

Statistical Modeling of the Spread of Mpox Disease in Burundi

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Abstract

Mpox has become a significant public health problem and Burundi is one of the countries that has been affected by Mpox outbreak. This study aimed to explore the factors that can influence the variation of the Mpox incidence rates across 49 health districts by using aggregated data. This was a descriptive and analytical cross-sectional study using three statistical models: Poisson Regression, Mixed-Effect Poisson Regression and Bayesian Hierarchical Model. For the Poisson Regression, the number of health facilities (IRR = 1.1), laboratory workers (IRR = 1.01), community health workers group (IRR = 0.88), population density (IRR = 0.99), number of people outside the districts using first antenatal consultation services (IRR = 0.92) and number of children full vaccinated from outside the districts (IRR = 1.11) were significant. For the Mixed-Effect Poisson Regression Model, the random effects between groups are almost nil. For the Bayesian Hierarchical Model, the number of laboratory workers had the plot that showed a good convergence. Based on the aggregated data, the results show that in order to improve the reporting of new Mpox case, it is necessary to act on availability of different categories of resources for health promotion, diagnosis and case management. A study based on individual data could complete the findings of this study.

Keywords

Statistical Modeling, Mpox, Health District, Burundi

1. Introduction

Mpox, a disease caused by the simian orthopoxvirus, is a zoonosis closely related to the smallpox virus, which has become a significant public health problem due to its increasing prevalence and the risk of large-scale epidemics [1]-[4]. It shares many clinical features with smallpox such as fever, rash, and lymphadenopathy [5] [6]. The literature has shown that after 30 years of cessation of smallpox vaccination campaigns, an upsurge in Mpox cases has been observed in several tropical regions [7] [8]. Mpox has recently been reported in various non-endemic countries, raising global anxieties about its ability to cause large-scale outbreaks [9]. According to studies on recent outbreaks, more than 90% of Mpox patients are under 30 years of age, and they have not been vaccinated against smallpox because they were born after 1980 [10] [11].

The identification of the first pools has led to the beginning of categorization of some specific environments that could be linked to the emergence of Mpox cases. Villages located near dense forests appeared to be at higher risk [11]-[13]. In addition, there is evidence that the disease is transmitted primarily through direct contact with the blood, body fluids, or skin lesions of infected animals or humans [14]. Human-to-human secondary transmission occurs via respiratory droplets and contaminated objects, making it a highly contagious disease [15]. A systematic review carried out in 2022 highlighted other risk factors, including homosexual and bisexual behaviour, the presence of HIV and sexually transmitted infections, human-to-human transmission through direct contact and through different bodily fluids in the majority of cases. Lesions of the genital, perianal and anogenital parts were more common. Pharyngitis and proctitis were more common in the 2022 outbreak than in outbreaks prior to 2022 [16].

However, these elements of understanding Mpox remain limited, not yet allowing us to answer many questions raised by the dynamics of the mode of Mpox transmission, particularly with regard to country-specific interventions [10] [12] [17].

One of the main limitations of the current work lies in the size of the scales on which this research has been conducted. These spatial scales are either very large (continent) or local (district or health zone in a country), which makes it impossible to highlight the mechanisms related to the emergence and recurrence of these Mpox epidemics [11] [12] [17] [18].

Understanding the dynamics of Mpox transmission is essential for developing effective public health interventions in each country. Traditional epidemiological models, such as the Susceptible-Infectious-Recovered model, have been widely used to estimate key parameters such as baseline reproduction number and to predict the course of infectious disease outbreaks [19] [20]. However, these models often assume homogeneous mixing within populations, which may not accurately reflect the complexity and heterogeneity of the real-world population. Factors such as regional/provincial variations in population density, access to health care and services, and social behaviour (mobility, cultures, mores and customs,

etc.) can significantly influence the dynamics of disease transmission [21]-[27].

To address these limitations, another study using three models including the Poisson Regression Model, the Generalized Linear Mixed Model (GLMM) and the Bayesian Hierarchical Model [2] to analyse the spread of Mpox in different regions was used. This model offered a more complex and detailed understanding of Mpox transmission dynamics and provided a robust method to predict the potential spread of the disease but gave overall results for all 13 African Union member states (Burundi, Cameroon, Central African Republic, Congo, Cote d'Ivoire, Democratic Republic of the Congo, Gabon, Liberia, Kenya, Nigeria, Rwanda, South Africa and Uganda) and used three variables, namely population density, health care capacity, and population mobility.

In Burundi, the first case of Mpox was reported on 25th July 2024 and was identified as linked to the outbreak in the Democratic Republic of the Congo. According to the situation report on Mpox in Burundi of 31st December 2024, a cumulative of 5980 suspected cases, 2975 confirmed cases (with a positivity rate of 51.0%), one death and 46 out of 49 affected districts have been reported [28].

