Multi Zone-Based Surface Air Quality Monitoring via Internet of Things

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Abstract**—**Air pollution has become a problem across the globe and is still arising as a major concern in a country with booming economy. In the Philippines, laws were outlined to reduce air pollution and incorporate environmental protection into its development plans. However, limited means to conduct air quality monitoring that could determine if the standards in the National Ambient Air Quality Guidelines are met have been implemented. This study aims to design and create a system that could monitor the surface air quality from the different distant zones of a local municipality. The primary focus is to develop a cost-effective and portable air quality monitoring system that can hook up online and equipped with sensory system of major pollutants namely Carbon Monoxide, Nitrogen Dioxide, and Sulfur Dioxide. This study also aims to engage in implementation of an integrated technology that will infuse WiFi development board modules built on ESP8266 based modules, Arduino microcontroller and elements of Internet of Things to form an intelligent and connected environment. The system also aims to provide a view for the citizens for them to be aware of the air that they breathe, an air quality index calculator and repository of collected air quality data that could help other researchers and experts in implementing ways to control pollution problems

Index Terms**—**Air quality monitoring, internet of things, zone-based sensory, ESP82266, WiFi module.

I. Introduction

Philippines is one of the countries that follows the trend of industrialization to pursue a better economy. To accommodate services and employment, more factories, establishments and local transportation means are being built. However, according to health experts, the quality of air in the Philippines is becoming worse, and citizens who use public transportations are highly vulnerable to the harmful effects of air pollution [1]. To balance the environmental impact of the developments in the country, laws were created to guide and protect the welfare of the people. A law has been enacted in the Philippines entitled as the “The Philippine Clean Air Act” or also known as “RA 8749 or the CAA”. This act aims to provide a sustainable environment in the Philippines through prevention and control of air pollution by setting standards, guidelines and regulations for government, people, and industries to follow [2].

On a municipal level, major source of air pollution is from mobile sources. Currently, the only way to determine the occurrence of air pollution in the local areas is through reports given to the municipality. Once they receive a report, the municipal pollution officers will immediately inspect the area and investigate where the sources and causes of pollution and from there, decide what actions to take. Yet usually, upon arriving at the reported area, the trace of pollution has already been diminished, gone, or was already replaced by other air pollutants. With this, the study would like to focus and monitor criteria pollutants that contribute to the greenhouse effect and are from the major source of air pollution namely: Carbon Monoxide (CO), Nitrogen Dioxide (NO2), and Sulfur Dioxide (SO2). The ability to measure air pollution in real-time will enable the municipality to improve its implementation of Clean Air Act in its vicinity.

The objective of the study is to develop IoT based surface air quality monitoring devices placed strategically in the two key areas of a target local municipality that can help in determining whether the standards provided in the National Ambient Air Quality Guideline [2] are met by collecting actual concentration of air pollution data. The system have an IoT device that utilizes a WiFi enabled board that enables real-time collection through the sensory system of the air pollution concentration data in distant zones, and retrieval whenever it is needed to help the experts in their investigation. This arise from identified problems in the study: (1) Difficulty in conducting air quality monitoring in key areas that can help in determining if standards provided in the National Ambient Air Quality Guideline are met, (2) Limited recorded air pollution data of key areas as basis in fully implementing the standards and policies provided in the Clean Air Act, and compliance under the Municipal Environment Code when air pollution reaches dangerous level in key areas, and (3) Difficulty in collecting data in distant zone when the need for such act arise.

II. Literature Review

Monitoring of environmental pollutants is a rapidly developing branch of analytical chemistry. A monitoring network focused on air contaminants provides an

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objective and reliable set of data on the state of the air over a given area at a given instant. "Ref [3]" also suggests appropriate systems for dispersing and storing measurement data that enable the public to be informed about the quality of air and to think up of suitable sedative measures within a short time, should pollutant levels become excessive. Air Quality Index (AQI) are numbers that are used by different countries to tell the public how polluted the air in a certain area. To calculate AQI, several concentrated air pollutants are taken into account and compared to the limits fixed by the law. According to US EPA, the AQI is obtained by getting the highest AQI among the air pollutants that was monitored, measured in a particular hour of the day, and the limit values specified by national regulations. AQI is simple to understand as it requires no specific knowledge to interpret the results. According to [4], the higher the index value, the more the air is polluted. Another way of computing the AQI is through moving average. It is used to determine the direction of the current trend. Each type of moving average is a mathematical result that is calculated by getting the average number of previous data. In this study, the researchers used the simplest form of moving average known as simple moving average (SMA). It is calculated by getting the mean of a set of concentration values of pollutants. For an instance, when calculating a basic 8 hour moving average, you would add the values from the past 8 hours and then divide the sum by 8 [5]. After computing for the average, it will be used to get the AQI of the pollutant using the given formula of AQI. An example for this is the CAQI or the Common Air Quality Index of Europe, wherein they calculate CO by getting the 8 hours moving average and incorporate it in their own formula [6].

