IQAr: A Web Based GIS for Air Quality Monitoring in Real-time

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***Abstract*— This paper describes the features of the software IQAr that aimed at improving the process of management of air quality data generated by automatic stations. The IQAr includes verification of incoming files for monitoring, processing, validation and storage of data. This tool enables the reporting, the dissemination of results of monitoring over the web with a dynamic map, the visualization of the current direction and speed of wind through a wind rose chart, and the display of the Air Quality Index (AQI) of the last 24 hours. The IQAr allowed the Environmental Institute of Paraná (IAP) and the LACTEC Institutes to improve the equipment evaluation of air quality stations and consistency of the generated data, besides diagnosing air quality in real-time. Due to the ability to continuously validate the data, the software made it possible the dissemination of georeferenced information of air quality in real-time to the general population through the IAP website.**

Keywords-AQI; air quality; real-time monitoring; dynamic thematic map.

I. Introduction

Recent population boom in urban centers caused an increase in industrial production, the number of vehicles on the streets, and in energy consumption, generating an enormous raise in the use of fossil fuels to meet the demand of people. This led to an increase in the level of air pollution and the degradation of air quality as consequence, which has been damaging the health of the population.

Data concerning the monitoring of air pollutant concentrations should be measured in places where the population is exposed to air pollution. Generally, the levels of air pollution are higher in places close to highways (mobile sources) and industries (stationary sources) [1].

The analysis of monitoring data allows evaluating the tendencies of pollutants daily and long term, besides the observation of the effectiveness of the regulations of air pollution and check compliance with standards established by law in order to improve the air quality management [2]. Monitoring should be used to inform the public of critical situations creating emergency programs [3]. The results of monitoring can be related to levels of traffic or industrial activity for urban planning, assisting in environmental licensing [4].

The importance of achieving agility in the process and reliability of the monitoring data of air quality has recently driving interesting and promising research in the area, involving the use of different technologies, such as artificial intelligence for description and classification of air quality [5][6], mobile devices with pollution sensors [7], remote sensing with Geographic Information System (GIS) techniques [8], and wireless sensor networks as an alternative to the conventional measuring stations [9][10].

Automatic monitoring stations of air quality have been playing a key role in the continuous measurement of pollution levels in the atmosphere. However, the amount of data generated by these stations is very large and not always available in a friendly data format for easy interpretation by the end-user.

In order to improve the interpretation, validation and dissemination of information of air quality, it is common for technical experts to use computational resources available in many different types of software, a fact that often makes the process even more costly, time consuming and complex.

Given the above, it is clear the importance to improve monitoring, processing and information management of air quality, as well as make them available to society with simplicity and easy access. The IQAr (acronym of air quality index in Portuguese) aims to meet all these demands.

In this article, the information is organized as follows: The management of data from the air quality stations and the advantages of using IQAr are discussed in Section II. Section III details the developed solution, describes the architecture, each part of the system and its features, including comparisons with the state of the art in air quality. The conclusions, recommendations and future work are described in Section IV.

II. Air quality data management

To manage the raw data received from the air quality stations it is necessary performing mathematical operations in order to generate meaningful information for both expert operator and end-user, like calculating average hourly values for each parameter per station, calculating the Air Quality Index (AQI) to classify the air, converting data in order to compare them to standard of the legislation 03/90 defined by the national environmental council of Brazil (CONAMA), among others.

The air quality standards stipulated by the legislation of each country have the role of protecting the health of citizens, assisting in risk management and environmental policies [1].

The AQI is a dimensionless index used to facilitate the disclosure of pollution data for the general public. This index

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is also used to get pollutants in the same scale and enable the comparison of the level of pollution between pollutants.

The AQI must be presented together with the referenced period, the name of the critical pollutant, and the category following the indicative color. It also needs to present the concentration of pollutants and their effects on health [11].

