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# Meteorological Variables in the Spread of COVID-19 in a Commercial and Andean-Amazonian Region of Peru

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**ABSTRACT**

The Junin region, located in the central Andes of Peru, boasts a great diversity of natural resources and commercial flows. This region has reported a high number of positive COVID-19 cases in a short period, which raises interest in understanding the most significant factors influencing the spread of this epidemic. Meteorological variables influencing the spread of COVID-19 in a commercial and Andean-Amazonian region of Peru were analyzed. Secondary data on epidemiology, climate, and social aspects from 124 districts in Junin were used to analyze the evolution and territorial distribution patterns of positive COVID-19 cases from March 10 to November 27, 2020. This was achieved through correlations and multiple regression ($\alpha = 0.05$) between temperature, absolute humidity, solar radiation, altitude, population density, number of markets, poverty, and elementary occupations with infection rates. All variables showed significant correlations ($p < 0.01$) except for solar radiation ($r = 0.08$). The most important factors were temperature ($r = 0.39$; $p = 0.006$) and the number of markets ($r = 0.61$; $p < 0.001$). The results suggest that one of the most important factors in the spread of COVID-19 in a commercial region is the number of local markets, which are key social interaction spaces and primary hotspots for respiratory pandemic infections.

## 1. INTRODUCTION

Coronavirus (COVID-19) spread rapidly throughout the world [1], causing a devastating pandemic that mainly affected countries such as China and the United States [2].

In Latin America, the evolution of COVID-19 cases was heterogeneous and was related to the health measures implemented in the affected countries according to their pre-existing health conditions [3, 4]. The country with the highest rates of spread and incidence of COVID-19 in Latin America was Peru [5], despite being one of the first countries to take measures before the appearance of the first report of contagion [3].

In the center of Peru lies the Junin region, with an approximate population of 1246000 inhabitants [6], distributed across nine provinces and 124 districts. It comprises Andean and mountainous areas covering 20821 km², situated between 2739 and 4415 meters above sea level, which include the provinces of Huancayo, Concepcion, Jauja, Chupaca, Tarma, Yauli, and Junin. Additionally, it encompasses Amazonian areas covering 23376 km², where the provinces of Chanchamayo and Satipo are located [7], situated between 275 and 1200 meters above sea level.

The various altitudes and climates give rise to a diversity of natural resources, establishing the Junin region as the primary source of food for the Peruvian capital [8]. Several economic corridors [9] facilitate frequent commercial exchanges, with primary product markets serving as the main spaces for economic flow and interaction among the population.

The first reported case of COVID-19 in the Junin region was recorded in the city of Huancayo, the main commercial capital. Since then, the virus has spread to all districts and provinces, surpassing 155000 confirmed cases and 7584 deaths regionally. Consequently, the region was classified as having an extreme level of contagion due to the high rates of spread [10].

In South America, there are some studies on the association of environmental conditions and social aspects with the spread of COVID-19, as reported in São Paulo [11] and Lima [12]. However, there is still limited knowledge about the relationship between climate, social aspects, and the behavior of the pandemic [13].

Based on this, the objective of the present study is to analyze the meteorological variables that influence the spread of COVID-19 in an Andean-Amazonian region of Peru, such as Junin. The method used is the ecological one to evaluate environmental and social interactions on the spread of the virus in a commercial region that will provide necessary information for the strengthening of control measures [14] in future epidemiological episodes.

## 2. MATERIAL AND METHODS

A descriptive correlational ecological study was conducted for the period from March 10 to November 27, 2020, involving secondary epidemiological, climatic, and social data collected from 124 districts of the Junin region (Figure 1).

