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Original Article

Temporal, seasonal, and spatial patterns of Mpox in the DRC, 2002–2022: longitudinal surveillance study

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Abstract

Introduction: Mpox has shown increasing incidence and geographic spread since its first identification in the Democratic Republic of the Congo (DRC) in 1970.

Methodology: We analyzed weekly mpox surveillance data reported from 2002-2022 in the DRC. Temporal trends were assessed using time-series decomposition to separate secular trends, seasonal patterns, and residual variation. Change-point analysis identified distinct transmission phases. Spatial trends were analyzed through thematic mapping of incidence rates across Health Zones.

Results: Between 2002 and 2022, a total of 55,072 suspected mpox cases and 1,297 deaths were reported, corresponding to an overall case fatality rate (CFR) of 2.4% and a mean CFR of 2.15% (95% CI: 1.8–2.5). Incidence increased progressively, with marked rises after 2010 and further intensification after 2015. Recurrent seasonal peaks were observed at the beginning of the year (February) and during mid-year (May–July). Change-point analysis identified four distinct transmission phases, during which annualized incidence increased from 0.78 to 2.67 cases per 100,000 population, alongside a steady geographic expansion from 56 to 159 health zones. By the most recent phase (2018–2022), approximately 30% of health zones nationwide had reported mpox cases. While CFRs declined during the intermediate phases, they increased again in recent years, reaching 2.63% in Phase IV.

Conclusions: Mpox remains persistently endemic in the DRC, with progressive geographic expansion. These findings underscore the need for sustained surveillance, strengthened community engagement, and targeted prevention strategies embedded within a broader One Health framework to address zoonotic and ecological drivers of transmission.

Key words: Mpox; surveillance; seasonality; epidemiology; spatial; Democratic Republic of the Congo.

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Introduction

Mpox, formerly known as monkeypox, is a viral zoonosis caused by the *Monkeypox virus* (MPXV). The disease typically presents with flu-like symptoms followed by vesiculopapular rashes concentrated on the face, limbs, palms, and soles [1–3]. Although the animal reservoir remains unknown, African rodents and non-human primates are believed to play a role in maintaining and transmitting the virus to humans [3,4].

Two genetically distinct clades of MPXV are recognized: clade I (formerly the Congo Basin strain) and clade II (formerly the West African strain), now further divided into subclades Ia, Ib, IIa, and IIb [5]. Infections with clade II are generally less severe than those with clade I [1,2].

The first human case of mpox was identified in 1970 in the Democratic Republic of the Congo (DRC) [5–9]. Since then, the country has experienced a notable rise in incidence, an approximately twentyfold increase between the 1980s and 2006–2007 [10], and the disease has become endemic since 2003. This resurgence has been attributed to the cessation of smallpox vaccination [7], increased human–animal contact, deforestation, and exposure to infected wildlife [11,12]. While improved surveillance systems have enhanced detection, the rise also likely reflects a true increase in transmission [13].

Mpox outbreaks have been reported in several

African countries since 2016, primarily via zoonotic transmission [14]. In the DRC, a sustained increase in reported cases since 2002 has marked a transition from sporadic outbreaks to more persistent community transmission [14,15]. Environmental and socioeconomic factors—such as primary forest cover, temperature, and economic hardship—have been associated with elevated mpox incidence [16]. In Tshuapa Province, current reproduction number estimates exceed previous levels, possibly due to waning smallpox vaccine–induced immunity [17,18]. More recently, transmission patterns have evolved, with the first documented case of sexual transmission in the DRC reported in 2023 [2,18–20].

Neighbouring countries, such as the Central African Republic, have also observed rising incidence, influenced by increased rodent consumption [21] and genomic lineages closely related to those circulating in the DRC [22]. Beyond Central Africa, mpox gained global attention following a large multi-country outbreak in 2022, primarily involving sexual transmission among men who have sex with men in Europe and North America [23]. Similar shifts in epidemiology, including higher incidence and wider geographic distribution, have been reported in Nigeria [24], linked to viral adaptation, poor community hygiene, and limited healthcare resources [25]. In response, WHO has classified mpox as a priority disease for reporting in the African region [26,27].

While recent studies have characterised the epidemiological and laboratory features of mpox in the DRC (2010–2023) [28], few have examined the long-term temporal, seasonal, and spatial evolution of the disease. Despite growing evidence of mpox's re-emergence in Central Africa, comprehensive assessments of long-term transmission patterns across the DRC remain limited. This study addresses that gap by analysing two decades (2002–2022) of national surveillance data to characterise the evolution of mpox in the country. The findings provide insights into the changing epidemiological dynamics of the disease and serve as a reference for future retrospective analyses on emerging transmission trends.

