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Evolution of infant mortality in Ecuador: a spatial analysis from 2010 to 2019

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Abstract

The health situation of children is fundamental for the big picture of public health in a country. Particularly, the death of children under one year of age, calculated through the infant mortality rate is still a key indicator, especially in Latin America where the overall rate has been constantly decreasing down to 13.9 infant deaths per 1000 live births. But this global figure encompasses geographical and temporal disparities within the same country. This is why it is interesting to analyze this evolution through a geomatic method of spatial prioritization. By combining hotspots detection (Local Indicators of Spatial Association, LISA) and time trend over 20 years (Mann-Kendall) at municipal level data from Ecuador, a country with infant mortality similar to the regional average, we obtain the most critical townships that should receive special attention with respect to maternal and infant health.

Keywords

Infant mortality, Ecuador, spatio-temporal analysis, LISA, Mann-Kendall.

Background

All around the world, statistic measures of mortality are used to evaluate the health state of a population [1] and consequently reflect the socio-economic development, general conditions of life and social wellbeing of a country [2]. Among these measures, the infant mortality rate (IMR) is one of the indicator most used in health [3] and is defined as the likelihood of a live birth to die before the age of one [4].

In Latin America and the Caribbean, progress in child survival has been remarkable, starting with the United Nations (UN) Millennium Development Goals (MDGs). Between 1990 and 2015, the mortality rate of children under five, including those under one year of age, has been reduced by 67% [5]. However, there is evidence that the mortality rate affects populations with lower socioeconomic levels more strongly [6, 7]. According to information obtained from the National Institute of Statistics and Censuses (INEC) [8], Ecuador's IMR has decreased by 12.7% for every 1000 births between 1990 (21.8‰) and 2016 (9.1‰). According to Pan American Health Organization / World Health Organization (PAHO/WHO) [9], in 2017 Ecuador recorded an IMR of 8.9 per 1000 children born, below Bolivia (50.2‰), Colombia (17.2‰), Brazil (15.1‰), Peru (15‰), Venezuela (14.7‰), Paraguay (14.7‰) and Argentina (9.7‰).

There are studies that have focused on understanding infant mortality from a spatial [10] and temporal [11] or both [12] point of view. With the advance of technology in geographic information systems (GIS), spatial analysis methods have begun to be used for epidemiological and health research [13], which can contribute to policy intervention at the geographic area level [10]. For example, some studies suggest that mortality varies according to geographical region, and show spatial patterns with strong regional differences where high-risk areas can be identified for policy planning and efficient resource allocation (demographic, socio-economic) [14, 15].

This study proposes an analysis of the spatial and temporal variations of infant mortality (IM) in Ecuador at the municipality level and seeks out those areas where there are significant groupings below or above the national average. This could help to prioritize sectors where greater accessibility and availability of child health care services are needed. In order to

prioritize areas of action, it is of interest to identify the municipalities in which the highest rates are found and in which the trend is strongly increasing.

No studies have been found in Ecuador where spatial analysis is used for infant mortality, however our analysis is congruent with other research in Ecuador on suicide, cancer, and neglected tropical diseases that have used significant spatial clusters to determine critical areas [16, 17, 18]. The methods used in this analysis have also been applied in other countries to determine spatial variation, spatial clusters and risk factors influencing infant mortality [10, 19].

Methods

Study area and infant mortality rate

Ecuador is located in South America, bordering Colombia (north), Peru (south-east) and the Pacific Ocean (west). Politically, it is divided into 24 provinces (Figure 3. A) and 221 counties that correspond to municipalities or communes (second political-administrative level after provinces). It has four natural regions: coast, highlands, Amazon and Galapagos Islands. For this study only continental Ecuador was considered.

The public databases of live births and general deaths are downloaded from the INEC website from 2010 to 2019 [8]. The data on deaths of children under one year of age in the study area together with the data on live births are totalized by spatial unit. These data are used to calculate the infant mortality rate per 1000 live births during a year and to construct thematic maps.

