AirQ2: Quito Air Quality Monitoring and Visualization Tool

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***Abstract*—This work describes the AirQ2: Quito Air Quality Monitoring and Visualization Tool, which is a web application for data visualization of meteorological and contaminant data of the Ecuadorian capital. The tool was implemented in R-shiny and allows the users to visualize hourly, daily, monthly profiles of the variables; a variety of univariate and multivariate graphs for exploratory data analysis; as well as, a spatial geolocalized representation of the contaminants. AirQ2 can support decision and policy makers to develop environmental policies and regulations; as well as, help to the general public to better understand and educate on air pollution tendencies in urban conglomerates.**

***Index Terms*—Data visualization, Pollution heatmap, Temporal profiles, R-Shiny**

I. Introduction

Visualization of meteorological and contaminant data is crucial to gain insight on the behavior of urban pollution levels. In this sense, a visualization tool is proposed to analyze contaminant and meteorological variables according to time, geolocation and contaminant profiles. AirQ2: **Q**uito **Air** **Q**uality is a tool that will help to monitor and visualize urban pollution levels of the capital city of Ecuador. AirQ2 involves processing and visual representation of meteorological and air pollution data, to communicate information about the quality of air. The data visualization is carried out using statistical graphics, time series plots, time profile representation, wind and pollution roses, and geographical representation of the profile of the contaminants, among others. Previous to visualization stage, data tidying, preprocessing and cleaning tasks are carried out for a better manipulation of the information to be visualized.

The AirQ2 application can help inform local and central authorities to make effective policies and regulations. In this sense we present an application to visualize meteorological and pollutant data that may be used to assess policy makers and educate the general public on the pollution levels of the city of Quito, Ecuador. The stakeholders that can benefit of the AirQ2 application are the local/central governments, citizens, media and academics, in order to become informed on pollution levels patterns of the city and their neighborhoods.

The rest of the article is organized as follows: next section II presents briefly the related work. In section III we describe the implementation of the web application and the principal libraries for data visualization employed. Section IV describes the data sources and data tidying steps. In section V we present the system functionalities and analyze some examples of visualization and describe the principal plots that can be generated by the app. Finally, section VI concludes the paper discussing the present utility of the web app as well as future add ons that will be implemented, mainly a forecasting module for spatial and temporal prediction of pollution levels.

II. Related work

Urban air quality is a rising concern world-wide. Air pollution is responsible for millions of premature deaths due to cancer and cardiovascular diseases, and is a major cause for an array of respiratory and cardiovascular health problems [1]–[3]. While developed world has been decreasing the air pollution, it is significantly more concerning in the low- and middle- income countries [4]. Latin America is no exception with their larger cities implementing policies and regulations to mitigate dangerous pollution levels. Recent works have explored the relevance for the public health, the exposure to air pollution in South America, from the perspective of the citizens in Colombia cities [5]; as well as quantifying the evolution of air pollution over the last decade in Quito, Ecuador [6].

Levels of urban pollution can be influenced largely by meteorological conditions and the topography of the area, Quito being a high altitude city with unique micro-climatic conditions [7]. In addition to the impact of urbanization, motorization, and rapid population growth, particulate pollution is modulated by meteorological factors and geophysical characteristics, which complicate the implementation of the most advanced models of weather and air quality forecasting

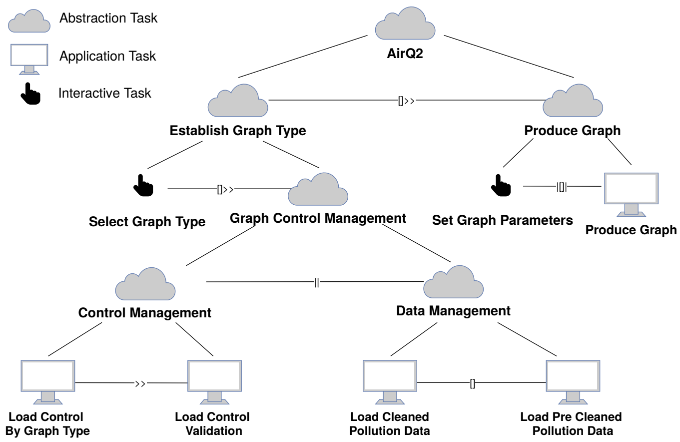

Fig. 1. Concur Task Tree of the AirQ2 application.

