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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

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Abstract

John Snow's map made it possible to save many human lives by interrupting the spread of cholera, in an area of London in 1854 after the study of a relevant number of cases which allowed him to put his assumptions and research into practice. His work had a crucial role for future developments of epidemiology and provided the basis for (geo)spatial discussions and density studies in relation to risk factors and his insights enabled cartographic and successively GIS approaches, as support to medical studies, to have remarkable advances. In this contribution – conceived on the basis of a practical initiative held for the GIS Day 2019 *Medical geography and GIS applications for social utility* (Rome, 11 November 2019) – we propose a re-elaboration of John Snow's map in a GIS environment, underlining how demonstrative-laboratory activities focused on specific cases can provide remarkable inputs for transferring methodological and applied skills, being inspired by a virtuous example of social utility. In particular, we discuss and provide guidelines for the application of georeferencing, editing and Kernel Density for a modern John Snow's map and to provide several inputs for analysing today's diseases and relative risk factors, also at the light of new functionalities which make it possible to spread the results of the work. Some considerations are also provided regarding the importance of didactical activities adequately thought out and planned and held in geocartographic laboratories or specially equipped GIS lecture halls, since they can contribute to a rigorous geographical education with links to modern sectors of interdisciplinary research. As support for this specific case, the main results are presented of a short questionnaire submitted to the participants at the demonstrative-application course focused on the re-elaboration in a GIS environment of John Snow's map.

Keywords: Editing, Epidemiology, Georeferencing, GIS, John Snow's Map, Kernel Density, Medical Geography, Social Utility

1. Introduction and contextualization

"*It is amongst the poor, where a whole family live, sleep, cook, eat, and wash in a single room, that cholera has been found to spread when once introduced, and still more in those places termed common lodging-houses, in which several families were crowded into a single room*".

With these words John Snow, in his famous book of 1855 (*On the mode of communication of cholera*) dedicated to the cholera epidemic in London, described how the spread of the disease was particularly rapid in the poorest districts of the city where living conditions facilitated interpersonal contagion.

The cradle of cholera is still considered today the delta of the Indian river Ganges, the region of origin of the pandemics of the nineteenth and twentieth centuries. The first pandemic began in 1817 with the increase in the number of cases in the region, reaching the city of Calcutta, the capital of British rule in India. Through navigation to Asia, which was increasingly rapid thanks to steam, the disease spread to China and Oceania, following the seas as far as Java, the Philippines and Japan. The land trade routes, as well as the movements of British armies in northern India, favored the spread of the disease in the Persian Gulf in 1821, and Asia Minor reaching Egypt in 1823. The harsh winter that Europe experienced that year interrupted the advance of cholera on the frontier of Asia, delaying industrial Europe knowledge of its first catastrophe of the nineteenth century.

In fact, in 1826 the Ganges delta once again saw the spread of an exorbitant number of cases of cholera. This time the disease advanced westwards in the direction of Europe. In the trade and displacement routes of populations and armies, sick people moved, speeded up by the use of the steam engine, bringing the disease with them and pushing it towards the European industrial cities (Arnold, 1986).

In Great Britain, the disease found fertile ground for transmission in the new social organization. Factories were responsible for introducing a series of social transformations into the European continent, especially in England, which influenced the spread of infectious diseases in the 19th century. The urban population increased exponentially, and large urban agglomerations began to appear in the places where industrial centers flourished, close to the factories. Between 1801 and 1840, the population of London grew from about one million to two million, as many people migrated from the countryside to the city in search of a factory job. As a result of these changes, the quality of life and especially the health conditions deteriorated dramatically, thus contributing to the spread of infectious diseases and increasing the mortality rate. The living conditions in industrial Europe were crucial for the birth and spread of infectious diseases. Families were forced to live in dilapidated and unhealthy premises because of low wages and high rent costs. The houses were built in a disorganized manner near the factories to allow a rapid movement of workers and more immediate earnings. Families crowded into these poor areas, creating neighborhoods with the same social conditions. The dwellings were dumps, with no sewerage or garbage removal system, and many of them had no latrines. The lack of sewage caused the contamination of water used for domestic purposes and led to the spread of many diseases with fecal-oral transmission, including cholera (Davenport et al., 2019).

In this environment, in the second half of the 1840s, the anesthetist John Snow, opposing the still fashionable theory of cholera transmission through effluvia, hypothesized the possibility of cholera transmission through the ingestion of food or water. Snow began to dwell on the mode of transmission through water as his notes and observations confirmed this hypothesis.

In July 1849, when eighty cases of cholera were recorded on Silver Street, Snow connected them to the well used by the locals. He found that it was receiving water from an opening in the nearby sewerage system and once it was detected, he was able to stop the spread of the disease (Snow, 1855, p. 30). But it was only in 1854 that he was able to study a greater number of cases in order to put his research into practice. While five hundred people sharing the same well died on Broad Street, the five hundred poor people in a nearby shelter who used water from another source were spared from the disease, as were the workers in a brewery in the same location who were not ingesting water but only beer (Snow, 1855, p. 120). His theory of contamination and transmission through water was getting stronger.

Snow's great intuition was to superimpose maps of the city water distribution and cholera mortality. This analysis, fundamental for the development of modern epidemiology, allowed him to demonstrate that the water supplied by the Southwark and Vauxhall aqueduct was contaminated by sewage discharges and therefore responsible for the epidemic (Snow, 1855, p. 137).

Snow presented his work in the book *On the mode of communication of cholera* that clarified the transmission of cholera but the theory of effluvia was still in vogue in Europe, so his ideas were initially rejected, despite being a convincing demonstration in favor of the contagion of diseases. It will be necessary to wait for Pasteur's future work before the theory of contagion can be definitively accepted.

