Effect of COVID-19, Vaccination Ratio, and Human Population on the Reported Canine Rabies Cases in Davao City, Philippines: A Panel Regression Analysis

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ABSTRACT

Objective. Given that rabies remains endemic in the Philippines despite government interventions and the pandemic-related restrictions have hampered its surveillance, this study aimed to estimate the effect of human population, anti-rabies vaccination efforts, and COVID-19 situation on the spread of rabies cases in the districts of Davao City, Philippines.

Methods. A retrospective study of the canine records at Davao City Veterinarians' Office was done from January 2018 to June 2021. Monthly rabies cases were ascertained, and the effect of the human population, COVID-19 season, and vaccination ratio on rabies cases was estimated using panel regression models adjusting for confounding factors.

Results. The reporting of rabies cases was lower during COVID-19 than during the non-COVID-19 season, with an IRR of 0.52 [95% confidence interval (CI): 0.33–0.82]. Furthermore, rabies cases increased by 2.23% (95% CI: 0.60–3.89) per 1% increase in vaccination ratio. Additionally, high-population districts recorded more rabies cases than low-population districts.

Conclusion. Consistency in monitoring rabies cases during the pandemic is suggested as a roadmap for future program initiatives. Vaccination efforts should be reinforced to increase rabies awareness and ensure early response to emerging diseases. Moreover, high-populated districts should be prioritized in implementing rabies control interventions to gain optimal development.

Keywords: rabies, COVID-19, vaccination, panel regression analysis, human population

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INTRODUCTION

Rabies virus (RABV) is a neurotropic virus belonging to the Rhabdoviridae family's Lyssavirus genus. RABV is transmissible to all domestic and wild mammals and almost always fatal,[1] with rabies-related human mortality of approximately 59,000 deaths per year globally. In addition, 56% and 44% of these deaths are happening in Asia and Africa, respectively, especially in rural communities with substantial stray dog populations.[2] Domestic dogs are responsible for up to 99% of RABV transmission to humans. The virus is transmitted to humans and animals by bites or scratches, most commonly via saliva.[3] Moreover, human rabies deaths can be prevented via two complementary interventions: (1) post-exposure prophylaxis (PEP) administered to individuals bitten by suspected rabid animals to prevent disease onset, and (2) sustained mass dog vaccinations (MDV) to eliminate transmission within the primary source (reservoir) of infection.[4]

Animal rabies surveillance is a vital public health role and a cost-effective method of directly influencing human rabies PEP recommendations.[5] Government interventions like mass dog vaccination have been implemented to reduce the number of rabies cases. This intervention is essential to the global strategy for rabies elimination, aiming for a 70% coverage rate.[6] However, during the COVID-19 pandemic, several countries endemic to dog rabies reduced their resources for rabies control (e.g., staff or resource reallocation to COVID-19 activities), with dog vaccination as the first intervention being affected.[7]

The COVID-19 pandemic also posed several challenges and interruptions in rabies vaccination and control campaigns in rabies-affected areas. In Latin America, the rabies surveillance system is one of the rabies control programs impacted by COVID-19.[8,9] In the Philippines, rabies is endemic, ranking among the top ten countries for human rabies deaths between 200 and 300 yearly.[10,11] Majority of these rabies victims are children and adolescents.[12] While, the National Rabies Prevention and Control Program (NRPCP), in collaboration with the Department of Agriculture (DA) and Department of Education (DepEd), recommended that information, education, and communication (IEC) sessions be undertaken to help achieve a zero dog-mediated human rabies by 2030[13,14], the implementation of this in-person intervention was challenging due to stringent COVID-19 restrictions.