A. Internet of Things in Environmental Elements Monitoring

With the latest trend of technology, Internet of Things (IoT) is becoming a popular solution not just only in businesses, but also in the government. Internet of Things (IoT) contains all other computing devices apart from PCs, tablets, and smartphones. An IoT device contains modules, actuators, and a microcontroller. Modules like sensors and Wi-Fi boards provides the ability to collect data, transfer and received information and data. A systematic review of literatures in [7] identifies the need that this study is aiming at in terms of IoT . The concept of IoT allows data collected to be transferred in a secure process to the web server through the gateway, which acts as an entrance and protocol conversion to and from an IP network. This gateway connects through various of wide area networks and other internet connections and then later can be accessed by the user using a standard web application utilizing web services.

III. Results and Discussions

The results of the study can be viewed based on the conceptualized diagrams, tests performed, and device evaluation. The general set-up of the study can be viewed in the succeeding figure.

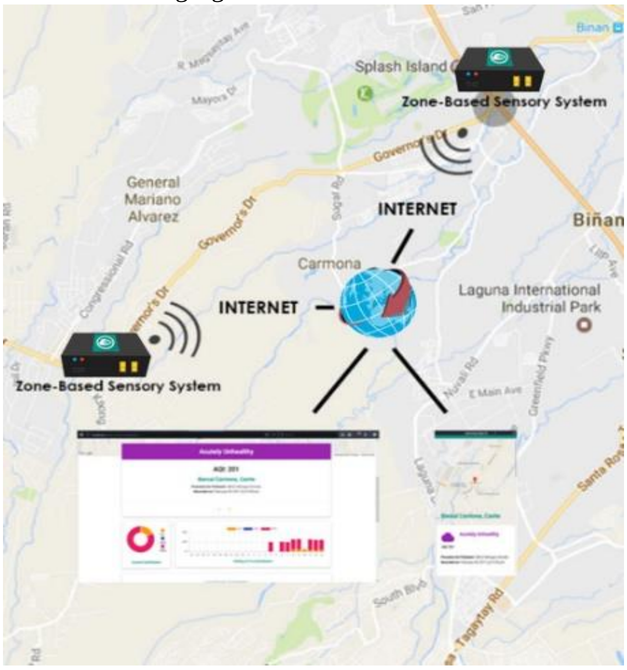


Fig. 1. General system setup

Fig. 1 illustrates the system set-up of the sensor y devices from two (2) different distant zones in a target local municipality. In order to collect air concentration data and send it to the cloud server, each device was connected to the internet with the use of a Wi-Fi module (Wemos D1 R2 mini) installed in it. The data collected were used to calculate the AQI of the area, and was displayed on the web application. The results can be viewed by the experts, Municipal Environment Officers, and citizens of municipality, and researchers through the web application. Alternatively, they can access the website on their smartphone.

Before the sensory system of the device is deployed, several tests were performed. The study followed the concept provided by [8] in performing the tests for the sensors used. In this study the identified sensors needed for the elements are: MQ-135 for Nitrogen Dioxide 36 (NO2), MQ-2 for Sulfur Dioxide (SO2), and MQ-7 for Carbon Monoxide (CO). As provided by the identified literature, the researchers conducted Self-Calibration Tests and actual data collection tests.

A. Self-Calibration and Third Party Testing of Sensors

To recognize the normal yield, self-testing was directed utilizing the data for every sensor. For self-calibration, each sensor that were used were exposed to different substances that contains Carbon Monoxide, Nitrogen Dioxide, Sulfur Dioxide, in expected clean air. Fig. 2 indicates the sample readily available baseline data from the sensor datasheet of MQ2 sensor [9].

This study considered the process done in [9] in performing self-calibration. According to the study cited, mathematically, a specific ppm can be pointed out by identifying the Rs/Ro ratio, given on the graph. In order to get the Rs/Ro ratio, the Rs and Ro values were identified. Ro can be identified in the graph as air, while Rs is identified by calculating the resistance of the gas sensor to a specific gas. After determining both values, the ratio can be solved by dividing the Rs to Ro.

