

MAKERERE



UNIVERSITY

**SPATIAL-TEMPORAL PATTERNS OF RABIES OUTBREAKS IN UGANDA: A
RETROSPECTIVE STUDY 2018-2022**

BY

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DECLARATION

I **Nannozi Beatrice Kasirye**, declare that this is an original piece of work, which has been done by me and has never been submitted for any award before any other institution of learning and all quotations, illustrations, and citations have been duly referenced.

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ACRONYMS AND ABBREVIATIONS

ASEAN	The Association of Southeast Asian Nations
CAH	Commissioner Animal Health
DVO	District Veterinary Officer
FAO	Food and Agriculture Organisation
GARC	Global Alliance for Rabies Control
HMIS	Health Management Information System
IHR	International Health Regulations
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MoH	Ministry of Health
NADDEC	National Animal Disease Diagnostic and Epidemiology Centre
NOHP	National One Health platform
NRCS	National Rabies Control Strategy
PARACON	Pan-African Rabies Control Network meeting
PEP	Post-Exposure Prophylaxis
QGIS	Quantum Geographical Information Software
RABV	Rabies virus
RIG	Rabies Immunoglobulin
SARE	Stepwise Approach towards Rabies Elimination
UN	United Nations
UNMA	Uganda National Meteorological Authority
WHO	World Health Organization
WOAH	World Organization for Animal Health

ABSTRACT

Rabies is a major global public health concern, with the majority of cases occurring in the developing countries of Asia and Africa. The disease is endemic in Uganda and has been ranked among the top-priority seven zoonotic diseases that impact public health in the country. Effective management of the disease in endemic countries has been greatly affected by the absence of reliable data. This study aims at determining the spatial-temporal patterns of rabies outbreaks in domestic animals (dogs, cats, goats, and cows) in Uganda. A retrospective study was carried out based on rabies reporting data from January 2018 to September 2022 as compiled by NADDEC. Descriptive statistical techniques were employed to calculate the prevalence of the disease. The temporal patterns of rabies were achieved by creating a line graph that depicted how rabies cases changed over time. QGIS software version 3.28 was used to explore the spatial patterns of the disease, enabling the visualization of the distribution of rabies cases across various districts in Uganda. ARMA (13,4) model was opted to predict rabies cases in Uganda from October 2022 to December 2023. A total of 2,081 rabies cases were reported in Uganda from January 2018 to September 2022. This represents 2.29% of the total number of animals (90,895) reported to be at risk. The predominant method of diagnosis used by veterinary technical staff was clinical manifestation; only 8 cases were laboratory confirmed. The year 2019 had the highest number of cases (29.56%), whereas 2020 had the lowest number of cases (7.11%). Of the reported cases, 23 (goats and cows) were slaughtered, 515 died, and 581 (cats and dogs) were euthanized. Districts of Mukono, Tororo, Iganga, Kalangala, Busia, and Serere reported the highest number of cases (between 35 and 688) while Kiboga, Mityana, Sheema, Rubirizi, Moyo, and Pader reported the least cases. The most predominant method of rabies prevention was vaccination where total a of 39,735 animals were vaccinated. The model projected 89 cases of rabies between October and December 2022 and a total of 248 rabies cases in the year 2023, January was predicted to have the fewest cases while April had the highest.

The main outbreak management methods used were culling, movement control, and awareness creation. The spatial-temporal patterns of rabies identified in this study indicate a heterogeneous distribution of the disease throughout the country. This, therefore, calls for appropriate planning and resource allocation by key actors to achieve the global target of “Zero rabies by 2030.”

CHAPTER ONE: INTRODUCTION

1.1 Background

Rabies is a fatal viral zoonotic disease with a mortality ranking of about eleventh of all infectious diseases in humans (Hampson et al., 2015; Eke et al., 2015). The disease is caused by a non-segmented, negative-stranded RNA virus from the family *Rhabdoviridae*, order *Mononegavirales*, and genus *Lyssavirus* (Dietzgen et al., 2017). The virus is bullet-shaped and composed of two parts; the first part is considered more structural and is a viral envelope while the second part is more functional and contains the ribonucleocapsid core (Dietzgen et al., 2014).

The disease is transmitted primarily through bites from infected mammals; however, it can also be transmitted through licks or scratches from infected animals and rarely through transplantation of tissues/organs from infected individuals (Tenzin et al., 2017; Brunker & Mollentze, 2018). Approximately 85 to 90% of animal-human bite injuries are caused by dogs, 5% to 10% by cats, and 2% to 3% by humans and rodents (Ngugi et al., 2018). However, the disease has also been reported in wildlife like bats foxes wolves, and other wild animals in developed countries (Pantha et al., 2020; Fooks et al., 2014; Garg, 2014)

The incubation period in dogs varies from 10 days to 6 months, however, clinical signs manifest between 2 weeks to 3 months (Caicedo et al., 2015). The disease in humans has an incubation period of 20 to 60 days on average but can be longer (Crowcroft & Thampi, 2015).

It has been estimated that one person dies from rabies in a rabies-endemic country every 10 – 20 minutes and that 40 –50% of fatalities are in children below 15 years of age. Children are more likely to be bitten by both domestic and free-roaming dogs due to their frequent and sometimes playful interactions with the dogs (Ponsich et al., 2016). Studies have shown that there is a rapid clinical progression of rabies in scenarios where animal bites occur on the head, this is because of the proximity of the head to the central nervous system (Ngugi et al., 2018). However, the disease in humans is preventable where clinical intervention in the form of PEP that involves wound washing, rabies vaccines, and sometimes RIG is given promptly (Changalucha et al., 2019; Rupprecht et al., 2010). This vaccine is administered to victims of bites from suspected rabid animals as soon as possible while the animal is being observed for

10–14 days or pending the results of laboratory tests (Crowcroft & Thampi, 2015). However, PEP requires multiple doses, is not always available, and must be administered promptly to be effective. It is therefore more cost-effective to prioritize dog vaccination as compared to using PEP in humans. The cost of PEP is highest in Asia, with estimates of up to US\$ 1.5 billion per year (Gongal & Wright, 2011). Despite the high prevalence of rabies in the region, Africa is estimated to spend the least on PEP (Nesadurai, 2008). As per the definition of the WOA, a country that has no record of indigenously acquired cases of human or animal rabies within two years due to surveillance and import regulations can claim a rabies-free status (WOAH, 2011). Such a country should adopt continuous monitoring and ensure movement control of animals/animal products at all international borders (Castrodale et al., 2008).

