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Using GIS in the Time of the COVID-19 Crisis, casting a glance at the future. A joint discussion

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Abstract

This paper was born as a joint discussion about the possible use of GIS for tackling health emergencies in cases of infectious diseases and pandemic. After providing some considerations regarding the COVID-19 sanitary and epidemiological aspects and implications, we underline and discuss some GIS applications produced to support the emergency phases and representing and sharing data in some continuously updated dashboards and becoming reference elaborations. In particular, the need for the development of rigorous GIS systems for pandemic response is highlighted and some recommendations for recording a notable added value are expressed, with a first reference to a set of applications focused on the United States. Other considerations, deriving from the experience that we have actively had working in Italy, are then focused on the need to elaborate detailed models of spatial and temporal diffusion in a GIS environment, according to ad hoc data, and digital flow (or route) maps, based on data tracking, with the aim to save human lives. For this purpose, some thoughts are expressed on the importance of finding the way to overcome a number of difficulties due to the management of sensitive data and privacy aspects, guaranteeing appropriate confidentiality.

Keywords: COVID-19, Dashboards, Data Tracking, Geocoding, GIS Applications and Models, Pandemic, Spatial and Temporal Diffusion

1. COVID-19 sanitary, epidemiological and geotechnological considerations

The 8th December 2019 is the day when cases of atypical pneumonia of unknown aetiology started to be reported in China, Wuhan City, Hubei Province. Many of these cases were people who worked or lived around the local Huanan Seafood Wholesale Market, even if there were also subjects affected that were not exposed to the market (Lu et al., 2020)

The Chinese Health Authority informed the WHO of this outbreak only on 31st December 2019 and on January 9th a novel coronavirus, later named SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2), was first isolated by a throat swab of a patient (Hui et al., 2020).

Despite all the efforts made by the Chinese health authorities to contain the outbreak in Hubei Province, the virus spread first to other parts of China and then worldwide until the WHO announced the COVID-19 outbreak a pandemic on 12th March 2019. Two and a half months have passed since that day, and today 27th May there are 5,728,020 confirmed cases of COVID-19 and 353,660 deaths worldwide.

Initially, given the mode of transmission of the disease (through droplets) and the scarce knowledge of the severity of the disease, the epidemiological debate immediately focused on whether a strict social distancing should be enforced to reduce the risk of infection or whether the virus could be allowed to spread in the population so as to achieve a herd immunity that would extinguish the epidemic. As the number of cases increased in European countries (Italy was the first country in Europe to tackle COVID-19 cases and isolate the virus) and in the USA, most of them opted to impose draconian measures to mitigate the spread of the virus and reduce the impact on health care systems and in particular on hospitals which were struggling to provide care for the many patients with severe pneumonia who needed specialized intensive care. These measures, mostly addressed by epidemiological studies based on data from China and high-income countries predicting catastrophic scenarios in the absence of policies aimed at mitigating or suppressing transmission (Walker et al., 2020), have been implemented in different ways in European countries, from total lockdown in Italy to semi-closure in Sweden and in the United States. The main goal was to reduce the basic reproduction number of the infection, the so called R_0 (i.e. the expected number of cases directly generated by one case in a population where all individuals are susceptible to infection). The temporary closure of most stores, offices, schools and the activation of smart working and distance learning seem to have had an effect while pushing countries into an unprecedented economic recession due to the lockdown measures. At present, in order to reduce economic impact, most countries have opted for a reopening of activities, given the results achieved in terms of reducing contagions, ready to close again if contagions increase beyond the safe threshold. This alternation of opening and closing will probably continue until we have a medical solution to the problem. The magic bullet would be an effective treatment or a vaccine whose availability however is not expected before 2021.

In this scenario, it seems more fundamental than ever to have systems available that allow the tracing of cases and the almost real-time detection of epidemic outbreaks that allow their rapid control and extinction. In some countries, case tracking has taken advantage of new technologies that have allowed the use of web-based health applications with different purposes: monitoring of the epidemic, tracing, or tracking of one's own movements (Vokinger et al., 2020). These "apps" involve the acquisition and use of personal data and seem to have had some success in countries with less stringent privacy legislation (COVID-19 National Emergency Response Center, Epidemiology & Case Management Team, Korea Centers for Disease Control & Prevention, 2020). In other countries, however, the use of apps has been faced with privacy issues that have hindered their full use so far. From a privacy perspective, the collection of data through digital devices is extremely sensitive, for which robust privacy safeguards are of paramount importance (Vokinger et al., 2020).

Despite the privacy issues, concerning which considerable efforts are being made to overcome, the importance of using GIS technology to obtain spatial information on the degree of spread of the disease and its evolution in real time is striking in the eyes of the scientific community. When the epidemic began to spread around the world, the use of dashboards became crucial to move information faster than the advance of the virus. However, GIS technology can be very useful in providing health professionals with a wide range of information. First, the use of real-time case mapping can allow the early detection of new oubreak sources and identification of spatial boundaries to allow confinement. Second, the use of GIS combined with satellite technology can prove to be of great help in times of emergency to identify specific sites for the construction of hospitals, as was done for example in China. Third, the detection of public events with high risk of concentration of people, an event much feared for the high risk of transmission of the disease, can be implemented in real time and could become an effective surveillance system to reduce the re-ignition of outbreaks (Kamel Boulos and Geraghty, 2020).

