Geographic Information Systems and COVID-19: The Johns Hopkins University Dashboard

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Short Report

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Abstract

Background: This article presents a single case study on the development of a GIS for global monitoring of coronavirus (COVID-19). For such concepts presented about GIS, its use and evolution in epidemic events and a presentation of the context of the current coronavirus outbreak and the meaningless results of consolidating a panel with reliable data.

Methods: A single case study of a GIS in continuous development with data sharing and comments from the scientific community was carried out. Because it is not a post-mortem analysis, or a follow-up to a successful case, it was not possible to use more rigorous and systematic approaches such as those used by Lee (1989) and Onsrud, Pinto and Azad (1992) for case studies in GIS.

Results: The case study presents the results of the development of a control dashboard, as well as the availability of consolidated data made by researchers at Johns Hopkins University and who showed a reliable platform and a world reference for health community.

Conclusions: Efforts to develop a dashboard and provide data on the coronavirus outbreak resulted in the immediate replication of several other information systems with different approaches (Power BI, R, Tableau), becoming a reference for any new global epidemic outbreak events.

Introduction

This article deals with the development of a Geographic Information System (GIS) and data on the recent Coronavirus outbreak (COVID-19) and its monitoring by Johns Hopkins University, which has become a world reference in the monitoring of epidemic outbreaks. For that, the researchers made daily monitoring of its evolution, witnessing its evolution until its current stage, which became a global case of success. The research followed the daily evolution of the outbreak, and an example is that the term 2019-nCoV was used (the same used in the initial versions in the header of the JHU dashboard). This name, 2019-nCoV, was temporary and, on February 11, 2020, received the name COVID-19 (PAHO Brasil, 2020). Its importance goes beyond the intrinsic aspects of GIS and moves to solutions for monitoring global epidemic outbreaks and their monitoring. We present concepts related to the theme, as well as the evolution of the way we have mapped epidemic outbreaks since John Snow map of cholera in 1854. Finally, we hope that it will contribute not only to the evolution of GIS linked to the health area but also any other manifestation involving location (violence against women, natural disasters, earthquakes, energy, water, housing density, murders, robberies, thefts, environmental pollution, among others).

An example is the efforts of the Bill & Melinda Gates Foundation, who developed a digital mapping system in Nigeria to help health professionals target specific areas for immunization efforts in the fight to eradicate polio (Gates Notes, 2012). These vaccination teams are using field tracking devices with mobile phones; collect GPS location data. This example shows the power of GIS not only for storytelling, such as sharing places (Flickr or Picasa) but for decision making like predicting a city or region to be impacted by a natural catastrophe.

Among the benefits of an information system, better information, improved services, and increased productivity can be highlighted (Nickerson, 1998). Decision-making processes and their results can be affected by several factors. Among them, data quality is critical. Although this fact is widely known, data quality is still a critical

issue in organizations due to the vast volumes of data available on their systems. Weak quality data could lead to terrible decisions.

Cerchiari and Erdmann (2008) report that epidemiology deals with the study of the factors that determine the appearance, frequency, distribution, evolution, control measures, eradication, and prevention of diseases. Buss (1995), about Brazil, reports that there are difficulties in discussing health conditions also as deficiencies concerning the indicators customarily used to measure it, as well as the precariousness of the available information on, in particular, morbidity and mortality.

Thus, this article, through the presentation of a successful case, aims to provide a contribution not only to the information systems area but for legislators and health services management, in general, to be aware of the need to expand the use of location-based systems. Some questions to be answered from the dashboard are common to information systems such as: What problem are JHU trying to solve? What gaps exist in dashboard performance? What are our goals? Where does the data reside? How many data sources are the dashboard looking at using? What are the data delay requirements?

Literature Revision

Geographic Information Systems

A Geographical Information System (GIS) is a computer-based technology designed to analyze, manage, store, and display geospatial data (Chang, 2014). They are systems equipped with software capable of analyzing and displaying data using digitized maps in order to improve planning and decision making (Laudon & Laudon, 2011). The GIS allows us to see, understand, question, interpret, and visualize our world in order to reveal patterns, relationships, and trends in the form of maps, globes, reports, and graphs. The technologies related to geographic information are broad and involve analytical methods, cartography, and visualization, design, data modeling, geospatial data, geocomputing, data manipulation, in addition to organizational and institutional aspects and linked to society (DiBiase et al., 2006).

