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Analysis of risk factors for confirmed cases and resurgence of measles epidemics associated to Covid-19 effects, in Senegal

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Abstract

Introduction : Measles is one of the most contagious infectious diseases, responsible for significant morbidity and mortality through recurring epidemics. With Covid-19, a resurgence of measles cases was observed, with epidemics occurring between 2021 and 2024. The goal of this study is to identify significant factors associated with confirmed cases of measles epidemics in the post-Covid-19 context. It also specifically aimed to investigate the influence of Covid-19-related factors on the resurgence of measles.

Methodology : A cross-sectional analytical study was conducted on confirmed cases of measles recorded in the health districts of Senegal from January 2015 to December 2024. Statistical analyses were performed using R software with Cramer's v, Multiple Correspondence Analysis and multiple binary logistic regression.

Results/findings : A total of 2 448 confirmed cases were recorded. Patients ranged in age from 1 to 81 years, with a mean age of 9 years. Several factors were associated with the occurrence of measles outbreaks. The Kédougou region (OR : 5, 95% CI [3.71-6.78], $p < 0.000$) was associated with a fivefold increased risk of contracting measles. Insufficient vaccination coverage for the second dose (RR2) was strongly linked to the spread of the disease (OR : 3.34, 95% CI [2.83-3.95], $p < 0.000$). The risk was also four times higher in unvaccinated individuals (OR : 4.03, 95% CI [3.54-4.6], $p < 0.000$). Finally, children aged 1 to 5 years (OR : 1.39, 95% CI [1.23-1.55], $p = 0.000$) appear to be a particularly vulnerable age group, with an increased risk compared to other age groups.

Conclusion : The study ranked the risk factors associated with the resurgence of measles epidemics in Senegal in order of importance. It also proposed integrating these factors into a machine learning algorithm to develop an application for the automatic detection of measles cases and extending it to other diseases with epidemic potential.

1. Introduction

Measles is a highly transmissible viral infection caused by a Morbillivirus, for which humans are the sole reservoir [1]. Although an effective vaccine has been available for several decades, the disease remains a major cause of morbidity and mortality in many countries, particularly in Africa [2]. Measles outbreaks, often widespread, continue to result in significant loss of life and disrupt health systems, jeopardizing global elimination efforts [3]. According to the World Health Organization (WHO), of the 9 769 600 measles cases recorded worldwide, there have been 142 200 deaths, the vast majority of which were among children under 5 years of age. The African continent alone reported 1 759 000 cases, with 52 600 deaths [4]. Covid-19 has contributed to a significant worsening of the situation. It caused a massive disruption to vaccination campaigns in many countries, leaving more than 94 million children in 26 countries without vaccine protection. Furthermore, human and logistical resources were reallocated to the Covid-19 response, which weakened routine immunization programs and reduced access to health services, particularly for the most vulnerable populations [3].

All WHO regions experienced a resurgence of measles cases during this period. This increase was also correlated with insufficient vaccination coverage, prolonged humanitarian crises, armed conflict, and large-scale population movements. Some countries recorded particularly high incidence rates, including the Democratic Republic of the Congo, Madagascar, Liberia, Somalia, and several Pacific island states [4]. Globally, first-dose measles vaccine coverage remains around 85%, a level significantly lower than the 95% threshold required for establishing and maintaining durable herd immunity [5]. In Senegal, estimates indicate average first-dose coverage (RR1) of 85%, while second-dose coverage (RR2) remains limited to approximately 60%.

In this context, the precise identification of epidemic risk factors is essential for controlling outbreaks and effectively guiding prevention and response efforts. The objective of this study is to identify the factors associated with the occurrence of measles epidemics in Senegal from 2015 to 2024, taking into account the specificities related to the influence of Covid-19, particularly during the period 2021–2024.

It is structured as follows: Section 2 describes the methodology, Section 3 presents, analyzes, and discusses the results, and Section 4 concludes the work.

2. Methodology

2.1 Type and period of study

This is an analytical cross-sectional study based on the analysis of secondary data from measles epidemiological surveillance collected between 2015 and 2024.

