SPECIAL COLLABORATION

INTERACTIVE MORTALITY ATLAS FOR ANDALUSIA (AIMA)

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ABSTRACT

The mortality atlases published to date are static tools. Most describe the geographical distribution of mortality by grouping data from a series of years and using standardised mortality rates that summarise mortality in all age groups. This methodology, however, has certain limitations when used to study changes over time in the geographical distribution of mortality or differences between age groups.

The Interactive Mortality Atlas for Andalusia (AIMA) uses a different approach, i.e. a dynamic Geographical Information System (GIS) that displays, on a website, over 12,000 maps and 338,000 graphs of trends for the spatio-temporal distribution since 1981 of the leading causes of death in Andalusia according to age groups and gender. This paper aims to describe the methodology used to develop AIMA, to provide details of its features and technical specifications and to show the interactive options it can provide. The system is available from the productos tab (products) at www.demap.es.

AIMA is the first interactive GIS with such characteristics implemented in Spain. Spatio-temporal, hierarchical Bayesian models have been used to analyse data, and the results have then been incorporated into the web-site using a PHP environment and Flash-formatted dynamic mapping.

The selection of themed maps shows the dynamic character of the geographical distribution of mortality, with a different pattern for each year, age group and gender. The information currently contained in this system and any future updates will contribute towards a reflection on the past, present and future of health in Andalusia.

Key words: Bayes Theorem. Atlases [Publication Type]. Morbidity. Mortality. Health status Indicators. Medical informatics Data display. Geographic information systems.

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RESUMEN

Atlas interactivo de mortalidad en Andalucía

Los atlas de mortalidad publicados hasta la fecha son estáticos. La mayoría describen la distribución geográfica de la mortalidad agrupando datos de varios años y usando razones de mortalidad estandarizadas que resumen la mortalidad de todos los grupos de edad. Sin embargo, esta metodología presenta limitaciones para estudiar cambios temporales en la distribución geográfica de la mortalidad o diferencias entre grupos etarios. Aplicando una metodología alternativa surge el Atlas Interactivo de Mortalidad en Andalucía (AIMA), un Sistema de Información Geográfica dinámico que permite visualizar en web-site más de 12.000 mapas y 338.000 gráficos de tendencias correspondientes a la distribución espacio-temporal de las principales causas de muerte en Andalucía por grupos de edad y sexo desde 1981. El objetivo de este trabajo es describir la metodología utilizada para el desarrollo de AIMA, dar a conocer sus características y especificaciones técnicas y mostrar las posibilidades interactivas que ofrece. El sistema está disponible en el hipervínculo productos de www.demap.es. AIMA es el primer SIG interactivo de estas características implementado en España. Para el análisis de datos se han utilizado modelos jerárquicos bayesianos espacio-temporales, integrando posteriormente los resultados en web-site utilizando entorno PHP y cartografía dinámica en formato Flash. La selección de mapas temáticos muestra el carácter dinámico de la distribución geográfica de la mortalidad, con un patrón diferente para cada año, grupo de edad y sexo. La información contenida actualmente en este sistema y las futuras actualizaciones contribuirán a la reflexión sobre el pasado, presente y futuro de la salud en Andalucía.

Palabras clave: Análisis de Bayes. Atlas geográfico. Morbimortalidad. Indicadores de salud. Informática médica. Mortalidad. Presentación de Datos. Sistemas de información geográfica.

INTRODUCTION

The study of the geographical distribution of disease in small areas, or disease mapping, is currently a major research area. Here, hierarchical Bayesian models have played a leading role over the past few years, particularly the Besag-York-Mollié autoregressive conditional model.[1, 2]

One of the indicators that is most widely used to monitor the health status of the population through geographical maps is the general mortality rate, or mortality according to specific causes. Accessibility to this source of information, together with advances in computer systems, the availability of powerful Geographical Information Systems (GIS) and the implementation of complex mathematical models in specialised software have all encouraged the publication of many Mortality Atlases and ecological small-area studies over the past decade.[3]

Most Atlases published to date describe the geographical distribution of mortality by grouping year on year data into a single period. Some studies have even used periods spanning over 20 years, providing a very static view of mortality that occasionally groups together years when very distinct health plans and related legislation were in force. The use of time periods may also lead to a bias in the estimates for relative risk, such that the excess deaths seen in certain geographical areas may only be reflecting a past situation that, due to the aggregated nature of the information, is still being perceived.[4]

Additionally, most atlases use adjusted rates or standardised mortality rates by age groups and gender. The aim here is to summarise mortality data using a single indicator. However, the geographical distribution of mortality is not always the same in all groups. Therefore, a standardised indicator may not be appropriate to provide accurate information on the geographical pattern.[5-7] As a result, decision-making and health policies based on the interpretation of static maps and aggregate information may be inappropriate.

