AqVision: A Tool for Air Quality Data Visualisation and Pollution-free Route Tracking for Smart City

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***Abstract*—Air quality is an important factor in planning activities in our everyday life. The information presented though captured data using Internet of Things (IoT) in smart cities is mostly single-dimensional where citizens do not have much opportunities to directly interact with the system to get personalised insights. Recent years have seen dire reports of extreme air pollution in mega cities around the world, which has led to government authorities grappling with solutions. Taking into account the existing IoT sensor setup in smart cities, it is now very convenient to visually explore the level of pollution of any places in real-time. In this context, this paper presents *AqVision*, a flexible visualisation tool for future citizens in smart cities that combines personalised awareness with generalised needs and leverages to envisage air pollution hotspots using more interactive manners considering individualised health and safety concerns.**

***Index Terms*—Smart Cities, Air pollution, Air quality, Data visualisation, Internet of Things**

I. Introduction

Sensors are becoming increasingly available in the smart city context - both as evolving technology platforms such as IoT and as networks already installed - however their implementation and use is often confined to a simplistic model of top-down data collection and analysis that results in the environment and citizens being acted upon by city, government, or statutory authorities as passive agents [1].

While such a mode of data use can have benefit in formulation of policy or action plans by authorities on broad scales, such as overall CO_2 emission targets for example, it leaves citizens disengaged as participants in their own cities, and nuance of citizen opinion, preferences, and desires may not be captured in outcomes. Further, where the citizen thought is to be captured, a secondary process outside of the sensor and data workflow might be needed (e.g. tracking letters to the editor, or polling of citizens based on questionnaires, or by the crude near-binary electoral process).

Instead, citizens must be responsive not passive participants in change, so that they, acting as individuals with self interest in their own needs, are clear participants in the smart city 'data flow' and decision-making loop. Core to this is provision of sensor data to citizens with presentation of data clearly comprehensible to the general public [2], [3]. Hence, citizens, when participating as part of the data analysis loop, may react directly to ameliorate effects of extant conditions in the urban environment and a smart city overall may garner nuance of citizen opinion though changed behaviour and opinion capture through use-metrics of the tool itself.

This research presents a novel presentation platform for Air Quality Index (AQI) data [4] that is extensible to a wide range of urban metrics and allows citizens to participate and react to their urban environments in their own self interest. The described online platform, AqVision, targets air pollution which is a severe problem in many countries [5]. Air pollution is recognised as a public health threat linked to heart diseases, cancer and cognitive decline [6]. The accumulative effect of pollution exposure on persons moving in urban environments can have serious health consequences, especially for sensitive individuals such as asthmatics, and can be serious even in countries with relatively clean urban environments. However, even relatively minor modification of a citizen's transportation behaviours can reduce their exposure to pollutants. Kaur et al [7] showed, in a study of pedestrian exposure to air pollution along a major road in central London, England, that ostensibly trivial pedestrian decisions such as choice of the interior or exterior side of a footpath can and do affect exposure to air pollution. Given supporting informed pedestrian agency is vital to reducing pollution exposure, effective visualisation of complex air quality data to assist this amelioration must facilitate both accessibility and decision-making use of that information for the non-specialist user.

The main contributions and innovations of the AqVision platform are as follows:

- A tool to provide a unified solution to combine and correlate data from heterogeneous sources and visualise air pollution hotspots.
- Present the air quality in an easy-to-understand format from which all users can get insights and use accordingly.
- Visualise personalised information tailored for a specific user such as recommendations in route planning.

II. Related Work

A number of authors have in recent years contributed to developing accessible presentation of complex air quality data through streamlined web interfaces, including, but not limited to [8]–[10]. Smart-SMEAR [8], an online tool for displaying data from the Station for Measuring Forest Ecosystem -

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Atmosphere Relations in Finland, confined selection from a multi-parameter air-sample dataset to time limitations, arrival height, and back-trajectories so that "users are not distracted by the complexity of the data and can really focus only on the phenomena in question." Cleary et al [9] developed an Interactive Map of Chinatown Traffic Pollution that reduced interaction with a complex statistical model of traffic-related pollution to a user-friendly set of interaction parameters of wind speed, temperature, traffic volume, and wind direction and easily-comprehensible display on a cadastral basis. Such pollution visualisation tools have, despite the simplification of user interaction, largely focused on specialist users or use in guided educational contexts.