Time trend

The Mann-Kendall non-parametric statistical test is used to determine the time trend over a period of the annualized IMR. To apply this test, the data do not need to fit any particular distribution [20]. The statistic makes combinations of each pair of observed values, over time, that is, it checks whether $IMR_j > IMR_i$ or $IMR_j < IMR_i$ and counts the number of pairs that increase or decrease over time (it is the relative frequency of increases minus the relative frequency of decreases), it is calculated for each spatial unit as [21]:

$$S = \frac{2(t-2)!}{t!} \sum_{i=1}^{t-1} \sum_{j=i+1}^t \text{sign}(IMR_j - IMR_i)$$

86 where the sign function is given by

$$\text{sign}(IMR_j - IMR_i) = \begin{cases} 1 & \text{if } (IMR_j - IMR_i) > 0 \\ 0 & \text{if } (IMR_j - IMR_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0 \end{cases}$$

87 IMR_i is the IMR in year $i \in \{1, 2, \dots, t-1\}$ with t as the number of available years and IMR_j is
88 the IMR in year $j = (i+1) \in \{1, 2, \dots, t\}$.

89 Mann-Kendall values range from -1 to +1. When a value approaches +1 it means there is a
90 monotonic upward trend, when it approaches -1, the trend is downward and a value of 0
91 indicates no trend.

92 **Spatial trend**

93 The observed variable, in this case the IMR in the study area is represented with maps and
94 using the spatial statistics technique for cluster detection using the Moran Indicator both
95 globally and locally. The aim is to observe the spatial dependence that may or may not exist
96 between nearby locations.

97 Considering a set of N spatial units in a region, the spatial autocorrelation represents the
98 relationship between the IMR, in one spatial unit, and the IMR values of its n neighbors, which
99 can be visualized through a connectivity map. To quantify the closeness between two spatial
100 units, a positive $n \times n$ matrix W is used, made up of $n(n-1)$ spatial weights called $w_{i,j}$ which are
101 defined based on binary contiguity, like this:

$$w_{i,j} = \begin{cases} w_{i,j} = 1 & \text{if } j \neq i, \text{neighbouring space units} \\ w_{i,j} = 0 & \text{opposite case} \end{cases}$$

102 The Moran Index (I) is the test considered to be the most applied and statistically strongest to
103 detect spatial independence from debris, this being a summary measure of the intensity of the
104 spatial association between units [22, 23]. Its range of values is based on the weight matrix,
105 usually varying between -1 and +1 but not necessarily restricted by this, unlike a correlation
106 coefficient. If its neighboring municipalities tend to have similar values in their IMR, I will be

positive indicating that the pattern is clustered, if they are different, I will be negative, that is, the pattern is regular and when spatial randomness is present the expected value of I is given by $E[I]=(-1)/(n-1)$, as n increases, $E[I]$ approaches 0 [24]. It is similar by Waller as a spatial extension of the Pearson correlation coefficient.

Given i and j in $\{1,2,\dots,n\}$, the index is defined by:

$$I = \frac{n}{\sum_{i=1}^n \sum_{j=1}^n w_{i,j}} \frac{\sum_{i=1}^n \sum_{j=1}^n w_{i,j} (x_i - \bar{X})(x_j - \bar{X})}{\sum_{i=1}^n (x_i - \bar{X})^2} \text{ for } j \neq i,$$

where n is the total of municipalities, x_i the IMR in municipality i , x_j the IMR in another municipality j , $\bar{X}$ the average of the IMR and $w_{i,j}$ the elements of the contiguity matrix W that links municipality i to j .

As there are spatial effects such as heterogeneity that refer to the indistinct behavior of the variable observed in each of the units, local patterns can be detected that with the global measure were ignored, so local measures are introduced as Local Spatial Association Indicators (LISA) is calculated as [25]:

$$I_i = (x_i - \bar{X}) \sum_{j=1}^n w_{i,j} (x_j - \bar{X}) \text{ for } j \neq i$$

With this analysis, using the calculation of Moran's I_i and the scatter plot, four categories of groupings can be identified by the type of spatial association: the hotspots, which are municipalities with an above-average rate and the rate of their neighbors as well, the high-high category, or otherwise the below-average rate, the low-low category, and the outliers (or outliers), which are municipalities with an above-average rate but the rates of their neighbors are below the average, the high-low category, or otherwise the low-high category. To see if these groupings were not created randomly, a hypothesis test is done, a significance test that uses a permutation test.