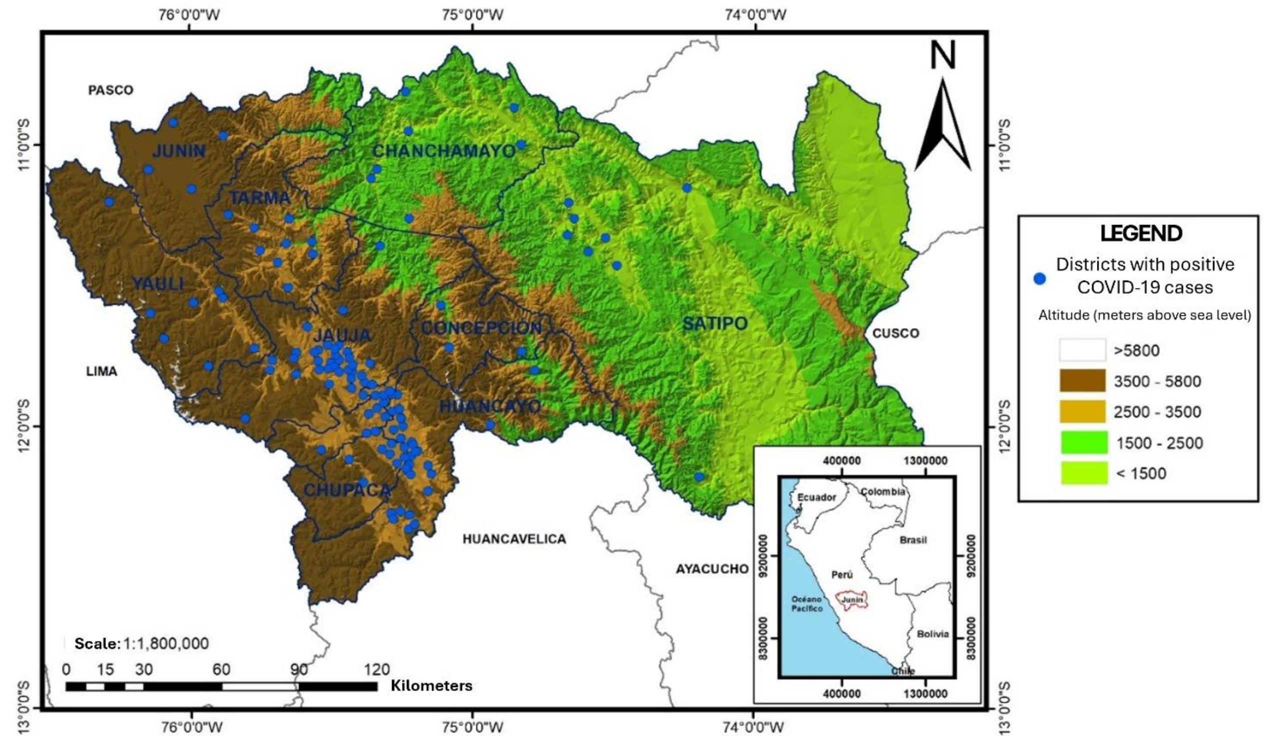


**Figure 1.** Geographical distribution of the 124 districts comprising the Junin region in central Peru

### 2.1 Epidemiological data

The epidemiological data consisted of the numbers of positive COVID-19 cases defined by confirmation through serological and molecular tests [15]. These data were compiled daily from March 10 to November 27, 2020, from the official website of the Epidemiology Office of the Dirección Regional de Salud de Junin (DIRESA-Junin) of the Ministerio de Salud (MINSA) (http://www.diresajunin.gob.pe/).

### 2.2 Climatic data

The climatic data considered in the study were temperature, water vapor pressure, and solar radiation from the period 1970-2000 obtained from the WorldClim version 2.1 website with an approximate resolution of 1 km² (https://www.worldclim.org/). Also considered was the absolute humidity calculated using the following formula:

$$HA = \frac{PV * 216.5}{273.15 + T} \quad (1)$$

where, *HA*=Absolute humidity; P*V*=Vapor pressure; *T*=Temperature (C°).

Additionally, altitude (meters above sea level) data for each district in the Junin region were obtained from the Geographic Information System (GIS) (http://sige.inei.gob.pe/test/atlas).

### 2.3 Social data

Official secondary data were collected on population density, percentage of elementary occupations (unskilled workers in services; agricultural, forestry, fishing, mining and quarrying laborers, manufacturing industry, construction, cargo handlers, street vendors, and similar occupations), and number of local markets from the Instituto Nacional de Estadística e Informática (INEI, the governing body for national statistics and informatics systems in Peru) [7, 16]. Additionally, poverty percentages were retrieved from the Ministerio de Desarrollo e Inclusión Social available in the Digital Information Repository (REDinforma, http://sdv.midis.gob.pe/RedInforma/).

### 2.4 Infection rate

The spread rate of COVID-19 was defined as the infection rate using the formula [17]:

$$Infection\ rate = \frac{Number\ of\ infected\ individuals}{Days\ of\ infection} \quad (2)$$

## 2.5 Statistical analysis

Firstly, a spatial analysis based on the average of confirmed COVID-19 cases in each district on a monthly basis was conducted to provide information on the spread of the pandemic in the study area. The geographic location of confirmed cases was determined by district location using ArcGIS 10.6.1 GIS software [18]. The analysis of COVID-19 case distribution patterns was conducted using spatial statistical tools: (1) Average Nearest Neighbor and (2) High/Low Cluster Analysis [19]. The first method calculates the distance between each point to see if the distribution is random or clustered, the high/low cluster analysis was used to identify the points where COVID-19 cases present significant spatial concentrations of both high and low values, considering the relationship of proximity between locations and number of cases.

