https://doi.org/10.22319/rmcp.v16i4.6806

Article

Temporal trends and geographic distribution of diseases in cattle, pigs, sheep, and horses in the province of Napo (2019–2024)

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Abstract:

This study aimed to analyze the temporal and geographic distribution of diseases affecting important livestock species in the province of Napo, Ecuador, during the period 2019–2024, based on passive surveillance records provided by Agrocalidad. A total of 154 official reports of pathologies involving cattle, pigs, sheep, and horses were collected and analyzed. Descriptive statistics were applied, along with simple linear regression models to project trends until 2026, and spatial analysis using DBSCAN clustering to identify relevant geographic foci. The results show a sustained increase in the incidence of rabies and brucellosis, with a marked concentration of cases in the cantons of Tena and Quijos, respectively. The spatial analysis allowed to identify non-random clusters; meanwhile, the projections indicated that, if control measures were not strengthened, both pathologies would continue to increase in the coming years. In contrast, diseases such as circovirus type II and vesicular stomatitis showed a decreasing trend. These findings suggest that current health control strategies have not been sufficient to contain the spread of certain zoonotic diseases, particularly in areas of high interaction between domestic animals and wildlife. It is recommended to prioritize actions in critical cantons, strengthen epidemiological surveillance, expand vaccination coverage, and establish stricter controls on livestock mobility. The study demonstrates the usefulness of spatial-temporal analysis as a support tool for decision-making in animal health, providing concrete evidence for the design of targeted interventions and regional public policies.

Keywords: Animal health, Passive surveillance, Rabies, Brucellosis, Vesicular stomatitis.

Received: 05/02/2025

Accepted: 06/08/2025

Introduction

Diseases affecting farm animals pose a significant challenge to animal health and the sustainability of the livestock sector and significantly impact economic aspects, including production, prevention, and trade. Understanding these impacts is vital to developing policies that ensure safe and efficient livestock production[(1)]. In the province of Napo, the presence of various animal species, including cattle, pigs, and horses, in mixed and backyard production systems, poses a complex epidemiological scenario that requires active surveillance and continuous health control. The notification of outbreaks of bovine rabies in recent years (with more than 25 confirmed cases between 2019 and 2023), the persistence of brucellosis in herds with low vaccination coverage (<40 % in some cantons), and the circulation of circovirus type II in pigs (with rebounds recorded especially in 2020 and 2021) represent clear antecedents of diseases with a productive impact and, in some cases, zoonotic potential. Additionally, there are reports of an increase in the movement of cattle between cantons, especially from marketing areas like Pichincha and Santo Domingo to Napo, which raises the risk of spreading infectious diseases. Previous studies in the Amazon region of Ecuador have reported incidences of rabies in cattle associated with contact with hematophagous bats (*Desmodus rotundus*), which reinforces the need for strengthened epidemiological surveillance to prevent the spread of these diseases and mitigate their health and economic consequences[(2)].

Early detection and monitoring of pathologies allows for improved health management strategies and reduces the risk of spreading diseases of economic and zoonotic importance[(3)]. In the province of Napo, animal health actions are part of the national campaigns led by Agrocalidad, which include vaccination against brucellosis and rabies, passive surveillance, and control of animal movement. However, limitations such as underreporting, low coverage in rural areas, and poor integration of technology persist. These factors increase the risk of the emergence and spread of diseases, especially those transmitted by vectors or with wild reservoirs. Climate change modifies the distribution of insect and mammal vectors, while anthropogenic activities, such as deforestation, agricultural expansion, and the uncontrolled movement of animals to urbanized areas, favor the breakdown of ecological barriers and the spread of infectious agents. This represents a challenge for surveillance campaigns, which must adapt to dynamic and complex scenarios[(4)].