2. Discussion

"John Snow's accomplishments in medicine, anesthesia, and epidemiology constituted an achievement that changed the face of medical practice. […]. He mapped out the spread of cholera and […] described cholera to be a communicable disease spread by contamination of the water supply" (Ramsay, 2006, p. 24), also working in terms of quantification and distribution of the disease and providing remarkable inputs as investigative model based on a concrete case study, with many positive repercussions on prevention and risk factors. Even if the relevance of his figure has not always found the same unanimous consensus (McLeod, 2000), he introduced a method that inspired numerous epidemiological studies (Shephard, 1989, p. 238) and that can have notable importance also for medical geography, applied analysis and laboratory didactics.

John Snow's map provided a crucial evidentiary basis for (geo)spatial discussions, arguments and developments, and his insights make it possible for cartographic and successively computerized cartographic approaches, as support to medical studies, to have fundamental advances (Koch and Denike, 2010, p. 29). This experience is often taken as a virtuous example to show how a map can become an essential instrument for studying the distribution of the causes of deaths, for assessing the presence of risk factors even when not known and for explaining anomalous phenomena of concentration and thickening (De Blij, 1994, p. 179). John Snow's work was one of the most significant examples of dot map of a disease as support to an analytical applied use in epidemiology, opening various pathways to a modern medical geography and statistical approach for the handling and interpretation of the data collected (Koch and Denike, 2004, p. 78). Practically, his research sank its roots in a *modus operandi* which showed the "prodromes of a GIS application" (Dangermond and Pesaresi, 2018, p. 10).

Starting from the assumption that John Snow's cholera map is one of the main pioneering examples of a cartographic representation illustrating spatial distribution and the number of victims caused by a disease outbreak, some papers have revisited his map and introduced geostatistical functionalities aimed at translating the model into a modern application useful to feed additional observations and implementations (Shiode, 2012). Specific tools in a GIS environment enable scientific literature add both detailed elements in terms of space-time patterns and a notable aesthetic-figurative effect functional to the analysis (Shiode et al., 2015).

From a didactical point of view, the re-elaboration of John Snow's map in a GIS platform suggests aspects of remarkable interest for laboratorial activities aimed at transferring *ad hoc* competences and skills, giving new lymph and vitality to the original one that makes it possible to save a considerable number of human lives. In particular, the re-elaboration of John Snow's map in a GIS platform can represent the prerequisite to introducing a number of functionalities, as for example georeferencing, editing and Kernel Density. It is a noteworthy applied example based on a determinate case study of the past to transmit didactical and professional attitudes which can successively be extended to the fields of interdisciplinary research and strategic and preventive planning.

New opportunities and elements are also provided by the possibility to work through online systems for the diffusion and sharing of the elaborations and findings:

- fostering an international debate on the GIS functionalities and potentialities for social utility related to medical geography and epidemiology;
- showing concrete examples of elaborations which can be adapted to contemporary risk factors which menace exposed people and whose geolocalization must be well known;
- supporting a wide process of population education and awareness to risk factors.

Furthermore, these opportunities are enlarged by the possibility:

- to overlay different templates which are constituted by satellite imagery (also with labels), digital street maps, topographic and geological maps etc. which show the position of specific elements and support detailed studies;
- to create 3D models which offer a particularly effective modality for meticulous analysis and to better know the relations and dynamics of specific areas;
- to work in cloud and build in networks, sharing and integrating data and output products according to a synergic perspective;
- to use, on the basis of adequate criteria and logics, big open data which can enrich the investigation, helping to advance hypotheses, organize and evaluate enormous amounts of information;
- to use together official data and data acquired by field survey (through GPS, drones etc.) with instruments which can be filled in a GIS platform for a synthetic and exhaustive framework.

In fact, it would seem extremely relevant to create figures of modern geographers able to support healthcare professions in order to put at the service of medical research and social utility a set of competences founded both on a matured awareness acquired with disciplinary contents of geography and advanced geo-technological skills around GIS, geospatial and geostatistical analysis, and web applications.

As highlighted some years ago, speaking about the current traditional use of GIS in public health, important applications can be found: "in the areas of health disparities, resources availability, and health-related behaviors, as well as continued use in more foundational fields such as cancer and environmental epidemiology"; "to assess proximity, aggregation, and [global, local and focal] clustering, as well as to perform spatial smoothing, interpolation and spatial regression"; "for disease surveillance and intervention monitoring. By mapping disease cases in geographic space, local and national governments can easily identify the distribution and spread of disease across geographic regions, optimize planning of intervention locations, and monitor their effectiveness" (Musa et al., 2013, p. 113).

Moreover: "Disease modeling extends the disease-mapping application to (a) predict the future spread of disease, (b) identify factors that may foster or inhibit disease transmission, (c) pinpoint high-risk areas for disease prevention or intervention, (d) target control efforts, (e) identify gaps, and (f) increase stimulus for data collection in these areas" (Nykiforuk and Flaman, 2011, p. 66).

All of this is possible also giving the sense of changes and dynamic display, considering the cumulative sum, aggregate data and refined statistics and functions, proposing multilevel, multilayer and data-driven models, in a mix of exponential increase in benefits, new methodologies and fashion (Pfeiffer et al., 2008).

In addition, in terms of healthcare services, the use of GIS can have an essential role: to assess the spatial and temporal distribution and accessibility of different structures for population health maintenance and to identify the areas which require additional or more effective facilities; to understand specific problems which determine healthcare migration towards attractive centers (with high quality service and staff, adequate accommodation, cultural appropriateness etc.); to assess potential risk factors that are widespread and concentrated on the territory and to prevent related diseases and connected high costs (Musa et al., 2013, p. 113).

Furthermore, many studies have highlighted the possible applications of the use of GIS in public health, health promotion, community-based initiatives and decision-making according to the problems and characteristics of the different local situations (Ricketts, 2003; Mullner et al., 2004; Nykiforuk and Flaman, 2008).