In addition, epidemiological data on canine rabies cases in the Philippines faces several challenges. Highly precise surveillance requires a deep awareness of the difficulties unique to the target location.[15] In Davao City, Philippines, the local government spearheaded interventions to control rabies cases with an impounding program strongly correlated with a decline in reported rabies cases. However, there are concerns about the long-term sustainability of dog impounding, as it can be resource-intensive and lead to dog population instability.[16] Despite being the most cost-effective measure, dog vaccination was the most interrupted rabies control activity, especially during COVID-19.[17]

On the other hand, it is noteworthy to mention that the human population is another indicator used by local health offices in studying rabies virus circulation.[14] It is mainly because human population density can be used as a proxy measure for dog activities since it is expected to have an increased dog density and increased human-dog contact in dense populations. Moreover, 99% of human rabies cases are caused by dogs,[3] suggesting the importance of considering the human population when studying canine rabies. Additionally, as DOH[14] prioritizes the distribution of anti-rabies vaccines to areas with the highest numbers of human and dog rabies incidence, they also give special attention to areas with high human-animal populations.

While there are a handful of rabies-related studies done in Davao City, including analyzing the trends of canine rabies and the impact of the intensified rabies control program, risk factor analysis for dog bite victims, cointegration analysis of rabies cases and weather components, cost optimization of the intensified rabies control programs, and understanding rabies transmission dynamics and control using modified SEIV (susceptible-exposed-infectious-vaccinated) model,[18-22] these papers primarily analyze data from before the COVID-19 pandemic. To provide valuable insights into how the local government office of Davao City, Philippines, can assess their rabies monitoring and surveillance during a pandemic, this study aimed to evaluate the effect of COVID-19, dog vaccination ratio, and human population on the reported canine rabies cases. Specifically, to present how the reporting of rabies cases between the COVID-19 period and pre-pandemic differ, how increasing the vaccination efforts affects the reporting of rabies cases, and how the rabies cases differ between high-populated and low-populated areas.

MATERIALS AND METHODS

Study Area and Research Design

A panel data research design was employed to evaluate the effects of COVID-19, vaccination ratio, and human population to the reported positive canine rabies cases in the study area. Monthly data per district from January 2018 to June 2021 were used in the analysis. The study area, Davao City, is one of the significant and most prominent cities in the Philippines. Davao City has over 1.78 million inhabitants across its 11 administrative districts, namely: Agdao, Baguio, Buhangin, Bunawan, Calinan, Marilog, Paquibato, Poblacion, Talomo, Toril, and Tugbok.[23] In this paper, the Agdao and Poblacion districts were treated as one due to the combined data collection process conducted in both areas. The geographical map of Davao City showing district boundaries along its human population count is illustrated in Figure 1.

Outcome Assessment, Exposure Assessment, and Confounding Factors

Rabies cases, the outcome of interest in this study, is the number of positive canine rabies cases recorded in each district per month. It is assumed that rabies cases are affected by exposure variables and confounding factors as shown in Figure 2 (see Appendix A for variable description). The identification of confounding factors between the outcome of interest and the exposure variables was necessary to minimize bias in the analysis.

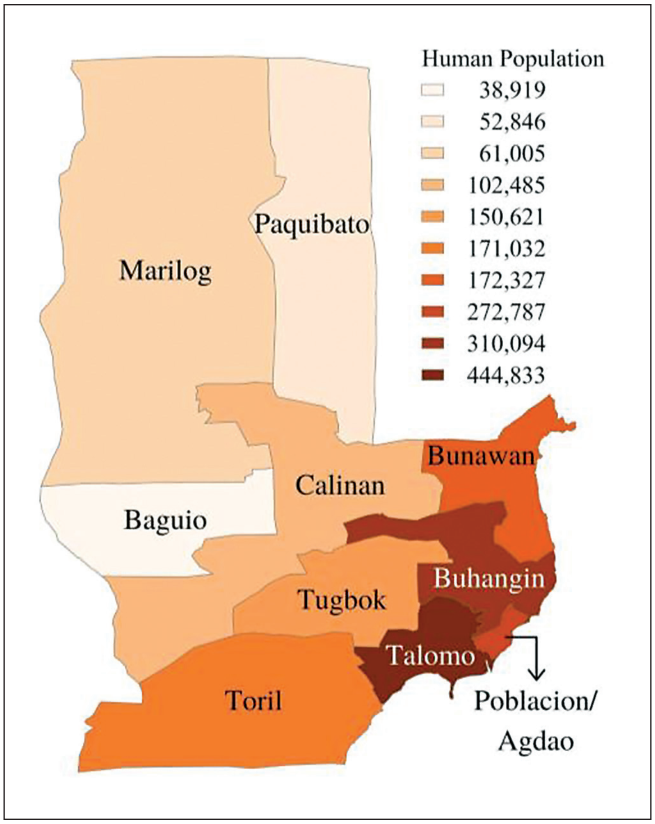

Figure 1. Geographical map of Davao City indicating the human population per district.