In this context, passive surveillance, based on the collection of clinical reports and veterinary diagnoses in the field, is a fundamental tool for monitoring the distribution and frequency of diseases in the region[(5)]. This type of surveillance allows to identify areas of greater risk and more affected species, facilitating decision-making regarding prevention and control[(6)]. Nonetheless, its effectiveness may be limited by underreporting, uneven coverage, and the lack of integration of geospatial technologies. The incorporation of georeferenced databases and tools such as geographic information systems (GIS) can enhance epidemiological analysis and health response, as has been demonstrated in experiences in other Latin American countries.

This study aimed to analyze the geographical and temporal distribution of health pathologies in cattle, pigs, horses, and sheep in the province of Napo during the period 2019–2024 to identify the highest incidence rate of cases of diseases that affect livestock species in each canton, evaluate their evolution over time, and highlight the possible factors influencing the presence of cases. With this information, it is intended to generate scientific evidence that contributes to designing more efficient control and prevention strategies, optimizing resources allocated to animal health, and strengthening epidemiological surveillance policies in the region.

Material and methods

Study area

The research was conducted using data provided by the Phytosanitary and Zoosanitary Regulation and Control Agency of Ecuador (Agrocalidad) from passive surveillance results in livestock farms in the province of Napo, located in north-central Ecuador, a region characterized by diverse geography rich in biodiversity. This area belongs to the Ecuadorian Amazon and covers an area of approximately 12,500 km^2. Its terrain is varied, combining the presence of tropical forests, mountains, and the influence of the Andes Mountains, which give rise to a transitional ecosystem between the Andean piedmont and the Amazon rainforest.

The province of Napo has a tropical rainy climate (type Af of Köppen), with an average annual temperature of 21.7 °C, and a month-to-month variation of less than 2 °C. Rainfall is abundant, with precipitation reaching between 800 and 3,800 mm per year. The average relative humidity remains high (~92 %). Between 2019 and 2024, the months with the highest rainfall were June (≈415 mm) and March (≈361 mm); nevertheless, February, May, and other months also exceed 250 mm. These climatic conditions favor the persistence of pathogens and vectors; therefore, they are a determining factor in the epidemiological analysis of diseases in production species.

To estimate the magnitude of the health problem, the cumulative incidence rate by species and canton was calculated using the following formula: $Incidence_{ij} = (C_{ij} / N_{ij}) \times 100$

Where: $Incidence_{ij}$: Incidence rate (%) in canton j for species i. C_{ij}: Number of registered cases of the disease in species i and canton j. N_{ij}: Estimated animal population at risk for species i in canton j.

Data source

This study is based on data collected through passive surveillance (n=154) carried out by Agrocalidad, the Phytosanitary and Zoosanitary Regulation and Control Agency of Ecuador. The data correspond to official records of diseases diagnosed in various animal species within the cantons of the province of Napo (canton: secondary administrative division in Ecuador, equivalent to a municipality or county in other countries) in the period 2019–2024 (El Chaco n= 15, Quijos n= 35, Archidona n= 25, Tena= 60, and Arosemena Tola= 19). Each record includes information on the date of diagnosis, the canton and parish of origin (parish: territorial subdivision within a canton, similar to a district or locality), the species affected, the age of the animal, the type of diagnosis made, and the pathology identified.

A descriptive and exploratory observational analysis was carried out, which focused on characterizing the spatial and temporal distribution of the diseases reported in the province of Napo. To this end, the cases reported by canton and parish were analyzed in order to identify areas of high incidence; the evolution of the pathologies over time was evaluated through the frequency of cases per year and month; finally, the distribution of diseases according to the affected species was examined, identifying the main pathologies present in cattle, pigs, and horses. For the geographical component, a provincial map was created using R with the *sf* and *leaflet* packages, representing the location of the cases reported by parish through georeferenced points. Each point was color-coded according to the pathology recorded. This representation allowed to identify the spatial distribution and relative concentration of diseases in the province of Napo during the period 2019–2024.

