

Spatial and temporal distribution of cholera in Ecuador between 1991 and 1996

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Background: The seventh pandemic of cholera affected South America in 1991 after a century of absence. Favoured by local conditions, the epidemic of cholera in Ecuador had a rapid impact. The epidemic of cholera evolved with temporal and geographical variations. **Methods:** The temporal and geographical variations of cholera in Ecuador between 1991 and 1996 have been analysed. The Ecuadorian epidemiological surveillance system is a semi-active one based on obligatory weekly declarations. A geographical representation of annual impact rate has been made. Using a smoothing technique by cross-validation, time curves were identified and spatial diffusion was studied by cartography. **Results:** In 1991 and 1992, cholera in Ecuador evolved in an epidemic mode with two explosive epidemic peaks. Cholera then entered a phase of regression. The disease spread from two main epicentres, one in the South (El Oro, Guayas, Los Rios) and the other in the North (Esmeraldas and Imbabura). These focal outbreaks spread to neighbouring provinces during the peak outbreaks between 1991 and 1993. **Conclusion:** This study demonstrated that the epidemic spread from the affected provinces in the South and the North of the country.

Keywords: cholera, epidemiology, temporal and geographical variations

The current pandemic of cholera commenced in 1961 in Indonesia. In January 1991, it reached South America via the west coast of Peru after a century of absence of the disease in this continent.¹ The epidemic was particularly explosive in Peru. The epidemic rapidly reached neighbouring countries: to the North, Ecuador in February 1991, Columbia in April 1991, to the East, Brazil in April 1991, and to lesser extents in other South American countries.

Ecuador is a country of 270,000 km², bordered by Peru and Columbia, and comprising three main regions, from west to east: the coastal plain or Costa, the mountainous region or Sierra and the Amazonian plain or Oriente (figure 1, maps 1 and 2). The altitude ranges from 0 to 6300 m, leading to wide variations in equatorial climate between these regions. The population, a little over 10 million,² is particularly dense in the capital Quito and the port of Guayaquil.

The present study was designed to survey the epidemic of cholera in Ecuador between 1991 and 1996, in order to better understand factors underlying the origin and spread of cholera in Ecuador and to make proposals for reinforcing preventive measures.

METHODS

Data studied

The data were supplied by the epidemiological survey system set up by the Ecuadorian Ministry of Public Health. Cholera is placed in the 'Epi-1' alert category. It consists of a system of weekly semi-active epidemiological surveys based on obligatory declarations. It involves a total of 19 diseases declared each week by all care-providing units in the Ecuadorian Public Health system and other health systems. Data are collected by epidemiological units in the 22 provinces before being centralized and analysed by the central epidemiological unit in the Ministry of Health in Quito. Declared cases are cases suspected on the

grounds of the clinical definition of the WHO:³ in zones affected by cholera, a case is suspected in the event of an onset of acute watery diarrhea, with or without vomiting. In the absence of cholera in the zone under consideration, a suspected case of cholera is defined by the onset of serious dehydration or death after acute watery diarrhea. The first cases are confirmed by bacteriological tests. In the absence of differential diagnosis, no cases in children were included.

The study period extended from the first appearance of cholera in Ecuador in 1991, until 1996.

Analytic methods

The overall description was based on country-wide data. It comprised incidence data and plots of national weekly incidence. We used national data for total population from the 1991 census.²

In the subsequent analysis, we considered data at the provincial level thus providing a geographical and temporal view, which due to their interrelation necessitated more specific methods of analysis.⁴

In order to identify the most affected provinces, the average weekly incidences were mapped for each year (geographical distribution). The geographical unit was the province, the administrative unit in Ecuador. The choice of classes for this cartographic representation was based on a division of rate of incidence into four equal parts, in order to highlight provinces at the extremes.

