Dynamics of Rabies Spread Using Mathematical Modeling and Simulation

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Abstract: *This study investigates the dynamics of rabies transmission in Camarines Norte using a compartmental SEIR model. The model has been developed by collecting data about population size and disease parameters and was simulated in NetLogo for the prediction of the spread of disease. Simulation results point toward the fast, yet steady, spread of rabies outbreaks and how intervention strategies such as vaccination and culling should be employed on time. Culling, being effective in controlling the early stages of the infection, often leads to an outbreak at a later stage. In other words, over-culling leads to resurgence. So a balanced approach is needed: vaccination with culling and raising public awareness. The present study supports the need to control populations of newborn puppies, increase vaccination coverage among dogs as well as among humans, and post-exposure prophylaxis for rabies elimination.*

Keywords: *SEIR model, simulation, vaccination, culling, rabies transmission, NetLogo*

I. INTRODUCTION

Rabies is an acute viral infectious disease of humans and other vertebrates belonging to the group of mammals, the etiology of which is the rabies virus of the Rhabdoviridae family and the Lyssavirus genus. It is acquired from the saliva of infected animals, mostly through a bite or an attack [8]. Globally, rabies is estimated to kill 59,000 humans every year, with 99% of the victims having been bitten by dogs[13].

The first time that dog rabies was noted in the Philippines was in 1910, when a human case had been documented and Negri bodies seen in the cerebral tissue of the biting dog. A case analysis of human rabies reports in the Philippines from 1987 to 2006 reveals that a higher prevalence of rabies is associated with contact with animals with rabies, specifically dogs. According to the review, there is a strong call for continued awareness and control measures in preventing rabies transmission in the country[4].

In this regard, innovative technologies, such as the Machine Algorithm-based Journey Assistant (MAJA), have demonstrated potential in improving various aspects of community service delivery, as noted by [10]. While their study focused on enhancing tourism experiences and promoting engagement with local government sectors, their findings underscore the broader applicability of intelligent systems in addressing community-specific challenges. Adapting such technologies to public health initiatives, particularly in rabies prevention, could provide a smart platform for raising awareness, enhancing access to information, and improving coordination between stakeholders. By leveraging intelligent systems to track cases, disseminate preventive measures, and educate at-risk populations, it becomes possible to align technological innovation with public health goals, ultimately reducing rabies transmission and fatalities nationwide.

To offer post-exposure prophylaxis (PEP) to bite patients, the Philippine government has set up fifteen Animal Bite Treatment Centers (ABTCs) in different regions throughout the island country. Yet the frequency of bite patient presentations has escalated, exponentially and rabidities in domestic dogs is still on the rise. Weak surveillance worsens the problem, resulting in low caseload identification and slower response to outbreaks[15].

The contact patterns in this model were therefore influenced by the environment or density and interaction rates of the dogs[11]. Rabies prevalence and incidence studies across the geographical context shows that rabies may differ due to regional characteristics, thus may require customized vaccination and intervention programmes across specific groups of the population[14].

In the study titled “Sensitivity Analysis and Numerical Simulations for the Mathematical Model of Rabies in Human and Animal within and around Addis Ababa”, the researchers found that factors such as the annual dog birth rate and the natural death rate of dogs are critical in influencing rabies transmission dynamics[5].

Rabies attacks rise by 100 percent in three provinces of Bicol region from January 1 to March 9 this year as per DOH-Bicol Region report on March 21, 2014 as sourced by Manila Bulletin. This rise underlines the major health risks associated with rabies in rural provinces including Camarines Norte[18]. Previous and post-intervention assessment of a study conducted in Bicol proved that raising awareness before and after project implementation improves rates of mass rabies vaccinations and other preventive measures[1].

Available information indicates that the best approach to controlling human rabies is through mass vaccination of animals especially dogs[2]. Analyses from another model indicated that a vaccination approach may cut down rabies occurrences, especially among stray dogs[16].

Several studies have pointed out that due to rabies altering the behaviour of affected dogs, the disease has a longer survival rate in dogs. Another study used a network-based model in an attempt to explain how behavior modification in infected dogs contributes to the transmission of rabies; the study posited that over 70% vaccination rate may be required to stem the disease[3]. Programs of vaccination and public health measures have been proved to reduce the incidence of rabies in domestic and wild animals, which translates directly to human health [9].

Simulation model on the other hand refers to the use of mathematical models to mimic the functioning of a process or a system at different time intervals. Various mass dog vaccination strategies are most conveniently analyzed with simulation models to estimate the public cost-effectiveness, and the information gained from the simulation outcomes can be useful for the animal health authorities to make the decisions on rabies control in the areas like Flores Island [17].

Various studies have adopted mathematical models to analyze rabies dynamics and the impact of control strategies. The study titled “Mathematical Models for Rabies focused on the rabies virus and its associated host–pathogen population dynamics, using this remarkable model system to develop mathematical models of infectious disease emergence and spread. Their work signifies a progression from simple susceptible-infectious-removed (SIR) compartment models of fox rabies emergence and spread across Western Europe to more complex models incorporating dynamics across heterogeneous landscapes, host demographic variation, and environmental stochasticity [12].

