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The Use of Poisson-Mixture Models for Evaluating the Risk of Typhoid Fever in Oyo State, Nigeria

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Abstract

Poisson and negative binomial regressions are popularly used to model count data. However, they have limitations of not accounting for excess zeros and over-dispersion. Hence, this study compared the performance of four Poisson-mixture models in identifying factors influencing the number of typhoid fever cases(TFC) in Oyo State. Surveillance data on TFC, extracted from the Oyo State Integrated Disease Surveillance and Response database (2011 to 2014), were used. Presence of over-dispersion (variance exceeds mean) in the data was investigated. The zero-inflated Poisson, zero-inflated negative binomial (ZINB), zero-inflated generalized Poisson, and zero-altered Poisson models were fitted to the data, and the best model was selected based on the least AIC value. There were 38,342 reported cases of TFC within the year 2011 to 2014 and 8,118 (73.2%) zero cases. The mean was 3.46, while the variance was141.39 which indicated over-dispersion. There was a decline (89.0%) in TFC between 2012 and 2014.There was a 74% lower risk of typhoid fever in 2014 (IRR=0.742, 95%CI: 0.647, 0.852) compared to the risk in 2011. The highest risk was recorded in Lagelu (IRR=4.072, 95% CI: 2.847, 5.823), while the lowest was in Ibadan North. (IRR = 0.599, 95%CI: 0.425, 0.846). The zero inflated negative binomial regression was the best model to estimate factors associated with typhoid fever cases in the presence of over-dispersion.

L'utilisation des modèles 'poisson-mélange' pour l'évaluation de risque de typhoïde dans l'état d'Oyo au Nigéria

Résumé

Des régressions du Poisson et du binôme négatif sont populairement habitué dans un compter modèle donnés. Cependant, ils ont des limitations de non comptabilité pour le zéro excès et la sur-dispersion. Cette étude compare la performance de quatre 'poisson-mélange' modèles pour identifier des facteurs influençant le nombre de cas de typhoïde dans l'état d'Oyo. Les données de surveillance sur tfc, et réponse base de données (2011 à 2014), ont été utilisées. Présence de 'sur-dispersion' (variance dépasse moyenne) dans les données ont été enquête. Le zéro-gonflé poisson, zéro-gonflé négatif binôme (zinb), zéro-gonflé généralisée poisson, et zéro-modifié poisson modèles ont été équipé aux données, et le meilleur model a été choisi fondé sur le moindre valeur 'AIC.'Ils ont été 38,342 signalé cas de tfc au sein de l'année 2011 à 2014 et 8,118 (73.2%) zéro cas. Le moyenne a été 3.46, tout le variance was141.39 qui indique sur-dispersion. Il y a été un déclin (89.0%) dans tfc entre 2012 et 2014. Il y a été un 74% risque inférieur de typhoïde dans 2014 (irr = 0.742, 95% ci: 0.647, 0.852) comparé à la risque dans 2011. Le plus risque a été enregistré dans lagelu (irr = 4.072, 95% ci: 2.847, 5.823), le plus bas a été dans le nord d'Ibadan. (Irr = 0.599, 95% ci: 0.425, 0.846). Le 'zéro gonflé négatif binôme régression' a été le meilleur modèle à estimer a propos des facteurs associés avec le cas de fièvre typhoïde dans la présence de sur-dispersion.

Introduction

Occurrence of zero observations in count data may be challenging. The Poisson, binomial and negative binomial distributions are commonly used to represent the distribution of such count data. Usually, the Poisson model is assumed for analysing or approximating the distribution of the count observations. However, presence of dispersions in the observed counts is under-estimated using the Poisson model. The Poisson models are violated when the array of count values is restricted or when over-dispersion is present. Over-dispersion occurs as a result of a single Poisson parameter often used to describe the population; which is insufficient. In many cases, population heterogeneity which has not been accounted for can be suspected to be causing the over-dispersion. Population heterogeneity occurs when there are several subpopulation membership that are unobserved in the sample. (Raykov, Marcoulides, and Li, 2016). Occurrence of over-dispersion has led to the development of zero-inflated count models (Lee *et al.,* 2011) that account for excessive zero counts.

