A New Approach for Air Quality Monitoring: A Case Study of Recife, Brazil

Ryan Gomes Paiva(✉), Rômulo César Carvalho de Araújo(✉), Juliana de Albuquerque Souza Costa, Paulo Vitor Barbosa Santana, Silvanio da Silva Assunção, Welton Pereira da Luz Felix, Henrique Correia Torres Santos(✉), Izavan dos Santos Correia, and Steffano Xavier Pereira

Instituto Federal de Educação, Ciência e Tecnologia de Pernambuco (IFPE), Campus Recife, Recife, PE, Brazil
{rgp,jasc,pvbs,ssa,wplf,isc1,sxp}@discente.ifpe.edu.br,
{romuloaraujo,henrique.santos}@recife.ifpe.edu.br
https://www.ifpe.edu.br/

Abstract. The association of quality of life and air quality are intrinsic to the factors of analysis of the development of urban spaces and their sustainable assessment. Inserted in urban expansion and population growth, factors such as air pollution are commonly related to the understanding of the dynamics of the city and therefore, this factor constitutes a fundamental study for solution and planning. Thus, every year, new guidelines are formulated for the understanding of air pollution and its monitoring, however, contexts such as those of Brazil present the growth of urban spaces and therefore the increase of air pollution but still without the presence of appropriate plans for the management of air quality, which leaves cities helpless as to the level of pollutants in the air. In 2021, IEMA [9] showed that 16 Brazilian state capitals did not have air quality monitoring, one of them being Recife, capital of Pernambuco, therefore, this work gathers methods already used in the state of the art and proposes a new approach as to the development method for monitoring networks in places that present monitoring deficiency, being addressed the case study of Recife. The results of this work a modifiable methodology for the implementation of monitoring networks evaluating essential collection points and proposing a device model to meet the urban contexts in order to assess urban pollutants and collaborate with the urban dynamics and for the city management through the improvement of data collection and air quality management.

Keywords: Air-quality · Pollutants · WSN · Low-cost sensors · Sustainability

1 Introduction

The concern for climate change and its impacts on the way of life in the city brings up the debate about air quality [19], so every year new studies arise

T. Guarda et al. (Eds.): ARTIIS 2022, CCIS 1676, pp. 42–56, 2022.
https://doi.org/10.1007/978-3-031-20316-9_4

regarding the topic and it is important an effective participation of technological innovations in the process of air monitoring. To develop this point of sustainability, that is, the control of air pollution, researchers around the world have been applying solutions in remote monitoring network hardware [13].

Such technological advent, according to [13], has come to promote a revolutionary change for the advancement in air quality assessment and monitoring. Through low-cost sensors increasingly popularized in the last decade, it has been possible to develop new monitoring programs designed by foreign research groups and government organizations, this is the case of the Environmental Protection Agency of the United States of America (USA) as well as being worked on by the European Union for its new air quality directive [2]; thus moving from monitoring based on the single system of governments to a monitoring network coming from decentralized and sometimes collaborative groups with government data, something made official in Europe and the USA.

In the resolution of CONAMA (National Council of Environment) in 1989, Brazil presented its first action in air quality monitoring, establishing the basic monitoring instruments aimed at the welfare and development of the population through an environmentally safe management, adopting strategies for national air quality standards and monitoring. Still, the Air Quality platform, created by the Institute of Energy and Environment (IEMA) [9] shows that 16 of the 26 Brazilian states do not monitor air pollution, and among those that currently monitor, not all have autonomous stations, presenting only averages of daily measurements. Therefore, these stations are not always monitored with the aforementioned hardware and also do not provide real-time information. Data from the World Air Quality Index, a non-profit project that promotes a database prepared by environmental protection agencies around the world, shows that only in São Paulo are air quality data available in real time [20], a necessary reality for accurate data and better-grounded measures, but still uncommon in Brazil.

The paradigm shift addressed by [17] is definitely established in Brazil through the release of the Technical Guide for Monitoring and Assessment of Air Quality prepared and presented by the Ministry of Environment in 2019 [10]. In the guide, new objectives and instructions for monitoring are presented, with the implementation of standardized monitoring networks now planned for the entire national territory. The new instructions date new priorities regarding the types of pollutants and new types of sensors are already included, such as those cited by [13], thus establishing the new need to modernize the ways of supervising the quality of life in Brazilian cities using new electronic artifices along with a friendly environmental management.