Methodology

Study area, DRC: brief description

The DRC, located in Central Africa, is the second-largest country on the continent by land area, covering approximately 2.34 million square kilometres and with a population of over 100 million people (many of whom reside in rural areas). The DRC's diverse geography - dense tropical rainforests, vast savannas, and numerous river systems, including the Congo River- facilitates human proximity to wildlife reservoirs and the risk of zoonotic disease transmission [29].

The DRC has an equatorial type climate in the center (hot and humid), and a tropical type climate in the south and north [30]. This climatic configuration offers the DRC two seasons, namely: (i) the dry season with rare and little rain, which lasts from December to May north of the equator and from May to September south of the equator; (ii) the rainy season, with heavy precipitation, from May to November in the north and from September to May in the south [30,31].

The country's healthcare system is organised into health zones (HZ), which serve as operational units for service delivery [32] and are divided into health areas. These zones face persistent challenges, particularly in rural areas, including underfunding, inadequate infrastructure, and limited personnel [33]. These factors contribute to high mortality rates, particularly in conflict-affected areas, and a heavy burden of infectious diseases such as malaria, HIV, tuberculosis, Ebola, and mpox, as well as malnutrition and maternal mortality [34–36].

Despite these obstacles, efforts are being made to strengthen disease surveillance, implement integrated control programs, and adopt a One Health approach to address the complex interplay between human, animal, and environmental factors in disease transmission [29].

Sources of data

Mpox case data were collected from weekly active and passive reporting to the DRC Ministry of Health [37]. Each week, health facilities (hospitals, health centers, health posts, medical centers, etc.) report the cumulative number of cases and deaths related to diseases with epidemic potential (including mpox) to the Central Office of their Health Zone (*Bureau Central de la Zone de Santé, BCZS*), with onward reporting to the Epidemiological Surveillance Directorate (ESD), and WHO.

Community-based surveillance complements reporting in healthcare facilities. Community health workers, using simplified community case definitions, actively search for cases during home visits and contribute to risk communication during epidemics. Their alerts enable healthcare facilities to intervene quickly as soon as the first suspicious signs appear. These alerts are then studied and validated at the health center level by staff nurses, based on standard case definitions, before being officially notified in the national system. Before weekly submission to the Epidemiological Surveillance Directorate, the Central

Office of the Health Zone reconciles community alerts with health-facility line lists to prevent duplication and ensure that only validated cases are integrated into the official database. When an epidemic is declared, each health zone establishes a case register (or linear list), which records the geographical coordinates and individual characteristics of each confirmed case.

Due to limited laboratory availability for laboratory confirmation, the analysis focused on suspected cases reported by surveillance. According to the standard IDSR-3 definition, a suspected case corresponds to an acute febrile attack (> 38.3 °C) accompanied by headache, lymphadenopathy, myalgia, back pain, and severe asthenia, followed by a rash developing from the face to the rest of the body, including the palms and soles [38].

Population denominator data originate from HZ census [37]. We used the province-specific projection indices to derive annual population estimates. We report incidence rate as the annual number of reported suspected mpox cases per 100,000 population (cases/mid-year population × 100,000) and mortality rate as deaths per 1,000,000 population. Case fatality rate (CFR) is the proportion of deaths among reported suspected cases in the same calendar year (deaths/cases × 100%). When we refer to "incidence" in the text, we mean incidence rate unless explicitly stated otherwise.

Statistical analysis

We conducted temporal and spatial analyses of mpox surveillance data from 2002 to 2022, starting from the establishment of the national database for epidemic-prone diseases by the Ministry of Health in 2002 [39].

Temporal analysis

Weekly time series of reported mpox cases were decomposed using an additive model in R software (version 4.0.2). The decompose() function [39] was applied to separate the data into three main components: long-term trend, seasonality, and random residual variation. The results were validated using STL (Seasonal and Trend decomposition using Loess) to confirm the stability of seasonal amplitude. The cyclical component was excluded, as the objective was to capture residual variation after adjusting for trend and seasonality.

To identify distinct temporal phases in mpox dynamics, we performed changepoint detection using the *changepoint* package [39,40]. The Binary Segmentation (BinSeg) method with a Modified Bayesian Information Criterion (MBIC) penalty (pen.value = 0.0005) detected three significant change points. Alternative penalties (AIC, BIC) and different numbers of change points (Q = 2–6) produced consistent results within ± 1–2 quarters, confirming robustness.

For exploratory projections, we applied the additive Holt–Winters exponential smoothing model (ETS A,A,A). Diagnostics, including RMSE, MAE, and AICc, were computed and compared with *auto.SARIMA*, confirming the suitability of the smoothing-based approach for short-term forecasting.