2.2 Study population

The study covers all positive cases of measles recorded in the national database, reported to the Directorate of Prevention (DP) through the Division of Epidemiological Surveillance and Vaccine Response of the Ministry of Health and Public Hygiene (MHPH), during the study period and meeting the defined inclusion criteria.

2.3 Sampling

The sampling is based on the exhaustive inclusion of all confirmed cases of measles recorded, thus ensuring a faithful representation of the epidemiological dynamics of the disease and providing a robust basis for precise and in-depth analyses.

2.4 Data Collection

2.4.1 Data collection Tools

The data comes from a national public health database; the collection was based on measles case notification forms as well as microbiological analysis results provided by the Pasteur Institute of Dakar (IPD).

2.4.2 Data collected

Table 1 below presents information on confirmed cases of measles extracted from the epidemiological surveillance database.

Table 1
Information contained in the measles database, Senegal, 2015 to 2024

Module	Information collectée
I. Individual determinants:	Age, sex, vaccination status, patient background, hospitalization status
II. Environmental and Community Determinants	Health regions, health districts, urban/rural area.
III. Organizational and Health System Determinants	Sample status, sample transport time (delivery time), date of onset of symptoms (notification time), vaccination coverage

2.4.3 Definition of analysis variables

A measles resurgence refers to a sudden and significant increase in the number of cases in a given population over a short period of time. It is influenced by several factors.

- **Response variable**

Final classification (measles): this corresponds to the final status of each case (confirmed, doubtful, and ruled out).

- **Explanatory variables**

Age

expressed in years; this is a key indicator of the risk of infection;

Sex

a dichotomous qualitative variable (Male, Female);

Region of residence

a nominal qualitative variable, used to identify the most affected regions (Dakar, Louga, Sédhiou, etc.);

Urban/rural area

classification between urban and rural areas, influencing access to vaccination (Urban, Rural);

Vaccination coverage

this corresponds to the percentage of children who have received the recommended doses of the measles vaccine in a target population at a given time, according to the national immunization schedule.

2.4.4 Data analysis

The data were analyzed using the R software. Multiple correspondence analysis (MCA) and Cramer's similarity index were used to highlight the associations between the different variables. MCA allows us to assess the associations between risk factors for measles transmission and measles based on the proximity between categories.

Exploratory analysis, while useful for describing the data and identifying trends, is insufficient to establish the significance of the associations between risk factors for measles transmission and measles. Therefore, the application of a logistic regression model is essential to strengthen the precision of the association significance.

Multivariate regression was applied to identify the risk factors for measles transmission. For this, we transformed the FinalClassification variable into a binary code, using "1" for confirmed cases ("Positive") for which we sought to identify the risk factors, and "0" for excluded and doubtful cases ("Negative"). The most significant risk factors for spread were selected using the stepAIC method, which performs variable selection based on the Akaike Information Criterion (AIC). The significance of the risk factors for spread was established using the following indicators :

- **p-value** : A p-value less than 5%, associated with the coefficient of a risk factor, suggests that the factor is significant. A low p-value reinforces the importance of the odds ratio (OR) in interpreting the results ;
- **OR (Odds Ratio)** : An odds ratio greater than 1 indicates a risk factor for disease spread ;
- **OR Confidence Interval (CI)** : A 95% CI that does not include the value 1 indicates a significant association between the risk factor and the disease.

The results obtained using the binary multivariate logistic regression model are presented in a table summarizing the most significant risk factors for measles spread identified (Table 3).

2.5 Ethical considerations

The use of sensitive data from the national measles surveillance database in Senegal required strict adherence to several ethical principles.

Confidentiality and protection of personal data :

- the information collected potentially included personal data (e.g., age, sex, vaccination status, location) and was anonymized to ensure confidentiality. No information that could directly identify patients or small-scale regions was disclosed in the results.

Informed consent

and institutional authorization :

- although the primary data collection was not carried out, the use of national databases required authorization from the competent authorities.

The Senegalese Ministry of Health, Department of Prevention, granted permission to use deidentified case base surveillance data collected during the study period in the country. No local ethical committee approval was required for this secondary data analysis of routine surveillance data.

3. Results/findings

3.1 Similarity Matrix Analysis

Table 2 provides the strength of the association between risk factors and confirmed cases of measles.

