International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:13, No:6, 2019

Microclimate Variations in Rio de Janeiro Related to Massive Public Transportation

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Abstract**—**Urban public transportation in Rio de Janeiro is based on bus lines, powered by diesel, and four limited metro lines that support only some neighborhoods. This work presents an infrastructure built to better understand microclimate variations related to massive urban transportation in some specific areas of the city. The use of sensor nodes with small analytics capacity provides environmental information to population or public services. The analyses of data collected from a few small sensors positioned near some heavy traffic streets show the harmful impact due to poor bus route plan.

Keywords**—**Big data, IoT, public transportation, public health system.

I. Introduction

RIO de Janeiro is a dense populated city with an unique geography and a not so planned public transportation system. It is a coastal city with several elevations, hills, mountains, valleys, and also bays, islands, reefs, lagoons, and rivers. With more than 12 million residents, Rio de Janeiro is the second most populous metropolitan area in Brazil. Once its hills are not suitable to build houses, the city has a high-density occupancy and very few highways it. Many of Rio's streets pass through valleys or the coast, leaving only a few route options for transit. Also, buses are the primary public transport, since there is just four metro lines connecting just a few portions of the city. More than 8000 buses are running daily through the city. Some streets are so busy that one bus passes by every 20 seconds.

The city has undergone significant changes in recent years, mainly because of several global events like World Cup and Olympic Games. The Federal, State and Municipal Governments have faced new challenges in urban mobility. In addition to alterations in some itineraries, many bus lines have been changed, created or extinguished. New transportation modalities were made available, such as the VLT (LRV - Light Rail Vehicle) and a new subway line. But these initiatives only cover small parts of the city. This accelerated urban growth has made a considerable impact such as more traffic jams and saturated mass transportation.

Several studies have been conducted showing the impacts on population health due to air pollution widely in the world, and especially in Brazilian cities [1]-[5].

Recently researchers have been trying to evaluate each aspect that impacts on the urban planning. They assess microclimatic variations related to different city issues. Li and Tang discuss bus station plans [6]. Meanwhile, Huang presents a model of building energy in high-density cities [7] and Swapan analyses several viewpoints of urban design [8].

The goal of this work is to evaluate how the increase of vehicles in the streets generates a higher accumulation of atmospheric pollution, in a city with climatological conditions such as Rio de Janeiro. The implications on formation and dispersion of vehicular pollutants in the microclimate of an area are addressed, using the entire data cycle - from the preparation of the meteorological station, through the collection and processing of data, to the analysis and final generation of reports.

II. Infrastructure

The system's infrastructure, as can be seen in Fig. 1, encompasses a set of sensors in a box collecting environmental properties, the city GPS bus tracking information, and public healthcare information provided by DATASUS (Ministry of Health) [9]. All data collected are sent to Google BigQuery [10] and a MongoDB [11] UFRJ server. From Big Query, a small sort of online queries can be visualized through *redash*. Besides NoSQL storage, the UFRJ server provides capacity to perform machine learning processing on MapReduce environment.

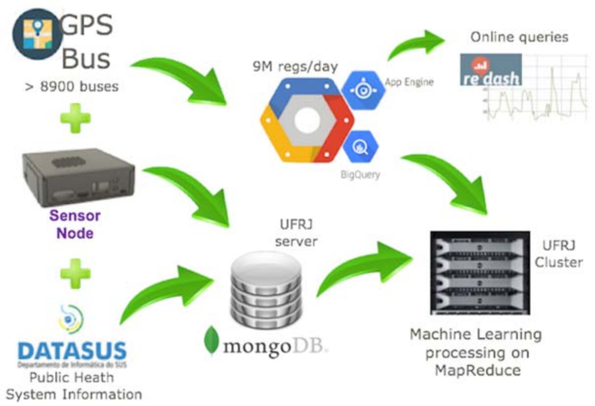

Fig. 1 System's infrastructure

The sensor node, presented in Fig. 2, consists of three main pieces: an *in loco* sensor, an edge computer, and a connection to the cloud server. The sensors collect environmental data

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every 15 seconds, such as temperature, humidity, luminosity, air quality, particulate matter volume, and ozone. The hardware platform used to collect data is based on Arduino, and the sensors are from different suppliers.