Within these parameters, the RailBee® Telemetric System uses its structure to develop a module for monitoring pollutants, autonomously and in real time, with a system of modular technology and low cost. The RailBee® Telemetric System is an innovative system for monitoring and automation of road and rail networks that uses the transmission of signals via radio frequency, according to the ZigBee communication protocol, which is in accordance with the international standard Institute of Electrical and Electronic Engineers (IEEE) IEEE

802.15.4 and is composed of embedded systems, sensors and microcontrollers. This system allows a constant evaluation of factors that influence the performance of the trains and currently monitors the South Line of the Companhia Brasileira de Trens Urbanos/Metrô do Recife (CBTU - Recife), located covering the Metropolitan Region of Recife (RMR), and connecting the center of the city of Recife to its outskirts and neighboring cities.

Thus, it is proposed the development of the Air Quality Monitoring Module applied to the RailBee® Telemetric System, to be applied as a system for monitoring the air quality, in real time, inside the trains (passenger lounge), in the public areas of the passenger stations and on the traffic lane where the metro-rail vehicles circulate, analyzing the air quality index in the transportation on rails and on the permanent way of the South Line of the RMR subway system and enabling a database that contributes to the improvement of sustainable environmental management in RMR and Recife subway system. Applying the system method to the city's subway system as a small case study that contributes to the construction of new methods of monitoring network air quality for similar study regions.

2 Objectives

The goal is to develop an innovative and sustainable low-cost technology to improve management and sound decision making for the reduction of air pollutant emissions. As also, the advancement of the research, extension and innovation group contributing to the growth of services for transportation users as a form of clean transportation. Even more specifically, it is intended to:

- Develop the Air Quality Monitoring Module for application in the RailBee® Telemetric System;
- Monitor in real time the levels of atmospheric pollutants through the RailBee® Telemetric System;
- To provide an inventory of air pollutants present inside (passenger hall) trains circulating in the South Line of the Metro Rail System of the Metropolitan Region of Recife;
- Analyze results of the application process and report difficulties and necessary improvements to the regulations;
- To provide an inventory of the atmospheric pollutants present on the track where the trains of the Southern Line of Recife's Metropolitan Area Subway System circulate;
- Analyze the data collected by the Modules and enable improvements in data collection for the new meters that contribute to the improvement of CBTU-Recife's Management and Utility.

3 Methods

3.1 The Study Site: The RailBee® Telemetric System

The RailBee® System is composed of four subsystems differentiated by the functions of their devices in the Wireless Sensor Network (WSN) and by the direction of the information, the subsystems are named as follows: Mobile Stations (MS), Router Stations (ER), Base Stations (EB) and the Central Station (EC).

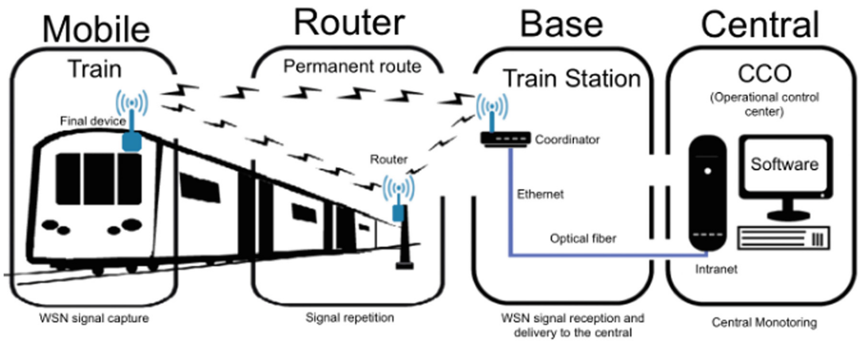

Fig. 1. RailBee® telemetry system overview

The Mobile Station (see Fig. 1) is an embedded electronic device that is located inside the command cabin of the Train Electric Unit (TUE), acting as an end node of the network, obtaining data from the sensors by the on-board computer in the cabin [14]. Also, according to [14], the basic composition of a ME is formed by sensors, a microcontroller, and a radio frequency (RF) XBee transmitter. The sensors are the devices that capture the electrical signals from the monitored variables. The microcontroller is responsible for receiving the electrical signals from the sensors and performs its encoding, such as data packaging, while the transmitter is responsible for transmitting these signals via radio signal to other parts of the system with the Base Stations as the final destination.

The Routing Station is a device located along the track, more specifically between the passenger stations throughout the CBTU-Recife South Line, and has the function of system communication. The ER acts as a router in the network, it receives information and amplifies the signal to another device in the network through its XBee Module responsible for receiving the Radio Frequency signals coming from the MS and sending these signals to the Base Station, in case direct contact between Base Station and Mobile Station is not possible.