Other contributions have advanced considerations and examples regarding the benefit of GIS use for (Cromley and McLafferty, 2012, pp. 303-406): analyzing access to health services according to population characteristics, distance and travel time measures and consequent costs, healthcare facility density, variations in healthcare use, service areas (containing the amount of population served) etc.; studying the location of health services in order to minimize travel time, maximize coverage and emergency service distribution, ensure a satisfactory and homogeneous enough coverage, modeling optimal hierarchical facility systems, solving routing problems etc.; evaluating and defining health disparities in terms of socioeconomic aspects and inequality (income, ethnicity, gender), built-up environments, migratory flows, neighborhood context.

Therefore, there is a clear added value that a geographer's expertise in GIS use can provide as support to healthcare planning moving towards social utility.

3. Considerations on applied didactical activities

In the perspective of high and expendable training, harmonic, tested and validated didactic experimentation activities in geocartographic laboratories or specially equipped GIS lecture halls can have an essential role in contributing to a rigorous and applied geographical education towards modern sectors of interdisciplinary research.

A similar activity has recently been carried out in a lecture hall of the Faculty of Letters and Philosophy, at the Sapienza University of Rome, on the occasion of the GIS Day 2019 *Medical geography and GIS applications for social utility* (Rome, 11 November 2019)[1], organized by the Degree Course in *Geographical Sciences for the Environment and Health* and by the GeoCartographic Laboratory, with the support of ESRI Italia and the Ph.D. course in *Documentation Studies, Linguistics and Literature*. The demonstrative-application course focused on the re-elaboration of John Snow's map in the GIS environment has also been the central component of the training activity *Medical geography and GIS applications. Examples and study cases*. For this activity about fifty licenses and relative extensions of ArcGIS for Desktop have been installed, operating in a very capacious and homogenously equipped GIS lecture hall and working according to the steps and guidelines used many times in intensive courses (Pesaresi and Pavia, 2017; Pesaresi, 2019a) but for the first time with such a wide worker audience in a dynamic and interactive way. About forty people attended the activity, above all students of the Degree Course in *Geographical Sciences for the Environment and Health*, but also some Ph.D. students, specializing in medicine, expertise in the use and analysis of data and imagery.

The two main aims of this activity were:

- to show and transmit specific competences and skills for operating with GIS software (georeferencing, editing and Kernel Density);
- and to present a tangible example able to make participants think about replicable cases based on actual problems and risk factors.

Particularly, the replicability can be considered both for communicable and, above all for developed countries, noncommunicable diseases, which are generally characterized by progress and degeneration and can be often related to the presence of exogenous risk factors as different polluting sources (industrial activities, dumps, busy roads, mineral extraction sites, construction sites, base stations for telecommunications etc.).

At the end of the activity, which let the participants repeat all the steps and procedures shown in a practical way, a questionnaire – composed predominantly of questions with predetermined fixed answers – was submitted to obtain specific inputs and to collect proactive

[1] https://web.uniroma1.it/lcm/news/gis-day-roma-11-novembre-2019-geografia-medica-e-applicazioni-gis-l%E2%80%99utilit%C3%A0-sociale; https://www.esriitalia.it/component/eventiesri/calendario/539/geografia-medica-e-applicazioni-gis-per-l-utilita-sociale.

impressions concerning different but related aspects.

From the questionnaire – based on a scale of values between 1 (minimum) and 5 (maximum) – a general framework with different aspects emerged, confirming the importance of moving towards demonstrative-laboratory activities focused on specific cases.

In fact, to the question *For your course of university studies, how useful is the demonstrative-laboratory type activity in this format?* almost 70% of the respondents chose the option with the maximum value (5) and 97% opted for the whole of answers 4-5, while none chose options 1 (minimum) and 2 (Figure 1a). This shows that the respondents perceive these activities as essential in order to undertake a stimulating and professionalizing training process able to join theory and practice, promoting an active and engaging didactics and satisfying the participants' expectations.

An analogous situation appeared with the question *How useful are the ideas of such demonstrative-laboratory type activity in terms of geographical-interdisciplinary research?*, since almost 70% of the respondents chose the option with the maximum value (5) and 93% opted for the whole of answers 4-5, while none chose options 1 (minimum) and 2 (Figure 1b). Therefore, similar activities are configured as effective stimuli for evidencing and starting research fronts common to various disciplinary-scientific fields, providing demonstrative examples and planning ideas able to finalize GIS skills towards studies characterized by modern innovative prerequisites.

A high utility was also perceived by the respondents regarding the methodological-application impact. To the question *How useful is the methodological-application impact of such demonstrative-laboratory type activity?* 62% of the respondents chose the option with the maximum value and 97% opted for the whole of answers 4-5; none chose options 1 and 2 (Figure 1c). Therefore, similar activities can be useful to channel the theory and geographical contents towards methodologies and applications able to conduct the territorial screening and detailed analysis of different components. This thus creates a synergic mix where a steady basis of geo-technological innovation is added to the bricks of knowledge.

The same opinions were expressed in answering the question *For your future career, how useful is the demonstrative-laboratory type activity in this format?* (Figure 1d). Having robust foundations in the use of GIS and its functionalities and extensions can be an optimum visiting card: to match specific professional profiles required by institutions and companies; to attend a job interview with the conscious awareness of possessing important operative skills; to undertake one's own activities by combining precision and creativity. These activities can be concrete examples whereby to give substance to the form, above all if contextualized in events with greater reach.

A certain utility was also perceived regarding the capacity of these activities to broaden one's mind and transfer theoretical knowledge to applications of social utility: 59% of the respondents chose the option with the maximum value and 93% opted for the whole of answers 4-5, while none chose options 1 and 2 (Figure 1e). Nevertheless, in this case the results were minor with respect to the ones obtained with the other questions. Yet, an important goal of these activities is to have highly positive feedback in terms of social utility. In fact, the use of GIS and specific applications in medical geography and in the epidemiology and healthcare system fields can offer a very wide range of possibilities, triggering remarkable positive results for a better quality of life, an adequate use of assistance services and for prevention. For this very reason, this must be a focal point on which to continue to focus the attention.