The index is calculated accordingly to the concentration and the limits of each region. In Brazil, the air quality index is based on the already mentioned CONAMA 03/90 standard. It is divided into six categories (good, regular, poor, bad, hazardous, critical), where each category represents the level of pollution and health risks. The criteria used follow the primary and secondary standards, level of attention, alert and emergency stipulated in this legislation. The Brazilian system is very similar to the one used in the United States developed by the Environmental Protection Agency (US EPA), where the classification is also divided into six categories: good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, hazardous [1]. In Canada, the rate is called the index of air quality on health and is used as a tool for the protection of people's health, aiding in decision making to minimize the risk exposure generated by pollution. The index is divided into ten intervals contained in four categories, separated into low, moderate, high and very high risk to health [12].

In 1998, when LACTEC started the operation of the first air quality stations in the state of Paraná, the disclosure was made through an annual report. After the development of the first system by LACTEC for processing and validation of air quality data and partership with environmental institute of Paraná (IAP) it had become possible, in 2010, to release monthly reports.

With the improvement in transmission and validation techniques it had become possible in 2012, the disclosure of daily reports; now, IQAr is in real-time.

In this paper, whenever “real-time” is mentioned, it must be comprehended from 5 to 10 minutes after data are measured by stations, since there is a delay in data transmition by the stations. Regarding air quality area, it should be considered real-time.

Before IQAr, it was not possible for the IAP to provide information about air quality in real-time, since data were not unified into one management system. This required more than one software tool to process, validate and even other software for reporting and disseminating those data. The presented project allowed having all these tasks in one software, making obsolete other systems used previously for this purpose, as Excell, Scanair, Migris and Anagis (previously developed by LACTEC). IQAr joined all the data processed in the various stations of the air quality in a single database. Once incoming data files are at the right format (Figure 2) the processing occurs naturally. Thus, the system is able to process data from stations of different manufacturers, even them using distinct software for measurement and transmission of data.

III. THE IQAR SOFTWARE

The IQAr program was developed by the LACTEC Institutes for IAP in order to manage the periodic measurement data from air quality stations. It analyzes the text files from the stations, processes them, provides features for editing data, performs calculation of the AQI and makes them available on the web using GIS technology in real-time.

A. System architecture

As it can be seen in the diagram of Figure 1, data flow begins in the air quality measuring stations.

The stations measure meteorological parameters and pollutants (chemical parameters) in the atmosphere. The pollutants, generally, are: nitrogen oxides (NO_X), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO), total and inhalable particulate matter (MPTS, PM10) and hydrocarbons (HCT). The meteorological parameters are temperature, humidity, wind speed and direction, pressure, global radiation and precipitation.

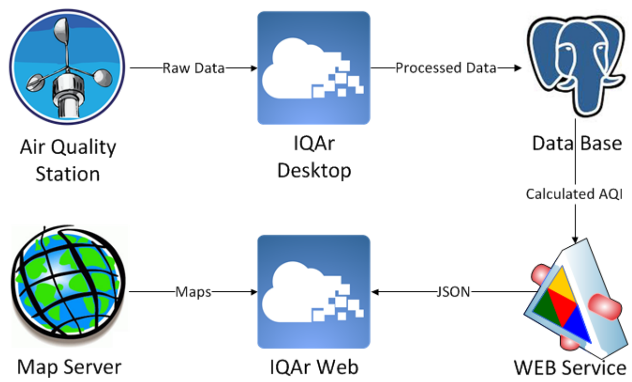
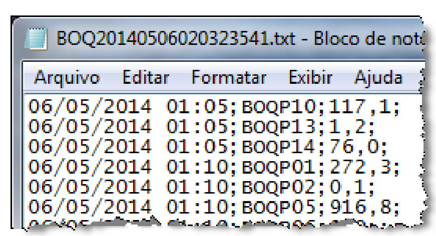


Figure 1. Data flow diagram.

The stations make continuous measurements and store the data in intervals of five to fifteen minutes. Through dial-up line or TCP / IP, they transmit the files to the computer in the data center where it is installed the IQAr Desktop that receives the text files of these stations and performs the processing. In the files, each line represents a measured parameter. The format of these files received by the central consists in date / time, a parameter code and its measured value separated by a semicolon (Figure 2).