Health phenomena are dynamic and most European countries have experienced radical, rapid changes over the past few decades. Health determinants, healthcare technology and healthcare resources change over time and, in turn, also have repercussions for the population's welfare.[8] So, the evaluation of health outcomes, including mortality, should be approached from a dynamic time perspective that is specific for each age group and gender. This is the only way to describe the trends seen in health indicators, to evaluate the repercussion of past health policies and to ascertain the current health status of the population so that future improvements may be undertaken.[9]

Since 1984, several research articles have been published in Spain describing the geographical distribution of mortality from a static standpoint, using aggregate information and adjusted or standardised rates. Part of these studies allow information to be extracted for different geographical areas in set time periods,[10-19] but they do not enable conclusions to be drawn on the changes occurring over time in different population groups. As a complement to the atlases published to date, analysing both spatial and temporal trends in mortality in the towns of Andalusia according to year, age group and gender, would provide a both a historical and dynamic image of the population's health status. A description of these patterns would be a key starting point to evaluate healthcare measures implemented within the Region and would contribute towards advances in health outcome research, towards devising new interventions and the implementation of health policies targeting improvements in healthcare delivery and in the population's health.

This is the context in which the Interactive Mortality Atlas for Andalusia (AIMA) has been devised. This dynamic, web-site implemented Geographical Information System shows the spatial distribution and evolution of mortality over time by age group and gender for all Andalusian towns since 1981. This is the first system of its kind in Spain that can display over 12,000 maps and 338,000 trend graphs for 19 causes of death by age group and gender.

The aim of this paper is to describe the methodology used to devise AIMA, to provide details of its features and technical specifications as well as to show the interactive options it offers so that any professional may select and view the available information via the *productos* link on the www.demap.es website.

METHODOLOGY

Design. Ecological study using the town as the territorial unit for analysis.

Scope of the Study. The Autonomous Region of Andalusia, comprising 770 towns with a population of 8,039,399 inhabitants (3,988,887 men and 4,050,512 women), according to the revised 2007 Local Census. In 2006, Andalusia recorded 17% of all deaths occurring in Spain.[20]

Study subjects: This includes all deaths occurring as a result of the leading causes of death among citizens in Andalusia since 1981. The leading causes of death considered here represent over 1% of all deaths registered for each gender. This criterion was applied to analyse the specific causes of death described in Table 1.

Variables.

Mortality: Number of deaths recorded in each town for each year, cause of death, age group and gender. Seven age groups were considered, as follows: under 1 year, 1-14, 15-44, 45-64, 65-74, 75-84 and 85 or over.

Table 1

Causes of death considered in AIMA

Cause of death	ICD-10	ICD-9
All cause mortality	A00-Z99	001-E999
HIV-AIDS	B20-B24, R75	279.5, 795.8
Acute respiratory infection, pneumonia and influenza	J00-J22	460-466, 480-487
Stomach cancer	C16	151
Colon cancer	C18	153
Cancer of the liver and intra-hepatic biliary tract	C22	155
Lung cancer	C33-C34	162
Female breast cancer	C50	174
Prostate cancer	C61	185
Bladder cancer	C67	188
Diabetes mellitus	E10-E14	250
Alzheimer	G30	331.0
Ischemic heart disease	I20-I25	410-414
Cerebrovascular diseases	I60-I69	430-434, 436-438
Atherosclerosis	I70	440
Chronic lower respiratory tract diseases	J40-J47	490-496
Cirrhosis and other chronic liver diseases	K70-K74, K76	571
Road accidents	V01-V89	810-819
Suicide and self-inflicted injury	X60-X84	E950-E959

Population: Number of inhabitants living in each town by age group and gender for each year.
Spanish mortality rate: Number of deaths per 10,000 inhabitants in Spain for each year, age group and gender. For children under 1 year of age, the mortality rate was recorded per 1,000 inhabitants.

Sources of information. Town mortality was derived from the Andalusian Mortality Registry. The number of inhabitants living in each town was taken from the population estimates conducted by the Andalusian Statistics Institute (IEA) between official censuses for all years between 1981 and 2002. From 2003 onwards, the resident population was taken from the Local Census.