Translated into present times, John Snow's map can be useful as a trailblazer to conduct medical geography research aimed at investigating the relationships between the presence of risk factors and incidence, prevalence or mortality for noncommunicable diseases, above all cancers. That it is to say, the re-elaboration of John Snow's map in a GIS environment – during demonstrative-laboratory activities in geocartographic laboratories or specially equipped lecture halls – can provide inputs for transferring methodological and applied skills, being inspired by a virtuous practical example of social utility.

By carrying out field surveys with specialized instruments, using databases produced by institutions which carry out a census and register of the localization of specific polluting sources on the territory, and by taking advantage of the availability of official data concerning the causes of death for different diseases, it is possible to conduct relational studies, with the support of geostatistical and geospatial evidence, functional to the scientific state of the art progress; it can also provide tangible positive effects on the health of the population (and environment). Moreover, working in teams in geocartographic laboratories or specially equipped GIS lecture halls, where people pursue common aims, for example in interdisciplinary projects of high technological caliber, it is possible to create strongly proactive and stimulating environments, where GIS applications can act as a link among different scientific-disciplinary sectors and as a core to advance and verify hypotheses and to suggest checks and measures, interventions and corrections, alternatives and best practices. Virtuous contexts where it is possible to reach tangible results can grow and they can be considerably important for training because here research and didactics come together towards research applied to didactics and a didactics projected into the research perspective.

The carrying out of intensive laboratory activities creates the assumption of obtaining a continuous flow of benefits, which are promptly received by participants keen to try:

- to work according to correct guidelines and alternative steps in the case of obstacles and problems;
- to have profitable discussions as far as concerns technical aspects, theoretical ones and specific contents;
- to be an active and integral part of their own educational course, with a steady approach and a creative mind which works more efficiently;
- to acquire new knowledge in terms of applied research and possible elaborations;
- to be gratified for operating in GIS equipped contexts and in team-work;
- to be readers of work for the world and with a wider set of competences and inputs, bringing elements of originality;
- to easily acquire very important skills which can be applied in situations of notable complexity for planning and research…,

as highlighted by the respondents (Table 1).

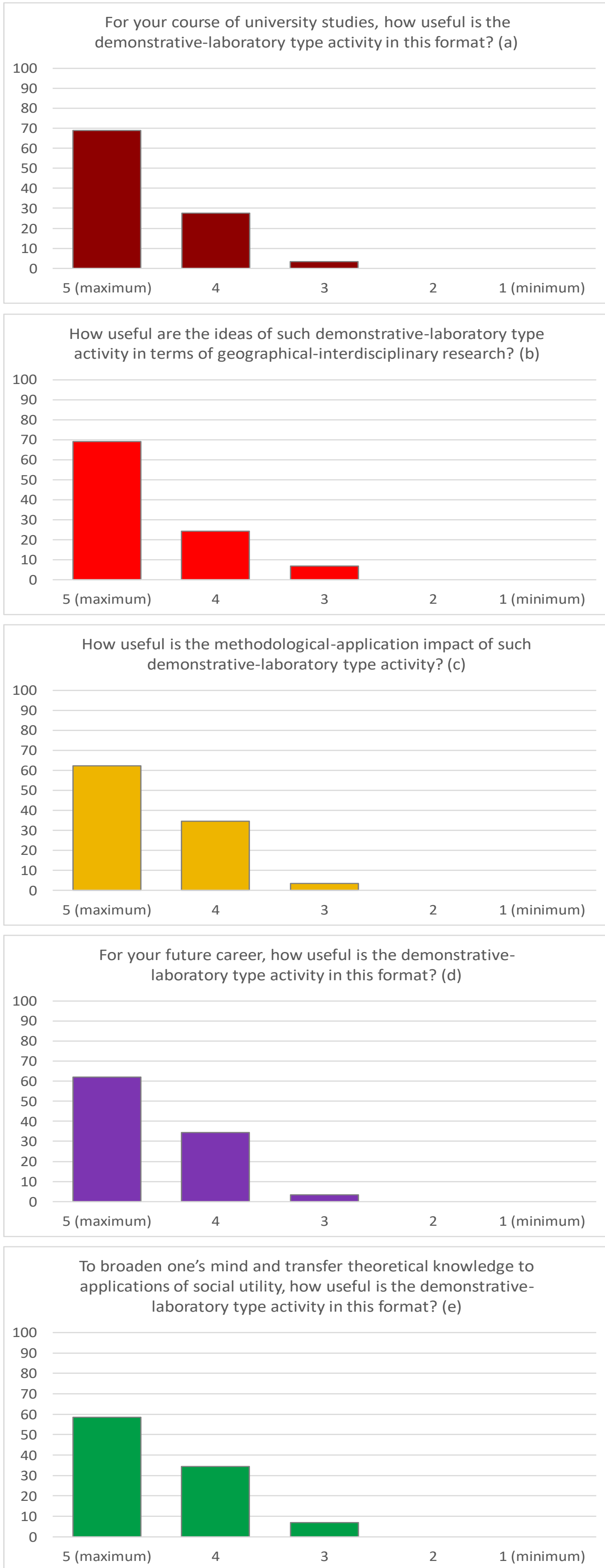

Figure 1. The results obtained with some of the questions submitted on the occasion of the training activity *Medical geography and GIS applications. Examples and study cases*. Source: Authors' elaboration.

