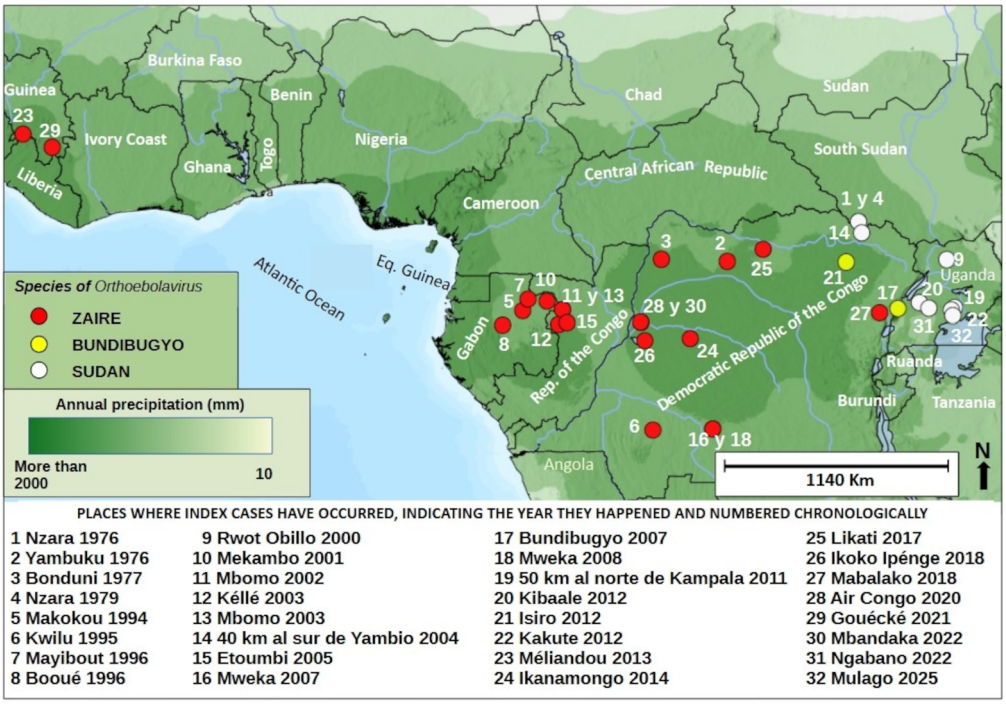
Source: Own elaboration based on data from IRIS (WHO, n.d.) and the Terrain: Elevation Tinted Hillshade layer (ESRI, 2023a).

3.2.2. Total Annual Precipitation

Figure 3 shows the locations where the primary cases occurred, indicating the species of causative *Orthoebolavirus*, over a map of total annual precipitation. Each epidemic has been assigned a number in chronological order, with the earliest being the Nzara outbreak, labelled as number 1.

It is observed that all primary cases are located within a narrow latitudinal band around the equator (between 4.65°N in Nzara and 5°S in Kikwit), except for the two located in Guinea-Conakry. The nine epidemics caused by the Sudan *Orthoebolavirus* are confined to Uganda and the area near the border between the DRC and South Sudan, with annual precipitation ranging from 1,000 to 2,000 mm, areas where no epidemics caused by other *Orthoebolaviruses* have occurred. The two epidemics caused by the Bundibugyo *Orthoebolavirus* occurred in northeastern Democratic Rupublic of the Congo and southwestern Uganda, with precipitation between 1,000 and 2,500 mm, in a zone that separates the group of epidemics caused by the Sudan virus from those caused by the Zaire species. The epidemics caused by the Zaire *Orthoebolavirus* occurred further west and in areas with 1,500 to 3,000 mm of annual precipitation. Overall, there is a longitudinal distribution of epidemics based on the causative *Orthoebolavirus*: Sudan in the east, Zaire in the west, and Bundibugyo in between. A correlation is also observed between total annual precipitation and the *Orthoebolavirus* species responsible for the epidemics, with the Zaire, Bundibugyo, and Sudan species appearing in that order from the wettest to the driest regions.

FIGURE 3.
ZOONOTIC-ORIGIN EBOLA EPIDEMICS (1976 – APRIL 2025) BY CAUSATIVE *ORTHOEBOLAVIRUS* SPECIES, CHRONOLOGICALLY ORDERED ON A MAP OF ANNUAL PRECIPITATION



PLACES WHERE INDEX CASES HAVE OCCURRED, INDICATING THE YEAR THEY HAPPENED AND NUMBERED CHRONOLOGICALLY

1 Nzara 1976	9 Rwot Obillo 2000	17 Bundibugyo 2007	25 Likati 2017
2 Yambuku 1976	10 Mekambo 2001	18 Mweka 2008	26 Ikoko Ipénge 2018
3 Bonduni 1977	11 Mbomo 2002	19 50 km al norte de Kampala 2011	27 Mabalako 2018
4 Nzara 1979	12 Kéllé 2003	20 Kibaale 2012	28 Air Congo 2020
5 Makokou 1994	13 Mbomo 2003	21 Isiro 2012	29 Gouécké 2021
6 Kwilu 1995	14 40 km al sur de Yambio 2004	22 Kakute 2012	30 Mbandaka 2022
7 Mayibout 1996	15 Etoumbi 2005	23 Méliandou 2013	31 Ngabano 2022
8 Booué 1996	16 Mweka 2007	24 Ikanamongo 2014	32 Mulago 2025

Source: Own elaboration using ArcGIS Online based on data from IRIS (WHO, n.d.), the U.S. CDC (2023), and the layers Average Annual Precipitation (ESRI, 2025), ne_10m_rivers_lake_centerlines, and ne_110m_lakes (Natural Earth Data, n.d.).

