ISSN 1828-5961

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Mapping and visualisation of health data. The contribution of the graphic sciences to medical research from New York yellow fever to China Coronavirus.

This paper will discuss the role of data visualization in the field of medical science and the relationships between health research and graphic sciences. Graphic representation allows the survey and the visualization of intangible phenomena. For this reason, computer graphics and technologically innovative imaging are now gaining a central role in all the disciplines based on the analysis of phenomena that occur in the territory and from which decision making depends. Thus, knowledge, techniques and tools of the graphic sciences are increasingly being asked to contribute to interdisciplinary research. Health data visualization can be a useful tool to reveal new insights on the spatial patterns of disease spread, mainly in the study of risk factors for diseases considered "environmental" because a considerable part of their spread can be attributed to environmental factors so that their distribution patterns result strongly associated with the spatially heterogeneous environment to which they are referred. The simultaneous visualization of health data with environmental data obtained from different sources can further the understanding of environmental-health linkages and can generate new hypotheses to be tested in future research. Disease mapping and environmental risk assessment using digital geospatial data resources are now established analytical tools in both human and veterinary public health. Participatory GIS, Volunteered Geographic Information communities as OpenStreetMap, Virtual Globes, online live tracking dashboards and other computer-assisted applications made it possible to translate datasets from different sources and users into maps easily understandable from the public. The use of these tools in geospatial health has been firmly established as a useful tool for collating, exploring, visualizing and graphically analyzing health data. As a result, new approaches aimed to visualize, describe and explain the spatial patterns of diseases are being developed in different research fields, that will be analyzed in this paper.

Keywords:
maps; data visualisation; geospatial visualisation; graphic representation; medical research

INTRODUCTION

In this paper will be discussed the relationship between health research and geospatial visualization techniques and tools. Health data visualization can be a useful tool to reveal new insights into the patterns of disease. Furthermore, the simultaneous visualization of health data with environmental data obtained from different sources can further the understanding of environmental-health linkages and can generate new hypotheses to be tested in future research (Stensgaard et al 2009).
Disease mapping and environmental risk assessment using digital geospatial data resources are now established analytical tools in both human and veterinary public health (Bergquist, Rinaldi 2010; Richardson et al, 2013). Indeed, new subdisciplines aimed to visualize, describe and explain the spatial patterns of diseases are being developed in different research fields. In the last decade, the dedicated scientific journal has started to focus on these topics. Moreover, in 2002 started the publication of International *Journal of Health Geographics* and in 2006 *Geospatial Health*. An essential aspect of health research is the study of risk factors for diseases considered "environmental" diseases because they are attributable to environmental factors (Listorti and Doumani 2001; Prüss.stün, Corvalan 2007). Thus, distribution patterns are strongly associated with the spatially heterogeneous environment in which they are entranced (Woolhouse et al., 1997; Brooker and Clements, 2009).
Geographical information systems (GIS), satellite-based remote sensing (RS), geographical positioning systems (GPS), spatial statistics and other computer-assisted applications made it possible to translate datasets into maps. Indeed, the use of GIS in geospatial health have been firmly established as a useful tool for collating, exploring, visualizing and analyzing health data in a graphic manner (Hendrickx et al. 2004, Cringoli et al. 2005, Yang et al. 2005; Rinaldi et al. 2006, Brooker, 2007).

GEOSPATIAL INFORMATION FOR HEALTH RESEARCH

ILocation is traditionally considered important for health. Hippocrate (460 to 377 BC) in *De aeris aquis et locis* observed that certain diseases tend to occur in some places and not in others. Spatial analysis using maps to associate geographic information with disease can be traced as far back as the 17th century. Examples of the use of maps for the visualisation in the field of health research are been highlighted (Bergquist, Rinaldi 2010; Utzinger, Jürg, et al.) including the world map of diseases produced by the German physician Finke in 1792 and the mapping of yellow fever occurrences in the harbour of New York in 1798 (Fig.1), the map of the addresses of cholera victims that in 1854 shown the relationship with the location of water supplies in London's Soho district (Fig. 3). The GIS development started in this century, in the 1832, with the spatial analysis of mortality in Cholera epidemic in the city of Paris experimented by the French geographer Charles Picquet (Yasobant, Vora, Upadhyay 2016) (Fig.2). In 1874, Dr. Sidney H. Carney, then Associate Medical Director for the New York Life Insurance Company, used data from the company's files to represent incidences of disease in the eastern United States. The charts show prevalence of malaria, pneumonia, rheumatism, typhoid fever, and phthisis. Carney decided to chart five of the diseases that were then commonly understood as being tied to the physical environment (Fig. 4). Starting from these experiments, mapping the phenomena linked to health became usual. The map of the distribution of hookworm in Texas, drawn at the beginning of