The presence of laboratory activities in this format is important for students insofar as they are able to improve their GIS knowledge, a fundamental element for any future work in this field as well as being of great academic interest.
One of the strengths of this lies in the fact of being able to use highly specialised university rooms by means of these laboratories.
These activities give the opportunity for a direct contact and practice with useful instruments during the university course and in a possible future working environment.
Activities of this kind give students the opportunity to directly speak to the lecturer as far as concerns not only the technical elements but also the theoretical ones relative to the contents.
The mind works more efficiently with this type of demonstrative-laboratory activity.
Real knowledge of the instruments is acquired and not just the memorising of a series of complex steps. One is able to discover that there is more than one way to reach a same result without having to stop at each problem that arises during a specific step. […]. Moreover, in the event of a laboratory activity followed by persons at the same level, it is possible to work well together with a first approach to team type work.
The possibility to give explanations and elaborations directly with a PC (that is, from theory to practice) means being an active and integral part of the educational activity.
Similar activities are useful to learn the use of geographic information systems at practical and technical level, which are fundamental for geographers and thus indispensable to know. In my opinion, even for those who are not too familiar with the computer, it is easy to follow and to learn the techniques being taught.
These activities represent experiences that are useful to better understand the workflow behind the creation of a GIS elaboration, with the added possibility of seeing such instruments applied to wide-ranging operational contexts of great complexity.
A number of strong points regard the possibility to: make conceptual knowledge concrete; explain the importance of IT education; stimulate creativity.
With activities organised in this way it is possible to acquire new knowledge about a type of research which, not known by everyone, instead becomes a reason to pay attention.
These activities provide an excellent focus on the capacity of software and its possible applications.

Table 1. Opinions expressed by the respondents to the questionnaire submitted on the occasion of the training activity *Medical geography and GIS applications. Examples and study cases* where it was required of briefly summarise what the main strengths are of the demonstrative-laboratory type activity in this format. Source: Authors' elaboration.

4. Application of georeferencing for a modern John Snow's map

In more than fifty years of history, many tools have been introduced to extend the functionalities of GIS software: from the early designed GIS and its digital turn, Geographic Information Systems were developed to handle a broader set of events, characterized by different requirements in terms of calculations, visualizations and so forth. From a didactic perspective, a frame of reference offers a series of important inputs to understand their aims and properties.

In the context of the GIS Day 2019 *Medical geography and GIS applications for social utility*, this frame was represented by John Snow and his map of the London 1854 cholera outbreak, considered "the starting point for the field of epidemiology and community health" (Boxall, 2011, p. 114).

During the hours of the demonstrative-application course, the participants were first introduced to the course's objective: the re-elaboration of John Snow's map in a GIS environment[2], in order to practise some tools from various actions, such as georeferencing, editing, representing and analyzing geographical data, for example after applied Kernel Density function.

[2] The lecture hall computers were provided of an ArcGIS for Desktop v. 10.5.1 "Advanced" license.

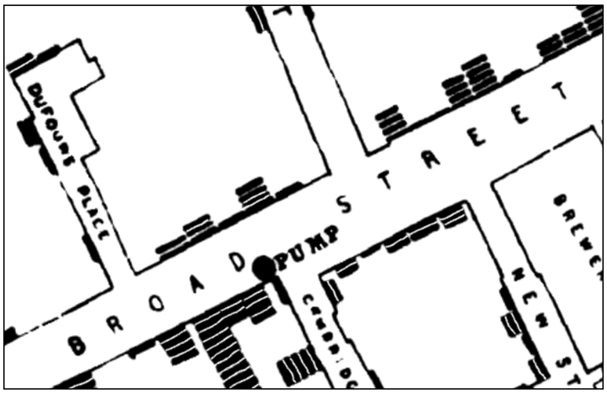

Figure 2. The Broad Street Pump, a detail of John Snow's cholera map. Source: Snow, 1855. Authors' contrast enhancement.

Then, Snow's map (Figure 2) characteristics were described: using a street map of 30 inches to mile scale, Snow marked the single casualties of the Soho district by tracing a line on each address; however, what makes the map a prodrome of the modern spatial analysis is the presence of another "layer" of information: the water pumps, that he suspected were the sources of the outbreak (Koch and Denike, 2010, p. 77-78).

Like any other paper document which can be used, for the aims of this activity, Snow's map was scanned and georeferenced to be displayed correctly in a GIS project.

From this premise, the participants were at first asked to practise on this action using two Italian historical maps: the "*Nuova pianta di Roma*", made by Giovanni Battista Nolli in 1748, and one of the "*Tavolette*" of the *Istituto Geografico Militare* (IGM), dating back to 1936.

Considering a portion of Rome's historical center, Nolli's map was used to explain how to create a Ground Control Point (GCP) by visually locating it on both the layers. Using the window "Viewer", the (from) point was first created on the ancient layer, looking for specific recognizable spots such as fountains, monuments and building corners (Figure 3); to obtain its coordinates, the same location (to point) was then searched for on a target layer (an aerial image) which was already spatially referenced. Finally, four GCPs were added to Nolli's map, enough to apply a first-order polynomial transformation to georeference it. Nolli's map was chosen as representing Rome and one of its portions was selected for the exercise. That it is to say, a context known by participants was chosen in order to simplify the georeferencing activity and this map, concerning a period in the distant past, can be useful to capture the attention and transmit useful skills.