Statistical analysis

A linear regression model was applied using the ordinary least squares (OLS) method to project the evolution of cases in the years 2025 and 2026. The selection of this model is due to its simplicity and effectiveness in identifying general trends in time series[7]. Linear regression allows to detect constant increases or decreases in the incidence of diseases over time. In addition, it is a suitable tool when working with annual data and looking to make short-term projections. This method also makes it easier to interpret the results and communicate the findings to non-specialist audiences.

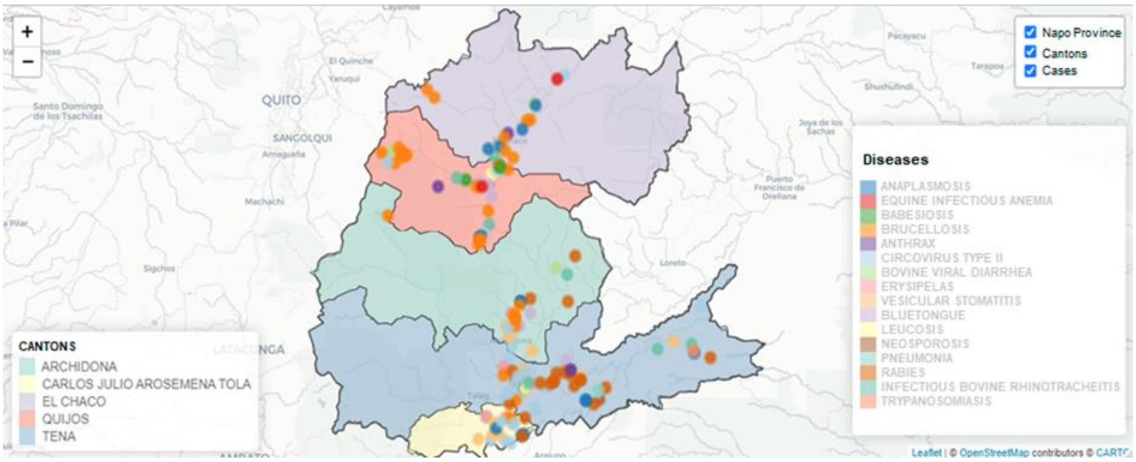
Limitations of the study

It should be noted that the data obtained may be subject to underreporting, especially in rural areas where diagnostic capacity, campaign coverage, or reporting mechanisms are limited. For example, studies conducted in the Amazon regions of Brazil and Peru have estimated that, for every confirmed case of bovine rabies, there could be between 5 and 10 unreported cases due to lack of active surveillance[8]. In the case of brucellosis, research in extensive production areas in Ecuador has reported that underreporting can exceed 60 %, which is associated with informal management practices and the absence of systematic serological diagnosis[9]. This situation represents a significant limitation in the interpretation of the results, especially in cantons with low livestock activity or limited institutional presence.

Results

The analysis of geographical distribution showed an unequal concentration of health diseases in the different cantons of the province of Napo (Figure 1). In total, reports were registered in 5 cantons and 19 parishes during the period 2019–2024. The Tena and Quijos cantons had the largest number of notifications. In Tena, rabies was the most frequent pathology, with a presence in five parishes; on the other hand, in Quijos, a high incidence of brucellosis was observed, which was distributed in six parishes.

Figure 1: Geographical distribution of animal diseases reported in the province of Napo, Ecuador



The incidence by species and canton (Table 1) shows notable differences in disease distribution. In general, the cantons of Tena and Quijos registered the highest percentages of affected animals, particularly in bovine and pig species. Incidences greater than 10 % were observed in some combinations of canton and species, suggesting areas with greater health risk. These variations could be related to productive factors and access to veterinary services.