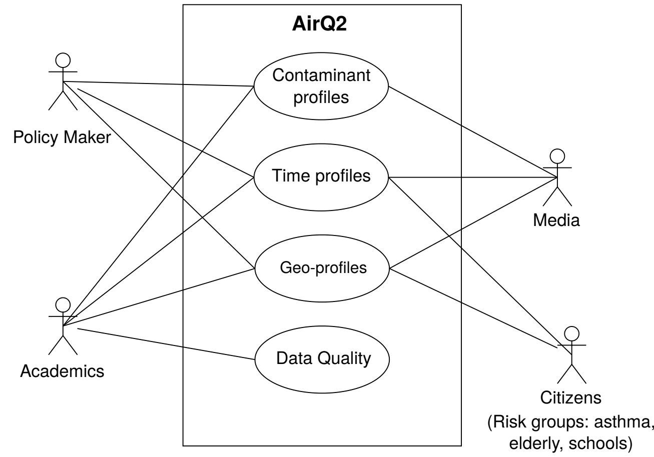

Fig. 2. Use case of the AirQ2 application. Actors and AirQ2 interest graphs.

using machine learning [8]. Outdoor air quality modeling using machine learning has focused mainly in estimation using Ensemble Learning and Regressions, and forecasting using Neural Networks and Support Vector Machines [9]. Using low-cost sensors is also of interest for mapping and modeling information of contamination [10]–[12]. Finally, interactive visualization tools are considered crucial for smart city approaches to monitor, model, and understand local emissions to better guide policy making actions [12]–[15].

III. AirQ2 System Implementation

A. *AirQ2 technology: R-Shiny and main packages*

AirQ2 is based on `Shiny`, which is an `R` language package focused on the implementation of interactive web apps using a client-server architecture. Shiny allows for the resolution of R bases user petitions via browser and it is compatible with most common R packages.

Shiny uses a basic front-end/back-end structure separating both the user UI and the function implementation in two files denominated “ui” and “server”, respectively. Communication between both is managed by the package using a group of functions for the translation of R code to HTML/JavaScript sentences, this allows for the implementation of a complete web site using only common R sentences. The translation to JavaScript allows to have very dynamic web sites in which communication between the front and the back-end is almost seamless.

To produce graphs, AirQ2 makes use primarily of `ggplot2` [16], `Plotly` [17] and `Lattice` [18]. Plotly allows for the implementation of dynamic web-based graphs that are fully compatible with Shiny, the package also provides a wrapper for the display of ggplot2 graphs with the same functionality. Lattice provides an alternative with some benefits primarily on the management of graph legends but its use in the system is related for the most part to its implementation in the package `openair` [19].

The openair package is developed by the Natural Environment Research Council for the analysis of pollution data. The package provides a set of graphs, tools for the manipulation of data, functions for the transformation of coordinates (polar to Cartesian) and test data compatible with the package and its functions. The focus of the package in the analysis of pollution data makes it a reliable tool to data process and visualization for the AirQ2 of project [19].

B. *AirQ2 system implementation*

Fig. 1 shows the Concur Task Tree (CCT) of the AirQ2 application. A CTT diagram allows to represent a task model, describing a scenario in which there are interaction, system and abstract tasks, to illustrate a process that is divided in activities [20].

The AirQ2 system implements multiple data visualization functions. All of the graphs grant customization to the users via a group of controls that allow for the selection of the data station used, scale of graph used, color representation, etc. The system makes use of a dynamic set of controls that are shared among common sets of graphs to allow easier navigation of the web site when analyzing any given station. The use of common controls also allows for visualization of the same data from multiple perspectives using different functions but the same parameters.

The user is presented with a set of predefined control for the selection of a type of graph from the available collection, this includes, among others, the following: geolocated heatmaps, time profiles generated by time window (hourly, daily, monthly, yearly), density histograms, data quality graphs and Wind/Pollution Roses. After the type of graph is selected the system will dynamically load the correct dataset type to be used and display controls for the parametrization of the graph as to allow for user customization, this includes selection of station data, date ranges, colors used for the display of variables and other depending of the selected graph. As the controls are shared across multiple graphs they provide validation that is loaded dynamically as to assure the correct function of the system and the correct display of the selected graphs. Once the user “ui” is fully loaded, the user can interact