The aim of this study was to explore the factors that may influence the variation in the number of Mpox cases across health districts in Burundi, using statistical models supported with epidemiological interpretations to guide prevention interventions.

2. Research Methods and Design

2.1. Study Design

This was a cross-sectional study with a descriptive and analytical purpose using three statistical models.

2.2. Setting

The health system of Burundi is organized in a pyramidal form and is structured around four levels, namely the central, intermediate, peripheral and community levels. These levels are linked together by hierarchical operating relationships. The present study was carried out at the peripheral level, which is composed of 49 health districts and constitutes the operational level of the health system.

With regards to the situation of Mpox disease, Burundi is one of the countries in Africa that has been affected by this disease. The 31st December 2024 situation report showed that a cumulative 46 out of the 49 health districts have already reported at least one confirmed case of Mpox, *i.e.* 93.8% [28].

2.3. Study Population and Sampling Strategy

The primary unit of the study was the health district. This level was chosen because it is an operational level of the health system and has the role of coordinating health action (promotional, preventive and curative) and supervising community activities.

Inclusion criteria: All 49 health districts were included in the study regardless

of the number of Mpox cases that were reported from July 25th, 2024 to December 31st, 2024.

Non-inclusion criteria: A district with incomplete data for almost all of the explanatory (independent) variables or with a data quality problem for a significant number of the explanatory (independent) variables should not be considered in the analysis.

2.4. Data Collection

2.4.1. Data Sources

The data used are from District Health Information Software version 2 (DHIS-2); Mpox status reports; Reports from district and provincial health offices and Burundi's population projection reports.

2.4.2. Study Variables

Dependent variable:

The Mpox incidence rate is the number of new confirmed Mpox cases reported from 25th July 2024 to 31st December 2024 in the health district, divided by the number of inhabitants of the health district.

Independent variables:

- *Population density*: The number of inhabitants per health district according to the National Institute of Statistics projections.
- *Population mobility*: The number of people from outside the district and out of the country who use the services of health facilities was collected. Services that make it possible to distinguish clients or patients by origin have been taken into account, including the curative consultation service, prenatal consultation, family planning and the vaccination service for children aged from 0 to 23 months. The proportion of these people from outside the district and out of the country in relation to the total number of people who have been received has been calculated, the period that has been taken into account is from July to December 2024.
- *Health care and services indicators concerning health promotion component*: data on the availability of resources that contribute to the promotion of good practices in the prevention of infectious diseases have been collected, these are number of medical providers (physicians, nurses, etc); health promotion technicians; community health workers (CHWs); number of health facilities and number of hospitals in the health district. Medical providers, Health promotion technicians and CHWs are involved in health promotion especially in the delivery of information, education and communication for behaviour change sessions. The more they are sufficient in numbers, the more likely it is that the population will be reached by health education messages. In addition, most health education sessions are carried out in health facilities and hospitals, so the coverage of health infrastructure increases the population's accessibility to health education messages. The latter increases the level of knowledge, improves attitudes and behaviours and contributes reducing the number of cases of infectious diseases such as Mpox.

- *Mpox case management capacity*: The number of physicians and number of treatment sites per health district was collected.

2.5. Data Analysis

Data Collection and Processing

The data was collected on paper by the data managers of the District Health Offices to facilitate their validation with the District Medical Officers. The collected data was entered into a data entry application developed on a web platform Kobo toolbox and regularly transmitted to the server for clearance.

Descriptive results

The distribution of the Mpox incidence rates was presented using different statistical parameters.

Analytical results

Three models were used: 1) Poisson regression model, 2) Generalized linear mixed model and the 3) Bayesian hierarchical model.

The following is a description of the three models:

a) Poisson regression model

The Poisson regression model was used to predict the factors that should influence the increase or decrease of Mpox cases by health district. This model is used for the count data, assuming that the dependent variable (number of Mpox cases or incidence rates) follows a Poisson distribution.

Model Specification

Let Y_i be the number of cases of Mpox for District i . The Poisson regression model is given by:

$$Y_i \sim \text{Poisson}(\lambda_i)$$

$$\log(\lambda_i) = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \dots + \beta_k X_{ik}$$

where

- λ_i = incidence rate parameter for *district i*, related to the covariates by the function given above;
- $X_{i1}, X_{i2}, \dots, X_{ik}$ = covariates (population density, number of medical providers, ...);
- $\beta_0, \beta_1, \dots, \beta_k$ = coefficients to be estimated.

Model validity

Interpretations of the exponentials of the coefficients have been performed. The factors that explained the variation (increase or decrease) of Mpox cases across health districts were identified. The relationship between the explanatory variables and the predicted Mpox incident rates with the final model was explored to show how each variable individually influenced the predicted number of Mpox cases. R and Stata 18 software were used to produce the analytical results.