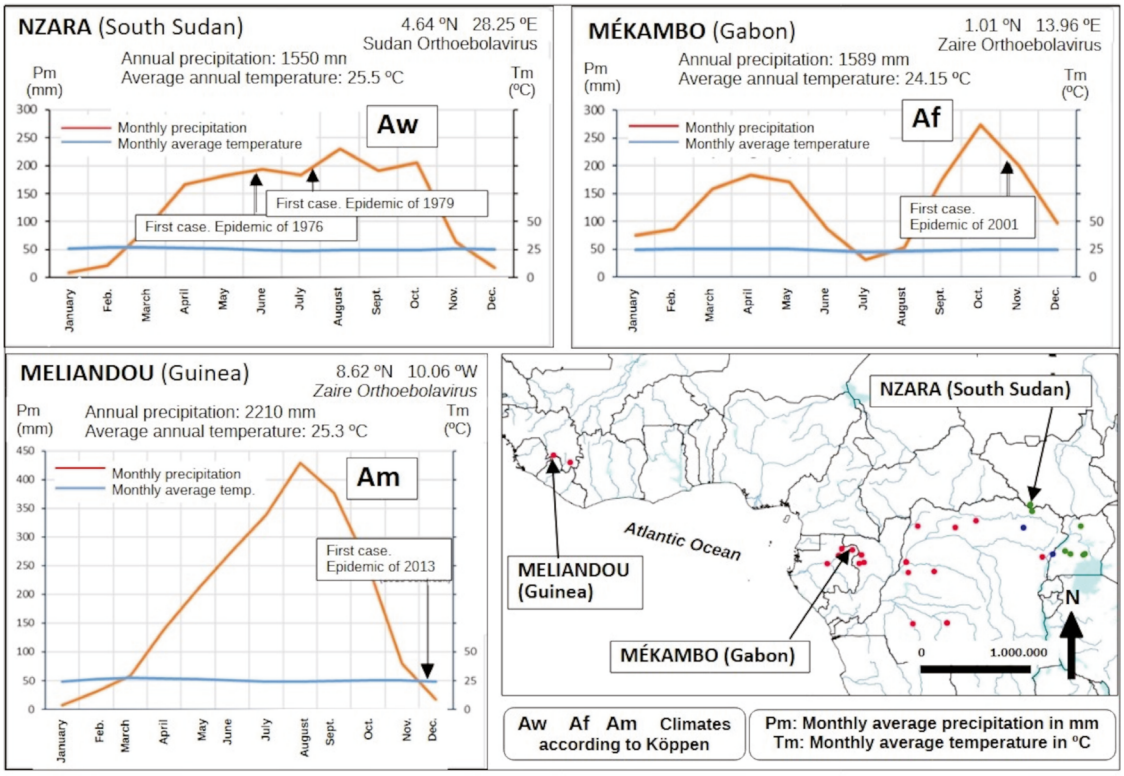
3.2.3. The Climate

Temperature and average monthly precipitation data for the locations where primary cases occurred were obtained from the Met Office Climate Data Portal of the UK's National Meteorological Service, using layers available in AGOL. Based on this data, corresponding climographs were created, from which the climate type of each location was determined according to the Köppen climate classification. Figure 4 presents three examples of the resulting climographs. The complete set of climographs can be viewed in the interactive map embedded in the StoryMaps associated with this study.

Three existing varieties of Köppen's climate type A, characterized by average monthly temperatures above 18°C and high annual precipitation, have been identified (Table 5). The Af variety, typical of latitudes very close to the equator, features two precipitation peaks and no dry season, and corresponds to equatorial rainforests. The Aw variety, with a dry season during the winter of its respective hemisphere, is typical of tropical savannas. The Am variety appears in Guinea and corresponds to a monsoon climate, with a peak in precipitation during the summer. This occurs when the southeast trade winds, loaded with moisture due to the warm Guinea Current, are drawn inland by the low-pressure system that forms over the Sahara in summer. These winds shift to blow from the southwest toward the continent, releasing heavy rainfall as they are forced upward by the Guinean Mountain Ridge. The emergence of a weak dry season in the transition between Af and Aw climates sometimes makes it difficult to distinguish between the two. Following Gaussen's definition of dry months, we have considered the climate to be Aw whenever the precipitation line in the climograph falls below the temperature line at any point.