In the present mathematical modeling of rabies, vaccination and culling have been incorporated in order to study the efficacy of the general preventive measures to control the disease [6]. Optimal control studies have established that effective vaccination with knowledge of rabies transmission dynamics can contribute to significant reduction of rabies incidence and towards the vision of no human rabies fatalities from dog bites by 2030 [7].

In this preliminary paper, we propose SEIR model simulation using the NetLogo software for the spread of rabies in Camarines Norte in hopes to expound the ongoing rabies situation. We simulate the model with the observed number of infected human cases in Camarines Norte in the year of 2023. We then analyze the influence of initial conditions and parameter values on the number of infected humans.

II. MATERIALS AND METHOD

This research aimed at finding out the pattern of transmission of rabies from dog to human in Camarines Norte through modeling with SEIR model. The SEIR framework divides both human and dog populations into four distinct compartments:

(i) **Susceptible (S)**: People who are more at risk of getting this disease.

(ii) **Exposed (E)**: People who have been exposed to the rabies virus but have not developed clinical signs of rabies, and are not yet contagious.

(iii) **Infected (I)**: People of any age and both genders who have been identified as passing on the virus to other people.

(iv) **Removed (R)**: People who are out of the transmission loop whether by reason of having been infected and developed immunity or died.

A. DATA COLLECTION

The data were collected from the Provincial Outpatient Department of the Animal Bite Center and the Provincial Veterinarian Office. The data set contained the most important epidemiological characteristics necessary for the modeling of rabies transmission. Also, the initial population size was obtained from the Cities and Municipalities Competitiveness Index (CMCI) [19], while other disease-related parameters were collected from the literature and officials.

B. Model Development

The simulation of the SEIR model was done using the NetLogo software in which the environment of the disease spread is modeled using agents. An initial model based on a third-party SEIR framework was employed and observed parameters from different sources incorporated to accurately model rabies transmission.

TABLE 1. PARAMETERS

Parameter	Value/Unit
Initial Population	609, 226 individuals [19]
Ticks per Day	5 ticks/month
Transmission Chance	5%
Average Incubation Period	1.0 months
Incubation Standard Deviation	0.33 months
Average Infectious Period	5.0 months
Infectious Standard Deviation	1.03 months

Table 1 presents the parameters utilized by the researcher. The simulation parameters included an initial population size of 609226 people, that is calculated using the data from the CMCI[19]. The levels of temporal aggregation were defined at 5 ticks per month. The transmission probability defined as the chance for one susceptible person to be infected after coming across an infected person was taken as 5%. The time that subjects spent in the "Exposed" compartment was assumed to have a negative binomial distribution with a mean of 1.0 month and standard deviation of 0.33 months. Likewise, the infectious period, the period within which an individual is capable of transmitting rabies, was estimated to be a mean of 5.0 months and standard deviation of 1.03 months. Incubation period was modeled by exponential or gamma distribution in order to take into account inter-individual differences.

C. SIMULATION

This simulation was carried out in the NetLogo programming language which is in the NetLogo environment. Elements of the model under consideration included size of populations and transmission probability, as well as time-related factors. The number of ticks per day defined the temporal resolution of the simulation, and the probability of transmission defined the disease spread under certain circumstances.

This way, the study was able to mimic the pathway of rabies transmission over the SEIR compartments at a given time and understand the different effects that certain parameters had on the disease. They mapped out this modeling and simulation process as a model for using the results to gain insights into the potential scenarios of rabies transmission and to strategise management of the disease.

III. Results And Discussions

The compartmental SEIR model is a mathematical model of description of the spread of infectious diseases. Finally, the analysis shows that the SEIR model is an effective approach to modeling and controlling dog rabies. It helps one understand ways in which the disease can spread, ways in which vaccination campaigns can be conducted and how one can effectively control the disease. This model previously applied to estimate the patterns of rabies transmission in dog populations and the impact of infection, recovery, and vaccination

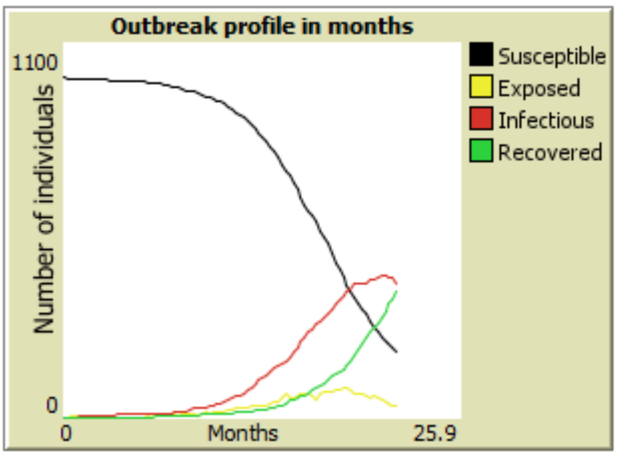

Figure 1. Simulation Graph

Figure 1. Illustrate the outbreak profile over approximately 25.9 months and highlights critical findings about rabies spread. The number of the susceptibles (black line) decreases over the years and many persons get infected thus reducing the number of persons that can get infected. This shows how easy it is for rabies to spread when no methods of preventing the spread are put in place. On the other hand, the exposed population (yellow line) increases gradually then increases sharply then gradually falls down due to incubation period that delays the infection profile of the disease. The infected population (red line) continues to rise gradually in the middle of the simulation, and then gradually decreases as the people enter the recovery phase. This peak corresponds to the period of the most uncontrolled dissemination of the rabies virus which is at the utmost level at this stage. Last, the recovered population (green line) rises steadily and even more sharply once the infectious population is on the decline, representing people who are no longer infectious. This pattern indicates that the outbreak flattens after a while but a good percentage of the population is infected by the virus.