The Base Stations are located in the passenger stations and their purpose is to receive the radio frequency signals coming from the ER and EM, so that the information from these signals are now sent back to the Central Station through a CBTU-Recife intranet. This station is composed of an XBee Module configured as network coordinator, receiving the signals, and a microcontroller, which will perform the network gateway function, encoding the data for the Ethernet/IP (Internet Protocol) protocol, which assigns an IP Address for each passenger station and is interconnected to CBTU-Recife's operational intranet, sending the data to the CE through an operational fiber optic network.

The Central Station is a desktop that has the RailBee® monitoring software installed and is located in the Operational Control Center (CCO). The CE receives the data coming from all the EBs through the CBTU-Recife intranet, processes this data, stores it in a hard drive, and finally displays it in real time to the CCO Traffic Controllers, giving them the same vision as the train operator in the cabin.

3.2 Air Quality Monitoring

Although it has as cause the search for better quality of life, the disorderly expansion of urban spaces can be a challenge to the maintenance of sustainable relations in cities. Among the types of pollution discussed in the current scenario, air pollution is one more concern because of the degradation of ecosystems and its widespread effect on the health of their populations (MOLINA; MOLINA, 2004). Thus, the association between better quality of life and cities is undone when living in these urban spaces exposes the population to higher concentrations of pollutants.

Based on guidelines from the World Health Organization (WHO), CONAMA Resolution No. 491 of 19/11/2018 [6] defines that air pollutants are: "Any form of matter in quantity, concentration, time or other characteristics, which make or may make the air unfit or harmful to health, inconvenient to the public welfare, harmful to materials, flora and fauna, or harmful to the safety, use and enjoyment of property or to the normal activities of the community".

As for the formation of these gases, the WHO, in its guidelines, establishes that a pollutant can be defined in 2 ways, emitted or formed. Primary pollutants are those emitted into the atmosphere directly from a source, such as car exhaust or a chimney. Secondary pollutants, on the other hand, are those formed in the atmosphere from chemical or photochemical reactions between primary pollutants and natural components of the atmosphere, such as water or oxygen.

Large cities like Beijing, Los Angeles, Mexico City and São Paulo often have high concentrations of the main atmospheric pollutants, these are: Particulate Matter (PM), Ozone (O3), Sulfur Dioxide (SO2), Carbon Monoxide (CO), Nitrogen Oxides (NOX) and Greenhouse Gases such as Carbon Dioxide (CO2) and Methane (CH4), responsible for environmental changes on a global scale (MOLINA; MOLINA, 2004). The emission of these pollutants has origins already known as the burning of fossil fuels coming from non-modernized transport and industrial chimneys, which in turn are representatives of essential urban activities, whether the work or their daily transport.

Although the relationship between environmental effects and population growth is already a concept that justifies the increased concentration of pollutants in urban centers, populations do not stop growing. In a United Nations

[18] report on estimates for the urban world, the urban population will increase from 4.22 to 6.68 billion by 2050, more than $\frac{2}{3}$ of the projected population for the year. However, according to [12], based on UN Reports, they argue that even with a large population concentration, it is still possible to build sustainable cities by following 3 criteria:

– Appropriate plans for air quality management that include the establishment of adequate monitoring capabilities for the supervision of environmental quality and health status of populations;
– Adequate access to clean technologies, including the provision of a training and development of international information networks;
– Improved data collection and assistance so that national and international decisions can be based on sound information.

Thus, air quality monitoring plays a key role in the sustainability of cities. The city of São Paulo besides [12] report, was already cited in reports by the UN and the World Health Organization (WHO); due to its importance as a Megacity and since 1985, the State of São Paulo issues reports on air quality based on WHO guidelines. The Environmental Company of the State of São Paulo (CETESB) is responsible for the publication of data and reports, which presents some of its methodologies, of which served as reference for the Technical Guide for Monitoring and Evaluation of Air Quality of the Ministry of Environment, and publishes them each year in its Air Quality report [4].

3.3 Low-Cost Sensors for Air Quality Monitoring

Low-cost sensors have become popular with the promotion of advances in electronics and electrical engineering. From the advances in microfabrication techniques and the development of MEMS, it was possible a strong presence of these sensors in applications using WSN and Internet of Things (IoT) due to its easy acquisition and advances in computing, which promoted a user-friendly data visualization [17]. As an example, these sensors can be used in different segments of Air Quality management, such as deploying sensors in order to complete a monitoring network, expand data that can be used by the community, monitor compliance by pollution sources, and monitor personal emissions.