Epidemiological indicators

Annual incidence and mortality rates were calculated as the number of suspected cases or deaths per 100,000 and 1,000,000 inhabitants, respectively. The case fatality rate (CFR), also referred to as the fatality, was defined as the proportion of deaths among suspected cases within the same calendar year. These terms are used interchangeably in this study.

To quantify the statistical uncertainty of rate estimates, 95% confidence intervals (CIs) were calculated assuming a Poisson distribution for incidence and mortality, and a binomial distribution for CFR. Poisson-based CIs were computed as $[\lambda \pm 1.96 \times \sqrt{\lambda}]$ / population × multiplier (100,000 for incidence; 1,000,000 for mortality), and binomial CIs for CFR as $p \pm 1.96 \times \sqrt{[p(1-p)/n]}$, where p = deaths/cases.

Visualization and spatial analysis

The epidemic curve (2002–2022) was generated in Excel 2016, with annual counts displayed as bars and the CFR superimposed as a secondary line chart. Spatial patterns were mapped in QGIS (version 3.14) to illustrate annualized incidence per 100,000 population by health zone and epidemic phase. A multiplicative decomposition, presented in Supplementary Figure 1, yielded results comparable to the additive model, confirming robustness.

All analyses were performed using R (version 4.0.2), Excel (2016), and QGIS (3.14).

Ethical considerations

This study analyzed anonymized mpox surveillance data obtained from the national IDSR database. Authorization to use these data was granted by the Directorate of Epidemiological Surveillance, Ministry of Health, DRC. No individual-level identifiers were included, and ethical approval was not required for secondary analysis of routine public health surveillance data.

Results

Temporal, secular and seasonal trends of mpox in DRC, 2002-2022

During the period from 2002 to 2022, a total of 55,072 suspected mpox cases and 1,297 deaths were reported in the DRC. The mean case fatality rate (CFR) over the study period was 2.15% (95% CI: 1.8–2.5%), corresponding to an overall CFR of 2.4%.

The annual number of suspected cases increased substantially over time, with a marked rise observed after 2010 and further increases during 2020 and 2022. CFRs were higher during the early years of surveillance and declined progressively until 2011. From 2015 onward, CFRs increased again, reaching their highest levels in 2020 and 2022, with a peak CFR of 4.0% recorded in 2022.

These temporal trends in suspected cases and case fatality rates are illustrated in Figure 1, while the complete annual numerical data are provided in the Supplementary Table 1.

Figure 1 provides the annual number of cases and CFR of mpox in the DRC, from 2002 to 2022. Blue bars represent the number of suspected cases per year, while the red line shows the CFR (%).

The analysis of the weekly mpox surveillance data reported in the DRC between 2002 and 2022 shows a progressive increase in incidence over the study period. Following an initial phase of low transmission intensity in the early 2000s, the secular trend exhibits a more pronounced upward trajectory from 2010 onward, with a marked acceleration after 2015.

Alongside this secular trend, interannual fluctuations increased in magnitude over time, with more frequent and higher peaks observed during the later years of the study period, particularly after 2015.

Analysis of seasonal patterns demonstrates recurrent intra-annual cycles that remain consistent across the study period. Incidence peaks are consistently observed at the beginning of the year, particularly in February, and during the mid-year period, mainly between May and July. Seasonal troughs are regularly recorded toward the end of the year and at the onset of the dry season.

Finally, examination of the residual variation reveals irregular fluctuations not accounted for by the secular trend or the seasonal component, with distinct episodic peaks observed particularly after 2020.

A detailed additive decomposition of the weekly time series into secular trend, seasonal patterns, and residual variation is provided in the Supplementary Materials for illustrative purposes.

Figure 2 depicts the monthly notifications of suspected Mpox cases in the DRC, including epidemiological week data, from January 2002 to July 2022.

Figure 1. Annual number of cases and CFR of mpox in the DRC, from 2002 to 2022.