The analysis of temporal distribution was based on a smoothing technique, designed to reduce data variability. Three factors can account for the variability in temporal series: the inherent variability in all temporal series in which the data are not continuous (our present data were weekly), the intrinsic variability of the epidemic, and variability derived from irregularities in notification.⁵

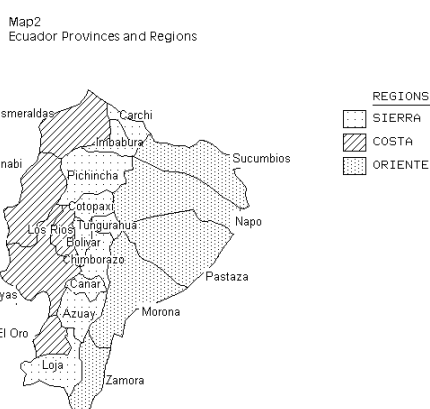
The smoothing method was based on the method of moving averages: each value in the chronological series was replaced by a weighted average of this value and neighbouring ones. The sum of the weights is equal to 1 and each weight is decaying as a function of the distance between the value to be replaced and the neighbouring one. Moreover the speed of this decay is governed by a parameter the 'window width' such that for a distance greater than this parameter the weight vanishes. We attempted to optimize window width by cross-validation using

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National curve of cholera weekly incidence rates per 100,000 people

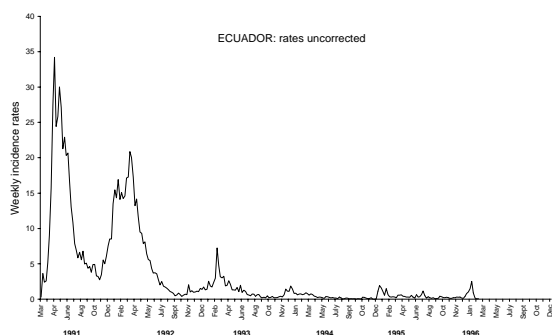


Figure 1 Ecuador: geographic situation maps, national curve of Cholera weekly incidence rates in Ecuador per 100,000 people from 1991 to 1996 (all provinces)

the function *supsmu* of S-Plus (see Hardle and Vieu⁶ or Venables and Ripley⁷ Chapter 9).

We employed this smoothing procedure on the weekly incidence rates in each of the 22 provinces. The 1991–1993 period was treated separately from the 1994–1996 period in order to distinguish the epidemic from the endemic periods. The rates obtained, referred to as the smoothed weekly incidence, were plotted as a function of time. This produced a series of curves that were analysed graphically, enabling study of the time course of the epidemic in each province. The curves did not always have the same scale on the ordinate axis. In this analysis, we focused on the most affected provinces, by specifically excluding

provinces of Oriente, where the low incidence rates would have led to errors in interpretation.

Finally, taking into account the temporal and spatial dimensions of the epidemic, temporal series of charts were analysed. For each week, charts were drawn representing the smoothed weekly incidence rates in each province. Alterations on a weekly basis in the class of each province could be discerned by study of a sequence of these 300 charts. The classes were multiplicative (logarithmic scale) in order to demonstrate marked variations. The two periods 1991–1993 and 1994–1996 displayed quite different peak smoothed weekly incidence rates due to the transition from the epidemic to the endemic phase, which is why they were distinguished by different classes.

Excel[®] was used for the descriptive analysis. Smoothing was carried out using the command ‘*supsmu*’ in the S-Plus software package,⁹ which has invaluable graphical outputs. EpiMap2 was employed for the geographical representations.¹⁰

RESULTS

General evolution of cholera in Ecuador between 1991 and 1996

The cumulated number of cases of declared cholera from 1991 to 1996 was 89,756, equivalent to a cumulated rate of incidence of 933 cases for 100,000 inhabitants (table 1).

87% of cases occurred during of the first two years, 1991 and 1992. In subsequent years, the number of cases fell to slightly over 1000 in 1996.

Nationwide, cholera outbreaks followed a first explosive epidemic phase in 1991 and 1992, followed by a phase of regression punctuated by epidemic peaks from 1993 to 1996. The national epidemic curve permits the visualization of those two phases (figure 1, national curve).

Geographic distribution

With more than 30,000 cases cumulated between 1991 and 1996, the province of Guayas contained a third of all the cases in Ecuador, and two-thirds of cases occurred in the Costa provinces. Over this period, Guayas had the highest annual number of cases, except in 1996, when it was replaced by Imbabura. The Oriente provinces had relatively few cases, and so little attention was devoted to these provinces in the rest of the study.

Referring the number of cases to the relevant population, the most affected provinces in 1991 (figure 2, map 3) were Esmeraldas and Imbabura, in 1992 (figure 2, map 4), El Oro, and from 1993 to 1996 (maps not shown) the provinces with the highest weekly incidence rates were Imbabura and Esmeraldas. In 1996 (map not shown), only the province of Imbabura had elevated average weekly incidence rates.