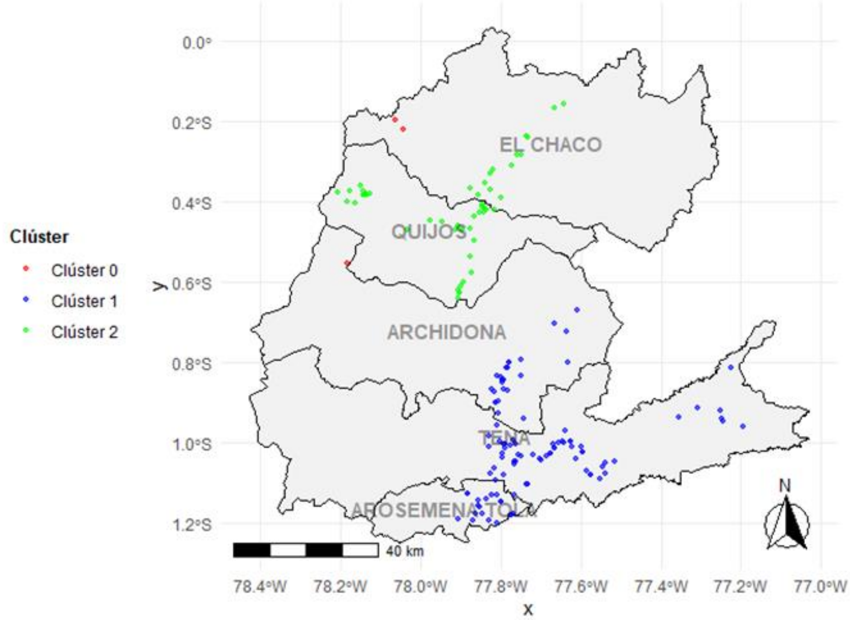
Table 1: Percentage distribution of the incidence of reported diseases in domestic animals in the province of Napo, classified by canton and species

Canton	Cattle	Horses	Sheep	Pigs
Archidona	0.25	0	0	0.06
C.J Arosemena Tola	0.41	0	0	0.3
El Chaco	0.06	0.01	0.01	0.01
Quijos	0.2	0.01	0.01	0.03
Tena	0.52	0	0	0.34

Diseases with a more dispersed distribution, such as circovirus type II and vesicular stomatitis, were reported in multiple cantons without a defined concentration pattern. Previous studies have indicated that viral diseases transmitted indirectly or through fomites tend to spread in areas with high animal flow and deficient biosecurity measures[10]. In the case of vesicular stomatitis, its presence in cantons with mixed livestock activities could indicate sporadic outbreaks associated with mechanical vectors and favorable environmental conditions, as has been documented in areas with hot and humid climates[11]. The province of Napo, due to its location bordering the province of Pichincha, is located in a place of transit of productive species that are acquired at large-scale marketing fairs in provinces like Santo Domingo and Pichincha, whose final destination is neighboring provinces such as Orellana, Sucumbíos, and Pastaza. Notification of cases of circovirus type II and vesicular stomatitis showed a dispersion in multiple cantons, but without a defined concentration pattern. On the other hand, pathologies such as anaplasmosis showed a more uniform distribution, with cases registered in different parts of the province, indicating their possible endemic nature in the region.

To analyze the territorial grouping pattern, the DBSCAN algorithm was applied with georeferenced coordinates of the cases reported between 2019 and 2024. This analysis allowed to identify three well-defined spatial clusters in the province of Napo (Figure 2). Three spatial groups were identified: cluster 0 (red) includes scattered cases in the northern zone (El Chaco), possibly associated with low notification density or underreporting; cluster 1 (blue) is concentrated in the cantons of Tena and Carlos Julio Arosemena Tola, reflecting a higher density of reports, probably due to greater accessibility to health services; and cluster 2 (green) is mainly located in Quijos, with an intermediate distribution. These results allow to identify epidemiological priority areas for the strengthening of veterinary surveillance.