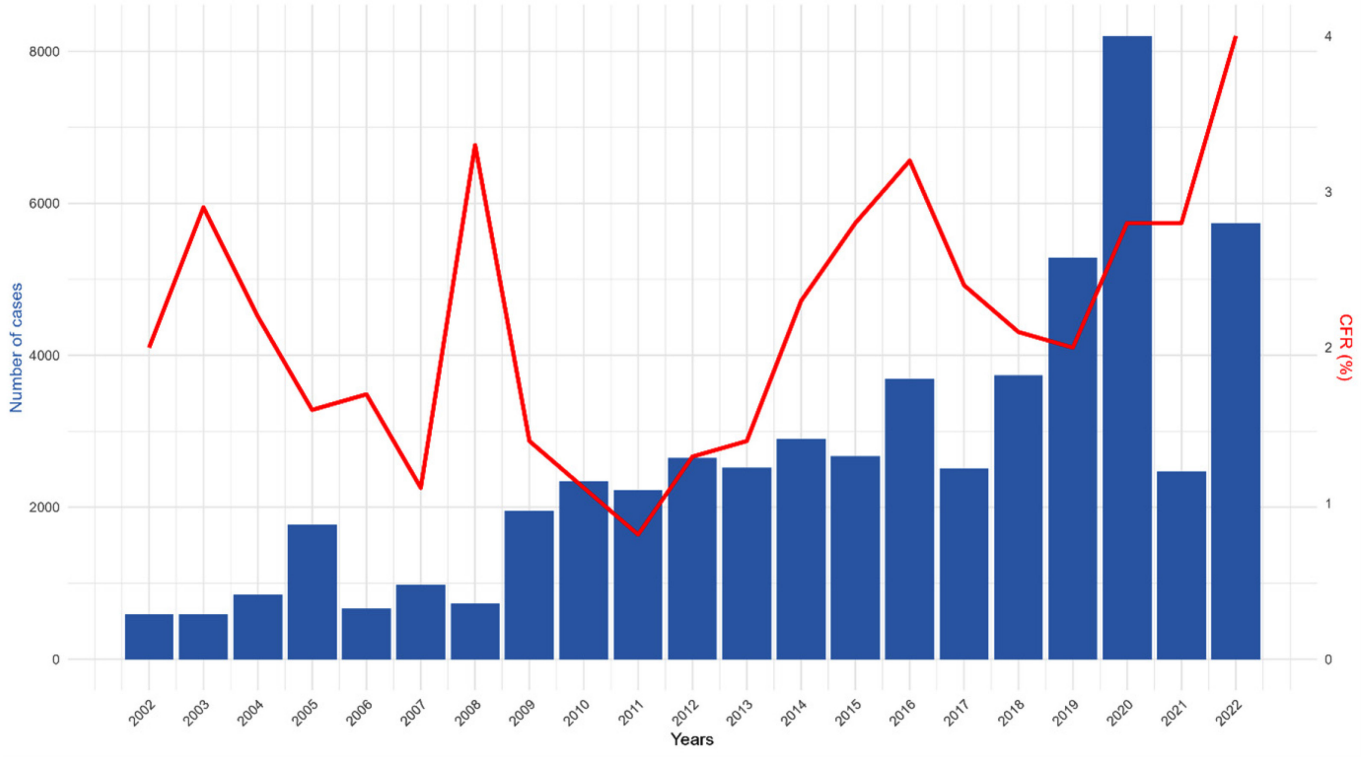


Figure 2. Monthly notifications of suspected cases of mpox in the DRC (including epidemiological weeks) from January 2002 to December 2022.

