A retrospective study and predictive modelling of Newcastle Disease trends among rural poultry of eastern Zambia

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Abstract

Newcastle disease (ND) is a highly infectious disease of poultry that seriously impacts on food security and livelihoods of livestock farmers and communities in tropical regions of the world. ND is a constant problem in the eastern province of Zambia which has more than 740 000 rural poultry. Very few studies give a situational analysis of the disease that can be used for disease control planning in the region. With this background in mind, a retrospective epidemiological study was conducted using Newcastle Disease data submitted to the eastern province headquarters for the period from 1989 to 2014. The study found that Newcastle Disease cases in eastern Zambia followed a seasonal and cyclic pattern with peaks in the hot dry season (Overall Seasonal Index 1.1) as well as cycles every three years with an estimated provincial incidence range of 0.16 to 1.7% per year. Annual trends were compared with major intervention policies implemented by the Zambian government, which often received donor support from the international community during the study period. Aid delivered through government programmes appeared to have no major impact on ND

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trends between 1989 and 2014 and reasons for this are discussed. There were apparent spatial shifts in districts with outbreaks over time which could be as a result of veterinary interventions chasing outbreaks rather than implementing uniform control. Data was also fitted to a predictive time series model for ND which could be used to plan for future ND control. Time series modelling showed an increasing trend in ND annual incidence over 25 years if existing interventions continue. A different approach to controlling the disease is needed if this trend is to be halted. Conversely, the positive trend may be a function of improved reporting by farmers as a result of more awareness of the disease.

Key Words: Rural Poultry, Newcastle Disease, Trends, Modelling

1. Introduction

Poultry provides an important protein and revenue source for communities in tropical regions of the world. Most rural households in Africa own some scavenging chickens or other domesticated wild birds such as guinea fowl (Nwanta et al., 2008b). Since rural households traditionally find it difficult to trade off their cattle and other larger livestock, chickens and other domestic birds (guinea fowl, ducks, and pigeons) act as a quick source of income for their daily needs, like school requirements for their children (Songolo and Katongo, 2000; Alders et al., 2009). Furthermore, domestic birds act as the most reliable and affordable source of protein for these communities (Songolo and Katongo, 2000; Alders et al., 2009; Copland and Alders, 2009). Because poultry in these areas are left to scavenge freely within and between villages (Otim et al., 2007), poultry diseases like Newcastle disease (ND) pose a significant challenge to this sector. ND outbreaks mostly go unnoticed but in extreme cases can wipe out all flocks of rural poultry. Consequently, this impacts significantly on food security and the general welfare of households (Harrison and Alders, 2010).

ND is caused by Newcastle disease virus (NDV), a member of the genus *Avulavirus* from the family *Paramyxoviridae* (Alexander and Senne, 2008; Diel et al., 2012). Chickens are highly susceptible to virulent NDV, that is notifiable to the World Animal Health Organization (Dortmans et al., 2012). The incubation period varies with the strain of virus, and is generally 4 to 5 days (range 2 to 15 days). The disease is characterized by neurological symptoms (e.g. tremors, tonic/clonic spasms, wing/leg paresis or paralysis, torticollis, and aberrant circling behaviour), weak limbs, cyanosis of the wattle and comb, nasal and eye discharges, greenish diarrhoea, weight loss, loss of egg production and high mortalities (Cattoli et al., 2010; Rakibul Hasan et al., 2010; OIE, 2012). At post-mortem, the characteristic lesions may include haemorrhages in the trachea, brain and spleen. Petechial haemorrhages coupled with ulcers that have raised borders on the mucosa of the proventriculus, caecal tonsils and inflamed lungs are also consistent with the disease (Kahn, 2005; OIE, 2012). Since most of the signs and lesions described above are not pathognomonic for ND, differential diagnosis in the absence of laboratory confirmation should be considered.

The faecal-oral route has been described as the main mode of transmission for ND (Nwanta et al., 2008b). Indigenous chicken breeds are thought to be more resistant to ND than commercial broilers and layers (Alders et al., 2009). Young birds are more susceptible than older ones (Alexander, 2000) and vaccination prevents clinical disease. However, when immunized birds are infected with virulent NDV, they are still able to transmit the disease to other susceptible birds despite their failure to succumb to clinical ND (Nwanta et al., 2008b; Miller et al., 2009; Dortmans et al., 2012) This may complicate the epidemiology of the disease in rural flocks where there may be a mixture of vaccinated and unvaccinated flocks that frequently mix through free movements.

Conventional vaccination in commercial chickens is effective but the use of these vaccines in local village systems is limited by cost, dose format and lack of thermostability. As a result, rural scavenging chickens are rarely vaccinated, and flocks remain highly susceptible to ND with periodic outbreaks that almost completely destroy the flock (Adene, 1997; Nwanta et al., 2008a).

Zambia's Eastern Province is a typical tropical habitat where rural poultry is common. It has three seasons comprised of the rainy season (December to April), which is characterised by high humidity and high rainfall exceeding 800 mm and temperatures averaging 20°C. The cool dry season (May to August) has a low humidity and temperatures averaging around 16°C, and temperatures in the hot dry season (September to November) are as high as 45°C (Our-Africa, 2015). Unfortunately, the region is challenged by ND on an almost annual basis despite attempts to control the disease through several development plans by the Government of Zambia (GRZ) (Government-of-Zambia, 1989, 2006, 2011).

Few studies that analyse the endemic status of ND in tropical regions of the world and in particular southern and central Africa have been conducted. Analysing the trends of the disease in eastern Zambia by utilising historic disease reports would help understand the cyclic nature of the disease in tropical environments within village poultry populations. It would also assist in evaluating disease control policies in controlling the disease in the region over a period of time.

With the above background in mind a retrospective epidemiological study of ND disease reports submitted to the Provincial Veterinary Office of the Eastern Province of Zambia between 1988 and 2014 was conducted. Information from this study was then used to develop a predictive model of ND annual incidence for the province in the next 25 years.

2. Materials and Methods

2.1. Study Design

The rural chicken population in the eastern province of Zambia was used as the population at risk. Morbidity/mortality annual and monthly reports of ND submitted to the Provincial Veterinary office by district state veterinarians in the period between 1989 and 2014 was used as the data base for the epidemiological study. Part of this data was stored in Damasyl®- a livestock disease data storage programme used from 1999 to 2005.

Demarcation of veterinary districts changed on three occasions as a result of changes in political delineation of the eastern province of Zambia. From 1989 to 2005, rural chicken disease data was collected from five veterinary districts (Fig. 4; Chadiza, Chipata, Lundazi, Katete and Petauke). Later in the period from 2006 to 2010 data came from eight veterinary districts (Fig. 5; Chadiza, Chipata, Lundazi, Katete, Petauke, Mambwe, Nyimba and Chama). Finally, from 2011 to date Chama district was excluded from the province, and the province was further demarcated into 9 districts (Fig. 6; Chadiza, Chipata, Lundazi, Katete, Petauke, Mambwe, Sinda, Nyimba and Vubwi districts). Consequently, data collection and analysis for this study followed a similar pattern.

The first step involved collection of demographic data that would be vital for estimations of incidence, mortality rates and case fatality rates as well as indicating the growth or decline of the chicken population over the period 1989-2014. Spatial patterns were determined by categorizing the province into districts and temporal patterns were determined according to the year and month for the period of study.

Missing provincial chicken disease data from 1995 to 1998 posed a challenge for analysing trends during the study period. Therefore, in order to reduce bias during interpretation of results, most analysis conducted was restricted to the period from 1999 to 2014. However, annual trends were presented and described from 1989 to 2014. This was done in order to highlight the aspect of missing data as a weakness that might exist in institutions with passive disease surveillance systems.