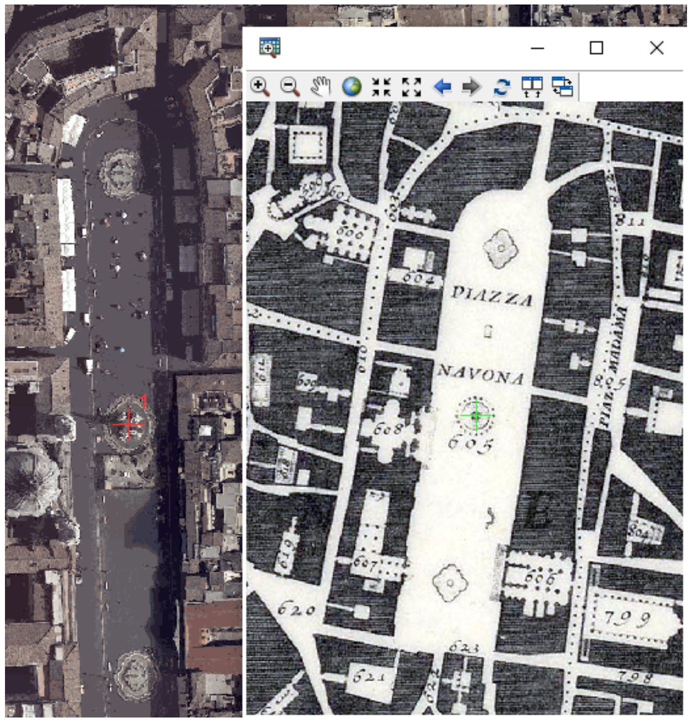

Figure 3. A GCP located on Bernini's "*Fontana dei Quattro Fiumi*" in the Rome city centre. Source: Authors' elaboration.

Due to the content represented, this method was not suitable for the IGM map: indeed, the map chosen ("Monte Circeo", in the Lazio region, from the "Serie 25V" collection) just represents the land on the north-east corner, while the main part of the grids coincide with the Tyrrhenian sea, with obviously no spots to recognize; however, as the document reports the coordinates of the grid vertices, the map can be georeferenced by creating a from point on every corner by manually typing its coordinate value. Therefore, this map was chosen to stimulate other knowledge and competences and to provide a wider panel of possible documents to use (Figure 4).

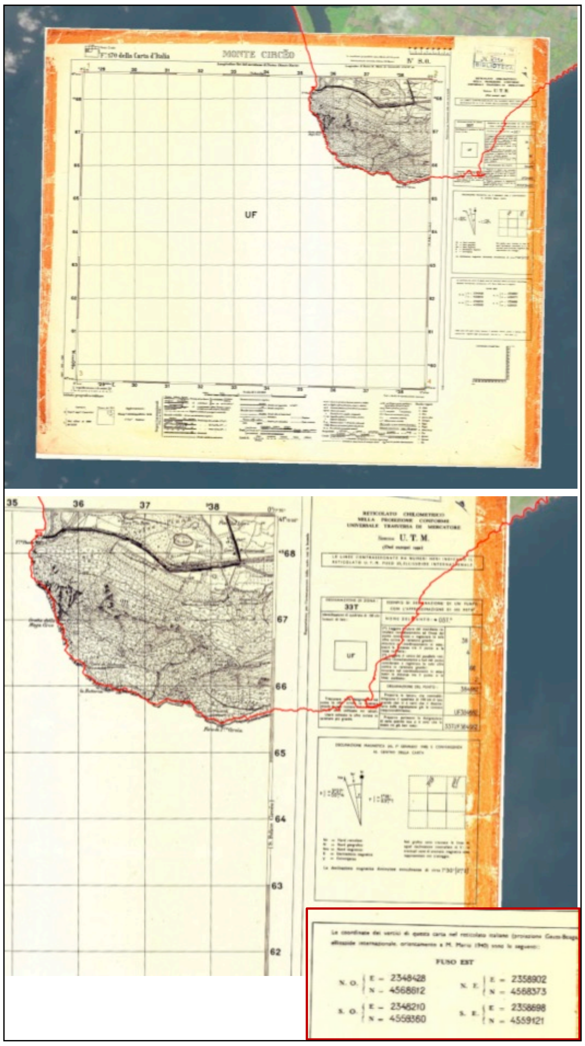

Figure 4. The "Monte Circeo" map of the "*Tavolette*", georeferenced on a satellite image (above) and a zoom on the context of Monte Circeo, with the vertex coordinates in evidence (below). Source: Authors' elaboration.

John Snow's map can be georeferenced by looking for the GCP visually, because of the absence of the vertex coordinates[3]. Once georeferenced, Snow's map could be introduced and overlaid with other layers, such as contemporary pictures of the Soho district, taken from satellite or aerial vectors; moreover, its statistical information (the casualties and water pump locations) can be vectorized, in order to be used as inputs for other geoprocessing tools.

Showing its features and properties, georeferencing benefits were thus introduced: to reconstruct the landscape of the past, making it easier for the viewer to understand the changes that occurred during the centuries, in terms of natural and human transformations, by the overlay of the historical documents in the same map (Giannini, 2018, p. 95); to gather information from the map analysis, investigating the relationship between the pattern of the past and the present and so forth (Chias and Abad, 2009, p. 530).

5. Application of editing and Kernel Density to provide modern input

Once converted into a dataset, two precise layers were created on Snow's map to locate the casualties and the water pumps: using a customized symbology, the first were represented as dots, while the icon of a drop was used to represent the latter. In this way the pattern of the outbreak was already visible, concentred in the surroundings of the Broad Street pump, above all using a suitable symbology with dots having graduated colours and dimensions (Figure 5). However, at smaller scales the clarity of the dots tends to become confusing, because of their number and proximity.

To better represent the pattern of the casualties, a density map was realized using the Kernel Density tool.

Since the tool lets the user weigh the input features, an attribute was specified for every point (conventionally in red), relating to the number of casualties for every address[4]. Therefore, each point contains the number of casualties for a specific address and this number is recorded in the attributes table (Figure 6).

In the perspective of providing different competences in a wide range of options, the same elaboration was proposed onto a modern World Street Map (with the actual streets indicated) and the swipe effect can be used in order to show a particular representation where the points concerning Snow's map appear transferred onto the actual street map (Figure 7).

[3] Participants know two different systems and can choose according to the materials available.

[4] The idea of weighing each feature with the number of the casualties was given by the blog "John Snow's Cholera Map using GIS Data" of Caitlin Dempsey (https://www.gislounge.com/john-snows-cholera-map-gis-data).