The use of the most advanced GIS technologies is undoubtedly a very useful tool to guide choices in times of emergency, but it should be taken into consideration to guide choices in the health sector even in peacetime.

2. GIS in the Time of the COVID-19 Crisis

Around the world, the GIS community is responding, collaborating, and sharing approaches, models, apps, and data in response the COVID-19 crisis. GIS is being used to map the spread, locate vulnerable populations, visualize hospital capacity, engage the public, forecast impacts, design interventions, and communicate effectively. This effort is helping to save lives; protect workers; and provide evidence-based models for safety measures like social distancing, business closures, and travel restrictions.

Pandemics, and COVID-19 in particular, are uniquely spatial. Their geographic spread over time is precisely what must be seen, controlled, and ultimately stopped. GIS is one of the greatest tools that we have to make a difference in this fight.

In response to COVID-19, GIS teams are standing up dashboards and other applications. Supported by web services, these applications enable surveillance and planning for logistics, operations, mitigation, and near real-time awareness. Interactive, online dashboards engage communities, inform the public, and facilitate collaboration within and among agencies.

The Johns Hopkins University coronavirus dashboard developed by the University's Center for Systems Science and Engineering (Figure 1)[1] – and other related applications (Figures 2-4) – includes an interactive map with the number of confirmed infections, fatalities, and recoveries, and where they happened in near real time[2].

Graphs detail the progress of the virus over time. Viewers can also see the day and time of the most recent data update and review the data sources used to produce the dashboard.

Five authoritative sources selected by Johns Hopkins for the effort include the World Health Organization, the Centers for Disease Control and Prevention, the National Health Commission of the People's Republic of China, the European Centre for Disease Prevention and Control, and the online medical resource DXY.cn. The Johns Hopkins dashboard provides links to these authoritative sources where viewers can learn more.

Web services allow GIS users to easily ingest and display disparate data inputs without having to host or process the data centrally. This eases data sharing and speeds the aggregation of information for improved understanding.

Other notable dashboards include those deployed by the World Health Organization (WHO), the US Federal Emergency Management Agency (FEMA), the American Red Cross, and a plethora of countries, regions, US states and cities. Hospitals are also standing up dashboards and using them extensively to monitor the virus alongside bed capacity and resource inventories such as ventilators and personal protective equipment.

GIS-based modeling is also crucial to COVID-19 response. Penn Medicine's Predictive Healthcare Team adapted the susceptible, infected, and recovered (SIR) mathematical model, to create a new model it calls CHIME (COVID-19 Hospital Impact Model for Epidemics)[3]. The CHIME model provides up-to-date estimates of how many people will need to be hospitalized, and of that number how many will

[1] "The dashboard, first shared publicly on Jan 22, illustrates the location and number of confirmed COVID-19 cases, deaths, and recoveries for all affected countries. It was developed to provide researchers, public health authorities, and the general public with a user-friendly tool to track the outbreak as it unfolds" (Dong et al., 2020, p. 1).

[2] All the dashboards here shown have been taken on 8th May 2020. For a wide framework see the "COVID-19 GIS Hub": https://coronavirus-disasterresponse. hub.arcgis.com/.

[3] For insights see: https://penn-chime.phl.io/.

need ventilators. It also factors social distancing policies and how they might impact disease spread[4].

Public health administrators, hospital administrators, and government authorities from around the world have been quick to recognize the need for forecasting models, like CHIME, to guide public policy and plan hospital response.

Bringing such models into a GIS adds great value. By integrating with the data sources that drive a model, GIS provides the means to visualize a problem geographically and tie model outputs to solutions designed for immediate action.

Within GIS, users can drill more deeply into specific geographies to see model outputs alongside other spatially varying data – such as senior populations or communal living places which are more vulnerable – to explore what the model results mean for people and places. This approach also fuels the next question, which is, "where and when should resources be augmented to meet the demand?". Tools such as location-allocation can guide these decisions and make sure demand is met as effectively and equitably as possible.

Incorporating CHIME and other forecasting models within GIS directly supports discussions within Emergency Operations Centers where model outputs can be shared on large screens to guide collaborative planning discussions. Then, when decisions about what actions to take are made, GIS provides the means to push data and directives into map-driven apps and solutions first responders use in field work.

For emergency response and other essential functions, GIS has long been a standard. It supports the creation of data-driven maps and other visualizations, construction of models to analyze geographic processes, and solutions that guide workers in the field. GIS users around the world are applying these capabilities to a number of different COVID-19 activities to improve health, safety, and economic outcomes.