Subsequently, altitude ranges were established based on physiological changes in individuals [20] to compare the spread of the virus among capital districts (commercial centers), adjacent districts (bordering the capitals), and distant districts. The Kruskal-Wallis test with the Holm-Bonferroni multiple comparisons test ($\alpha = 0.05$) was applied.

Subsequently, Spearman correlation coefficients were calculated between climatic and social variables and infection rates as the dependent variable.

Finally, a generalized linear model was performed with the variables showing significant correlations ($\alpha = 0.05$) to determine significant associations.

## 3. RESULTS

The average nearest neighbor analysis (z-score=2.02; $p=0.043$) and high/low cluster analysis (z-score=-4.96; $p<0.001$) indicate significant clustering (Figure 2), with the capital districts of each province as central points (blue circles). The geographic distribution shows a higher concentration of districts in the altitude range (orange circles) between 2500-3500 m, located in the mountainous Andes, where 53% of the total population resides. They are followed by districts located at lower altitudes (<1500 m, green circles) in the Amazonian area of the region, which houses 40% of the total population.

Regarding climatic variables by altitude range, districts located at low altitudes (green circles in Figure 2) recorded higher temperatures (21.3 ± 2.4 °C) and higher absolute humidity (14.5 ± 1.7 g/m³). Conversely, solar radiation reached higher values in high-altitude districts (orange circles in Figure 2, 16088.3 ± 585.1 KJ/m² day) and very high-altitude districts (purple circles in Figure 2, 15623.2 ± 585.1 KJ/m² day).

The highest population density (457.2 ± 1395.5 inhabitants/km²), percentage of elementary occupations (31.9 ± 14.4%), and the highest number of markets (1.6 ± 2.1) are recorded in high-altitude districts.

According to the study period, the first COVID-19 infections occurred in the capital district (Huancayo) and its surrounding areas: El Tambo and Chilca (Figure 3), considered the main commercial centers of the entire study area (Figure 3A). In the following month (April), new cases were confirmed in other provinces, with capital districts being the first to report new infections (Figure 3B and Figure 3C).

Subsequently, the disease spread to the surrounding districts of each province (Figure 3D, Figure 3E, Figure 3F and Figure 3C), and then to more distant towns. Seven months after the outbreak, all districts recorded confirmed cases of COVID-19 (Figure 3G). In the following months, the city of Huancayo continued to be the main point of contagion (Figure 3H and Figure 3I) due to having the highest number of positive cases.