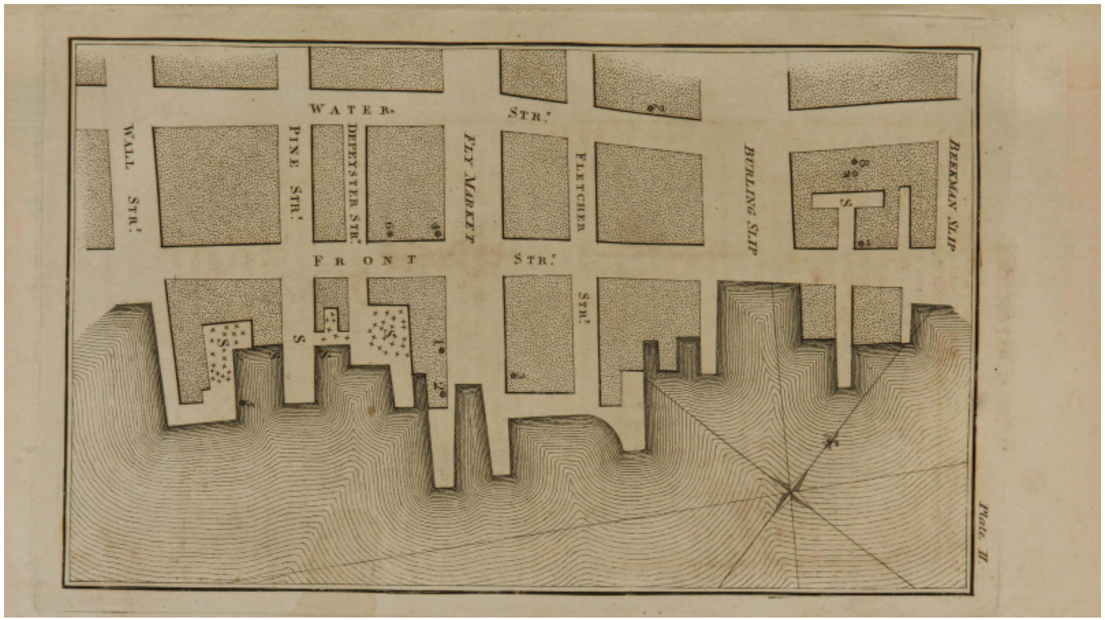


Fig. 1. Map of yellow fever occurrences in the harbour of New York, 1798.

Twentieth century was crucial to the elimination of hookworm disease in the United States, as well as worldwide risk mapping of malaria was a key feature to guide control approaches.
In 1970 Dr Barnett Cline experimented the application of computer technology and advanced statistics, until then applied only for military and economic needs, for epidemiological investigations for epidemiological research and public health (Cline 2006). These technologies continue to develop thanks to more sophisticated and user-friendly instruments and software and to the accessibility to data and applications through the Internet.

HEALTH MAPPING AS A PUBLIC TOOL

Even today, geographically related data continues to receive increasing attention and are considered essential for monitoring the health of the population and for health planning. Many countries, and even some private organizations, consider spatial data as one of their resources of most significant interest in their development. This information allows each country to identify and geographically locate its weak points and geographical potential. Even the World Health Organization, sensing this potential, has started to collect these spatial data all over the world to facilitate the mitigation and control of the spread of certain diseases. Since the World Health Organization (WHO) is the authority, within the United Nations system of surveillance and coordination for public health, it must provide technical support to countries, monitoring and to evaluate health trends worldwide.
In this regard, geographic information systems (GIS) and remote sensing data are fundamental in order to keep infectious diseases and their geographical distribution under control. At the same time, the analysis of the spatial developments of the diseases allows mapping the populations at risk, allowing to plan and direct the useful interventions and monitoring its evolutions in real-time. Therefore, giving significant value to GIS, for the public health information, in 1993 the joint WHO-UNICEF program on health mapping and GIS (HealthMap) was created to meet the map-