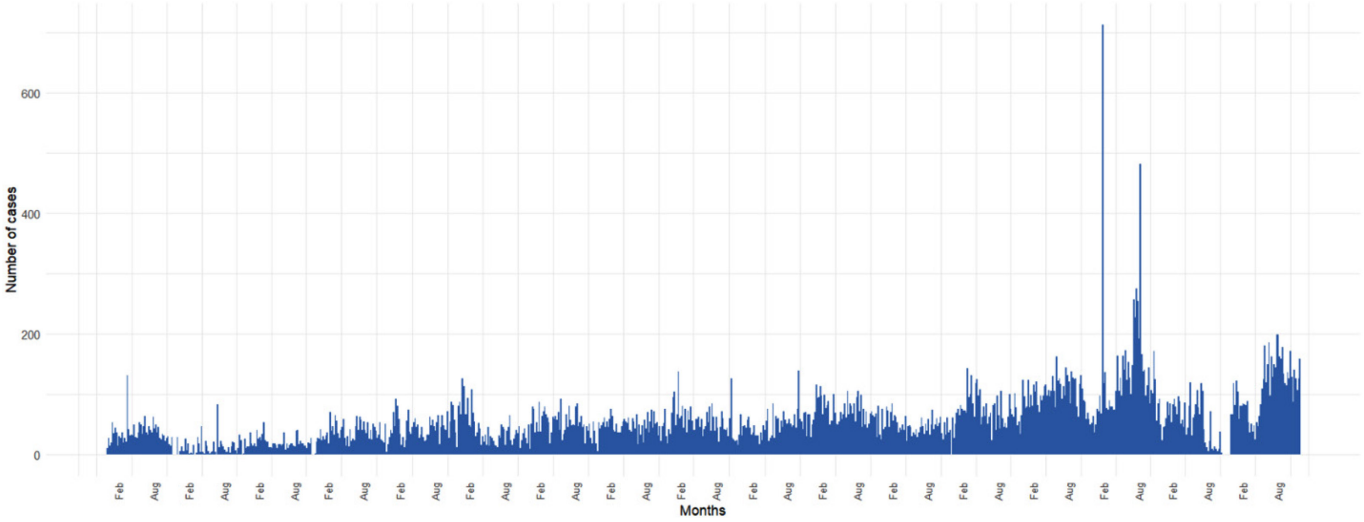
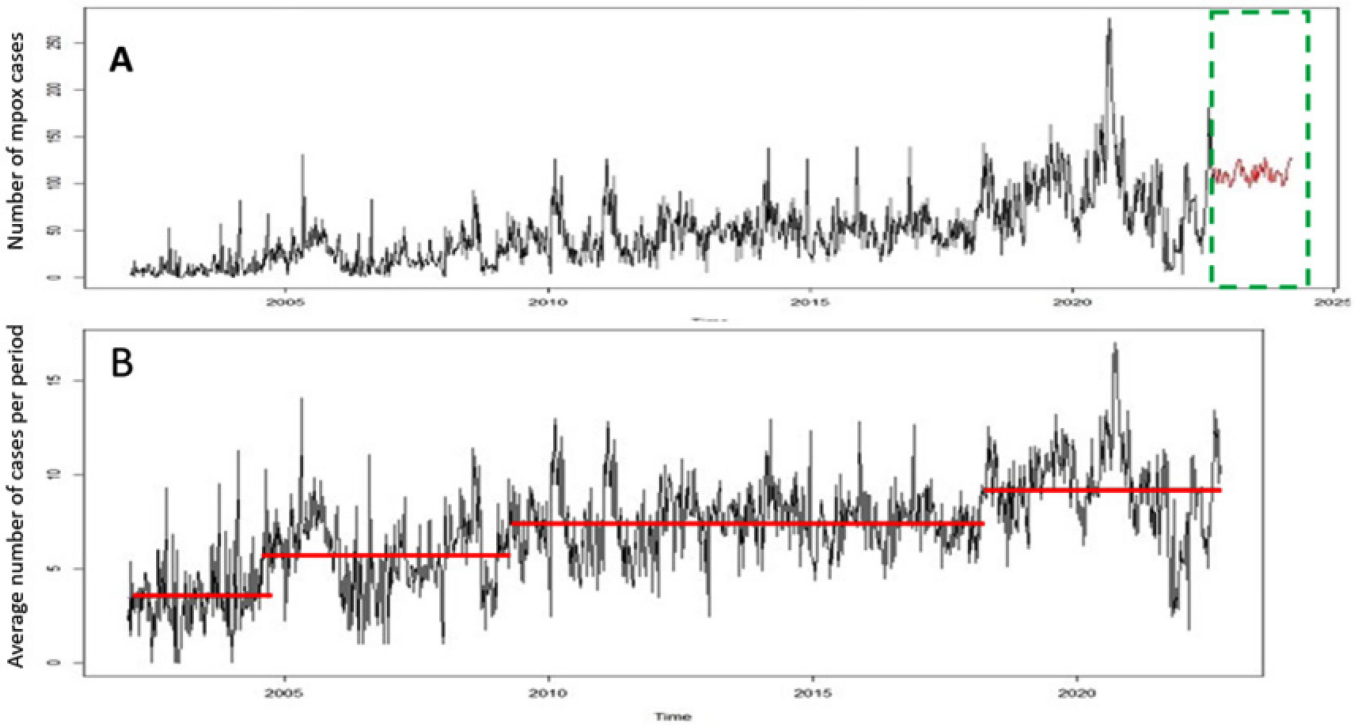


Figure 3. The curve (A) of the temporal evolution of the cases of monkeypox and the prediction of two previous years (2023-2025), and the breakdown (B) into four phases of the temporal evolution of the chronological dynamics of Monkeypox data reported per week in DRC, 2002-2022. CPAIncidSqr2 <- cpt.meanvar(varIncidSqrt, penalty = "MBIC", pen.value = 0.005, method = "BinSeg", test.stat = "Normal", Q = 3). On B), the red lines show average levels of cases for different periods.



A detailed analysis of the monthly distribution of notified suspected cases reveals peak periods of high numbers of reported cases, as well as off-peak periods with fewer cases (Figure 3). The total cases reported per month (over all years), the peak periods identified, namely [February (4,805 cases), May (4,686 cases) and July (5,267 cases)] as well as the periods of troughs namely [December (2,746 cases), April (3,537 cases) and June (3,832 cases)], it appears that there would be seasonal fluctuations, with peaks more marked at the beginning of the year (February) and in the middle of the year (May and July), while the troughs are mainly located towards the end of the year (December).