The need for simple and effective visualisation becomes more important with increased availability of real-time air quality data from government authorities [11]–[13]. Previous research has highlighted how such data could be used for effective decision-making such as pollution free route planning for cyclists [14]. While some recent literature has proposed using neural networks for air quality prediction [15], [16], they are not yet accurate enough for integration as part of such decision making, making it essential that data visualisation facilitates and is widely accessible for human decision making.

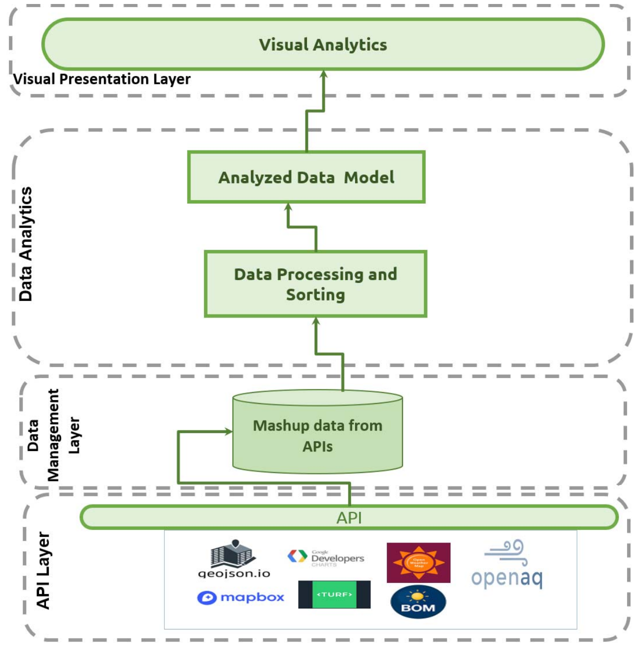

Fig. 1: The architecture of AqVision System

III. System Design

A. Architecture

Figure 1 describes the overview of the system. The developed system is divided into four layers.

- **API Layer**: This layer consists of several APIs such as openaq, turf, MapBox, and OpenWeatherMap that connects to collect the data from the heterogeneous sources for visualisation purposes such as Bureau of Meteorology (BoM), Environment Protection Authority (EPA) and other open source datasets.
- **Data Management Layer**: The data collected through APIs are in different formats and are processed into an unified format (i.e. geoJSON) which simplifies the visualisation in map view.
- **Data Analytics Layer**: The unified data from the data management layer are processed in this layer to extract useful features and co-relate these extracted features for finding insightful pattern information.
- **Visual Analytics Layer**: This is the presentation layer of the system. This layer enables the end users to interact with and interpret the information from the previous layer.

B. Functions and Interfaces

- **Colour-coded AQI Level**: The US EPA AQI categorises air quality in six categories of Good with range (0 to 50), Moderate with range (51 to 100), Unhealthy for Sensitive Groups with range (101 to 150), Unhealthy with range (151 to 200), Very Unhealthy with range (201 to 300) and Hazardous with range (301 to 500). These categories in order have increasingly severe effects on human health and are assigned standard colours for easier identification and reporting. This AQI is defined for pollutants of O_3, $PM2.5$, $PM10$, CO, NO_2 and SO_2.
- **Real-time AQI**: Our developed tool provides interfaces to view AQI in real-time using interactive maps. Hovering over a specific region on a map displays the detail graphs of AQI for that region and a corresponding health recommendation. In addition, there are options to visualise current and most recent histories (e.g. last 48 hours) of individual pollutants using graphs and maps. All AQI values are colour-coded in map and graph views. For example, green indicates a good AQI level.
- **Real-time weather**: The tool also contains information about recent weather conditions such as temperature, humidity, wind speed and rainfall. Like AQI, the weather information of the recent past also can be viewed in graphs. There is in addition a separate interface to view a 4 day weather forecast.
- **Planning Pollution-free Route**: Another interesting functionality of this application is route planning. From the interface a user can select source (point A) and destination (point B) points similar to Google Maps. The user can search a location using a text-box or a mouse drag on the map. The interface then provides multiple route options to users along with colour coded AQI for each route. A user can then decide about the route by considering these multiple options and can hence select a less-polluted or pollution-free route.

IV. Implementation

AqVision has been implemented using multiple software development technologies. The technologies used to develop various modules of the visual analytics are discussed below.