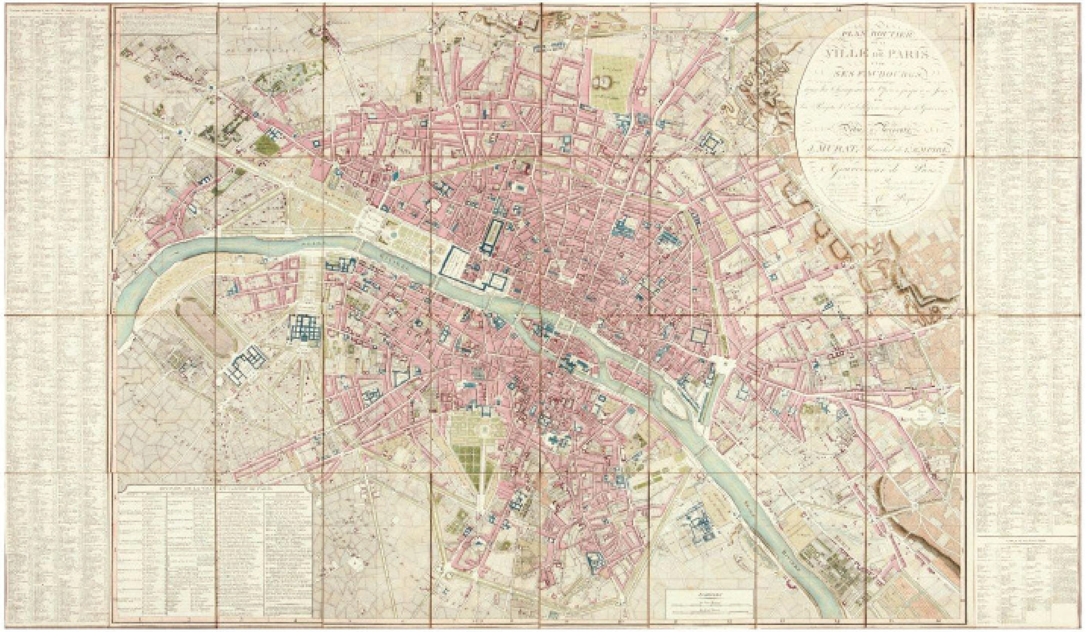


Fig. 2 - Map of mortality in Cholera epidemic in the city of Paris, 1832.

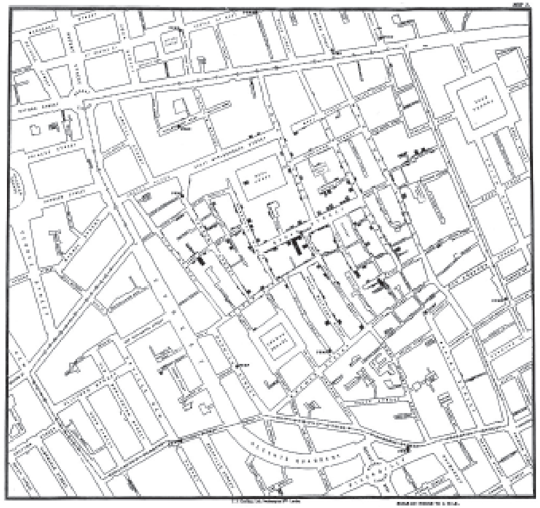


Fig. 3 - Map of the addresses of cholera victims that in London's Soho district, 1854.

ping and monitoring needs of the dracunculiasis eradication program. To continue with this aim, they have developed some easy-to-use tools and GIS services that assist the organization, allowing the information to be disclosed to the authorities concerned. Some essential tools developed by the organization are The Remote Field Data Collection Tool, The Global Health Atlas and The Health Mapper, accessible through download from the WHO website (Hossain I., Firdausy T.P, Behr F-J., 2010). On a single web platform, The Global Health Atlas, based on the characteristics of The Health Mapper, standardized data and statistics are collected for the analysis of the twenty diseases selected with three hundred indicators at the national, regional and global level. This information represented through maps that allow easy visualization of geo-referable conditions, such as the number of villages infected with the disease or the state of resistance to it. This tool, and the various GIS applications developed by WHO, as well as providing support to surveillance bodies and warning systems, are easy to use even for non-professional users.
Many studies show how issues related to the geography of places and their mapping, in particular through geographic information systems (GIS), have become increasingly relevant for research and political management in the field of public health. Among the most critical issues, we note: how the mapping of health structures allows measuring accessibility to health systems; the ability of GIS systems to define a geographical unit to evaluate the delivery of healthcare; and lastly, the optimization of the efficiency of the methods to plan the location and allocation of health resources (Wang F., 2019).