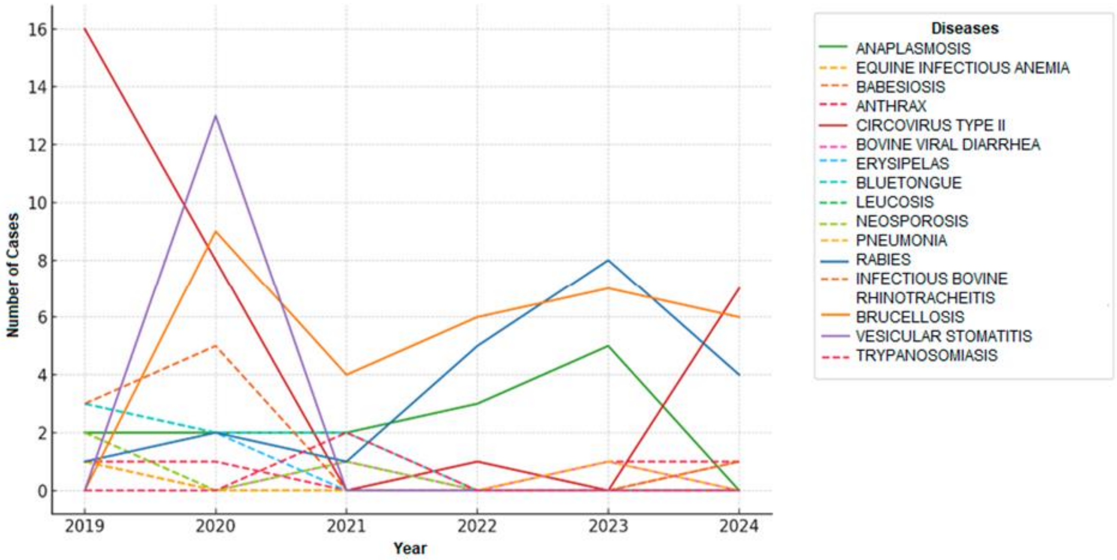
Figure 2: Cluster analysis of pathologies reported in the province of Napo (2019–2024)



Other diseases, such as circovirus type II and vesicular stomatitis, are distributed in several cantons, suggesting possible environmental factors or livestock mobility factors in their spread. The concentration of certain pathologies in specific areas highlights the need to strengthen surveillance and health control strategies in the most affected cantons, emphasizing vaccination, epidemiological monitoring, and movement restrictions to prevent outbreaks.

The annual trend analysis of the pathologies reported in the province of Napo between 2019 and 2024 (Figure 3) showed a heterogeneous epidemiological behavior among the different diseases. From 2019 to 2020, a low frequency of notifications was observed, possibly associated with the decrease in surveillance activities during the COVID-19 pandemic. From 2021 onward, there was a progressive increase in reports, reaching the highest number of cases recorded in 2023. In the years with the highest number of rabies cases (2020 and 2023), the province of Napo also recorded some of the highest levels of precipitation, with monthly averages exceeding 400 mm in March and June, respectively. These conditions of high rainfall could favor the activity of hematophagous bats (*Desmodus rotundus*), the primary vector identified in outbreaks of bovine rabies in the region, as has been reported in previous studies in the Ecuadorian Amazon[2].

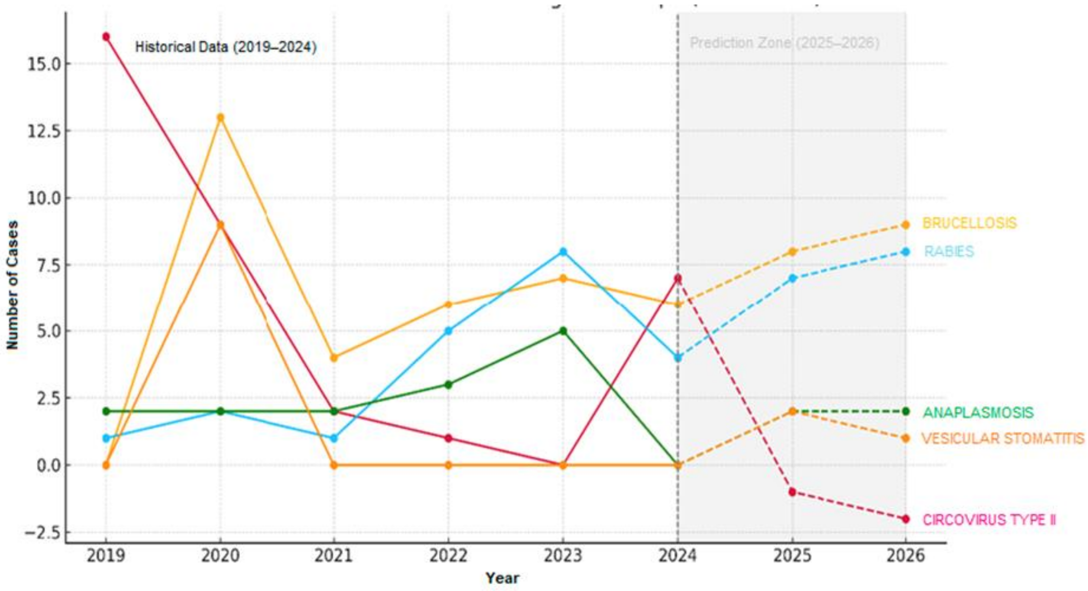
Figure 3: Pathology trends in the province of Napo (2019–2024)