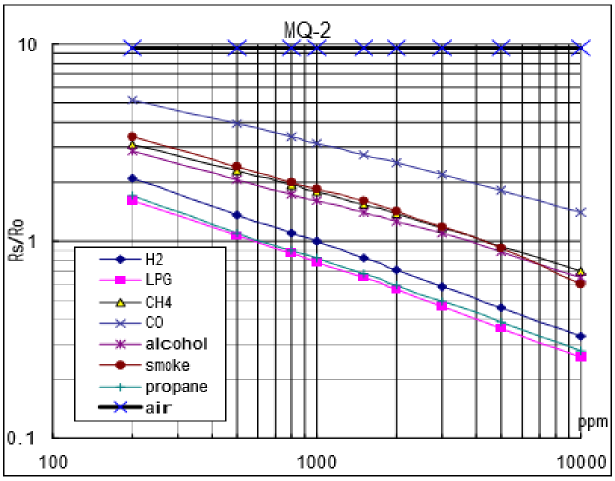


Fig. 2. Baseline data for MQ2.

In order to create a self-calibrating algorithm, the slope was used as the graph in the data sheet shows linear growth of values. To create the said algorithm, the 3 values needed, which are the logarithmic value of initial ppm and initial Rs/Ro, and the slope were identified. To solve for the slope, 2 points were identified using the datasheet of MQ2 (pollutant nitrogen dioxide) sensor. In the datasheet of MQ2, LPG line was used since LPG contains sulfur compounds, which will form sulfur dioxide (SO2) when combusted(from mobile sources). Referring to the datasheet, these points are (200, 1.75) for the first x,y point in the graph, and (10000,0.165) for the second x,y point in the graph. For the MQ2 sensor specifically, the first point is the log value of the first x,y points identified (2.301029996, 0.243038049) and the second point is the log value of the last x,y points which is (4, -0.782516056). Using the log scale value of x and y points, the result of the slope can be viewed (-0.782516056 - 0.243038049) /(4 - 2.301029996) which yielded to 0.60363284965919. The 3 values computed namely: value1 or the x intercept (2.301029996), value 2 or the y intercept (0.243038049) and the actual slope value (-0.60363284965919) can now be used in slope formula to yield an algorithm that computes for actual ppm value.

To compute for ppm, the value is computed based on the formula provided by one of the manufacturers of the sensors and the slope concept as shown in Equation (1).

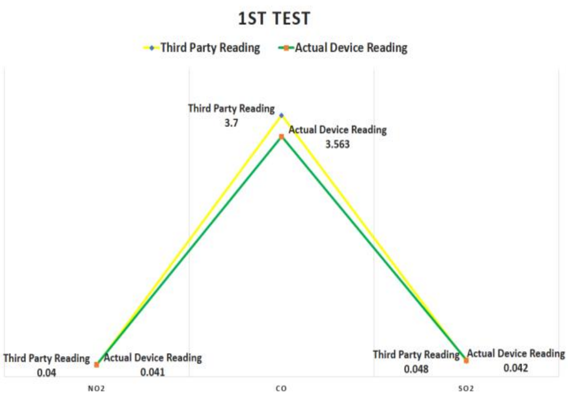
pow (10, (((log(rs_ro_ratio)-value 2)/value 3) + value 1)) (1)

Third Party testing was performed in order to check the accuracy of the self-calibration testing done by comparing actual reading from hand held device used in an Industrial plant and actual reading from the calibrated sensors. The test was performed under the supervision of a Pollution Control Expert.

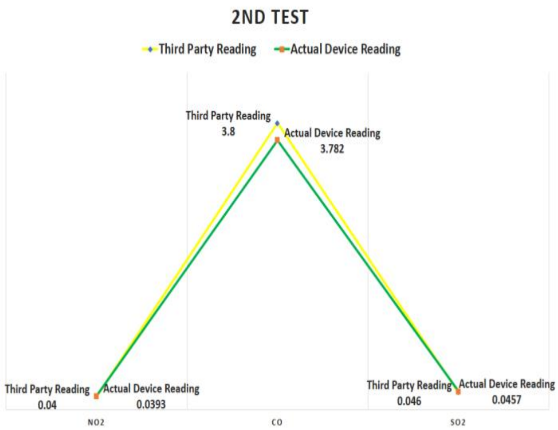
Table I show the result of the testing performed.