GIS professionals can help their organizations understand and predict at many different scales. Modeling and analytics are a central part of this work—looking at patterns, modeling predictions, and performing site selection.

Location information can also help responders understand the impact of interventions. Officials can use GIS maps to see whether certain actions have changed the virus's spread among specific populations or locations. Disease distribution maps display cases and show changes to counts and rates across time. By visualizing the intensity of infections, health care professionals and policy makers can confront difficult decisions about ramping up or dialing back control measures.

Monitoring and even simulating interventions based on other approaches may help quell the infection rate. For policy makers and emergency responders, maps are one of the most efficient ways to communicate, assess, and understand the scope and scale of unfolding events. A carefully crafted map can make the difference in allocating resources while keeping the public informed. The science and evidence-based underpinnings of GIS maps also serve to suppress misinformation.

GIS provides many capabilities to make the most of limited resources in order to safeguard community health. Evolving cloud and online services support GIS capabilities and innovations for scientific analysis and strategic planning in health emergencies, drawing on the power of GIS language (Dangermond and Pesaresi, 2018).

[4] See for example: Weissman et al., 2020.

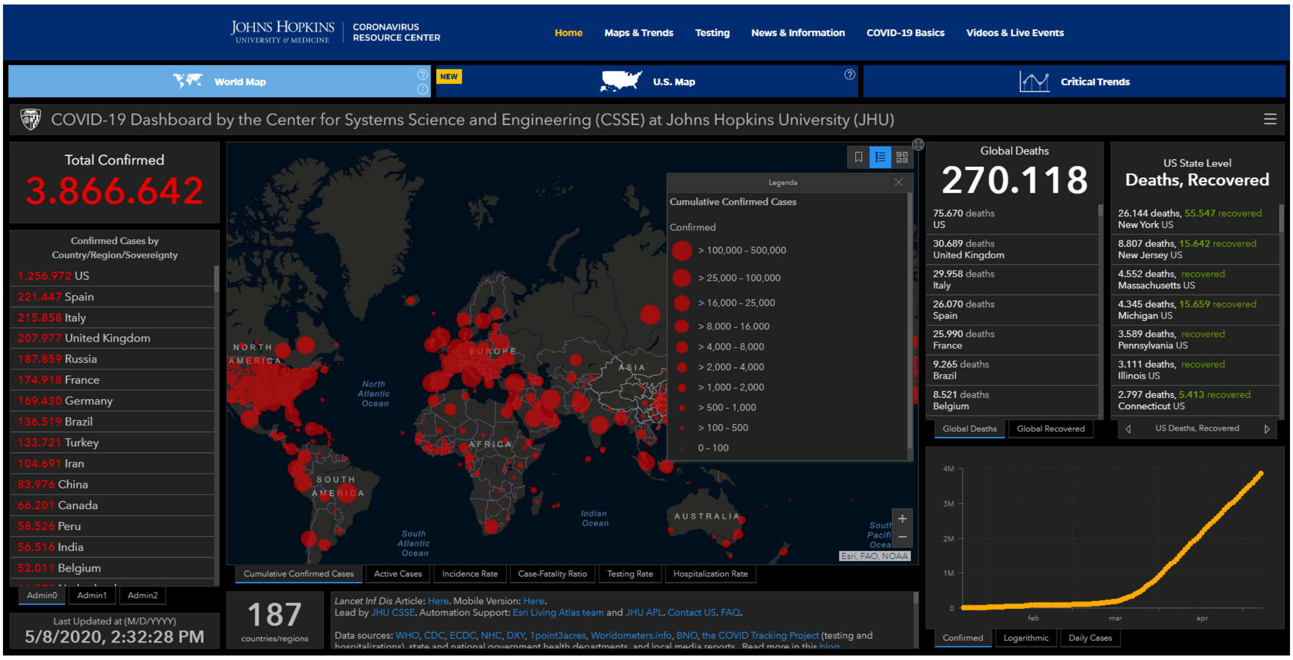

Figure 1. COVID-19 dashboard by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU). This screenshot shows the cumulative confirmed cases in the different countries of the world. Source: https://coronavirus.jhu.edu/map.html.