Also, according to [17], the measurement principle used in these devices can be divided into two: sensors that interact with the sensing material by means of reactions, and sensors that perform their measurements by measuring the absorption of visible light. As for its hardware composition, as seen in Fig. 2, the sensor can be comprised of a sensor element, responsible for detection; a transducer, capable of transforming the responses into electrical signals; data storage or connection with a communication device (radio transmitter); and a power source (battery, power supply by wire, or photovoltaic panels). For [13] and [17], these devices fulfill a paradigm-shifting role in air quality monitoring because of their usefulness for monitoring by communities and researchers. For [17], as citizens are exposed to more information about air quality, it is possible to familiarize them with the topic and then develop strategies to reduce air pollution based on community decisions.

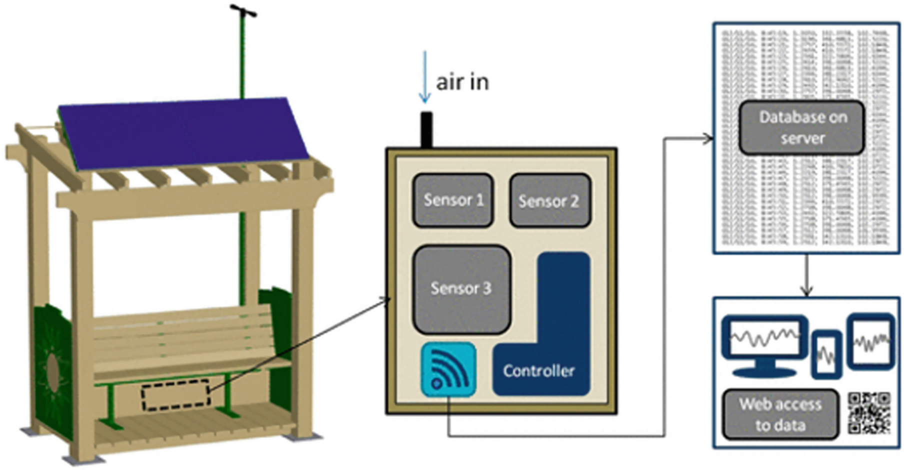

Fig. 2. New monitoring models based on WSN [17]

3.4 State of the Art of Implementations in Use

For the analysis and air quality, first we need to understand which materials can be harmful to human health, according to The NATIONAL COUNCIL OF THE ENVIRONMENT - CONAMA, in the form of RESOLUTION No. 491, OF NOVEMBER 19, 2018, the following materials, from specific and individual concentrations, determined in the resolution, can generate health risks: Particulate Matter - MP10, Particulate Matter - MP2.5, Sulfur Dioxide - SO2, Nitrogen Dioxide - NO2, Ozone - O3 and Carbon Monoxide - CO. However, it is good to make it clear that it is not necessary, in cases of studies that aim to determine their analysis from the standpoint of a specific pollutant, that this analysis be extended to the others, as we can see in [11], which focuses its study on PM2.5.

Moreover, as exposed in [8], a complete understanding of the dynamics and meteorological parameters in the planetary boundary layer is necessary, since this is the medium of propagation, over long distances, of the pollutants present in the air. One of the factors that can influence the fidelity of the data collected through the analysis and monitoring of air quality is the dispersion of pollutants, according to [5] the dispersion is influenced directly by the turbulence found in the planetary boundary layer, but with the natural randomness of turbulence, this cannot be determined precisely, except an approximation through statistical methods, which will result in the impossibility of having a monitoring method that accurately portrays reality, since there will always be a minimum value of dispersion that cannot be eliminated.

With the popularization of means that allow the democratization of the analysis and air quality, this has been gaining space, a fact that increasingly encourages the development of new methods for this purpose, consequently improving the measurements, from the reduction of distortions caused by interference, since such new methods seek an advance in the state of the art.

3.5 The Recife's Context and Structure on Air Quality Monitoring

According to data from the Brazilian Institute of Geography and Statistics [7], the Metropolitan Region of Recife, present in the State of Pernambuco, has an estimated population of over 4 million inhabitants, being the 6th most populous in Brazil. Given the large population of the RMR, public transportation is of fundamental importance for locomotion in the urban region, highlighting the Recife Metro, which connects important points of the city, transporting about 400,000 passengers per day, according to the Brazilian Company of Urban Trains (CBTU, 2022) [1].

According to [11], the Metropolitan Region of Recife (RMR) presents air quality problems related to the emissions of pollutant gases from land vehicles, thus requiring the adoption of policies aimed at improving air quality. If not properly treated, these problems can lead to serious health risks for the inhabitants of the metropolis.