- **Mapbox**: This is part of the API layer. Mapbox is called "a live location platform". It is a powerful location data API solution designed for developers to visualise maps and planning routes [17]. Mapbox APIs are used in the tool to view air quality data using different map views and for geocoding. Mapbox GL JS, a JavaScript library, uses WebGL to render interactive maps from vector tiles and Mapbox styles. It is part of the Mapbox GL ecosystem, which includes Mapbox Mobile, a compatible renderer written in C++ with bindings for web and mobile platforms.
- **The Google Chart API**: An interactive tool to create graphical charts from user-supplied data. The APIs supports a wide variety of chart information and formatting. This is also part of the API layer and is used for plotting historical and forecasting data in the tool. The plots are presented in the visual analytics layer using heat maps, bar graphs etc.
- **GeoJSON**: This is the standard format designed for representing simple geographical features (e.g. points, polygons, line strings), along with their non-spatial attributes (e.g. temperature, air quality index, humidity). The data we have used for visualisation is in GeoJSON format so they can be easily visualised using maps. GeoJSON format is also supported by Mapbox APIs. It is a subset of the JSON format and can be parsed in modern software and native to the JavaScript language. All GeoJSON data are stored in the Data Management layer.
- **Turf API**: A JavaScript library for spatial analysis. It includes traditional spatial operations, helper functions for creating GeoJSON data, and data classification and statistics tools [18]. In the tool, this API is used for route planning and showing alternative routes.
- **Open weather API**: Open weather API provides current weather, daily forecast for 7 days, and 3-hourly forecast for 5 days for any city. Open Weather API also provides interactive maps to display precipitation, cloud cover, pressure, and wind around a location [19]. This API is used in the tool to show weather related information.

V. Visualisation and Interactions

AqVision uses historical data of individual stations which is collected from publicly available air pollution data of Australia [20] and China [12]. It also uses live data from EPA Victoria [21]. The data are collected in CSV format and converted to GeoJSON to visualise them using Mapbox. This section demonstrates different user interactions scenarios using the collected data in the application.

A. Interaction Scenario-1: Historical air quality

A historical air quality map can be visualised in the application. The map shows a global information which is the status of the air quality for a given amount of time (e.g. one year). It contains in depth data analysis of the air quality over a given period and visualises the data on heat-maps. Figure 2 displays such an AQI heatmap of China for the year 2014 along with colour coding.

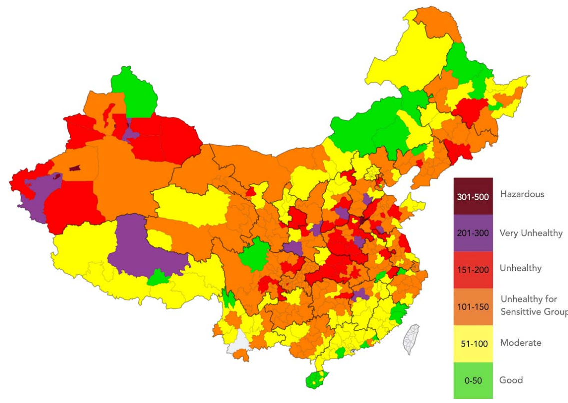

Fig. 2: AQI Heatmap for China in 2014

B. Interaction Scenario-2: Live AQI

The live AQI option in the main panel brings up a live EPA data visualisation page. It shows the live AQI from all the EPA stations for a selected region in the map view. Figure 3 illustrates a live AQI of the Melbourne region with all stations reporting good air quality when the data was observed. The top bar displays the AQI level at a certain location with the time it was last updated along with the current level of pollution colour coding. Clicking on a location displays the details about the AQI level which includes AQI levels of individual pollutants present in the area. A more detailed panel shows the past 48 hours AQI and pollutants information along with climate factors such as temperature, air pressure, humidity, wind speed, and precipitation (see Figure 5).

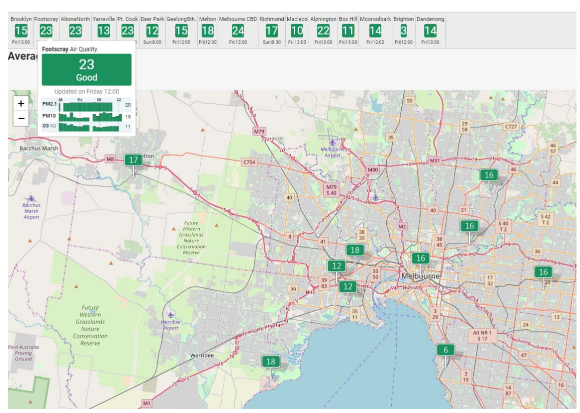

Fig. 3: Real-time map of AQI

The right panel displays the legend which informs about the colour codes and different levels of pollution so that users dont confuse the different levels of pollution. Other options on the left can be selected to get the live data according to the individual pollutants.

