Research Article ISSN: 2996-3893

Trends in General Medicine

Emergence of Vaccine-Derived Polioviruses (VDPVs) in Haut Katanga (DRC): Mapping of Risk Areas and Analysis of Eco-epidemiological Determinants, 2018-2023.

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Received: 10 Aug 2025; **Accepted:** 18 Sep 2025; **Published:** 29 Sep 2025

Citation: YOBO IYALA Jean Blaise, DEGBEY Comlan Cyriaque, KAPOUR KIENG Germain. Emergence of Vaccine-Derived Polioviruses (VDPVs) in Haut Katanga (DRC): Mapping of Risk Areas and Analysis of Eco-epidemiological Determinants, 2018-2023. Trends Gen Med. 2025; 3(3): 1-5.

ABSTRACT

Poliomyelitis is a highly contagious enterovirus caused by wild poliovirus, which is currently being eradicated. This challenge is hampered by the resurgence of so-called vaccine-derived poliovirus variants. Circulating vaccine-derived poliovirus (cVDPV) represents a persistent threat to polio eradication, particularly in areas with insufficient vaccination coverage. This study aims to map areas at risk of cVDPV emergence in Haut-Katanga (DRC) and to analyze eco-epidemiological determinants.

Methods: *This was an observational, ecological analytical study with a spatio-temporal component conducted in the 27 health zones of Haut-Katanga between 2018 and 2023. Epidemiological data (cVDPV cases), vaccination coverage, access to drinking water, latrine use, malnutrition, diarrheal diseases, and measles were collected and analyzed. Mapping of risk areas was carried out using QGIS software.*

Results: *Our study identified several factors associated with the emergence of cVDPVs, including the rural type of health zones, high incidence rates of malnutrition, measles, and diarrheal diseases, low OPV3 and IPV coverage (less than 90%), and poor OPV3 VCT results (less than 90%). Of the 27 health zones, 6 were at high risk of cVDPV emergence, including the health zones of Lukafu, Kilelabalanda, Kafubu, Kasenga, Kisanga, and Kashobwe.*

Conclusion: *Controlling cVDPVs in Haut-Katanga requires an integrated approach combining improved vaccination coverage, strengthened environmental surveillance, child nutrition, and sanitation. Risk mapping is a strategic tool to guide response efforts by targeting priority areas in a resource-limited context.*

Keywords

Emergence, Vaccine-derived poliovirus, Haut-Katanga, Risk mapping, Eco-epidemiological determinants, DRC, vaccine coverage.

Introduction

Vaccine-derived poliovirus (VDPV) represents a growing public health threat, particularly in settings with insufficient vaccination coverage. Haut Katanga province recently reported several cases of cVDPV [1].

The DRC has been certified as a "polio-free country" by the World Health Organization since November 2015. However, the country remains at particularly high risk because there has been a resurgence of cases of variant polioviruses (derived from the vaccine strain) since 2017. The DRC, a vast country spanning East, West, and Central Africa, presents several eco-epidemiological features that reflect the impacts of this disease caused by a so-called environmental virus [2-4].

A recent study on the temporal and spatial dynamics of PVDV has revealed the extent of variant poliovirus epidemics and their heterogeneous distributions in the DRC. Almost all provinces were affected by the 3 serotypes of PVDV during the 6 years of

our study. The SZs of the Grand Katanga provinces were the most affected. This analysis highlighted the contribution of the seasonal component to the circulation of poliovirus, the variation in relative humidity according to the season and the Health Zones can partly explain the fluctuations in the number of PVDV cases [2,5]. Several eco-epidemiological factors are involved in the emergence and restart of poliovirus epidemics, which is an environmental virus [6,7].

Diagnosis of Territorial Vulnerability to Epidemic Risks and Definition of Concepts

The theoretical methodological framework used in this study was adapted from the 2009 Confalonerie framework. According to this model, vulnerability is defined by three components: sensitivity, exposure, and adaptation [8]. The methodological transfer to the study of vulnerability to epidemics requires a clarification or redefinition of concepts such as vulnerability. In epidemiology, it often refers to biological and physiological processes; it has expanded to include social and economic aspects of diseases of poverty such as tuberculosis and malaria. It therefore provides a new perspective with a broader vision that goes beyond physical and mental dispositions, and its study refers to social and economic dimensions. Frédéric Leone distinguishes different forms of interconnected and measurable vulnerabilities using criteria and indicators (physical, bodily, human or social, organizational, environmental, and functional [9].