The edge computer is an NVIDIA Jetson TK1 [12] - responsible for cleaning and analyzing the meteorological data just collected. The Jetson TK1, running Linux, evaluates the data and performs short-term machine learning model, focused on improving the meteorological prediction confidence rate. An attached screen informs current microclimate conditions and predictions for near future. It is built using the Array of Things [13] source code and recommended sensor hardware. Its sensors provide real-time insights about air quality. The NVIDIA TK1 provides the integration between the sensors array, the embedded data analytics software, and the cloud servers. Another environmental data collected consists of georeferenced buses data, which produces traffic density data, passing through the routes where the sensors are placed. The bus GPS data streams are gathered and made available on the Government's open data portal. The edge computer can access the data from the cloud server for machine learning model processing if necessary.

All information collected and analyzed is sent through an active internet connection to an application server in a cloud server. The infrastructure uses Google Big Query and App Engine due to some interesting characteristics. Its non-relational, column based and has high data ingestion capacity, allowing aggregations and joins between different tables. Hundreds of millions of buses GPS data records are analyzed and summarized in 1-hour time slices. Redash is an open source tool for data visualization, generating graphs, tables, maps. It allows user management and access levels, recurrent queries, versioning. Currently, the infrastructure gathers 9 million registers per day. The server receives the input, does some cleaning preprocessing and stores the results in a database focused on big data and data mining so that we can extract information from it on demand.