The monitoring and adoption of policies to control the emission of pollutants in the São Paulo Metropolitan Region, as verified by [3], resulted in a tendency to reduce the concentration of pollutants in the atmosphere, with the Vehicle Emission Control Program being responsible for reducing about 90.

Thus, following the guidelines as to the objectives of the Technical Guide for Monitoring and Evaluation of Air Quality, the monitoring in strategic regions of the Recife Metro will bring an unprecedented survey of the air quality in population concentrations, allowing an evaluation of the impacts of emissions, due to the proximity between the railroads and these spaces, thus being an essential landmark as a case study for the development of air quality monitoring networks, since it is a large urban center that is not yet listed in the Air Quality Platform of IEMA [9] or other databases. Furthermore, a study of emissions from combustion vehicles can contribute to solutions and a monitoring of the means of transportation for the cities, as well as evaluate the pollution from the traffic routes and the impact on the environment of the terminals of the Integrated Structural System (SEI), the current bus transportation system in the city of Recife. This contributes to sustainable decision making and technological innovation by organizations that use the data.

The RailBee® Telemetric System was chosen as a site study due to its current structure already installed on the South Line of the Recife Subway. This line is a key strategic location for the reading of data on pollutants emitted in Recife, since it passes through points of high population density, large circulation of motor vehicles, and transition zones between road and subway transport. In addition, it is the line that circulates more people in the city of Recife, counting with 12 stations, where these stations are located among the municipalities with the highest population concentration.

4 Results

4.1 Most Indicated Variables to Be Considered

The Recife Metro is an important tool in the urban life of the Metropolitan Region of Recife, connecting important points of the city, from the center of Recife to 3 neighboring municipalities, while the RMR is composed of 15 municipalities in the State of Pernambuco, with an estimated population of over 4 million inhabitants [15]. Following the guidelines as to the objectives of the Guide, the monitoring in strategic regions of the Recife Metro will bring a survey on Recife's air quality in population concentrations, allowing an evaluation and comparison with the variation in the emission matrix of pollutants, such as peak hours, holidays, vehicle fleets and etc. This contributes to sustainable decision making, allied to technological innovation, by the organizations that will use the data.

The parameters used are being chosen due to their concentrated presence in urban environments, which will enable the study in urban transition environments, from an external environment with a high concentration of pollutants from the burning of fossil fuels, to the routes between passenger stations, an environment without burning fuels. Currently, the project is studying four pollutants to be detected: Carbonic Gas (CO2), Carbon Monoxide (CO) and Nitrogen Dioxide (NO2), and Particulate Matter up to $2.5\,\mu$m (PM2.5).

Although carbon dioxide is essential for the most varied activities of living beings, such as breathing, its high concentration in the atmosphere, enhanced by human action, makes it one of the main atmospheric pollutants and participant gases in the Greenhouse Effect. This pollutant has a difficult detection and a high life span in the atmosphere, and because of this, this gas can move between hemispheres or even globally, causing impacts on a much larger scale than other urban pollutants. According to the WHO, carbon dioxide, because of its nature, is not found in concentrations much higher than the environment, and it is possible to detect large differences in environments that have one source emitting large amounts. This makes it possible to evaluate how much carbon dioxide needs to be reduced near the stations. In addition, processes such as burning of fossil fuels, wildfires, and deforestation are related to the release of carbon dioxide, so with CO2 monitoring it is also possible to monitor possible outbreaks of such phenomena.

Carbon monoxide is one of the pollutants released in the incomplete combustion of coal-based fuels. This pollutant is invisible to the human senses, but its effects are serious to health, and can even cause poisoning when exposed to high concentrations [22]. Based on a region close to sources such as cars and other vehicles, it will be possible to understand the concentrations in real time based on the dynamics of the city throughout the day, which will contribute to measures aimed at reducing the emission of the pollutant.

NO2 - Nitrogen Dioxide, like the other two pollutants, is formed from combustion, however, in 2005 the WHO already warned about the danger of this specific pollutant. Nitrogen Dioxide is one of the primary pollutants responsible for the formation of harmful pollutants, such as tropospheric ozone. Besides its role in forming other pollutants, it can also lead to other environmental impacts, such as photochemical smog. Based on the alert issued by the WHO in 2005 and the CONAMA resolution issued in 2018, by monitoring the Nitrogen Dioxide levels it will be possible to observe what measures have been taken to reduce its emission and contribute to new standards to be proposed. Particulate Matter or PM can be classified into two categories:

– PM10 are particles with size between 2.5 and 10 μm usually found in industrial regions, which require specific analysis and escape the focus addressed in the present work.
– PM2.5 are particles up to 2.5 μm in size found in urban regions, which is the region of interest in this work.