2.2. Study Procedures

2.2.1. Seasonal and annual ND trends

Annual and monthly records of ND in rural chickens from 1989 to 2014 (available up to district level) were obtained from the provincial veterinary office. This was followed by collection of census data from the 2002 and 2006 livestock census as well as from the rural chicken census data extracted from stock registers of 2014, which were segregated up to district level. In cases where data were missing at the provincial office, a follow-up to the district veterinary offices was done to obtain this data. Maps with Geographical Information System overlays were collected from the provincial office and used to conduct spatial analysis using Epi Map®.

Population models were developed using baseline population data obtained from previous census activities for chickens for 2002, 2006 and information from stock registers for 2014. This involved use of the principle of exponential growth and decay (Bernstein, 2003) and was required for the estimation of population size in years where census data were not available.

Population models for each district and the entire province were developed by calculating the village chicken population growth rates in two blocks- 2002 to 2006 and, 2006 to 2014 using Equation 1.

Equation 1; PGR=$(X_t\ /X_0)$^$\frac{1}{t}$ - 1

Where X_t was the population after a number of years (t) and X_0 was the initial population.

An exponential model with four time blocks (A, B, C, D) was considered because of gaps in available census data (Table 1 and Fig. 1). Population growth in the four blocks were modelled as follows:

Period A 1999 - 2002

Respective growth rates for the period 2002-2006 were used for extrapolating populations for Chadiza, Lundazi and Katete while the provincial growth rate was used for Petauke and Chipata populations. The provincial growth rates were used for Petauke and Chipata districts to normalise values in the model since these two districts recorded negative growth rates that were giving extreme values when based on the 2002-2006 data. Provincial population growth rate was calculated by using Equation 1 where X_t was the total population of village chickens for the province in the 2006 census and X_0 was the total population of chickens for the province in 2006.

Period B 2002 - 2006

In this period population growth rates were extrapolated from the 2002 and 2006 census.

Period C 2007 - 2011

Mambwe, Chama and Nyimba districts were created by the Zambian government by re-demarcating Chipata, Lundazi and Petauke districts respectively thus ending up with eight districts during this period. Population size in this period was extrapolated by using respective calculated growth rates for the population growth between the 2006 census and population data obtained from stock registers in 2014.

Period D 2012 - 2014

In 2012, the Zambian government realigned Chama district to another province (Muchinga Province) and Chadiza was re-defined thus creating Vubwi district. Secondly, Petauke and Katete districts were also re-demarcated to create Sinda District thus ending up with 9 districts within the province. Within this period, population growths were extrapolated from the 2006 census and 2014 stock registers.

The extrapolated population was required for calculating district apparent incidence of ND at yearly intervals using Equation 1 (Thrusfield, 2005).

$$\text{Equation 2; } AI = \frac{D}{N}$$

Where *AI* was the apparent incidence of ND per year, D was the total number of new ND cases per year and N was the total population of chickens in the district.

Since district ND incidence values were calculated from clustered chicken populations, weighted analysis was used to calculate adjusted provincial annual ND incidence (Thrusfield, 2005). This was done by initially adding district chicken populations for each year to obtain provincial chicken populations. Respective district populations were then divided by provincial populations in order to weight the district chicken populations proportionally within the province. This was multiplied by the district apparent incidence calculated using Equation 2 and the subsequent proportional district incidences were then summed to compute the annual provincial ND incidence for that year.

In order to account for an incomplete sample of the population due to under reporting and misdiagnosis of ND by field Veterinary Assistants, the 95% confidence interval for the estimated incidence of the disease was calculated using Equations 3 and 4 derived from Cameron, 1999:

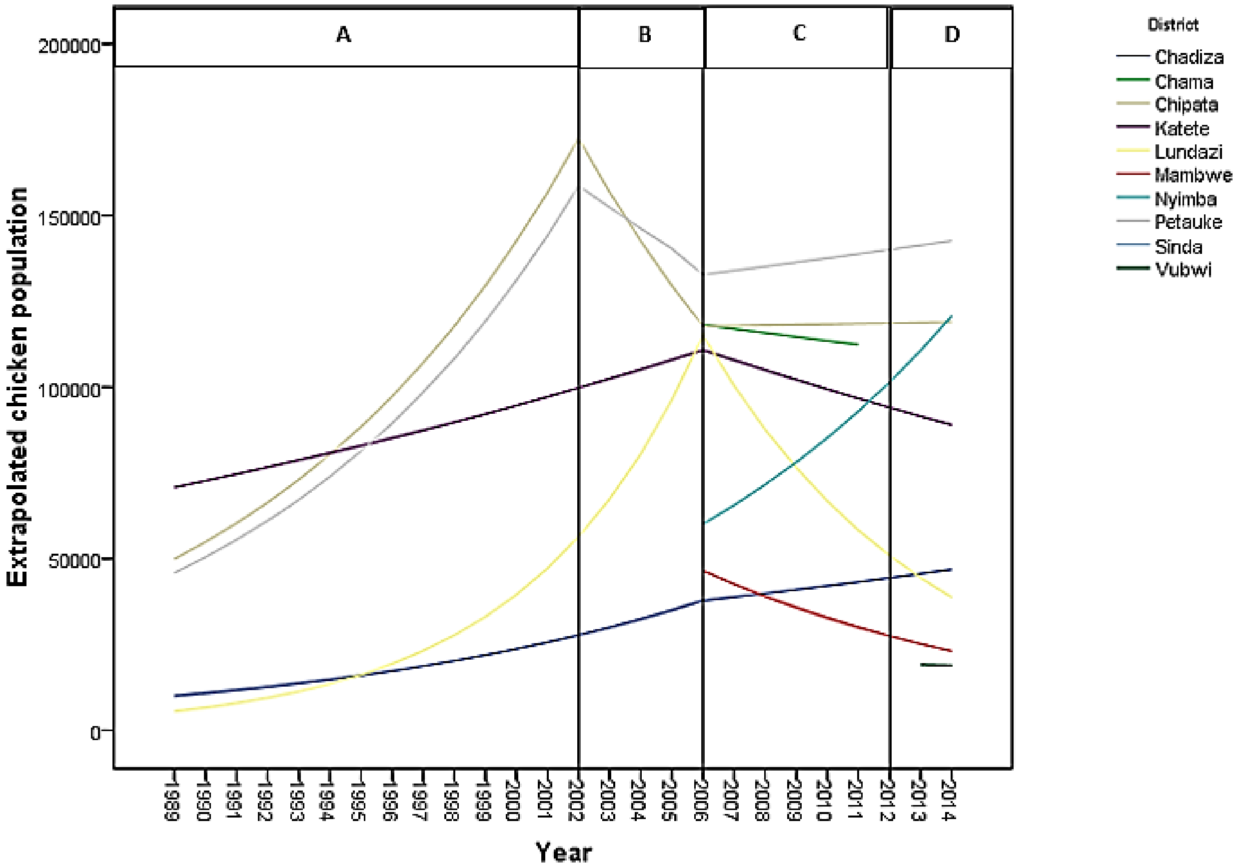

Fig. 1. Modelled village chicken population for districts in eastern Zambia from 1989 to 2014 divided into four time blocks (A, B, C and D).

Table 1. Village chicken population in eastern province of Zambia and calculated exponential population growth rates for 2002-2006 and 2006-2014 periods.