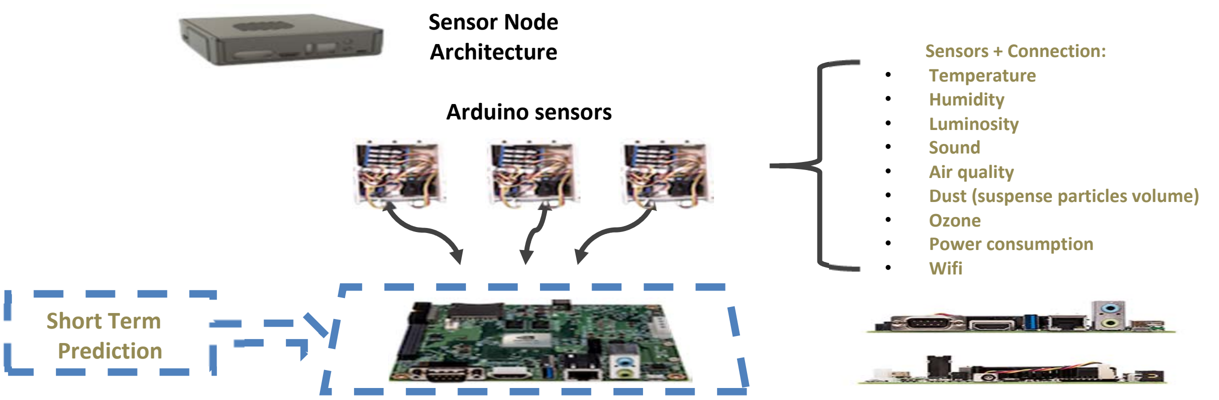

Fig. 2 Nvidia Jetson TK1 sensor node

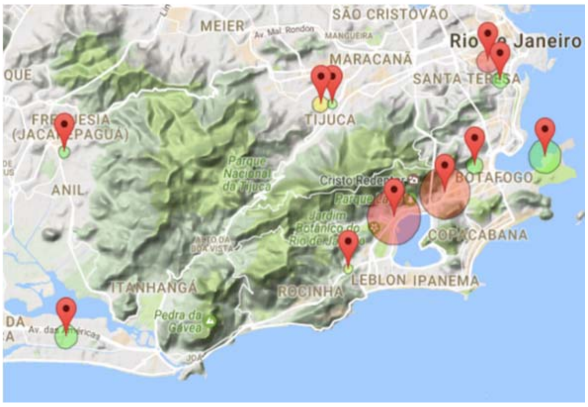

Fig. 3 Sensors locations

The first study conducted has been made with a set of sensors spread over Rio de Janeiro for "DataCanvas - Sense Your City" [14] - a visualization competition, funded by SwissNex [15] - with the purpose of collecting and publicly providing environmental data for artwork or academic research. Locations of the sensors are shown in Fig. 3. These data were gathered with public transportation GPS to correlate the heavy vehicle traffic and an increase in pollution [16], [17]. Each circle denotes the average pollution measured by the dust sensor. The color indicates the distance between each sensor and bus traffic. Redder tones show high bus traffic less than 50 m from the sensor as for greener tones, almost no bus traffic less than 50 m from the sensor. It can be noticed that sensors near high bus traffic areas presented not only more permanent high air pollution rates, but also a much higher difference between the lowest day value and its peak.

Rio de Janeiro is located in the tropical zone with local changes due to altitude. Normal temperature is 24 degrees Celsius, and pluviosity is around 1,250 mm for each year. Summer season are generally stickier than the winter. Tropical timberlands used to cover over 90% of its domain. It has the biggest zone of urban timberland in Brazil: the Floresta da Tijuca, reminiscent of the Atlantic Forest, saved amidst the city. Jardim Botânico (Botanical Garden) is a favorite residential area and it differs from most of Rio's neighborhoods due to large number of detached houses, not so common in the densely populated south zone. But it is crossed by one of the city's busiest avenue. High values on the particulate matter sensor were found at high bus traffic areas near an urban forest, at Jardim Botanico's neighborhood. This accumulation is due to limited atmospheric pollution dispersal, since the forest is near high traffic and the Tijuca massif makes it difficult to pollutants dissipation. As traffic gets lower, usually at night, the atmosphere disperses the gases and pollution returns to lower levels. The accumulation of pollutants on the ground levels of the atmosphere causes the formation of photochemical smog, which poses a great threat to human beings and a big concern for public health.

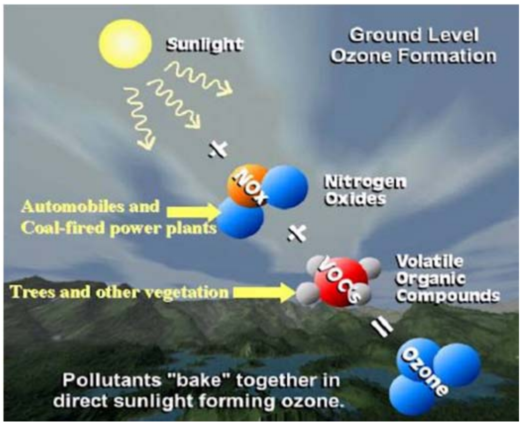

Fig. 4 Smog Formation [18]

Photochemical smog is produced when pollutants from the combustion of fossil fuels react with sunlight, and occurs more often in summer. The main components of photochemical smog are nitrogen oxides, Volatile Organic Compounds (VOCs), tropospheric ozone, and PAN (peroxyacytyl nitrate). Ozone (O_3) is formed primarily by Nitrogen Oxides (NOx) reacting with volatile organic compounds (VOCs), exhaled by the trees on warm, sunny days [18], as can be seen in Fig. 4. Diesel bus NOx emissions are equivalent to 40 gas cars. Ozone on ground level causes respiratory diseases, increases infant mortality and intensifies cardiovascular problems. Photochemical exhaust cloud can affect the earth, on individuals' wellbeing and even on different materials. It decreases perceivability and aggravates eyes, nose and throat, influencing respiratory framework and makes serious harm verdant plants. Synthetic substances, for example, nitrogen oxides, ozone and peroxyacetyl nitrate (PAN) can have additionally destructive impacts on plants. These substances can decrease or even stop development in plants by diminishing photosynthesis. Ozone, even in little amounts, can accomplish this; however, PAN is much more dangerous to plants than ozone. The example of correlation between increased traffic and increased pollution data, collected between 01/25/16 and 01/31/16 were presented in TABLE I. It should be noticed that the pollution reached harmful levels, exceeding 450 μg/m^3. According to the International Air Quality Index (AQI), over 250 μg/m^3 is already attained the worst level of pollution, posing great health risks.