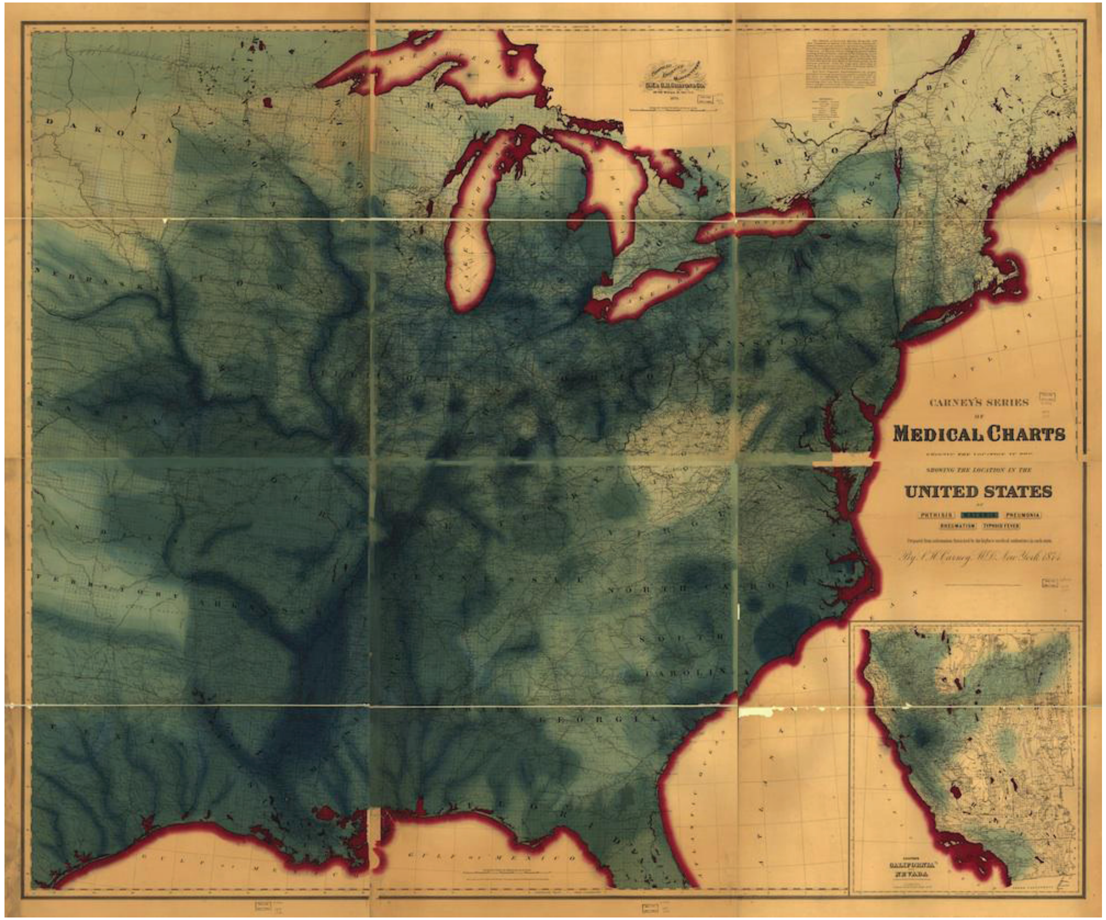


Fig. 4 - Map of malaria occurrences in the eastern United States, 1870.

COLLABORATIVE MAPPING FOR HEALTH

Paying attention to maps, as a graphic representation of space and the dynamics associated with it, shifts the field of interest towards the disciplines of design and graphics. The exploration of maps as representation expands the vision of cartographies as communication tools where essential skills related to symbolic representation take the field. From the methodological point of view, the realization of a traditional map requires the careful choice of graphic symbols that allow recognizing the elements of the earth that intend to represent and expert knowledge for its realization.
The introduction of IT systems and the ease of these open source mapping tools have also made it possible to create interactive maps based on the collaborative mapping community method. The spread of these powerful technologies and tools has allowed the easy creation and dissemination of content on the net. Collaborative mapping is a community action that allows creating maps by contributing cartographic elements into a uni-