A GIS is an information system that provides information for decision making based on geographic location. Certain information depends on where it originated. A GIS includes a database in which one organizes all data by geographic location. Almost any type of data can be stored in this database. The data is stored in joined layers just as a geographic location. A GIS can provide information to support decision making (Nickerson, 1998).

GIS is a particular category of DSS (Decision Support Systems) (Laudon & Laudon, 2011; João, 2015) that, thanks to data visualization technology, analyzes and displays data for planning and decision making in the form of maps scanned. The software can collect, store, manipulate and display information geographically, tying data with points, lines and areas on a map. The GIS also has a modeling feature, allowing managers to change data and automatically review business scenarios in search of better solutions.

Geographic analysis is the main form of GIS. Depending on the project, there are many different analytical approaches to perform a choice. GIS modeling tools make it relatively easy to perform simple or complex analyzes and create new results.

As Chang (2014) mentioned, GIS can store, manipulate, and display geospatial data on computer systems. After the data is collected, edited, and referenced to a designed coordinate system, the following step is to make the data readily available to users to make maps, assist in fieldwork and perform spatial analysis.

Web GIS, the product of integrating web and GIS technologies, is different from traditional GIS in that it masks the differences between the various types of databases, networks, hardware, and software (Lu et al. 2010). It is a platform to provide GIS resources to many organizations that share and collaborate GIS resources on the Internet to easily access and use geographic information (Law, 2013). Therefore, Web GIS provides accessible, manageable, and shareable global geographic data, information data indiscriminately (Liu et al. 2009).

Modern GIS systems use GPS (Global Positioning Systems), which is one of the GNSS (Global Navigation Satellite System). There are others like the Russian GLONASS system and the European Galileo system. Even social networks like Twitter present spatial data represented by latitude and longitude data for each twitter posted, which facilitates tracking in outbreak situations. The science and technology associated with the earth's image is called remote sensing. More advanced systems use lasers for mapping with those used by LIDAR (Light Detection and Ranging). This technique is capable of generating extremely detailed three-dimensional models of the earth's surface, being a technique used, for example, to measure the effects of a hurricane-like Sandy off the coast of New York and New Jersey in 2012. Earthquakes are another example of GIS use using beyond the latitude, longitude, and depth beyond, of course, the magnitude reported for the event.

Roux and Mair (2010), in a work on neighborhoods and health, on how residential environments can affect health and contribute to ethnic and racial inequalities in health, focusing on the results of chronic diseases (specifically obesity and related risk factors) and mental health (specifically depression and depressive symptoms) state that the explosion of GIS and spatial analysis techniques allow the examination of space in a much more detailed and sophisticated way than was possible in the past.

GIS for disease outbreaks is not new. An example, of a proto-GIS, is the work carried out by Dr. John Snow, in the late summer of 1854, to map the sources that caused a cholera outbreak in London's Soho region, mapping the detected cases. From August 31 to September 3, 127 people died of cholera (ARCGIS, 2020). As a result, and within a week, 500 people died, and about one in seven people who developed cholera and, eventually, died. All of this occurred 250 meters from the intersection of Cambridge Street and Broad Street (Figure 1 - shown in detail on the right). This proto-GIS allowed Snow to accurately locate contaminated water as well as the source of the outbreak.

Although the techniques have advanced considerably since the John Snow cholera map, the basic principles established by Snow still exist in current epidemiological thinking. Figure 2 presents a rereading of Snow's cholera map using current techniques.

An example of how to develop a GIS project is presented by Brewer (2006) on the development of a system for monitoring prostate cancer mortality in a timeline (how a set of events occurs over time) and including different populations.

About Wuhan and Coronavirus

Wuhan is a traditional industrial center. Of the 500 largest global companies, 230 have investments in the city (BBC News, 2020). In the automobile sector alone, there are ten factories, with Dongfeng Peugeot Citroen, Nissan, Honda, and GM standing out. There is also a nascent innovation industry, with 1656 high-tech companies (Wuhan Optics Valley Area) focused on biomedicine and medical equipment. Companies like PepsiCo and Siemens have operations in Wuhan. With the outbreak, companies like McDonald's, KFC, Pizza Hut, H&M, Ikea, and Apple temporarily closed their stores.