- **Hazard:** a threat that may be of natural or human origin to a system whose health can cause damage to human health [10].
- **Risk:** The result of the spatial and temporal conjunction (coexistence) of a hazard and vulnerable exposed elements. Resilience capacities can reduce its effects [11].
- Vulnerability or Risk Map.

To establish the level of risk in these health zones, we consider both hazard and vulnerability. The infectious hazard is reflected in the presence of vaccine-derived poliovirus through the variables "present or absence of confirmed cases of VDPV." These two variables were taken from the National Institute biomedical research (INRB) 's biological confirmation database.

Vulnerability is defined as a community's predisposition to destabilization by an external phenomenon, whether natural or artificial [10]. It depends on three parameters: the community's susceptibility to infection, exposure to the poliovirus, and the resilience of the at-risk population [10]. It can be summarized by the following formula: **Vulnerability = Susceptibility x Exposure x (1 - Resilience).** The susceptibility, or likelihood of a community being affected, depends on the level of immunity, which is primarily reflected in the proportion of vaccinated individuals in the various health zones [11]. Exposure is defined as the likelihood of a community coming into contact with the poliovirus. Resilience is the ability to control and recover quickly during an epidemic, and this depends on the ability to quickly detect outbreaks and launch mass vaccination campaigns.

Objective of the Study

This study aims to:

- Identify areas at risk of cVDPV emergence in Haut Katanga.
- Analyze the eco-epidemiological determinants associated with this emergence using mapping and statistical analysis tools.

Methods

This is an observational, ecological analytical study with a spatiotemporal component.

It was conducted in Haut Katanga province, located in the southeastern DRC, from January 2018 to December 2023.

Data Sources

- **cVDPV cases:** Collected from the INRB's biological confirmation database, compared with those of acute flaccid paralysis (AFP) managed by the EPI and the WHO.
- **Vaccination coverage:** Administrative data on OPV vaccination coverage extracted from DHIS2.
- **Environmental and health variables:** Data from secondary sources such as the general population census, and data on access to drinking water and latrine use from surveys and the operational action plan (PAO) of the health zones.
- Health data are collected from medical records and VDPV case investigation forms in the health zones through document review.
- **Geographic data:** shapefiles of health zones and health areas from the WHO Health Mapper.

Unit of Analysis

The geographic unit of analysis was the Health Zone, which constitutes the operational level of the Congolese health pyramid.

Study Variables

The dependent variables were the presence or absence of cVDPV cases and their cumulative number over the period. Explanatory variables included: vaccination coverage rate, population density, rate of access to drinking water, and the rate of households with latrines.

Spatial Analysis

The spatial analysis was conducted using QGIS 3.22, which allows visualization of the geographic distribution of cVDPV cases and risk variables. Statistical tests were used to identify significant eco-epidemiological determinants.

Multivariate logistic regression analysis was performed in R software (version 4.2.1) to identify eco-epidemiological determinants associated with the occurrence of cVDPV cases by health zone. The significance threshold is set at $p < 0.05$. Using the R package FactoMine, we performed a multiple correspondence analysis (MCA), which allowed the use of a dendrogram to group the different zones into clusters. Within each cluster we calculated an index based on the scores assigned to each modality according to the risk level, for example the presence of PVDV cases in an area was rated at 1 and its absence at 0. The rural nature of the

area at 0.75, semi-rural at 0.5 and urban at 0.25, such that the sum of scores within the modality was equal to 1. The average score within each modality was calculated. The different average scores of all the modalities within the cluster were added together to obtain an index.

The average score within each category was calculated. The average scores across all categories within the cluster were summed to obtain an index. The risk level for each cluster was determined based on its index; as long as the index was low, the risk level was also low.

A risk map was finally created based on the indices calculated using QGIS software.

Results

CLUSTER	SCORE	Risk level	
5	2,5	Very low	
4	3,5	low	
3	5,6	Moderate	
2	6,9	High	
1	7,4	Very high	

Table 1: Determination of risk level based on calculated scores.