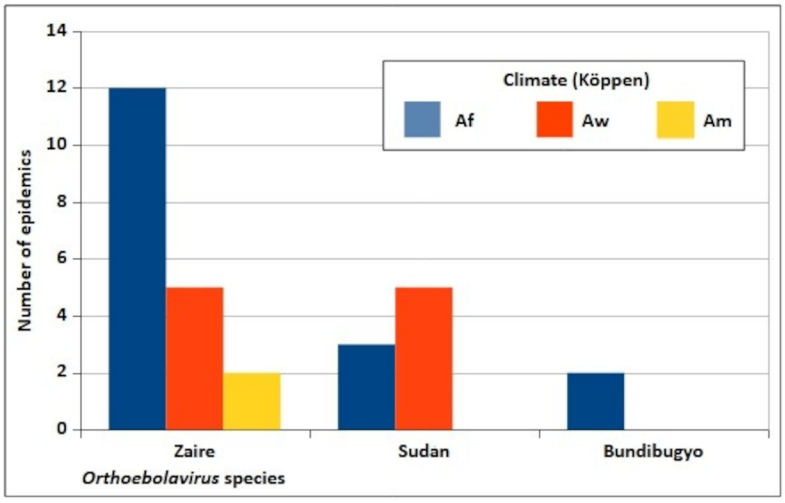
As shown in Figure 5, epidemics caused by Zaire *Orthoebolavirus* predominantly occur in Af climates, those caused by Sudan *Orthoebolavirus* mainly occur in Aw climates, and the two known cases caused by Bundibugyo *Orthoebolavirus* correspond to Af climates. In Am climates, only the Zaire species has been reported. Thus, Af is the predominant climate type among all recorded cases.

FIGURE 4.
CLIMOGRAPHS FOR NZARA (SOUTH SUDAN), MÉKAMBO (GABON), AND MELIANDOU (GUINEA-CONAKRY), INDICATING THEIR CORRESPONDING CLIMATE TYPES ACCORDING TO THE KÖPPEN CLIMATE CLASSIFICATION



Source: Own elaboration based on data extracted from the layers Monthly Global Temperature 1981–2010 (National Meteorological Service for the United Kingdom [Met Office], 2022a) and Monthly Global Precipitation 1981–2010 (Met Office, 2022b). The vertical arrows in the climographs, based on data from WHO (n.d.), indicate the moment when the primary case of the corresponding epidemic occurred.

FIGURE 5.
NUMBER OF EPIDEMICS OCCURRING IN EACH CLIMATE TYPE ACCORDING TO THE CAUSATIVE *ORTHOEBOLAVIRUS* SPECIES



Source: Own elaboration based on data extracted from IRIS (WHO, n.d.) and the layers Monthly Global Temperature 1981–2010 (Met Office, 2022a), Monthly Global Precipitation 1981–2010 (Met Office, 2022b).

TABLE 5.
CLIMATIC DATA OF LOCATIONS WHERE PRIMARY CASES OF THE 32 STUDIED EPIDEMICS OCCURRED, SORTED BY THE TYPE OF CAUSATIVE *ORTHOEBOLAVIRUS*

Primary Case Locality	Orthoebolavirus Species	Altitude (m)	Annual Precipitation (mm)	Annual Average Temperature (ºC)	Climate (Köppen)
Makokou	Zaire	475	1597	24,7	Af
Mayibout	Zaire	497	1572	24,8	Af
Mekambo	Zaire	503	1589	24,15	Af
Kéllé	Zaire	393	1671	24,82	Af
Mbomo	Zaire	489	1604	24,05	Af
Etoumbi	Zaire	393	1627	24,4	Af
Ikanamongo	Zaire	376	1890	25,28	Af
Likati	Zaire	423	1617	24,76	Af
Ikoko Ipenge	Zaire	344	1666	25,63	Af
Mabalako	Zaire	952	1276	19,66	Af
Air Congo	Zaire	326	1612	25,3	Af
Mbandaka	Zaire	314	1612	25,3	Af
Mweka	Zaire	595	1504	25,4	Aw
Yambuku	Zaire	483	1623	24,7	Aw
Bonduni	Zaire	413	1733	24,7	Aw
Booué	Zaire	203	1739	25	Aw
Meliandou	Zaire	471	2210	25,3	Am
Gouécké	Zaire	451	1942	24,57	Am
15 km north of Kikwit	Zaire	435	1606	25,5	Aw
50 km north of Kampala	Sudan	1112	1351	23,4	Af
Kakute	Sudan	1198	1351	23,44	Af
Kibaale	Sudan	1207	1179	22,83	Aw
Rwot Obillo	Sudan	1006	1248	25,1	Aw
40 km south of Yambio	Sudan	737	1600	25,2	Aw
Ngabano	Sudan	1313	1179	22,83	Aw
Nzara	Sudan	620	1550	25,5	Aw
Mulago	Sudan	1184	1393	22,8	Af
Isiro	Bundibugyo	754	1775	24,4	Af
Bundibugyo	Bundibugyo	1063	1187	22,5	Af