On the last day of 2019, the World Health Organization (WHO) was informed of an outbreak of "pneumonia of unknown cause" detected in the city of Wuhan, Hubei province, China - the seventh-largest city in China, with 11 million people. As of January 23, there were more than 800 cases of COVID-19 confirmed globally, including cases in at least 20 regions in China and nine countries/territories. The first reported infected individuals, some of whom have had symptoms since December 8, were found among street vendors in the seafood market in South China of Wuhan. Subsequently, the wet market closed on January 1. The virus causing the outbreak was quickly determined to be a new coronavirus. On January 10, genetic sequencing further determined the new Wuhan coronavirus, namely COVID-19, a beta coronavirus, related to the Middle East Respiratory Syndrome virus (MERS-CoV) and the Severe Acute Respiratory Syndrome virus (SARS-CoV). However, the mortality and transmissibility of COVID-19 are not yet fully known (Gardner, 2020).

Still, according to Gardner (2020), infected travelers (mainly by air travel) are known to be responsible for introducing the virus outside Wuhan. On January 13, Thailand reported the first international case outside of China, while the first cases in China, but outside Wuhan, were reported on January 19 in Guangdong and Beijing. On January 20, the National Health Commission of China (NHC) confirmed that the coronavirus could be transmitted between humans. On the same day, Japan and South Korea confirmed human infections by COVID-19, and the following day cases detected in the US and Taiwan in travelers returning from Wuhan. On January 21, several provinces in China were also registering new cases, and the infection was confirmed in 15 health professionals, with six deaths reported. Additional travel cases have been confirmed in Hong Kong, Macau, Singapore, and Vietnam. On 22 January, a WHO emergency committee met to discuss whether the outbreak should be classified as a public health emergency of international interest (PHEIC) under International Health Regulations but was initially undecided due to a lack of information before deciding against the declaration.

Of immediate concern is the risk of additional transmission resulting from high volumes of travel and mass meetings in celebration of the Chinese New Year on January 24. In an attempt to mitigate local transmission in China, unprecedented outbreak control strategies have been implemented in (initially) three cities. On January 23, 2020, Wuhan suspended all public transport and air travel (inside and outside the city), quarantining all 11 million people in the city. On January 24, Huanggang and Ezhou, cities adjacent to Wuhan, will also be placed in a similar quarantine. Besides, many cities have canceled Chinese New Year celebrations.

Johns Hopkins University, was founded in 1876, is the first research center in the USA. A vital mark is the presence of 36 Nobel Prize winners, who have studied, taught, or conducted research. It has six schools for graduation (Krieger School of Arts and Sciences, Whiting School of Engineering, School of Education, Carey Business School, School of Nursing, and Peabody Institute). School of Nursing students prepare for the fields of medicine in specific master and doctoral courses. Johns Hopkins has three graduate schools: School of Medicine, Bloomberg School of Public Health, and School of Advanced International Studies - SAIS. Johns Hopkins also has facilities in Nanjing, China. The medical school is in Baltimore, Maryland. The hospital was

opened in 1889 and is rated No.1 in the USA by the News & World Report for 22 consecutive years (Hopkinsmedicine, 2020).

The Johns Hopkins Gis Dashboard

Previous works

Monitoring dashboards in global outbreaks, such as SARS, are not new. An example was the Dashboards developed by the Canadian government (Wells et al., 2009) at the time of the SARS outbreak where performance measurement is activated through the Critical Care Information System (CCIS), implemented in 183 units of intensive care, representing 85% of the provincial level 3 and 2 beds. It is a secure online data entry system, updated several times a day, and able to summarize the unit's data in dashboards and bulletins in real-time for performance monitoring and peer comparison. Data points covering patient identifiers/demographics, patient flow, clinical interventions, bed utilization, and various quality measures are captured.

For the development of the dashboard (maps and data), ArcGIS was used, which is a GIS used to create and use maps, compile geographic data, analyze mapped information and manage geographic information in databases. Dice.