Analysis of the similarity matrix using Cramer's v index revealed that some factors showed a moderate association with confirmed measles cases. These included medical region (v = 0.30), vaccination status (v = 0.23), and RR2 (WUENIC) vaccination coverage (v = 0.14). In contrast, other variables such as RR1 vaccination coverage (v = 0.08), age group (v = 0.06), sex, and place of residence (v = 0.05) showed weaker associations. Although these associations were limited, they nevertheless suggest that all of these factors could contribute, to varying degrees, to the distribution of positive measles cases.

Table 2
Measles risk factor similarity matrix in Senegal

Region	Region	Sex	UrbanRural	StatutVaccinal	RR1	RR2	grpage	Measles
	1	**0.03**	**0.63**	**0.22**	**0.27**	**0.17**	**0.18**	**0.30**
Sex	0.03	1	0.03	0.02	0.00	0.00	0.03	0.05
Urban/Rural	0.63	0.02	1	0.03	0.07	0.01	0.16	0.05
Vaccination Status	0.22	0.02	0.03	1	0.14	0.14	0.17	0.23
RR1	0.28	0.00	0.07	0.14	1	0.21	0.04	0.08
RR2	0.17	0.00	0.01	0.14	0.21	1	0.04	0.14
Grouping	0.18	0.03	0.16	0.17	0.04	0.04	1	0.06
Measles	0.30	0.05	0.05	0.23	0.08	0.15	0.06	1

3.2 Factor analysis between risk factors and measles

Figure 1 is the circle of association of significant risk factors associated with measles on the factorial plane.

The analysis of the circle of association highlights a marked proximity between positive measles cases and certain specific health conditions, notably the medical regions of Diourbel, Kédougou, and Matam, average RR1 (WUENIC) vaccination coverage, and the under-14 age group. Other factors, such as the Tambacounda medical region and unvaccinated status, also appear to be relatively associated with positive cases, suggesting their potential role in the spread of the disease.

3.3 Assessment of risk factors associated with measles

The study shows that the risk of measles is significantly increased in several regions (especially Kédougou, Diourbel, and Dakar), among females, unvaccinated individuals, and young children aged 1 to 5 years. Low vaccination coverage, particularly for the second dose (RR2), is a major aggravating factor. These results underscore the need to strengthen vaccination efforts (especially the second dose) and targeted surveillance in outbreak areas (Table 3).

Table 3
Risk factors associated with measles from 2015 to 2024 in Senegal

Risk Factors	Logistic model		
	OR	95% IC	p-value
Medical regions (Measles outbreak hotspots)			
Dakar	3.5	2.74–4.52	< 000
Diourbel	4.65	3.58–6.09	< 000
Kaffrine	1.64	1.07–2.58	0.0281777
Kédougou	5	3.71–6.78	< 000
Kaolack	1.84	1.17–2.94	0.001
Kolda	2.4	1.67–3.45	000
Louga	2.82	2.11–3.79	000
Matam	3.09	2.25–4.26	000
Saint-Louis	1.53	1.06–2.20	0.0216573
Tambacounda	2.47	1.89–3.26	000
Sex			
Female	1.28	1.15–1.41	000
Vaccination Status			
Unvaccinated	4.03	3.54–4.60	< 000
Vaccination coverage			
RR1 Average	1.49	1.30–1.71	000
RR2 Average	3.34	2.83–3.95	< 000
Age Group			
[1, 5[years	1.39	1.24–1.55	000
[15, 81] years	1.3	1.08–1.57	0.0060955

Importance of the Most Significant Associated Risk Factors

Figure 2 shows the most important risk factors associated with the spread of measles at the national level

The study prioritized the risk factors associated with the resurgence of measles epidemics in Senegal. Residing in the Kédougou region increases the risk of contracting measles fivefold compared to other regions of the country. Furthermore, insufficient vaccination coverage for the second dose (RR2) is strongly linked to the spread of the disease. The risk is also four times higher among unvaccinated individuals, thus highlighting the essential role of vaccination in measles prevention. Finally, children aged 1 to 5 years appear to be a particularly vulnerable age group, with an increased risk compared to other age groups.