Zero-inflated models are statistical models based on a zero-inflated probability distribution (i.e.frequent zero valued observations are allowed in the distribution). These models are designed to accommodate extra zeros in count data; they are referred to as added zero models (Preisser *et al.,* 2012). Zero-inflated models have been developed based on the Poisson distribution (ZIP), the negative binomial distribution (ZINB) (Preisser *et al.,* 2015), and the generalized Poisson (ZIGP).

Application of Poisson Mixture Models to Typhoid Fever Cases

Typhoid fever remains a global disease endemic in many parts of the developing world, and the number of cases increase as global travel rises (Parry *et al.,* 2014). Although Typhoid fever is common amongst the countries in Asia, Africa, Latin America, the Caribbean, and Oceania (Masoumi Asl *et al.,* 2013), countries in Southeast Asia and sub-Saharan Africa have reported frequent epidemics (Muyembe *et al.,* 2009; Baddam *et al.,* 2012).

Globally, nearly 22 million (incidence of 3.6 per 1,000 populations) and 200,000 people were respectively infected and killed with typhoid fever (Cook *et al.,* 2009). In Africa, a yearly incidence of 7.6 per million have been reported (Lynch *et al.,* 2009). Most documented typhoid fever cases involve school-aged children and young adults. However, occurrence is thought to be higher amongst very young children and infants in urban areas where sewage disposal is lacking or inadequate, water supplies get contaminated and thus cause the outbreaks of typhoid fever. The contamination of food is another most frequent cause of infection(Rahman *et al.,* 2011).

According to the World Health Organization (WHO), children age 4years and below have the highest reported case fatality rates (WHO, 2016). The disease is most commonly spread through poor hygiene habits and public sanitation conditions. Symptoms of typhoid fever include high temperature, diarrhea, constipation, abdominal pain and encephalopathy may occur.

Data on typhoid fever cases in Oyo State are counts which includes lots of zeros. The excess zeros often lead to overdispersion and failure to account for them constitutes a model misspecification, which results in biased standard errors. To overcome the limitation of not taking into account these extra zeros, the zero-inflated count models together with ZAP models provide a way for modelling excess zeros as well as allowing for over-dispersion.

Hence, this study modelled the occurrence of typhoid fever cases in Oyo State using the ZIP, ZINB, ZIGP, and ZAP regression models.

Materials and Methods

Study Area

Oyo state is the second largest state in the South-West geopolitical zone of Nigeria with a land area of 27,148km^2 and a population of about 6 million. Administratively, the state consists of 33 LGAs. Oyo State has an equatorial climate with dry and wet season and relatively high humidity. The dry season lasts from November to March, while the wet season starts from April and ends in October. The state operates three-tier health care systems which are primary, secondary and tertiary health centres across urban and rural areas. There are 1,648 health facilities disaggregated into 631 Primary Health centres (PHCs), 46 Secondary Health Facilities (SHFs), 5 Tertiary Health Centres (THCs) and 968 registered private health facilities (SMoH, 2012).

Study Design

A retrospective review of TFC (2011-2014) was obtained from the Integrated Disease Surveillance and Response (IDSR) of Oyo State Ministry of Health.

Study Population

Records of outpatients and inpatients aged 0 to 40 years and above from the 764 health facilities in the 33 LGAs of Oyo State were obtained from the state IDSR. A total of 2,970 records of patients across all age groups (0-28days to 40 years and above) who were infected with typhoid fever from 2011 to 2014 were obtained. Year, month and LGA of reporting were used as the explanatory variables

Data Management

Descriptive statistics such as percentages, means and variances were determined for all independent variables. Mean and variance were determined to investigate the presence of under-dispersion or over-dispersion. The incidence rate ratios (IRR) of the ZIP, ZINB, ZIGP, ZAP and 95% CI were reported to examine the effect of the given exposure and approximate relative risk of typhoid fever among all age groups over the years in all the 33 LGAs. All the models (ZIP, ZINB, ZIGP, and ZAP) were compared and the best of the four models was selected using the Akaike information criteria (AIC).