Verification of the assumptions of the Poisson regression model, including the dependent variable that follows the Poisson distribution and the absence of dispersion has been performed.

The equilibrium of the model was sought to keep only the variables that better

explained the model using the top-down elimination method and the adequacy of the final model was demonstrated. The verification of the adequacy of the final models was done using the Akaike Information Criterion (AIC) which is a statistical measure used for the selection of the best model. The model with the lowest AIC was retained as the best model.

b) Generalized Mixed Linear Regression or Mixed-Effects Poisson Regression Model

General linear models are an umbrella term for a mathematical program written with enough generality to include the ANOVA, ANCOVA, MANOVA, and multiple regression methods in the same package. Linear mixed models are an extension of linear models that include both fixed and random effects. The use of the generalized linear regression model (case of the Poisson regression model) with mixed effect in this study made it possible to extend the Poisson regression by taking into account random effects.

Model Specification

Let Y_i be the number of cases of Mpox for District i . The mixed-effects Poisson regression model is given by:

$$Y_{ij} \sim \text{Poisson}(\lambda_{ij})$$

$$\log(\lambda_{ij}) = \beta_0 + \beta_1 X_{ij1} + \beta_2 X_{ij2} + \dots + \beta_k X_{ijk} + u_j$$

where

- λ_{ij} = incidence rate parameter for *district i*, related to the covariates by the function given above;
- $X_{ij1}, X_{ij2}, \dots, X_{ijk}$ = covariates (population density, number of medical providers, ...);
- $\beta_0, \beta_1, \dots, \beta_k$ = coefficients to be estimated;
- u_j = random effect for group j, assumed to follow a normal distribution.

Model validity

The province level, old delimitation and new delimitation were used to organize the data into groups. Coefficients for fixed effects were calculated, as well as group-based random effects based on the province variable. R and Stata software were used to produce the analytical results.

The validity of the generalized linear mixed-effects model was verified as follows:

- the verification of the underlying assumptions according to the distribution of the Poisson distribution;
- the clear identification of groups and individuals;
- the normality of the residues;
- comparing the different models to determine which one is the most relevant and performing best using the Akaike Information Criterion (AIC).

c) Bayesian hierarchical model

The Bayesian hierarchical model is similar to the generalized linear mixed model but uses a fully Bayesian approach to estimate parameters, incorporating prior distributions on fixed and random effects.

Model Specification

Let Y_i be the number of Mpox cases for District i . The Bayesian hierarchical model is given by:

$$Y_{ij} \sim \text{Poisson}(\lambda_{ij})$$

$$\log(\lambda_{ij}) = \beta_0 + \beta X_{ij1} + \beta X_{ij2} + \dots + \beta X_{ijk} + u_j$$

where

- u_j follows a normal distribution with distributions prior to the parameters

$$\beta_0, \beta_1, \dots, \beta_k \sim \text{Normal}(0, \sigma_\beta^2)$$

$$\sigma_u^2 \sim \text{Inverse-Gamma}(a, b)$$

σ_u^2 : variance of the a priori for fixed effects and A, B: Hyperparameters for the gamma inverse a priori on the variance of random effects:

- λ_{ij} = incidence rate parameter for *district i*, related to the covariates by the function given above;
- $X_{ij1}, X_{ij2}, \dots, X_{ijk}$ = covariates (population density, number of medical providers, ...);
- $\beta_0, \beta_1, \dots, \beta_k$ = coefficients to be estimated.

Model validity

The verification of the validity of the model consisted in checking whether the standard Monte Carlo errors (MCSEs) are close to 0 for all parameters (variables). The closer the MCSE of the mean estimate is to 0, the closer the posterior distributions of the parameters are to the observed distributions.

The verification of the fit of the model to the actual data was done by the diagnostic graphs. The plots of the parameters should show a good mix. The autocorrelation should gradually decrease and the posterior distribution of parameters should resemble the normal distribution.

2.6. Ethical Considerations

Data collection was carried out through the use of databases, reports and other sources of information available in the districts, provinces offices and at the level of the National Health Information System in the Ministry of Public Health.

Although there was no interaction between the data collector and the population to take into account the requirements of ethics in research, national ethical approval for the protection of human beings participating in research has been requested and obtained pursuant to decision CNE/03/2025. The statistical approval was also granted under decision 540/95.42/NT/DG/INSBU/241/2025. The use of aggregated data has also ensured anonymity.

3. Results

3.1. Distribution of Mpox Cases for the Period from July to December 2024

Table 1 shows the distribution of Mpox cases according to the different units as-

signed to the dependent variable.

Table 1. Distribution of Mpox cases according to the different units.