1.2 Problem Statement

The Ministry of Health estimated that 26 Million individuals in Uganda are at risk of exposure to rabies annually (MOH, 2016; Wallace et al., 2017). In 2015, WHO, FAO, and WOAHA set the global target to eliminate dog-mediated rabies in humans by 2030 hence the "Zero by 30 Global strategic plan". This target is also in line with the UN Sustainable Development Goals which advocate for the eradication of neglected tropical illnesses within the same timeframe. Recently, the tripartite together with the Global Alliance for Rabies Control (GARC) joined forces to support countries as they seek to accelerate their actions towards the elimination of dog-mediated rabies by 2030 (Minghui et al., 2018). However, studies have shown that the absence of reliable data on the actual burden of rabies has led to the underinvestment in control programs in endemic countries (Hampson et al., 2015), this study, therefore, defines the spatial and temporal patterns of the disease in Uganda, it adds on the already existing knowledge base of the disease in the country.

1.3 Justification of the Study

Uganda is a signatory to the International Health Regulations (IHR) 2005, which mandates member states to strengthen capacities for health security. Combating biological threats and health emergencies is a cornerstone of Uganda's vision for healthy, wealthy, and resilient communities by 2040 (NAPHS, 2019). Rabies was identified as one of the seven priority zoonotic diseases of Uganda not only because it is a threat to public health and socio-economic structure but also because of the availability of an effective animal vaccine which is the cornerstone of dog-mediated rabies eradication in Uganda. Much as underreporting and data inconsistency have been mentioned as partial reasons for the lack of effective control of rabies in Africa (Cleaveland et al., 2002), the existing data should be utilized to explore the outbreak trends of the disease in domestic animals in Uganda and therefore guide policymakers establish better and sustainable rabies control interventions, provide a basis for policy advocacy and budgetary justification for rabies control.

1.4 Study Objectives

1.4.1 General Objective

To determine the spatial-temporal patterns of rabies outbreaks in Uganda from January 2018 to September 2022.

1.4.2 Specific Objective

- i. To determine the prevalence of rabies in domestic animals in Uganda from January 2018 to September 2022.
- ii. To determine the temporal and spatial distribution of rabies outbreaks in domestic animals in Uganda from January 2018 to September 2022.
- iii. To conduct a time series analysis of rabies cases between January 2018 and September 2022. and predict rabies cases in Uganda from October 2022 to December 2023

1.5 Research question

- i. What is the prevalence of rabies in domestic animals in Uganda from January 2018 to September 2022?
- ii. What is the temporal and spatial distribution of rabies outbreaks in domestic animals in Uganda from January 2018 to September 2022?
- iii. What is the predicted rabies cases in Uganda from October 2022 to December 2023 using time series modelling?
- iv. ?
- v.

CHAPTER TWO: LITERATURE REVIEW

2.1 Prevalence of rabies

Millions of reports have shown evidence that rabies has been in existence since 4000 BC, however, it was not until the start of the 19th century that dog-mediated rabies was reported (Pantha et al., 2020; Baxter, 2012; Rupprecht et al., 2017). Rabies is responsible for approximately 59,000 deaths in humans, in more than 150 countries and 8.6 billion USD (95% CIs: 2.9–21.5 billion) in economic losses annually (Zubair Yousaf et al., 2012). In Asia, the disease is responsible for 35, 172 deaths in humans annually; India is responsible for 59.8% of those deaths and 35% of the total human deaths globally (World Health Organisation, 2018). In Africa, an estimate of the rabies burden in humans is about 23,800 deaths per year, most of these cases are concentrated in rural Africa (Hampson et al.,2015; Fooks et al., 2014; Ward, 2012). With a lethality of almost 100%, the disease is responsible for an estimated 21, 000–25,000 deaths annually in Africa with 3.6 cases per 100,000 people especially among rural communities with large stray dog populations (Vigilato et al., 2013). The actual burden of the disease is highly underestimated due to challenges faced in diagnosis which lead to underreporting (Gibbons et al., 2014). Furthermore, the lack of surveillance (Banyard et al., 2013) due to limited healthcare in both medical and veterinary practices are often complicated by other native social and cultural practices in some communities (Dodet et al., 2013). Therefore, rabies is often not prioritized by policymakers due to inaccuracies in the burden of the disease (Hampson et al., 2015). In the year 2011, a total of 33 African countries reported 1607 outbreaks of rabies, 2779 cases, and 1524 deaths (Nyasulu et al., 2021).Some studies show that, rabies accounts for 7.2% of all animal disease outbreaks reported, making it one of the biggest challenges to animal health in Africa in 2011. In the same year 2011, Uganda reported 466 rabies cases and 40.9% deaths due to rabies (Nyasulu et al., 2021).

2.2 Spatial -Temporal distribution of rabies

In Greece and Egypt, the disease was first recognized in 2300 BC, sixth century in Persia, and first century in India (Hanlon & Childs, 2013). It is believed that both environmental and

anthropogenic factors contribute to rabies (Yu et al., 2020); environmental factors include elevation, temperature, and land cover (Guo et al., 2018), while anthropogenic factors include population density and economic development level (Wilson et al., 1997).

The large-scale threat of rabies exposure to humans and domestic animals in Europe and North America was significantly reduced a number of decades ago through coordinated, methodical, population-based vaccination of dogs and control of stray dog populations. Similar to trends in the USA and Europe during the 1950s and 1960s, recent substantial improvements in canine rabies control have occurred in Latin America, therefore, reducing the disease substantially. (Schneider et al., 2011; Ruiz & Chávez, 2010; Belotto, 2004).

However, the current distribution and impact of RABV across the globe contrasts with how it was historically studied (Fisher et al., 2018): foundational understanding of RABV spread and transmission is due to studies done in wildlife in America and Europe, unfortunately, fewer studies have been done in Africa and Asia where the majority of cases occur (De Nardo et al., 2018). Africa and Asia together account for 95% of all human rabies cases of which 99% are acquired from infected dogs (Horta et al., 2022) and Africa alone carries an estimated 36.4% of human cases globally (Wright et al., 2021).

Over time, the reduction in the number of rabies cases in developed countries has been a result of consistent vaccination in both wildlife and pet dogs (Fooks et al., 2014). The geographical distribution of animal rabies in Tunisia from 2012 to 2018 showed that the disease was mainly restricted to the North and the Centre of the country (Kalthoum et al.,2021).

Seasonality of the disease has been found in Peru, South Asia, Morocco, and Algeria (Malaga et al., 1979; Tenzin et al., 2011; El Harrak., 2011; Khayli et al., 2019). Some studies also suggest that the absence of immunity in younger puppies could lead to seasonal outbreaks of the disease (Douangngeun et al., 2017).

2.3 Rabies Outbreaks in Uganda

In Uganda, the disease was first confirmed in 1936 and has since then become endemic in the country (MAAIF, 2018). The disease is also a priority zoonotic disease in Uganda and is classified as a neglected tropical disease by the WHO. More than 60% of the districts were mapped as rabies high-risk areas or “hot spots” reporting more than five canine bite cases per

year (MAAIF, 2018). Globally, accurate estimates of rabies deaths are impossible to obtain as surveillance systems and laboratories are inadequate or nonexistent for the systematic detection and laboratory confirmation of human or animal rabies cases.

