GIS Open Source Application as a Support to a Hospital Morbidity Database
Hospital GIS

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Abstract: Geographical Information Systems (GIS) capabilities are increasing in health area. GIS have been used to investigate global health studies due to the huge capabilities to manipulation, storage, management, analysis, modelling and mapping of geographical data. A simple and intuitive graphic interface to represent spatially an administrative database information would be a great usefulness to the health community. In this work, an open source application was developed in Python language under a GIS open source software (QGIS). The application, incorporated in GIS software, is composed by two tabs: Symbology and Mapping. In order to test the developed application, a zone from Porto Metropolitan Area and a database with administrative data, hospital morbidity database, was considered. This data was previously added to PostGIS (an open source database) and automatically connected to the application. The difficulty of health professionals in the creation of multiple visualizations of tabular data defined by rigorous position, and the maps creation to later analysis and printing, can be overcome with this application. The large amount of data requires the connection to a free database in GIS environment enhancing the practical applicability, rapid, safe and efficient data representation.

1 INTRODUCTION

Spatial epidemiology is the study of geographical variation in disease risk or incidence (Kelen et al., 2012). In 1854, John Snow created the first map relating environmental factors in order to investigate the base of cholera deaths (Snow, 1855). Nowadays, Geographical Information Systems (GIS) capabilities are increasing in health area. GIS have been used to investigate global health studies due to the huge capabilities to manipulation, storage, management, analysis, modelling and mapping of geographical data. GIS presented new opportunities for researchers providing the tools required for exploring the geographic variation in disease risk relating the geographically indexed health events with demographic, environmental, behavioural, socioeconomic and genetic risk factors (Zhang et al., 2016). The spatial epidemiology takes advantage of GIS tools combined with Remote Sensing (RS) to enhance accessibility to spatial data and to measure the spatial-temporal variation in disease risks (Kelen et al., 2012; Jeong et al., 2016). For example, Zhang et al. (2016) review and analyse the types of spatial measurement errors more commonly encountered during spatial epidemiological analysis of spatial data combining GIS, RS, Global Positioning Systems (GPS) and statistical methodologies. In order to perform GIS spatial-temporal analysis, other study conducted by Shiode et al. (2015), prepares their own data on the estimated number of residents at each house location along with the space-time data of the victims. Several studies applied to health spatial-analysis were performed using GIS tools (Gómez-Barroso et al., 2016; Ferguson et al., 2016; Ruktanonchai et al., 2014; Ayres-Sampaio et al., 2014; Sadler, 2016; Jeong et al., 2016; Makanga et al., 2016; Panciera et al., 2016). Unfortunately, all these studies are mainly focused on applying GIS tools under proprietary software. Other works used GIS under web environment used PostGIS databases

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and open servers (Moncrieff et al., 2014; Smith and Hayward, 2016; Bui and Pham, 2016).

Some GIS applications were developed under free and open source software such as OpenJump (Fisher and Myers, 2011) and a new open source tool, openModeller was created (Muñoz et al., 2011).

There is not an open source application under QGIS software developed specifically with the purpose of spatially representing a huge amount of data storage in a database, and automatically symbolize and create a map. An open source application allowing health experts or common users (not familiarized with GIS environment) to represent spatially the database information, with a simple and intuitive graphic interface, would be a great usefulness to the health community. This research was addressed to health experts who handle with spatial geographic data in scientific research field improving the GIS analysis capabilities in health spatial information field.

The objective of this work is the development of a GIS open source application which allows: (i) to automatically connects to a database in order to access the (huge amount of) data; (ii) to create maps for printing with information provided by a database; (iii) to automatize the vector files symbology: graduated or categorized; (iv) to connects to Bing Aerial Maps in GIS environment in order to overlap the database information; (v) to create a polygon file with the extension of the study area, and; (vi) to convert a shapefile to Keyhole Markup Language (KML) format. This application can be easily used to improve the studies referred creating the required maps with an easy connection to an open source database.

This manuscript is divided into 5 sections: Introduction, Methodology, Results, Discussion and Conclusions. The Methodology section is divided into PostGIS database subsection and Hospital GIS subsection where are explained the API libraries (QGIS and Python) used and the application development.