Table 1 Number of cases and rate of incidence of cholera from 1991 to 1996

Years	Number of cases of cholera	Rate of incidence per 100,000
1991	45,542	473
1992	32,421	337
1993	6,838	71
1994	1,717	18
1995	2,184	23
1996	1,054	11
Total	89,756	933
Number of inhabitants in Ecuador ^a		9,622,608

a: INEC (Instituto Nacional de Estadística y Censos). V^o censo de población Quito, Ecuador, 1991.

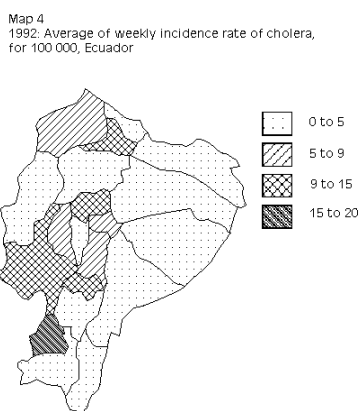
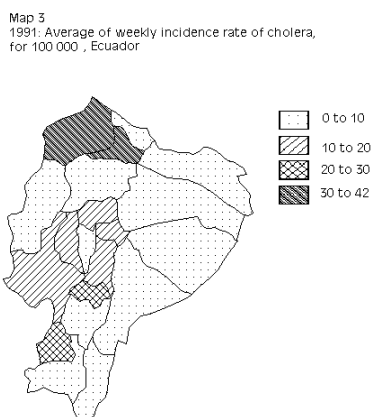


Figure 2 Geographic distribution: annuals maps 1991 and 1992

Outside the Oriente provinces, provinces with the lowest average weekly incidence rates per year were, from north to south: Carchi, Manabi, Pichincha, Azuay. From 1991 to 1995, the provinces with intermediate average weekly incidence rates (i.e. between the 2nd and 3rd quartiles of the distribution) were Canar, Guayas, Chimborazo, Los Rios, Cotopaxi and Tungurahua.

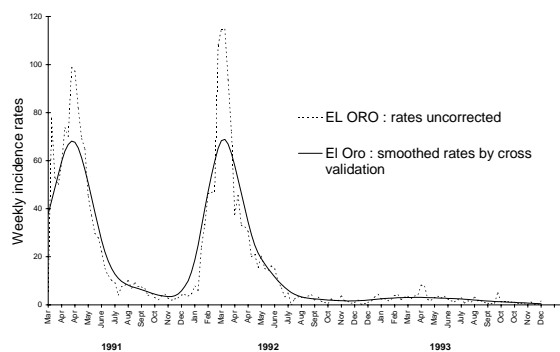
Time course

■ 1991–1992 (epidemic phase)

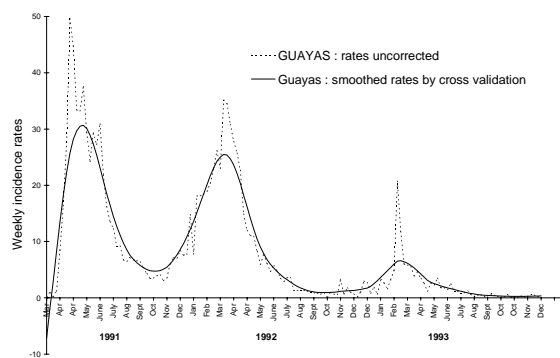
The smoothed curves over all provinces identified a first peak in 1991, a second in 1992. Figure 3 contains an illustrative sample of epidemics curves. In the provinces of El Oro (figure 3, curve 1), Guayas (figure 3, curve 2), Loja, Manabi, Chimborazo, Canar, Carchi and Bolivar, the first and second peaks had similar amplitude, indicating an equal impact of the epidemic over the first two years within these particular provinces. In this group of provinces, the smoothed curves of El Oro, Guayas and Loja exhibited similar time courses. In another group of provinces (Tungurahua, Los Rios, Imbabura, Esmeraldas), the first peak was more intense than the second, indicating a higher impact during the first year of the epidemic. By contrast, in the provinces of Pichincha and Cotopaxi (figure 3, curve 3), the second peak was markedly more intense than the first, indicating a larger and longer lasting impact of the second wave of the epidemic.