	N	Average	Standard Deviation	Median	1 st quartile	3rd quartile
Number of cases of Mpox	49	60.5	174.8	12	5	20
Incidence rate of Mpox per 1000 inhabitants	49	0.2	0.5	0.05	0.03	0.09
Incidence rate of Mpox per 10,000 inhabitants	49	2.0	5.0	0.47	0.21	0.86
Incidence rate of Mpox per 100,000 population	49	19.9	49.7	4.68	2.04	8.6

On average, 2 out of 10,000 people per health district contracted Mpox disease during the period from 25th July to 31st December 2024.

3.2. Analytical Results

3.2.1. Factors Influencing Variation in Mpox Cases According to the Poisson Regression Model

Initial model

The verification of the Poisson distribution assumptions showed the presence of value dispersion, which required the use of the Quasi-poisson regression model which solves this problem by introducing a dispersion parameter that adjusts the variance independently of the mean.

Bivariate analysis and the search for association between the incidence rate of Mpox and the different factors were done to identify the variables to be included in the initial model. All 14 variables that had a p-value less than or equal to 20% were retained to be part of the initial model. Top-down modelling was performed to determine the statistically significant variables associated with the Mpox incidence. At the end, a final model was retained at the 5% significance level (**Table A1** in **Appendix** shows the explanatory variables that were introduced into the initial model).

Final model

As shown in the table below, six variables came out significant in the final model. **Table 2** shows the explanatory variables that were retained.

Table 2. Final model of the quasi-poisson regression.

	Coef,	CI _{95%} Coef.	IRR*	CI _{95%} IRR	p-value
Availability of Health Facilities	0.11	[0.08 - 0.15]	1.12	[1.08 - 1.16]	0.000
Availability of Laboratory Workers	0.01	[0.00 - 0.02]	1.01	[1.00 - 1.02]	0.003
Availability of CHWs group	-0.22	[-0.31 - -0.13]	0.80	[0.73 - 0.88]	0.000
Population density	-0.001	[-0.001 - -0.003]	0.99	[0.99 - 0.99]	0.001
Use of ANC 1 services (Off-Distr.)	-0.08	[-0.11 - -0.04]	0.92	[0.89 - 0.96]	0.000

Continued

Use of vaccination services (Off-Distr.)	0.10	[0.05 - 0.15]	1.11	[1.05 - 1.17]	0.000
Intercept	0.59	[-0.59 - 1.77]	1.8	[0.55 - 5.85]	0.328
Dispersion parameter			0.516		
Coefficient of determination			72.2%		
AIC			111.55		
Number of observations			49		

*IRR: incidence rate ratio.

The summary of the final Poisson regression model shows that, for example, if the number of health centres increases by one unit, the Mpox incidence rates will increase by 1.12 times; the other predictor variables of the model being kept constant.

3.2.2. Factors Influencing Variation in Mpox Cases According to the Mixed-Effects Poisson Regression

Initial and final model

The initial model was composed of 14 variables, the procedures used for the Poisson regression were also followed. The 6 variables that were selected with the final Mixed-effect poisson regression model yielded the results described in **Table 3**.

Table 3. Summary of the mixed-effects poisson regression model.

		Coef.	CI _{95%} Coef.	IRR	CI _{95%} IRR	p-value
Fixed effects	Availability of Health Facilities	0.11	[0.08 - 0.15]	1.12	[1.08 - 1.16]	0.000
	Availability of Laboratory Workers	0.01	[0.00 - 0.02]	1.01	[1.00 - 1.02]	0.003
	Availability of CHWs group	-0.22	[-0.31 - -0.13]	0.80	[0.73 - 0.88]	0.000
	Population density	-0.001	[-0.001 - -0.003]	1.00	[1.00 - 1.00]	0.001
	Use of ANC 1 services (Off-Distr.)	-0.08	[-0.11 - -0.04]	0.92	[0.89 - 0.96]	0.000
	Use of vaccinat. services (Off-Distr.)	0.10	[0.05 - 0.15]	1.11	[1.05 - 1.17]	0.000
	Intercept	0.59	[-0.59 - 1.77]	1.8	[0.55 - 5.85]	0.328
Random effects	Province (pre-census)			<10 ⁻⁴		
	Province (new boundary)			<10 ⁻⁴		
AIC				111.2		
PEN				124.5		
Number of observations				49		

The above results show that for fixed effects, the coefficients of the variables retained in the final model are the same as for the Poisson regression.

In addition, the random effects that would explain the variation in the incidence rate of Mpox between the provinces (old and new boundaries) are almost nil. This shows that there is no significant variability either provinces or districts. The districts within each province all follow the same general trend, and the difference between the provinces is irrelevant.

3.2.3. Factors Influencing Variation in Mpox Cases According to Bayesian Hierarchical Model

Description of the Bayesian model

Table 4 shows the posterior means and their confidence intervals, the standard deviations of the Bayesian model parameters and the Monte Carlo standard errors (MCSEs).