Prioritization criteria for identification of spatial-temporal critical areas

Different types of criteria can be developed and implemented according to the prioritization needs of the study.

In this case, the methodology was designed according to logical criteria. First, in order to eliminate inconsistent rates, municipalities with less than 2 deaths were excluded. The counties with higher IMR during the most recent year were selected, using the 90% percentile threshold. The frequency, in number of year, of pertaining to a high-high or hotspot cluster is used to give priority. The third factor considered is the higher positive trend over all the period studied.

Eventually the hotspot repetition over years can be more strictly evaluated using the logical AND operator instead of the OR operator (Figure 1).

Figure 1. Methodology in 3 steps.

Results

Since 2000, the national IMR has been steadily decreasing, but as of 2014, the rate has begun to grow again which is of great concern (Figure 2).

Figure 2. Yearly evolution of the national infant mortality rate (2000-2019).

Regarding the leading cause of deaths in children under one year of age in 2019, of the 3355 children who died 15 % (504) died from respiratory difficulties, 7.7 % (257) from bacterial sepsis, 5.2 % (175) from pneumonia and 4.1 % (137) from other congenital heart malformations. The following chart shows the top ten causes of mortality in children under one year of age for 2019 (Figure 3).

Figure 3. Top ten causes of death in children under one year of age in 2019.

Figures 4 and 5 show the spatial distribution of the incidence rates of mortality in children under one year of age and the temporal trends analyzed by the Mann-Kendall method (the

number in brackets indicates how many municipalities are in the category) in the 221 municipalities of continental Ecuador. The trends show that the rates are not spatially constant. At the regional level, there is a slow increase in IMR rates, mainly in the highlands and the Amazon. In the highlands, the municipalities with rates above $>16.7\%$ are Ibarra, Cuenca, with high growth trends, and Guaranda and Tulcan with medium growth trends, and Latacunga and Quito with low growth trends. Similarly, the municipality of Guamote has a rate above the threshold, however, this trend is steadily decreasing over time.

Of the 41 municipalities in the Amazon, 15 maintain an increasing trend between medium and low, however, the municipality Morona, Lago Agrio and Quijos are the only ones rates above the threshold.

A particular case on the coast is the Piñas municipality, where the rate increased from 0% in 2010 to 157.77 deaths per 1000 live births in 2019, making it the municipality with the highest increasing trend in the entire country. Another important aspect to highlight within this region is that the municipalities of Manta and Guayaquil, being provincial capitals, have rates above the established threshold and with an average upward trend. San Lorenzo in the coastal Esmeraldas province is the only municipality that presents a high decreasing trend.

Figure 4. Provinces of Ecuador (Panel A). Infant mortality rate for 2010 to 2019 (Panel B-K).

Figure 5. Time trend map of Mann-Kendall (Tau) for the period 2010 to 2019.

Through the cluster analysis (LISA) that represents the spatial grouping of infant mortality for the years 2010 to 2019 (Figure 6), it can be deduced that during the 10 years of study, the central highlands concentrate the majority of clusters, which are reduced over time, until concentrating in 2019 in the provinces of Carchi, Chimborazo, Cotopaxi, El Oro, Sucumbíos and Morona Santiago. On the contrary, cold spots appear sporadically in Loja, Los Ríos and Morona Santiago.

Figure 6. LISA univariate (cluster) maps.

By means of the prioritization criteria, eight municipalities were defined, of which four belong to the highlands region, two to the coastal region and two to the Amazon region.

Table 1. Municipalities with higher risk of infant mortality.