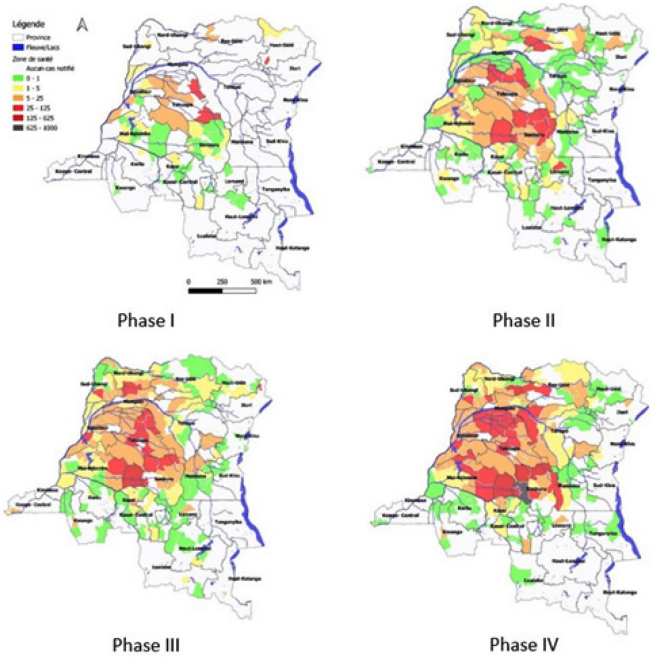
Figure 3 presents the time series of mpox cases and the segmentation of weekly case data into distinct phases as identified by the change point analysis. Projections for the years 2023 to 2025 indicate a potential stabilization in case numbers. The change-point analysis (Fig 3B), identifies four distinct phases: January 2002 to June 2004 (Phase I), June 2004 to March 2009 (Phase II), March 2009 to August 2018 (Phase III) and August 2018 to July 2022 (Phase IV).

Spatialization of the dynamics of mpox in DRC in four phases, 2002-2022

Table 1 presents the population size for each Phase identified above, as well as the mpox incidence and mortality rates, and Figure 4 presents the spatial spread of mpox by Phase. Each panel (Phases I–IV) represents a distinct time period showing changes in the geographic extent and intensity of reported cases, based on incidence rates per health zone.

In Phase I (2002–2004), the outbreaks were limited to 56 HZ, focused in the Tshuapa region and with spread towards Tshopo, Mai-Ndombe, and Sankuru. During this phase incidence was low (0.78/100,000 population), with a reported CFR of 2.87%. In Phase II (2004–2009), mpox affected 98 HZ, reached Ubangi and stabilized in the central basin, probably due to the fragmentation of foci evolving autonomously. The incidence rate was 1,62/100,000 population, with CFR of 1,79%. In Phase III (2009–2018), outbreaks spread

Figure 4. The spatial spread of mpox by Phase.



to 145 HZ, reaching new provinces including Bas Uélé, Haut Uélé, and Ituri; the incidence rate rose to 2.10 per 100,000 population, and the CFR dropped to 1.99%. In Phase IV (2018–2022), outbreaks impacted 159 HZ (around 30% of HZ in the country reported cases). All provinces have reported at least one case except the Haut Lomami. The incidence rate was 2.67 per 100,000 population and a rising CFR of 2.63%.

Discussion

This study provides a comprehensive overview of mpox epidemiology in the DRC from 2002 to 2022, based on two decades of surveillance data. Our analysis reveals a substantial increase in reported cases, with marked epidemic peaks at the beginning (February) and middle (May–July) of the year, corresponding to the country's dry seasons. The overall upward trend, coupled with variations not explained by seasonality alone, suggests complex interactions between biological, environmental, and health system factors. Improvements in diagnostic and surveillance capacity

Table 1. Population size in each Phase identified (above), as well as the incidence rate and mortality rate for mpox.

Parameters	Phase I	Phase II	Phase III	Phase IV
Average population size (no. persons)	72,163,145	77,798,743	92,781,187	109,962,888
Start date of Phase	01/01/2002	25/06/2004	21/03/2009	03/08/2018
End date of Phase	24/06/2004	20/03/2009	02/08/2018	30/07/2022
Number of weeks in Phase	131	249	568	232
Number of Health Zones	56	98	145	159
Total suspected cases	1,427	5,516	23,346	21,789
Total Deaths	41	99	464	572
Case fatality rate	2.87% [1.97-3.53]	1.79% [1.89-2.63]	1.99% [1.69-2.05]	2.63% [2.46-2.88]
Annualized incidence/100,000 population	0.78 [0.772-0.778]	1.62 [1.54 -1.66]	2.1 [2.07-2.13]	2.67 [2.56-2.75]
Mortality/1,000,000 population	0.22 [0.07-1.14]	0.36 [0.355-0.365]	0.41[0.399-0.411]	1.22 [1.21-1.23]

likely contributed to higher case detection. The brief decline after the 2020 peak may reflect temporary stabilization or targeted interventions during that period. However, as noted by WHO [27], mpox was largely neglected before triggering a global epidemic in 2022, contradicting earlier expectations of stabilization. Following the declaration of mpox as a Public Health Emergency of International Concern, case numbers surged, prompting the DRC to declare a national epidemic and implement a coordinated response [41].