Table 4. A posteriori parameters of the Bayesian model.

	Posterior average	CI95% average	Standard deviation	MCSE
Availability of Health Facilities	0.12	[0.09 - 0.16]	0.02	0.002
Availability of Laboratory Workers	0.01	[0.00 - 0.02]	0.01	0.001
Availability of CHWs group	-0.24	[-0.31 - -0.18]	0.04	0.002
Population density	-0.001	[-0.001 - -0.003]	0.01	0.001
Use of ANC 1 services (Off-Distr.)	-0.08	[-0.12 - -0.04]	0.02	0.002
Use of vaccination services (Off-Distr.)	0.11	[0.05 - 0.15]	0.03	0.003
Intercept	0.65	[0.55 - 1.76]	0.06	0.006

The above results show that for the Poisson regression coefficients are very similar to the posterior averages. The credible intervals of the post average estimate are also given. The Bayes prefix estimation table also shows the Monte Carlo standard errors (MCSEs), and the credibility intervals.

Bayesian Model Diagnostic Graphs

The following graphs (**Figure 1**) illustrate the plots, autocorrelation and normality of the posterior distributions of the six variables.

The plot of the number of laboratory workers shows a good mix, the autocorrelation gradually fades and the posterior distribution resembles the normal distribution, as expected for the specified likelihood and the a priori distributions, which shows good convergence.

For the other variables (number of health facilities, number of community health workers group, population density, number of people outside the health districts using antenatal consultation services and the number of children aged 0 to 23 months outside the districts using vaccination services), it can be seen that they do not show a good mix and that there is the persistence of autocorrelation.

The normality of the distribution is not effective for all variables, in particular for population density.