						Mann Kendall	
						2010-2019	
Province	Region	Municipality	Infant deaths 2019	IMR 2019 (‰)	Repeated hotspot	Tau	p-value
Bolívar	Highlands	Guaranda	29	17.86	5	0.64	0.0073
Morona Santiago	Amazon	Morona	29	24.05	1	0.69	0.0123
El Oro	Coastal	Piñas	68	157.77	0	0.84	0.0004
Azuay	Highlands	Cuenca	179	19.44	0	0.80	0.0030
Imbabura	Highlands	Ibarra	56	16.74	0	0.73	0.0024
Carchi	Highlands	Tulcán	32	21.67	0	0.60	0.0318
Guayas	Coastal	Guayaquil	994	21.38	0	0.56	0.0200
Sucumbíos	Amazon	Lago Agrio	50	20.6	0	0.56	0.0491

Discussion

Eight municipalities were identified as a priority (Table 1), where policies could be implemented to improve the socioeconomic conditions of the population, infrastructure, coverage and accessibility to health services, or even improve the registration of deaths and births, among other strategies that could potentially help reduce the high IMR and reverse the trend. While there are many more municipalities with high IMR, these eight municipalities are of more concern as they have higher IMR values, the trend is increasing over the years, and they generate statistically significant spatial clusters. It is most appropriate that the IMR is reduced over time to the lowest possible levels, yet certain municipalities do not show improvement over the period (increasing and stable trend), which could indicate that more national, provincial or municipal efforts are needed to reduce the IMR.

According to the results obtained, the Sierra region has the majority of municipalities with high IMR rates, a growing trend and High-High hotspot values. A study conducted in 1995 in Ecuador showed that the sierra region had the highest rate of the three regions [26], and agreed that the infant mortality profile was mainly due to perinatal conditions (P00-P96), congenital anomalies (Q00-Q99) and respiratory system diseases (J00-J99), which

established the need to improve the quality of Essential Obstetric and Neonatal Care in order to prevent and treat these important health problems in a timely manner [27].

Another important point in this study is that the highest infant mortality rates are in the most important urban areas of the country (Quito, Guayaquil and Cuenca) and the trend in these areas is increasing, despite the fact that sanitary conditions and medical assistance are much better than in rural areas; however, it should be taken into account that the information considered was analyzed by municipality of death, so it would also be important to apply it to municipality of residence in order to identify the main focus of risk; secondly, birth and death data should be better recorded in cities than in rural areas, which suggests that there could be an underestimation of the information in areas away from urban centers.

Conclusions

The application of spatial analysis methods in public health, allowed to analyze the temporal and spatial trend of infant mortality rates in continental Ecuador, the findings of this research can provide important inputs for the correct policy intervention [10] in relation to the prioritization of places that require greater accessibility and availability of child health care services, which contribute to the reduction of deaths of children under one year of age.

The municipalities with the highest risk of infant mortality should be identified as priorities and benefit from policies and the efficient allocation of resources [13, 14]. Associated with the above, this study provides relevant information for decision makers when planning policies and programs focused on this population sector. The geographic location of hotspots in different regions (amazon, coast, and highlands) and settings (urban or rural) makes it possible to combat health inequalities through the spatial targeting of areas [12], since the social and health characteristics are different for each municipality.

Finally, the proposed spatial prioritization method allowed the identification of priority municipalities, specifically those with high rates, increasing temporal trends and significant spatial clusters (Guaranda, Morona, Piñas, Cuenca, Ibarra, Tulcán, Guayaquil and Lago

Agrio), where actions can be taken to prevent and reduce infant mortality. Future studies could focus on determining the social and environmental factors that explain the observed patterns.

Abbreviations

IMR: Infant mortality rate; LISA: Local Indicators of Spatial Association; INEC: National Institute of Statistics and Censuses

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: Raw data are freely available at (open access): https://www.ecuadorencifras.gob.ec/nacimientos_y_defunciones/

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Contribution of the authors. EQ conceived the original study and reviewed the manuscript; KL and KR collected and processed the data, interpreted the results and wrote the first version of the manuscript; CS and GS supported the application of the LISA method. All authors have read and approved the manuscript and have contributed significantly to the work.

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