The Ministry of Public Health launched a national preparedness and response strategy emphasizing (i) surveillance and detection, (ii) case management and infection control, and (iii) training and capacity building [41]. These interventions aim to strengthen epidemiological surveillance, enhance diagnostic capacity, and improve outbreak response. Post-2022 transmission dynamics—marked by sustained human-to-human spread, including sexual transmission—represent a major epidemiological shift requiring continued investigation.

Seasonal patterns identified in this study suggest cyclical environmental and behavioral drivers of mpox transmission. Factors such as forest cover, temperature, deforestation, agricultural cycles, and food insecurity influence human-animal interactions and exposure to reservoirs [16,42,43]. Climate change could further expand the geographic range of reservoir species, altering mpox distribution. Random residual variation in our model may reflect socio-political disruptions—such as armed conflict and displacement—that weaken health systems and facilitate transmission.

Neighboring countries like the Central African Republic have reported similar trends linked to rodent consumption, with genomic analyses showing viral lineages closely related to those in the DRC [22,44,45]. This underscores the need for integrated, cross-border surveillance and strengthened research on animal reservoirs and environmental determinants.

Our findings align with recent studies reporting increased mpox incidence associated with enhanced surveillance and diagnostic capacity in the DRC and other endemic regions [21,43,46]. This consistency reinforces the hypothesis that part of the observed rise in reported cases reflects improvements in disease detection and reporting rather than solely a true epidemiological expansion.

The findings of this study must nevertheless be interpreted in light of several limitations. First, the analysis relied primarily on suspected rather than confirmed mpox cases, owing to limited PCR confirmation capacity. This may have introduced misclassification bias—either under- or over-estimating the true burden of disease—and the degree of bias may have varied across provinces and over time. Second, regional disparities in diagnostic capacity could have influenced the spatial distribution of reported cases. Third, improvements in surveillance after 2010 likely increased case detection, contributing to part of the observed rise in incidence. Finally, the use of aggregated surveillance data precluded disaggregation by age or sex and limited control for potential confounders.

Beyond these considerations, recent analyses of national mpox surveillance in the DRC (2010–2023) have provided updated insights into epidemiological and laboratory trends, emphasizing the growing incidence and geographic spread, as well as the need for decentralized diagnostic capacity [46]. Our study complements these findings by offering a broader longitudinal perspective (2002–2022) that captures the early phases of mpox resurgence following the cessation of smallpox vaccination. Unlike recent studies focusing mainly on confirmed cases and demographic correlates, our approach integrates temporal, seasonal, and spatial dimensions, thereby revealing the progressive establishment and expansion of endemic transmission over two decades. Together, these complementary perspectives delineate both the historical trajectory and the current dynamics of mpox in the DRC, informing strategies for sustainable surveillance and control.

Future research should prioritize confirmatory testing, expand access to molecular diagnostics, and strengthen laboratory infrastructure nationwide. Improving data quality will refine our understanding of local transmission dynamics. Beyond technical aspects, mpox control requires a sustained, multisectoral approach that integrates surveillance, vaccination, and community awareness—anchored in strong health systems and regional collaboration—to sustainably reduce transmission and prevent future resurgence. Overall, these findings underscore the persistent endemic nature of mpox in the DRC and highlight the urgent need for more sensitive surveillance systems and deeper investigation of the ecological and social drivers of transmission.

Conclusions

In summary, our findings confirm the persistent endemic nature and progressive geographic expansion of mpox in the Democratic Republic of the Congo. The observed long-term increase in incidence and recurrent seasonal peaks underline the importance of sustained

epidemiological surveillance and improved diagnostic capacity. Strengthening laboratory systems, enhancing community awareness, and considering vaccination strategies for populations at risk may contribute to mitigating transmission. Integrating these actions within a One Health framework, linking human, animal, and environmental health, will be essential for sustainable mpox control.

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Authors contributions

DMB initiated and led the writing of the manuscript, facilitated access to national surveillance data, and led the analysis; TZM supported the manuscript preparation, and reviewed the manuscript; TKM, FM, and JKK assisted in the analysis interpretation; AA facilitated access to national surveillance data, guided the interpretation of results in the context of national health strategies, and reviewed manuscript; HMM and PMM, supported the literature review, manuscript preparation, and reviewed the version. VMT supported the literature review and manuscript preparation. OM, AJ, CJ, and CG reviewed the manuscript. All authors have read and approved the final version of the manuscript.