Previous work, including dashboard, by researchers from John Hopkins University, already using ArcGIS web-based technology (cloud), dealt with predictive analysis of measles outbreaks in the USA. Sarkar et al. (2019) identified 25 U.S. counties most likely to experience measles outbreaks (Figure 3). The predictive analysis was based on the volume of international air travel, non-medical exemptions from childhood vaccines, population data, and information reported on measles outbreaks.

The Coronavirus dashboard

The GIS coronavirus Dashboard (COVID-19) from the CSSE (Center for Science Science and Engineering) at Johns Hopkins University (Figure 4) was developed in response to this public health emergency. It is an online dashboard, but not in real-time, to view and track reported cases on a daily time scale. Its development included the team from Esri Living Atlas and the data services team from Johns Hopkins University (JHU Data Services). An important detail is that a complete set of data can be downloaded. Initially, as a google spreadsheet and later as a CSV file for use by other applications around the world, the Johns Hopkins dashboard is also a reference for monitoring the outbreak's evolution.

Initial data were collected from various sources, including WHO (World Health Organization), CDC in the USA, CDC in China, ECDC (European Center for Disease Prevention and Control), NHC, and DXY. DXY is a Chinese website that aggregates situation reports from the NHC and local CCDC in near real-time, providing more current regional case estimates than national reporting organizations are capable of and is therefore used for all cases Mainland

China reported on the panel (confirmed, suspected, recovered, deaths). US cases (confirmed, suspected, recovered, deaths) are taken from the US CDC, and all other country case data (suspected and confirmed) are collected from the corresponding regional health departments. The dashboard aims to provide the public with an understanding of the outbreak situation as it unfolds, with transparent data sources. A comprehensive view of the various data sources is provided at <https://github.com/CSSEGISandData/COVID-19>.

Gardner cited by Donovan (2020) on the dashboard initiative

"We created this dashboard because we think it is essential for the public to understand the situation of the outbreak as it develops with transparent data sources. For the research community, this data will become more valuable as we continue to collect it over time. Making data available for download is "critical" for researchers."

Table 1: Initial Data Sources

Source	Available at
WHO	World Health Organization https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports
CDC	Centers for Disease Control and Prevention https://www.cdc.gov/coronavirus/2019-ncov/index.html
ECDC	European Centre for Disease Prevention and Control https://www.ecdc.europa.eu/en/geographical-distribution-2019-ncov-cases
NHC	National Health Commission of the People's Republic of China http://www.nhc.gov.cn/yjb/s3578/new_list.shtml
DXY	Dingxiangyuan (a social networking site for healthcare professionals that provides real-time case information) https://ncov.dxy.cn/ncovh5/view/pneumonia?scene=2&clicktime=1579582238&enterid=1579582238&from=singlemessage&isappinstalled=0

The dashboard is structured into several small panels with an emphasis on Total confirmed cases (Total Confirmed), total confirmed deaths (Total Deaths), Total recovered patients (Total Recovered), Cases confirmed by Country or Province, data from the last update. Panel with the linear scale with the evolution of the total cases for Mainland China and other locations, its evolution, now including the total recovery and now including graphs on a logarithmic scale and another of the daily increment (new confirmations versus new recoveries). It is thus making the evolution and consequent regression of new cases clearer. Finally, a panel with data on the dashboard itself and the various data sources (Table 1).

Data and its consolidation

All data collected and displayed are made available, initially through Google Spreadsheets (Figure 5), which presents the data for each bulletin (upper part of Figure 5) and the one which presents the data on a time basis (lower). This data is now presented in CSV text format (comma-separated values) through the GitHub repository (<https://github.com/CSSEGISandData/COVID-19>), along with the control panel feature layers, which are now included in the Esri Living Atlas.

This format, CSV files, can be used directly by software such as Excel, BI tools or by languages such as R and Python, allowing its immediate use by the international scientific community. Between January 22nd and 31st, all data collection and processing was done manually, and updates were usually done twice day, morning, and evening (Eastern time). The manual reporting process became impracticable as the outbreak evolved as of February 1, a semi-automated loading of data was adopted (Dong, Du, & Gardner, 2020). A Johns Hopkins University team coordinated all manual updates (for countries and regions outside Mainland China).