The specific mortality rates in Spain for each cause, gender, age group and year, as well as the Spanish population estimates between official censuses between 1981 and 2002 were taken from National Statistics Institute (INE) data. From 2003 onwards, the number of inhabitants in Spain was taken from the Local census.

Statistical data analysis. Two spatio-temporal hierarchical Bayesian models were estimated for each cause of death according to age group and gender. One of these was used to estimate the specific mortality rate, together with its time trends, and the other to estimate the specific rate ratio of each town compared with Spain as a whole.

In each model, it is assumed that the number of deaths observed in each town and year exhibit a Poisson distribution for each cause of death, age group and gender. The logarithm of the specific rate and rate ratio is expressed as the sum of a constant, a linear time line, a squared time effect and two random spatial terms. One of these is unstructured and captures heterogeneity between areas, while the other is structured to account for the clustering of cases in a given area. Both terms are common in *Conditional Autoregressive Models* (CAR) of this kind. [1, 2, 21]

Both models include a spatio-temporal interaction which enables the trend of the specific mortality rate and the rate ratio for each town to be modelled.[21] This estimate also pinpoints those geographical areas that have experienced an increase or decrease in mortality rates over time for each cause, age group and gender.

The model estimates were obtained by means of *Markov Chain Monte Carlo* (MCMC) algorithms, with 1,000 iterations for burn-in and at least 10,000 later updates. The convergence between estimates was verified using two chains through the Gelman-Rubin statistical model as modified by Brooks and Gelman.[22] We used WinBUGS software.[23] This methodology is an extended version of that proposed by Besag, York & Mollié and Bernardinelli *et al*.[1, 2, 21]

In all, 336 different models were estimated to meet our proposed aims.

Implementing the Geographical Information System on the web. The GIS developed for this study is based on the client-server architecture operating in the PHP environment and uses dynamic mapping in Flash format. The information collected from the estimation of the spatio-temporal Bayesian models was compiled through the Géoclip server, with an interface that manages data bases in MySQL, PostgreSQL, Oracle and SQL Server.

FEATURES AND TECHNICAL SPECIFICATIONS OF AIMA

AIMA is an interactive GIS that allows 12,768 maps and 338,000 trend graphs referring to the geographical distribution and trends over time of the leading causes of death in Andalusia to be viewed by age group and gender. The system is accessed via the *productos* link on the www.demap.es website.

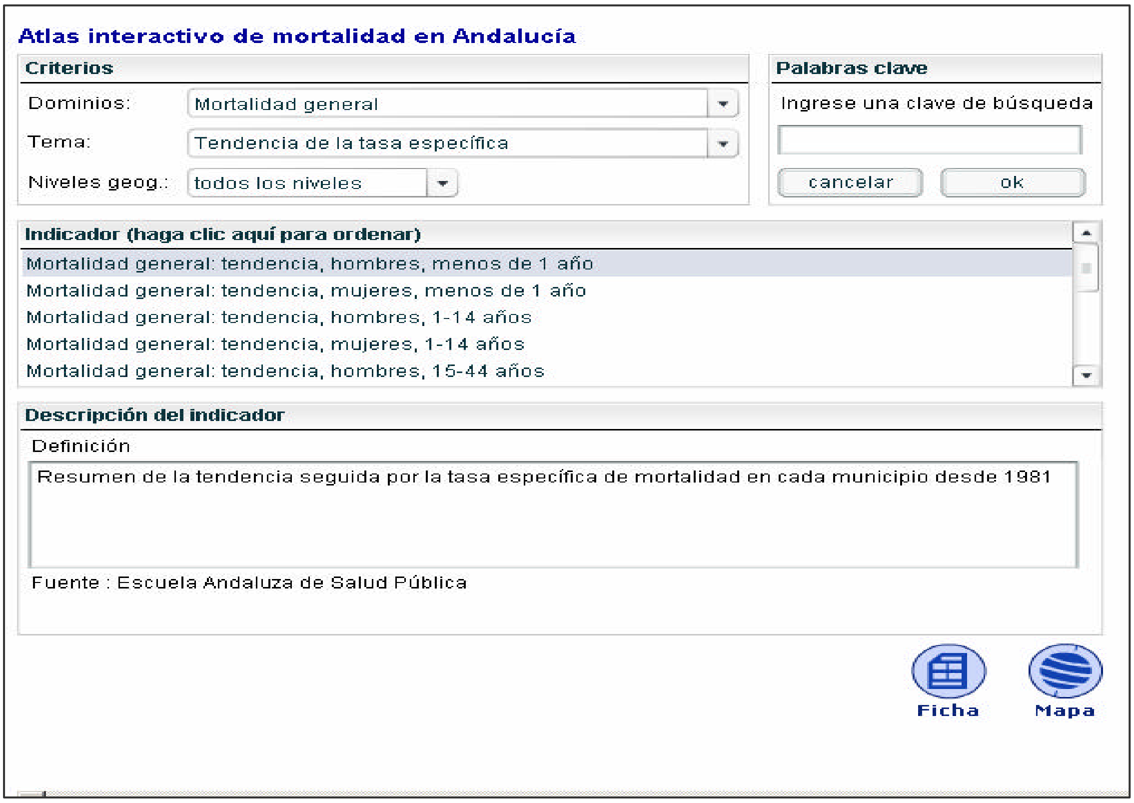
Selecting theme maps. The home screen for AIMA shows the selection criteria available for viewing the mapping information (Figure 1). There is an interactive menu with the following scroll down options:

*Domains***:** This allows for selection of any of the causes of death examined.

Topic: This allows selection of the kind of theme map to be viewed. For each cause of death, the user may select four options, namely, *Trend of the specific rate*, *Geographical distribution of the specific rate*, *Comparison with the Spanish national rate* and *Towns with significant excess mortality.* Below we provide a detailed description of the features and information contained in each option.

Geographical level: AIMA currently shows results on the town scale. However, future developments will build in the option of analysing on a census section, provincial or other territorial division.

Figure 1
Interactive interface to access AIMA



Year: Except for the topic *Trend of the specific rate*, this key selects the year for which information is to be displayed. The study period starts in 1981 for all causes of death except Alzheimer's disease and HIV/AIDS. Information on these two causes has only been available since 1985 and 1989, respectively.

Indicator: The age group and gender for viewing information can be selected here. We omitted from the study any cases where no or very few deaths were recorded for an age group or gender. As a result, the system only displays those groups examined within each cause of death.

The interactive interface also has an internal search option. When a key word is given, the application shows all indicators containing the search term.

Once the theme map has been selected, the result can be displayed by pressing either one of two keys, namely *Mapa* (Map) or *Ficha* (Report).

The *Map* key opens up a new screen showing the selected interactive choropleth map (figure 2). Here the user may, amongst other options, change the cut-off points, the range of colours and extract specific information for each town. Detailed assistance on the various options available can be accessed by pressing on the question mark symbol on the lower right hand corner of the screen.

The *Ficha* button generates a read-only document that will allow the selected map to be printed.

Below is a description of the most outstanding features and interactive options for each of the theme maps within AIMA.

Trend for the specific rate. This shows qualitative information on the trends in mortality over time for each town since 1981 (Figure 2.1. *Trend for the specific rate*).

The trends in mortality for each town are represented in blue and orange. The towns coloured in the darkest blue tone showed a significant downward trend over the whole study period. The next tone, a lighter blue, marks those towns where there was a statistically significant increase followed by a drop at some point between 1981 and the last year of the study. Towns showing no significant trend are marked in grey. Light orange denotes those towns where the trend changes from a decrease to a statistically significant increase, while the darker orange marks those towns with a trend towards a significant increase throughout the period.

The trend was considered to be statistically significant when the linear or squared coefficient included in the hierarchical Bayesian model had a probability of over 0.95 of being greater or smaller than zero.

Geographical distribution of the specific rate. This shows how the smoothed specific mortality rate, i.e. estimated from the above-mentioned hierarchical Bayesian model. The colour range on the map is organised with the indicator divided into quartiles (Figure 2.2 *Geographical distribution of the specific rate*). This division is independent for each year of the study, so that the same colours appearing on maps for different years will not be comparable as the categorisation of the specific mortality rate is different.

By placing the mouse over the town, specific information on the town will appear on the screen. On pressing the *Ctrl* key and left mouse (*ctrl+clic*), a contour of the town's boundaries will appear in red on the screen. Then a new window opens with trend graphs. The orange line represents evolution over time of the town's smoothed specific mortality rate, while the blue line refers to the specific rate for Spain as provided by the INE (Figure 2.2 *Geographical distribution of the specific rate*).

Comparison with the Spanish national rate. Taking Spain as the reference, the proportion of specific rates is the quotient between the specific mortality rate for the town and for Spain as a whole. The maps in this section show the smoothed specific rate ratio, estimated using the hierarchical Bayesian model mentioned earlier. Values over one indicate a mortality rate that is higher for the town than for Spain as a whole for the age group, gender and year selected, while values under one indicate a lower mortality rate for that town compared with Spain as a whole.