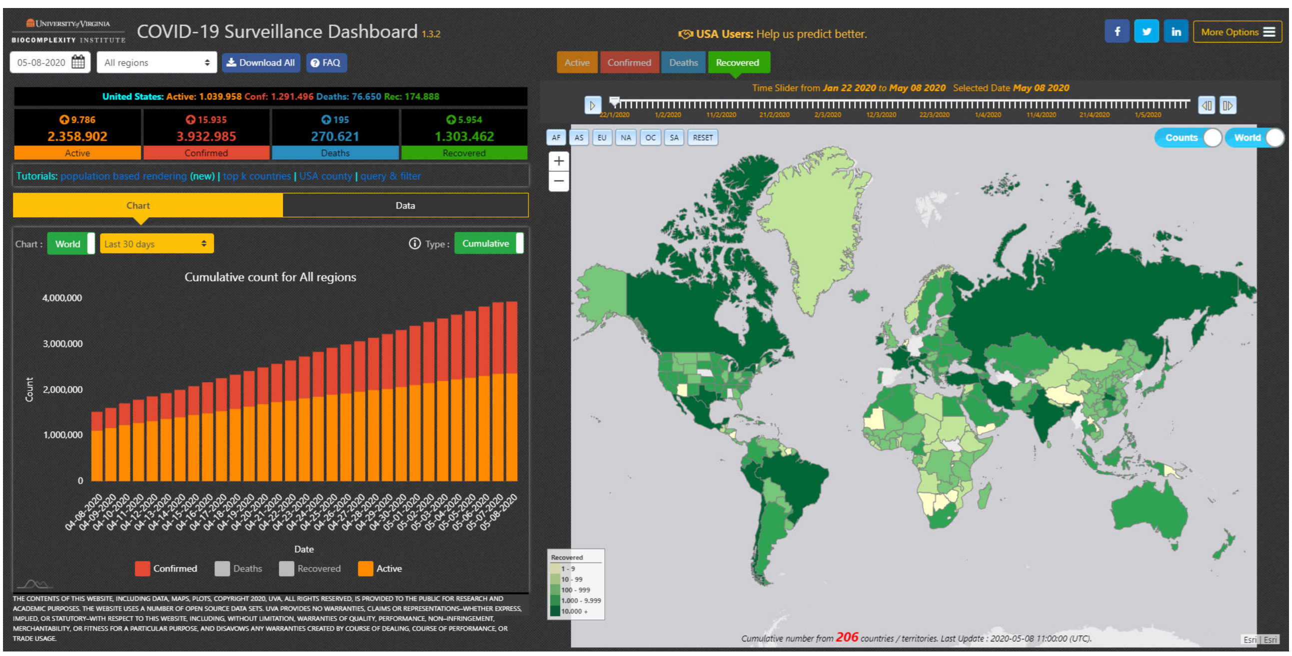

Figure 2. COVID-19 surveillance dashboard (Biocomplexity Institute, University of Virginia). This screenshot shows the number of recoveries in the different countries of the world (the timeline at the top of the elaboration makes it possible to see the data evolution). Source: https://nssac.bii.virginia.edu/covid-19/dashboard/.

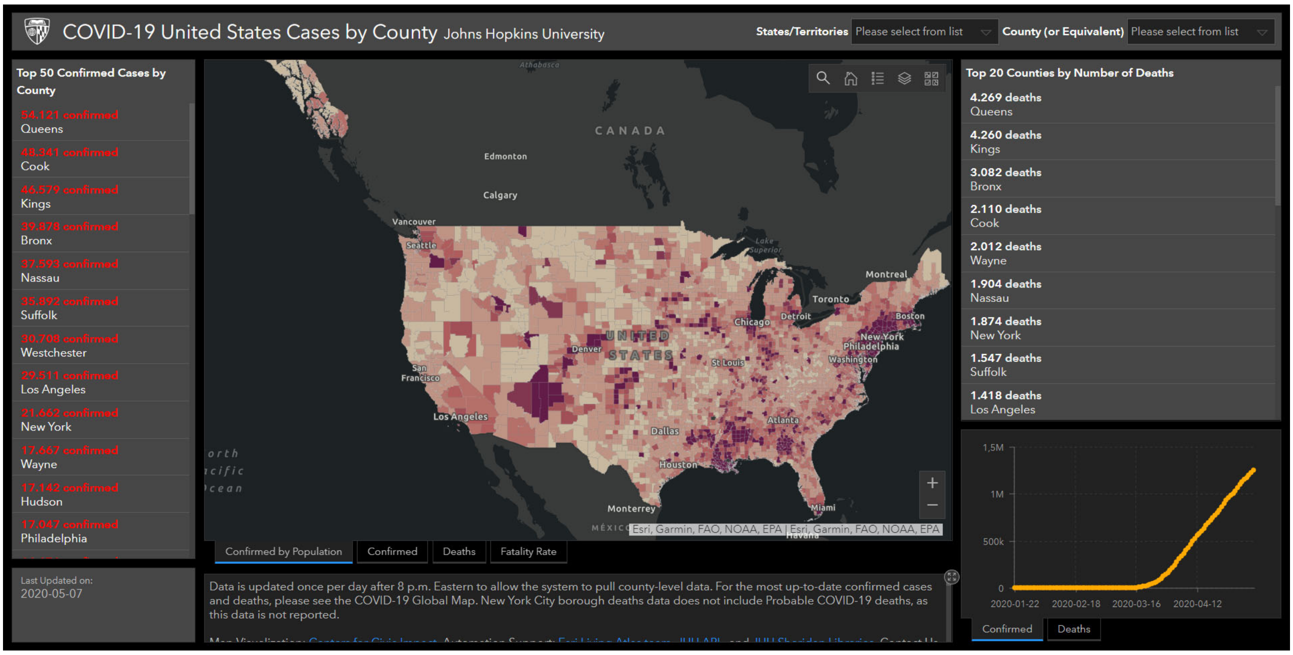

Figure 3. COVID-19 United States cases by county (Johns Hopkins University). This screenshot shows the confirmed cases by population per U.S. county.
Source: https://www.arcgis.com/apps/opsdashboard/index.html#/409af567637846e3b5d4182fcd779bea.