Statistical Models

In general:

$$y_i \sim \begin{cases} 0 & \textit{with probability } \varphi_i \\ g(y_i \mid x_i) & \textit{with probability } 1-\varphi_i \end{cases}$$

Hence, the probability of $\{ y_i = y_i \}$ can be described as:

$$P(y_i \mid x_i) = \varphi_i + (1-\varphi_i) g(y_i) \text{ for } y_i = 0$$

$$P(y_i \mid x_i) = (1-\varphi_i) g(y_i) \text{ for } y_i \geq 1$$

Where g (y_i) follows either the Poisson or the negative binomial distribution.

When the probability φ_i is influenced by the characteristics of observation i, φ_i is a function of $z'_i\gamma$, where z'_i is the 1 x (q+1), the vector of zero-inflated covariates to be estimated. This is associated with the identified zero-inflated covariate vector z'_i = $(1, Z_1, ..., Z_q)$ and γ is the (q +1) x 1 vector of zero-inflated coefficients to be estimated. The intercept for the zero-inflated is γ_0, while the coefficients for the q zero-inflated covariates are $\gamma_1, \gamma_2, ...\gamma_q$ and q is the number of the z covariates excluding the intercept.

Also, the parameter φ_i is the probability of zero counts from the binary process; it is frequently stated as the zero-inflation factor. This parameter φ_i is usually characterized in terms of logistic regression model as logit (φ_i) = z_i' γ. The zero-inflated link function is F which is relating the product (scalar) to the probability φ_i .

The zero-inflated link function F can be specified as the logistic function;

$$F(z_i'\gamma) = \Lambda(z_i'\gamma) = \frac{exp(z_i'\gamma)}{1 + exp(z_i'\gamma)}$$

Model Comparison using the Akaike Information Criteria (AIC)

All models (ZIP, ZINB, ZIGP, and ZAP) used in this study were compared using the Akaike information Criteria (AIC).

The AIC estimates the quality of a set of models relative to each of the other models for the given data. Hence, AIC provides a means for model selection. The AIC focuses on the strength of evidence and gives a measure of uncertainty for each model. The AIC value in a given statistical model is defined by;

AIC= 2k-2ln (L)
Where,

L is the maximum likelihood function of the model,
k is the number of parameters to be estimated in the model.

Results

The Distribution of Reported cases of Typhoid Fever in Oyo State

The dataset consists of 38,342 reported cases of typhoid fever within the year 2011 to 2014 and 8,118 (73.2%) zero cases (Figure 1). The mean number of cases in the population for the four years was 3.46 with a variance of 141.39. In addition, Typhoid fever cases (TFC) increased by 35% between 2011 and 2012 but reduced by 89% from year 2012 to 2014 (2012: Mean=5.77, VAR =308.12), (2013: Mean=3.65, VAR =141.29), (2014: Mean=0.64, VAR =9.60) (Figure 2). Typhoid fever cases was highest (1883) in December, 2012 (Mean=8.15, VAR =1419.70) but lowest (11) in October 2011 (Mean=0.08, VAR=0.22) (Figure 3). In addition, adults 20 to 40 years of age had the highest (12071) TFC between 2011 and 2014, while those aged 40 years and above had higher TFC compared to children 0 to 28 days who had the lowest cases (Figure 4).