TABLE I: COMPARISON OF EMISSION DATA AGAINST THIRD PARTY RESULTS

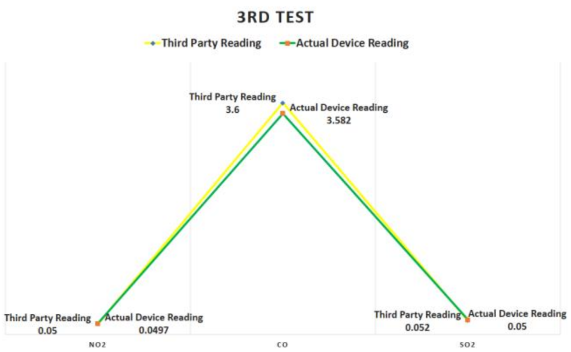
Element	Actual Reading from Hand held device (in ppm)	Actual Reading from sensor (in ppm)	Percent Error	Remarks
NO2	0.04	0.041	0.975*	Acceptable
CO	3.7	3.563	1.038*	Acceptable
SO2	0.048	0.042	1.142*	Acceptable



a. Third party test 1.



b. Third party test 2.



c. Third party test 3.

Fig. 3. Behavior of the results of third party test.

Sensors were tested three (3) times with 1 hour difference between tests. As the sensors are exposed to the gas, the expected percent errors are expected to decrease. This can be seen in the behavior of the results of tests in Fig. 3a, Fig. 3b and Fig 3c respectively. This means that the longer the sensors are exposed to the gas, the more accurate it becomes [10].

B. System Set-Up

In IoT, connected things should follow a components framework: the need for smarter storage, and management; the need for security; high-performance microcontrollers (MCUs); sensory systems and actuators; and the ability to communicate [11]. This components framework was followed in the study alongside critical analysis of segment of published body of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles. Results are armed by baseline data aligned with the standards and indices provided in the Clean Air Act and National Ambient Air Quality Guidelines. A special modified prototyping intended for IoT, Nurun was used as a methodology that provides a way to use microcontrollers in fusion with IoT [12].

Fig. 4 shows the system setup that was in the study. First, the calibrated gas sensors were connected to analog inputs and set to send emission readings to the Arduino Mega 2560. These analog readings are converted into an actual ppm emission data through the mathematical algorithm within the microcontroller base on the formula made in the self-calibration process. The data is then serially written to a WEMOS WiFi Board Module. This is then fetched by a Representational State Transfer (RESTful) Web API using POST and GET methods in a cloud server. A dedicated computer server was set to a local Municipal Environment and Natural Resources Office to retrieve pollution concentration report and real-time air quality monitoring. A separate mobile friendly web application was also developed to allow citizens to view air quality status.

WEMOS D1 Mini WiFi board was utilized in this study. “Reference [13]” was used as the basis in implementing the use of the WiFi Board. The WEMOS D1 Mini is built on the ESP8266EX 32 bit RISC micro-controller powered at 3.3V and running at 80MHz. It has a full WiFi transceiver, utilizing 802.11 IEEE protocol with 64KB of instruction RAM, 96KB of data RAM and 4MB flash memory. It is light and small with approximately 34.2 mm x 25.6 mm in size with only 10 grams of weight. It also has 11 Digital I/O pins and 1 analog input pin. This WiFi module is a development board and can be programmed using the Arduino IDE. The development board can be added to Arduino IDE and be programmed using the language used in Arduino Microcontrollers [13]. The process of connecting the WEMOS D1 board to the Arduino IDE including the web service programming can be viewed in [14], [15]. Fig. 5 shows the actual WEMOS D1 WiFi board used in the study.