Automated classification platform for suspected measles cases based on associated risk factors

Based on the results of this study, we were able to develop an application for the automated diagnosis of suspected cases, thus contributing to improved early detection. This application, which automatically ranks significant factors, is a valuable tool for the early identification and prioritization of suspected cases in epidemiological surveillance systems. It supports and assists in rapid public health decision-making. Figure 3 illustrates the diagnostic interface and the automated ranking of risk factors associated with measles in Senegal, based on estimated odds ratios.

Compared to the regional distribution of confirmed cases, the study showed that the Kédougou region has a fivefold increased risk of contracting measles. This result correlates with those of [5–6], which showed regional trends in Senegal between 2010 and 2021 and estimated a higher incidence in the Kédougou region. However, those of [5–6] did not highlight the importance of the risk ratio of significant factors associated with the spread of measles, nor did they analyze factors related to the second dose (RR2) and the 1–5 year age group. Furthermore, those of [7] constructed a typology of health districts based on the number of confirmed cases of ten infectious diseases with epidemic potential in Senegal, enabling them to identify well-defined outbreak clusters and demonstrating that measles was significantly associated with the Dakar health district.

Regarding vaccination, the results suggested insufficient vaccination coverage, particularly among children aged 1 to 5 years, thus contributing to the persistence of outbreaks. This finding is consistent with that of [8], concerning the determinants of first-dose measles coverage (RR1), which showed that an unvaccinated child has a higher risk of experiencing signs or suspected cases of measles. This study did not address the second dose and did not include regional comparisons [8]. The association between certain age groups, children aged 1 to 5 years (OR : 1.39 ; 95% CI [1.23 ; 1.55], p = 0.000), and an increased risk of measles is also highlighted in epidemiological studies [9], as is the higher risk in girls (OR : 1.28 ; 95% CI [1.15 ; 1.41], p = 0.000), which validates the findings on demographic factors related to the occurrence of measles.

Covid-19 has contributed to a significant worsening of the situation. It has caused a massive disruption of vaccination campaigns in many countries, leaving more than 94 million children in 26 countries without vaccine protection [10]. Furthermore, human and logistical resources were reallocated to the Covid-19 response, which weakened routine immunization programs and reduced access to health services, particularly for the most vulnerable populations.

Insufficient second-dose vaccination coverage (RR2) is strongly associated with the spread of measles (OR : 3.34, 95% CI [2.83–3.95], p < 0.000). This finding is consistent with the influence of Covid-19, which showed that all WHO regions experienced a resurgence of measles cases during this period [11]. This increase is often correlated with insufficient vaccination coverage, prolonged humanitarian crises, armed conflicts, or mass population movements. Some countries recorded particularly high incidence rates, including the Democratic Republic of Congo, Madagascar, Liberia, Somalia, and several Pacific island states [12]. Analysis of vaccination status revealed that the risk was also four times higher in unvaccinated individuals (OR : 4.03, 95% CI [3.54–4.6], p < 0.000). A study in the Democratic Republic of Congo showed that significant factors associated with the occurrence of measles included: unvaccinated children (OR : 10.31, 95% CI (4.183–25.413), p < 0.05); malnourished children (OR = 22.091, 95% CI (12.986–37.58), p = 0.0001); and lack of vitamin A intake (OR = 5.763, 95% CI (2.27-14.631), p < 0.05) [13].

In Senegal, epidemiological data from the past four years reveal significant measles cases among children under one year old and individuals over 10 years old. In 2023, a major resurgence was noted, with more than 400 confirmed cases spread across several regions. Enhanced epidemiological surveillance and various reports on infectious disease emergencies have highlighted the crucial role of non-recourse to vaccination in the spread of measles. For example, the incidence in the Tambacounda region increased from 16 per 1 000 000 inhabitants in 2013 to 144 per 1 000 000 in 2022 [14].

Between January 2022 and February 2023, 33 health districts were experiencing a confirmed measles epidemic [15]. Further case analysis showed that 84% of those affected were unvaccinated, highlighting the direct link between non-vaccination and the resurgence of measles [16–17]. To address this, Senegalese health authorities planned nationwide vaccination response campaigns from December 2 to 11, 2024, targeting children aged 9 months to 15 years [18] with the aim of increasing vaccination coverage and reducing virus transmission. This campaign is consistent with findings that demonstrated insufficient second-dose vaccination coverage is strongly linked to the spread of measles.