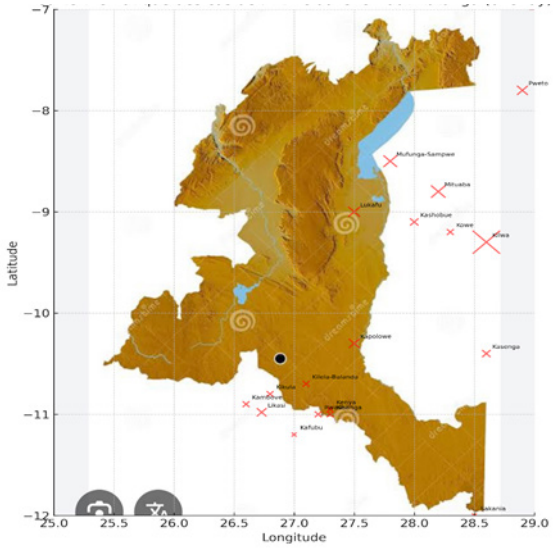

Figure 1: Map of the spatial distribution of VDPV in Haut Katanga, 2018-2023.

Clusters at risk of cVDPV in Haut Katanga

Using Multiple Correspondence Analysis, a dendrogram grouped the health zones into five clusters based on the scores assigned to them after calculations (Figure 2). Thus, the different risk levels

	Bivariate			Multivariate		
	OR non ajusted	**CI 95%**	**p-value**	**ajusted OR**	**CI à 95%**	**p-value**
Type of Health Zone						
Urban	1	-	-	1	-	-
Urban-rural	8,41	0-NA	0,986	1,6110^{e-6}	0-NA	0,994
Rural	**5,06**	**2,54-10,01**	**<0,0001**	**6,34**	**2,63-15,27**	**<0,0001**
OPV3 Coverage						
High	1	-	-	1	-	-
Low	**3,12**	**1,41-8,02**		**3,43**	**1,27-9,21**	**0,015**
OPV3 Vaccination Coverage Survey 2023						
High	1	-	-	1	-	-
Low	**4,72**	**1,75-8,85**		**0,29**	**0,01-0,90**	**0,032**
IPV Coverage	1					
High	1	1		1	-	-
Low	1,95	0,45-4,56		179	0,95-3,37	0,957
Polio SIAs Visits	2,24	1,55-6,85		1,511	0-NA	0,801
<2 **SIAs**	-	-		0,55	0,28-1,060	0,553
≥2 **SIAs**	2,65	1,80-5,46		1	-	-
Drinking Water						
Faucet	1	1		1	-	-
Well	0,75	0,20-2,77	0,666	0	0-NA	
River	**5,57**	**2,80-11,10**	**<0,0001**	**0,075**	**0,02-0,28**	**<0,0001**
Malnutrition incidence						
Low	1	-	-	1	-	-
High	**3,18**	**1,38-7,28**	**0,006**	2,30	**0,97-5,47**	**0,049**
Diarrheal disease Incidence						
Low	1	-		1	-	-
High	**2,21**	**1,02-6,90**		**18,04**	**3,75-86,75**	**<0,0001**
Measles incidence						
Low	1	-		1	-	-
High	3,53	2,45-7,54		0,38	0,15-0,94	0,037

correspond to colors ranging from green, a very low risk level, to red, corresponding to a very high risk level (Table 1). Finally, a risk map was developed (Figure 3) and classified the 27 health zones in Haut Katanga province into the following 5 clusters:

- Very high-risk health zones: Lukafu, Kisanga, Kashobwe, Kilelabalanda, Kafubu, Kasenga
- High-risk health zones: Kikula, Tshamilemba, Mufunga sampwe, Kilwa, Kapolowe, Mitwaba, Pweto. − Moderate-risk HZs: Kenya, Kampemba, Rwashi, Mumbunda, Likasi, Panda, Sakania, Kambove, Kipushi.
- Low-risk HZs: Katuba, Kamalondo, Kowe
- Very low-risk HZs: Lubumbashi, Vangu

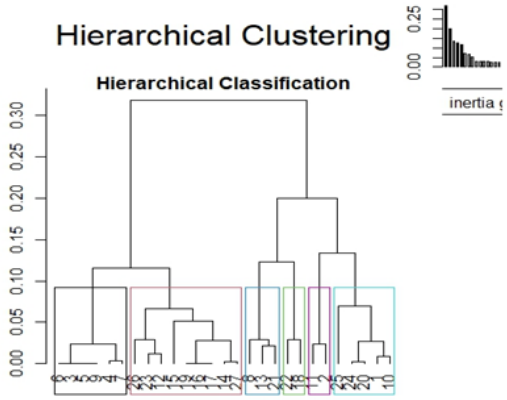

Figure 2: Determination of risk level based on calculated scores.