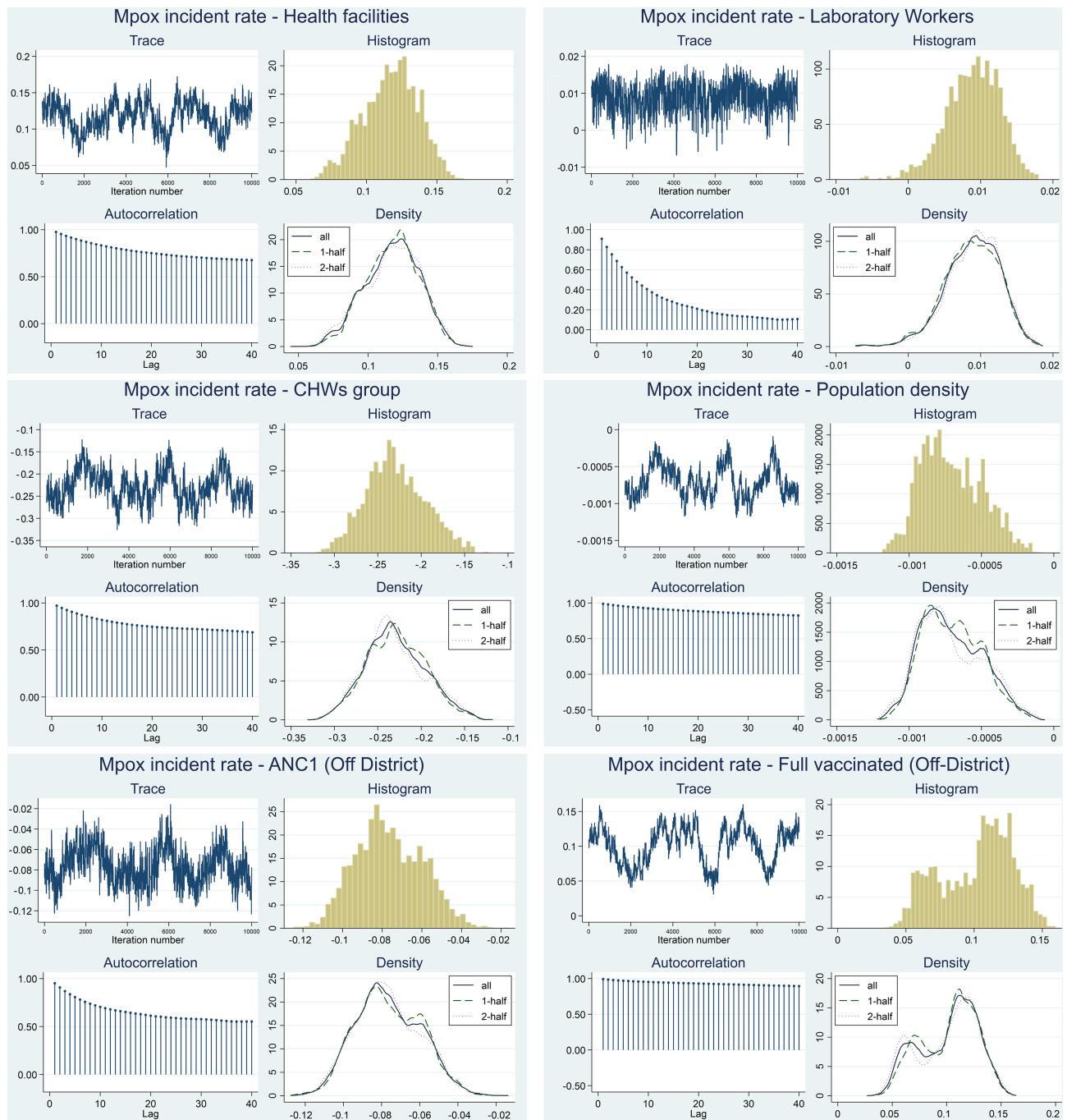


Figure 1. Analysis of the visual convergence of posterior distributions.

4. Discussion

4.1. Mpx Incidence Rate

The dependent variable in this study was the number of Mpx cases. However, as the health districts do not have the same population size, it was considered neces-

sary to calculate the Mpox incidence rate with the unit of 10,000.

The verification of the impact of the units (1000; 10,000; 100,000) that could be assigned to the Mpox incidence rate was done. For the Poisson regression, the constant is that the coefficients of the variables do not change, but the intercept does (**Table A2, Appendix**). For the Mixed-Effect Poisson Regression, the coefficients change for two variables, the intercept differs depending on the unit used. The random effect is zero for the unit of 1000 and the unit of 10,000 (**Table A3, Appendix**).

Regarding the impact of the units (1000; 10,000; 100,000) assigned to the incidence rate of Mpox on the Bayesian hierarchical model, the coefficient differs slightly except for the number of CHWs group where the coefficient was -0.32 , the intercept differs according to the unit used (**Table A4, Appendix**).

4.2. Validity of the Poisson Regression Model

We first investigated whether the standard poisson regression assumptions were met. We checked whether the dependent variable followed the poisson distribution by comparing the mean (1.99) and the variance (24.72). The nonparametric Wilcox test was used to check whether the mean was equal to the variance. The p-value found was equal to 0.0000 (<0.05), which led to the conclusion that there was a significant difference between the mean and the variance, *i.e.* an overdispersion. The quasi-poisson regression model solves this problem by introducing a dispersion parameter that adjusts the variance independently of the mean. This flexibility allows for more reliable estimates and hypothesis testing when dealing with data that do not match the assumptions of the Poisson model.

The equilibrium of the model was sought to keep only the variables that better explained the model using the top-down elimination method and the adequacy of the final model was demonstrated. The AIC values showed that the final model (111.55) had a good fit because the AIC of the final model was lower than that of the initial model (125.51).

4.3. Validity of the Mixed-Effects Poisson Regression Model

The generalized linear mixed-effects model is based on the generalized linear model with the addition of the random effect that shows the variation between groups. In the context of this study, the generalized linear model is the Poisson regression model.

To explore whether there were random effects that should be taken into account to predict and explain the variation in the incidence rates of Mpox provinces in Burundi, the Mixed-Effects Poisson Regression analysis was performed. The use of this model requires a data grouping and prioritization factor. Since the health district was taken as a primary entity and had only one record, we took the provincial level as a factor around which to look for the random effect. Thus, we used the delimitation of the 18 provinces (old delimitation before the census) and the new delimitation of the 5 provinces.

The validity of a model was ensured by verifying the underlying assumptions according to the distribution of the Poisson distribution, clearly identifying the groups (province) and comparing the different models to determine which one was the most relevant and efficient using the Akaike Information Criterion (AIC).

4.4. Validity of the Bayesian Hierarchical Model

The “a priori” flat non-informative distribution was used to analyse the data for the Bayesian model. We considered that apart from the data from the current study, the mean and variance of the incidence rates of Mpox are not available. In this case, it is advisable to use a more general uniform distribution that considers the mean to be 0 and the variance to be 10,000. The “a priori” generated by the iterations is not very informative and does not significantly influence the a posteriori means because it was noted that the standard Monte Carlo errors (MCSEs) were close to 0 for all variables ([Table 4](#)).

4.5. Explanatory Factors for the Incidence Rates of Mpox

The results of this study showed that the availability of health facilities and laboratory workers justifies the increase in the number of Mpox cases across health districts. First, the health structures contribute to the detection of suspected cases by using the case definitions during consultations, then the laboratory technicians contribute to the confirmation of suspected cases, which makes it possible to act on the positivity rate in the event of an epidemic.