TABLE I: Recommendation based on air quality index and weather condition

AQI	Temperature	Wind speed	Humidity	Condition	Recommendation
0-50	below 22°C	6-11 km/h	below 29%	Good	No health effects
51-100	between 22°C and 30°C	20-28 km/h	30%-45%	Moderate	Minor effects if stayed out for longer hours
101-150	between 30°C and 35°C	6-11 km/h	30%-45%	Unhealthy for sensitive individuals	Some effects for sensitive individuals
151-200	above 35°C	below 2 km/h	30%-45%	Unhealthy for all	High effects if stayed out for longer hours
201-300	above 35°C	0 km/h	above 45%	Very unhealthy	Very high health effects

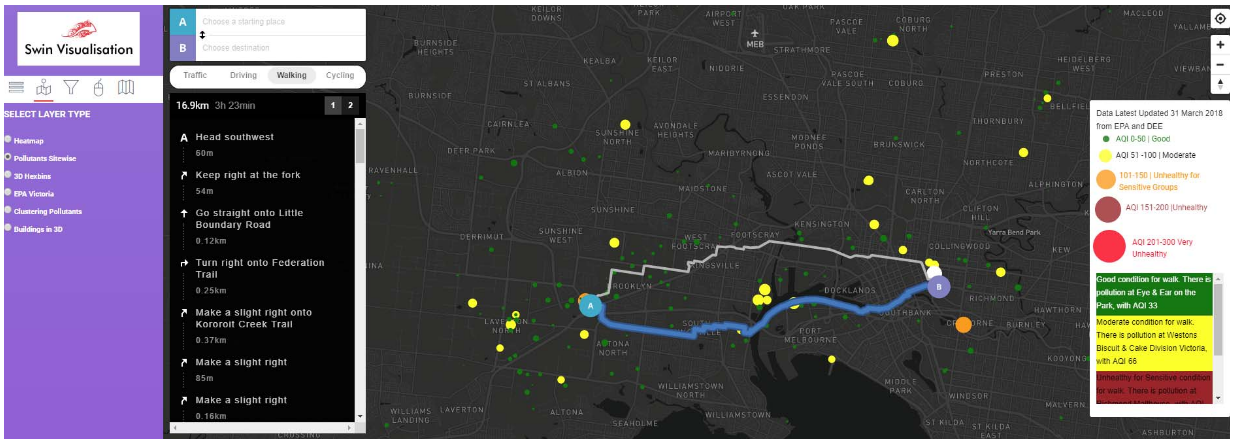

Fig. 4: Recommendation of air quality of route planning

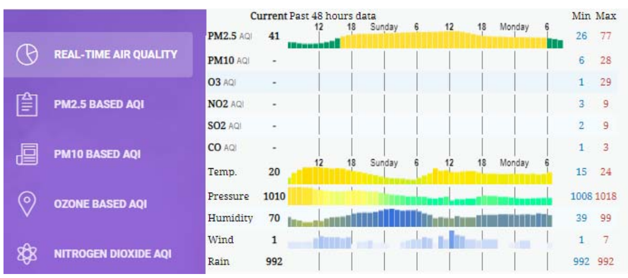

Fig. 5: Real-time AQI with weather condition

C. Interaction Scenario-3: Health recommendation

The developed tool also provides a recommendation based on correlation of air quality with environmental aspects such as temperature, humidity, wind speed and wind direction. As described in literature, these aspects collectively create an atmosphere that affects people with different respiratory diseases. We developed rules and recommendations about how these different aspects collectively affect people with or without respiratory diseases. We used these rules to show how the current AQI level and environmental aspects affect people and recommend if it is safe to go out for different activities. This is presented in Table I. The corresponding interface is shown in Figure 7.

D. Interaction Scenario-4: Route planning

By selecting a point “A” and another point “B” on the map, routing options pop up and display the shortest path and, in addition, an alternative path that avoids highest levels of pollution. Within the legend window, a recommendation about the exertion activity is given along with the mention of nearest polluted site. Routing also includes step by step guide of the selected route. This is shown in Figure 4.