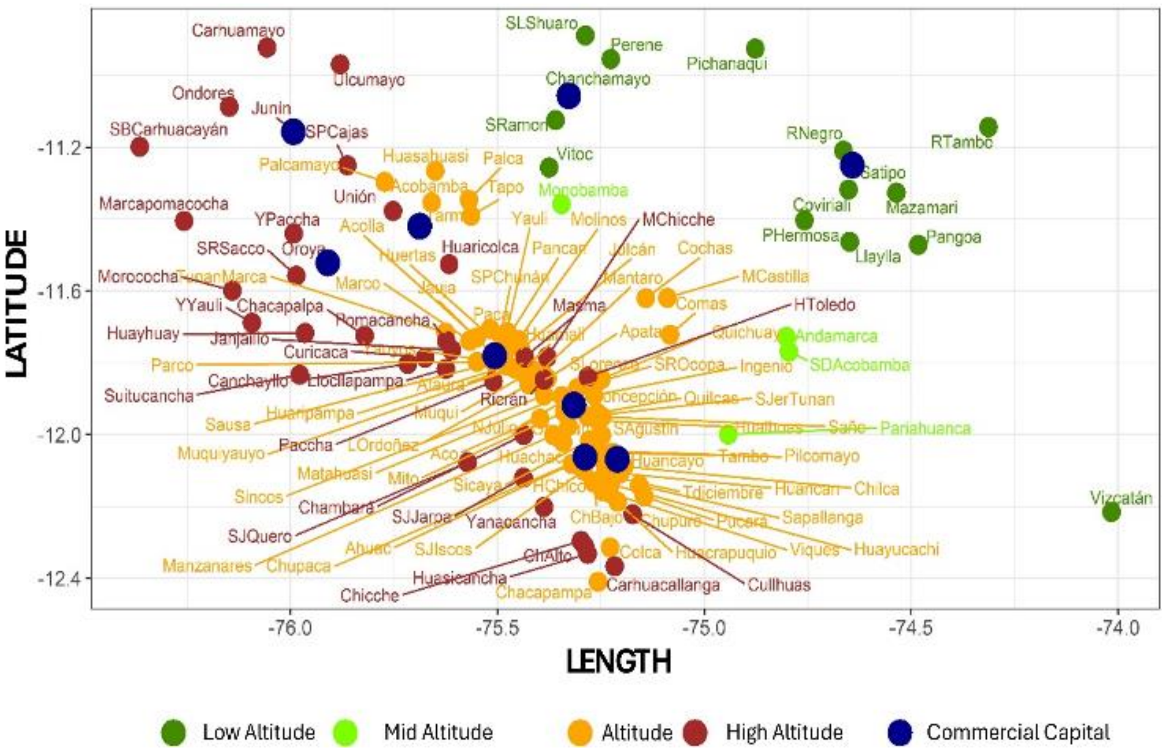


**Figure 2.** Geographical distribution of districts according to altitude ranges in the Junin region (Peru)

Note: Low Altitude (<1500 meters above sea level), Mid Altitude (1500-2500 meters), High Altitude (2500-3500 meters), and Very High Altitude (3500-5800 meters)