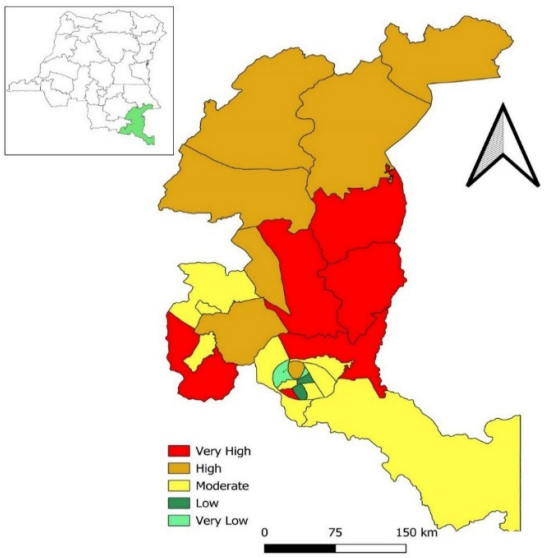

Figure 3: VDPV Risk Map for the province of Haut Katanga.

Discussions

This study identified areas at high risk of circulating vaccine-derived poliovirus (cVDPV) emergence in Haut-Katanga Province, Democratic Republic of Congo, using an integrated eco-epidemiological approach. The results highlight a significant concentration of cases in rural areas, characterized by low vaccination coverage, a high incidence of vaccine-preventable diseases, malnutrition and diarrheal diseases, and precarious conditions and health vulnerability [12,13]. Correlations between cVDPV cases and factors such as malnutrition, limited access to drinking water, and the occurrence of vaccine-preventable diseases (measles, diarrhea) reinforce the need for an integrated response [14-16]. The use of mapping allows for more effective targeting of interventions, particularly in border or isolated areas such as Kilwa and Pweto. Limitations of this study include the lack of precise geographic coordinates and the lack of up-to-date data for some variables.

The Global Polio Eradication Initiative (GPEI), in its 22nd surveillance report dated September 22, 2023, deplores the inaction of governments in taking measures on water, hygiene, and sanitation because, like other enteroviruses, dirty water and poor sanitation are an open invitation for the poliovirus to continue infecting [17].

The identification of Kilwa, Mituaba, Mufunga-Sampwe, and Kapolowe as primary foci confirms that border or remote areas, often less well served by health services, are particularly vulnerable.

The observed link between the use of river water and the occurrence of cVDPV cases suggests potential transmission facilitated by fecal contamination of the environment, which is consistent with the pathophysiology of poliomyelitis, transmitted by the fecal-oral route. The high incidence of diarrheal diseases and measles in the same areas reinforces the hypothesis of a widespread failure of primary health services [18].

The low vaccination coverage, confirmed by both administrative data and 2023 vaccination coverage surveys of less than 80%, is not sufficient to interrupt the circulation of the virus, particularly in a context where the oral vaccine can mutate and become virulent again [19-21]. This underlines the urgency of strengthening routine and catch-up vaccination strategies, particularly in geographically isolated areas [22,23].

This study nevertheless has certain limitations. First, the quality of administrative data may be affected by reporting issues or overestimated actual coverage. Second, the ecological analysis does not allow for individual inference, and the observed relationships must be interpreted with caution. However, the combination of spatial analysis and multivariate modeling allows for the identification of robust trends at the population level. Despite these limitations, the results of this study offer interesting operational perspectives for targeting areas to intensify control actions to halt the circulation of cVDPV in the country.

Conclusion

The emergence of circulating vaccine-derived poliovirus (cVDPV) in Haut-Katanga province illustrates the persistent vulnerability of certain rural areas to vaccine-preventable diseases. This study highlighted a concentration of cases in health zones where several

risk factors converge: low vaccination coverage, water insecurity, high prevalence of infectious diseases and limited access to health services. These results call for urgent strengthening of routine and catch-up vaccination strategies, particularly in geographically remote or border areas. An integrated eco-epidemiological approach, combining spatial analyses and contextual data, can contribute to accelerating polio eradication. While the widespread use of oral polio vaccine (OPV) in endemic countries has significantly reduced the incidence of this disease, the challenge of eradication has not yet been won due to the emergence of pathogenic viruses derived from OPV. In any case, to effectively eradicate polio, replacing the oral vaccine with the injectable inactivated vaccine is essential. In addition to sanitation programs, public authorities must provide optimal conditions to enable children to be sufficiently immunized and to have access to adequate health and nutritional care, not forgetting access to drinking water and hygienic latrines.

Acknowledgments

Professors Jean Jacques Muyembe and Didier Bompangue for initiating the creation of the One Health for Africa Institute, which provided us with knowledge, tools, and keys to addressing ecological approaches to community health problems.

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