District	Population 2002	Population 2006	Population 2014	PGR 2002-2006	PGR 2006-2014
Chadiza	28,361.00	37,918	46,843	0.075	0.027
Chipata	172,552.00	117,848	119,031	-0.091	0.001
Katete	100,150.00	110,904	89,222	0.026	-0.027
Lundazi	62,855.00	115,080	38,961	0.163	-0.127
Petauke	158,702.00	132,825	142,885	-0.044	0.009
Mambwe		46,568	23,145		-0.084
Nyimba		60,185	121,395		0.092
Chama		118,231			
Sinda			76,982		
Vubwi			18,992		
Provincial	**522,620**	**739,559**	**677,456**	**0.091**	**-0.011**

Equation 3; Var (*AI*)= $AI(1-AI)/N(pp+pp)^2$

Where Var (*AI*) was the sampling variance for the apparent incidence per year, N was the chicken population in the district, Se and Sp were the sensitivity and specificity respectively. The sampling variance was then used to calculate the Lower Confidence Level (LCL) and Upper Confidence Levels (UCL) using Equation 4 (Cameron, 1999):

Equation 4; $AI\!-\big)Z*\big)\,\overline{rrr(AI)}\big)rdd\ I+\big)Z*\big)\,\overline{rrr(AI)}\big)$

Were Z, was α/2 at 95% confidence level which is 1.96. Estimates of variance for incidence estimates, LCL and UCL were then presented in tables.

Sensitivity (Se) was the ability of field veterinary assistants to detect the ND positive birds in the population concerned and the specificity (Sp) was their ability to identify ND negative cases correctly (Mubamba et al., 2011).

Selected experts were sent a small questionnaire that asked the respondents questions on their experience, qualifications and specific questions on ND. From these experts, estimates for sensitivity and positive predictive value (PPV) were obtained. All experts were veterinarians who were serving in the Zambian Government and particularly, the eastern province for a minimum of nine years during the study period. The Sp was then calculated based on the expert opinion of Se and PPV and a ND incidence of 0.48%. This incidence rate was based on the results of this study, which found a median apparent annual ND incidence rate of 0.48% for the study period 1989-2014.

The average Se and calculated Sp obtained from expert opinion were then used to calculate sampling variance (var (*AI*)) for the estimated incidence (Mubamba et al., 2011).

Seasonal trends were analysed by grouping provincial monthly ND incidence data from 1999 to 2005 into the rainy season (January, February, March, April and December), the cool dry season (May, June, July and August) and the hot dry season (September, October and November) aligned with the Zambian Climate (Our-Africa, 2015). Seasonal incidence rates for each season in each respective year were calculated and followed by computing of ND mean seasonal incidence for each year, seasonal index (SI) and overall seasonal index (OSI) (Barnett and Dobson, 2010) using Equations 5, 6 and 7 respectively.

Equation 5; $r\,r\ mSad\ lSall\ dal\ dlddlSddS = \frac{SSS\ \ ff\ r\,D\,llll\,fl\,l\,l\,dl\ dddll\,l\,dl\,l}{r\,SS\ rlr\ ff\ llll\,fl\,l\ plr\,yll\,r}$

Equation 6; $SI = \frac{Il\ dddll\,l\,dl\ \ ffr\,l\ \ llll\,fl\ \ dl\ \ ll\,dh\,rll\,pl\,dtdvl\ \ yll\,r}{r\,D\,S\ lll\ \ llll\,fl\,l\,l\,dl\ dddll\,l\,dl}$

Equation 7; $OSI = \frac{lSS\ \ ff\ lllllll\,fl\,l\,l\,dl\ dddll\,l\ ffr\,l\ \ rll\,pl\,dtdvl\ \ llll\,fl}{r\,SS\ rlr\ ff\ dl\ dddll\,l\ ffr\ thl\ \ llll\,fl}$

Overall seasonal indices were then used to compare ND apparent incidence for the three seasons where seasons with OSI values greater than one were considered to have incidence higher than an average season and *vice versa*.

For annual trends, confidence intervals of annual ND incidence were plotted and compared with main government policies implemented during the period 1989-2014.

2.2.2. Government plans for controlling livestock diseases 1989 - 2016

In Zambia, attempts to control ND disease among rural poultry have been part of the greater plans implemented by the Government of Zambia with the help of funding agencies like the International Monetary Fund (IMF), the World Bank and other cooperating partners (Government-of-Zambia, 1989). This has been implemented through the Fourth National Development Plan (1989 to 1993), the Structural Adjustment Programme (SAP), The Fifth National Development Plan (FNDP) from 2006 to 2010 (Government-of-Zambia, 2006) and the Sixth National Development Plan (SNDP) which is currently running from 2011 to 2016 (Government-of-Zambia, 2011, 2014b).

Fourth National Development Plan (1989-1993)

During this period control of ND in rural poultry was mainly based on restriction of poultry movement from outbreak areas with limited control and awareness campaigns due to lack of funding specifically meant for ND control. ND vaccinations were voluntary and at the farmer's cost.

Structural Adjustment Programme (1994-2005)

In this period there was less disease control extension than in the previous time block due to a wage and employment freeze. As a result, poultry movement control during outbreaks was also reduced. ND vaccination control was voluntary and at a farmer's cost.

Fifth National Development Plan (2006-2010)

There was recruitment of additional extension workers during this period and subsequently more disease control and prevention awareness was carried out. Consequently, movement restrictions for poultry from outbreak areas was increased. Free ND vaccinations were conducted in 2006 and 2007 using a Poverty Reduction Programme (PRP) and African Development funds. However, there were no funds specifically allocated to ND control during this period.

Sixth National Development Plan (2011-2016)

More funding was allocated to the control of ND in the province through the Livestock Development and Animal Health Project (LDAHP) funded by the World Bank. Free vaccination campaigns were conducted in 2015 where over 700 000 birds were vaccinated against ND within the eastern province of Zambia.

2.2.3. Spatial analysis

Spatial trends were analysed by first dividing the study period into three time blocks that corresponded to the Zambian government's demarcation of districts and then computing for each district the median incidence for ND for that time period (1999 – 2005, 2006 – 2011 and 2012 – 2014). These medians were then exported to Epi Map where choropleth maps that analysed median estimates of ND incidence for districts in each time block were developed.

2.2.4. Statistical Tests

IBM SPSS Statistics® version 24 was used to conduct all statistical analysis.

The Kolmogorov-Smirnov and Shapiro-Wilk tests for normality of estimated incidence values was done in order to determine whether to use parametric or non-parametric statistical tests.

The Friedman test, a non-parametric alternative to the one-way repeated measures ANOVA test which is used to determine whether there are statistically significant differences between the distributions of three or more related groups (Conover, 1999; Laerd-Statistics, 2015), was used to determine statistical significance of differences in time blocks for annual incidence of ND as well as differences in ND incidence between districts for spatial patterns. Where differences were significant, post hoc tests involving pair wise comparisons between related groups were carried out in order to pinpoint pairs of groups that significantly differed.

2.2.5. Predictive model for ND prevalence

A model for predicting future ND incidence in the study area was developed based on the modelling of the province's mean annual incidence rates from 1999 to 2014 using the @Risk[†] software package.

Maximum likelihood estimates (MLE) of the parameters was used to achieve the closest match between the time series processes and the input. This was done by using a fit command which fits a Time Series process to data based on the defined input (estimated average ND incidence values from 1999 to 2014). As stationarity could not be assumed when examining the historical data, input data was de-trended using first order differencing with the last value of the historical data set as a starting point for the forecast (Vose et al., 2004).