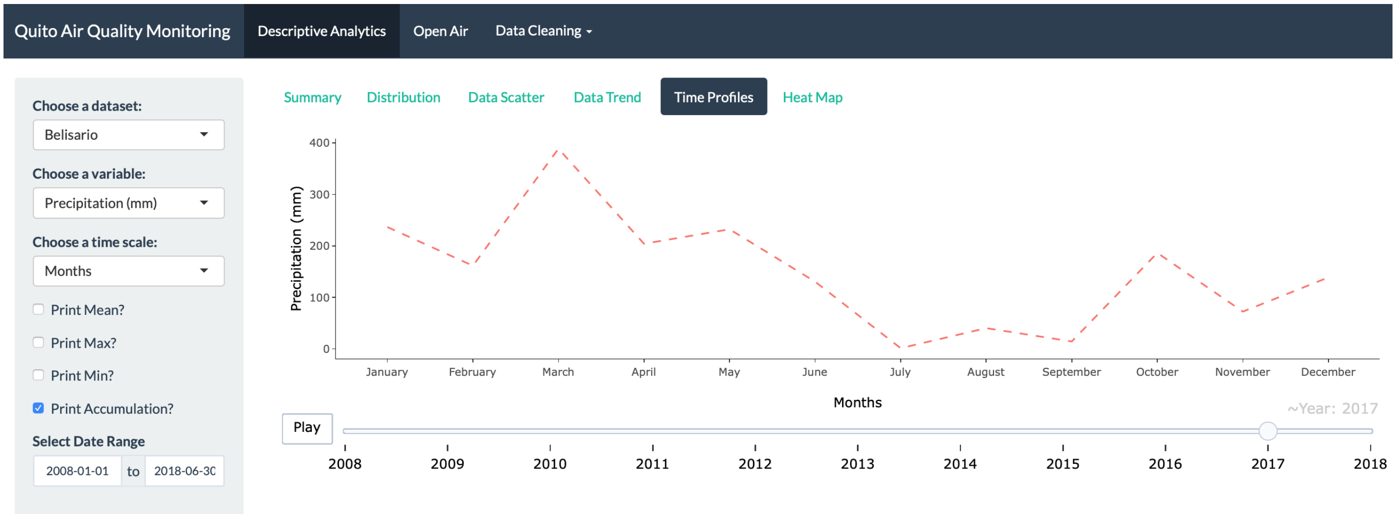

Fig. 3. AirQ2 UI screen shot. Descriptive analytics menu.

with the graph controls as to further customize the graph displayed.

Fig. 2 depicts a use case for the different stakeholders and the main graphs of interest which they can access to visualize and analyze the data. Some of the scenarios of possible actions that can be taken by the stakeholders/actors are described as follows. The AirQ2 identified actors are: a) Policy Makers (Local/Central Government, Major Office, Health ministry). They can have access to the contaminant profiles, time profiles, geo-profiles graphs to better take actions/policies such as: air quality monitoring, traffic limitation, smart city planning (exceptional traffic limitation), and alerts for contamination. b) Citizens. Risk groups: asthma, elderly, schools. They may have interest in the time profiles, geo-profiles graphs, to plan day to day activities (exercising, house ventilation), air quality monitoring, radiation alert to remain indoor. c) Media. They can access contaminant profiles, time profiles, geo-profiles to emit alerts for contamination and reporting air quality monitoring in general. d) Academics. They can access the data quality, contaminant profiles, time profiles, geo-profiles, sections to perform air quality monitoring data availability and analysis, reproduce results and carry out new studies.

A screen shot of the application is presented in Fig. 3, the elements of the "ui" are depicted for the time profile graph, where the user can select the dataset (Belisario), the variable (precipitation), the time scale (Months), and the data summary value (accumulation), within a date range of 2008 to 2018. In particular the accumulation profile of the year 2017 is selected in the slider control below the plotted data.

In Fig. 3, is also shown, the main menu where Descriptive analytics, openair analysis (windroses), and Data quality assessing and preprocessing operations can be carried out. In particular the screen shot presents the different visual analysis that can be performed to describe the data:

- Summary,
- Distribution,
- Scatter plot,
- Trend (temporal series),
- Time profiles, and
- Geolocated heatmap of pollutants.

IV. Data Approach

A. Data understanding

The data comes from the Quito Metropolitan Atmospheric Monitoring Network (REMMAQ by its initials in Spanish) which is part of the Secretariat of Environment of the Municipality [21]. REMMAQ aims to produce reliable data on the concentrations of atmospheric pollutants in the territory of the Metropolitan District of Quito. The REMMAQ data serve as an input for the planning, formulation, execution and evaluation of policies and actions to improve the air quality. REMMAQ also, aims to disseminate this information and make it understandable to the general public.

Ten remote monitoring stations conform the REMMAQ: 1) Belisario, 2) Carapungo, 3) Centro, 4) Cotocollao, 5) El Camal, 6) Guamani, 7) Jipijapa, 8) Los Chillos, 9) San Antonio and 10) Tumbaco. These stations continuously and automatically (every hour) analyze the following criteria air pollutants:

- carbon monoxide (CO);
- sulfur dioxide (SO2);
- nitrogen oxides (NO, NO2 and NOX);
- ozone (O3); and,
- fine particulate matter of aerodynamic diameter smaller than 2.5 micrometers (PM2.5) and smaller than 10 micrometers (PM10).