2 METHODOLOGY

The application was developed under the GIS open source software QGIS (QGIS, 2016). QGIS is an open source software developed by Gary Sherman in 2002 which respects the Stallman four freedoms: freedom to run the program for any purpose, to study how the program works and modify it, to redistribute copies and to distribute copies of modified versions (Stallman, 2007). It is developed in C++ and complemented with Python extensions or plugins. QGIS presents several advantages in the plugins development using Python language, as it had several libraries to use. Python language is also an open source language, interpreted, high level, and object oriented language (Python, 2016). Several libraries and Application Programming Interfaces (API's) were used. QGIS has its own API's such as QGIS API, Geospatial Data Abstraction Library (GDAL)/OGR API and PyQt4 API (PyQt4, 2016; QGIS API, 2016; GDAL, 2016) and it supports vector files, raster formats and spatial databases (e.g., PotgreSQL and PostGIS; QGIS, 2016). The APIs are composed by modules, classes and functions which help to connect the graphic interfaces with the spatial information manipulation. With the implementation and use of the algorithms provided by QGIS software, this application improves the using of GIS functionalities and connection to databases with multiple data using a simple and intuitive interface.

2.1 PostGIS Database

PostgreSQL is a Relational Database Management System (RDBMS) which manages data stored with relationships. PostGIS is a GIS spatial database which adds spatial support to PostgreSQL and follows the interoperability standards from Open Geospatial Consortium (OGC; PostGIS, 2016). It is open source and is available through GNU General Public License (GLP) license. PostGIS supports specified geometries from OGC: point and polygon, and supports geographic objects allowing their location through SQL (SQL, 2016). SQL language is a standard universal language used in the database manipulation through RDBMS and allowing several tasks such as insertion, modification and object creation, user management, information query, among others. The most common operation in SQL, the query, makes use of the declarative SELECT statement which retrieves data from one or more tables or expressions. In the work presented, the SELECT command was used to database queries (SQL language, 2016).

2.2 Hospital GIS

The aim of this work was the creation of HospitalGIS application which allows to relate the database information in an intuitive and simple way. The graphic interface was created through Qt Designer and all the configurations were applied automatically. The application is composed by a button added to QGIS tools.

Through the mouse click in the button, a dock widget opened as a panel incorporated in QGIS environment in a way that the user can obtain information from the data visualization. Figure 1 presents the button and the HospitalGIS graphic interface.

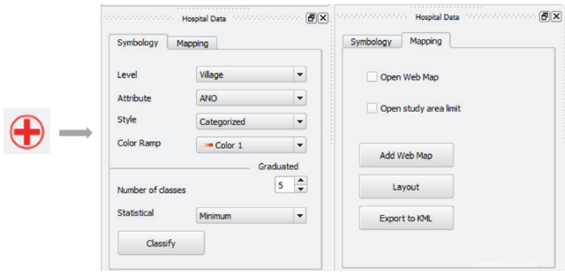

Figure 1: HospitalGIS graphical button and graphic interface.

HospitalGIS is composed by two tabs with different functionalities: *Symbology* and *Mapping*. The first one is composed by the symbology parameters regarding the maps and presents four combo boxes: the information level (village, municipality, district, Nomenclatura das Unidades Territoriais para Fins Estatísticos (NUTS II) residential, NUTS II hospital, NUTS III residential, NUTS III hospital); the attribute to visualize; the symbology style according to the information type (it can be *Categorized* when the attribute is discrete or *Graduated* when the attribute is numeric); and finally the ramp color. In *Symbology* tab, some parameters from graduated classes are also presented, such as: number of classes which the user can choose and the statistical method which can be applied to the study variable (minimum, maximum, average, mode and standard deviation). The labels (text) defined in the combo box *Attribute* are automatically defined from the village shapefile attribute table. This shapefile is automatically incorporated in the application. The other combo boxes were created with predefined styles according to the symbology type (*Categorized* or *Graduated*). The color ramp was assigned with a set of colors and added to the respective color ramp. The number of classes is defined with value 5, by default, but can be modified by the user.