The proportion of rabies cases detected and reported to the WHO in 1999 was estimated to represent only 3% of the total global rabies (Knobel et al., 2005). Novel methods of estimating human rabies deaths have focused on extrapolations from studies estimating domestic dog population densities in different regions especially, Africa and Asia (Childs et al., 1997), or directly from the incidence of dog bites in African countries, such as Uganda and Tanzania (Cleaveland et al., 2002).

Between 2001 and 2015, the overall incidence (per 100,000 populations) of animal bites in Uganda was 58.1 cases per year. The Northern region had the highest overall incidence of 75.7 compared to 58.0 in the central, 52.5 in the western, and 49.9 in the eastern region. From 2001 to 2015, the incidence of animal bites significantly increased across the country as seen in Fig 1.0. Similarly, in a study that was done from 2013 to 2017 by Birungi and colleagues, bites from animals were reported in most districts; however, the most affected districts were in the West; followed by the North, Central, and East respectively; in this study, 36% of the of the samples tested positive (Birungi et al., 2021).

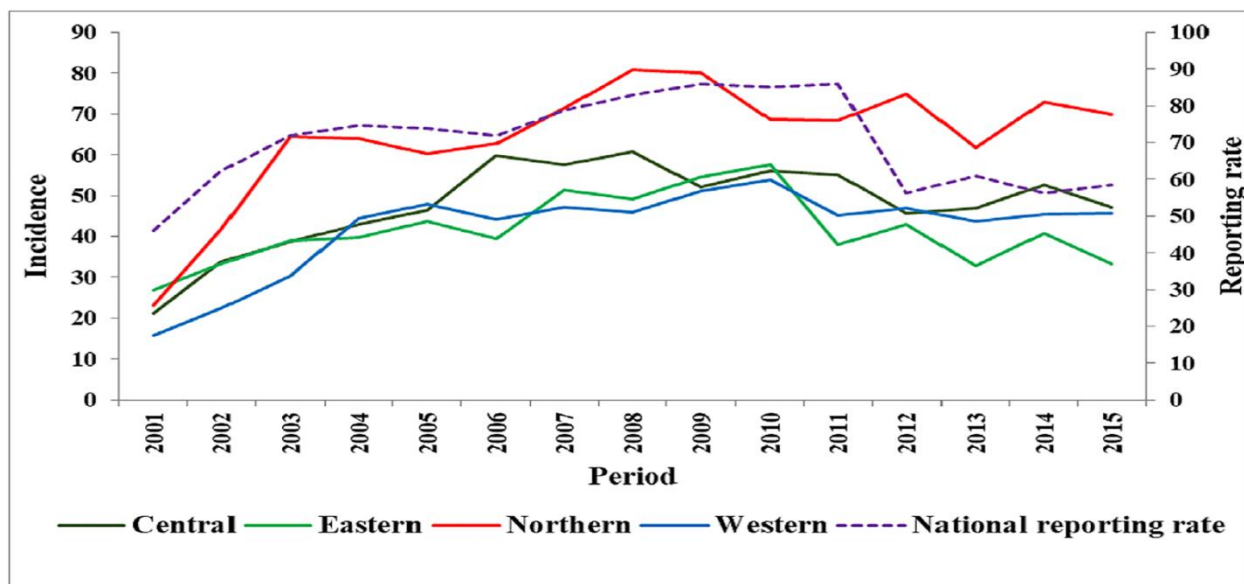


Figure 1.0: The trends of incidence and reporting of animal bites from 2001 to 2015

2.4 Control of Rabies

Vaccination is a pre-exposure prophylaxis preventive measure that involves giving a series of intramuscular or intra-dermal injections of a drug to trigger the immune system to create a memory of a target micro-organism (Kessels et al., 2017); the impact of vaccination is that there is recall by the immune system once an individual is re-exposed to the micro-organism (Nagarajan & Rupprecht, 2020). Consistent mass vaccinations have greatly contributed to the elimination of dog rabies in Europe, North, and Latin America, and Japan (Velasco-Villa et al., 2017; Maki et al., 2017), however, the disease in developing countries is still a challenge (Lembo et al., 2010).

In Uganda, animal health professionals spearhead anti-rabies vaccinations of pets and community sensitization in an attempt to control the disease arising from domestic animal bites/scratches while the disease in humans is managed by human health care professionals (World Health Organisation, 2018). People who have received pre-exposure prophylaxis require fewer doses of post-exposure rabies vaccine and can be treated without rabies immunoglobulin, which is costly and difficult to procure (Rupprecht et al., 2009). In developed countries, multi-annual vaccination campaigns with vaccination coverage of at least 70% of the domestic dog population significantly reduced the disease (Wobessi et al., 2021). It is therefore upon this

background that the WHO and its partners have adopted a goal to eliminate rabies mediated by dogs by the year 2030 via the control of the disease in dogs (Wobessi et al., 2021).

The animal surveillance system in Uganda is manned by the Department of Animal Health at MAAIF and implemented by District Veterinary Officers. The surveillance system involves routine animal data collection and submission from the districts to the center (MAAIF) (Nantima et al., 2015). Standard semi-structured questionnaires prepared by MAAIF are used by the districts to capture the data and transmit to it the central authority. Recently, as an effort to improve data quality, computers, geographical positioning systems, and modems were procured by the government and given to some districts to enable them to submit electronic data (Nantima et al., 2015).

The laboratory diagnosis of the disease in developing countries is hampered by reasons, including laboratory infrastructure and logistics (Eggerbauer et al., 2016). The gold standard for rabies diagnosis is the fluorescence antibody test (FAT) (Dean DJ, Abelseth MK, 1996), which is internationally approved by WOAAH and WHO. Following the fixing of the brain tissue on slides, there is staining with fluorophore-conjugated antibodies; the slide is later observed under a fluorescence microscope. The recognized confirmatory tests are; mouse inoculation test (Koprowski, 1996), and virus isolation in cell culture (Webster and Casey, 1996), however, mouse inoculation has been banned by international Organizations (WOAH/WHO).

The other diagnostic methods used are the assays for the detection of viral RNA or antigens (Dacheux et al., 2010; Fooks et al., 2009).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Study design

A retrospective study was done to determine the spatial-temporal patterns of rabies outbreaks in Uganda from January 2018 to September 2022 using rabies reporting data from NADDEC.

3.2 Study Area

The study was undertaken in Uganda which is an agriculturally based developing country in East Africa. Uganda is a landlocked country with an elevation of 3527.33 feet, longitude

32°17'24.99s" E, and latitude 1°22'24" N at easting 421,045.88 and 151806.57. The current population of Uganda is 49,265,298 as of Friday, October 7, 2022, based on World Meter elaboration of the latest United Nations data. Uganda ranks number 31 in the list of countries (and dependencies) by population. In Uganda, the population density is 229 per Km² (593 people per mi²). The country is stratified into several administrative units namely; regions, counties, districts, constituencies, sub-counties, parishes, and villages. The study was done in all the districts that reported rabies outbreaks from January 2018 to September 2022.