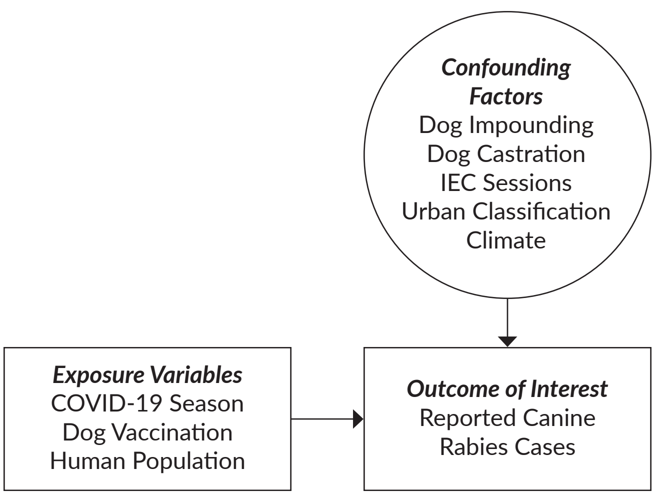

Figure 2. Conceptual framework of the study.

The primary exposure variables include COVID-19 season, dog vaccination, and human population. For exposure assessment, COVID-19 season was categorized as pre-COVID-19 and COVID-19 periods. Dog vaccination was expressed as the monthly vaccination ratio or the ratio of vaccinated dogs to the estimated total dog population per district. The total dog population was estimated using the dog-to-human ratio of 1:10.[24] The vaccination ratio was used instead of the actual number of vaccinated dogs to account the differences in dog populations per district. Human population was expressed as a binary variable having a value of 1 if the district has a total population greater than the median (160,826.5), and 0, otherwise.

The confounding factors were identified *a priori* as important predictors of rabies cases. These are government-initiated interventions such as dog impounding, dog castration, and IEC sessions. Additionally, the urban classification of the district and climate conditions were considered. The dog impounding was expressed as the monthly impounding ratio or the ratio of the number of impounded dogs to the dog population per district. The dog castration was expressed as the ratio of the number of castrated dogs to the dog population per district. The IEC sessions were expressed as the ratio of the number of IEC participants to the human population per district. The urban classification is a binary variable having a value of 1 if the district is categorized as a rural district, and 0 if it is an urban district. The climate condition is another binary variable representing the wet (value = 1) or dry (value = 0) season.

Monthly data per district on dog rabies-related variables and factors were collected from the Davao City Veterinarian's Office (CVO). Data for human population per district was obtained from the 2020 Census of the Philippine Statistics Authority (PSA).

Panel Regression Analysis

In a panel data research design, five regression models should be considered in order to identify the most suitable model specification for the analysis. This study estimated the following panel regression models: pooled ordinary least squares (OLS) model, fixed effects Poisson (FE-P) model, fixed effects negative binomial (FE-NB) model, random effects Poisson (RE-P) model, and random effects negative binomial (RE-NB) model. The regression analysis framework for panel data was used for model selection and parameter estimation (see Appendix B for the process flow).

The model selection started with testing whether the OLS model is appropriate for the analysis using the Breusch and Pagan Lagrangian multiplier test. If this test is insignificant, then the OLS model specification is the suitable model, otherwise, fixed effects or random effects model should be explored.[25] For the latter case, the Durbin-Wu-Hausman test was employed to determine whether the fixed effects model or the random effects model is appropriate for the analysis.[26] Both models consider two distributions, the Poisson and negative binomial distributions. To determine which distribution is appropriate for the analysis, the Akaike Information Criterion (AIC) and Bayesian Inform Criterion (BIC) were estimated. The lower AIC and BIC values, the better the model.[27]

The best or the most suitable model specification was then used to determine the effects of the COVID-19