The following meteorological variables are registered hourly:

- atmospheric pressure,
- cumulative precipitation,
- relative humidity,
- solar radiation,

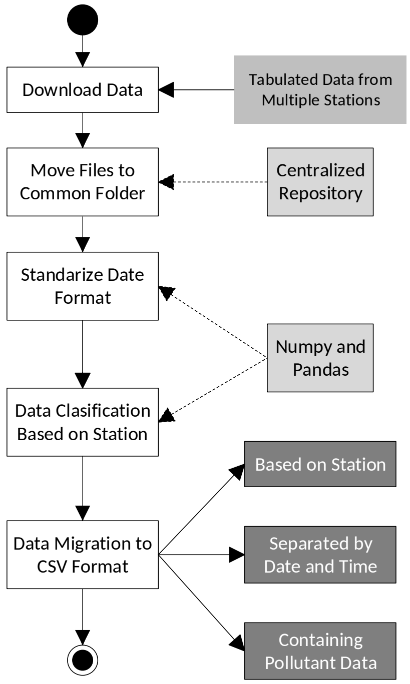

Fig. 4. Diagram of REMMAQ data pre-processing.

- mean temperature,
- wind speed, and
- wind direction.

These variables and pollutants will be visually analyzed within the AirQ2 web app.

B. Data tidying

The data tidying process can be summarized as shown in continuation. The original data files from the source are in Excel format (REMMAQ [21]). The files are organized differently according to the dates 2004-2007, 2008-2016 and 2016 to date. Next, all files are copied to a single folder. Once all the data is centralized in one directory, all files are standardized with the same format for date and time. Afterwards, a melt process is carried out using date-time and station as key. The libraries `numpy` and `pandas` from Python are employed for the data tidying task.. Finally, all data is converted to `csv` format and separate files are saved for each station encountered in the data. The process is represented schematically in Fig. 4.

C. Data visualization

AirQ2 was developed in conjunction with experts, whose input was used for the implementation of the diverse graphs available in the app. Based on their input it was determined that factors such as maximum, minimum, mean values and standard errors were common to describe the multiple pollutants/variables, as well as time scales such as hourly, individual week days, monthly and yearly reports were common in the study of pollutants.

Variables such as temperature, solar radiation, pressure, wind speed and wind direction were used to analyze the behavior of the pollutants as well as to control the quality of the data used. For example, values of solar radiation drop to zero at night but do not completely disappear as sensors pick up on the artificial lights that illuminate the cities. It was also determined that it was necessary to be able to visualize the variables and their relationship with the pollutants in the different time scales as to provide insight into the correlation between them.

It was also determined that some variables present specific characteristics. For example, in the case of precipitation, it is important to determine the accumulation besides the mean value of a given month, as total precipitation accumulation better reflects the significance of this variable for city planning, risks and policies. Thus, the data visualization techniques require to reflect specific characteristics for different variables.

D. Deployment

The AirQ2 app is currently deployed in a test server provided by the service Shinyapps.io in the following link https://airquito.shinyapps.io/airq2/. This service is provided by RStudio and allows for the easy deployment of R based web apps. The services allow for the integration of various URLs in such a way as to provide Fault tolerance and Scalability. The various metrics provided by Shinyapps allow for the quantification of the processing load demanded by the app.

Shinyapps.io service allows to rapidly deploy a Shiny web app. However, as we are using a basic account, performance is not ideal in terms of traffic and computational power. For the final release of the app, an Ubuntu based server will be installed with the suitable configuration to support the amount of traffic established by the quantity of users and processing load of the graphs/functions. The server is expected to be able to run continuously 24/7, provide fault tolerance and be publicly accessible.

V. AirQ2 System Functionality

In its current state AirQ2 serves as a data visualization tool for the analysis of historic pollution data generated by the different REMMAQ stations during the period of 2004 to 2018. The app contains multiple types of data visualization functions used in pollution datasets divided by the different stations. This data is also divided in pre- and post-cleaning datasets. All pollution graphs make use of the cleaned dataset, the pre-cleaned datasets are only used in data quality graphs to provide context to how data was altered. The app makes use of the multiple packages available in R, mainly the functions predefined in the package openair. Among the data visualization techniques used there are: geolocated heatmaps, time profiles generated by time window (hourly, daily, monthly, yearly), and wind/pollution roses.