3.3 Data collection

The study used the rabies data set from January 2018 to September 2022 at the NADDEC. This data originated from the production departments of the district local governments that reported rabies outbreaks in Uganda, it was then sent to NADDEC where it was compiled and fed into the MAAIF database. NADDEC is the national referral animal disease diagnostic laboratory responsible for the prompt collection, collation, and dissemination of epidemiological data/disease reports in Uganda. Therefore, there was no sampling strategy in this study since no sampling was employed.

The outcome variable extracted was the number of cases in domestic animals (dogs, cats, goats, and cows). Independent variables were; the temporal factors (years) and spatial factors (districts) of Uganda.

The other data that was utilized was on animals at risk and animals vaccinated; the data also had animals that were slaughtered, died, or euthanized. Data was further verified through telephone communications with Local government Veterinary officers.

Case definitions;

- (i). A suspect rabies case is one where there is an onset of drooling/salivation, aggressiveness, restlessness, hydrophobia with or without paralysis, and seizures.
- (ii). A probable rabies case is a suspected case with contact/bite with a confirmed case or RDT-positive test.
- (iii). A Confirmed rabies case is one with a positive direct fluorescent antibody assay (DFAA).

All three above were considered rabies cases for this study.

3.4 Data Management

The obtained data was reorganized in Microsoft Excel 2021 and verified for accuracy, consistency, and completeness. Then cleaned and edited before analysis in SPSS software version 20 and QGIS software version 3.28.

3.5 Data Analysis

Descriptive statistical techniques were employed to calculate prevalence; this was accomplished by dividing the number of cases by the number at risk of the disease, as specified in objective 1. Objective 2 involved capturing the temporal patterns of the disease by creating a line graph that depicted how the rabies cases changed over time across the different years, namely 2018, 2019, 2020, 2021, and 2022. QGIS software was utilized to conduct spatial data analysis, enabling the visualization of the disease distribution across various districts in Uganda from January 2018 to September 2022.

Finally, for objective 3, an analysis of univariate time series data was conducted and ARMA (1,3,4) model was opted to predict rabies cases in Uganda from October 2022 to December 2023.

3.6 Data quality control

To ensure both reliability and validity, the data collected were selected and validated for completeness and timeliness.

3.7 Ethical considerations

Clearance for this research was sought from the Research Ethics Committee (REC) at the School of Biosecurity, Biotechnical and Laboratory Sciences (SBLS). In upholding ethics during data retrieval, written consent from the relevant office (Commissioner of Animal Health) during the process was obtained. This helped to erase doubts, and known benefits that may arise in this

study. Ethics of anonymity and confidentiality by not exposing the identity of all those who were involved were considered.

CHAPTER FOUR: RESULTS

4.1 Epidemiological characteristics of rabies in the study population.

A total of 2,081 rabies cases were reported among the study domestic animals with a total prevalence of 2.29% (229 cases per 10,000 animals). Consequently, 23 animals were slaughtered, 515 died, and 581 were euthanized.

The year 2019 was the most affected with 617 cases (29.65%), followed by 561 cases (26.96%) in 2018, 404 cases (19.41%) in 2021, 351 cases (16.87%) in 2022, and the least number of cases, 148 (7.11%), occurred in 2020 (Table 1.2). These cases were distributed among five animal species, namely dogs, cats, goats, and cows.

The most predominant method of rabies prevention was vaccination where a total of 39,735 animals were vaccinated; methods of disease management were; culling, movement regulation, and community awareness programs.

There were 90, 895 animals at risk of rabies in this study. Table 1.2 summarizes the epidemiological characteristics of rabies in the study population.

Table 1. 1: Epidemiological characteristics of rabies of the study population.

Year	Animals at risk, n (%)	Animals vaccinated, n (%)	Rabies cases, n (%)	Slaughtered, n (%)	Died, n (%)	Euthanized n (%)
2018	11956(13.2)	8666(21.8)	561(27.0)	1(4.3)	203(39.4)	59(10.2)
2019	10701(11.8)	8869(22.3)	617(29.6)	6(26.1)	113(21.9)	423(72.8)
2020	40002(44.0)	6805(17.1)	148(7.1)	6(26.1)	40(7.8)	51(8.8)
2021	21215(23.3)	9790(24.6)	404(19.6)	2(8.7)	113(21.9)	24(4.1)
2022	7021(7.72)	5605(14.1)	351(16.9)	8(34.8)	46(8.9)	24(4.1)

4.2 Temporal distribution of rabies in the study population

Figure 2.0 illustrates the annual distribution of rabies cases in the study population. There was a general rising trend in the cases from 2018 with the year 2019 showing the highest peak at 617 cases (29.56%). The lowest number of cases was reported in 2020 but thereafter the numbers start to increase again in 2021 to 404 cases. There were 351 cases reported in the year 2022.