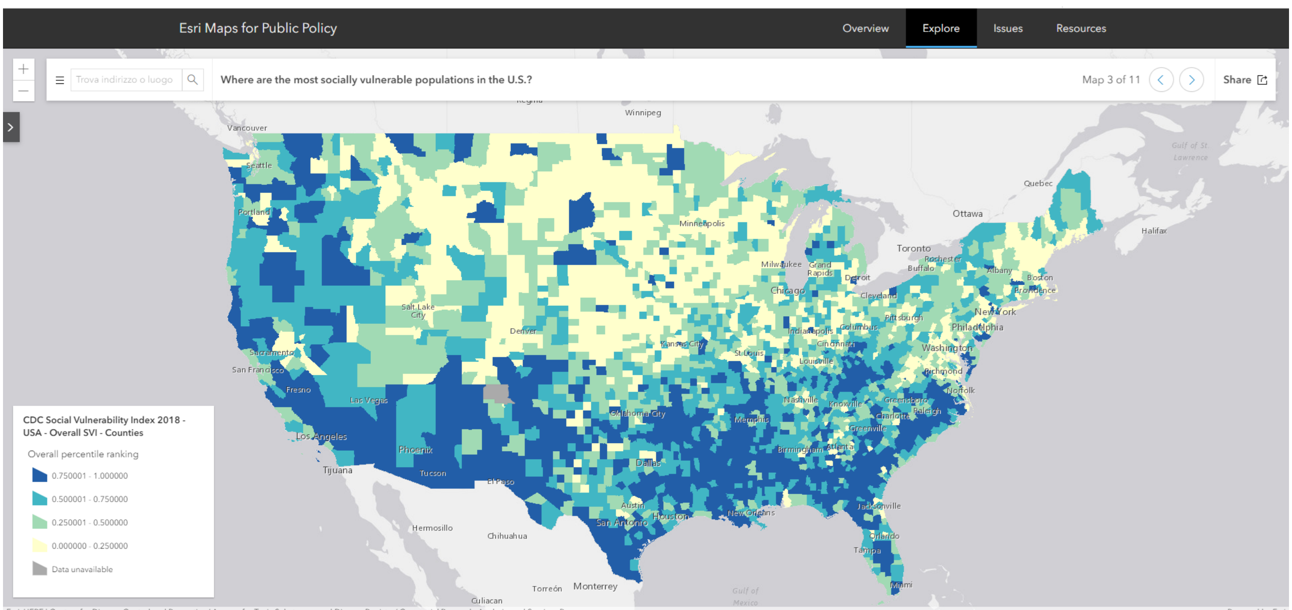

Figure 4. Esri map for public policy. This screenshot shows the distribution of the most socially vulnerable populations per counties in the U.S. Source: https://livingatlas.arcgis.com/policy/browse/?loc=-96.96,39.64,5&col=45e6bb0c0960449cb29031f590af9a59,88f17b4580e846609f92c9f75a9d9eee,2c8fdc6267e4439e968837020e7618f3,48638a1be455429287d6756985013910,02a82293e2dd475391cb3699b5e82d61,d89c527f2e6b4d658db0948ea9d49cd9,48a70b524601428ba297e3106b751401,be559110b5c34591b1a767fbb807bcbf,e0427fbc472f4a45b7d94d182a5e9591,142e65436bed4063973380feae6ed248,f9a130f43abb404fbdffefa8f5ec0ed1&viz=2c8fdc6267e4439e968837020e7618f3&hs=0.

3. Casting a glance at the future in a geographical and interdisciplinary perspective

In this period of the COVID-19 crisis, relevant support activities to the sanitary and epidemiological studies have been provided by geotechnological applications and interdisciplinary approaches.

In particular, in the scientific research and planning of strategic healthcare activities and decision making, GIS has been used in different modes to map the COVID-19 widespread, both in terms of spatial and temporal distribution and diffusion. Many useful elements have emerged from the geographical, geospatial and geostatistical analysis and specific applications have provided notable added value for the interpretation of the dynamics, trends, patterns and clusters and for the supporting of healthcare planning and activities. The potentialities of similar applications have also increased thanks to the synergy with the web which is able to share and spread data and information.

In terms of scientific argument, the dialogue among the experts of different disciplinary sectors has enriched the possibility of discussing the risk factors, meteorological and pollution influences, territorial discrepancies, different systems of health management, the repercussions of social and demographic data, the implications of people and goods flows on global scale. In these cases too, the possibilities to use software and geo-technological programs have helped to simulate and estimate effects, impacts and relationships and the recourse to data and dashboards which are updated daily and available on the web has made it possible to discuss at a distance debating hypotheses and possible actions.