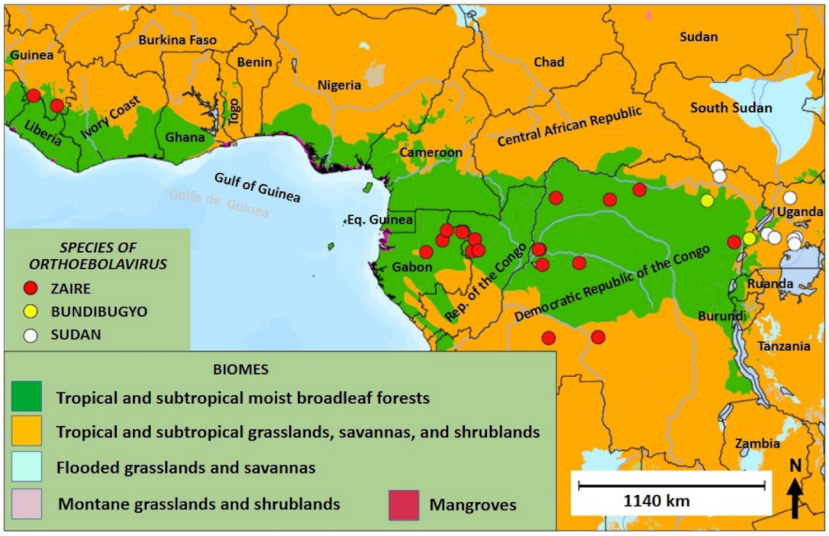
Source: Own elaboration based on data extracted from the WHO IRIS (n.d.) and the layers Monthly Global Temperature 1981–2010, Monthly Global Precipitation 1981–2010, and Terrain: Elevation Tinted Hillshade.

In the climographs, a vertical black arrow has been used to indicate the month (or months, in locations where more than one epidemic originated) in which the index case occurred, in order to observe whether there is any correlation with the season of the year. However, no clear patterns could be established.

3.2.4. Biomes

The information from the index cases layer was cross-referenced (Figure 6) with the Ecoregions and Biomes layer made available by the non-governmental organisation RESOLVE on ESRI AGOL platform (2023b), which represents the 14 biomes and 846 ecoregions defined by Olson *et al.* (2001) and modified by Dinerstein *et al.* (2017). It was found (Table 6) that 15 of the 19 index cases caused by Zaire *Orthoebolavirus* are located in the "tropical and subtropical moist broadleaf forests" biome; that 7 of the 9 caused by Sudan *Orthoebolavirus* appear in the "tropical and subtropical grasslands, savannas, and shrublands" biome; while the two epidemics caused by Bundibugyo *Orthoebolavirus* are located, according to the map, on the boundary between both biomes. The information on ecoregions presented in Table 6, although offering a higher level of detail, does not appear to provide additional insights beyond those already obtained from the biome classification.

FIGURE 6.
DOCUMENTED ZOONOTIC EBOLA OUTBREAKS (1976 – APRIL 2025) BY CAUSATIVE *ORTHOEBOLAVIRUS* SPECIES OVER A MAP SHOWING THE BIOMES DEFINED BY OLSON *ET AL.* (2001) AND MODIFIED BY DINERSTEIN *ET AL.* (2017)



Source: Own elaboration using ArcGIS Online based on data from IRIS, CDC (2023), and the layers RESOLVE Ecoregions and Biomes (ESRI, 2023b; Olson et al., 2001 and Dinerstein et al., 2017) and ne_110m_lakes (Natural Earth Data)

TABLE 6.
BIOMES AND ECOREGIONS OF LOCATIONS WHERE INDEX CASES OF THE STUDIED EPIDEMICS OCCURRED, ORGANIZED BY *ORTHOEBOLAVIRUS* SPECIES

Virus Species	Biome (Dinerstein *et al.*, 2017)	Ecoregion (Dinerstein *et al.*, 2017)	Primary Case Locality
Zaire	Tropical and Subtropical Moist Broadleaf Forests	Western Guinean lowland forests	Gouécké
		Central Congolian lowland forests	Ikanamongo Ikoko Ipenge
		Northeast Congolian lowland forests	Likati Mabalako Bonduni
		Northwest Congolian lowland forests	Makokou Mayibout Mekambo Kéllé Mbomo Etoumbi
		Eastern Congolian swamp forests	Air Congo Mbandaka
		Guinean forest-savanna	Meliandou
	Tropical and Subtropical Grasslands, Savannas, and Shrublands	Northeast Congolian lowland forests	Yambuku
		Western Congolian forest-savanna	Booué
		Southern Congolian forest-savanna	Mweka 15 km north of Kikwit
Sudan	Tropical and Subtropical Moist Broadleaf Forests	Albertine Rift montane forests	Kibaale Ngabano
	Tropical and Subtropical Grasslands, Savannas, and Shrublands	Victoria Basin forest-savanna	50 km north of Kampala Kakute Rwot Obillo Mulago
		Northern Congolian Forest-Savanna	40 km south of Yambio Nzara
Bundibugyo	Tropical and Subtropical Moist Broadleaf Forests	Northeast Congolian lowland forests	Isiro
	Tropical and Subtropical Grasslands, Savannas, and Shrublands	Albertine Rift montane forests	Bundibugyo

Source: Own elaboration based on the RESOLVE Ecoregions and Biomes layer (ESRI, 2023b; Olson et al., 2001 and Dinerstein et al., 2017).