4. Limitations

This study relies on routine surveillance data, which may include underreporting of measles cases and potential interruptions in data collection, potentially affecting the completeness and accuracy of estimates in Senegal. Furthermore, the absence of variables such as nutritional status and population mobility may introduce residual confounding bias, thus limiting the explanatory and predictive capacity of the resurgence model.

5. Conclusion

This study highlights the factors associated with the resurgence of confirmed measles cases in Senegal. The results reveal that non-vaccination in children under five, low vaccination coverage, and residence in the Dakar, Diourbel, and Kédougou regions are the most significant risk factors for the disease's

resurgence. With a view to automating the detection and anticipation of epidemic outbreaks, the integration of these factors into a predictive model based on machine learning algorithms is being considered, with the aim of developing a decision-support tool. This application could be extended to other diseases with epidemic potential and deployed on mobile platforms as well as via DHIS2, in order to strengthen the epidemic surveillance and response system in Senegal.

Abbreviations

AIC Akaike Information Criterion

DP Directorate of Prevention

MHPH Ministry of Health and Public Hygiene

WHO World Health Organization

WUENIC WHO/UNICEF estimates of national immunization coverage

Declarations

The data used in this manuscript comes from the routine monitoring system. They are collected at the level of health facilities using a notification form. They are then entered into a database with anonymization. The prevention department has the administrative mandate for the use and analysis of data for public health decision-making purposes.