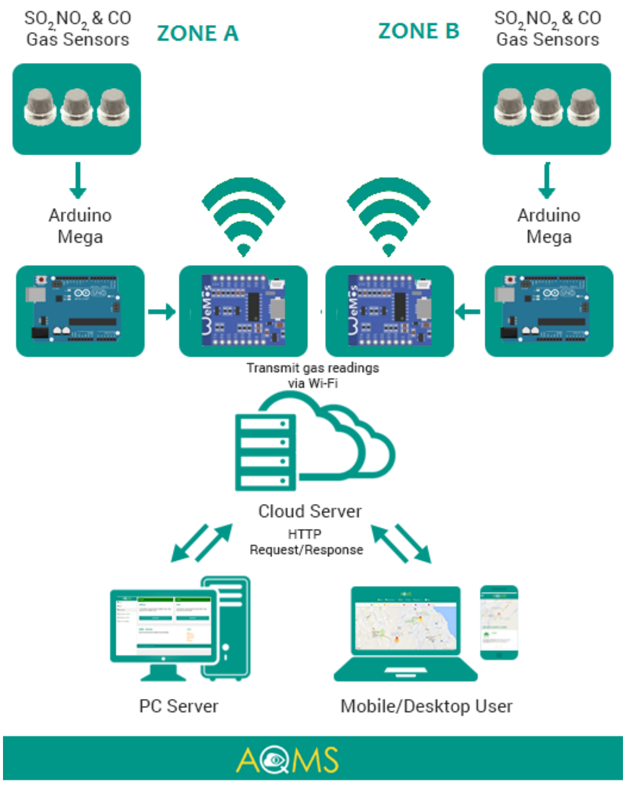


Fig. 4. System set-up diagram.

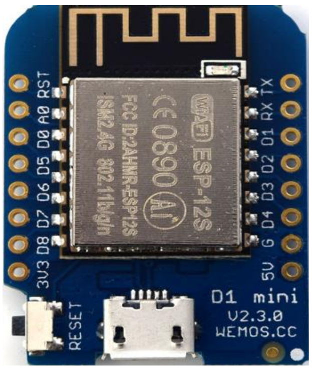


Fig. 5. D1 Mini WiFi board built on ESP8266 chip.

The WiFi Board was configured to Arduino Mega by connecting the Tx(Transmit) Pin of D1 Mini to the Rx(Receive) Pin of Arduino. The Rx Pin of D1 Mini was then connected to the Tx Pin of the Arduino respectively. This is to commence the data transmission of Arduino to D1 Mini, which is then communicated to the cloud server via WiFi connection.

C. Reliability and Actual Air Concentration Readings

A reliability testing was conducted by obtaining 3 hours worth of data for 3 days in each key area in the target local Municipality. The trials results were then computed for its average per day and an air pollution expert counter-checked the data to determine if it is aligned with the national ambient air quality guidelines.

The expert counter checked the computed average readings of air concentration data of Zone 1 and based on the national ambient air quality guidelines, CO having concentration values or 3.9 ppm, 3.8 ppm, and 3.4 ppm for groups 1, 2 and 3 respectively indicate that it is lower than the limit stated for CO – 8hr. Therefore the expert gave a passing remark for the CO readings. The expert then checked the readings for NO2, having 0.035 ppm, 0.029 ppm, and 0.012 ppm for groups 1, 2, and 3 respectively indicate that it is lower than the limit stated for NO2. The expert also gave a passing remark for the NO2 readings. The expert then checked the readings for SO2, having 0.05 ppm, 0.05 ppm, and 0.05 ppm for groups 1, 2, and 3 respectively indicate that it is lower than the limited stated for SO2, therefore the expert also gave a passing remark for the NO2 readings. Having a passing mark for all CO, SO2, and NO2 readings for Zone 1 indicates that the device senses acceptable and reliable values as shown in Table II.

TABLE II. AVERAGED CONCENTRATION DATA OF POLLUTANTS IN ZONE 1

Pollutants	Grp 1 (ppm)	Grp 2 (ppm)	Grp 3 (ppm)	Accceptable Ambient Value (ppm)	Remarks
CO	3.9	3.8	3.4	9	PASSED
SO2	0.05	0.05	0.05	0.07	PASSED
NO2	0.035	0.029	0.012	0.08	PASSED

The expert counter checked the averaged readings of air concentration data of Zone 2. Based from the National Ambient Air Quality Guidelines, CO having concentration values of 4.3 ppm, 4.2 ppm, and 4.2 ppm for groups 1, 2 and 3 respectively indicate that it is lower than the limit stated for CO – 8hr. Therefore the expert gave a passing remark for the CO readings. The expert then checked the readings for NO2, having 0.029 ppm, 0.029 ppm, and 0.025 ppm for groups 1, 2, and 3 respectively indicate that it is lower than the limit stated for NO2, therefore the expert also gave a passing remark for the NO2 readings. The expert then checked the readings for SO2, having 0.02 ppm, 0.03 ppm, and 0.04 ppm for groups 1, 2, and 3 respectively. The results indicate that it is lower than the limited stated for SO2 therefore, the expert also gave a passing remark for the NO2 readings. Having a passing mark for all CO, SO2, and NO2 readings for the Zone 2 area indicates that the device senses acceptable and reliable values as shown in Table III.