A. AirQ2 functions

1) Data quality exploration: The user can explore the quality of the data, and have a general view of their completeness

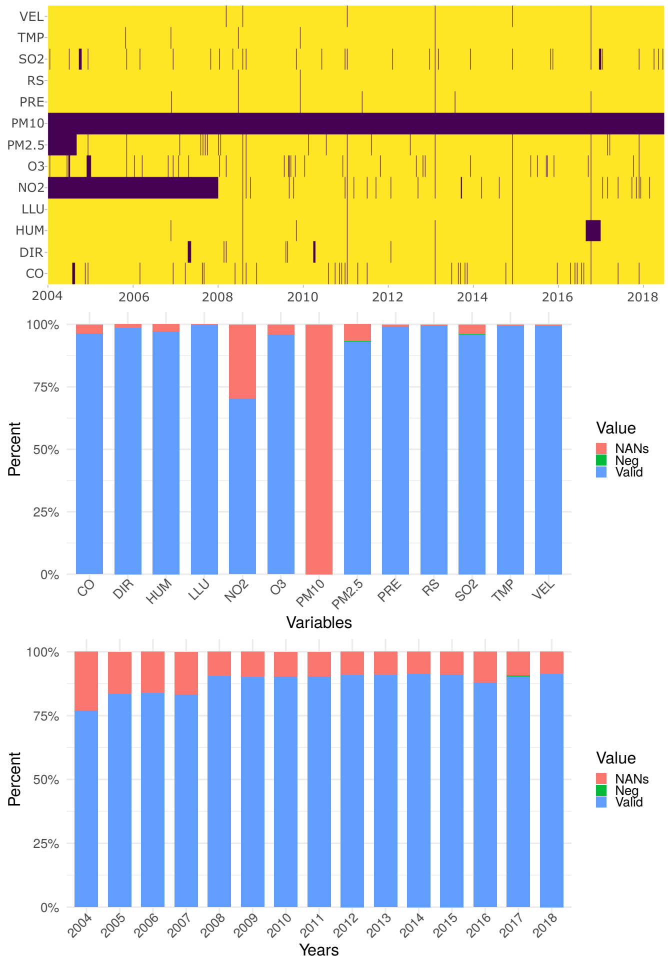

Fig. 5. Data quality of the data. Top panel: missing data map. Middle panel: summary of data quality according to dataset variables. Bottom panel data quality according to dataset years.

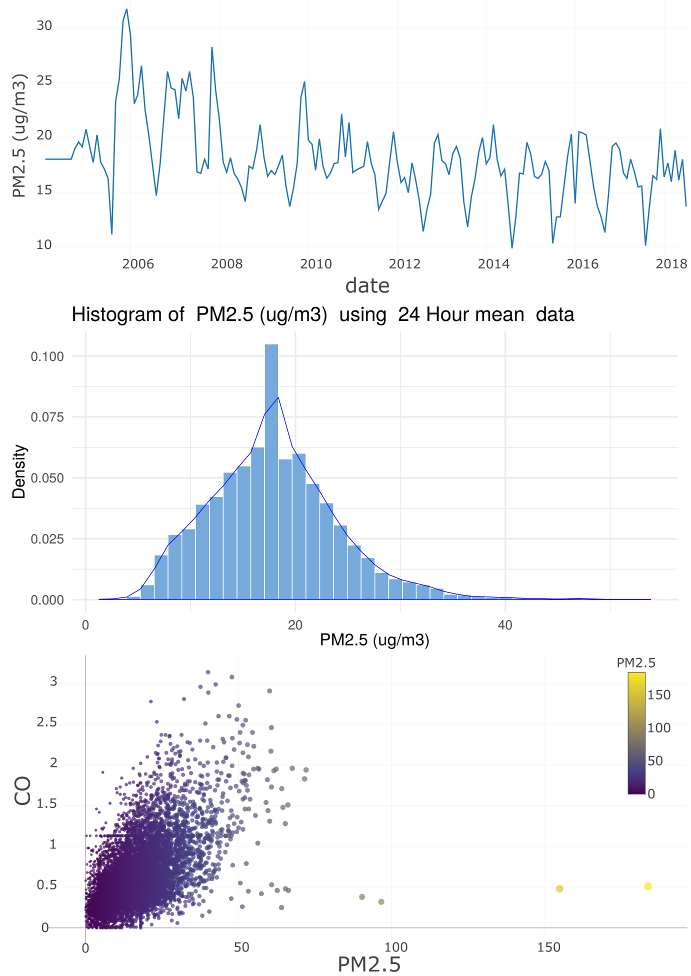

Fig. 6. Uni and multivariate graphs of meteorology and contaminants.

in a heat map as shown in the top panel of Fig. 5. The missing values are represented as the dark color (purple), and the non missing data as the clear color (yellow). Thus, the user can visualize in a single graph the quality of the data through time (x-axis), as strips for each variable in the y-axis. Here, the station of Belisario is shown, PM10 is not registered in this station, and NO2 was not registered before 2008.