BOQ20140506020323541.txt - Bloco de not

Arquivo Editar Formatar Exibir Ajuda

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06/05/2014 01:05;BOQP10;117,1;
06/05/2014 01:05;BOQP13;1,2;
06/05/2014 01:05;BOQP14;76,0;
06/05/2014 01:10;BOQP01;272,3;
06/05/2014 01:10;BOQP02;0,1;
06/05/2014 01:10;BOQP05;916,8;
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Figure 2. Example of a file generated by a station called BOQ

With the files in the input folder of IQAr Desktop, the data is processed and inserted into the database (more details in Section *C. IQAr Desktop*). Then, the IQAr Desktop calls a stored procedure – a function stored in the database - developed to calculate the hourly average values of each parameter per station and stores this information in another database table, different from the measured raw data table.

This hourly average is a key to the entire system, since the calculations of the AQI for each chemical parameter are based on them. Instead of storing the averages in the bank, the calculation of averages could be done in real-time when the user clicks to generate a report, chart or web viewing; but, in doing so, the time spent to finish the request would be much higher, since the mass of five minutes data (most of the information contained in the database) is 12 times greater than the mass of hourly averages.

Calculated the averages, the data are ready to be accessed by the monitoring module IQAr Web. This access is made via web service that performs the request to the database, calculates the AQI and packages the data in JavaScript Object Notation (JSON) [13] using the main library of IQAr. JSON is an open standard format used to transmit data as an alternative to Extensible Markup Language (XML).

Once the AQI is calculated and returned in JSON format, the monitoring module of IQAr Web updates the information on the map returned from the map server.

Besides, the web service is responsable for all communications between IQAr web and the database, including performing queries to create the wind rose graph, the charts per parameter/station, the monthly reports and the information required by the diagnosis module. This module performs periodical tests to ensure the availability and reliability of the whole system like checking web servers status, database connections, last data inserted, last file processed and last connection done by IQAr Desktop.

Most software developed for air quality management throughout the world has an hourly update routine; which is the case of the South Coast Air Quality Management District system (AQMD) [14]: a web software using GIS to display the state of the air quality in Southern California. On the other hand, the IQAr can provide the information to the end-user within three minutes after being measured and transmitted by air quality stations. This is due to the fact that IQAr manages, fully automatically, from the raw data generated by the stations until the web visualization. For example, nowadays, at most 13 files arrives hourly, one by station. Each transmition takes around one minute and happens just after the hour is completed.

Once the file is ready to be processed, the system takes in average three seconds to process each file which varies according to the number of parameters measured by each station. The hardware used in this processing is a quad core i5 3470 3.2 GH processor with 4GB of RAM memory and Windows 8. IQAr Desktop searches for new data every minute, so the database is always updated within at most one minute and a few seconds of delay in relation to the transmitted data.

The data is then presented to the end-user at web through a JavaScript routine that updates the IQAr Web by default every five minutes, but can be set to do it even more often. For example, setting it up to one minute, the software will display information with less than three minutes of delay since the data arrival from the stations, which is pretty up to date regarding air quality.

It is important to mention that the total delay depends also on the configuration of the measurement frequency and transmitting of each station. For example, if a station sends updated data within 20 minutes, IQAr can ensure that the information displayed was measured within 23 minutes.

B. Used Technology

Most of the system was developed in Java, including the the main library used by the desktop module and web service, as well as the web service and the IQAr Desktop itself. Due to political issues of the project in relation to the data storage, the system had to be designed so that the database and the web application were executed on different servers of different institutions. Thus, we chose to use a web service brokering data between the database and the IQAr Web. This peculiarity made the development more laborious, but, on the other hand, it turned the system into a more portable and flexible solution according to the demand and environmental policy of each institute, since this feature facilitates the adaptation of the system to handle data from other environmental institutes of Brazil.

As database management system, it was used PostgreSQL [15]. To improve the performance of the database and to make it robust enough to hold millions of records it was necessary to use the partitioning of the main tables (raw data and average data). With the partitioning each table holds data for only one month and, as result, every system query became faster than one second. As map server, it was used ESRI ArcGIS Server [16]. The IQAr Web was developed using the ArcGIS API for JavaScript [17] and the PHP language [18]. To transfer information from the web service to the IQAr Web, it used the JSON format. We opted for the JSON instead of XML markup language in order to reduce the amount of information transmitted every request, since the IQAr Web is a monitoring system and makes automated queries often to keep always updated the information on the map. For charts in IQAr Desktop it was used JFreeChart [19] and for charts and other visuals interface effects in IQAr Web it was used the JQuery [20] library.