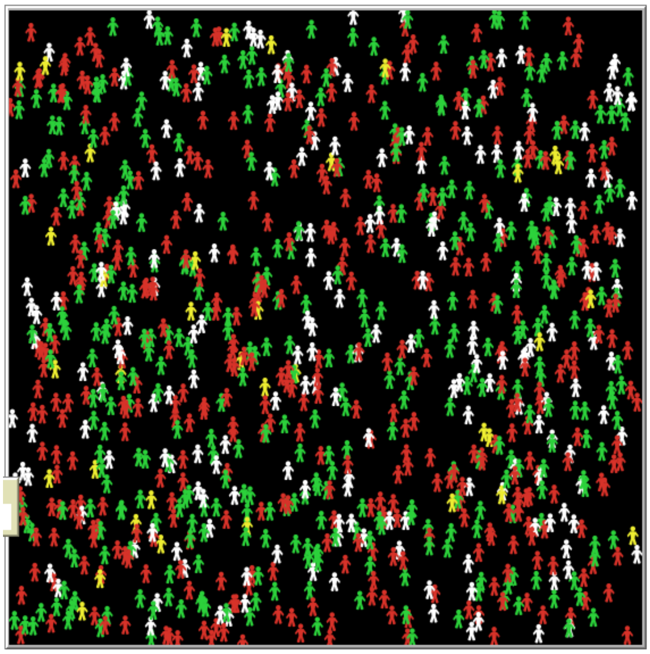

Figure 2. Population State Simulation of Rabies Spread

Figure 2. Graphically displays how the rabies spreads within a population, and with icons that are susceptible (white), exposed (yellow), infectious (red) and recovered (green). A large chunk of the population is red, which means there are many infective cases, few green people are few recovered ones, and the yellow dots depict few exposed persons. The white (susceptible) people are scantily distributed but are comparatively less in number which means that the number of susceptible persons is reducing as the disease is transmitted. In this simulation, the enemy changes quickly from being susceptible to infection, infectious, and recovery. The implications show that after its emergence rabies poses a serious threat of infecting a significant part of the population, which indicates the need for prophylactic measures to reduce vulnerability and prevent the virus from spreading rapidly.

In general, the results presented provide the evidence for the high potentiality and the length of the rabies virus infection in the population. The results show the need to develop early intervention measures including immunization, community sensitization, and surveillance to avoid spreading of the disease when the susceptible population is high and before the infectious phase reaches its peak. The SEIR model successfully demonstrates its applicability to model rabies transmission dynamics and complements the study’s goal of examining rabies transmission to facilitate decision-making.

IV. CONCLUSION

The present work analyzes rabies transmission dynamics in Camarines Norte through mathematical modeling and simulation employing the SEIR model. This simulation reflects on key phases of disease transmission susceptibility exposure, infection, and removal from the cycle The results demonstrate the rapid and expansive nature of rabies, with the absence of intervention leading to devastating outcomes. It further explore out the strong requirement of time efficient interventions aimed at controlling the progression of disease due to the shrinking size of the susceptible population and expanding the size of the infected population.

Key factors influencing rabies transmission are the incubation period and the infectious period. Infected individuals continue spreading the virus even after the onset of illness. Therefore rabies is a long-term highly contagious disease requiring early intervention and continuous surveillance to prevent a general outbreak.The simulation also focuses on the significance of vaccination campaigns in reducing the susceptible population, especially if done early and on a large scale. The SEIR model has been shown to be a good model for simulating and evaluating the effectiveness of different control strategies.

The model gives insights into the relative effectiveness of vaccination, public awareness campaigns, and proactive surveillance systems. Through analysis in different scenarios, the study has shown how prompt responses and resource allocation can cause a significant shift in the course of the disease and reduce transmission and its impact. The study also establishes the importance of coordination between the local government units, the public health organizations, and the community in effectively controlling the transmission of rabies.

Public education and the establishment of animal bite treatment centers form the core component of rabies prevention with easy access to post-exposure prophylaxis within a shorter time frame for new cases of infection. These results are in support of the WHO's goal for the elimination of human mortality due to rabies by 2030 which is applicable in a rural setting such as Camarines Norte wherein the disease burden is very significant. This research provides insights towards achieving this global objective. The implications extend beyond Camarines Norte, providing a framework for other regions facing similar challenges. The study portrays the effectiveness of mathematical models in simulating rabies transmission and evaluating impact of control strategies.

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