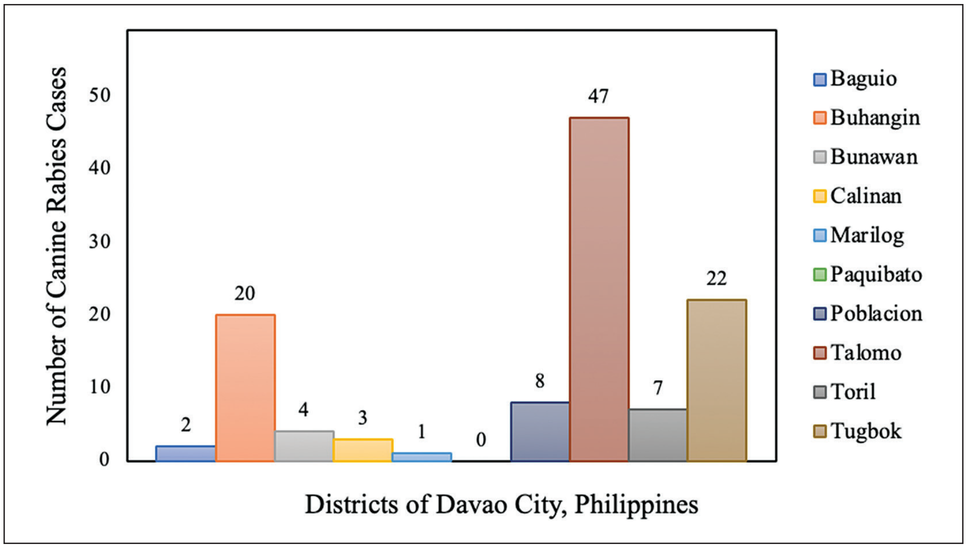

Figure 3. Total number of reported canine rabies cases in the districts of Davao City from January 2018 to June 2021.

season, vaccination ratio, and human population to the reported canine rabies cases in Davao City. The estimated effects of these exposure variables along with the covariate (or confounding) variables were reported and interpreted in terms of the adjusted incidence ratio rate (IRR). The 95% confidence interval was presented and 5% level of significance was used in the analysis. The STATA version 17, a statistical software, was used to perform panel regression analyses.

RESULTS

From January 2018 to June 2021, Davao City recorded 114 reported canine rabies cases (Figure 3). The highest number of rabies cases was in Talomo, with 47 cases, followed by Tugbok, with 22 cases, and Buhangin, with 20 cases. Poblacion recorded eight, Toril had seven cases, while Bunawan, Calinan, Baguio, Marilog, and Paquibato recorded 4, 3, 2, 1, and 0 cases, respectively.

Table 1 displays the descriptive statistics summary of the variables used in the study, with 420 observations in the ten districts for 42 months. Talomo recorded the highest number of rabies cases, with 7 cases and an average of 1.12 cases per month. Regarding vaccination ratio, Toril and Tugbok recorded the highest, 78.7 and 73.5, respectively. In addition, their average monthly vaccinations were similar to Calinan and Bunawan at more than 7 and 6, respectively. Moreover, monthly records of castration were minimal. Its highest is 2.9 in Poblacion and 0.11 on average. On the IEC participants' records, Paquibato had the highest record of 2.12; on average, Baguio had the highest at 0.31 monthly. For the impounding ratio, since its per-district data was calculated as a ratio of the computed number of impounded dogs to the total number of dogs per district, the per-district average was similar across districts. Furthermore, for the binary variables considered, 45% of the time considered is in the wet season, there are an equal number of urban and rural areas, 60% of the districts are highly populated areas, and 38% of the time is during the COVID-19 period.

The Breusch and Pagan Lagrangian Multiplier test was insignificant which implies that the pooled OLS model is not the appropriate model specification. Additionally, Durbin-Wu-Hausman test revealed that the data contain random characteristics across the panel. Thus, random effects model specification was selected for the analysis. Furthermore, both RE-P and RE-NB were estimated and presented since both have lower values in BIC and AIC, respectively.