C. IQAr Desktop

IQAr Desktop is the part of the system responsible for continuously processing data received from stations. It runs on a regular PC within the LACTEC Institutes and is operated by a team of engineers and technical experts in air quality monitoring to ensure the quality of the information processed by the system.

As described in Section III.A, the process starts with the arrival of the station files in the system's input folder. This directory is checked periodically for new data in a time interval defined by the operator, by default it is set to one minute. When new files are detected, the IQAr proceeds with the format verification of each file, it analyzes if it is empty or truncated, which can occur systematically. In positive case, the IQAr does not process the file and alerts the user in the monitoring log about the detection of an invalid file; otherwise, all lines of the file (Figure 2) are split into

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information regarding date, time, the measured parameter code and its value in the measurement.

With this information in memory, it begins the process of checking each data contained in the file. Basically, according to predefined chemical and meteorological parameters, three types of validation are made by the system: range, endurance and step. The range validation establishes a minimum and maximum limit for each parameter, for example, in Curitiba, temperature will hardly be less than zero and higher than 35 degrees. The endurance validation verifies if the value is being repeated over a long period, which is generally indicative of a sensor malfunction. Finally, the step validation evaluates large variations over short periods, for example, if the air temperature is close to 20 degrees in a moment, and 30 minutes after, it decreases to 5 degrees, this is an indicative of wrong value; probably, a failure occurred in the station of the air quality. All these validations are adapted to each station because the meteorological and emission conditions are different. The goal is to automatically recognize and classify data errors due to calibration procedures on station, power failure and inconsistent values, allowing data to be disseminated reliably. In the new versions of the IQAr, we plan to implement more types of automatic validation using correlations of chemical data with meteorological data and comparison of data between stations.

In the case of invalid data considered by one of the validations, those data remain available for query and modification by the operator; but, they are not used in the calculation of the indices shown to the end-user.

The system also allows editing of the data processed through screens that allow the operator to perform basic mathematical operations such as addition, subtraction, multiplication and division on a single specific value or all values comprised within a certain period of time. This is important to make manual corrections to the data to ensure the reliability of information. The role of the data validation staff as system operator at this stage is critical; since they are the ones with the expertise to assess whether the data from the stations are correct and after the automatic validation of the system, they can also manually validate or invalidate a block of data from one station. After processing, the files are physically transferred from the incoming directory to the directory of processed files. The system has a settings screen where the operator can set these directories and also the processing interval, which is the time that the system will automatically scan the incoming directory for new data to be processed.

Once the data are stored in the database, the system allows the visualization of information through charts and graphs. In both, the operator can search by station, period and type of data that can be: raw data, hourly average, daily average, hourly AQI or daily AQI. Such information can then be converted into spreadsheets and reports for external use.

As it can be seen in Figure 3, in the system home screen the operator can monitor the latest processed data of all stations divided into two tables: the chemical parameters above and the meteorological parameters below. To monitor the current status of processing, the processing screen displays a status bar with the progress of the file that is being processed; a second bar with the processing status of the complete list of new files found by the system; the amount of files to be processed; the amount of files that have been processed; the date and time of the last completed processing; the current processing status (scheduled, processing, or stopped) and also a log that shows the operator if any problem occurs during inserting data in the database, for example, if there is already a record in the database with the same date, station and parameter.

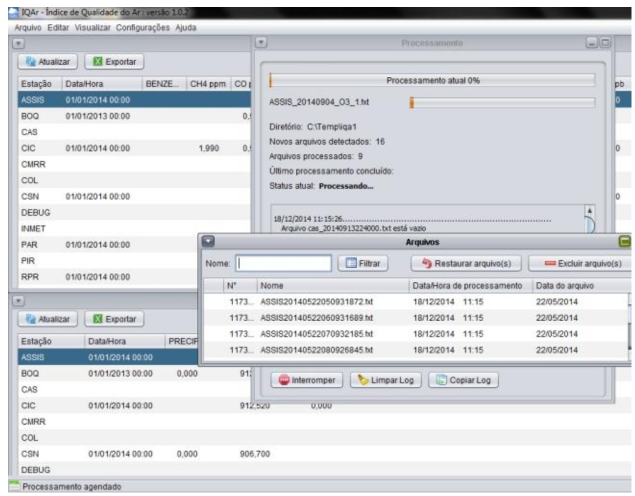

Figure 3. Home screen of IQAr Desktop (chemical parameters; meteorological parameters; processed files; current processing).