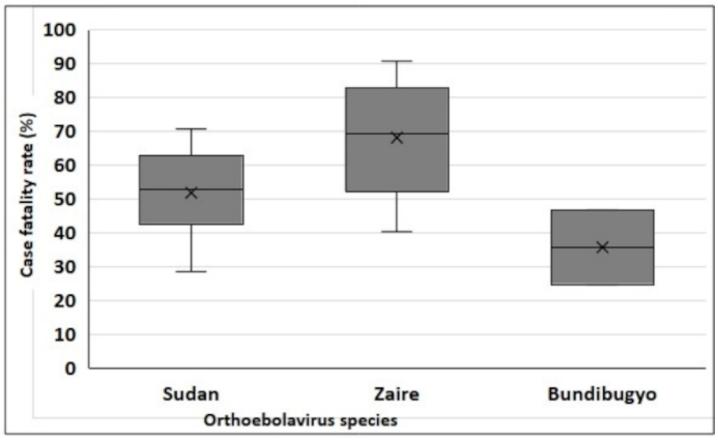
3.3. Case fatality rates

To study case fatality rates, the following aspects were investigated: i) their values according to the causative *Orthoebolavirus* species, ii) their evolution from 1976 to April 2025, and iii) internal differences in the case fatality rates of the 2013–2016 West Africa epidemic and the 2018–2020 northeastern DRC epidemic, in both cases due to their particular significance and the availability of data.

3.3.1. Case fatality rates by Orthoebolavirus species

The boxplot in Figure 7 shows the case fatality rate values by causative *Orthoebolavirus* species for zoonotic epidemics with more than five documented cases from 1976 to April 2025. Epidemics with five cases or fewer show a 100% fatality rate (Table 7) and have therefore been excluded to avoid introducing bias into the results. Zaire *Orthoebolavirus* has significantly higher fatality rates than Sudan and Bundibugyo *Orthoebolaviruses*, with the latter being the least lethal.

FIGURE 7.
CASE FATALITY RATES FOR EPIDEMICS WITH MORE THAN 5 CASES (1976 – APRIL 2025) BY CAUSATIVE *ORTHOEBOLAVIRUS* SPECIES



Source: Own elaboration based on data from IRIS (WHO, n.d.).

3.3.2. Evolution of case fatality rates over the period 1976 – April 2025

Table 7 presents a list of the 32 epidemics under study, indicating for each one the total number of cases, the number of deaths, and the case fatality rate. They are also arranged in chronological order. When comparing the case fatality rate of the major West African epidemic that originated in Meliandou in 2013 with those that followed, it can be observed that, except for the one in Mulago (Uganda) in 2025, all have higher fatality rates.

TABLE 7.
TOTAL NUMBER OF CASES, NUMBER OF DEATHS, AND CASE FATALITY RATE FOR THE EPIDEMICS UNDER STUDY (1976 – APRIL 2025), ARRANGED CHRONOLOGICALLY

LOCALITY PRIMARY CASE	YEAR OF ONSET	VIRUS SPECIES	TOTAL CASES (Confirmed, suspects and probables)	TOTAL DECEASED (Confirmed, suspects and probables)	CASE FATALITY RATE (%)
Nzara	1976	Sudan	284	151	53
Yambuku	1976	Zaire	318	280	88
Bonduni	1977	Zaire	1	1	100
Nzara	1979	Sudan	34	22	64,7
Makokou	1994	Zaire	51	31	60,8
15 km al norte de Kikwit	1995	Zaire	315	254	80,6
Mayibout	1996	Zaire	31	21	67,7
Booué	1996	Zaire	60	45	69,2
Rwot-Obillo	2000	Sudan	425	224	52,7
Mékambo1	2001	Zaire	124	97	78,2
Mbomo2	2002	Zaire	11	10	90,9
Kellé	2003	Zaire	143	128	89,5
Mbomo	2003	Zaire	35	29	82,9
40 km al sur de Yambio	2004	Sudan	17	7	41,2
Etoumbi	2004	Zaire	12	10	83,3
Mweka	2007	Zaire	264	187	70,8
Bundibugyo	2007	Bundibugyo	149	37	24,8

Table 7.
TOTAL NUMBER OF CASES, NUMBER OF DEATHS, AND CASE FATALITY RATE FOR THE EPIDEMICS UNDER STUDY (1976 – APRIL 2025), ARRANGED CHRONOLOGICALLY

LOCALITY PRIMARY CASE	YEAR OF ONSET	VIRUS SPECIES	TOTAL CASES (Confirmed, suspects and probables)	TOTAL DECEASED (Confirmed, suspects and probables)	CASE FATALITY RATE (%)
Mweka	2008	Zaire	32	15	46,9
50 km al norte de Kampala	2011	Sudan	1	1	100
Kibaale	2012	Sudan	24	17	70,8
Isiro	2012	Bundibugyo	77	36	46,7
Kakute	2012	Sudan	7	4	57,1
Meliandou	2013	Zaire	27862	11281	40,5
Ikanamongo	2014	Zaire	66	49	74,2
Likati	2017	Zaire	8	4	50
Ikoko Ipenge	2018	Zaire	54	33	61,1
Mabalako	2018	Zaire	3470	2287	65,9
Air Congo (Mbandaka)	2020	Zaire	130	55	42,3
Gouécké	2021	Zaire	23	12	52,2
Mbandaka	2022	Zaire	5	5	100
Ngabano	2022	Sudan	164	77	47
Mulago	2025	Sudan	14	4	28,6