In this critical situation, this has shown the importance of having ad hoc data in real time and that the capacity of hospitals and emergency departments has been put under extreme stress (often causing the collapse of single facilities), and it has practically been made clear that:

- GIS improves and refines the overall capability of information technologies to enhance public safety and an efficient response to health emergencies and, therefore, it is logical to apply GIS to support disease surveillance and disaster preparedness in the hospital and healthcare sectors (Skinner, 2010, p. 2);
- rapid epidemic detection is a key objective of surveillance to make a timely intervention possible, but data should be quickly available, that it is to say within the required time frame for incisive and effective epidemic control, and the increasing volumes of data on the web have prompted interest in methods that could support rapid epidemic intelligence (Yan et al., 2017, p. 77);
- geoinformatics and geographical mapping, in a harmonic and performing GIS environment, can play an essential role in the study and control of global outbreaks with particular reference to severe infectious diseases which represent a serious menace for public health (Kamel Boulos, 2004, p. 1);
- the synergy between GIS elaborations and statistical methods can have a notable relevance in the analysis of the observed start, peak and decline of an infectious disease, above all grouping and disaggregating data at different geographical scales and working according to an adaptable approach able to improve local level epidemic intelligence (Muscatello et al., 2019, p. 1307);
- reflexive mapping of the contagious can help to better understand and contextualize different aspects and variables, from the localisation of the phenomenon, to the importance of its territorial dimension, from its social repercussions, to its interpretative complexity (Casti and Adobati, 2020);
- systems of Epidemic Intelligence (EI), conceived as proactive processes for identifying neuralgic information about emerging infectious diseases (and outbreaks) which can affect global human morbidity and mortality, recover a central position for integrating technologies, indicator-based and event-based components to protect communities from public health risks and emergencies (Wilburn et al., 2019, p. 146);
- the infectious disease threats are far from over and they should be contained with lower magnitudes of risks and loss to human life and social components; therefore it is necessary to invest in building up people-centric health systems, to support a reliable early

warning, alert and response system, and to mount a transparent and well tested containment measure system (Chatterjee et al., 2020, pp. 154-155).

Since it cannot be excluded that a new epidemic-pandemic will happen in the coming years (Hick and Biddinger, 2020, p. 3), it is necessary to operate in the perspective of further emergency preparedness, both planning some sanitary measures and precautions that can rapidly and effectively hinder the diffusion and impact of infectious disease, and going beyond some limitations that have been ascertained during the COVID-19 crisis.

From a geo-technological and applicative point of view, one of the main problems has been, for example in Italy but also in other EU Member States, the lack of a system able to share fundamental detailed data, capable of supporting many GIS functionalities which could provide a very important added value in the framework of a geographical screening. Privacy restrictions and the impossibility for scientific committees, also in the case of specific requests, to have sensitive data (to manage with the guarantee of confidentiality) – concerning incidence, mortality, persons who have been tested positive etc. for address of residence (or domicile) – have not made it possible to use very useful functionalities and tools in a GIS environment, as for example geocoding with which to support the elaboration of models of spatial and temporal diffusion for territorial screening. Similar functionalities would be able to highlight fundamental details and facets, moving a magnifying glass over the different zones and similar applications would be of considerable utility for epidemiological and sanitary actions and a hierarchy of priorities. In situations of severe health emergencies, where several hundreds (or sometimes more than a thousand) of people die every day in various countries, it does not seem reasonable to not communicate data that opportunely elaborated could contribute to saving human lives. Therefore, a rigorous system of data sharing with high specific guarantees of confidentiality in data management and processing seems an essential goal to greatly increase the capacity of the scientific community in providing precious information, also involving researchers such as geographers in the crucial analysis and decision making in an important role.

For example, the application of an accurate geocoding on the data regarding the persons who have been tested positive for place of residence (or domicile) and the elaboration of related digital dot maps would make it possible to identify the areas with a hign concentration of cases, providing a very useful instrument for detailed analysis. The update and implementation of the model with the data in progress and the aggregation of the data i.e. for census sections or the use of specific functions, as for example Kernel Density, would help (maintaining confidentiality) to identify patterns, clusters and trends, creating a system of dynamic elaborations with precious multifaceted inputs for epidemiological and geographical studies and investigations[5].