Table 2 summarizes the effect estimates of COVID-19 occurrence, vaccination ratio, and human population on the rabies incidence rate ratio using the RE-P and RE-NB models. During the COVID-19 period, the IRR of rabies cases would be expected to decrease by a factor of 0.52 (95% CI: 0.33–0.82; p-value = 0.005) based on the RE-P model. Similarly, using the RE-NB model, the IRR of rabies cases would be expected to decrease by a factor of 0.58 (95% CI: 0.36–0.95; p-value = 0.031). For vaccination efforts, the IRR of rabies cases may increase by approximately 2% per 1% increase in vaccination ratio for RE-P and RE-NB models. Furthermore, the IRR of rabies cases in high-populated districts may increase 13 and 16 times more than those not highly populated districts using the RE-P and the RE-NB models, respectively.

DISCUSSION

Our paper explored the effect of COVID-19, the anti-rabies vaccination efforts, and how the human population plays a role in the spread of rabies cases. These associations were investigated using monthly and per-district counts of

Table 1. Descriptive Statistics of the Rabies Cases, Exposure Variables, and Covariates Stratified by District

Variable	District	Mean	Min	Max
Rabies Cases	Baguio	0.0476	0	1
	Buhangin	0.4762	0	3
	Bunawan	0.0952	0	2
	Calinan	0.0714	0	1
	Marilog	0.0238	0	1
	Paquibato	0.0000	0	0
	Poblacion	0.1905	0	1
	Talomo	1.1190	0	7
	Toril	0.1667	0	2
	Tugbok	0.5238	0	3
Vaccination Ratio	Baguio	4.6825	0	20.3243
	Buhangin	5.7851	0	41.5971
	Bunawan	6.0268	0	24.7021
	Calinan	7.8483	0.3025	32.8243
	Marilog	3.6527	0.0545	12.8140
	Paquibato	2.8939	0	18.5255
	Poblacion	3.6390	0	11.2029
	Talomo	5.9657	0	31.0026
	Toril	7.9093	0	78.7455
	Tugbok	6.3265	0	73.5090
Castration Ratio	Baguio	0.0569	0	0.8222
	Buhangin	0.0482	0	0.2225
	Bunawan	0.0378	0	0.4360
	Calinan	0.0530	0	0.5659
	Marilog	0.0143	0	0.3408
	Paquibato	0.0324	0	0.6055
	Poblacion	0.1071	0	2.9327
	Talomo	0.0239	0	0.3192
	Toril	0.0354	0	0.4444
	Tugbok	0.0642	0	0.6506
IEC Participants Ratio	Baguio	0.3089	0	0.9841
	Buhangin	0.1388	0	1.4122
	Bunawan	0.0957	0	0.4952
	Calinan	0.1164	0	0.9738
	Marilog	0.1951	0	0.8261
	Paquibato	0.1937	0	2.1250
	Poblacion	0.1081	0	0.4304
	Talomo	0.0451	0	0.3093
	Toril	0.1259	0	1.1641
	Tugbok	0.0683	0	0.3665
Impounding Ratio	Baguio	0.2514	0.1542	0.4625
	Buhangin	0.2505	0.1451	0.4644
	Bunawan	0.2500	0.1433	0.4609
	Calinan	0.2502	0.1464	0.4684
	Marilog	0.2499	0.1500	0.4635
	Paquibato	0.2514	0.1514	0.4541
	Poblacion	0.2506	0.1466	0.4619
	Talomo	0.2506	0.1461	0.4631
	Toril	0.2510	0.1462	0.4619
	Tugbok	0.2502	0.1461	0.4647
Climate Season		0.4524	0	1
Urban Classification		0.5000	0	1
Human Population Size		0.6000	0	1
COVID-19 Season		0.3810	0	1

Note: The mean of all the binary variables measures how many ones are present in the specific variable.