PM2.5 is present in some types of aerosols and emitted when organic materials and fossil fuels are burned. Because of its microscopic size, when present in the atmosphere it can easily be responsible for cases of respiratory and cardiovascular diseases, being a relevant pollutant in determining the air quality.

According to [16], particulate matter up to 2.5 μm is considered the main pollutant in European and Asian countries that perform monitoring, but in Brazil, besides monitoring being limited to only 10 states plus the Federal District, PM2.5 monitoring is only performed in 5 of them and all with considerable parcels of insufficient monitoring [9], thus PM2.5 is generally not considered in the calculation of the air quality index, resulting in a falsely favorable index due to the lack of one of the most relevant pollutants.

4.2 Model for an Air Quality Monitor Device

Based on the visualization needs at different urban points, 3 essential collection points are characterized: mobile points, fixed points for monitoring large concentrations of pollutants (background concentrations) and fixed points for monitoring large movements of people. For this, a monitoring device must have in its structure, the possibility of modularization that adapts it to such collection points.

The proposed model plans to integrate air pollution sensors to the RailBee® Telemetric System, so that downtown and peripheral regions are monitored in real time. There is an urgent need for real-time monitoring, both for alerts and immediate decision making for the gases that pose the greatest risk to human health, and so that the data can be used and analyzed at any time, without the dependence on waiting for the data to be released every certain time interval.

The proposed module has in its composition a set of sensors for pollutant gases, where each module has the ability to monitor up to 4 types of pollutants, being under study the following gases: Carbon Dioxide (CO2), Nitrogen Dioxide

(NO2), Carbon Monoxide (CO) and Particulate Matter 2.5; furthermore, its communication is given by a sensor network in star mesh, so the communication can be done continuously, even if one of the sensors falls and for this a ZigBee network is used (IEEE 802. 15.4), this is a basic structure for the construction of the Air Quality Monitoring Modules, this means that more sensors can be inserted or removed, depending on the choice of the object under study, so, as an example, sensors of other pollutants can be added, as well as the addition of GPS, accelerometer, pressure sensors, humidity and wind.

These sensors will be implemented in the RailBee® Telemetric System, installed in the Mobile Stations, where it is possible to use the device portably throughout the city, an installation in the Routing Station gives access to fixed points in the city, where pollutants near housing areas can be visualized, and the capture of background concentration pollutants, by being able to install in higher locations where these gases can circulate and analyze their effects considering climatic factors, and by installing at Base Stations, the pollutants circulating in areas where there is foot traffic are analyzed and data capture at combustion vehicle stations, as Base Stations are located between train and bus stations, location. Thus, a facility configuration like this will offer a strategic position and monitored at the Operational Control Center (CCO) of CBTU-Recife through management software, storage, processing and real-time display of data, which may in the future generate specific reports, which will be essential for an adequate and standardized monitoring following the norms of the Technical Guide for Monitoring and Evaluation of Air Quality or other international standards for monitoring.

For the local context of Recife, following the guidelines of the Guide, it was analyzed the viability through this model the disposal of reports of the impacts of the concentration of pollutants on vulnerable populations, the levels of background concentration or other impacts on the environment, being made the availability of these data for CBTU-Recife, in its sustainable management or any other environmental agency. It is also possible to analyze impacts of emissions near population dwellings, due to the proximity between the tracks and these study spaces. It is also feasible to study the emission of pollutants by means of transportation on tires, using the strategic position. A study of emissions from combustion vehicles can contribute to solutions and a monitoring of the means of transport for the cities, as well as evaluating the impact on the integration environment of the bus terminals, and also evaluating and monitoring the pollution coming from the transit roads, since stations like the Tancredo Neves Bus Station, present on the South Line, is at a distance from the carriageway of only 60 m, approximately (see Fig. 3). As such modules can be arranged at different points on the permanent way by the RailBee® System, depending only on the object of study targeted for supervision and monitoring.