The highlight for the central panel with the map with markers for Mainland China, North America, and Australia was presenting the total of confirmed cases. These are represented by legends in red circles with different proportions: (> 2000-100,000); (> 240-2,000); (> 153-240); (> 60-153); (> 21-60) and, finally, (1-21) confirmed cases. The maps can be customized in multiple styles: imagery hybrid, streets, topographic, navigation, streets at night, terrain with labels, light and dark gray canvas, geography style map, oceans, and, finally, OpenStreetMap.

As we can see, the data of the various daily bulletins are composed by Province / State, Country or Region, date and time of information, the number of confirmed cases, Number of deaths, and the number of recovered cases (returned to normal health). Greater detail can be seen in the structure of the same. The application structure consists of three layers: Deaths, Cases, and Cases_Country.

Dong, Du, and Gardner (2020) describe the evolution of the process of capturing and processing data from its primary source, the Chinese website DXY, where, every 15 minutes, the accumulated case counts are updated for all provinces of the country. China and other affected countries and regions. For countries and regions outside mainland China (which includes Hong Kong, Macau, and Taiwan), the data accumulated by DXY is often out of step with these new sources, so the dashboard data has been updated manually over the day as soon as new cases arose. For this, Twitter feeds, online news services, and direct communication were monitored. When working with Twitter data, there are two classes of geographic metadata: Tweet location, available when the user shares the location at the time of the Tweet and account location, based on the location of the “home” provided by the user in his public profile. It is a character field and may or may not contain metadata that can be georeferenced.

Before the manual update, the data was confirmed with the regional and local health departments, which resulted in more reliable data. The data are aligned with the CDC and WHO reports, and the dashboard, at certain times, was effective in capturing the moment of the appearance of the first reported cases of COVID-19 in new countries or regions, several of them before WHO itself (except for Australia, Hong Kong, and Italy). An observation of the dynamic character of the dashboard presents a specific case of the ship Diamond Princess, considered a location for monitoring and which presented on February 24, 2020, 691 confirmed cases with three deaths but with no indication of recovered cases.

The data as presented allows, among others, to determine daily new cases, growth factors of daily new cases, entire cases or new cases outside of Mainland China (worldwide), newly

infected versus newly recovered, a new case in Mainland China outside Hubei, total case trends. The change in diagnosis classification as the spike observed on Feb. 12.

Final Considerations

Regardless of the efforts of governments and international organizations such as WHO daily bulletins (WHO, 2020), the JHU dashboard became a world reference for monitoring coronavirus with accesses of the order of more than 400 million on February 5, 2020. Companies linked to the global financial market, such as Bloomberg, and information providers started to use data from the JHU dashboard for its information services. Media outlets like Newsweek, PBS News Hour, and ABC News cited the panel in their reports on the outbreak.

Also, according to Dong, Du, and Gardner (2020), given the popularity and impact of the dashboard, Johns Hopkins plans to continue hosting and managing the tool throughout the COVID-19 outbreak cycle and to develop its capabilities, as a permanent tool, to monitor and report future outbreaks. In his words, "We believe that our efforts are crucial to help inform the modeling efforts and control measured during the early stages of the outbreak." New systems were developed based on data from the JHU panel. On February 24th, there was at least one application on Tableau (Jean-Paul Cavalier, 2020), PowerBI (<http://bit.ly/38qeMbz>), and R Markdown (<https://github.com/kevinlanning/2019-nCoV>). Which in itself already shows the power to make data available to the community.

Kwan and colleagues (Kwan, 2004; Kwan & Lee, 2004) demonstrated that, in the space-time relationship, aided by GIS, show the highly individualized and complex spatial routines that people follow in their daily lives. This type of work demonstrates that the expansion of studies to include the measurement of individual exposure to multiple "Contexts" in time and space would be an essential step forward.

The environmental epidemiology uses information about existing risk factors (physical, chemical, biological, mechanical, ergonomic, and psychosocial) and as a character is that the environment interferes with the population's health standards, exposed people, and adverse effects the health. The use of GIS, according to Croner, Sperling, and Broome (1996), in this approach, of environmental epidemiology, improves the ability of researchers to study environmental risk factors for diseases.