Akaike Information Criterion (AIC) was used as the model selection statistic (Vose et al., 2004) to determine the best fitting model. Time Series models fitted were MA1 (Moving Average to the order

[†] @Risk, 2014. Risk Analysis Add-In for Microsoft Excel. Palisade Corporation

of 1), MA2 (Moving Average to the order 2), ARMA (Autoregressive, Moving Average) processes, GBM (Geometric Brownian Motion) and its variations, including ARCH (Autoregressive Conditional Heteroskedasticity) and its variations (Vose et al., 2004).

3. Results

3.1. Expert Opinion

Expert opinion results indicated that the average Se for detecting ND outbreaks was 66% and the average PPV value was 75% (Table 2). The median apparent annual ND incidence rate for the study period 1989-2014 was calculated to be 0.48%. Using this information it was possible to calculate the Sp, which was then 99.9%. Variability between experts with respect to Se and PPV was small with standard deviations of 7 and 13 for Se and PPV respectively.

3.2. Efficiency of reporting

From a total of 158 expected annual reports from districts at the provincial veterinary office, only 113 reports were received thus bringing the reporting efficiency during the study period to 72%. Most of the missing reports were from the time period 1994 to 1998 (18) where reports from all of the five districts were not found. With the exception of Mambwe and Chama in 2006, Petauke and Chama in 2009 as well as Mambwe and Nyimba in 2011, all of the reports from the period 2006 to 2014 were found. For monthly reports, only the period 1999-2005 had a 100% reporting efficiency thus only reports from this period were analysed for seasonal trends. Most monthly reports for the periods 1989-1998 and 2006-2014 could not be traced. Missing data was excluded during statistical analysis and was recorded as a blank cell. Records with a recording of zero meant a report was submitted but there were no cases for a respective district during a particular period.

Table 2. Expert opinion results from seven government veterinarians in eastern Zambia*

Position	Experience (Years)	Sensitivity (%)	Positive predictive value (%)	Calculated Specificity** (%)
Veterinary Officer	17	70	90	99.9
Senior Veterinary Officer	24	60	80	99.9
Provincial Veterinary Officer	18	60	55	99.7
Senior Veterinary Officer	24	65	65	99.8
Veterinary Research Officer	9	60	75	99.9
Veterinary Officer	9	78	85	99.9
Mean		66	75	99.9
Median		63	78	99.9
Standard deviation		7	13	0.1

*Experience was the number of years' respective experts served in eastern Zambia, sensitivity (Se) was the experts score for the ability of veterinary assistants' to detect birds affected by ND within their respective catchment, positive predictive value (PPV) was expert's scores on their ability to identify ND positive cases correctly. ** Specificity, their ability to classify negative ND cases correctly, was calculated using an assumed annual incidence of 0.48% and the expert's estimate of Se and PPV.

Table 3. Seasonal patterns of ND apparent incidence in eastern Zambia from 1999 to 2005

Year	**Rainy season**		**Cool & Dry season**		**Hot & Dry season**		**Mean**
	ND AI	S Index	ND AI	S Index	ND AI	S Index	
1999	0.15	1.42	0.14	1.39	0.02	0.20	0.10
2000	0.15	1.43	0.15	1.46	0.01	0.11	0.10
2001	0.02	0.29	0.04	0.81	0.10	1.90	0.05
2002	0.16	1.19	0.12	0.91	0.12	0.90	0.13
2003	0.04	0.71	0.06	1.02	0.07	1.28	0.05
2004	0.01	0.07	0.02	0.21	0.21	2.73	0.08
2005	0.54	1.59	0.28	0.83	0.20	0.57	0.34
Overall		**0.96**		**0.95**		**1.10**	

3.3. Tests for normality of estimated incidence values

Incidence data was not independent (reported from same districts within the province at different time points) as well as not normally distributed (Kolmogorov-Simonov test; $p<0.000$ and the Shapiro-Wilk test; $p<0.00$) hence the Friedman test, a non-parametric test for repeated measures was used to test for statistical significance.

3.4. Temporal Patterns

3.4.1. Seasonal Trends

ND presented a seasonal trend with highest overall seasonal index of 1.10 recorded in the hot dry season and low incidence recorded in the rainy season (0.96) as well as the cool dry season (OSI=0.95) (Table 3).

3.4.2. Annual Trends

A positive trend of ND annual incidence with peaks that occurred in cycles of roughly three years was observed during the study period (Fig. 2 and 3). The average provincial estimated incidence ranged from 0.16 to 1.71% (Fig. 3). However, Friedman test run to determine whether there were significant differences in ND apparent incidence between the 4^{th} NDP (median=0.37%), SAP (median=0.31%), 5^{th} NDP (median=0.61%) and 6^{th} NDP (median=0.96%) revealed that these differences were not statistically significant, $\chi^2(3) = 4.5$, $p = 0.212$

3.5. Spatial Patterns

There were spatial shifts of ND incidence between time blocks that were accompanied by an increasing trend. Overall, median ND incidence was significantly different between the three time blocks (Friedman test; $\chi^2(2) = 7$, $p = 0.03$). Post hoc pairwise comparisons with a Benferoni

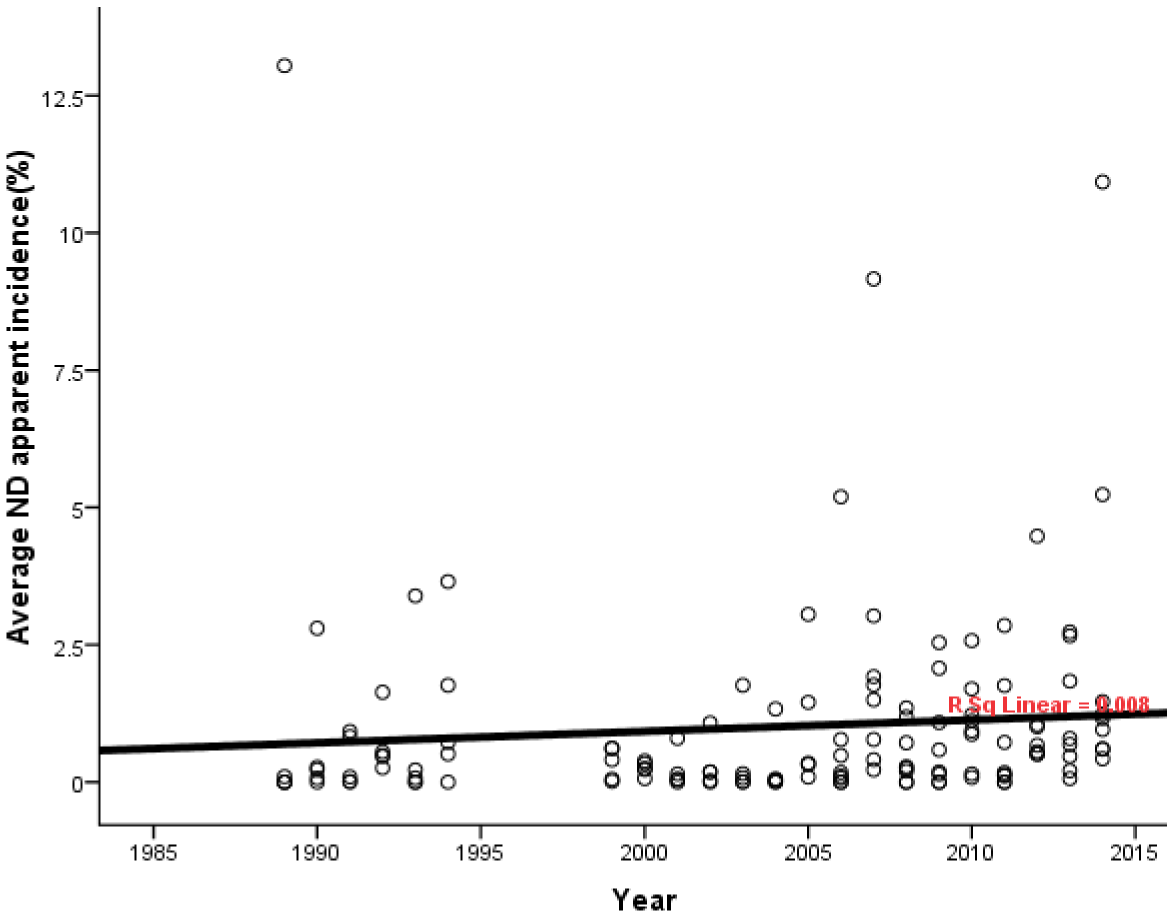

Fig. 2. Positive trend of estimated ND incidence per year in eastern Zambia from 1989 to 2014. Each dot represents a district's annual ND incidence for a respective year.