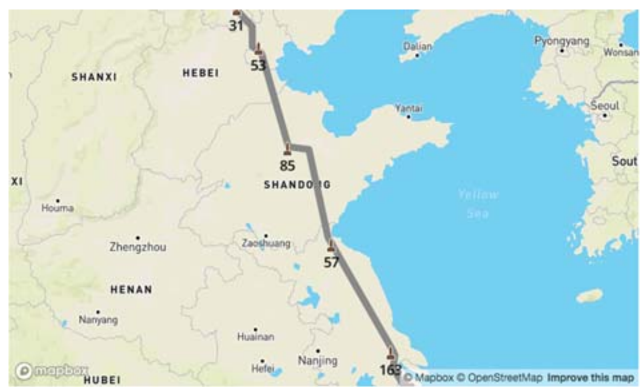

Fig. 6: Map view for route planning

Another view of route planning also displays a single route and live AQI information of different stations along the route. Such a view of route planning from Shanghai to Beijing in China is shown in Figure 6.

E. Interaction Scenario-5: Live weather

Left clicking on the weather button brings up the live weather along with the forecast for the next 7 days. The weather window also shows the current humidity, wind speed and wind direction. The weather can be shown for the current location or any location selected on the map. This is shown in Figure 8.

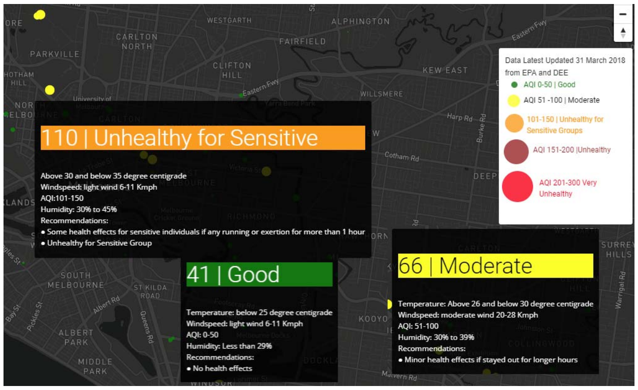

Fig. 7: Health recommendations using air quality and weather

F. Interaction Scenario-6: Forecast pollutants

The forecast panel shows the colour coded forecast values of selected pollutants for individual regions. A user who clicks on the live AQI of a region is navigated to a page that contains the detail information about the region and the bottom panel shows foretasted values of $PM2.5$ and O_3 along with weather such as temperature and wind direction in every 3 hours for next 5 days. The pollutants are colour coded according to the estimated AQI values. This is shown in Figure 9.

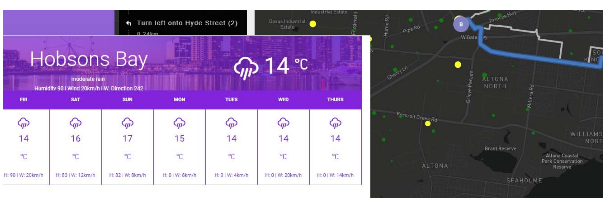

Fig. 8: Weather update

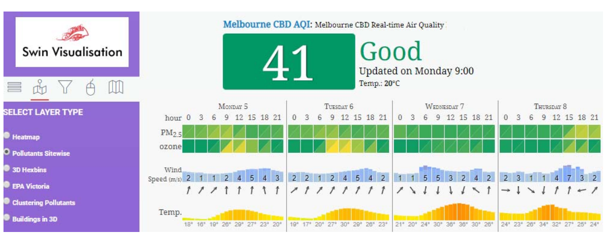

Fig. 9: Forecasting air pollutants by location

VI. Conclusion

In this paper we have proposed and demonstrated AqVision, a visual analytics tool for air quality data visualisation and pollution-free route tracking for smart cities that guides end-users to walk through the less-polluted or pollution-free areas of a city. The tool allows visual exploration of air quality information from multidimensional data obtained from diverse data sources through various APIs. AqVision provides the capability to correlate data from heterogeneous sources and visualise hotspots of air pollution. This tool can help citizens of smart cities to improve their health by minimising the high pollution areas traversed. Our future work will be conducting user studies to evaluate effectiveness of AqVision [22]. The final result is a bottom-up model of citizen participation in smart cities, and one that can be used by other application developers to create applications aimed at public awareness of, and decision making on, ambient built environment factors in real-time.

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