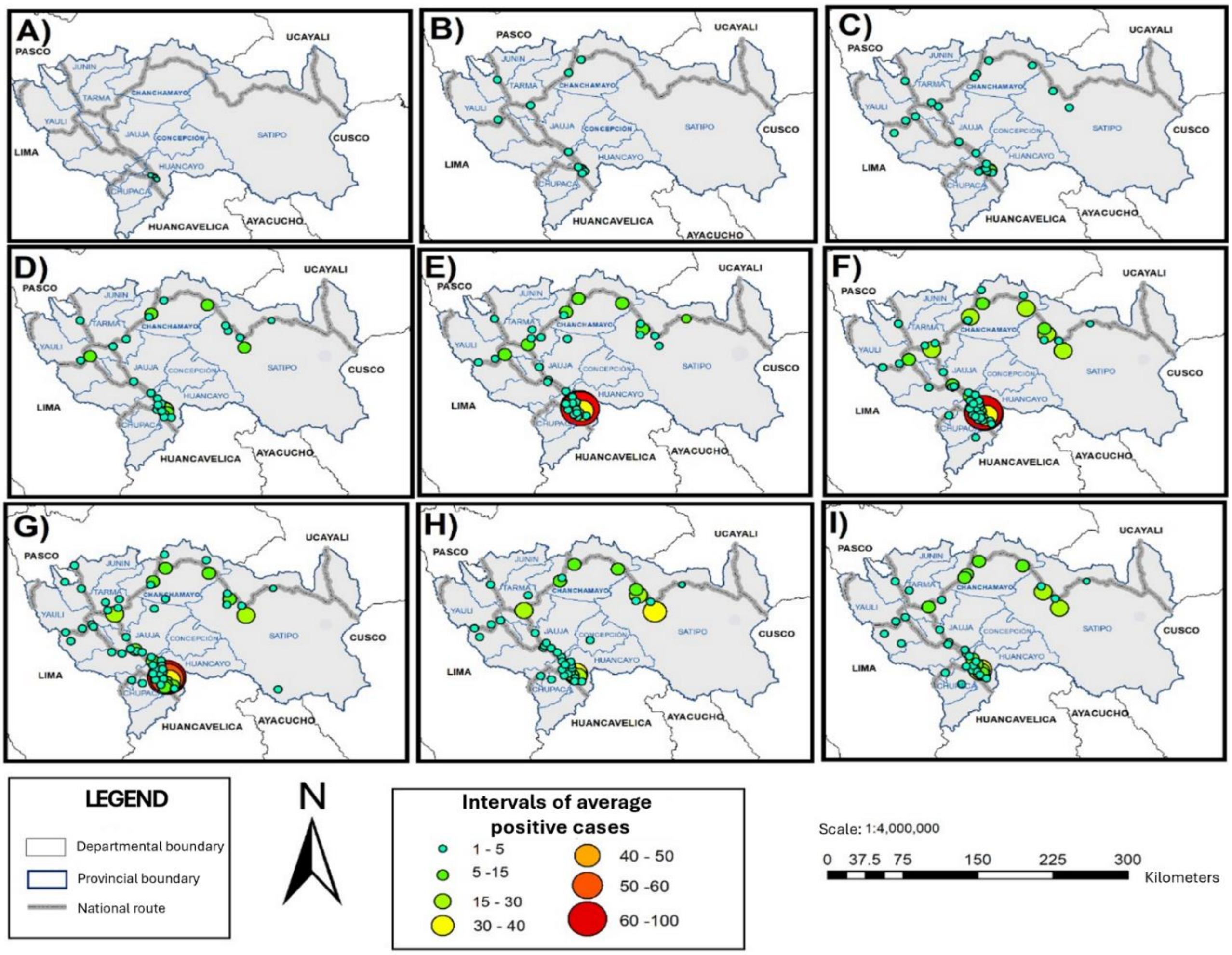

**Figure 3.** Monthly evolution of COVID-19 contagion in the districts of the Junin region (Peru), from March 22nd to November 27th, 2020: A) March, B) April, C) May, D) June, E) July, F) August, G) September, H) October, and I) November

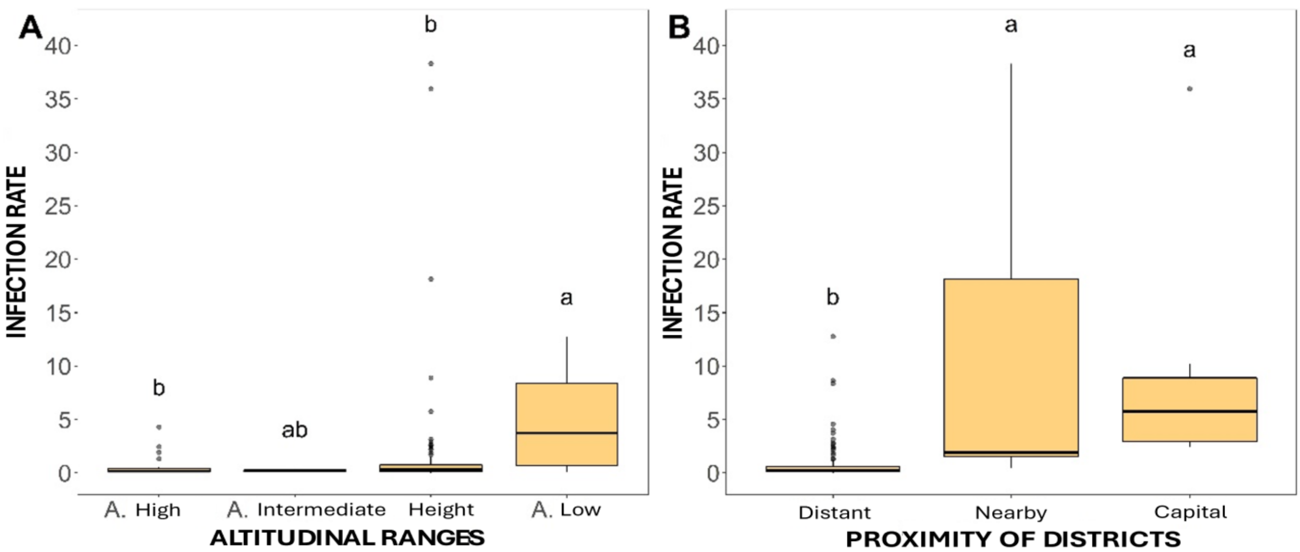


**Figure 4.** A) Infection rate according to altitude ranges and B) proximity to the capital districts of the Junin region (Peru), from March 22 to November 27, 2020

Note: Letters A and B indicate significant difference ($p < 0.05$) with the Kruskal-Wallis test

When comparing COVID-19 transmission by altitude ranges (Figure 4), districts located at lower altitudes in the Amazonian zone experienced a higher rate of spread ($p < 0.001$) compared to districts situated in the Andean zone, where high-altitude, very high-altitude, and mid-altitude districts are located (Figure 4A).

The capital districts and their surrounding areas recorded a higher infection rate (Figure 4B), with no significant difference observed between them ($p = 0.52$). However, a significant difference was observed among distant districts (p

< 0.05), where the infection rate was lower.