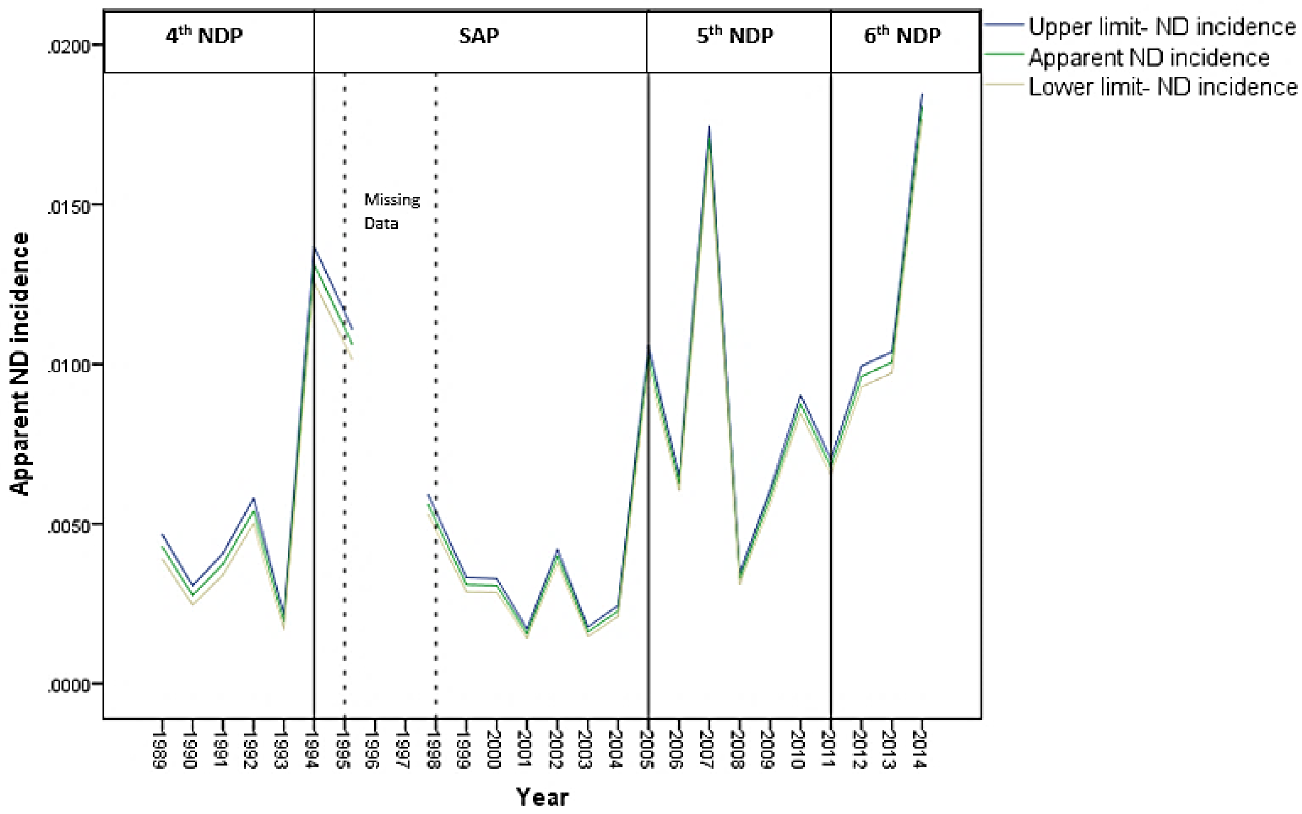

Fig. 3. Apparent annual incidence and confidence limits per year aligned with main government economic policies implemented in the eastern province of Zambia during the period 1989 to 2014.

adjustment revealed a significant difference between time block 1999-2005 and 2012-2014 (adjusted p= 0.028).

1999 to 2005

Petauke had the highest estimated median AI of 0.32% in the period from 1999 to 2005. This was followed by Katete and Lundazi. Chipata, which had the lowest median incidence (0.03%) (Fig. 4). However, differences in median annual incidence between the five districts in time block 1999 - 2005 were not statistically significant (Friedman test; χ^2 (4) 2.171, p= 0.704).

2006 to 2011

There were statistically significant differences in median incidence of ND between districts in time block 2006 – 2011 (Friedman test; χ^2 (7)17.47, p= 0.015). The highest median AI was recorded in Mambwe district (median AI = 1.6%) (Figure 5). However, pairwise comparisons with a Bonferroni adjustment (Laerd-Statistics, 2015) only revealed a significant difference of estimated apparent incidence between Chadiza and Chama (adjusted p=0.03).

2012 to 2014

When compared with time block 2006 – 2011 (Fig. 5), the number of high AI districts appeared the same in the period 2012 to 2014 but Chadiza was replaced by Sinda thus having Mambwe, Lundazi and Sinda as high ND districts. Additionally, the median AI was generally higher with high incidence districts being more widely distributed across the province in 2012 – 2014 (Fig. 6) than 2006 – 2011 time blocks (Fig. 5). However, differences in median AI of ND between districts in 2012-2014 were not statistically significant (Friedman test χ^2 (8)8, p=0.433)