versal system of geographic information (Rouse L. J., Bergeron S. J., Harris T. M., 2009). This approach to mapping prefers to use open scientific, educational and technological resources to obtain the mapping results sent with an open license. An example of this is the mapping of health structures of healthsites.io, which where the collaborative principles are fully applied, paying close attention to the quality of the geodata. The interactive maps applied to manage the possibilities for users to identify the healthcare facilities in a specific area and obtain information on the services and resources associated with them.
Until just over a decade ago, users only received access to information on a website but could not collaborate in data care. Today, operating models have changed with the implementation of Internet technology. Tim O'Reilly (2005) introduced the concept of Web 2.0 by suggesting decentralizing the management of the contents of a website. This tool allows to avoid that data is not managed by a specific group of people alone but can also be integrated by other users. This method allows not only to share but also to integrate information. In this regard, many studies have applied to apply the concept of Web 2.0, and some public health programs have seen the participation of several users who have contributed with their information to the creation of useful tools for monitoring health issues.
With the same principle of collaborative mapping, many other refined tools have listed for the visualization of georeferenced data and interactive maps. The geospatial and data visualization tool for cancer data (Wen-Yuan K., et al, 2019) has made it possible to modify a collaborative online map to allow the use of sharing and inspecting cancer data worldwide and locally. The cancer map (Fig. 5 - 6). uses an implementable database-based model, which was built through the

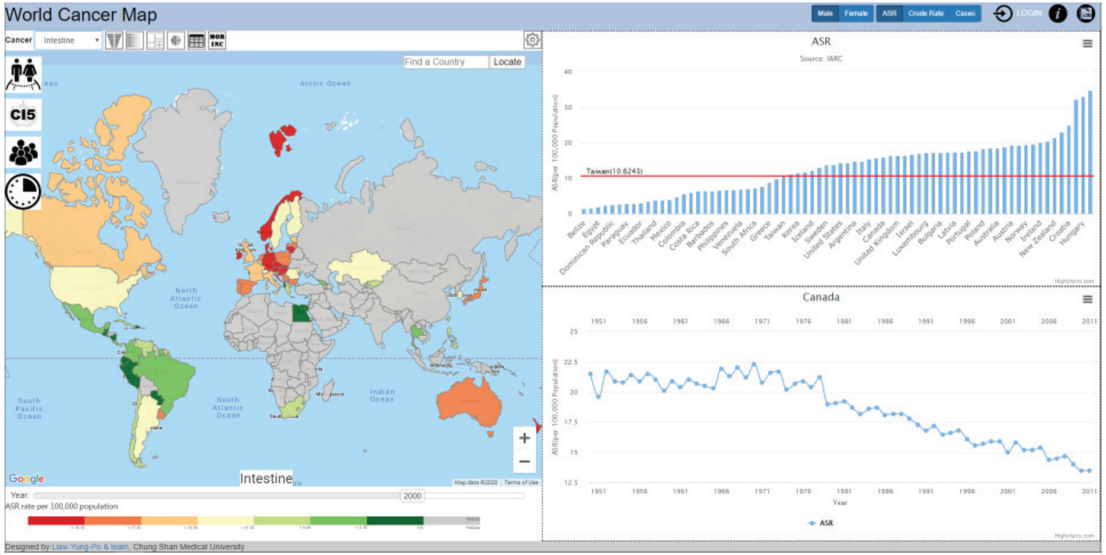


Fig. 5 - Map of intestine cancer using a choropleth map to present cancer mortality trends, https://worldmap.csmu-liawyp.tw/

Fig. 6 - Heatmap of leukemia showing variations in lung cancer across different countries by year, https://worldmap.csmu-liawyp.tw/.