Some recent works, studying COVID-19, have had the aim of:

- discussing a GIS technology for simulating disease outbreaks which can analytically shows realistic case distributions, and be easily adapted to represent different cases geolocations and distributions, in connection with outbreak detection algorithms and models (Sarwar et al., 2020, p. 6);
- examining the relationship between numerous and different potential key variables (environmental, socio-economic, demographic etc.) and the COVID-19 incidence rate (considered as the dependent variable) to define an explanatory GIS-based spatial modeling (Mollalo et al., 2020);
- identifying and monitoring the spatial and temporal patterns and trends, eventual abrupt changes in the time series of daily new con-

[5] Some inputs and evidence in this perspective have been recently underlined with the re-elaboration of John Snow's map in a GIS environment, also with the aim of showing the relevance, the possible added value and the possible transferring of methodological and applied models, based on detailed data, to other situations of health emergency (Pavia et al., 2019). This work has for example evidenced how by using and elaborating the address data concerning deaths due to a disease, it is possible to obtain a series of benefits and information in terms of high/low concentration, dynamics and diffusion.

firmed cases, according to nonparametric statistical methods and geographical analysis methods (Yang et al., 2020);

- recording and geocoding data (sometimes including symptoms, travel history, and dates of onset, admission and confirmation) to produce useful information able to support the emergency surveillance through an interactive web application that automatically shows the updated data and results (Xu et al., 2020).

Other problems and difficulties, which rapidly slow down solutions and models, always due to privacy aspects and data management, concern systems of data tracking[6] and possibilities to elaborate digital flow (or route) maps, that in a future perspective would require a common decision and an already tested official app and a GIS environment of implementation, elaboration and analysis.

These issues are attracting considerable international attention and becoming paramount as testimony of the interesting initiative organised on April 24th 2020 by the Arizona State University's Spatial Analysis Research Center (and particularly by Trisalyn Nelson) in the form of *ONLINE: Conversation on contact tracing in the time of COVID-19*. In fact, as underlined in the presentation[7]:

> New technologies are rapidly being developed with the purpose of digital contact tracing in response to the fight against COVID-19. As decision-makers and health professionals consider how technology can be used to protect public health and minimize social and economic impacts, there are many things to consider. Arizona State University's Spatial Analysis Research Center will bring together geospatial experts in an online conversation about the technical and ethical issues of digital contact tracing, with the purpose of answering questions about the accuracy of cell phone GPS data, how social media can be used for tracking, looming privacy issues, as well as questions brought forth from the audience during a Q&A session.

It is hoped that if there are new and serious health emergencies, starting from the lessons related to the COVID-19 crisis, national and international systems will have the strategic actions, tools and models ready and clear whereby to adequately tackle the problems and monitor infectious disease widespread.

After all, in the light of the advanced and swirling stage of technological intervention, a pandemic response requires not only a sanitary, medical and epidemiological response. It needs to profitably link different types of technologies, and the COVID-19 response has shown an extensive use of different technologies connected to medical applications and analysis (Shaw et al., 2020, p. 10).

In this perspective, in the fight against COVID-19 and other possible pandemics, GIS and open data must play an essential role, involving (Zhou et al., 2020, p. 77):

- the rapid elaboration and analysis of multi-source data;
- fast communicative visualization of pandemic information with different levels of detail;
- the spatial tracking of people testing positive and paucisymptomatic;
- the prediction of regional and local transmission;
- the analytic modeling concerning exposure risk;
- the distribution and organization of the sanitary devices and specific resources;
- the support for social-emotional aspects and panic elimination;

and all these providing rigorous geographical information for surveillance and prevention and to support logistics platforms and decision making.

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J. Dangermond wrote paragraph 2 starting from the considerations exposed in the interview "GIS in this Time of Crisis: A Note from Jack Dangermond" (https://www.youtube.com/watch?v=wF4uD4VkZrM&feature=youtu.be). C. De Vito wrote paragraph 1.
C. Pesaresi wrote paragraph 3.

[6] For a recent overview and guidelines towards a common solution see for example the document "Mobile applications to support contact tracing in the EU's fight against COVID-19 Common EU Toolbox for Member States" by eHealth Network, dated 15.04.2020 (https://ec.europa.eu/health/sites/health/files/ehealth/docs/covid-19_apps_en.pdf).

[7] https://sgsup.asu.edu/online-conversation-contact-tracing-time-covid-19.