Other collection points are spread around the city that already have the stations of the RailBee® System, one of them is the Central Station of Recife, located in the center of the city and located at a point where there is a large circulation of people, as well as being close to poor communities in the Metropoli-

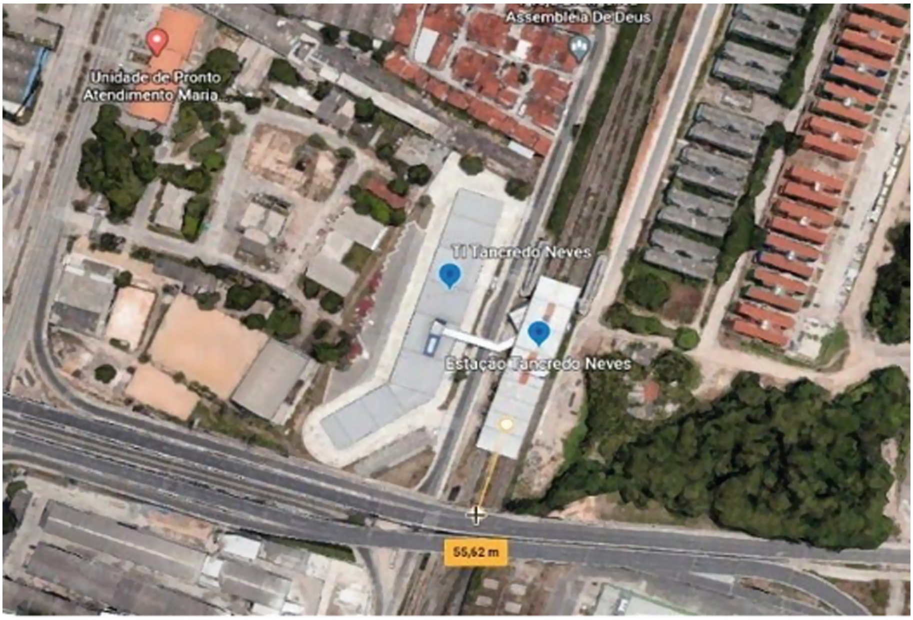

Fig. 3. Tancredo Neves Train Station next to the Tancredo Neves Bus Station and the avenue of great flow near the stations

tan Region of Recife (see Fig. 4), where through mobile and fixed points, it is possible to understand the pollutants of the social study object and the urban pollutants study object.

Therefore, the feasibility of a conscious planning and management of environmental footprints in the RMR is concluded, using the criteria recommended by the UN [21] through the monitoring network. Based on these recommendations, the Air Quality Monitoring Module will be able to monitor the main emission sources in urban space and will contribute to a good planning of urban spaces, which consequently will reduce the environmental impacts caused by air pollution, as well as reduce ecological footprints, a fundamental and urgent step to improve the quality of life in cities [12,21].

4.3 Methodology for Implementation

According to the Technical Guide for Air Quality Monitoring and Assessment, some factors should be taken into account when planning the implementation of air quality monitoring in urban regions, such as, for example, location of the monitoring stations, collection height, ground cover around the station and proximity to obstacles. For the measurement of pollution emitted by mobile sources, the distance from roads with high traffic is of particular importance, since the vehicles that are the source of the emission are in circulation and also emit pollutants in the residential area. For continuous monitors, in order

Fig. 4. Recife Central Station near the city center and housing communities

to ensure continuous generation and representation of the monitoring data, the collection of consecutive hourly averages is recommended.

For regions where the focus of the study is the analysis of air pollutants near communities for the study of general effects to the population and for observation of high concentration monitoring objects, according to the Guide, it is appropriate to use a neighborhood or urban scale, thus the distance between the monitoring station and traffic routes should vary between 15 and 140 m for when pollutants are observed on a neighborhood scale and between 80 and 140 when pollutants are observed on an urban scale.

Therefore, for the construction of the Monitoring Modules, the approximate radius of detection of the sensors is taken into consideration, which is on average close to 20 m. For the data collection methodology, in cases of studies on general effects on the population it is important to monitor by hourly averages, since this can contribute to the understanding of emissions along the hours of greatest peak urban activity, the same procedure is understood for the analysis of mobile sources. These data can also be separated and used simultaneously hourly averages for the cases presented and daily averages for the study of city background pollution, as these present more subtle changes and vary according to periods of the year, together the data can also be presented in monthly averages and in this way a macro view can be presented of the dynamics of urban pollutants throughout the year.

5 Discussion

The research presented brings as its results a methodology and development of monitoring networks for air quality in environments where these are currently non-existent. Through the review of the current rules and regulations for monitoring in Brazil, as well as evaluating which recommendations would be appropriate for the contexts found, being the 3 essential collection points: mobile points, fixed points for monitoring of large concentrations of pollutants (background concentrations) and fixed points for monitoring of large circulation of people. Through this the proposed device construction model comprises wide-range techniques see the necessity of using low-cost sensors for urban pollutants that can work in wireless sensor networks and the availability of data in real time, thus outlining the plan for the Recife site of study, where the necessary means and materials are presented, as well as the importance and how these methods can evaluate urban pollutants in order to collaborate with the urban dynamics and for the management of the city.