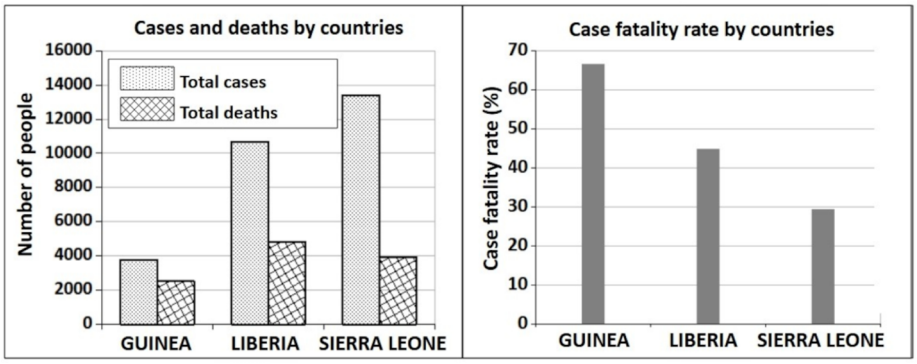
(1): This epidemic affected Gabon and the Republic of Congo. Sometimes, its data is presented as if it were two separate epidemics, one for each country. Here, it is considered as only one.
(2): It was not confirmed through analysis that this epidemic was caused by the Ebola virus, so sometimes it is not taken into account. However, the context suggests that it was.

Source: Own elaboration based on data from IRIS (WHO, n.d.). Shaded in grey: the 2013–2016 West Africa epidemic and subsequent outbreaks, all of which have higher case fatality rates except for the 2025 Mulago (Uganda) outbreak.

3.3.3. West Africa Epidemic (2013–2016)

Case fatality rates by epidemic can conceal significant realities, as can be seen when analysing in detail the 2013–2016 West Africa epidemic or the 2018–2020 Kivu and Ituri epidemic, the two most severe outbreaks on record. In the former, which mainly affected Guinea, Sierra Leone, and Liberia, it can be observed (Figure 8) that Guinea had a comparatively small number of cases but a very high fatality rate (66.65%), while Sierra Leone, in contrast, had three times as many cases as Guinea but managed to keep the fatality rate below 30%, a result only surpassed by the 2007 Bundibugyo virus epidemic in Uganda and the 2025 Sudan species epidemic, also in Uganda (WHO, n.d.).

Figure 8.
TOTAL NUMBER OF CASES AND CASE FATALITY RATE BY COUNTRY IN THE 2013–2016 WEST AFRICA EPIDEMIC



Source: Own elaboration based on data from IRIS (WHO, n.d.).

3.3.4. Northeastern DRC Epidemic (2018–2020)

Table 8 shows the case fatality rates by health zones (ZZSS) during the 2018–2020 epidemic in northeastern DRC. We excluded the Butembo health zone, which reports more deaths than cases, an impossible situation resulting from erroneous data in the Situation Information Reports (SITREP) issued by the WHO between April 16 and September 22, 2019 (reports 37 to 60). To avoid potential bias, we also excluded the health zones of Goma, Ariwara, Pinga, Tchomia, Nyakunde, Nyiragongo, and Bunia, which reported fewer than five cases and therefore have case fatality rates that are not representative. Of the remaining 22 health zones, sixteen exceed the average fatality rate of the 2013–2016 West Africa epidemic, which was 40.5%. Seven of these zones also have fatality rates above 64%, which can be considered very high.

Table 8.
CASE FATALITY RATE FOR HEALTH ZONES WITH MORE THAN FIVE CASES DURING THE 2018–2020 EPIDEMIC IN NORTHEASTERN DRC

HEALTH ZONE	**TOTAL CASES (Confirmed, suspects and probables)**	**TOTAL DECEASED** (Confirmed, suspects and probables)	CASE FATALITY RATE (%)
Alimbongo	6	3	50
Mwenga	6	3	50
Lolwa	6	1	16.7
Rwampara	9	4	44.4
Biena	21	14	66.7
Manguredjipa	23	17	73.9
Kayna	29	9	31
Kyondo	31	21	67.7
Mutwanga	32	12	37.5
Lubero	34	6	17.6
Masereka	56	23	41.1
Oicha	65	30	46.1
Komanda	66	54	81.8
Musienene	86	34	39.53
Mambasa	88	33	37.5
Vuhovi	117	51	43.6
Kalunguta	224	97	43.3
Butembo	302	360	119.21
Mandima	359	178	49.58
Mabalako	483	354	73.29
Katwa	676	495	73.22
Beni	737	478	64.86

Source: Own elaboration based on data from IRIS (WHO, n.d.).

4. DISCUSSION

A search in AJOL, a small database specializing in African scientific output that contains 260,000 references (AJOL, 2025), yielded 57 results for the term *Geography AND Ebola*, compared to 71 results in PUBMED, the vast biomedical database with over 38 million articles. This can be interpreted in contradictory ways. On one hand, it suggests that South-South scientific communication is being valued by African researchers themselves. On the other hand, it may indicate that scientific communication emanating from the Global South to the North faces various barriers to dissemination. In any case, it clearly demonstrates African interest in their own issues, contributes to the development of local platforms necessary for disseminating African scientific output (Sánchez, 2007), and advances toward parity with the rest of the world.