The operator has total control of all files that have already been processed by the system through the processed files screen. In this screen (also in Figure 3), the operator can search files by name, delete one or multiple files at once and therefore the data from these files. There is also the option to restore after deleting the files, which means removing the file from the processed files folder and put it back in the input directory; this option is useful if the operator wishes to reprocess a file.

IQAr has the ability to work with an unlimited number of stations; it only depends on available hardware resources to process all data. The same applies to the number of parameters per station; there is a screen to control parameters per station where the operator can set it up without limits.

The current air quality stations provide on average 14 parameters, including chemical and meteorological, but this number may be higher depending on setup, demand and technology used in new stations. Previously, the software used to process the data from most stations of the state of Paraná was the Scanair developed by Envitech [21]. The Scanair, unlike IQAr, had a limitation of parameters per station, where no more than 16 parameters could be processed at once by the system.

The system has a configuration screen for each station where the operator can set the geographic coordinates of the station so that the information appears correctly positioned in the map on IQAr Web, and also change parameters that

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dictate the behavior of the system to calculate the hourly averages of the station. For example, dealing with five minutes data, by default, the system considers valid the hourly averages composed of nine or more valid data on a total of 12, but the operator can configure the system to consider valid hourly averages composed of four valid data in a particular station.

All setup parameters needed to make the average and AQI calculations are customizable by the operator, which makes IQAr flexible and adaptable in case of changes in applicable laws of each country or region. The system can even process data from other systems, such as the case of Scanair itself. A big data exporting was successfully carried out recently: 230 MB of data divided into 247 files exported from Scanair regarding data of nine different stations along 10 years from 2003 to 2013. Even after all those data have been processed it was not noticed any decrease of performance of the system queries, which proves that the partitioning realized on data base (mentioned before) was properly implemented.

D. IQAr Web

The IQAr Web is the part of the system responsible for showing to the end-user the processed information contained in the database.

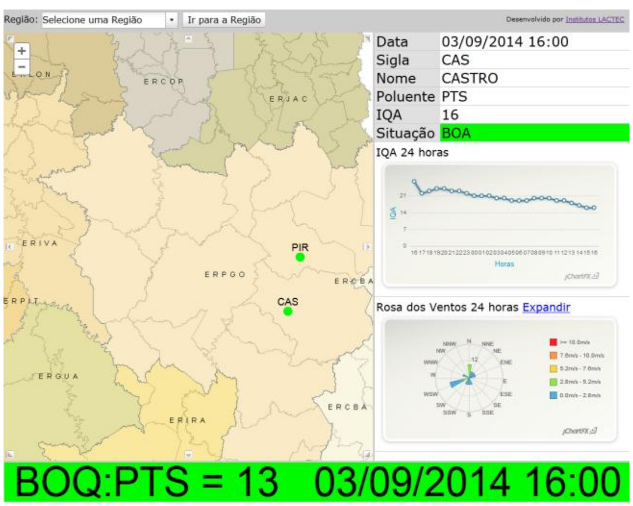

Figure 4. IQAr Web running.

Along with the processed data, geographical coordinates of each station are stored, as shown in Figure 4; they are represented punctually in a dynamic thematic map. Besides the air quality information, the municipal boundaries of the State of Paraná and the regional offices of the IAP are also represented on the map. The condition of air quality for each station is classified according to the following scale and color values:

- Green: good, AQI until 50;
- Yellow: regular, AQI from 51 to 100;
- Orange: inadequate, AQI between 101 and 200;
- Red: bad, AQI between 201 and 300;
- Purple: terrible, AQI between 301 and 400.
- Black: critical, AQI above 400.