3.6. Predictive Model (@Risk Time Series Model) for forecasting future ND incidence

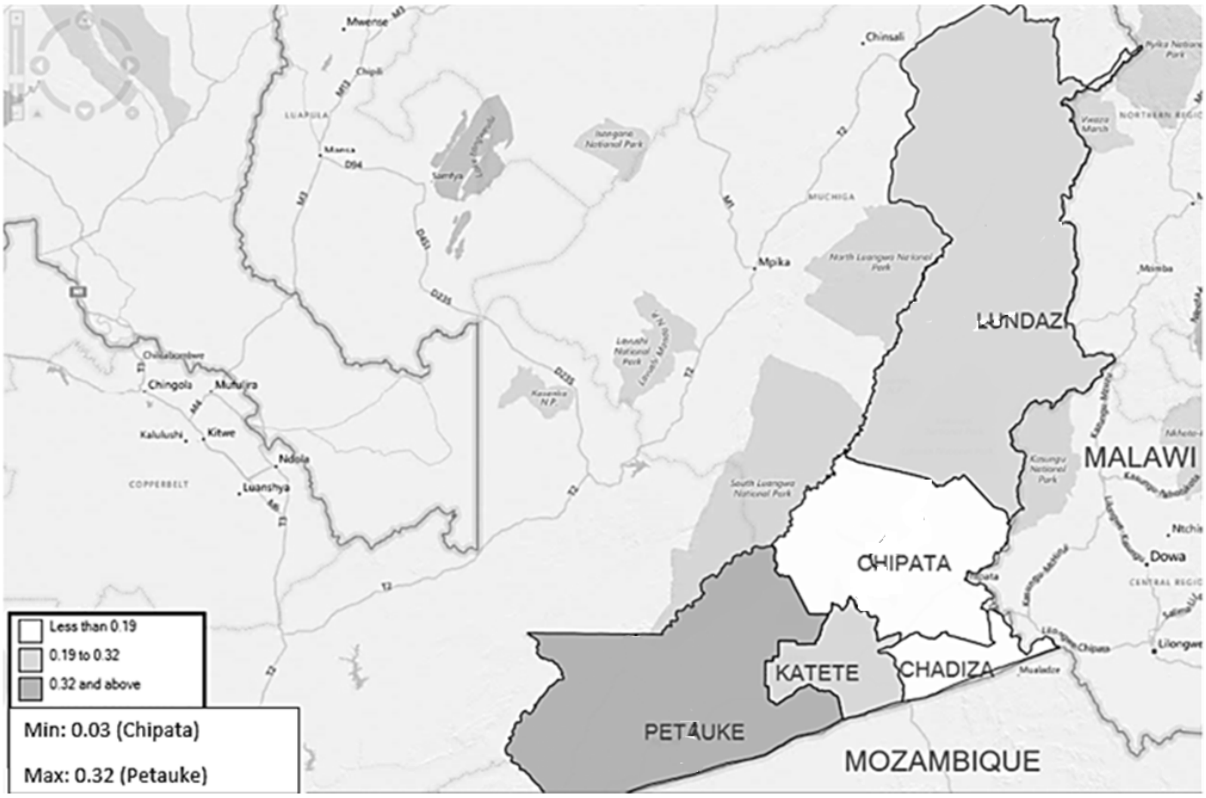

Fig. 4. Median apparent incidence of ND per year in five veterinary districts of eastern Zambia from 1999 to 2005

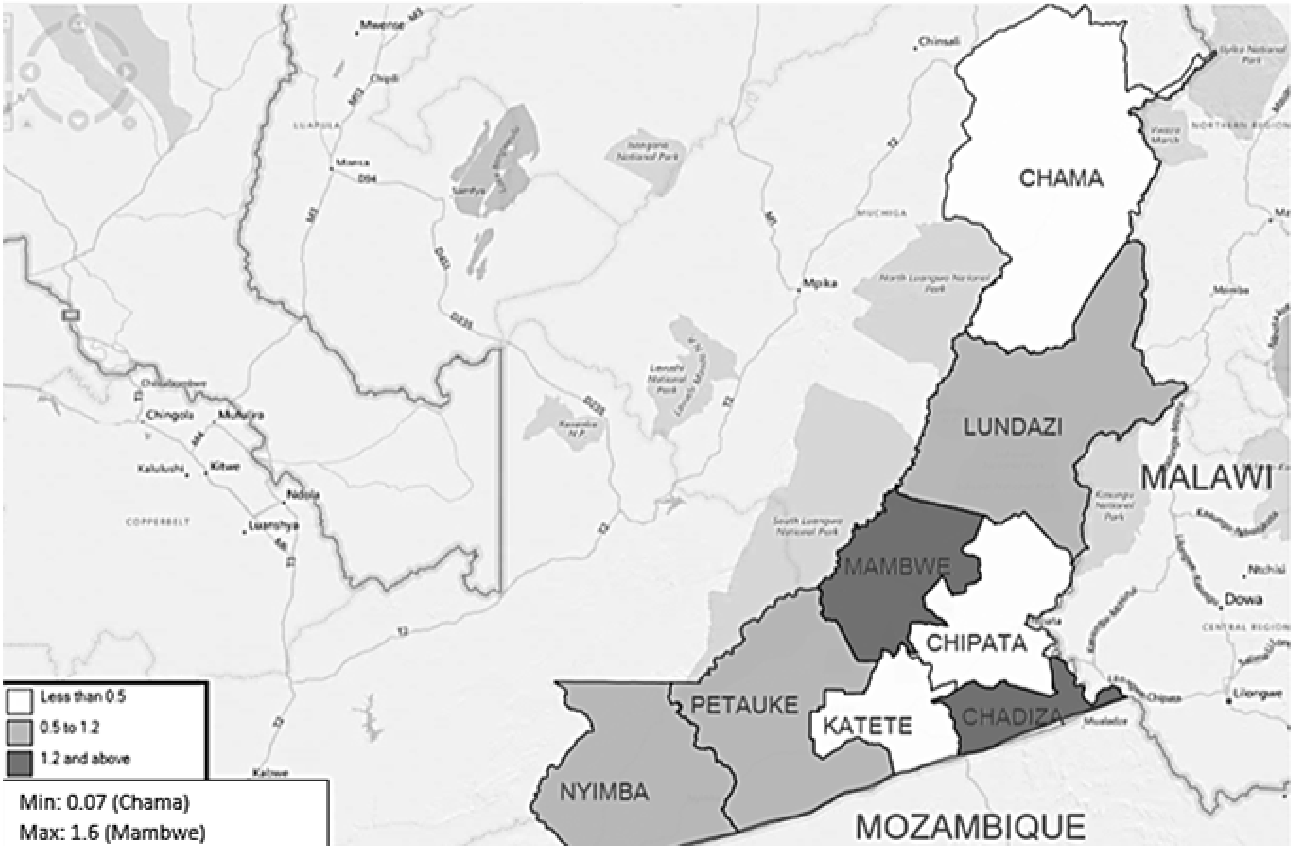

Fig. 5. Median apparent incidence of ND per year in eight districts of eastern Zambia from 2006 to 2011

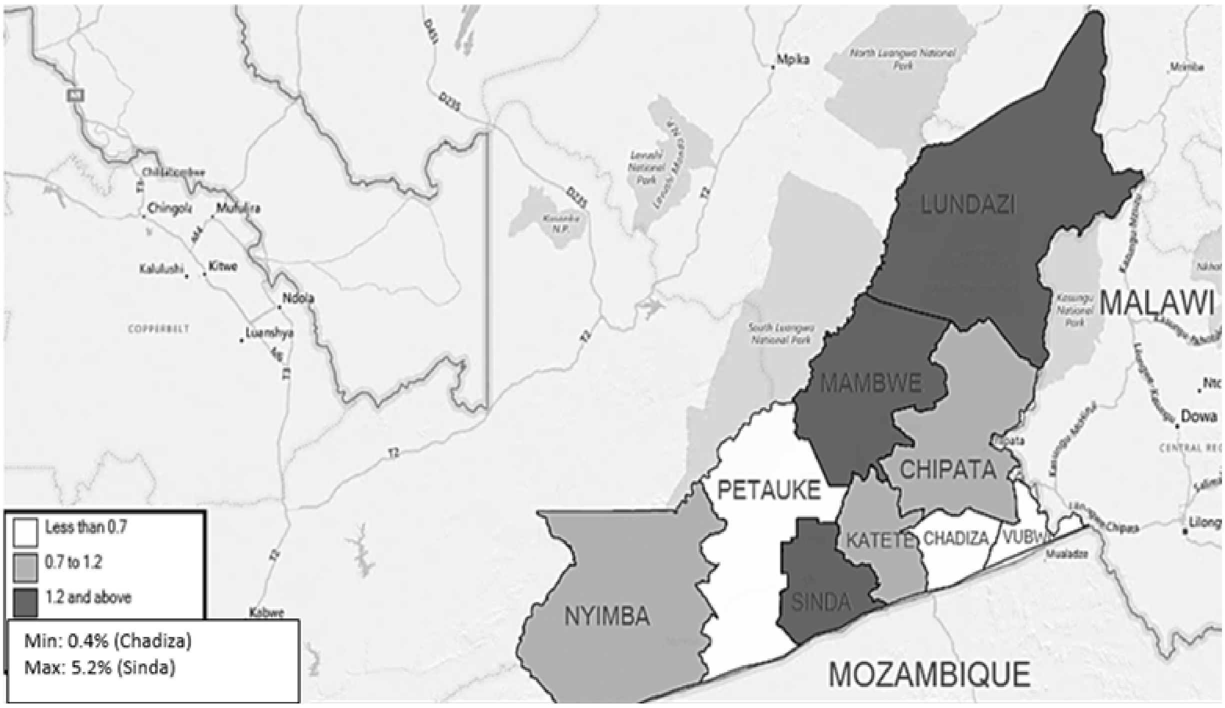

Fig. 6. Median apparent incidence of ND per year from 2012 to 2014 in nine districts of eastern Zambia.