The influence of CHW groups on the reduction of Mpox cases is justified by the promotional and preventive activities carried out in the community. Indeed, raising awareness on good practices, tracing the contacts of cases made by CHWs promote the reduction of new cases of Mpox.

Although population density was significant in relation to the variation in Mpox cases when considering the p-values, the IRR was almost equal to 1 and the confidence interval showed the minimum value to be equal to the maximum value: $IRR_{CI_{95\%}} = 0.99[0.99 - 0.99]$ for the Poisson model and $IRR_{CI_{95\%}} = 1.00[1.00 - 1.00]$ for the Mixed-Effects Poisson Regression model. Based on these values, we conclude that this variable was not significant in explaining the variation in the incidence rate of Mpox. Nevertheless, numerous studies have consistently shown that high population density is associated with the incidence rates of diseases with epidemic potential. The denser the population, the more frequent the contact between individuals, which facilitates the transmission of contagious diseases [2] [13].

The factor of use of ANC and vaccination services by people from outside the district came out significant but in two opposite directions. The hypothesis was that more people come from outside the district, more there is an increase in Mpox cases. This hypothesis has been tested for vaccination (increase in vaccinated children vs. increase in cases) but has not been conclusive for ANC services (increase in women with ANC, decrease in Mpox cases). In addition, other studies have shown that population movements influence the spread of Mpox [2].

Should this variable be used in a study based on individual data, the relevant question would need to focus on whether the respondent had a visitor from outside his district in their household during the period covered by the study.

Another hypothesis concerns the fact that the more users of prevention services increase, regardless of the origin, the more the number of cases of Mpox should decrease because a woman who has had ANC and another who has brought her child to vaccination will have access to useful information for lifestyle and prevention. This should limit the spread of diseases with epidemic potential.

Other longitudinal studies could deepen the involvement and influence of the use of preventive services by the population and the spread of diseases with epidemic potential.

4.6. Study Limitation and Research Perspectives

The study was carried out with aggregated data collected from 49 health districts. The main objective was to show the explanatory factors for the variation in Mpox cases across health districts.

One of the limitations observed is the over-dispersion of the values, this was adjusted using the quasi-poisson model instead of the poisson model.

Another limitation was that associations observed at population level cannot be reliably extrapolated to individual patients' risk factors. Hence the need to complete this research with a study of individual data using the same variables.

Another limitation was that we used data on users of healthcare services from outside the district because of no availability of mobility data for the same population. Based on the results of this study, the use of health services for people from outside the districts is not sufficient to reflect population movements.

5. Conclusions

The average of incidence rates is 2 per 10,000 habitats for a period of approximately 5 months. The analytical results, the incidence rate per 10,000 inhabitants was used as the dependent variable. Fourteen (14) variables were introduced into the initial model. Five (5) variables were released significantly in the final model for the Poisson regression. These are the number of health facilities (influences the increase), number of laboratory workers (influences the increase), group of community health workers (influences the decrease), the number of people outside the districts using antenatal consultation services (influences the decrease) and the number of children aged 0 - 23 months outside districts using immunization services (influences the increase).

For the Mixed-Effect Poisson Regression model, the results showed that for fixed effects, the mean coefficients in the final model are the same as the coefficients in the Poisson regression. In addition, the random effects that would explain the variation in the incidence rate of Mpox across provinces are almost nil. The health districts within each province all followed the same general pattern, and the difference between provinces and health districts was irrelevant.

For the Bayesian hierarchical model, the a priori generated by the iterations was not very informative and did not significantly influence the a posteriori means. The latter came out very similar to the Poisson regression coefficients.

The results show that in order to improve the reporting of new Mpox case, it is necessary to act on availability of different categories of resources for health promotion, diagnosis and case management.

A study based on individual data could complete the findings of this study.

Author Contributions

MK, FM and AN conceptualized and led this study. KM, FM, ON, LN and JBG contributed to data analysis, interpretation, drafting and editing the manuscript. AN, KNA, SN, AD, and XC contribute to proofreading and editing, data and interpretation validation. All authors approved the final manuscript and were responsible for the decision to submit for publication.

Conflicts of Interest

The study was carried out by researchers from the Institute of Applied Statistics of the University of Burundi and the team of the Ministry of Public Health of Burundi. The Ministry of National Education and Scientific Research provided a part of the funding through a research projects call. The World Health Organization, Burundi Country Office provided technical support and co-financing and Africa Centre for Disease Control and Prevention (Africa CDC) provided technical support. Supervision and coordination were provided by the Institute of Applied Statistics and Ministry of Public Health team. The results were fully communicated to the stakeholders, with an approved plan to manage any potential conflicts of interest arising from the involvement of the partners who funded the study. The terms of these funding agreements were reviewed and approved by the University of Burundi, in accordance with its policy on research impartiality.

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Appendix

Table A1. Initial model of quasi-Poisson regression.