The annual trend for the presence of cases, according to the type of disease, managed to identify different patterns. Rabies showed an increasing trend with peaks in 2020 and 2023, which could reflect a seasonality linked to sporadic outbreaks in specific risk areas. In contrast, brucellosis exhibited a more irregular trend, with rebounds in 2020 and 2023, without a clear seasonal pattern, suggesting a possible underreporting or influence of productive factors. Other pathologies, such as circovirus type II and vesicular stomatitis, showed a progressive reduction in reports since 2020, which could indicate better control or fluctuations in exposure. On the other hand, diseases such as anaplasmosis, neosporosis, and bluetongue remained with low and relatively stable frequencies throughout the period, which could reflect low endemicity or limitations in diagnosis.

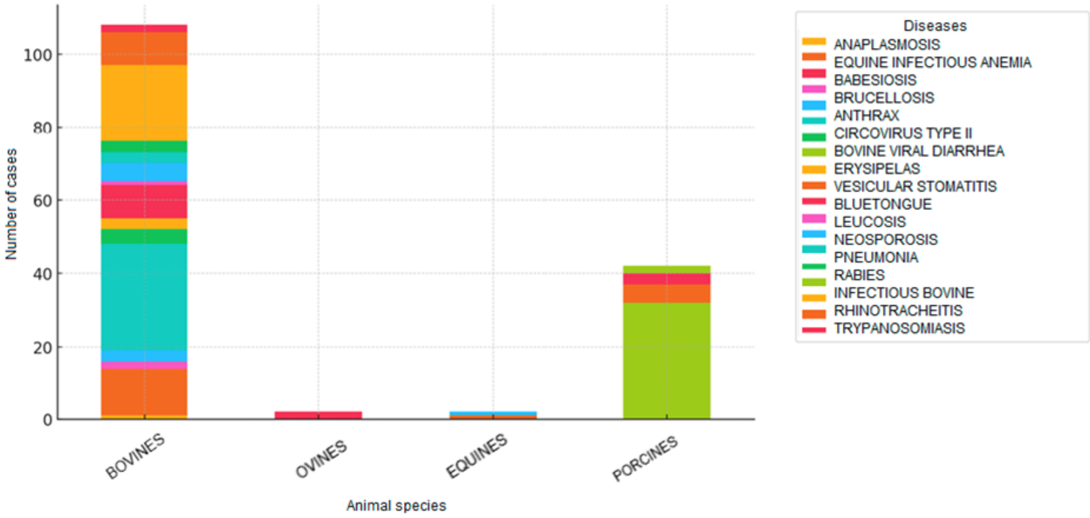
By applying linear regression models, a projection (Figure 4) of the behavior of the most prevalent pathologies in the coming years (2025-2026) was made. The results indicated that rabies and brucellosis will continue to increase if prevention and control strategies are not reinforced. Circovirus type II and vesicular stomatitis could continue their downward trend, suggesting that the measures implemented have been effective. Anaplasmosis and other diseases with stable incidence do not present significant variations in their projection. These projections emphasize the need to continue with epidemiological surveillance and prevention programs, especially in those diseases with growing trends.