References

1. Casti and Adobati, *Mapping riflessivo sul contagio COVID-19. Dalla localizzazione del fenomeno all'importanza della sua dimensione territoriale*, First Research Report, 2020, https://www.ageiweb.it/wp-content/uploads/2020/03/UniBG-1%C2%B0-Rapporto_Covid-19_.pdf.
2. Chatterjee et al., "The 2019 novel coronavirus disease (COVID-19) pandemic: A review of the current evidence", *Indian Journal of Medical Research*, 151, 2020, pp. 147-159.
3. COVID-19 National Emergency Response Center, Epidemiology & Case Management Team, Korea Centers for Disease Control & Prevention, "Contact Transmission of COVID-19 in South Korea: Novel Investigation Techniques for Tracing Contacts", *Osong Public Health Research Perspectives*, 11, 1, 2020, pp. 60-63.
4. Dangermond J. and Pesaresi C., "The power of GIS language", *J-READING (Journal of Research and Didactics in Geography)*, 2, 7, 2018, pp. 7-12.
5. Dong E., Du H. and Gardner L., "An interactive web-based dashboard to track COVID-19 in real time", *The Lancet*, 2020, pp. 2.
6. eHealth Network, "Mobile applications to support contact tracing in the EU's fight against COVID-19 Common EU Toolbox for Member States", 15.04.2020, https://ec.europa.eu/health/sites/health/files/ehealth/docs/covid-19_apps_en.pdf.
7. Hick J.L. and Biddinger P.D., "Novel Coronavirus and Old Lessons — Preparing the Health System for the Pandemic", *The New England Journal of Medicine*, 2020, pp. 1-3.
8. Hui D.S. et al., "The continuing 2019-nCoV epidemic threat of novel coronaviruses to global health – the latest 2019 novel coronavirus outbreak in Wuhan, China", *International Journal of Infectious Diseases*, 91, 2020, pp. 264-266.
9. Kamel Boulos M.N., "Descriptive review of geographic mapping of severe acute respiratory syndrome (SARS) on the Internet", *International Journal of Health Geographics*, 3, 2, 2004, pp. 12.
10. Kamel Boulos M.N. and Geraghty E.M., "Geographical Tracking and Mapping of Coronavirus Disease COVID-19/severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Epidemic and Associated Events Around the World: How 21st Century GIS Technologies Are Supporting the Global Fight Against Outbreaks and Epidemics", *International Journal of Health Geographics*, 19, 8, 2020.
11. Jenness S.M., Goodreau S.M. and Morris M., "EpiModel: An R Package for Mathematical Modeling of Infectious Disease over Networks", *Journal of Statistical Software*, 84, 8, 2018, pp. 1-47.
12. Lu H., Stratton C.W. and Tang Y.W., "Outbreak of pneumonia of unknown etiology in Wuhan China: the mystery and the miracle", *Journal of Medical Virology*, 92, 4, 2020, pp. 401-402.
13. Mollalo A., Vahedi B. and Rivera K.M., "GIS-based spatial modeling of COVID-19 incidence rate in the continental United States", *Science of the Total Environment*, 728, 2020, pp. 8.
14. Muscatello D.J., Leong R.N.F., Turner R.M. and Newall A.T., "Rapid mapping of the spatial and temporal intensity of influenza", *European Journal of Clinical Microbiology & Infectious Diseases*, 38, 7, 2019, pp. 1307-1312.
15. Pavia D., Pesaresi C. and De Vito C., "The re-elaboration of John Snow's map in a GIS environment. Input for transferring methodological and applied skills being inspired by a virtuous practical example of social utility", *J-READING (Journal of Research and Didactics in Geography)*, 2, 8, 2019, pp. 91-107.
16. Sarwar Su., Waheed R., Sarwar Sa. and Khan A., "COVID-19 challenges to Pakistan: Is GIS analysis useful to draw solutions?", *Science of the Total Environment*, 730, 2020, pp. 7.
17. Shaw R., Kim Y.-k. and Hua J., "Governance, technology and citizen behavior in pandemic: Lessons from COVID-19 in East Asia", *Progress in Disaster Science*, 6, 2020, pp. 11.
18. Skinner R. (Ed.), *GIS in Hospital and Healthcare Emergency Management*, Boca Raton, CRC Press, 2010.
19. Vokinger K.N., Nittas V., Witt C., Fabrikant S.I. and von Wyl V., "Digital health and the COVID-19 epidemic: an assessment framework for apps from an epidemiological and legal perspective", *Swiss Medical Weekly*, 150, 2020.

20. Walker P.G.T. et al., "Report 12: The Global Impact of COVID-19 and Strategies for Mitigation and Suppression", 2020, https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-12-global-impact-covid-19/.
21. Weissman et al., "Locally Informed Simulation to Predict Hospital Capacity Needs During the COVID-19 Pandemic", *Annals of Internal Medicine*, 2020, pp. 9.
22. Wilburn J., O'Connor C., Walsh A.L. and Morgan D., "Identifying potential emerging threats through epidemic intelligence activities—looking for the needle in the haystack?", *International Journal of Infectious Diseases*, 89, 2019, pp. 146-153.
23. Xu B. et al., "Epidemiological data from the COVID-19 outbreak, real-time case information", *Scientific Data*, 7, 106, 2020, pp. 1-6.
24. Yan S.J., Chughtai A.A. and Macintyre C.R., "Utility and potential of rapid epidemic intelligence from internet-basedsources", *International Journal of Infectious Diseases*, 63, 2017, pp. 77-87.
25. Yang W., Deng M., Li C. and Huang J., "Spatio-Temporal Patterns of the 2019-nCoV Epidemic at the County Level in Hubei Province, China", *International Journal of Environmental Research and Public Health*, 17, 2020, pp. 11.
26. Zhou et al., "COVID-19: Challenges to GIS with Big Data", *Geography and Sustainability*, 1, 1, 2020, pp. 77-87.