This classification was defined by CONAMA and adapted by IAP.

Whenever the user clicks on a station on the map the system shows on the right side of the screen the AQI of the pollutant of highest value for the station in real-time. Since AQI is measured hourly, this value is truncated to the current time, i.e., if the user accesses the system at 15:19, it shows the pollutant with the highest AQI at 15:00. Then, the system displays the name of the pollutant, the corresponding time, the name of the clicked station and the description of the status (good, regular, etc.).

Under the station status, the system shows a chart with the variation of the higher AQI value for the last 24 hours. This way, the responsible by monitoring at the environmental department can have an updated overview of air quality in the city.

It is also presented a wind rose chart indicating the direction and speed of wind for the last 24 hours. This chart allows the monitoring team to identify possible causative of pollution in case of episodes where the air quality is not good and also issue warnings to the population if there is an accident with some toxic gas. At the bottom of the web page, the system shows the current situation of air quality for all stations in the format: "Station: pollutant parameter of higher concentration and its value of AQI, date and time". On the map, the user can zoom with the scroll button or choose a predefined region in the system with several stations contained and use the button "go to the region", so the system automatically positions the map in the given region. The web module is used today to show data from three different institutions, but it can hold data from stations of more institutions from different parts of the country. There is no limitation in terms of software; again depends only on hardware resources to be allocated.

A similar solution to IQAr Web was developed by AQICN [22] in China with the support of the United States Embassy and is being used for dissemination of data from various countries in Asia, Europe, North America and some countries in South America as Brazil, with data being supplied by the company of environmental sanitation technology of São Paulo (CETESB) [23]. The visual quality of the system is very friendly; They used Gmaps [24] as the map server and also developed a version for mobile devices, but the reliability and timeliness of the information shown in the AQICN system are responsibility of the air station owners, and most often environmental institutes do not have software and staff able to provide such information accurately and reliably in real-time. The AQICN software does not replace IQAr in Brazil also because of the standard for calculating the AQI. They use US's EPA index system that is not the one used in Brazil.

IV. CONCLUSION AND FUTURE DEVELOPMENTS

The great advantage of this system is the possibility to alert people of critical episodes of air pollution in time to perform preventive actions to minimize or avoid the population to contact with the polluted air.

Before IQAr, preventive actions were impossible, because all data used to be compiled into a daily report up to

24 hours of delay. Thus, in case of criticals pollution events, the population would be inevitably exposed to a polluted air which might cause serious health damage.

Nowadays, IQAr continuously processes data from 13 air quality stations and this amount will possibly double in 2015. Prior to the implementation of IQAr, it was necessary to use various software for processing, validation, reporting and dissemination of data. There was no standardization about the format of the data received by the processing central, and, for some stations, the own manufacturer's software with its own standards was supposed to be utilized. Those characteristics hardly limited the agility of the process turned the dissemination of information in real-time into an impossible task.

IQAr enabled to automate the boring and costly process of collecting, processing and disseminating data - previously held by environmental engineers - so that these professionals could became able to focus on the work of supervision and evaluation of data, which the system cannot do on its own, because it requires the expertise of the professional in the area.

In Brazil, the IQAr was the first software to provide information on air quality in real-time using dynamic maps. In the state of Sao Paulo, by CETESB, data are disseminated in real-time in a geo-referenced way [16]. But the map is not dynamic, and thereby, all stations cannot be seen on a single map, forcing the user to click on each region and open a new static map for viewing it. In the State of Rio de Janeiro, the state environmental institute has also a solution using maps, but the information is not updated in real-time. By the time of this paper was being written, the most recent information was dated 11 days ago.

One of the future implementations that can be mentioned is the development of a mathematical modeling of pollutant dispersion module. With this feature it would be possible to simulate in real-time the dispersion of pollution (plume) emitted by industries and vehicles around the stations using the updated meteorological data from these stations.

In the short term, other implementations are planned like to provide data from IQAr to the AQICN system, so that information relating to Curitiba and other Brazilian cities monitored by IQAr can be used for comparison in relation to other urban centers of the world; and also to increase the level of detail and interactivity of the dynamic map in order to facilitate the use and access to information by society.

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