The *Mapping* tab incorporates the auxiliary cartography and contains several functionalities to add other types of maps or creation of maps for printing. The tab is composed by two check boxes and three buttons. The check boxes allow the addition of an interactive map from Bing Aerial Maps (*Open Web Map*) and the possibility of adding the extension zone shapefile, so the user can verify the delimited extension (*Open study area limit*). These options can be performed after the map symbology. The user can create a map for printing (*Layout*) with the symbolized map and export the shapefile to kml format to verify the result through Google Earth or Google Maps (*Export to KML*).

2.2.1 API libraries (QGIS and Python)

QGIS API or PyQGIS allows to virtually control the QGIS graphic environment and it is based on QGIS C++ API divided by five categories: Core, GUI, Analysis, Map Composer and Network Analysis (QGIS API, 2016). The PyQt4 API is composed by several Python modules developed for Qt framework. This is a multiplatform framework composed by a set of C++ libraries built to the development of graphic interfaces, Structured Query Language (SQL) databases, Scalable Vector Graphics (SVG), Open Graphics Library (OpenGL), eXtensible Markup Language (XML) and other configurations (PyQt4 API, 2016).

Processing Toolbox algorithms were also used in the developed application. Processing Toolbox belongs to QGIS and it is a framework composed by a set of algorithms disposed in a tree (Sextante, 2016). The algorithms belong to external applications with geoprocessing capacities, such as System for Automated Geoscientific Analyses (SAGA), Geographic Resources Analysis Support System (GRASS) or R (SAGA, 2016; GRASS, 2016; R, 2016). These algorithms were crucial to the application development. The plugins development follows a specified structure provided by QGIS official page (QGIS, 2016): have an idea, create the files required, write the code and test while writing, and in the end publish the plugin in the official page. Several scripts were developed according to the rules defined. The graphic interface was created through the *Plugin Builder/Qt Designer* extension which configures all the files needed (Plugin Builder 2015; Plugin Builder Documentation 2015). Widgets from Qt API were created, such as combo boxes, check boxes, push buttons, labels, edit lines, among others.

2.2.2 Application Development

The application architectureis presented in Fig.2. The application was created based in two classes, the main class (composed by 15 functions) and a class referred to the kml conversion. Through the *initGui* function, an automatic reading of hospital database is performed to verify the existent attributes and add them to the *Attribute* combo box. In this function the

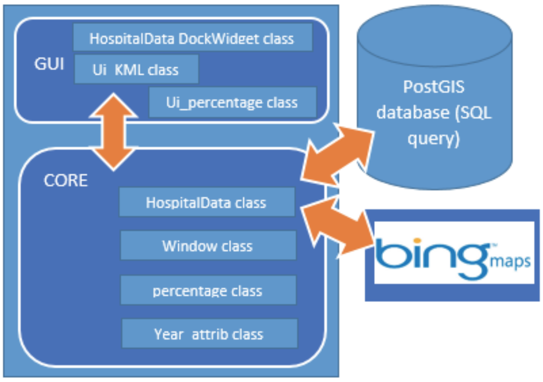

Figure 2: HospitalGIS architecture.

strings to the *Level*, *Style* and *Color Ramp* combo boxes are also added, such as:

```
self.dockwidget.comboBox_2.addItems(['C
ategorized', 'Graduated'])
```

The *Color Ramp* combo box incorporates an image. This image is considered as an icon, so *QIcon* class was used. The buttons connections through the clique action are also performed in this function. The *Classify* function is called through the clique action and incorporates the *Categorized* and *Graduated* types of symbology. After that, if the check box *Open Web Map* is activated, Bing Map is added to the QGIS area and then the map is symbolized. If the symbolization is *Categorized*, symbology_categorized is called, and if is *Graduated*, symbology_graduated function is called.