Table 2. Adjusted Incidence Rate Ratio (IRR) with 95% Confidence Interval (95% CI) Estimates for the Association between COVID-19 Season, Vaccination Ratio, and Human Population Ratio and the Reported Positive Canine Rabies Cases Using Random Effects Panel Regression Models (Poisson and Negative Binomial)*

RE Panel Regression Models	AIC / BIC**	Exposure Variables	Adjusted IRR	95% CI		*p*-value
Poisson	475.37	COVID-19 Season:				
	515.77	Pre	1.00			
		During	0.52	0.33	*0.82*	0.005
		Vaccination Ratio	1.02	1.01	*1.04*	0.007
		Human Population Size:				
		Low Populated	1.00			
		High Populated	13.28	2.27	*77.71*	0.004
Negative Binomial	**474.44**	COVID-19 Season:				
	518.88	Pre	1.00			
		During	0.58	0.36	*0.95*	0.031
		Vaccination Ratio	1.02	1.01	*1.04*	0.018
		Human Population Size:				
		Low Populated	1.00			
		High Populated	16.51	2.91	*93.8*	0.002

**All models were adjusted for climate season (wet, dry), urban classification (rural, urban), information, education, and communication (IEC) participants ratio, impounding ratio, and castration ratio.*

***AIC - Akaike Information Criterion, BIC - Bayesian Information Criterion*

rabies cases to consider potential differences from our previous study.[18] In our earlier study, we assessed the impact of rabies control strategies in Davao City by analyzing the monthly pattern of rabies incidence and comparing it before and after implementing the Intensified Rabies Control Program (IRCP) using count regression models.[18]

In our current study, we employed monthly data on rabies cases at the district level. We identified that COVID-19 season (the difference between before and during the pandemic), vaccination ratio (the proportion of vaccinated dogs to the total dog population in each district), and human population (the number of individuals in each district) as significant drivers affecting the rate of rabies cases in Davao City. Compared with our previous study, these three variables are more important drivers affecting the rate of rabies cases in the city than previously identified factors, including castration ratio, impounding ratio, and climate season.

For the effect of COVID-19 season on the reported canine rabies cases in Davao City, the estimate of rabies cases was lesser during the COVID-19 pandemic than the pre-pandemic. We hypothesize that our finding may have resulted from decreased reporting or constrained surveillance/programs due to the pandemic's restrictions. The study of Nadal et al.[7] involving endemic countries also claims that rabies control activities will only resume their regular operations once substantial COVID-19 vaccine coverage and funding for rabies control programs is already prioritized.

Moreover, other zoonotic illnesses and food security concerns have caused contradictory immunization plans/priorities worldwide. COVID-19, or any pandemic, will continue to challenge public health organizations in the short and medium term.[8] Underreporting caused by a variety of factors can be made worse by insufficient surveillance.[28] Thus, any rabies elimination campaign must be supported by rabies surveillance to keep the disease on the agenda of policymakers, veterinary and public health officials, and the general public. COVID-19 could disrupt the government's decades-long rabies control operation in some localities. The drastic decrease in submitted samples for rabies testing since the start of COVID-19 control operations has hindered canine rabies control.[8] This study corroborated our findings of having fewer reported rabies cases during the pandemic since COVID-19 has affected rabies monitoring and surveillance in Davao City. In addition, it is crucial for the CVO to explore other public health alternatives in rabies monitoring and surveillance during the pandemic and to consider intensifying interventions post-pandemic to avoid the further spread of rabies caused by unmonitored incidences.

The effect of the vaccination ratio on the number of canine rabies cases in our study showed that rabies cases may increase approximately by 2% as the vaccination rate increases by 1%. Vaccination efforts make the general public more informed about rabies and further encourage reporting rabies incidence locally. In addition, the DOH[14] has stated that the vaccination rate is a reliable indicator of the potential for rabies virus suppression. Those areas where the infection has the potential to have severe consequences upon entering will require more immediate attention than those where consequences could be less severe.[14] These consequences include rapid transmission, a higher probability of infecting more dogs and humans, and mortality caused by limited access to PEP.