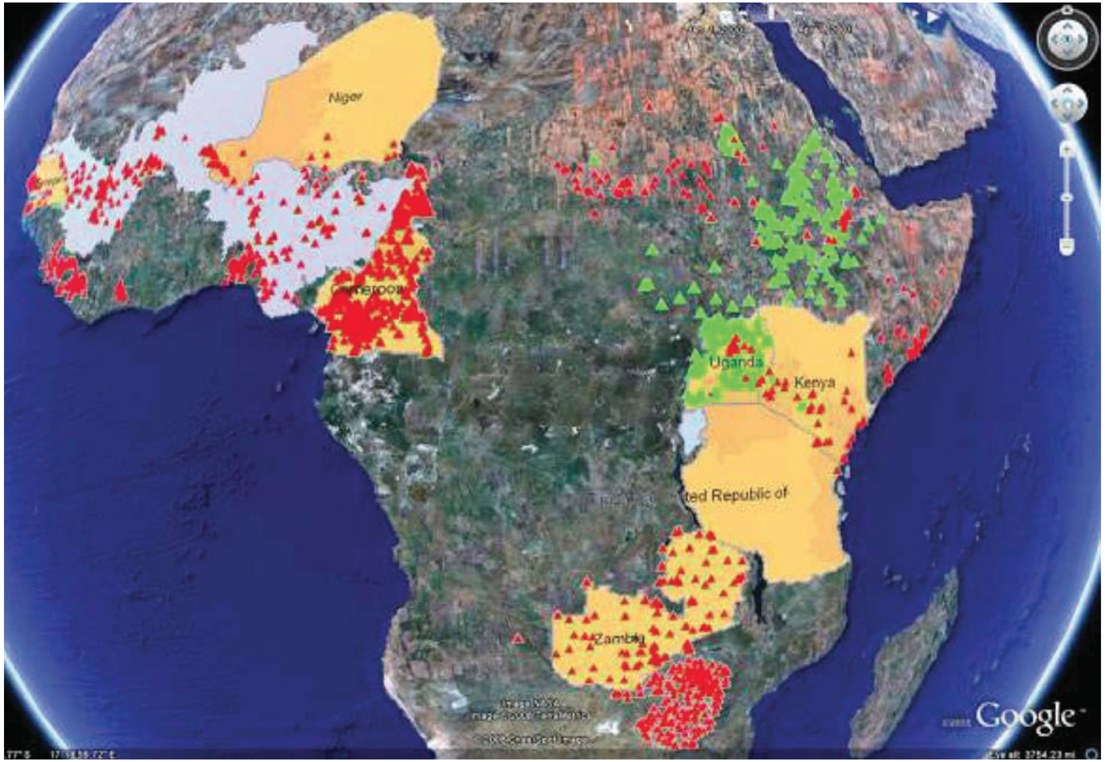


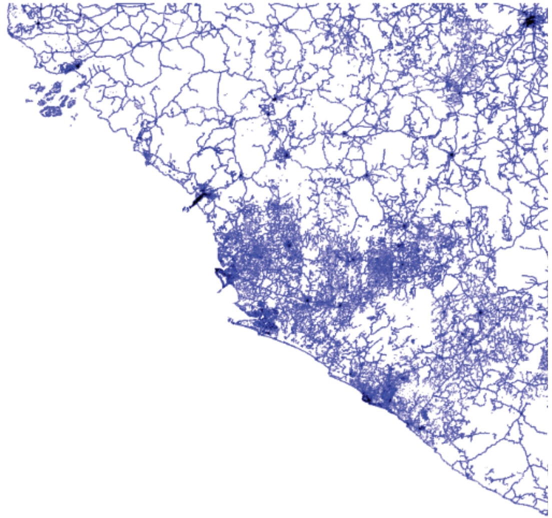
Fig. 7 - A Google Earth™ visualisation of the information contained in a single KML (A.S. Stensgaard et al., op. cit).

technologies of JavaScript XML (AJAX) and Google Map Application Programming Interface (API) countries to manage and share cancer data. Also, this platform allows any user to collaboratively disseminate and implement cancer data, making data processing and collaboration more complete.

OPEN SOURCE MAPPING TOOLS

A virtual globe is essentially a web-based GIS tools used for the 3D visualisation of the Earth based on satellite imagery upon which spatial information can be represented. Users are able to add and to share their own data and to freely explore the virtual environment by zooming and changing their position. Virtual globe technology has provided a cheap and accessible method to communicate data both to non-specialists and among scientists (Butler 2006) and the number of publication that use this virtual globe as tool for visualising and processing data is constantly growing in all the research fields (Stensgaard et al 2009). The most used virtual globe is Google Earth, primarily aimed at the general public, but also widely used for display and disseminate scientific data and research results. Creating Keyhole markup language (KML) files it is possible the visualisation of data in Google Earth™ (Fig. 7).
Individual citizens are contributing to the production and the gathering of geospatial data by the real-time interactive GPS/GIS functionality embedded in mobile phones. The accessibility to the data gathered by this type of participatory GIS, or volunteered geographic information, are expanding also the opportunities for mapping health data (Mooney et al. 2013). The Volunteered Geographic Information community (Goodchild 2007), is a global community, which collaborate to create a detailed base map, similarly with the Wikipedia model of information collection. Some of these, as OpenStreetMap has been analysed as source of heath data (Mooney et al. 2013). OpenStreetMap is a project with the mission of creating free maps. Contributors collect spatial data mainly from portable GPS devices and make this data freely. Furthermore dedicated tools, such as WHO' s Health-