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Conflict of interest

No conflict of interest is declared.

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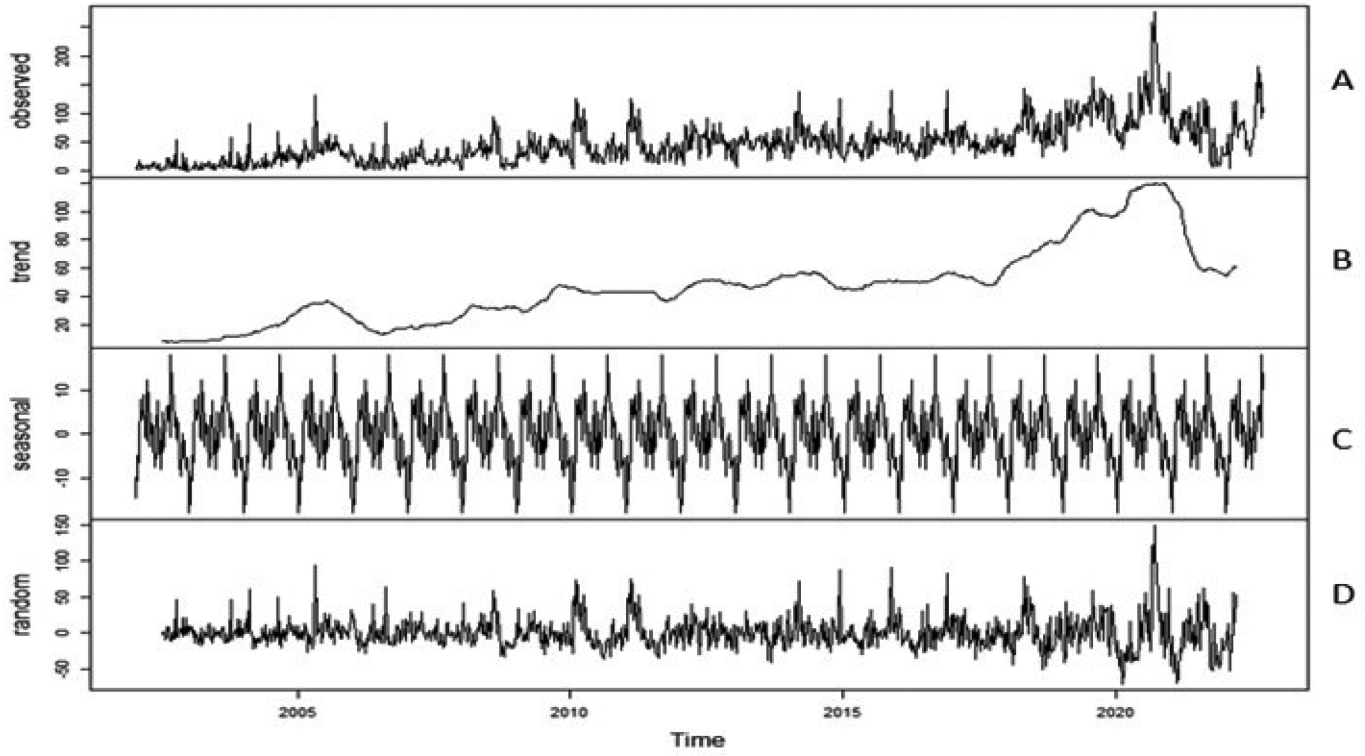
Annex – Supplementary Items

Supplementary Table 1. Annual numbers of suspected cases and deaths, and case fatality rates, from mpox in the DRC, from 2002 to 2022.

Year	Cases	Death	CFR (%) 95% CI: 1.8–2.5%
2002	588	12	2.0
2003	594	17	2.9
2004	848	19	2.2
2005	1766	29	1.6
2006	663	11	1.7
2007	978	11	1.1
2008	733	24	3.3
2009	1953	27	1.4
2010	2346	26	1.1
2011	2227	18	0.8
2012	2649	35	1.3
2013	2520	36	1.4
2014	2899	68	2.3
2015	2671	76	2.8
2016	3688	117	3.2
2017	2511	60	2.4
2018	3735	77	2.1
2019	5288	107	2.0
2020	8203	229	2.8
2021	2472	68	2.8
2022	5740	230	4.0

Supplementary Figure 1. Decomposition of the additive time series of the epidemiological curve of the mpox data reported weekly in the DRC, 2002-2022.



A: Observed data; **B:** Long-term (secular) trend; **C:** Seasonal component; **D:** Residual variation.