Figure 5. Screenshot of John Snow's map georeferenced on a modern satellite image, with its statistical data represented in a vector format and using a suitable symbology with dots having graduated colours and dimensions. Source: Authors' elaboration.

Figure 6. Screenshot of John Snow's map georeferenced on a modern satellite image. Each red point records the number of casualties for a specific address and this number is specified in the attributes table. Source: Authors' elaboration.

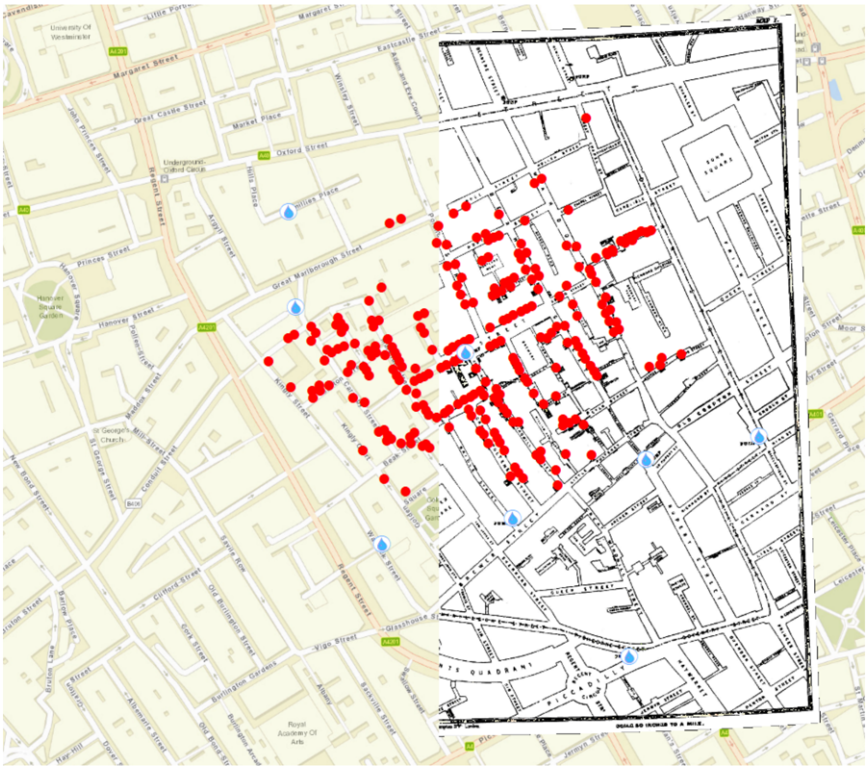

Figure 7. Screenshot of John Snow's map overlaid onto a modern World Street Map (with the actual streets). Each red point records the number of casualties for a specific address (the same as Figure 6). Through the swipe effect the points seem to be transferred onto the actual street map. Source: Authors' elaboration.

To practise with the editing environment, the participants was asked to add the clearly missing features from the map, typing the number of the casualties for any of the occurrences (Figure 8).

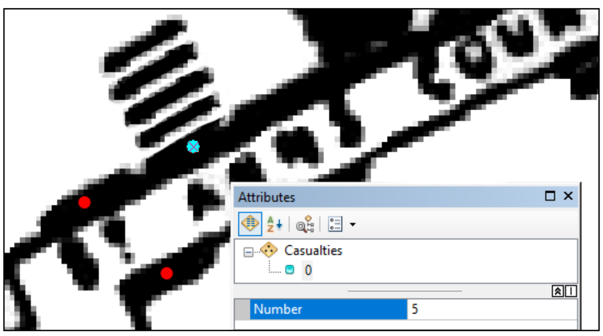

Figure 8. Editing of one point in Saint Anne's Court (representing 5 casualties). Source: Authors' elaboration.

At the end of the editing action, the Kernel Density tool was applied onto the casualties layer, setting the number of the deaths as the "Population field" parameter and the default search radius for the calculation. The output image was then symbolized in 5 classes, colored with the yellow to dark brown color ramp, useful to represent the hierarchy within the classes (Pesaresi, 2017, p. 26): as known, the highest class is placed in the surroundings of the Broad Street pump, as clearly represented by the image in dark brown (Figure 9).

To emphasize the effect and propose other solutions as exercise (Figure 10), only 3 classes were used also in order to increase the capacity of fast communication of the elaboration according to a tripartite from low values (represented in green) to high values (in red).