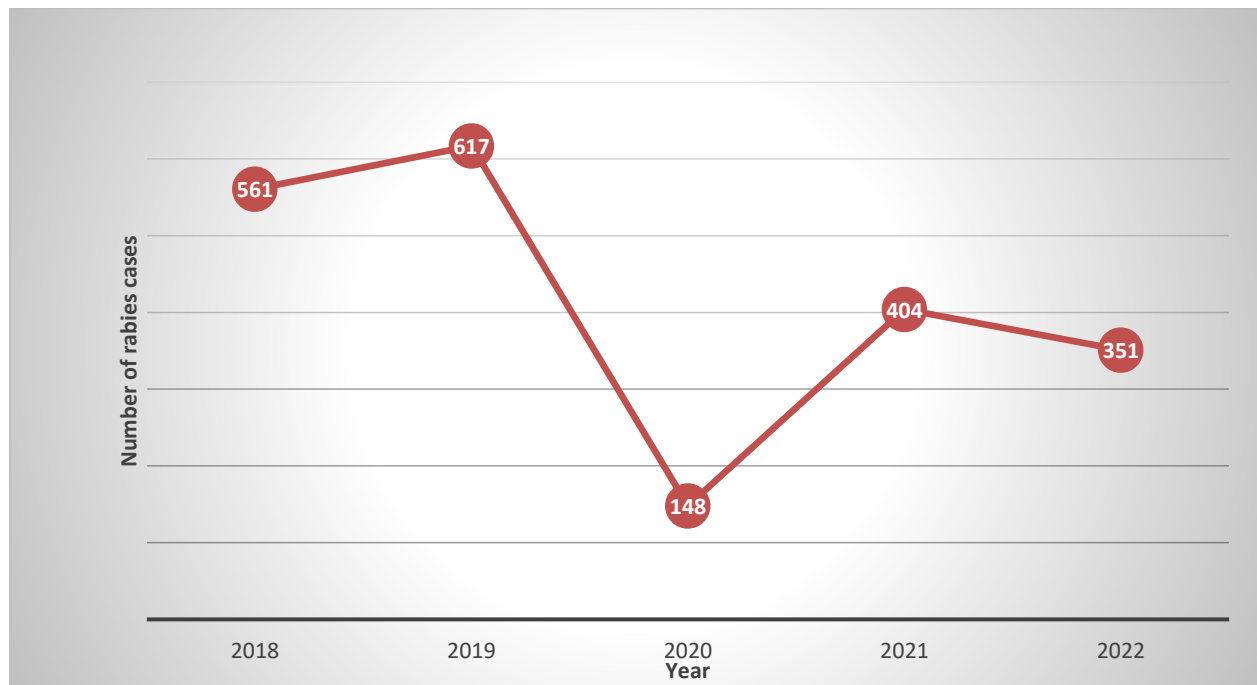


Figure 2.0 : Temporal distribution of rabies in the study population

4.3 Spatial distribution of rabies in the study population

The spatial-temporal analysis of the study showed that, Mukono, Tororo, Iganga, Kalangala, Busia, and Serere were high-risk districts for rabies; these districts had between 35 to 688 cases while Kiboga, Mityana, Sheema, Rubirizi, Moyo and Pader reported the least cases (1 to 5) (Figure 3.2) A total of 49 districts out of 146 districts reported rabies cases.

Spatial distribution of rabies cases in Uganda between 2018 and 2022

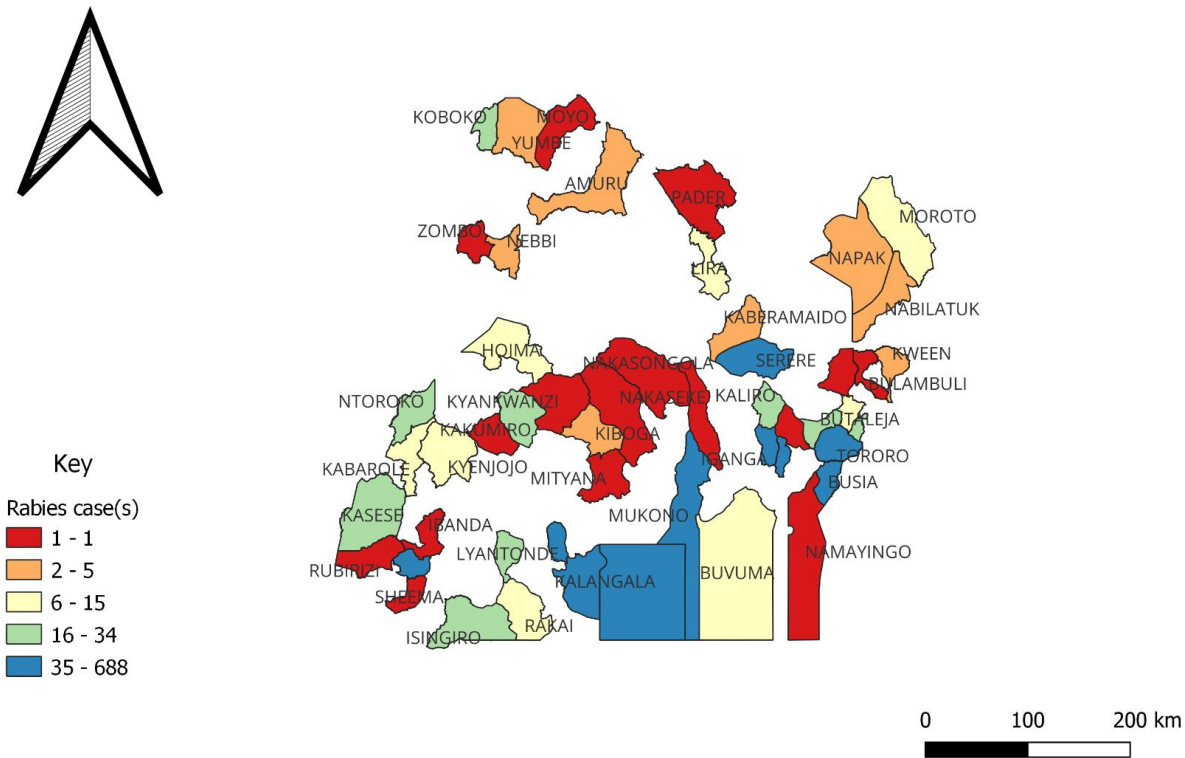


Figure 3. 0 Spatial distribution of rabies in the study population

4.4 The ARMA Model Analysis

The ARMA (13, 4) model projected 89 cases of rabies between October and December 2022. Additionally, its predictions for the year 2023 estimated a total of 248 rabies cases. The month of January 2023 was anticipated to experience the fewest cases (10), while April 2023 was expected to have the highest occurrence of rabies cases.