Regarding the impact of the human population, rabies cases may increase in high-populated districts compared to low-populated districts. This finding suggests that the number of canine rabies cases increases when the human population increases. It is worth noting that dogs are owned in urban and rural areas for various socioeconomic reasons, including home or herd security, hunting, and companionship.[29] Additional reasons include improvement of one's mental health and well-being, to be more physically active, and to share common interests with others to improve social life.[30] An increase in population will result in an overall dog population increase and not maintaining herd immunity.[20] Accordingly, considering canine demographics as a determinant in rabies spread can also inform the development, implementation, and administration of rabies control initiatives.[31]

The dog population is often estimated as one dog for every ten humans (1:10) in the Philippines due to lack of official data on dog population and for development considerations.[24] Since dense populations are expected to have high dog density and increase human-dog contact, using the actual number of dogs in any research analysis is recommended. However, the NRPCP advice to use the 1:10 ratio has remained unchanged due to a lack of dog population data. Since there are still gaps in the number of dogs data[32], additional research is warranted to assess the dog population, especially in regions with high rabies prevalence.

Moreover, this study is the first in the Philippines to evaluate the effect of critical indicators on rabies cases, mainly COVID-19, vaccination ratio, and human population. Our study used a regression analysis algorithm framework utilizing the five established panel regression models for model selection and parameter estimation, which may give robust estimates and reduce the bias in our study. The algorithm framework (Appendix B) can be extended to other diseases such as dengue, leptospirosis, etc. The study's use of panel data, combining inter-district differences and intra-district dynamics, is advantageous given that government interventions are conducted per district. Data accuracy is guaranteed as it is gained directly from the researchers' partnership with Davao CVO. PSA data was used for population statistics as it is more up-to-date and contains the high-quality data required for research.

Moreover, the panel data study design and the algorithm framework can be replicated in different cities in the Philippines to study the association of exposure variables (i.e., their rabies control interventions and other a priori exposures) and canine rabies cases (or other relevant health indicators such as rabies-related human deaths or biting incidents). Finally, the results of this study could give valuable insights as to how the local government units can improve their rabies surveillance in times of pandemic. It will also allow them to strategically set their goals regarding the extent of implementing these interventions by considering the human population size per area.

There are limitations present in our research. First, the outcome assessment for the reported cases relies solely on reporting cases. It may be lower than the actual cases per district, noting that stray dogs are often not reported because of their ownerless state. Therefore, outcome misclassification bias could exist in our study. It usually arises when a subject is classified into the wrong outcome subgroup or category because of some observational reporting or measuring mistake. When this outcome misclassification occurs, the actual correlation between exposure and outcome may be skewed and could result in a wider confidence interval in the effect estimates.

Our study had unmeasured confounding factor variables, including no district-level data on impounding and no surveillance of stray dogs that could affect the exposure-outcome relationship. Hence, we cannot rule out residual confounding bias in our study. Furthermore, we acknowledge that dogs are not the only source of rabies cases. However, in Davao City, there were no available monthly or district-specific data on feline rabies cases. Even if such data existed, the frequency would likely be significantly lower than canine rabies cases, which account for 99% of instances.[3] Including feline rabies cases might skew the results due to the overwhelming frequency of canine cases. Thus, future research could incorporate additional sources of rabies cases. Lastly, our findings may not be generalizable to cities in the Philippines or other countries. The effect of COVID-19 season, vaccination ratio, and human population on rabies cases in these other cities should be tackled in future studies.

CONCLUSION

The COVID-19 period, vaccination ratio, and the human population affect the canine rabies cases in Davao City. Disrupted rabies surveillance may occur during COVID-19 due to logistic limitations brought by the pandemic lockdown. In addition, government efforts may provide a broader scope of informing people about rabies and encourage participation in reporting dog rabies related incidences. High human populations suggest an increase in dog density and may indicate an increase in the risk of canine rabies exposure.

Consistency in monitoring canine rabies cases is warranted as a roadmap for future program initiatives and support agencies in evaluating research investment. Furthermore, as essential to the worldwide strategy for dog-mediated human rabies eradication, government measures should be reinforced by being proactive in implementing interventions to ensure an early response to emerging diseases. Empowering the system of selecting where to prioritize rabies control interventions to gain optimal development in each district is also warranted. Thus, effective management of endemic zoonoses such as canine rabies saves lives and fortifies essential capacities for responding to future health crises.

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Statement of Authorship

All authors certified fulfillment of ICMJE authorship criteria.

Author Disclosure

All authors declared no conflicts of interest.

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