TABLE I
WEEK OF MILD TEMPERATURE AT JARDIM BOTANICO

Data	*Increased Temperature (^{0}C)*	*Pollution ($\mu g/m^3$)*	*Traffic volume (vehicles/h)*
25	12.7	469.17	79
26	5.01	468.2	128
27	7.59	452.69	130
28	6.23	408.27	150
29	9.1	464.58	(not collected)
30	2.95	457.61	148
31	3.62	473.74	95

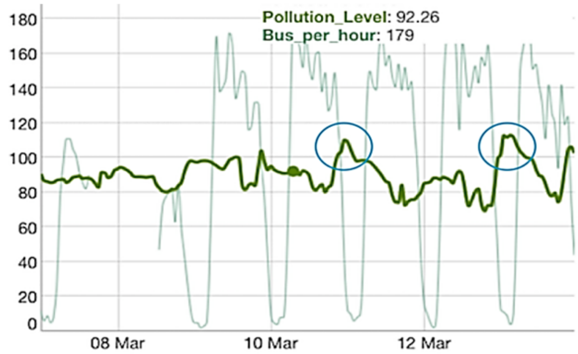

Fig. 5 Bus traffic and air pollution data from 03/13/17 to 03/13/17

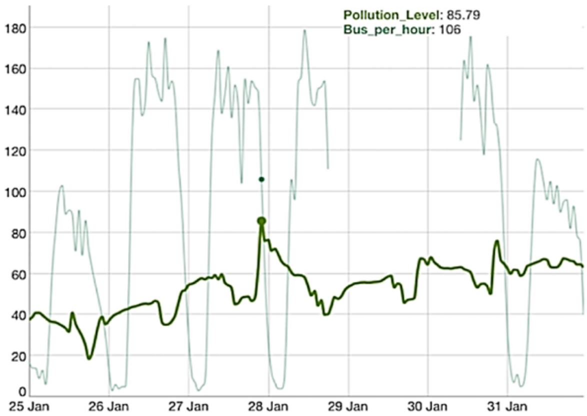

Fig. 6 Bus Traffic and Air Pollution data from 01/25/17 to 03/31/17

One week of mild temperatures with thermal inversion phenomenon were presented in Fig. 5. The highlighted areas indicate that even after bus traffic goes lower, the pollution continues to increase for a few more hours. The same behavior was found in a week of high temperatures with heavy showers (Fig. 6). Data collected in other areas of the city were also analyzed in this study. Sensors located within 50 m of bus traffic experienced a large increase in pollution rates during rush hours compared to stations that are located 50 m far from streets. This can be observed on TABLE II.

III. CONCLUSION

The first phase of this research showed that the system infrastructure made the microclimate study feasible at some specific areas of the city. Sensors spread over Rio de Janeiro presents new insights about air quality indicators. Even though some locations are near to an urban forest, they suffer from the lack of an efficient public transportation system. An air quality monitoring program should cover all metropolitan areas.

TABLE II
DIFFERENCES BETWEEN STATIONS LOCATED MORE THAN 50M AND LESS THAN 50M FROM TRAFFIC

Data	More than 50m		Less than 50m	
	Increased Pollution ($\mu g/m^3$)	*Peak Pollution ($\mu g/m^3$)*	*Increased Pollution ($\mu g/m^3$)*	*Peak Pollution ($\mu g/m^3$)*
25	16.15	53.74	97.93	349.99
26	48.39	82.79	110.0	210.11
27	40.06	75.12	137.97	276.16
28	57.28	91.16	193.24	381.75
29	29.81	66.04	134.7	296.63
30	53.27	82.54	94.69	250.49
31	36.45	69.89	55.77	188.87

Collaboration with public health researchers makes possible to correlate high air pollution rates with hospital admissions caused by respiratory complications and cardiovascular diseases.

A low-cost edge computer, with some local processing capacity, performs analytics on data collected from sensors and provides critical information without the use of a network. This solution minimizes the response time to predict air quality or pollution rate, calculated in each data acquisition.

ACKNOWLEDGMENT

The research for this paper was partially supported by the CAPES – Brazilian Federal Agency for Support and Evaluation of Graduate Education within the Ministry of Education of Brazil. The authors would like to thank the donation of sensors by Swissnex.org – The Swiss global network for education, research and innovation.

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