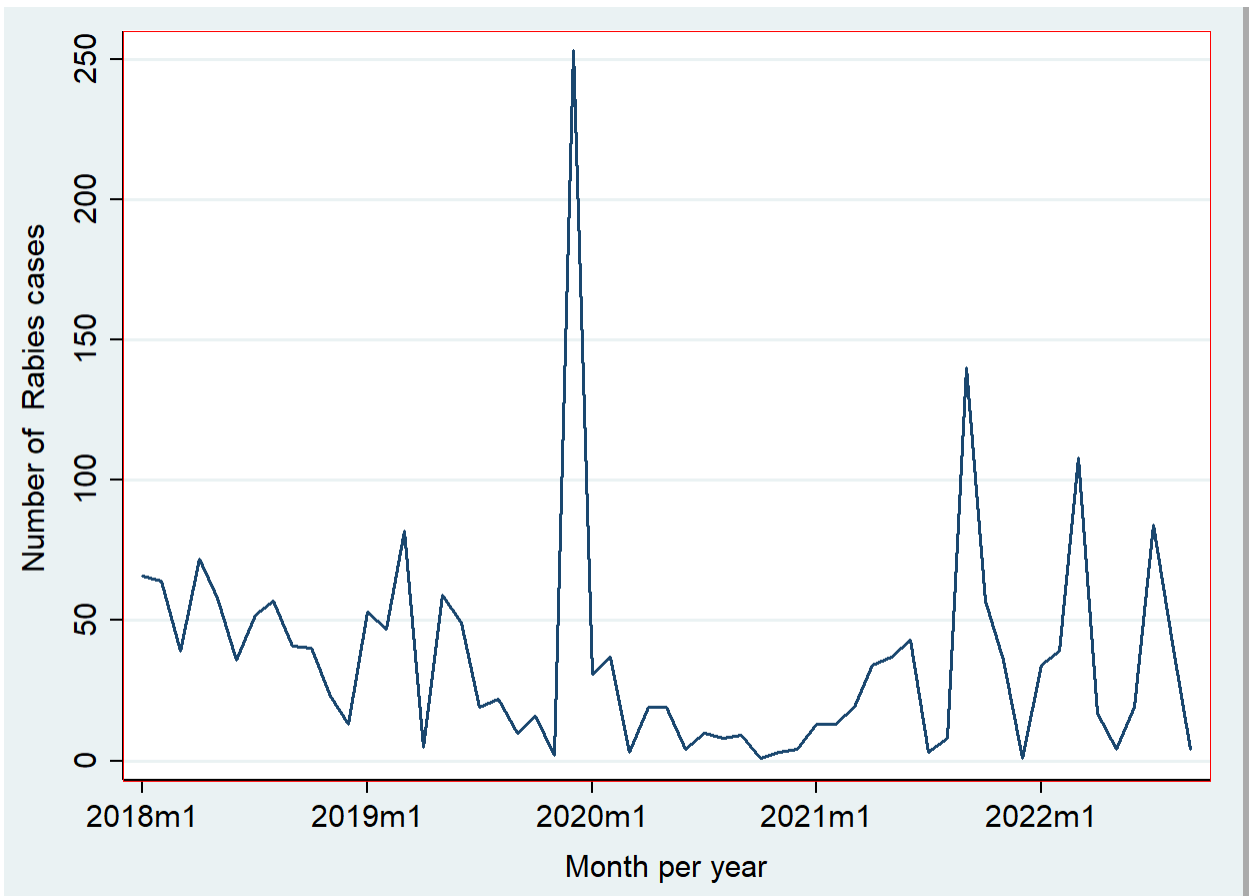


Figure 4.0: The monthly time series of rabies cases in Uganda from January 2018 to September 2022

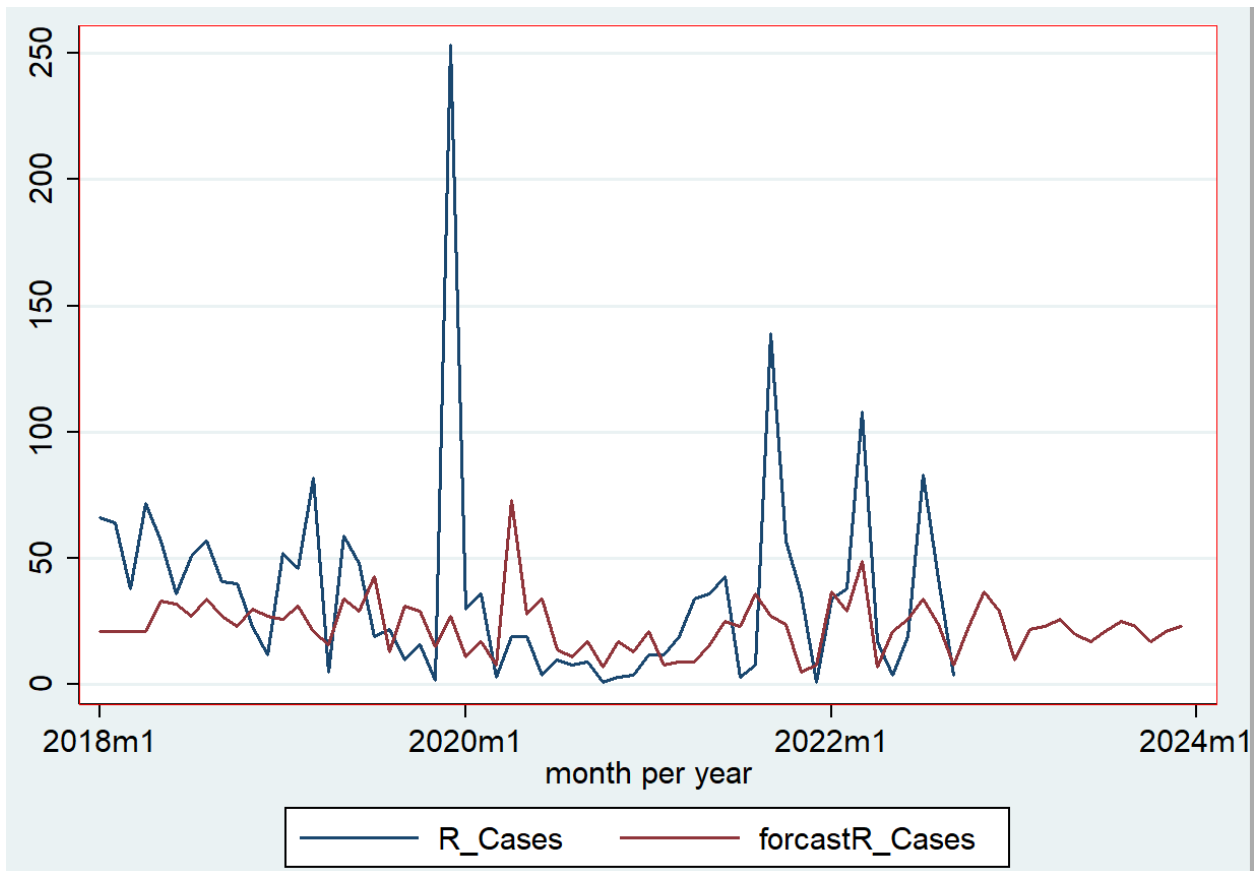


Figure 5.0: The univariate time series modeling with the forecasted monthly time series of rabies cases

CHAPTER FIVE: DISCUSSION

This study analyzed the spatial-temporal patterns of rabies outbreaks in Uganda from January 2018 to October 2022 using rabies outbreak data from NADDEC. A total of 2,081 cases were reported in this study and the general trend of the disease was increasing. According to earlier studies, Uganda had approximately 486 deaths due to rabies in humans between the years 2001 and 2015 although some authors have estimated the per capita annual death rate from rabies to be at 0.39/100,000 (Hampson et al., 2015). MoH reported that over 30,000 animal bites are reported to healthcare facilities annually and the rabies burden keeps on rising despite ongoing interventions like health education (MoH, 2016). A similar study on trends of animal bites associated with rabies by Masiira and colleagues showed increasing cases from the year 2001 to 2015 (Fig 1.0) (Masiira et al., 2018), this calls for increased efforts toward the prevention and management of the disease in Uganda. Inadequate knowledge of rabies and other socio-economic factors could be the reason for the increasing burden of the disease in endemic communities (Knobel et al., 2005).

The cases were mainly distributed among five animal species namely; dogs, cats, goats, and cows. However, due to aggregated data, the specific number of cases for each animal species could not be determined. For several decades now, research has shown that ninety-nine percent of rabies cases result from the bite of rabid dogs (Durrheim & Blumberg, 2017; Scott et al., 2015; Shim et al., 2009). It would therefore imply that except for cases where one rabid dog is transmitting the disease to several animals, for every single case, there is a rabid dog; therefore, making dogs the most affected species.