Examination of the dates of onset of peaks identified the three provinces of the Costa, El Oro (figure 3, curve 1), Guayas (figure 3, curve 2) and Loja, where the epidemic began in March 1991. In the other provinces, the first wave started in April 1991,

Curve 1: El Oro (Costa) 1991–1993



Curve 2: Guayas (Costa) 1991–1993



Curve 3: Cotopaxi (Sierra) 1991–1993

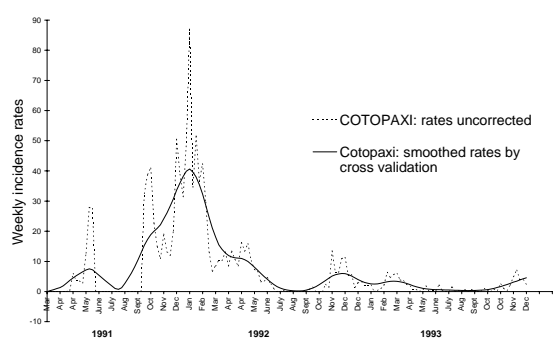


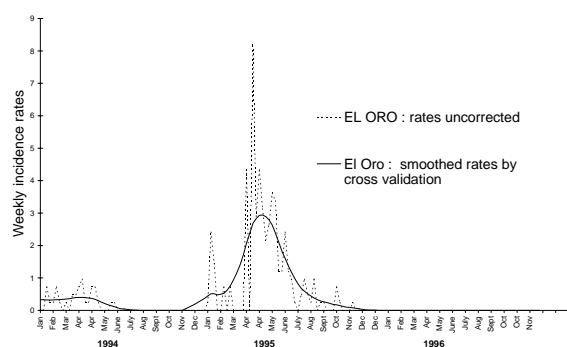
Figure 3 Time course: illustrative sample of curves of Cholera weekly incidence rates in Ecuador per 100,000 people by province from 1991 to 1993

with the peak between April and July. The second wave commonly started in November 1991, peaking between January and March 1992, and lasting longer than the first wave. However, there were variations between provinces, especially in Cotopaxi (figure 3, curve 3) and in Tungurahua.

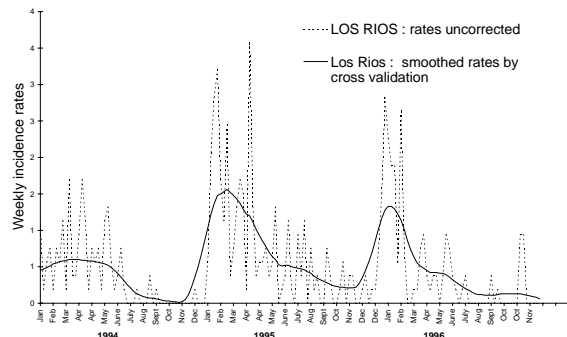
■ 1993–1996 (regression phase)

In the course of the period 1993–1996, the smoothed incidence rates did not exhibit clear-cut time courses, although the peaks could be identified. Figure 4 contains an illustrative sample of these epidemics curves. At the beginning of 1993, a peak was

Curve 1: El Oro (Costa) 1994–1996



Curve 2: Los Rios (Costa) 1994–1996



Curve 3: Imbabura (Sierra) 1994–1996

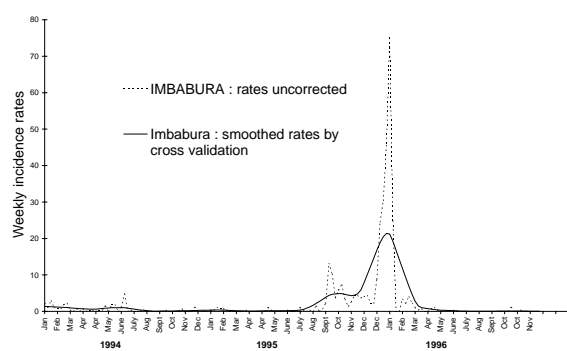
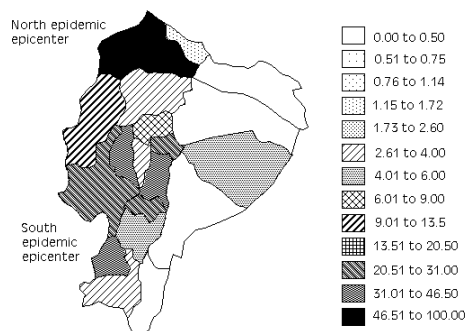


Figure 4 Time course: illustrative sample of curves of Cholera weekly incidence rates in Ecuador per 100,000 people by province from 1994 to 1996

observed in Guayas, Los Rios (figure 4, curve 2), Chimborazo, Imbabura (figure 4, curve 3), Esmeraldas, Cotopaxi and Tungurahua, peaking between January and April 1993. At the end of 1993, there was another wave in three northern and central provinces (Esmeraldas, Cotopaxi, and Tungurahua). From the end of 1994 to the beginning of 1996, a succession of peaks was identified in the Costa provinces (Guayas, El Oro (figure 4, curve 1), Esmeraldas), followed by Canar and Imbabura (January 1996) (figure 4, curve 3).