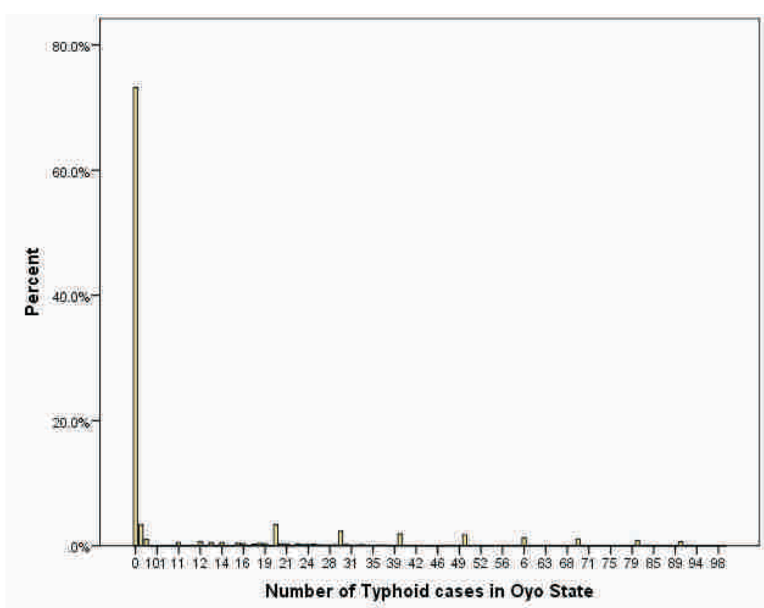

Figure 1: Distribution of Typhoid fever cases in Oyo State in the year 2011 to 2014

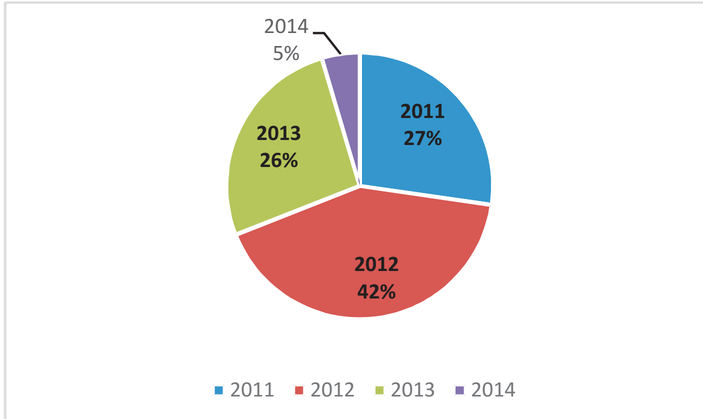

Figure 2: Percentage distribution of typhoid fever cases (TFC) in Oyo State by year