Figure 4: Historical evolution of the five most frequent pathologies in the province of Napo between 2019 and 2024, together with a projection for 2025 and 2026 based on a linear regression model



It is observed that rabies and brucellosis continue to show an upward trend, with estimates indicating a possible increase in cases in the coming years if effective control measures are not implemented. Anaplasmosis maintains a stable behavior without significant variations. On the other hand, diseases such as circovirus type II and vesicular stomatitis show a decreasing trend, which suggests that they could be under greater control thanks to previous health interventions. The analysis of the distribution of pathologies by animal species (Figure 5) revealed that cattle and pigs were the species with the highest incidence of diseases, whereas horses and sheep had significantly fewer registered cases. Regarding cattle, there was a high prevalence of brucellosis, rabies, and infectious bovine rhinotracheitis, suggesting that these diseases represent a recurrent problem in the cattle population. On the other hand, in pigs, a notable concentration of circovirus type II was identified, indicating a possible epidemiological trend within this species. The diversity of pathologies was greater in cattle, whereas in pigs, a specific disease predominated. These results allow to understand the distribution of diseases according to the species and may be key to the development of prevention and control strategies.

Figure 5: Distribution of pathologies by animal species



These findings coincide with previous reports made in Ecuador, where diseases such as brucellosis, rabies, and infectious bovine rhinotracheitis have been classified as of national health interest due to their impact on production and public health. In the Amazon region, sporadic outbreaks of bovine rabies transmitted by hematophagous bats have been documented, reinforcing its endemic nature in rural areas of Napo. On the other hand, the high frequency of circovirus type II in pigs has also been pointed out in studies carried out in producing regions of the country, indicating its expansion and need for specific surveillance; these antecedents support that the observed results are not isolated, but reflect a relevant epidemiological continuity in the area.

Discussion

The spatial dispersion observed in diseases like circovirus type II and vesicular stomatitis could be associated with factors such as high livestock mobility, trade between cantons, and the absence of adequate health controls in livestock transit areas. Previous studies have indicated that viral diseases transmitted indirectly or through fomites tend to spread in areas with high animal flow and deficient biosecurity measures[12].

In the case of vesicular stomatitis, its presence in cantons with mixed livestock activities could indicate sporadic outbreaks associated with mechanical vectors and favorable environmental conditions, as has been documented in areas with warm and humid climates[13]. The province of Napo, due to its location bordering the province of Pichincha, is located in a place of transit of productive species that are acquired at large-scale marketing fairs in provinces such as Santo Domingo and Pichincha, whose final destination is neighboring provinces like Orellana, Sucumbíos, and Pastaza.

The trends observed in the period 2019–2024 show a progressive increase in rabies and brucellosis, indicating that the control strategies applied so far have not been entirely effective in halting their advance. This behavior is worrying, since both diseases have implications for both animal and public health, as rabies is a high-risk zoonosis, and brucellosis is a disease with an economic impact on livestock production due to market closures, and also because it influences human health due to the consumption of products derived from infected animals[14]. Despite these challenges, the increase in reported zoonotic diseases also reflects a significant advance in surveillance and reporting systems, which could lead in the long term to better management and control strategies[15].

The study of epidemiological behavior in the province of Napo allowed to identify spatial and temporal patterns relevant to the spread of diseases in productive species. According to the results, rabies and brucellosis stand out as priority pathologies due to their high incidence and growing trend during the period 2019–2024, especially in the cantons of Tena and Quijos, respectively. These findings coincide with what has been reported in other studies in tropical areas of Latin America, where these diseases are endemic and are associated with deficiencies in vaccination coverage, animal mobility, and contact with wildlife[16,17].