This indicates that something is shifting in Africa, as also evidenced by the fact that the North Kivu and Ituri epidemic (2018–2020), the second most severe on record, did not spread to Uganda. Only four patients crossed the border, and they were quickly detected and contained without any secondary cases (WHO, 2019). This was a major achievement, considering that in 2019 alone, during the height of the Ebola epidemic, there were 1.4 million new internally displaced persons in the two Kivus and Ituri due to violence from an undeclared war (Internal Displacement Monitoring Centre [IDMC], 2020).

Georeferencing the locations of primary cases and mapping them has allowed us to characterize the natural environments where epidemics begin, revealing that these characteristics differ depending on the causative *Orthoebolavirus*. Epidemics caused by the Zaire *Orthoebolavirus* tend to occur in Am climates of West Africa and Af climates of the Congo River basin, at longitudes below 30° East, around 400 meters above sea level, and in the biome of humid broadleaf forests. The Sudan species appears in the environment of the drainage divide between the Nile and Congo river basins, in southern South Sudan, predominantly in Aw climates, in the biome of tropical and subtropical grasslands, savannas, and shrublands. The Bundibugyo species, known from only two outbreaks, appears in northeastern DRC, separating the areas affected by the other two species. The Sudan and Bundibugyo species prefer the higher altitudes typical of the elevated terrain in the Great Lakes region. No seasonal pattern has been established for the timing of primary cases.

The study of the temporal distribution of epidemics suggests the need to investigate why none occurred between 1980 and 1994, and why that changed starting in 1995.

From the study of case fatality rates, three questions arise. The first is why Sierra Leone had low fatality rates during the 2013–2016 epidemic, while Guinea had very high ones, despite the latter having a much higher number of doctors per capita (Barra, 2017). The second is why, during the 2018–2020 epidemic in northeastern DRC, there were seven health zones with fatality rates above 64%, even though two vaccines, one of them fully tested, and two new experimental drugs were available. Were these resources truly accessible? Did they meet the necessary quality standards? To what extent did the context of violence and the resulting internal displacement play a role? The third question is why the fatality rates of all epidemics after the 2013–2016 West Africa outbreak, except for the 2025 Uganda epidemic, have been higher than the 40.5% overall rate of that outbreak. In the case of northeastern DRC, one of the causes of such high fatality rates is the context of violence in which the epidemic developed. Hundreds of thousands of people were internally displaced and over a hundred paramilitary groups fought for control of the territory, among them the Allied Democratic Forces (ADF), affiliated with the Islamic State of Iraq and Syria (ISIS), and the March 23 Movement (M-23), a rebel faction armed with heavy weaponry and supported by Rwanda. The gravity of the situation led to the declaration of a state of siege in three northeastern provinces of the DRC in 2021 (Ebuteli *et al.*, 2024), which proved ineffective, as in January 2025 the M-23 seized Goma, capital of North Kivu, and in February captured Bukavu, capital of South Kivu (Callamard, 2025), while the ADF murdered 43 Christians gathered in a church on the night of 26 July (Palermo, 2025). All of this unfolded within an international context of competition for mineral resources, with which these territories are especially endowed (Bednik, 2019).

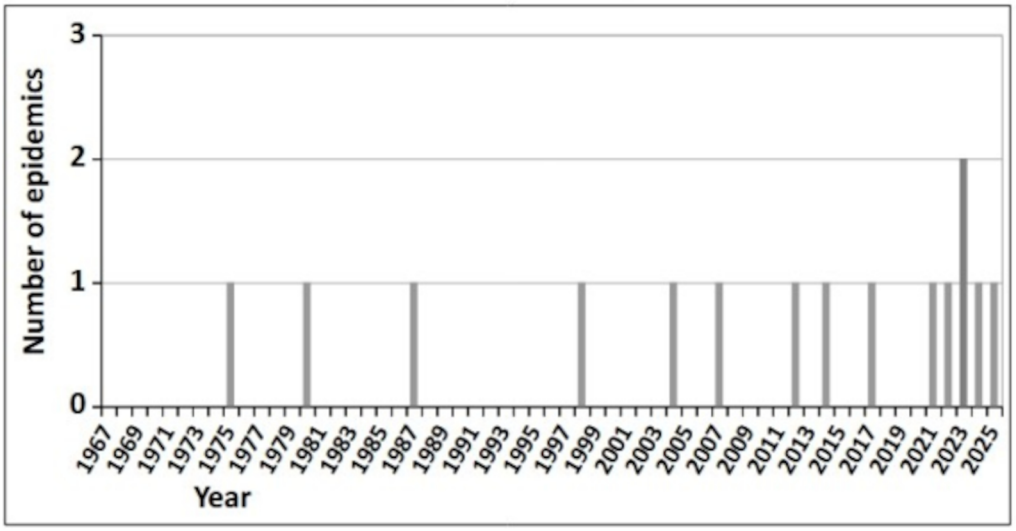
Nevertheless, fatality rates have remained high even in epidemics where such violent conditions were not present, which may be due to the challenges of providing early and appropriate care to infected individuals. Early care requires public trust in the health system so that families report suspected cases to the authorities; and appropriate care necessitates that Ebola Treatment Centres (ETCs) be sufficiently equipped, with facilities such

as oxygen therapy, dialysis and blood banks, alongside medications like Ebanga and Inmazeb. It can be asserted that poor internal governance, lack of state resources, and international interests are among the reasons why the technical and organisational advances made in combating Ebola have not been reflected in post 2013–2016 epidemic fatality rates.