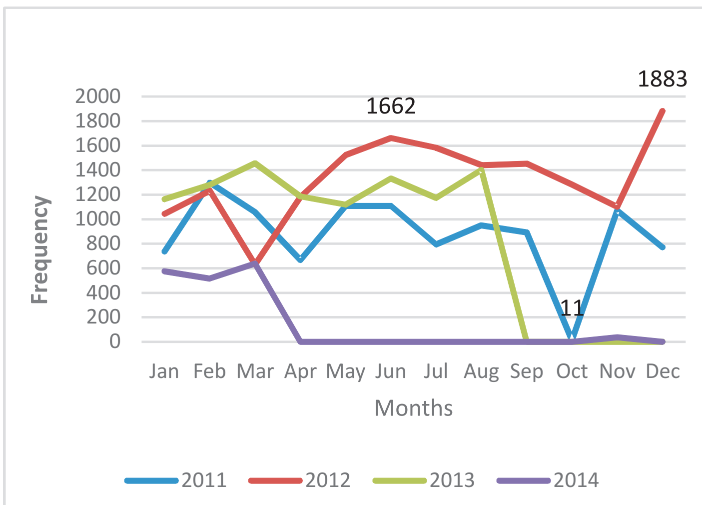

Figure 3: Pattern of TFC in Oyo State by month and year

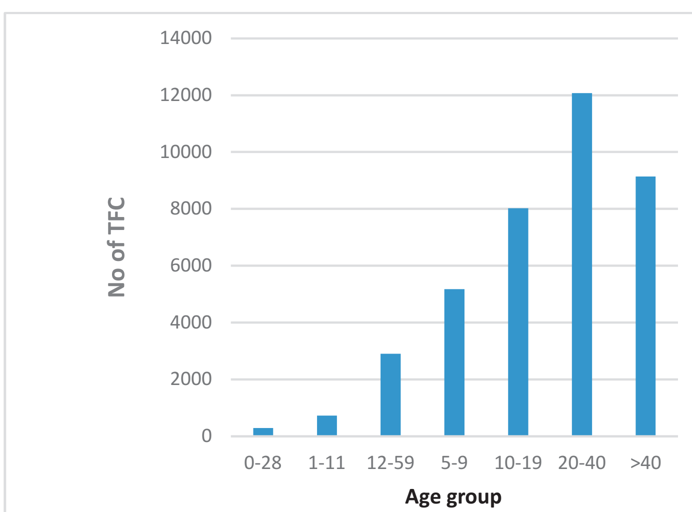

Figure 4: Distribution of TFC by Age group

Table 1: Comparison of the Models for Typhoid Fever in Oyo State

Model	AIC	DF
ZIP	51290.47	94
ZINB	30733.61	95
ZIGP	51290.47	94
ZAP	51285.73	94

Test for Comparison of the Regression Models: ZIP, ZINB, ZIGP and ZAP using the AIC.

Table 1 shows the comparison of the zero-inflated regression models.

The ZIP and the ZIGP model gave the same AIC value (51290.47), while the ZINB model gave the lowest AIC value (30733.61).

Effect of Selected Factors on the Occurrence of Typhoid Fever in Oyo State Using the ZINB Model

There was an 84% lower risk of Typhoid fever in 2012 (IRR=0.844, 95%CI: 0.735, 0.970), 81% in 2013 (IRR=0.810, 95%CI: 0.705, 0.929) and 74% in 2014 (IRR=0.742, 95%CI: 0.647, 0.852) compared to the risk in 2011. Lower risk of typhoid fever occurred only in the months of January, February and March, while the other months recorded higher risk. In terms of LGA, the highest risk was recorded in Lagelu (IRR=4.072, 95% CI: 2.847, 5.823), while the lowest was in Ibadan North, (IRR = 0.599, 95%CI: 0.425, 0.846).

There was a 19.3% increased risk of typhoid fever among those aged 20-40 years (IRR=1.193, 95% CI: 1.011, 3.204) and about 83% lower risk among children 0-28 days (IRR=0.828, 95% CI: 0.307, 1.070) compared to the risk among those above 40 years.

For the zero inflated part, the risk of a typhoid fever case being in the zero group was about 83%, 87%, and 85% lower in 2012 (IRR=0.827, 95% CI: 0.720, 0.949), 2013 (IRR=0.869, 95% CI: 0.757, 0.998), and 2014(IRR=0.848, 95% CI: 0.738, 0.974) respectively compared to the risk in 2011.

Furthermore, the risk of being in the zero group was three times higher in October (IRR=3.210, 95% CI: 2.416, 4.265), and about 67% higher in November (IRR=1.667, 95% CI: 1.303, 2.132). The risk of being in the zero group was lowest in July (IRR=0.989, 95% CI: 0.787, 1.243) compared to the risk in April (Table 2).