The linear regression model applied in this study allowed to project the most frequent pathologies for the years 2025 and 2026. The results indicate that rabies and brucellosis will continue to increase, which could be associated with inadequate veterinary services[18]. This reinforces the need to strengthen control strategies in the province of Napo, specifically in cantons such as Quijos and Tena. It is essential to expand vaccination coverage in critical areas, prioritize cantons with a high incidence of zoonotic diseases, and strengthen epidemiological surveillance. Community participation is essential to detect and respond promptly to outbreaks[19], as well as to implement stricter controls on livestock mobility. The analysis of animal movement patterns can serve as a basis for specific interventions in high-risk areas, emphasizing the need to establish rigorous controls[20].

The concentration of rabies in the canton of Tena may be associated with the interaction between cattle and wildlife, particularly with hematophagous bats (*D. rotundus*), which have been identified as the main vectors of the virus in Amazonian livestock systems[2,21]. In Napo, frequent activity of these bats has been reported in areas of extensive production. In the case of Quijos, the high incidence of brucellosis could be related to low vaccination coverage, poor reproductive control, exchange of animals without health control, and low risk perception by producers, which contributes to maintaining active transmission chains within the cattle herd[22]. The persistence of the disease in cantons such as Quijos also suggests vertical transmission and inadequate reproductive management practices; this is consistent with studies in extensive production areas of Ecuador[9].

The presence of circovirus type II and vesicular stomatitis in several cantons reinforces the hypothesis that these diseases may be related to the mobility of infected animals and the trade of livestock without rigorous health controls[23]. Epidemiological studies in production systems have shown that diseases with dispersed distribution are usually linked to commercial practices that facilitate the spread of pathogens in areas of high interaction between animals. The mapping of these movements reveals that the central countries function as nuclei of propagation, favoring the circulation of pathogens through commercial and logistical networks, which reinforces the importance of controlling and monitoring these flows to mitigate health risks[22]. On the contrary, while intensive systems are often criticized for their role in disease spread, extensive livestock practices also present unique risks due to lower biosecurity and increased animal populations, complicating the assessment of overall disease emergence risks[24].

The decrease in circovirus type II and vesicular stomatitis could be associated with the implementation of stricter biosafety regulations and the development of prevention campaigns promoted in recent years[25]. However, these improvements do not guarantee eradication, as changes in health policy, non-compliance with protocols, or the reintroduction of infected animals could lead to new outbreaks[26]. The low incidence of diseases in horses and sheep could be due to underreporting, rather than to a truly low prevalence, which represents a structural weakness in animal surveillance systems[27,28].

The results of the study show that climatic variables could influence some diseases. In particular, rabies showed peaks in cases in 2020 and 2023, coinciding with months of high rainfall, such as March and June, where rainfall exceeded 400 mm in affected cantons. This pattern suggests a possible relationship with environmental conditions that favor vector activity[29,30]. Although this study did not include a multivariate analysis with environmental variables, the observed patterns justify their incorporation in future research.

Conclusions and implications

The present study evidenced a progressive increase in cases of rabies and brucellosis in the province of Napo during the period 2019–2024, with a significant geographical concentration in the cantons of Tena and Quijos. These findings indicate that the current health control strategies have not been fully effective in containing the spread of these diseases, which poses a risk to animal health, public health, and the local economy. The use of statistical and geospatial tools, such as linear regression and DBSCAN cluster analysis, made it possible to identify high-risk areas and generate incidence projections that could guide health planning towards 2025 and 2026. These techniques are valuable in improving the responsiveness of the passive surveillance system. As a practical implication, it is recommended to prioritize interventions focused on the cantons with the highest health burden, reinforce vaccination programs, implement stricter controls on livestock mobility, and strengthen notification and diagnosis mechanisms in the field. Likewise, the proposed territorial approach can serve as a replicable model for other provinces with similar epidemiological conditions. Together, the results contribute to designing more effective health strategies and efficiently allocating resources, promoting a preventive and risk-based approach to controlling diseases of zoonotic and economic importance in tropical regions.

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