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Figures

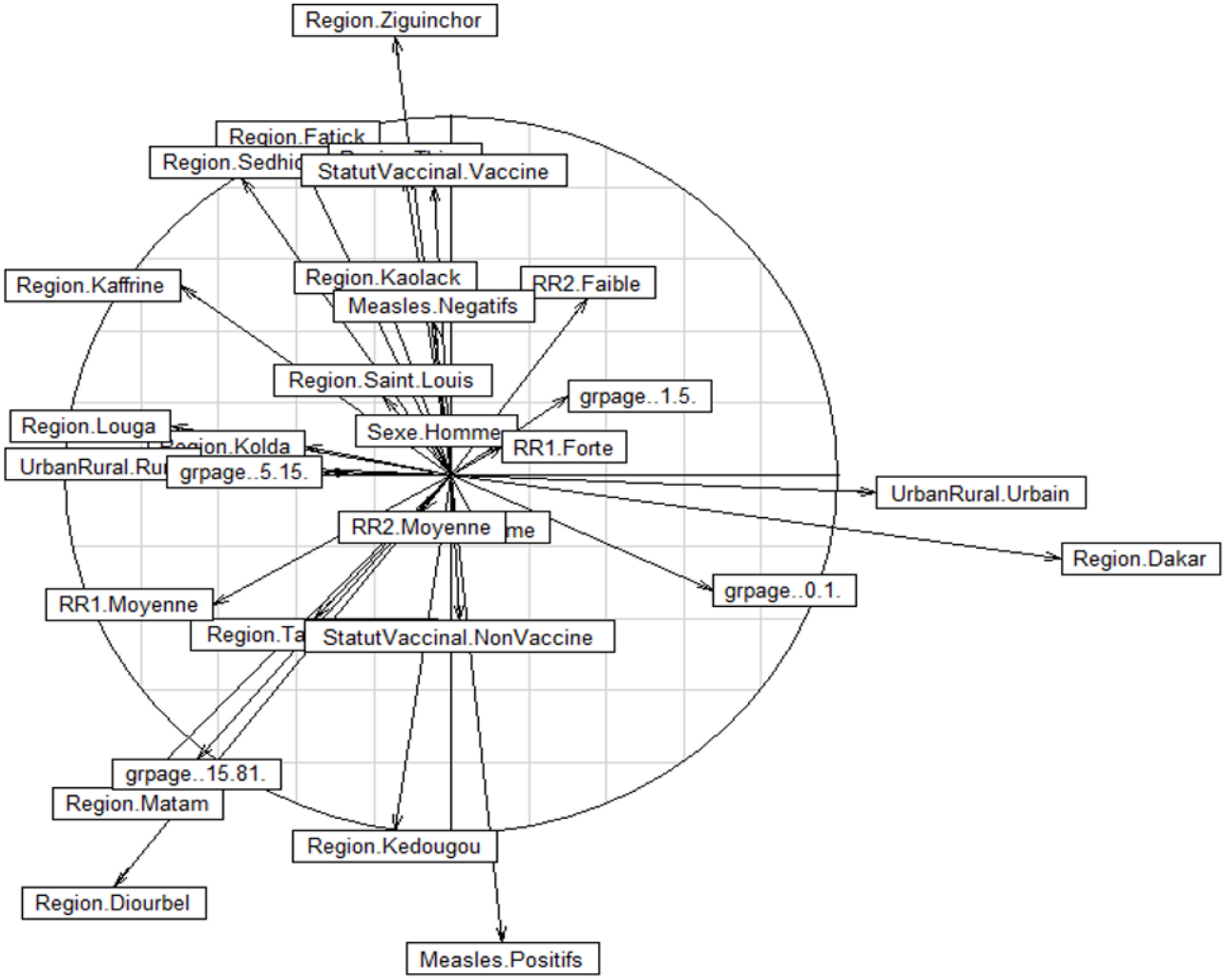


Figure 1

Circle of association of measles risk factors from 2015 to 2024 in Senegal

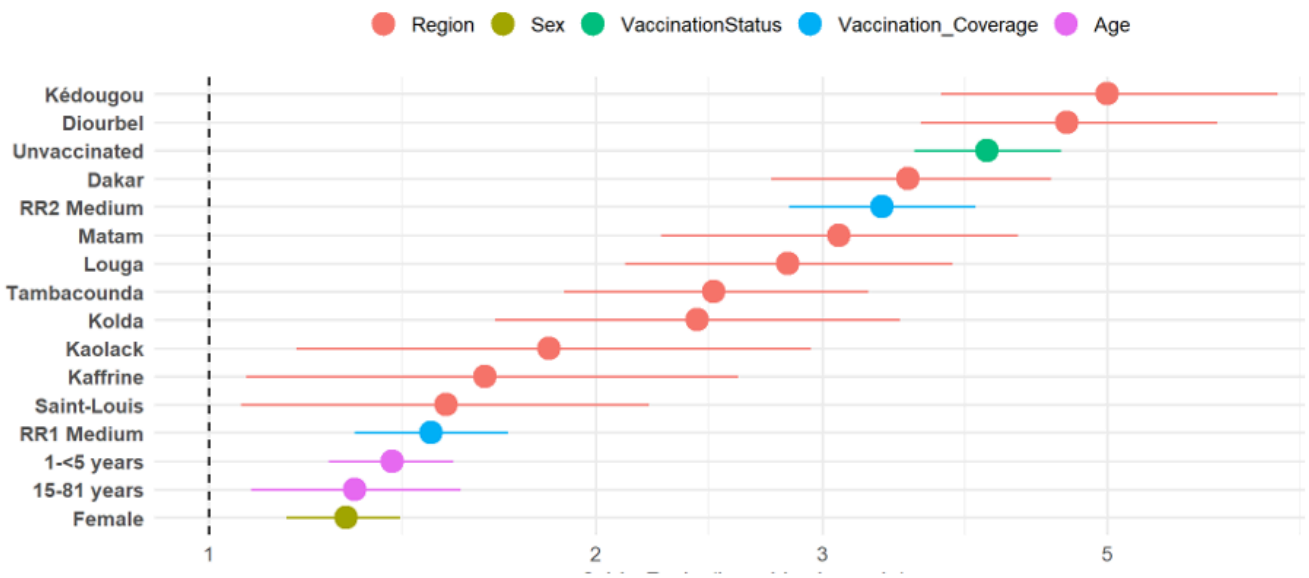


Figure 2

Ranking of measles risk factors according to their Odds Ratio from 2015 to 2024 in Senegal



Figure 3

Automated classification platform for suspected measles cases