	Coef.	CI95% Coef.	IRR	CI95% IRR	p-value
Availability of Health Facilities	0.11	[0.03 - 0.19]	1.12	[1.03 - 1.21]	0.006
Availability of Hospitals	-0.02	[-0.17 - 0.13]	0.98	[0.84 - 1.14]	0.788
Availability of Physicians	-0.01	[-0.04 - 0.02]	0.99	[0.96 - 1.02]	0.639
Availability of Healthcare Providers (nurses, ...)	0.00	[-0.01 - 0.01]	1.00	[0.99 - 1.01]	0.942
Availability of Laboratory Workers	0.01	[0.00 - 0.02]	1.01	[1.00 - 1.02]	0.082
Availability of Cleaning staff	0.00	[-0.01 - 0.01]	1.00	[0.99 - 1.01]	0.658
Availability of CHWs	-0.01	[-0.38 - 0.36]	0.99	[0.69 - 1.44]	0.974
Availability of CHWs group	-0.22	[-0.38 - -0.05]	0.81	[0.68 - 0.95]	0.010
Population density	0.00	[-0.00 - 0.00]	0.99	[0.99 - 0.99]	0.263
Availability of local radio stations	0.06	[-0.44 - 0.56]	1.06	[0.64 - 1.76]	0.809
Use of Outpatient services (Off-Distr.)	0.04	[-0.07 - 0.15]	1.04	[0.93 - 1.17]	0.479
Use of family planning services (Off-Distr.)	-0.02	[-0.17 - 0.13]	0.98	[0.85 - 1.14]	0.792
Use of ANC 1 services (Off-Distr.)	-0.07	[-0.21 - 0.07]	0.93	[0.81 - 1.07]	0.322
Use of vaccination services (Off-Distr.)	0.08	[-0.05 - 0.21]	1.08	[0.95 - 1.23]	0.224
Intercept	0.26	[-1.87 - 2.38]	1.29	[0.15 - 10.85]	0.813
Dispersion parameter			0.531		
Coefficient of determination			72.77%		
AIC			125.51		
Number of observations			49		

Table A2. Change in coefficient values by unit applied to incidence rate, Poisson regression model.

	Coefficients			
	Number of Mpox cases	Mpox incidence rate/1000 inhab.	Mpox incidence rate/10,000 inhab.	Mpox incidence rate/100,000 inhab.
Availability of Health Facilities	0.11	0.11	0.11	0.11
Availability of Laboratory Workers	0.01	0.01	0.01	0.01
Availability of CHWs group	-0.22	-0.22	-0.22	-0.22
Population density	-0.01	-0.01	-0.01	-0.01
Use of ANC 1 services (Off-Distr.)	-0.08	-0.08	-0.08	-0.08
Use of vaccination services (Off-Distr.)	0.10	0.10	0.10	0.10

Continued

Intercept	3.62	−1.71	0.59	2.88
Coefficient of determination	90.8%	72.2%	72.2%	87.5%
AIC	886.63	111.22	111.54	375.43
Number of observations	49	49	49	49

Table A3. Change in intercept values and unit coefficients applied to incidence rate, mixed-effects Poisson regression model.

		Coefficients			
		Number of Mpox cases	Mpox incidence rate/1000 inhab.	Mpox incidence rate/10,000 inhab.	Mpox incidence rate/100,000 inhab.
Fixed Effect	Availability of Health Facilities	0.12	0.12	0.12	0.11
	Availability of Laboratory Workers	0.01	0.01	0.01	0.01
	Availability of CHWs group	−0.16	−0.23	−0.23	−0.18
	Population density	−0.01	−0.01	−0.01	−0.01
	Use of ANC 1 services (Off-Distr.)	−0.08	−0.08	−0.08	−0.08
	Use of vaccination services (Off-Distr.)	0.08	0.11	0.11	0.10
	Intercept	2.56	−1.72	0.59	2.29
Random effect	Province (new boundary)	0.41	0	0	0.22

Table A4. Change in intercept values and coefficients as a function of unit applied to incidence rate, Bayesian hierarchical model.

		Coefficients			
		Number of Mpox cases	Mpox incidence rate/1000 inhab.	Mpox incidence rate/10,000 inhab.	Mpox incidence rate/100,000 inhab.
	Availability of Health Facilities	0.12	0.17	0.11	0.12
	Availability of Laboratory Workers	0.02	−0.01	0.01	0.01
	Availability of CHWs group	−0.22	−0.32	−0.22	−0.23
	Population density	−0.01	−0.01	0.00	−0.01
	Use of ANC 1 services (Off-Distr.)	−0.09	−0.05	−0.07	−0.08
	Use of vaccination services (Off-Distr.)	0.11	0.13	0.10	0.11
	Intercept	0.29	−1.68	0.58	2.89