ISSN 1828-5961



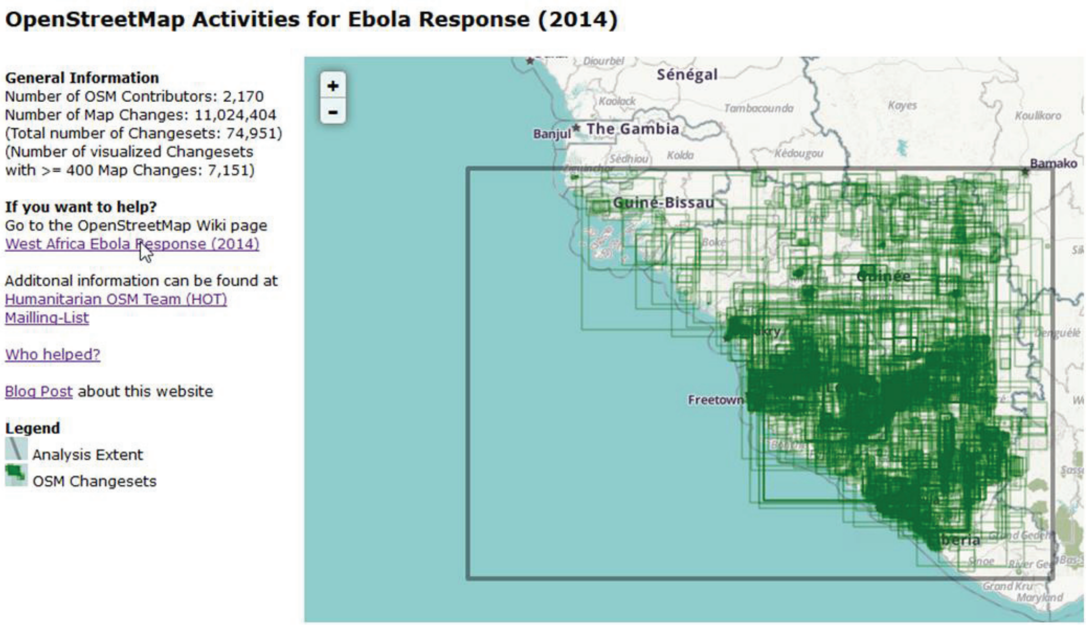


Fig. 8 and 9 - Visualization of all that mapping work West Africa's Ebola outbreak by Humanitarian OpenStreetMap Team.

Mapper or CDC's EpiMap, have been developed to mapping disease distribution and community treatment information (Fòetcher-Lertey, Caprarelli 2016), as well as to produce detailed maps of areas affected disease outbreak for humanitarian aims (Figs. 8 and 9).

BEYOND VISUALISATION: MAPS FOR HEALTH RESEARCH AND PUBLIC INVOLVEMENT

Knowledge in health research can be of different types and can be well represented by a knowledge funnel (Graham et al. 2006). As knowledge moves through the funnel, it becomes more distilled and refined and presumably more useful to stakeholders. Referring to the classification of Graham et al. it is possible to distinguish the different level of elaboration of data in health research in

- Raw data (First-generation knowledge).
- Visualisations (Second-generation knowledge). It consists in the processing of existing knowledge by the application of explicit and reproducible methods to the identification, appraisal, and synthesis of studies or information relevant to specific questions.
- Maps (Third-generation knowledge). It consists of knowledge tools or products aimed to present knowledge in clear, concise, and user-friendly formats and ideally to provide explicit recommendations with the intent of influencing what stakeholders do and to meet the stakeholders' knowledge or informational needs, thereby facilitating the uptake and application of knowledge.

From scientific publications in the field of health research emerges that the elaboration of health data has generally concluded at the second level (second generation knowledge), because of the lack of specific technical skills in the research teams that can allow the elaboration of information of the third level (third-generation knowledge).