The Lancet Infectious Diseases, in an excellent series on Ebola comprising two articles and an editorial, outlines the clear progress that has been made following the major West African epidemic of 2013–2016. It cites *The Lancet* (2025) as highlighting Rwanda's success in tackling the Marburg epidemic it faced between September and December 2024, achieving a notably low fatality rate of 22.7% for such outbreaks. *The Lancet* goes on to note that this achievement is difficult to generalise, a view supported by our study's findings, which show that fatality rates in post-West African Ebola outbreaks, excluding only Uganda's 2025 epidemic caused by the Sudan strain, have remained surprisingly high. This suggests difficulties in effectively applying resources and expertise that were demonstrably successful in Rwanda to other contexts.

Furthermore, examining the timeline of the 15 Marburg epidemics that did not occur in laboratory settings since the disease was first identified in 1967 (CDC, 2025b; WHO, 2025b), it is evident that the number of outbreaks, closely resembling Ebola, has increased over time (Fig. 9), a trend also noted in other diseases such as cholera, which has seen a rise in cases and outbreaks since 2021 (WHO, 2024a and 2024b). Put differently, technical and organisational capacities for epidemic control have improved, but the conditions that give rise to outbreaks remain unchanged, linked to extreme poverty, which pressures forests and leads to Ebola and Marburg outbreaks, or forces people to live without access to clean water and sanitation, thereby generating cholera. Resources exist, but when implemented, they act at the end of the cycle without addressing root causes.

Figure 9.
TEMPORAL DISTRIBUTION OF NON-LABORATORY MARBURG EPIDEMICS SINCE THE DISEASE WAS IDENTIFIED IN 1967 UNTIL APRIL 2025



Source: Own elaboration based on data from WHO (2025b) and CDC (2025b)

Another inconsistency observed, which deserves further investigation, stems from two Randomized Controlled Trials, one in West Africa (PREVAIL, 2016) and another in northeastern DRC (PALM, 2019), which produced contradictory results regarding the use of the drug Zmapp.

Finally, we want to highlight the ongoing relevance and necessity of health geography at a time when the globalization of infectious diseases continues to advance (WHO, 2004). Regarding Ebola, the bat *Rousettus aegyptiacus*, which appears to be one of the virus reservoirs, is currently found in the wild in three provinces of Andalusia

and in the Canary Islands (Ibáñez and Migens, 2006). Its presence does not imply the presence of the virus, but it does reflect the growing complexity of the relationship between geography and health.

The main limitation of this study was the lack of sufficiently disaggregated data, which prevented us from drawing deeper conclusions about the relationship between the origin of epidemics and the natural environment.

5. CONCLUSIONS

The link between Ebola epidemics and the natural conditions present in each territory has been demonstrated, conditions which vary depending on the specific Orthoebolavirus involved. It can be said that the primary cases of the epidemics exhibit a strong territorial component. However, as these outbreaks develop and evolve, indicated by the fatality rates, a diversification occurs that invites reflection on a new form of territoriality, one no longer determined by physical geography but rather by the full spectrum of elements that shape the broader environment. This includes cultural, economic, health-related, social and political factors, all of which influence the outcomes of each epidemic.

Africa is learning to manage its research, as evidenced by the findings published in AJOL, and is also improving its epidemic response. This is shown by the low fatality rates of the Marburg epidemic in Rwanda in 2024 and the Ebola outbreak in Uganda in 2025, as well as the fact that the 2018–2020 outbreak in the DRC did not spread to Uganda. These are encouraging signs that suggest the existence of capabilities and resources for tackling the disease. Nevertheless, the number of outbreaks is not declining, and the fatality rates of epidemics that followed the West African outbreak, except for the two mentioned, have been extraordinarily high. This leads to the conclusion that there is a disconnect between knowledge about Ebola and its real-world application, a gap closely tied to widespread poverty and limited government resources. All of this points to the need to continue research, addressing these and other factors that may help us understand why such inconsistencies occur, an endeavour that will be undertaken in future publications.

It would be highly beneficial if local and national agencies collected statistics and data with greater territorial precision, as the lack of such detail has been a clear limitation of this study.

The StoryMaps tool has enabled the integration of texts, maps, and significant images related to the geographic distribution of Ebola in Africa, highlighting its relationships with natural features such as rainfall, climate, and altitude, elements that shape the landscape and territory. This tool will help disseminate the results of this study in both scientific and educational ways, as it provides access to the interactive online maps used in this work. In doing so, it also represents a way of sharing with African researchers the technological resources that ESRI® has made available to us.

6. CONFLICT OF INTEREST

The authors of this article declare that they have no financial, professional, or personal conflicts of interest that could have inappropriately influenced this work.

7. AUTHOR CONTRIBUTION STATEMENT

José Antonio Barra Martínez: Conceptualization, formal analysis, investigation, methodology, writing – original draft, writing – review and editing.

Francisco José Morales Yago: Conceptualization, methodology, supervision, writing – original draft, writing – review and editing.

The English version has been reviewed using Artificial Intelligence (Copilot, Microsoft).

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