The importance of the study in gathering theoretical and technical information about air quality monitoring and in presenting a plan for the construction of a monitoring network, even in areas of null development in the sector through an adjustable device for the case studies, is believed. In this way, space is opened for the evaluation of this model when compared to other development and monitoring methods, since the approach presented in the model uses strategies focused on a local or urban scope, still without the knowledge of the functionality of this application in different quantitative contexts for the effective use of data for air quality assessment purposes.

References

1. CBTU homepage (2022). https://www.cbtu.gov.br
2. Borrego, C., et al.: Challenges for a new air quality directive: the role of monitoring and modelling techniques. Urban Clim. **14**, 328–341 (2015)
3. Carvalho, V.S.B., et al.: Air quality status and trends over the metropolitan area of São Paulo, Brazil as a result of emission control policies. Environ. Sci. Policy **47**, 68–79 (2015)
4. CETESB: Qualidade do ar no estado de São paulo 2019 (2020)
5. Chang, J.C., Hanna, S.R.: Air quality model performance evaluation. Meteorol. Atmos. Phys. **87**(1), 167–196 (2004)
6. CONAMA, Diário Oficial [da] República Federativa do Brasil: Resolução conama no 491, de 19 de novembro de 2018. dis-põe sobre qualidade do ar (2018). https://www.in.gov.br/web/guest/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/51058895/do1-2018-11-21-resolucao-n-491-de-19-de-novembro-de-2018-51058603
7. IBGE: Ibge population estimations (2022). https://www.ibge.gov.br/estatisticas

8. Jayamurugan, R., Kumaravel, B., Palanivelraja, S., Chockalingam, M.P.: Influence of temperature, relative humidity and seasonal variability on ambient air quality in a coastal urban area. Int. J. Atmos. Sci. **2013**, 264046 (2013). https://doi.org/10.1155/2013/264046
9. Instituto de Energia e Meio Ambiente: Plataforma da qualidade do ar (2021). https://energiaeambiente.org.br/qualidadedoar
10. Ministry of Environment - Ministério do Meio Ambiente: Technical guide for air quality monitoring and assessment (2019). https://www.gov.br/mma/pt-br/centrais-de-conteudo/mma-guia-tecnico-qualidade-do-ar-pdf
11. de Miranda, R.M., de Fatima Andrade, M., Fornaro, A., Astolfo, R., de Andre, P.A., Saldiva, P.: Urban air pollution: a representative survey of pm2. 5 mass concentrations in six Brazilian cities. Air Qual. Atmos. Health **5**(1), 63–77 (2012)
12. Molina, M.J., Molina, L.T.: Megacities and atmospheric pollution. J. Air Waste Manag. Assoc. **54**(6), 644–680 (2004)
13. Morawska, L., et al.: Applications of low-cost sensing technologies for air quality monitoring and exposure assessment: how far have they gone? Environ. Int. **116**, 286–299 (2018)
14. Pereira, S.X., de Araújo, R.C.C.: Desenvolvimento de módulos das Estações móveis para Aplicação ao Sistema Telemétrico RailBee. In: Engenharia Elétrica e de Computação: Atividades Relacionadas com o Setor Científico e Tecnológico 3, pp. 49–62. Atena Editora, October 2020. https://doi.org/10.22533/at.ed.6032006105
15. Governo Do Estado De Pernambuco: Região metropolitana do recife (2022). https://www.pdui-rmr.pe.gov.br/RMR
16. Siciliano, B., Dantas, G., Silva, C.M.d., Arbilla, G.: The updated Brazilian national air quality standards: a critical review. J. Brazilian Chem. Soc. **31**, 523–535 (2020)
17. Snyder, E.G., et al.: The changing paradigm of air pollution monitoring. Environ. Sci. Technol. **47**(20), 11369–11377 (2013)
18. UN-DESA: World urbanization prospects: the 2018 revision (st/esa/ser.a/420) (2019)
19. Völgyesi, P., Nádas, A., Koutsoukos, X., Lédeczi, Á.: Air quality monitoring with SensorMap. In: 2008 International Conference on Information Processing in Sensor Networks (IPSN 2008), pp. 529–530. IEEE (2008)
20. WAQI: World's air pollution: real-time air quality index (2021). https://waqi.info/
21. WHO: Urban air pollution in megacities of the world (1992)
22. WHO: Who air quality guidelines global update 2005. Report on a working group meeting, Bonn (2005)