Among the most recent applications in monitoring the expansion of epidemics is the case study of the coronavirus, recently discovered in China and whose spread has been monitored and graphically represented in real time. The Johns Hopkins Center for Systems Science and Engineering has built and have regularly updated an online dashboard

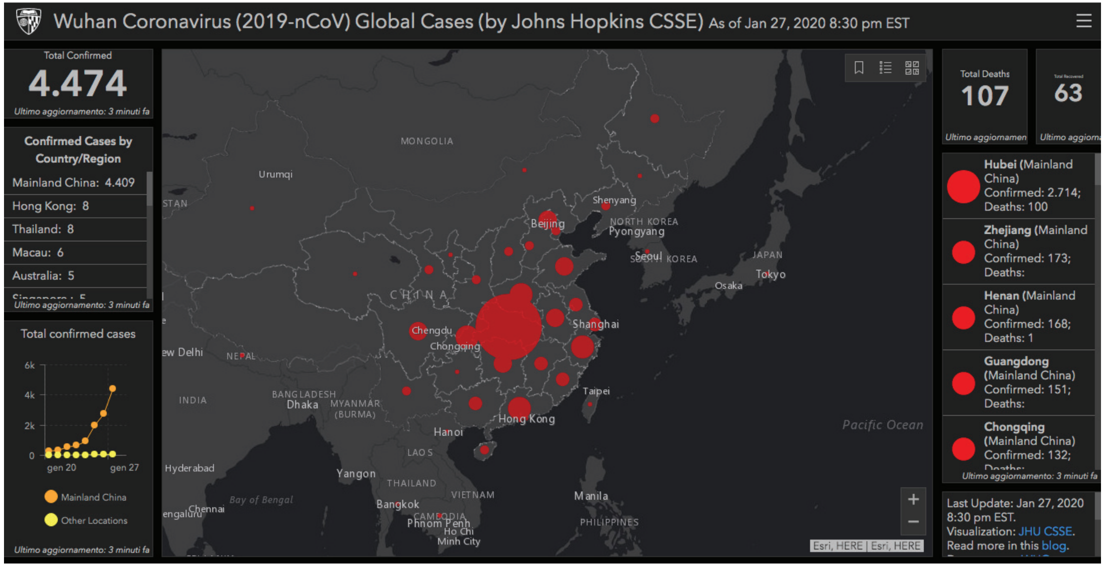


Fig.10 - Online dashboard for live tracking the worldwide spread of the coronavirus outbreak that began in the Chinese city of Wuhan.

for live tracking the worldwide spread of the coronavirus outbreak that began in the Chinese city of Wuhan. A mapping website was launched to displays statistics about deaths and confirmed cases of coronavirus, or 2019-nCoV, across a worldwide map. It also allows visitors to download the data for free. The website provides a link to a downloadable Google Sheet that contains information on confirmed and suspected cases. The online dashboard was build because it was considered important for the public to have an understanding of the outbreak situation as it unfolds with transparent data source, and for the research community, to continue to collect data over time (Fig. 10).

CONCLUSIONS

Visualizations provide policymakers of interfaces to visualize phenomena on health, helping them to make informed decisions about improving health policies. However, visualization tools and methods require particular technical skills (Caprarelli and Fletcher 2014), which are necessary to ensure that knowledge transfer occurs, differently from maps that can translate the knowledge in graphic forms easily readable and understandable. This kind of knowledge translation allows the transmission of the research result utilizing graphic representations that can use with different aims, as the involvement of stakeholders in the decision-making, the sensitization of the public opinion in topics of public interest and, lastly, the knowledge transmission in a historical perspective. Indeed, only through the knowledge translation in refined and finished graphic representations can ensure to visualization to be not only an useful tool for researchers involved in the phenomena interpretation at the moment of the production of research results but can be transmitted also to other scholars and research teams, thanks to mapping, the graphic translation processes aimed to codify information in a clear, unambiguous, and self-explanatory way. For this reason, it would be desirable a better collaboration between scholars involved in health research and experts with skills in graphic representation and visual communication. As evidenced by the case studies of historical medical maps presented in this paper, the knowledge transmission can be effective only thanks to specific attention to the graphic and visual dimension of the research results presentation, that graphic quality that makes maps able to communicate phenomena even after centuries.

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