In the middle panel of Fig. 5, a summary for the quality of the data is presented according to each variable in the dataset. The stacked bars depict the percentages of missing data (NANs), negative values, and valid data as red, green and blue pastel colors, respectively. Fig. 5 bottom panel shows the data quality summary according to each year in the dataset; it can be seen, that the quality of the data improves over time. Also, it is worth to note that for all of the variables X_i, their support is $R(X_i) \in (0, ...)$. That is, a negative value is an error of data acquisition or processing from the sensors. In addition, the tidy data sets are available to the users from this section.

2) (Uni)Multivariate and trend analysis: The Descriptive functions allow to perform a univariate and multivariate analysis of the data, as presented in Fig. 6. The top panel of Fig. 6 shows a time series visualization of Belisario's PM2.5 data. An increasing trend can be appreciated. A time series representation is of great importance given the nature of the data, which is dependent on years, seasons, daily, week-weekend, monthly profiles, among other types of analysis. All the aforementioned time scale can be chosen by the user to explore the time series of the dataset variables. Fig. 6 middle panel depicts a distribution plot of Belisario's PM2.5 data. A histogram describing the data distribution is shown with a density plot above it. Finally, Fig. 6 bottom panel presents a scatter plot, where a multivariate analysis can be performed. As example, PM2.5 is plotted against CO, a positive linear relationship can be observed, A third variable can be selected to depict the color and size of the points, here PM2.5 is selected.

3) Time profiles: yearly, monthly, daily, hourly: Fig. 7 depicts the time profile of the contaminants by each day of the week and hour of the day (top panels), also, monthly and yearly (bottom panels). The time profiles are depicted with standard error bars as shown in Fig. 7. Minimum and

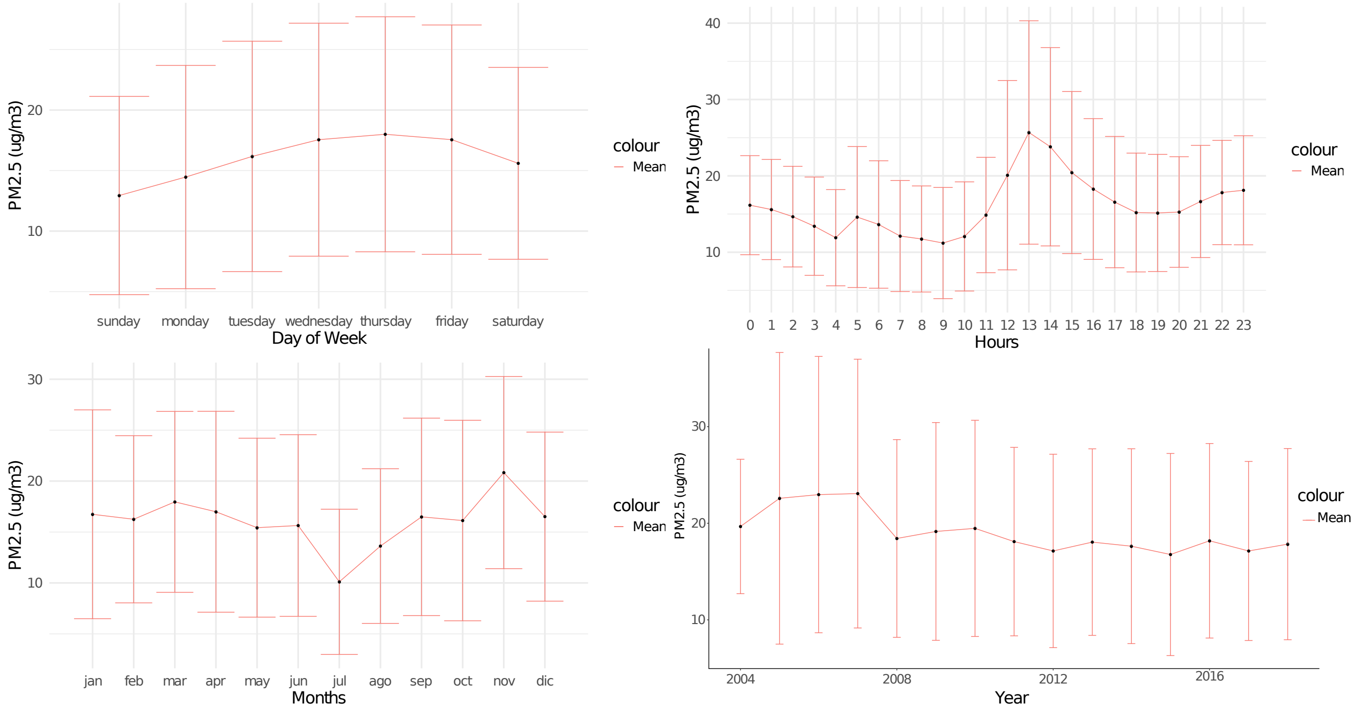

Fig. 7. Time profile of meteorological and contaminants data: day of the week, hour of the day, monthly and yearly.