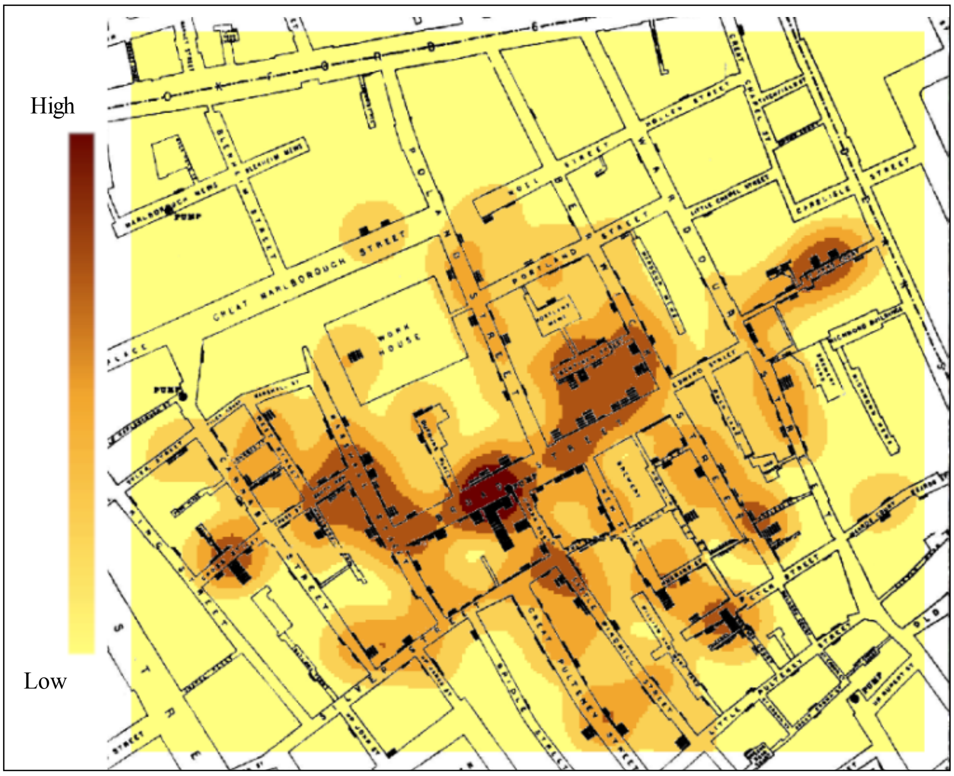

Figure 9. Screenshot of the Kernel Density map created from the weighted layer of the casualties, with the yellow to dark brown color ramp, in 5 classes. The highest class of values can be seen in the surroundings of the Broad Street pump. Source: Authors' elaboration.

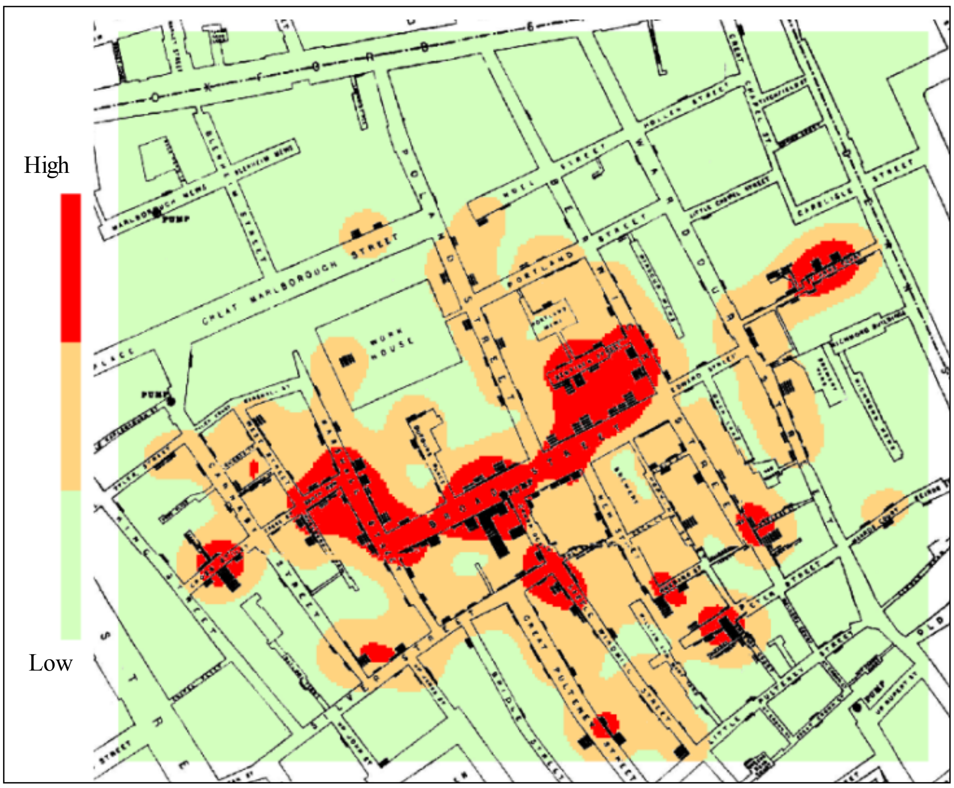

Figure 10. Screenshot of the Kernel Density map created from the weighted layer of the casualties, with a tripartite from low values in green, to high values in red. Source: Authors' elaboration.

To prompt space-time analyses and studies in the medical geography field, the Kernel Density algorithm has been used in several pieces of research, as for example:

- to look for the presence of clusters in the outbreak of some vector-borne diseases, such as dengue fever, by running the algorithm on a space-time dataset, in order to analyse the spread direction and locate resources to contain it (Delmelle et al., 2014, p. 144);
- to investigate the causes of road accidents by pointing out the links between the victims and the environment (Mennonna et al., 2018, p. 259);
- to evaluate the contribution of socio-economic factors to the number of births (MacQuillan et al., 2017, pp. 633-634).

6. Some reflections for further steps

In terms of future outcomes, many suggestions came from the GIS Day 2019 discussions, based on the demonstrative-application activity: John Snow's map and its re-elaboration showed the connection between the past and the present, considering the first as a source of inspiration for today's studies and analysis. Researchers who work like John Snow, to identify risk factors and explain local situations and exposure problems, could have a broader set of tools for their investigations and to make multi-temporal, geospatial and geostatistical analysis crucial for adding new relevant elements to the state of the art.

In fact, from data mining to communication phase, GIS has been developed to support decision-makers in their problem-solving, "with the aim of achieving a complete collaboration between Technology, Artificial Intelligence and Man" (Ratti, 2018, p. 125).

Data collection has been facilitated by modern applications such as ESRI Survey123 for ArcGIS, a questionnaire where the answers are spatially referenced and able to involve notable amounts of respondents from different areas. Moreover, digital mapping has magnified the way to represent the data, showing the presence of patterns with specific colors and techniques, such as density maps. Furthermore, the possibility to share geographic information has become much easier and a GIS project can be hosted by specific servers, converting local data into online resources, to be shared by web maps and web applications.

John Snow could end the analysis much faster, eventually saving more lives than ever. The same should be done today by working in teams. Geographers and epidemiologists, with a very good knowledge of the territory, the risk factors, the safety concerns of the different areas, the demographic and deprivation aspects, can operate together, in close conjunction towards social utility, a better quality of life and a more effective and efficient healthcare system.

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