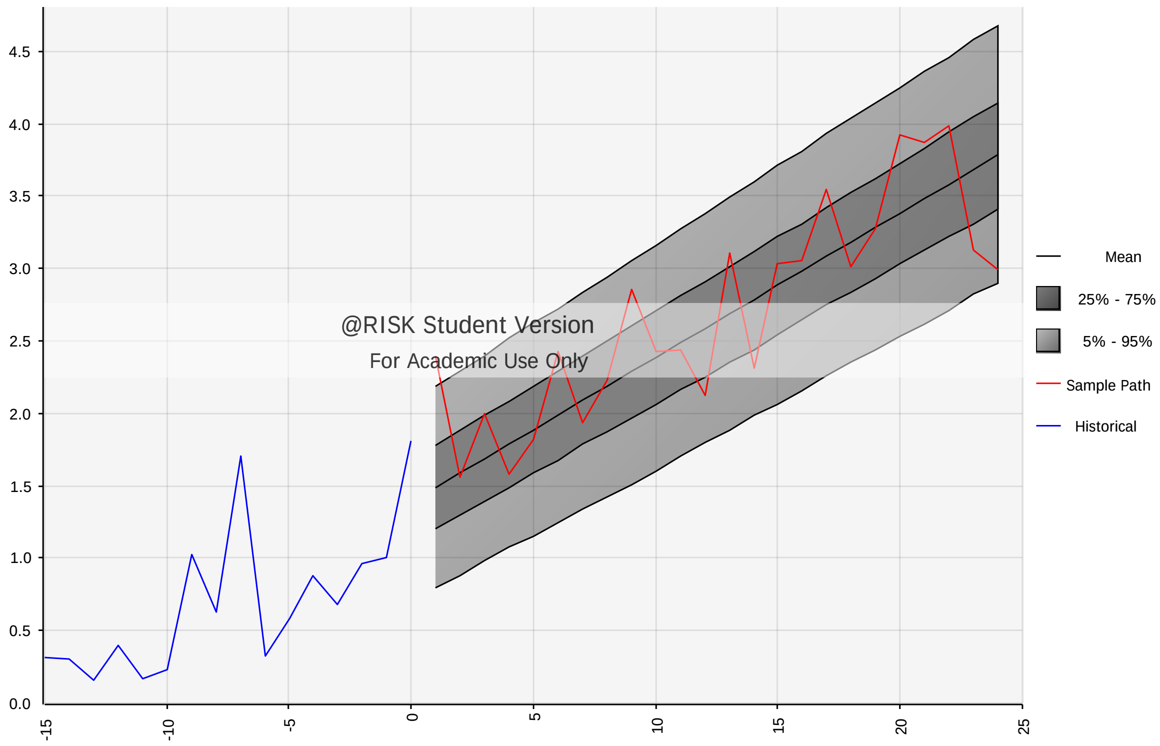

Fig. 7. Twenty five year (X axis) prediction of mean apparent ND incidence (Y axis) per year in eastern Zambia (from 2015 to 2040) if currently existing control strategies for the disease continue.

Table 4. Summary of model fit results from the first to the seventh ranked time series model for ND annual apparent incidence

Type	**AR1**	**AR2**	**ARCH**	**ARMA**	**GARCH**	**MA1**	**MA2**
Data Transform	Manual	Manual	Manual	Manual	Manual	Manual	Manual
Function	None	None	None	None	None	None	None
Shift	0	0	0	0	0	0	0
Detrending	First Order	First Order	First Order	First Order	First Order	First Order	First Order
Depersonalizing	None	None	None	None	None	None	None
Seasonal Period	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Akaike (AIC) Rank	#4	#5	#6	#3	#7	#1	#2
Akaike (AIC) Fit	27.25	29.80	32.60	26.01	33.71	16.94	24.46
Parameters	3	4	3	4	4	3	4
Parameter #1	Mu	Mu	Mu	Mu	Mu	Mu	Mu
Value	0.097	0.097	0.097	0.097	0.097	0.097	0.097
Parameter #2	Sigma	Sigma	Omega	Sigma	Omega	Sigma	Sigma
Value	0.46	0.46	0.33	0.39	0.15	0.42	0.37
Parameter #3	A1	A1	A	A1	A	B1	B1
Value	-0.61	-0.67	0.02	-0.21	0.61	-0.83	-0.95
Parameter #4		A2		B1	B		B2
Value		-0.10		-0.93	0.11		-0.35

The first order Moving Average (MA1) (μ= 0.1, ó= 0.4, b_1= -0.830 and Σ_0= 0.5) model fitted the historical ND incidence data best with an AIC of 16.94 (Fig. 7). This was followed by the Auto Regressive Moving Average (ARMA 1, 1) and the second order Moving Average (MA2) time series models (Fig. 7) with AIC of 24.46 and 26.00 respectively (Table 4). After considering these other two top ranked models, the MA1 model was finally selected as the model of choice because it presented a prediction that was in line with the past and current ND trends. The predicted positive trends show a likely slight increase of mean estimated ND incidence in the next 25 years from 1.7 to 3.8% (Fig. 7) if the current trend is not halted. Predictions of this model would only be valid if there is no major change in human and consequently poultry population in the region within the predicted time frame.

4. Discussion

Absence of poultry census data necessitated the development of an exponential population growth model that estimated poultry populations in each year of the study period. The model was developed with an assumption of a normal population growth in an open environment that is not severely affected by factors like poultry disease and natural disasters (Bernstein, 2003). That is, it assumed normal death and reproduction (Bernstein, 2003) of poultry in the study area. The model can be affected by high poultry mortality due to disease outbreaks. It can also be affected by interventions such as increased slaughter (due to increased trade of poultry) and improved poultry production technologies, like use of housing and hatcheries. Consequently, this would either lead to underestimation or overestimation of populations depending on the circumstances thus affecting the accuracy of the calculated ND incidence. Nevertheless, the model was used after considering the fact that most rural poultry is left to scavenge in villages with little or no disease control and poultry husbandry interventions.

Monthly trends were consistent with previous research findings where the ND cases increase in the hot dry season (Sharma et al., 1985; Musako and Abolnik, 2012) which recorded an OSI of 1.10

(Table 3). This was probably due to an increase in the movement of birds due to trade and different ceremonial occasions that precede the outbreaks. The economy for the eastern province is mainly dependant on agriculture (IMF, 2007). In the period of July to September, there is increased trade in agricultural products including chickens. This increases the movement of chickens within the province thus increasing the likelihood for ND outbreaks. The situation is probably worsened by different traditional ceremonies such as the Kulamba ceremony of the Chewa people conducted during the hot dry season (Phiri, 2014). Exchange of gifts in the form of live chickens is not uncommon during this event.