The values for the smoothed rate ratio are shown in diminishing shades of green (Figure 2.3 *Comparison with the Spanish rate*). The darkest green shows those towns where the rates ratio exceeds

1.10. The following tone is used for towns where the rate ranges between 1.01 and 1.10. The lightest green denotes the rates ratio that fall within the 0.91-1.00 range, while grey shows towns with a rate ratio lesser than or equal to 0.90.

The relevant information will be displayed when the mouse is placed over a town. By pressing *ctrl+clic*, a red contour around the trend graph will appear on the screen. On this graph, the orange line represents the trend over time of the specific rate ratio. The blue line gives a value of one as the reference to view years when there was an excess or deficit of mortality in the town compared to Spain overall (Figure 2.3 *Comparison with the Spanish rate*).

Towns with significant excess mortality. The maps selected under the tab *Comparison with the Spanish national rate* allow all towns with a specific mortality rate either higher or lower than the Spanish national rate to be viewed. These differences, however, are not always statistically significant.

The theme maps in the section named *Towns with significant excess mortality* show the *a posteriori* probability that the specific rate ratio is greater than 1. Those towns with a probability over 0.95 are shown in red, considering that there was a statistically significant excess mortality in that town compared to figures for Spain as a whole (Figure 2.4 *Towns with significant excess mortality*).

Towns with a specific rate ratio greater than 1 with probability less than 0.05 are displayed in green. In other words, in these towns the rate ratio was lesser than 1 with a probability of 0.95 or greater. Hence, these are considered as geographical areas with mortality that is significantly lower than the national rate.

The remainder of towns, in yellow, showed no significant differences in mortality compared with Spain as a whole.

Users can alter these cut-off points leading to a change in the number of towns with significant excess or deficit in terms of mortality, according to the criterion selected.

As with the preceding theme maps, placing the mouse over any town will display the relevant local information. By pressing *ctrl+clic*, a red contour will appear on the screen surrounding the town together with the trends graph. This graph shows the probability of the town having a specific mortality rate greater than for the country as a whole for each of the years included in the study (Figure 2.4 *Towns with significant excess mortality*).

Other theme maps. Besides mortality data analysis, AIMA includes a *Domain* on demographics showing the geographical distribution of the number of inhabitants by age group, gender and year. This graphical representation comes as a pictogram using circles that are proportional to the number of inhabitants in each town.

A contour of the town in red and a trend graph will appear after pressing *ctrl+clic* over any town. This graph shows the growth of the population for the town and Spain compared with the number of inhabitants in 1981. The dots that form the orange town line correspond to the quotient between the number of inhabitants for each year and the number of inhabitants in 1981 multiplied by 100. The blue line represents the same quotient with values for the Spanish population as a whole (Figure 3.1 *Number of inhabitants*).

The geographical representation of the population can be displayed over any of the mortality theme maps. This means that graphs on the evolution of the desired mortality indicator and the population can be viewed together for the same town (Figure 3.2 *Number of inhabitants and specific mortality rate*, figure 3.3 *Number of inhabitants and specific rate ratio*, and figure 3.4 *Number* *of inhabitants and significant excess mortality*).

Between 1981 and 2002, the IEA conducted population estimates between the official censuses in *homogeneous population units*. This means that two aggregate or segregated towns have been considered as a single area during this time period until 2002 for the purposes of estimating the number of inhabitants. As no separate population data is available for each of the towns, both thus form a homogeneous unit and have been assigned the same population from 1981 to 2002, giving rise to circles appearing on the map of the same size. From 2003 onwards, this limitation no longer applies as population data do not come from estimates but from information taken from the Local Census for each of the towns. During the implementation of this study, 11 homogeneous population units were recorded and are described in Table 2.