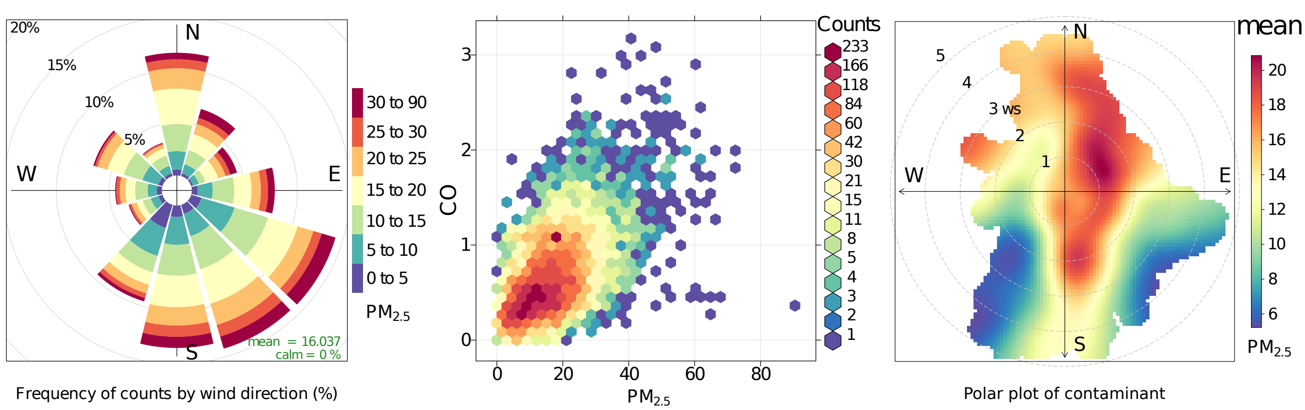

Fig. 8. Pollution roses. Left: discrete pollution rose. Center: discrete 2D-histogram of CO×PM2.5. Right: continuous smoothed polar plot (rose) of PM2.5.

maximum data values can also be selected by the user to be displayed.

Fig. 7 top-left panel shows how the value of PM2.5 increase over the week from Monday to Friday, with a peak around Wednesday. The weekend has lower value of this contaminant due to the decreased traffic activity, a major PM2.5 source in urban areas. Traffic busy Belisario station is shown in the whole paper, unless stated otherwise. Fig. 7 top-right panel displays the 24-hour profile of the contaminant for this station. The peak is around 8:00, the rush hour in the morning, and the minimum around 4:00 before dawn. Fig. 7 bottom-left panel shows a monthly profile of PM2.5. The peak is around November where the rainy season starts, the relative humidity increases around this date, but the presence of heavy rains is not frequent until the rainy season advances, this translates in higher concentrations of the contaminant [7]. The minimum is around July where the presence of strong winds in the city helps the removal of the contaminant, in addition to the reduced school bus traffic due to summer vacation. Fig. 7 bottom-right panel depicts the PM2.5 profile along the years 2004 to 2018. A decreasing behavior from 2004 to 2012 is observed. A number of public policies on traffic and fuel regulations have been issued around this period, such as rush hour license plate number limitation, and improving fuel quality in 2005, 2009 and 2012 [6]. From 2012 to 2018 this behavior has stalled, indicating that new actions must be taken by local authorities.

4) Pollution rose visualization: Multiple types of multivariate visualization are depicted in Fig. 8, using the openair package. It allows to represent pollution roses using both the

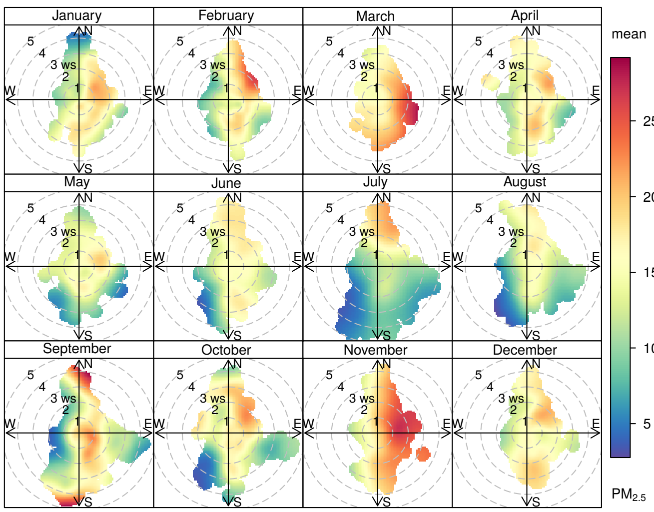

Fig. 9. Polar plot of contaminants by time profile (yearly).