However, we must highlight the human errors involved in the process, among which we can mention. 1) slow communication of the beginning of the outbreak, in which the mayor of Wuhan, Zhou Xianwang admitted that he did not immediately report the first suspicions of the virus; 2) lack of tests (diagnostic kits), which only arrived at the hospitals in Wuhan on January 20; and 3) mistaken assessment by the World Health Organization (WHO), which initially pointed to a moderate risk of epidemic. It subsequently declared an international emergency.

Pei (2020) points out that China has a long history of epidemic outbreaks, such as SARS (severe acute respiratory syndrome), in 2002, where he says that the Chinese Communist Party needs to keep the mind of the Chinese public convinced that everything is as planned by the Party. An example is that in an official statement, there was no evidence that the new disease could be transmitted between humans, in addition to stating that no health worker had been infected. These statements proved to be false. Another issue was that initially, there was

little coverage in the Chinese press apart from censors removing references to the outbreak and tighter government control over the Internet, the media (including the popular WeChat), and civil society.

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Figures

Figure 1

John Snow's cholera map and Detail (right) Source: https://johnsnow.matrix.msu.edu/book_images12.php

Figure 2

A rereading of Snow's cholera Map using GIS Source: <https://www.arcgis.com/apps/Cascade/index.html?appid=6dc59a81b5d34f22a3faa014d9915a69>

Figure 3

JHU measles outbreak dashboard in the USA Source: Available at <https://gisanddata.maps.arcgis.com/apps/opstdashboard/index.html#/33c650a3740f478e99e308da9e5908ec>

Figure 4

Johns Hopkins CSSE dashboard (Desktop version) Source:

<https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6>.

Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Novel Coronavirus (2019-nCoV) Cases, provided by JHU CSSE

Feb04_10PM						
Feb04_1150AM Feb04_8AM Feb03_940pm Feb03_1230pm Feb02_9PM Feb02_745pm						
	A	B	C	D	E	F
1	Province/State	Country/Region	Last Update	Confirmed	Deaths	Recovered
2	Hubei	Mainland China	2/4/20 23:43	16678	479	522
3	Zhejiang	Mainland China	2/5/20 1:33	895	0	63
4	Guangdong	Mainland China	2/5/20 2:03	870	0	32
5	Henan	Mainland China	2/5/20 1:13	764	2	41
6	Hunan	Mainland China	2/5/20 1:43	661	0	35
7	Jiangxi	Mainland China	2/5/20 1:33	548	0	27
8	Anhui	Mainland China	2/5/20 1:13	530	0	20

time_series_2019-ncov										
Confirmed Recovered Death										
	A	B	C	D	E	F	G	H	I	J
1	Province/State	Country/Region	First confirmed	Lat	Long	1/21/2020 10:00 PM	1/22/2020 12:00 PM	1/23/2020 12:00 PM	1/24/2020 12:00 AM	1/25/2020 12:00 AM
2	Anhui	Mainland China	1/3/2020	31.82571	117.2264			1	9	15
3	Beijing	Mainland China	1/3/2020	40.18238	116.4142	10	14	22	26	26
4	Chongqing	Mainland China	1/3/2020	30.65715	107.874	5	6	9	27	27
5	Fujian	Mainland China	1/3/2020	26.07783	117.9695			1	5	5
6	Gansu	Mainland China	1/3/2020	36.0611	103.8343				2	2
7	Guangdong	Mainland China	1/3/2020	23.33841	113.422	17	26	32	53	53
8	Guangxi	Mainland China	1/3/2020	23.82908	108.7881		2	5	13	13
9	Guizhou	Mainland China	1/3/2020	26.81536	106.6748			1	3	3
10	Hainan	Mainland China	1/3/2020	19.19673	109.7455			4	5	8
11	Hebei	Mainland China	1/3/2020	38.0428	114.5149			1	1	2
12	Heilongjiang	Mainland China	1/3/2020	47.862	127.7622				2	4
13	Henan	Mainland China	1/3/2020	33.88202	113.614			5	5	9
14	Hubei	Mainland China	1/3/2020	30.97564	117.7707	270	444	444	549	549

Figure 5

Database with bulletins (top) and Timebase (Confirmed, Recovered, Deaths) (bottom)