At NADDEC, the disease is diagnosed using FAT following the recommendation of WOA (WOAH, 2013), all samples are tested for the RABV antigen and results are promptly reported to the District Veterinary office which is responsible for the control of the disease in the districts (Omodo et al., 2020). However, just like in many developing countries, insufficient equipment, chemicals, trained staff, and cold chain logistics often hamper standard laboratory tests, therefore, often rabies diagnosis is through the observation of clinical signs by technical experts in the field (Banyard et al., 2013). This is evident in this study as only 8 cases were diagnosed

through standard laboratory tests. Unfortunately, this leads to the neglect of the disease as a result of fewer laboratory-confirmed cases and inadequate rabies surveillance consequently leading to underestimation of the disease in endemic countries especially in Africa and Asia (Cleaveland et al., 2014).

Research by Masiira and colleagues showed that deaths from suspected rabies in humans increased in the Eastern, Northern, and Central districts of Uganda between 2001 to 2015 (Masiira et al., 2018). Results from this study suggest similar trends in districts of Mukono, Tororo, Iganga, Kalangala, Busia, and Serere where the cases in domestic animals are significantly high. However, these results may imply that such districts have a high reporting rate or that it is indeed true that they had high numbers of cases when compared to other districts. Similarly, high cases could indicate that such areas have high populations of stray dogs. In addition, few cases were reported in some central, Southwestern, and Northern districts of Kiboga, Mityana, Sheema, Rubirizi, Moyo, and Pader; this could have resulted from prioritized disease control efforts specifically targeted vaccination of dogs and cats which in turn reduced the cases in those particular districts. There is an overall need for further studies on the patterns of the disease in Uganda.

The spatial heterogeneity of rabies is influenced by geographically varying risk factors such as host population densities primarily dogs (Kanankege et al., 2022). Similarly, socio-economic and cultural habits as well as food availabilities of the stray dogs also play a major role in the persistence of rabies (Hampson et al., 2009; Picard-Meyer et al., 2007; Hergert et al., 2016; Fooks et al., 2014; Morters et al., 2012). At a broader scale, the spatial patterns and the ecology of the disease is still poorly understood, urban areas were first thought to be hubs of rabies transmission but some studies show that rabies could only be eliminated temporarily in the cities through dog vaccination campaigns (Laager et al., 2019; Zinsstag et al., 2017). These case studies further suggest that urban areas are not hubs of rabies transmission but part of the complex spatial heterogeneity of dog ecology and movement, by exploring the dynamics of dog-mediated rabies circulation in urban, peri-urban, and rural areas, we could see an improved understanding of rabies ecology (Layan et al., 2021). Understanding the spatial distribution of rabies and its transmission is critical for forecasting its emergence and spread into new geographic regions and helps inform targeted interventions (Guo et al., 2013).

As Uganda moves towards rabies elimination by 2030 (NRCS, 2020), with guidance from the SARE which is a tool first developed by the FAO and the GARC in 2012 to provide a formal evaluation of rabies control (FAO et al., 2018), control efforts should be prioritized by focusing on high-risk areas as a way to achieve the Country's goal of a sustained rabies risk reduction with time (NRCS, 2020). As of 2019, Uganda was at Stage 2 as per the self-evaluation conducted during the second PARACON meeting held in Johannesburg, South Africa in September 2018 (MAAIF reports). In the second stage of the rabies progressive pathway, the government makes preparations for the implementation of the NRCS where inter-sectoral collaboration has been emphasized to build on routine government procedures to control the disease in pets while taking care of the challenges of lack of data, guidelines, resources, infrastructure and competent personnel (NRCS, 2020).

Results from the temporal analysis show a general increase in cases, however, a substantial reduction in the cases reported in 2020 could have been due to the Covid -19 pandemic where there was a total national lockdown and the priority activities undertaken then were those that particularly helped manage the pandemic. The cases began increasing steadily in 2021 when the lockdown came to an end. Similar scenarios were also noted in other countries where Public health ministries shifted their focus and resources to implementing stay-at-home orders and ramping up emergency preparedness efforts during the Covid -19 pandemic. Veterinarians considered rabies surveillance and dog vaccination a high-risk activity during the pandemic or a non-essential veterinary activity (e.g. non-urgent or non-emergency care) (DPCEMZ, 2020). In the case of rabies in Peru, and other Latin American countries, the yearly dog vaccinations, the cornerstone of rabies prevention, were postponed and downsized in 2020 (Quinchía AZ, 2020; RibeiroT, 2020). Some research studies have indicated that strong peaks of rabies are recorded in months characterized by hot and dry weather conditions (Gebru et al., 2019). Reports from Asian countries: Lao People's Democratic Republic, Vietnam, and Buhtan show that rabies cases are more during the dry seasons (Lee et al., 2018) This is thought to be associated with seasonal dog-breeding cycles. This biological phenomenon of dogs could increase the prevalence of rabies due to increased contact because of fights/bites among them leading to increased transmission of the virus (Malaga et al., 1979; Fevre et al., 2005; Fahrion et al., 2017; Mitmoonpitak et al., 1998)

An ARMA (13, 4) model was used to predict rabies outbreaks from October 2022 to December 2023 using rabies outbreak data from January 2018 to September 2023 from NADDEC. The model was opted for based on the log likelihood, Akaike Information criterion (AIC) and the Bayesian Information Criterion (BIC). The suitability of the model to predict rabies outbreaks was ensured by subjecting it to diagnostic tests. The portmanteau goodness-of-fit test indicated that the residuals exhibited characteristics of white noise. The stability of the ARMA conditions was assessed by examining the positions of all autoregressive (AR) and moving average (MA) roots, which were found to be within the unit circles. With these checks in place, we proceeded to utilize the aforementioned model for predicting rabies cases spanning from October 2022 to December 2023.

The results from this study may have been affected by the quality of data received from NADDEC; this data was collected purposely for surveillance and notification of rabies to the central authority (MAAIF) but not for research. Therefore, issues of non-reporting, aggregation of data, incomplete reporting, and missing data could have affected the results further. Although passive surveillance particularly in developing countries has been known to underestimate rabies burden (Hampson et al., 2015) the data can still be used to explore spatial distribution in such areas. Therefore, the results of this study may help guide resource allocations toward rabies control and hence reduce the prevalence of the disease in Uganda.

CHAPTER SIX: CONCLUSION

The spatial-temporal patterns of rabies in domestic animals shown in this study indicate a heterogeneous distribution of the disease in Uganda. Key actors, therefore need to pay close attention, especially to the hot spot districts, and make informed decisions as regards the control interventions of diseases. With rabies being a priority zoonotic disease in Uganda, collaboration among the key stakeholders of the NOHP will be key in eliminating the disease by 2030.