When correlating climatic variables with the infection rate, significant positive correlations were observed with temperature ($r = 0.39$; $p < 0.001$) and absolute humidity ($r = 0.49$; $p < 0.001$). Additionally, a significant negative correlation was found with altitude ($r = -0.41$; $p < 0.001$), while solar radiation showed no significant correlation ($r = 0.08$) (Table 1).

**Table 1.** Association between significant climatic factors and social aspects with the infection rate considering the 124 districts of the Junin region in Peru

| Predictors | Infection rate<br>Confidence Interval 95% | p |
|---|---|---|
| Intercept | -8.37–2.25 | 0.255 |
| **Temperature** | 0.06–0.34 | **<0.05** |
| Absolute Humidity | -0.25–0.45 | 0.587 |
| altitude | -0.006–0.001 | 0.464 |
| **Markets** | 1.31–1.50 | **<0.001** |
| Elementary occupations | -0.03–0.02 | 0.441 |
| **Density population** | 0.0005-0.001 | **<0.001** |

*Remarks (n)=124; $R^2$ / $R^2$ adjusted=0.92/0.91
**The total population of Junin is 1246000 inhabitants
***Spearman's rank correlation test was applied with a 95% ($\alpha$ = 0.05)

## 4. DISCUSSIONS

The monthly evolution of COVID-19 contagion in the 124 districts of the Junin region indicates that the greatest spread and distribution of the disease has occurred through commercial zones connected by economic corridors, associated with the availability of roads and economic flow. On the other hand, the lower numbers of cases were located in remote districts where there is higher poverty and less commercial flow. These findings are similar to the spread of the pandemic in the capital city São Paulo (Brazil), where shared transportation and commercial interaction were the most important predictors of infection rates [11].

The spread of viral respiratory diseases is a function of the relationship between climatic temperature and absolute humidity [21-25]; however, the results suggest that they increase COVID-19 infection, contradicting findings from other studies [26-28]. These findings align with those recorded in five Brazilian cities (São Paulo, Rio de Janeiro, Brasilia, Manaus, and Fortaleza) [29] and the concept of the viral transmission sweet spot [30], as warmer climates alone cannot reduce COVID-19 transmission [31].

On the other hand, climatic solar radiation did not show a significant correlation with the spread of cases, indicating that high insolation does not prevent COVID-19 transmission [32]. The Junin region has a high incidence of ultraviolet radiation [33], although daily records are not available. Further study is needed to understand its influence on COVID-19 transmission [34].

In relation to the influence of altitude on the incidence of COVID-19 cases, the following is a summary of the results, the results indicate that incidence decreases at higher altitudes [35, 36]. Comprehensive reviews indicate that people living at higher altitudes are unlikely to have an advantage in reducing the risk and severity of coronavirus infection [37], so the effect is still debated.

Regarding social aspects, while all evaluated social variables showed significant correlations, the number of local markets and population density were the most important. The actions taken by the Peruvian government have largely depended on social behavior [38], which has produced social and economic impacts within the population, leading to an increase in informal occupations and economic poverty [39]. Food markets were opened during the execution of the research, which ensured the availability of food for the population [12] and maintaining commercial relationships [23]. This exchange and connectivity were more significant in the capital districts and their surroundings, which became hotspots of infection. This commercial link between suppliers and customers, along with the congregation of people, has been one of the most important factors, a vital aspect to consider in strategies and plans to control the spread of coronavirus disease in the diverse and commercially active region.

The heterogeneity of social aspects masks the effect of climatic variables; therefore, it is important to consider the behavior of populations and social interactions, especially in a population with a commercial history. It is also deduced that commercial informality in emergency scenarios is a key aspect; if mitigation measures are relaxed or uncontrolled, episodes of high cases could occur rapidly [40]. Atmospheric pollution is also exacerbating diseases spread through meteorological variables [41].

The limitations of this study are: 1) the underestimation of real data on infection; the official data used corresponded mostly to infected persons with symptomatic and severe manifestations. But we consider that it does not influence the findings given the use of an epidemiological rate, 2) The use of long-term climate records; however, its application has shown consistency with other studies that could be corroborated with daily meteorological data in the different districts.

## 5. CONCLUSIONS

The most important factors in the spread of COVID-19 in a commercial region is the number of local markets, which are spaces for social interaction among the population and constitute main hotspots for respiratory pandemic infections.

It is recommended that specific control and prevention measures be implemented in local markets in provinces and commercial districts, such as regular monitoring of workers and customers, reduction of people density, and improvements in the ventilation of enclosed areas. These actions could help reduce future episodes of spread of respiratory epidemics, especially in areas where there is high social and economic interaction.

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