Table 2
Homogeneous population units in Andalusia between 1981 and 2002

Homogeneous population unit	INE Code	Municipality
1	04038	Dalias
	04902	El Ejido
2	04043	Félix
	04903	La Mojonera
3	11020	Jerez de la Frontera
	11902	San José del Valle
4	11023	Medina Sidonia
	11901	Benalup- Casas Viejas
5	18122	Loja
	18913	Zagra
6	18194	Zujar
	18912	Cuevas del Campo
7	23012	Beas de Segura
	23905	Arroyo del Ojanco
8	29067	Málaga
	29901	Torremolinos
9	41053	Lebrija
	41903	El Cuervo
10	41056	La Luisiana
	41901	Cañada Rosal
11	41079	La Puebla del Río
	41902	Isla Mayor

Source: National Statistics Institute (INE)

DISCUSSION

AIMA is the first Geographical Information System to be devised in Spain and enables the geographical distribution and trends over time for the leading causes of death for both men and women to be viewed on a website. The information within the system provides a dynamic image of the health status of the Andalusian population dating from a few years prior to our healthcare reform to the present day. This means that such data can be examined and regularly updated as a contribution towards understanding the past, present and future of health in Andalusia.

Over the past few years there has been growing interest in the development and implementation of different statistical models in order to study the geographical distribution of mortality in small areas.[24, 25] Despite its popularity, this kind of analysis poses certain limitations that also affect AIMA and should be taken into account if the results obtained in any small-area epidemiology study are to be interpreted correctly.

Firstly, any statistical technique allows the geographical distribution of mortality to be described, but it cannot explain the differences seen between areas. As all data is aggregate, we cannot know the level of exposure for any given risk factor for persons both dead and alive. Neither can we ascertain whether the individuals who currently reside in a given town have lived there most of their lives, and hence have been exposed to environmental risk factors. Therefore, any hypothesis suggesting a link between excess mortality detected in any of the areas and social inequities, use of healthcare services or environmental exposure may lead to what is commonly known as the ecological fallacy.[26]

Secondly, in small-area epidemiology studies it is common to find an information bias linked to unregistered migrations that are not recorded on official information systems.[27, 28] Studies conducted in Spain show that between 17% and 84% of deaths recorded in certain towns are for individuals who were not registered on the local census.[29-30] Further studies conducted in the U.S. revealed that 24% of deaths studied were recorded on the death certificate under an incorrect residence code.[31] Such flaws in information systems have led to major errors in estimating mortality rates.

Such errors are not only found in mortality studies. Research conducted on hospital admissions, cancer incidence and other health indicators have also revealed flaws in information records. For instance, 24% of all hospital admissions at a hospital in southern Spain were patients who lived in the town but who were not officially registered as residents, leading to an overestimation of the hospital admission rate per 100,000 inhabitants.[32] Likewise, certain studies have warned of major differences in figures for cancer incidence according to the denominator used in the calculation.[33, 34] Research in the U.S. also shows that rates based on population estimates differ by some 60% from rates based on census data, which may lead to a difference in calculations for breast cancer incidence of up to 22%.[34]

Since 1975, deaths in Spain have been classified according to place of residence and not place of death. No study has been conducted in Andalusia to date to assess the quality of data regarding town of residence and cause of death recorded on the Death Statistics Form. As a result, we should be extremely careful when interpreting mortality maps, or undertaking studies to correlate geographical distribution with different indicators or when positing hypotheses on the causes of death involved in differences in mortality between different geographical areas. Occasionally, health inequities recorded in small-area epidemiological studies may only be the result of unregistered migratory flows that are not recorded in official population figures.[35]

Given that death is the endpoint of a past health record, mortality indicators should be complemented by other sources of information that would provide an overall, dynamic view of the population's health status.

Over the past few decades, advanced societies have undergone far-reaching changes linked to phenomena such as globalisation, influx of immigrant populations or aging of the population that have brought about major transformations in the demographic, economic and social structure of the different countries.[36,37]

The magnitude of these changes has not always met with an organised response from the Epidemiology Surveillance Systems. As a result, the updating, monitoring and analysis of health indicators poses a key challenge for Public Health, for the prevention and control of the main health problems today, which are mostly linked to the new epidemics associated with social inequities or lifestyles seen in developed societies.[38,39]

Dynamic mortality maps provide up-to-date understanding of the geographical distribution and evolution over time of the leading causes of death, substantially improving on the information provided by conventional, static atlases. AIMA's interactive maps show that certain causes of death have very different geographical patterns according to the year, age group and gender studied, showing that it is not always appropriate to use time periods with aggregated years or to work with summary indicators such as standardised mortality rates or age-adjusted mortality rates.

Systematic updating of the information contained in AIMA and building this into current Epidemiology Surveillance Systems should enable us to pinpoint territorial inequalities in terms of health and to evaluate Public Health interventions and will serve as a useful tool to plan and evaluate health policies.

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APPENDIX

Below there is the list of all the professionals who have contributed towards the different stages of development of AIMA.

COORDINATION

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