Symbology_categorized function connects to PostGIS database through QGIS API classes which stored components from the Uniform Resource Identifier (URI) data source from PostgreSQL/RDBMS. The structure stored the information related to the database connection including server, database, username and password, scheme and, if exist, the SQL conditions. Then the database connection is performed and consequently opens. Through SQL language a code line was created to join the shapefile and the database through village code, municipality and district (dicofre), and the attribute variable mode estimation to each village. Figure 3 presents a schema with the connections established.

In order to execute the SQL condition, the pgsql2shp.exe application from PostgreSQL was used. This application applies a SQL condition saving the result into a new shapefile. The new shapefile should contain two fields, the village name and the statistical value (estimated) of the chosen variable to

Figure 3: HospitalGIS workflow presenting the connections.

each village. QGIS functions were used to read these functions. The second column (statistical variable) is acquired to use in the symbology.

In the next step, all the occurrences of attribute column, through a *for* cycle, were recorded in a new list. Repeated elements were eliminated through the *set* Python function. The categorized symbology should be built through a specific dictionary with the column values, the label and the associated color. Finally the shapefile is added to QGIS environment.

If the *Open study area limit* check box is checked, the extent function is used to zoom in the extension area. *Dissolve* function from Processing Toolbox was used to dissolve the extension zone in a unique polygon and overlap the shapefile. Another condition was added to verify if interactive map was selected. If true, the shapefile (European Terrestrial Reference System 1989 Portugal Transversal Mercator 2006 - ETRS89 PTTM06; European Petroleum Survey Group (EPSG): 3763) is projected to World Geodetic System 1984 (WGS84) Pseudo Mercator (EPSG:3857) through the QGIS *reprojectlayer* algorithm. ETRS89 PTTM06 system is actually mandatory in Portugal according to Infrastructure for Spatial InfoRmation in Europe (INSPIRE) directive (Inspire, 2015). Inspire directive has been in effect since May 15th 2007. It is composed by several areas: metadata, geographic data interoperability, network services, data share, and coordination and monitoring (Inspire, 2015). The WGS84 Pseudo Mercator system, also nominated by Web Mercator, Google Web Mercator, Spherical Mercator or WGS84 Web Mercator, is the coordinate system used in web mapping applications and it is associated to Google Maps, Bing Maps, OpenStreetMap, Mapquest, Mapbox among others (Web Mercator, 2015; Spatial Reference, 2015; Spherical Mercator, 2015).

The symbology_graduated function is connected to PostGIS database where the hospital information is stored. Several *if* statements were defined with a SQL condition according to the attribute and the statistical method chosen by the user. Table 1 presents an example of a condition which relate the hospital database with the study area shapefile through the join operation. The statistic is saved and applied to the chosen variable into a new shapefile. The following command line present an example of a SQL condition.

```
SELECT freguesia,
sum(totdias)/count(totdias), geom FROM
grande_porto LEFT OUTER JOIN
sample_reside_join ON
grande_porto.dicofre =
sample_reside_join.reside GROUP BY
freguesia, geom ORDER BY freguesia
```

The *Layout* button allows the automatic creation of a map for printing and is connected to the layout function. In this function, the following layout elements are defined: title, legend, graphic scale and north arrow. The shapefile projection system is verified and if it is ETRS89 PT-TM06, the layout is created. Other way, the shapefile is projected through *reprojectlayer* algorithm. The legend and title are composed through QgsComposerLegend and QgsComposerLabel classes, respectively. The north arrow is added as an image and corresponds to the cartographic north. Finally, a graphic scale is automatically created according to the coordinate system defined. The result is saved in *tif* format through the *printPageAsRaster* function.

The addMap function allows to add the Bing interactive map to the QGIS environment. The user can symbolize the shapefile after or before adding the map.

A new graphic interface to the kml conversion was created. This action is performed when the user clicks in *Export to KML* button. The QGIS environment could have several shapefiles open, so this graphic interface was created in order to give the possibility to choose which file would be converted. Figure 4 presents the graphic interface.

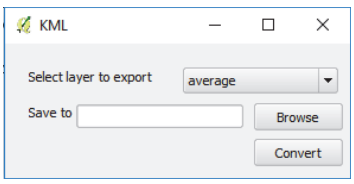

Figure 4: KML button graphic interface.