Table 2: Estimates of the Zero-inflated Negative Binomial Model (ZINB) for Typhoid Fever Cases in Oyo State

Parameters	IRR	Standard Error	95% CI for IRR		P-value
			Lower bound	Upper bound	
Intercept 2011(Year1)*	27.653	0.161	20.155	37.940	<0.001
2012(Year2)	0.844	0.071	0.735	0.970	0.017
2013(Year3)	0.810	0.070	0.705	0.929	0.002
2014(Year4)	0.742	0.070	0.647	0.852	<0.001
Jan	0.852	0.100	0.700	1.037	0.111
Feb	0.818	0.100	0.672	0.994	0.043
Mar	0.915	0.101	0.751	1.114	0.37
April*					
May	1.137	0.102	0.931	1.389	0.209
Jun	1.058	0.102	0.865	1.293	0.583
Jul	1.183	0.103	0.968	1.447	0.101

Cont'd

Parameters	**IRR**	**Standard Error**	**95% CI for IRR**		**P-value**
			Lower bound	**Upper bound**	
Aug	1.099	0.102	0.899	1.344	0.356
Sep	1.137	0.116	0.905	1.428	0.269
Oct	1.093	0.114	0.828	1.443	0.531
Nov	1.126	0.116	0.897	1.415	0.307
Dec	1.014	0.120	0.802	1.281	0.910
Afijio*					
Akinyele	0.814	0.211	0.539	1.231	0.329
Atiba	1.814	0.175	1.286	2.558	<0.001
Atisbo	1.290	0.212	0.851	1.957	0.230
Egbeda	0.869	0.187	0.603	1.253	0.451
Ibadan North	0.599	0.176	0.425	0.846	0.003
Ibadan North East	0.988	0.178	0.697	1.399	0.944
Ibadan North West	0.850	0.174	0.605	1.194	0.349
Ibadan South East	1.052	0.174	0.748	1.481	0.770
Ibadan South West	1.467	0.178	1.035	2.079	0.031
Ibarapa Central	2.383	0.168	1.714	3.313	<0.001
Ibarapa East	1.448	0.167	1.044	2.010	0.027
Ibarapa North	0.910	0.178	0.642	1.290	0.597
Ido	0.805	0.169	0.578	1.122	0.201
Irepo	0.954	0.174	0.678	1.343	0.787
Iseyin	0.715	0.169	0.678	1.343	0.048
Itesiwaju	0.947	0.170	0.514	0.997	0.749
Iwajowa	2.020	0.176	1.431	2.852	<0.001
Kajola	0.906	0.187	0.628	1.309	0.600
Lagelu	4.072	0.183	2.847	5.823	<0.001
Ogbomoso North	0.762	0.190	0.525	1.104	0.151
Ogbomoso South	0.762	0.188	0.527	1.102	0.149
OgoOluwa	0.982	0.184	0.684	1.409	0.921
Olorunsogo	0.746	0.181	0.523	1.064	0.105
Oluyole	1.211	0.188	0.837	1.751	0.310
Onaara	2.373	0.178	1.674	3.362	<0.001
Orelope	1.222	0.243	0.758	1.969	0.410
Orire	3.181	0.247	1.960	5.164	<0.001
Oyo East	1.574	0.268	0.930	2.665	0.091
Oyo West	0.425	0.292	0.240	0.753	0.003
Saki East	0.567	0.261	0.340	0.945	0.294
Saki West	0.776	0.244	0.481	1.251	0.298
Surulere	0.712	0.295	0.399	1.269	0.249
Agegrp 0-28	0.828	0.060	0.307	1.070	0.002
Agegrp 1-11	0.275	0.015	0.171	1.214	<0.001
Agegrp 12-59	0.421	0.022	0.407	1.822	<0.001