Map 5 Spatial distribution Smoothed weekly incidence rates of cholera, for 100 000, Ecuador 1991: week 23 (June)



Map 6 Spatial distribution Smoothed weekly incidence rates of cholera, for 100 000, Ecuador 1992: week 9 (March)

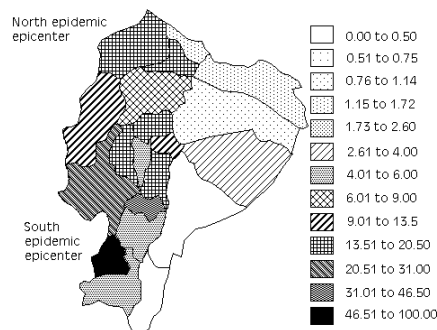


Figure 5 Spatial diffusion: illustrative sample of weekly maps

Spatial diffusion (time-based geographical progression)

Study of the 300 spatial diffusion charts (maps not shown) identified the epicentres of the epidemic. Figure 5, maps 5 and 6 are representative sample of diffusion charts and so, are static cross-sections of disease activity which depict the following key points. The epidemic started in the province of El Oro, to the south of the country, at the end February 1991, and by March 1991, it had reached the contiguous province, Guayas, and the provinces of Canar, Loja and Los Rios. These provinces constituted the first outbreak zone, centred on the province of El Oro, the 'southern epicentre'.

At the beginning of April 1991, the provinces of Esmeraldas and Imbabura, to the north, were strongly affected, constituting a second zone, the 'northern epicentre'. The provinces between the north and south epicentres, Manabi in the Costa, Pichincha, Cotopaxi, Tungurahua, Bolivar in the Sierra, were gradually affected between April and June 1991, constituting the 'central epicentre'.

After a variable fall in incidence depending on the province, a second epidemic started at the end 1991 in the provinces of the southern and central epicentres. This epidemic waned until December 1992 when incidence rates increased in each epicentre. In 1993 and in the beginning of 1994, the northern provinces were the most affected, with a moderately intense epicentre in the central provinces. In 1995, the epidemic resumed in provinces of the southern epicentre. 1996 was dominated by the epidemic in the northern province, Imbabura. From the end of 1993 to 1996, epidemic episodes observed in these provinces did not lead to any large-scale propagation to the other provinces.

DISCUSSION

Some comments concern the declaration process set up by the Ecuadorian epidemiological survey system. The definition of a case is a common problem in epidemiological surveying of cholera, and has yet to be standardized between countries.¹¹ The definition employed by the WHO is both clinical and epidemiological and is thus more suited to countries with limited microbiological facilities. Undernotification of cases, found in others studies in Latin America,³ may stem from various factors in Ecuador. Causes are linked to the current operation of the epidemiological survey system with its inherent difficulties in communication and overwork due to the large number of diseases to declare along with a lack of material resources. These difficulties may be particularly acute in some provinces, particularly in the Oriente, and at certain times of the year. An important cause is the underutilization¹² of data at the central or regional level, attributed in part to divisions of labour between the epidemiological survey and other departments in the Ministry of Health, which tends to lower staff morale. Other causes are political and may be related to the possible repercussions of outbreaks of cholera on tourism and food exports. However, this factor may be two-edged as the declaration of cases may also mobilize international aid.