The new dialog box (Fig. 4) was created through a new class Window. The function handleButton was created, allowing to read all the vector files open in QGIS environment, and to list the names adding them to the combo box (*Select layer to export*). Also, in this function, the *Browse* and *Convert* buttons connections were defined, for the new kml file directory and to convert the shapefile to kml format, respectively. This process uses ogr2ogr algorithm from GDAL/OGR library. This connection is performed through the Python function *subprocess*.

3 RESULTS

In order to test the developed application, a zone from Porto Metropolitan Area (PMA) and a database with administrative data were used. These data were previously added to PostGIS. The coordinate system used was ETRS89 PT-TM06.

The national hospital morbidity database (an administrative database, in PT, Morbilidade Hospitalar, previously designated as Grupos de Diagnóstico Homogéneo – GDH [in EN, Diagnosis Related Groups]) is very often referred in the hospital information system context. These databases are composed by clinical-administrative data related to hospital discharges (inpatient episodes, ambulatory surgery and medic ambulatory) and other variables. These administrative databases can contain incorrect data and also data with some quality issues, but are composed by data easily available, inexpensive and frequently used. In some situations, it can be the only available data to study a specified clinic question. It can, for instance, be used as a quality indicators production to the study and comparison of hospital activities or in the study of relations between hospital and environmental variables. In this context, GIS tools can assume a focus to easily provide the visualization and comparison of different outcomes (hospitalization taxes, hospital morbidity) to certain pathologies in time or in specified geographic areas with adjustment to population data.

The categorized symbology was tested based on the variable *ADM_TIP* attribute which corresponds to the patients' admission type (strings 1, 2 or 6). The string 2 corresponds to urgent admissions and the remaining strings are related to programmed admissions. Figure 5 presents the assigned characteristics in this specific case and the result obtained.

In this case, the variable is discrete so the application considers the mode and assign the value to each village. The second part of the graphic interface is blocked, so it can be used only with graduated symbology. In the future, the application will be improved to estimate the occurrences percentage beyond the mode. The symbols without

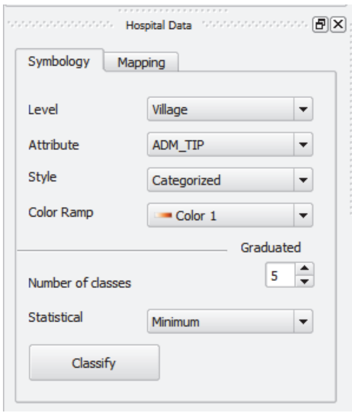

Figure 5: HospitalGIS graphic interface with the *ADM_TIP* attribute characteristics.

legend corresponds to village without information. The map for printing was created in A3 size and the elements related to Grande Porto zone. A numeric attribute was also tested, the variable *totdias* which corresponds to the total number of inpatient days. The study was also applied to the villages. The style chosen was *Graduated* and the classes number were defined by default as 5. The statistical method applied was the average. Figure 6 presents the categorized and graduated symbology with the respective maps.

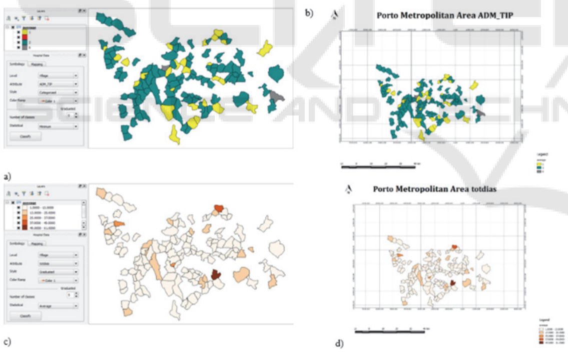

Figure 6: a) Categorized ADM_TIP attribute symbology; b) Categorized ADM_TIP attribute map for print; c) Graduated *tot_dias* attribute symbology; d) Graduated *tot_dias* attribute map for print.

Figure 7 presents examples using minimum value, standard deviation and mode related to the inpatient days variable.

In Figure 8 is presented the symbolized shapefile overlapped with the limit of study zone and the interactive map, in order to test the other functionalities.