Annual trends of ND in the province revealed an interesting pattern in that the average annual incidence had been increasing over the study period with notable peaks in 1994, 1999, 2003, 2005, 2007, 2010, 2012 and 2014 (Fig. 2 and 3). Highest provincial AI of 1.7% was recorded in the study period 1989 to 2014 (Fig. 3). The 3-year cyclic peaks in ND incidence could indicate a growth of susceptible village chicken populations every 2- 3 years or increase in immunity to ND due to increased immunisation as a reaction to ND outbreaks. Furthermore, the results revealed an increasing trend of ND incidence (Fig. 2). This was probably due to poor vaccination coverage and poor vaccine quality as a consequence of a weak ND control strategy. On the other hand, the increase in the ND trend may have been influenced by improved awareness of the disease by farmers over time but as very little has changed in terms of the surveillance and disease reporting during this time, this is less likely.

Spatial patterns revealed a possible failure to control spread of ND in the province from 1999 to 2014. This is because there was an apparent increase in trend of median AI that was accompanied by a spatial shift of high ND incidence districts from the northern and southern regions to some districts flanking the central region of the eastern province (Mambwe, Chadiza and Lundazi) from time block 1999 – 2005 to time block 2006 – 2011 (Fig. 4 and 5). The increasing trend in median AI continued in the time block that followed (2012 – 2014) but there was a wider spatial distribution of high ND incidence districts with only Katete, Chadiza and Vubwi districts recording low median AI (Fig. 6). This apparent spread of ND from high incidence districts to low incidence districts of the eastern province during the past 16 years (Fig. 4, 5 and 6) could indicate some failure in controlling ND spread within the province due to possible movement of poultry from vaccinated to non-vaccinated areas as a consequence of inadequate capacity of the veterinary department to monitor all poultry movement between districts coupled with socioeconomic pressure such as need to find markets for poultry and its products by farmers. On the other hand, conversion of formerly high incidence districts (Petauke and Chadiza in 1999 – 2005 and 2006 – 2011 time blocks respectively) to low incidence districts in time block 2012 – 2014 (Fig. 6) could indicate some success in containing the disease through ND vaccinations. Additionally, the spatial shifts in districts with outbreaks over time could also be as a result of veterinary interventions chasing outbreaks rather than implementing uniform control within the province.

Despite significant allocation of resources to livestock diseases during implementation of the policies highlighted above, most attention had been given to diseases affecting cattle - the livestock species perceived to be the most important in the country by many stakeholders (Mubamba et al., 2011; Government-of-Zambia, 2013, 2014a). The Zambian livestock development policy classifies ND as a management disease (Government-of-Zambia, 2015), which implies that control of this disease is entirely the responsibility of the rural poultry farmer. On the other hand, control of most diseases affecting other livestock, like cattle, receive significant funding because they are classified as diseases of national importance (DNEI) (Government-of-Zambia, 2015). Consequently, less resources and attention have been given to poultry diseases like ND. This is probably the reason why there was no impact of major economic policies on reducing the trend of ND AI in the last 25 years (Fig. 2) which is substantiated by the fact that there was no statistically significant difference in median ND incidence between the 4th NDP, SAP, 5th NDP and 6th NDP. This lack of statistically significant differences in the median AI between economic time blocks implies that ND incidence has remained constant despite control measures implemented by different economic plans (Fig. 3). The 25 year forecast predicts an increasing trend of ND and hence higher poultry losses if the existing lack of effective control strategies continue (Fig. 7). It may also be a function of improved disease reporting due to increased awareness and training. This is however less likely due to the devastating nature of the disease to poultry farmers who are unlikely to let the disease go unnoticed.

Confidence intervals that took into account the Se and Sp of the surveillance system were used to report annual ND incidence. However, for the time series model historical AI values were used as an input because only a single value of incidence was required for each year in order to produce the forecast in @Risk software (Fig. 7). This has the weakness that the Se and Sp of the surveillance system are not accounted for in the model. Cannon's (Thrusfield, 2005) formula to calculate true prevalence could be applied but generates unrealistic incidence values when used with low incidence estimates and poor Se and was therefore not applied in this case. Due to the lower Se and PPV of the reporting system the model is probably underreporting the True Incidence. The purpose of the model was not however, to obtain precise estimates of future incidence but rather to examine future trends and therefore despite this weakness serves its purpose.

There is no standard guide for identifying ND among veterinarians and their assistants who depend on their individual clinical skills to identify the disease. As a result, veterinarians may be overestimating the incidence of ND when visiting outbreaks. This is mitigated however by the fact that the surveillance system depends on the number of clinical cases reported to state veterinary services by farmers implying that in circumstances where cases exist but have not been reported, veterinary offices may not record them. By developing a standard case definition for a ND case the PPV of the surveillance system could be improved, while improving disease reporting by farmers is needed to improve the sensitivity of the surveillance system.

Accuracy of Se and PPV provided by nine experts may also affect the accuracy of the estimated ND incidence computed in this study. This is because it was based on individual opinions rather than Se and PPV estimates obtained through confirmatory laboratory testing. However, this is currently the only available method for computing Se and Sp for ND in eastern Zambia because confirmatory laboratory diagnosis has not been carried out in the past and such data does not exist. Much effort was therefore put into getting experienced experts to provide estimates of Se and PPV to minimise bias in this regard. Table 2 shows that there is good agreement between experts with relatively small standard deviations, which allows some confidence in their estimates of Se and PPV. In retrospect, an estimate of Sp by experts should have been asked for at the same time.

Quality of reporting by veterinarians and their assistants may also have had some impact on the incidence rates, since reports from 1994 to 1998 were not traced (Fig. 3). This may however, reflect a weakness in storage of data at both district and provincial veterinary offices rather than quality of reporting. There has been better record storage since 1999 but whether that reflects a better evolution in quality of disease reporting over time is hard to say. Because the Friedman test analyses differences between three or more related groups with related measures that are matched (Laerd-Statistics, 2015), missing data in respective time blocks would have significant effects on results of the analysis. This could be the reason why differences between time blocks were not statistically significant.

Despite the acknowledged weaknesses of this study, it provides an insight to the spatial and temporal trends of ND in the region. Furthermore, it demonstrates how historical livestock disease data obtained from livestock disease control agencies of low income countries could be used to analyse and predict future trends of ND and other diseases taking into account the bias that might arise due to misdiagnosis and under-reporting of the disease.

5. Conclusion and Recommendations

This study shows that there is a positive annual trend for estimated ND incidence in eastern Zambia and that this trend will most likely continue in the next 25 years. It also shows that livestock disease control programmes implemented in this region through major economic policies that existed from 1989 to 2014 probably had little impact on ND trends. Furthermore, the ND control strategies implemented during this period seem to have failed to halt the spread of the disease from affected districts to those that were previously ND free.

The study also demonstrates how incidence can be estimated with scanty poultry population data and re-emphasises the need to account for uncertainty when analysing poultry disease data obtained mostly through clinical diagnosis by field staff where misdiagnosis and under reporting can easily occur. This can be achieved by accounting for Se and Sp of the surveillance system.

By developing a standard case definition for a ND case and regular training of all veterinarians and their assistants on correct diagnosis of ND of the surveillance system could be improved provided it is supported by an efficient and well-resourced laboratory diagnostic capacity. Improving disease reporting by farmers through awareness campaigns and creation of poultry interest groups is needed to improve the sensitivity of the surveillance system.

In order to control ND in rural poultry effectively, better vaccination and control strategies than those currently used are required. This may involve better vaccines or better vaccination coverage together with targeted surveillance and disease prevention and disease control awareness campaigns.

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