Parameters	IRR	Standard Error	95% CI for IRR		P-value
			Lower bound	Upper bound	
Agegrp 5-9	0.591	0.018	0.561	2.492	<0.001
Agegrp 10-19	0.825	0.015	0.222	1.161	<0.001
Agegrp 20-40	1.193	0.014	1.011	3.204	<0.001
Agegrp>40*					
Inf.Intercept	4.413	0.171	3.159	6.164	<0.001
Inf.2011(Year1)*					
Inf.2012(Year2)	0.827	0.070	0.720	0.949	0.007
Inf.2013(Year3)	0.869	0.071	0.757	0.998	0.047
Inf.2014(Year4)	0.848	0.071	0.738	0.974	0.019
Inf.Jan	0.684	0.114	0.548	0.855	<0.001
Inf.Feb	0.662	0.113	0.530	0.827	<0.001
Inf.Mar	0.705	0.114	0.564	0.880	0.002
Inf.April*					
Inf.May	0.962	0.116	0.766	1.208	0.736
Inf.Jun	0.970	0.117	0.772	1.219	0.793
Inf.Jul	0.989	0.117	0.787	1.243	0.923
Inf.Aug	0.972	0.116	0.774	1.222	0.809
Inf.Sep	1.667	0.126	1.303	2.132	<0.001
Inf.Oct	3.210	0.145	2.416	4.265	<0.001
Inf.Nov	1.667	0.126	1.303	2.132	<0.001
Inf.Dec	1.869	0.128	1.453	2.404	<0.001
Inf.Afijio*					
Inf.Akinyele	1.546	0.221	1.004	2.382	0.048
Inf.Atiba	0.665	0.193	0.455	0.971	0.035
Inf.Atisbo	1.540	0.219	1.003	2.365	0.048
Inf.Egbeda	0.916	0.202	0.617	1.362	0.666
Inf.Ibadan North	0.534	0.193	0.365	0.779	0.001
Inf.Ibadan North East	0.603	0.193	0.413	0.880	0.009
Inf.Ibadan Northwest	0.588	0.193	0.403	0.858	0.006
Inf.Ibadan South East	0.616	0.193	0.422	0.899	0.012
Inf.Ibadan South West	0.553	0.191	0.380	0.803	0.002
Inf.Ibarapa Central	0.507	0.189	0.350	0.734	<0.001
Inf.Ibarapa East	0.390	0.187	0.270	0.562	<0.001
Inf. Ibarapa North	0.694	0.196	0.473	1.019	0.062
Inf.Ido	0.419	0.189	0.289	0.608	<0.001
Inf.Irepo	0.546	0.192	0.375	0.795	0.002
Inf.Iseyin	0.465	0.191	0.320	0.676	<0.001
Inf.Itesiwaju	0.443	0.189	0.306	0.642	<0.001
Inf.Iwajowa	0.569	0.191	0.391	0.826	0.003
Inf.Kajola	0.884	0.201	0.596	1.311	0.541
Inf.Lagelu	0.776	0.195	0.529	1.138	0.193

Parameters	IRR	Standard Error	95% CI for IRR		P-value
			Lower bound	Upper bound	
Inf.Ogbomoso North	0.909	0.202	0.611	1.350	0.636
Inf.Ogbomoso South	0.892	0.202	0.600	1.324	0.569
Inf.OgoOluwa	0.855	0.199	0.578	1.266	0.435
Inf.Olorunsogo	0.754	0.198	0.511	1.111	0.153
Inf.Oluyole	0.953	0.202	0.641	1.416	0.810
Inf.Onaara	0.660	0.193	0.452	0.963	0.031
Inf.Orelope	2.579	0.246	1.591	4.180	<0.001
Inf.Oriire	2.750	0.248	1.690	4.476	<0.001
Inf.Oyo East	3.562	0.269	2.102	6.036	<0.001
Inf.Oyo West	3.890	0.285	2.223	6.807	<0.001
Inf.Saki East	2.925	0.259	1.760	4.860	<0.001
Inf.Saki West	2.426	0.244	1.503	3.917	<0.001
Inf.Surulere	4.307	0.290	2.440	7.602	<0.001
Inf.Agegrp 0-28	121.389	0.265	110.341	132.318	<0.001
Inf.Agegrp 1-11	9.478	0.122	7.010	13.488	<0.001
Inf.Agegrp 12-59	2.088	0.099	0.542	4.930	<0.001
Inf.Agegrp 5-9	1.070	0.095	0.119	2.254	0.476
Inf.Agegrp 10-19	0.701	0.094	0.539	2.170	<0.001
Inf.Agegrp 20-40	0.599	0.093	0.295	1.329	<0.001
Inf.Agegrp>40*					

*Reference Category; **Significant at $p < 0.05$

Discussion

Results from this study suggest that the ZINB model provides more robust estimates than the other Poisson models in the presence of over-dispersion in the data. This is in agreement with a study by Tang *et al* (2015) who also confirmed that the ZIP model is inadequate for data with over-dispersion. Also, the selection criteria (AIC) indicate that the ZINB regression model was the best model to determine the effect of the selected factors (Month, Year, and LGA) on the occurrence of typhoid fever cases in Oyo state.