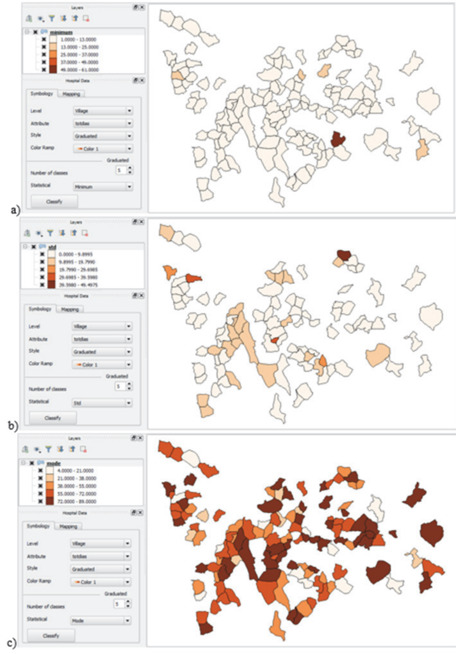

Figure 7: Examples considering a) minimum value, b) standard deviation and c) mode related to the inpatient days variable.

Figure 8: a) Symbolyzed shapefile overlapped with the limit of study zone and the b) interactive map from Bing Aerial Maps.

4 DISCUSSION

The database information was spatially distributed. Different combinations and possibilities were tested with the developed application and was concluded that, in health area, this application could be very valuable, improving the spatial analysis for the health professionals. For instance, Figure 6b shows an example of *ADM_TIP* attribute representation by village which corresponds to patients' admission type (strings 1, 2 or 6). From the results obtained it can be concluded that approximately 49% of the villages don't have information in the database (and they are not presented in Figure 6). 12% of the villages of PMA were classified as containing patients with programmed admissions (string 1 or 6) and 39% of the villages presented patients urgently admitted in the hospital of Porto. In this particular study case the mode of patients in each village was evaluated. If we consider a quantitative variable, such as the average total number of inpatient days (Figure 6d), we can conclude that 42% of the villages contains 1 to 13 patients in the hospital, 8% with an average of 13-25 patients and 1 village has more than 43 patients in the hospital (Vila Boa de Quires e Maureles (accessed taking advantage of QGIS tools)). Other type of relations can be performed with the tool. Also, this application is based on an open source software, easy to install and use. The database relationship with a shapefile allows to locate and visualize geographically and spatially the data, improving the data analysis and interpretation. The interaction with different information layers was also a great advantage to a user non comfortable with GIS software, or GIS operations such as PostGIS connection, shapefiles creation and symbolization, connections and calculations between several variables and statistics applications under spatial information. The application is free, open source, available for any user that needs a tool easy to use and understand, allows to create maps with associated data, and also perform geographic and statistical analysis from database information.

5 CONCLUSIONS

The developed GIS open source application is a valuable tool to health area where the user must deal with geospatial data with future applicability in the data access and hospital episodes data manipulation and analysis. The difficulty of health professionals in the creation of multiple visualizations of tabular data defined by rigorous position and the maps creation to later analysis and print can be overcome with this application. The large amount of data requires the connection to a free database in GIS environment enhancing the practical applicability, rapid, safe and efficient data representation. The presented tool is a preliminary version of a useful and efficient scientific tool to produce the maps required to study health variables, helping in the decision support. Some improvements will be done in the future automatizing even more the developed application such as (i) extending the data visualization to a WebGIS, through the creation of a web page that allows the hospital administrative data visualization using Google Maps or Google Earth as interactive maps, (ii) performing spatio-temporal statistical analysis, evaluating the trend prediction of the data with the creation of plots, (iii) developing functionalities to compare parameters in different regions, (iv) relating the information of the database with environmental risk factors such as temperature, precipitation or even vegetation indices and (v) the possibility of inserting satellite imagery will be implemented The application is easy to install and use in GIS environment and is available in http://www.fc.up.pt/pessoas/liaduarte /HospitalGIS.rar. The present application can only be tested under inside server.

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