With respect to the methods of analysis, the use of smoothing by cross-validation reduced irregularities in the declaration of cases (due to the weekly periodicity of the declarations and other delays in declaration), and also produced a descriptive analysis in the form of epidemic peaks and their spatial diffusion. The descriptive analysis of epidemic curves is frequently used in epidemiological surveys of infectious diseases. In descriptive epidemiology, disease mapping provides spatial variations of incidence rates.¹³ Finally, the geographical division was that of the 22 provinces or administrative units. This is a relatively large unit and it would have been of value to have finer scale data¹⁴ at the county level, to highlight variations between different zones (e.g. urban and rural),¹⁵ and characterize the spatial diffusion better.¹⁶

With almost 90,000 cumulated cases from 1991 to 1996, Ecuador is the third most affected country in South America, behind Peru (655,000 cases) and Brazil (331,000 cases). In terms of cumulated incidence from 1991 to 1996, Ecuador (933 cases per 100,000 inhabitants) comes in second position, behind Peru (2,700 cases per 100,000 inhabitants), but outstripping Bolivia (508 cases per 100,000 inhabitants), Brazil (201 cases per 100,000 inhabitants), and Columbia (102 cases per 100,000 inhabitants).³ Although these results have to be interpreted with caution due to national differences in definition of cases,¹⁷ studies¹⁸ have demonstrated a link between the impact of cholera and various economic indicators in Latin America. It would thus be of interest to have data on the socio-economic status of affected individuals. Reduction of the impact of cholera will undoubtedly hinge on improvements in sanitary infrastructure and conditions of hygiene in these countries.

The most affected provinces were distributed to the south of the Costa (Guayas, El Oro, Los Rios), the north of the Costa (Esmeraldas) and the north of the Sierra (Imbabura). In the Costa provinces, climatic conditions (heat, humidity), the presence of estuaries and swamps favours survival of the cholera vibrio.¹ Propagation of epidemics is also favoured by poor conditions of hygiene and overcrowding. Overcrowding is particularly significant in the province of Guayas (2.5 million inhabitants), which contains the large port Guayaquil, the most populated city in Ecuador, which can account for the large number of cumulated cases in this province. In the Sierra, provinces of the centre were highly affected. The involvement of these high altitude regions was somewhat surprising, although risk factors include poor sanitary conditions and hygiene and the numerous gatherings of people at traditional festival and

markets.^{19,20} The least affected provinces were in the Oriente, which can be accounted for by the low population density, the absence of population gatherings and undernotification. Despite the large number of inhabitants in the capital Quito, the province of Pichincha was the least affected due to the better socio-economic conditions prevailing there.

The epidemic of cholera in Ecuador from its onset in 1991 until 1996 evolved in the form of clear-cut epidemic peaks. The shape of the epidemic curve for the whole country over this six year period, with its two first peaks was comparable to that observed in Peru.²¹ There is thus a similarity in epidemic behaviour from one country to another. The explosive epidemic phase at the beginning of the epidemic can be accounted for by the absence of this disease from the South American continent for by more than a century: the population was not immunized, and curative and preventive measures had to be instigated with development of diagnostic resources, treatments, campaigns of hygiene, water purification, etc.²² In contrast, one can suppose that immunization of individuals, the response of the Ecuadorian health system, preventive measures, and improvements in hygiene conditions halted the epidemic phases in the following years. However, this still did not prevent a succession of epidemic peaks between 1993 and 1996. These factors were involved in all provinces to various extents, and there was considerable variation in the intensity of the second peak from one province to another. Analysis of the epidemic peaks did not evidence any seasonal occurrence. However, the largest numbers of outbreaks were observed between January and April, the months with the highest rainfall.²³

Study of the spatial diffusion of the epidemic showed that the epidemic comprised two epicentres, before spreading to provinces between them. The spread of outbreaks from one province to another from the two main epidemic epicentres in 1991 and 1992 can be largely explained by the migration of seasonal workers. Many Indians from villages in the Sierra work on farms in the Costa, where they contract cholera. The disease may spread on their return to their villages for traditional festivals. This tends to concentrate risk factors: population density, consumption of food in the streets, etc. Similarly, the epicentre observed in the provinces of Esmeraldas and Imbabura appeared to be linked to the return of seasonal workers from El Oro to Esmeraldas.²¹ One should also note that the disease spread along the main axes of communication, thus avoiding some provinces. Between 1993 and 1996, cholera had not spread from one epicentre to another, probably due to fact that rates of incidence were lower than those in the first two years of the epidemic.

In conclusion, our study showed that Ecuador was particularly affected by the seventh pandemic of cholera, with two main epidemic epicentres, one in the north and the other in the south of the country. The epidemic evolved in two phases, a first epidemic phase followed by a second declining phase of a succession of epidemic peaks. The existence of these epicentres indicates the need to focus epidemiological surveillance and prevention on these regions.

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