The findings from this study indicate that TFC was high between 2011 and 2012 but showed a sustained decrease from 2012 to 2014. This suggests a change (decrease) in disease occurrence pattern in recent years. Typhoid fever cases seemed to increase towards the latter part of the wet season (September and October) to the start of the dry season (November and December). The high risk of waterborne diseases during these periods might be an index of higher water pollution. This is in line with the findings by Oguntoke, Aboderin and Bankole (2009) who identified that common problems stated by residents of Ibadan are related to the hardship encountered sourcing for water. The monthly report indicates a clear shift of the disease occurrence pattern in the study areas which correspond very well with the recent change in the timing of the rainy and dry season.

The number of typhoid fever cases reported in some LGAs were higher compared to the occurrence reported in other LGAs. This might be due to the rural settlements in the LGAs, unreported cases, and traditional/home remedies practiced by the residents. This finding is in agreement with a WHO (2016) report that; higher risk of typhoid fever were reported in areas with low standards of hygiene and water supply facilities**.** Although, typhoid fever prevalence is lower in some parts of the state, there is still the need to strengthen typhoid fever control protocols that are currently being implemented in other parts of the states. High incidence of the disease in some of the LGAs may indicate the presence of its infective agent more than the infective agents of other water-borne diseases. However, the consequence of intervention programmes against the back drop of the previous epidemics in Oyo State may be the indicator for the low proportion of inhabitants that suffered the disease.

Results also showed that children were the most vulnerable to typhoid fever. High predisposition of children to infections due to their low immunity may be linked to the higher incidence of water-borne diseases among children, especially those aged 1-9 years. Also, children within this age group have little influence on the choice of water source unlike adults who determine where water is sourced for drinking and domestic uses.

Lastly, multi-national eradication and control programmes against several water-borne diseases including typhoid fever in western Africa might have influence on this decrease in occurrence. In 2014, UNICEF's water, sanitation and hygiene (WASH) team worked in over 100 countries worldwide to improve water and sanitation services, as well as basic hygiene practices. UNICEF's efforts provided nearly 14 million people with clean water and over 11 million with basic toilets during this period. This might as well be of great influence on the decline of typhoid fever cases in Oyo State.

The zero-inflated Poisson (ZIP) and zero-inflated generalized Poisson (ZIGP) models gave almost the same parameter estimates as well as the AIC statistics. The estimates from these models are very high in terms of the comparison statistic which suggests that the two regression models were not very good in modelling data with excess zeros. Also, the zero-altered Poisson (ZAP) gave a fair estimate of parameters and a much lower AIC compared to ZIP and ZIGP. This made it a slightly better model for the dataset. However, the zero-inflated negative binomial regression model (ZINB) gave the best parameter estimates and the lowest value for the AIC. The ZINB model consistently fits the data compared to other regression models considered in this study.

Conclusion

The zero-inflated negative binomial distribution better accommodates over-dispersion in the outcome data compared to other zero-inflated distributions. Although, all the models fit the data well, the ZINB fits best in predicting the effects of season, year of reporting and LGA on the occurrence of typhoid fever in Oyo State.

The month of reporting classified into seasons (wet and dry) as well as local government areas also have effect on the occurrence of typhoid fever. To establish the extent of typhoid fever burden, detailed environmental epidemiology of water related diseases in Oyo State and other parts of Nigeria should be embarked upon.

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