Fig. 10. Heatmap of contaminants. Left panel: REMMAQ 10 monitoring stations in the metropolitan area of Quito. Top-right panel: Carapungo station. Bottom-right panel: Belisario station

data of wind speed and direction to plot in polar coordinates the concentration of the selected contaminant.

Fig. 8 left panel depicts a pollution rose for PM2.5. Higher concentration levels of the contaminant are present when the wind is from the southeast, as can be interpreted from the color scale, with red as maximum color and blue as the minimum. The color scale is the same for all panels. This helps identify to which direction lay the pollution sources in relation to the monitoring site. The behavior of two contaminants against each other can be represented. For example, in Fig. 8 center panel, PM2.5 is plotted against CO, an approximate linear relationship can be observed where a steeper line, that is a large slope, meaning that CO increases faster than the value of PM2.5. The plot shown here, uses a hexagonal binning for a discrete count representation of the data, a continuous density representation or a classic scatter plot can be selected by the user. The left panels of Fig. 8 represent a polar plot of PM2.5, in which the data have been smoothed by using a generalized additive model (GAM) [22]. Such representation is continuous instead of a discrete plot as the left and center panels. The user can select to perform a prediction in the web app, for this last panel. In such case, three plots are produced on the same scale showing the predicted surface, together with the estimated lower and upper uncertainties at the 95%. These three scenarios, along with the prediction surface can be useful for modeling a spatial behavior of the contaminant along with a probabilistic response.

The openair package allows to perform a collection of additional analyses according to time profiles, in this case wind speed and wind direction are also depicted in the polar plots allowing a more complex analysis. For example, Fig. 9 depicts a polar plot comparing the monthly profile of Belisario's PM2.5. The behavior is consistent with the one observed in Fig. 7 bottom left panel. Again, the month with higher pollution level is November. Red color represents the maximum in the color scale for the pollutant. The wind speed levels are lower for this month due to the reduced solar heating (rainy season). The month with lower levels of contaminant is July, green corresponds to the minimum value of the contaminant. Higher levels of wind speed are present in this month.

5) Spatial visualization of contaminants: Similarly, to Fig. 8 right panel, the contaminant data is smoothed in a 2D continuous projection using an approximately Gaussian kernel [23], overlaying the result on top of the map geolocation of each monitoring station.

Fig. 10 left panel shows the location of the RENMMAQ ten monitoring stations. In the right panels of Fig. 10 the heatmap of the PM2.5 is shown for the stations of Carapungo (top right panel) and Belisario (bottom right panel). The profile of PM2.5 for Belisario shows a higher PM2.5 pollution when the wind is from the southeast, is similar to Fig. 8 right panel given that it is the same station and the same contaminant. For Carapungo a different profile is observed with predominant higher contaminant concentrations when the wind is from the west (main highway). A follow up analysis will be to interpolate contaminant levels for the whole city of Quito, using spatial interpolation, i.e. Kriging interpolation [24].

VI. Conclusions

This work presents a web application to process and visualize air quality, meteorological and air pollution data, for the high elevation Ecuadorian capital, Quito. The application is tool intended to visualize selective features of different parameters, like hourly, daily, annual trends of all features in average and maximum or minimum values. We know of similar initiatives in Latin America, for example, a similar application is being developed by the Department of Industrial Engineering at University of los Andes together with the

District Department of the Environment of Bogotá, Colombia, highlighting the importance of understanding and educating the citizens of the Latin American Cities on the levels of urban air pollution.

We have shown some examples of the web application possibilities for data visualization, many more options can be accessed by the users. This tool can be easily used by policy and decision makers to perform an educated planning of the city evolution in terms of transportation, parks, among others. It can help sensitive urban population plan their daily activities, through the visualization of air quality temporal and spatial tendencies. We will carry out a usability study of the AirQ2 tool to evaluate the usability of the system effectiveness, efficiency, and subjective user satisfaction for all the actors identified [25]. Finally, future functionalities of the tool will include forecasting using time series analysis and modeling, machine learning prediction, as well as spatial analysis and interpolation of the data, which will boost the value of the AirQ2 tool for the city and their inhabitants.

Acknowledgments

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