Recommendations

1. MAAIF as the lead ministry should liaise with other key actors through the NOHP to advocate for regular vaccination against the disease as a way of curbing rampant outbreaks.
2. MAAIF should advocate for the establishment of efficient laboratory systems at the regional and district level to appreciate the correct burden of the disease in the country.
3. MAAIF should increase public awareness of rabies management, risks, and modes of transmission throughout the country by constantly educating the communities.

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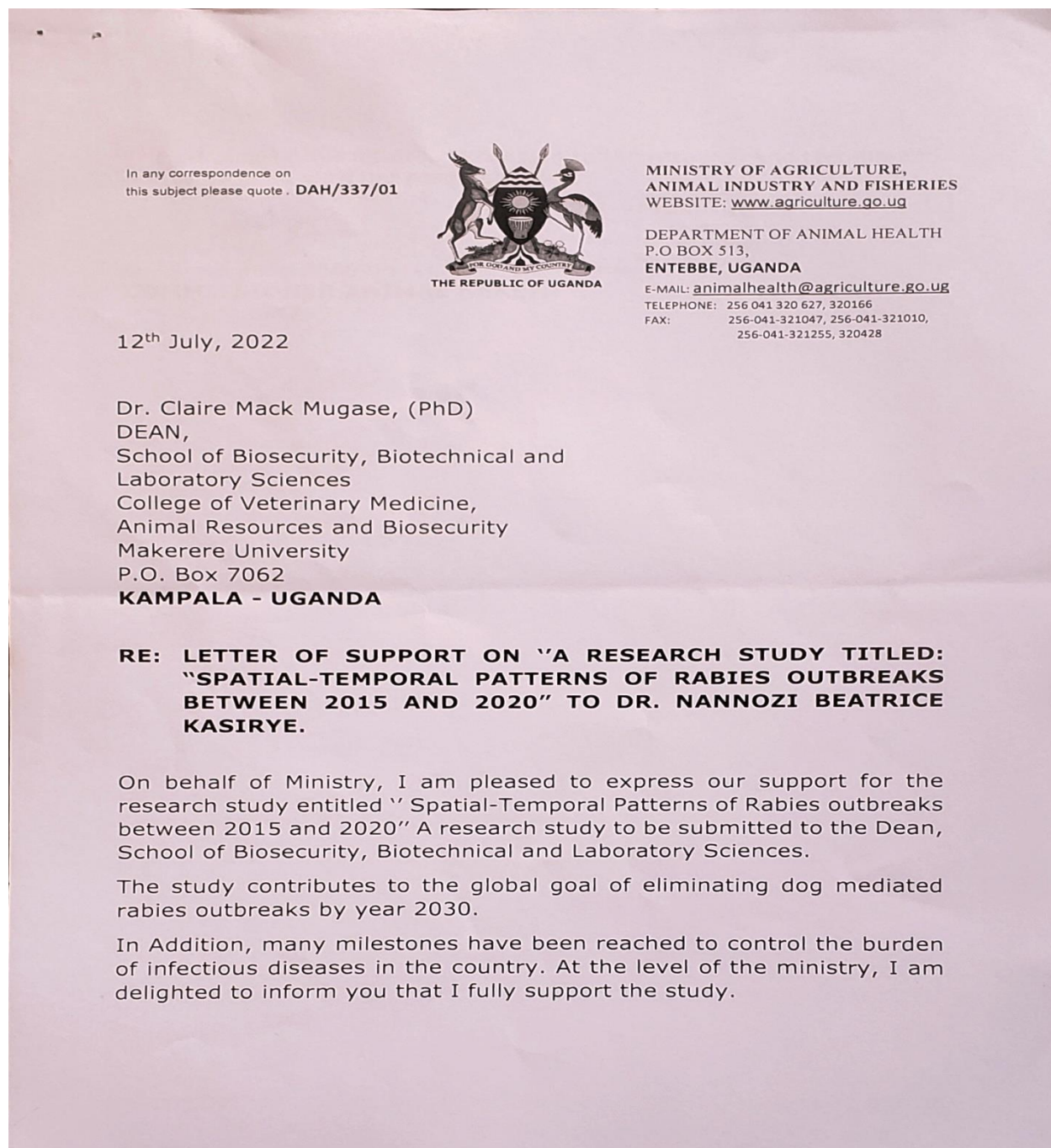
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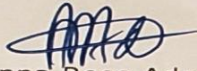
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APPENDICES

Appendix 1: LETTER OF CONSENT FROM COMMISSIONER ANIMAL HEALTH AUTHORIZING THE USE OF RABIES DATA FOR RESEARCH PURPOSES.



The purpose of this letter is to consent to the research and recommend her to proceed with her research work.



Dr. Anna Rose Ademun

COMMISSIONER ANIMAL HEALTH

COMMISSIONER ANIMAL HEALTH
MINISTRY OF AGRICULTURE,
ANIMAL INDUSTRY AND FISHERIES
P. O. BOX 513, Entebbe - Uganda

Appendix II: RABIES SAMPLE COLLECTION TOOL



THE REPUBLIC OF UGANDA

MINISTRY OF AGRICULTURE ANIMAL INDUSTRY AND FISHERIES

DISPATCH FORM

BRAIN TISSUE SPECIMEN FOR RABIES DIAGNOSIS

Name and title of originator/ sender:

Institute/Organization:.....

Locality: **District:**

Form number: **Date:**

Information	Remarks
Animal Species	
Date animal died or date animal was killed	
Main symptoms observed before death	
Place of origin of animal	
Name of owner (If any)	
Persons exposed (Yes or No)	
Other animals exposed (Yes or No)	
Date sample taken	
Place of sampling	
Date of dispatch	
Storage conditions (If dispatch delayed after sampling)	

Other relevant information	
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Appendix III: DISEASE INVESTIGATION/SURVEILLANCE QUESTIONNAIRE



THE REPUBLIC OF UGANDA
 MINISTRY OF AGRICULTURE, ANIMAL INDUSTRY AND FISHERIES
DIAGNOSTIC AND EPIDEMIOLOGY UNIT
DISEASE OUTBREAK INVESTIGATION /SURVEILLANCE QUESTIONNAIRE

Identification number	
Report Date	
Reporting Officer/Team	
Purpose of investigation/ surveillance	
Date of first occurrence	
Name of the location/ place	
LC/ Village	
Parish	
Sub-county	
District	
GPS: Latitude	
GPS: Longitude	
Farmer's details/ Name/farm	
Suspected disease	

Details of outbreak/ History	
History of feeding	
Watering information	
Treatment/ Vaccination history	
Production System	
Visit date/ Investigation	
Animal species affected /susceptible	
Number of animals susceptible/at risk	
Number of animals affected	
Number of animals slaughtered	
Number of animals dead	
Number of animals recovered	
Numbers of samples	
Sample type	
Transport media for the sample	
Lab test	
Lab results	

Comments	
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