TABLE III: AVERAGED CONCENTRATION DATA OF POLLUTANTS IN ZONE 2

Pollutants	Grp 1 (ppm)	Grp 2 (ppm)	Grp 3 (ppm)	Accceptable Ambient Value (ppm)	Evaluation
CO	4.3	4.2	4.2	9	PASSED
SO2	0.02	0.03	0.04	0.07	PASSED
NO2	0.029	0.029	0.025	0.08	PASSED

Table IV shows that there is a higher concentration of Carbon Monoxide at the Zone 2, while there are higher concentrations of Sulfur Dioxide, and Nitrogen Dioxide present at the Zone 1.

TABLE IV: COMPARISON OF THE AVERAGED GROUPS OF THE TWO AREAS

Pollutants	Zone 1 Group Average	Zone 2 Group Average
CO	3.7	4.2
SO2	0.05	0.03
NO2	0.025	0.027

D. Deployment and Application Output

a. Actual deployment in zone 1 (bancal junction, carmona, cavite Philippines).

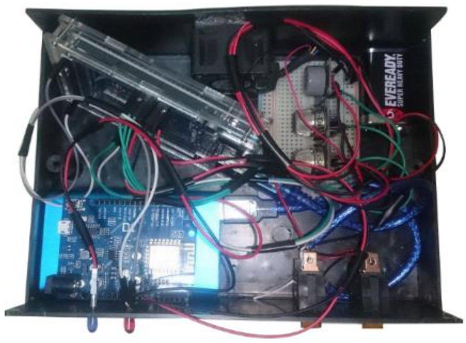
a. Actual deployment in zone 2 (SLEX, carmona, cavite Philippines)

Fig. 6. Actual deployment of the sensory devices in zone 1 (A) and zone 2 (B) of the target municipality vicinities.

The sensory devices were placed 1 to 2 meters above the ground level of two (2) distant key areas (for surface air quality, up to 10 meters is allowed) and were left for 3 hours to collect air concentration data which was sent to the cloud server in order for the users to view and evaluate the system. Fig. 6a and Fig. 6b shows the actual deployment in the identified key areas or zones in a local municipality.

Fig. 7 shows the prototype device that was used for testing and calibration.

a. Device enclosure.



b. Inside components.

Fig. 7. AQMS carmona prototype, (A) casing-enclosed, (B) inside-components.

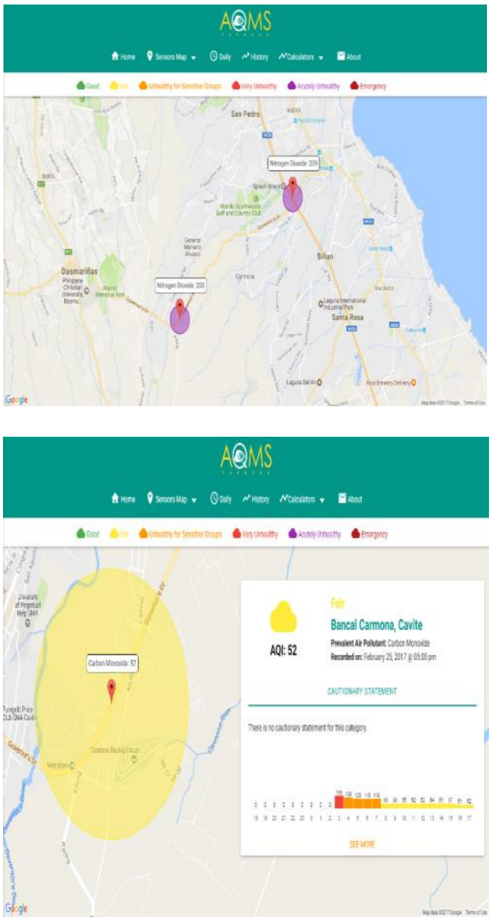


Fig. 8. The air quality monitoring system website.

Fig. 8 shows the website application, the following information are displayed based on the selected area: (1) the prevalent pollutant of the current hour, (2) its AQI equivalent, and (3) the cautionary statement that is based from the air quality indices. Furthermore, citizens could also view the website using their smart phones. In addition to this, generation of reports is also possible. The page shows a list of the actual readings, area on where these occurred, and when these occurred based on the user's selection of date, area, and pollutant. Also, the website contains a feed for MENRO officers to monitor the sensors' readings in real-time. Fig. 9 shows the actual mobile view of the application for Air Quality Monitoring System. The application can help citizen understand the air quality status and specific pollutant index. Furthermore, the data can be retrieved through reports generations where actual data can be used by researchers for analysis and comparison.

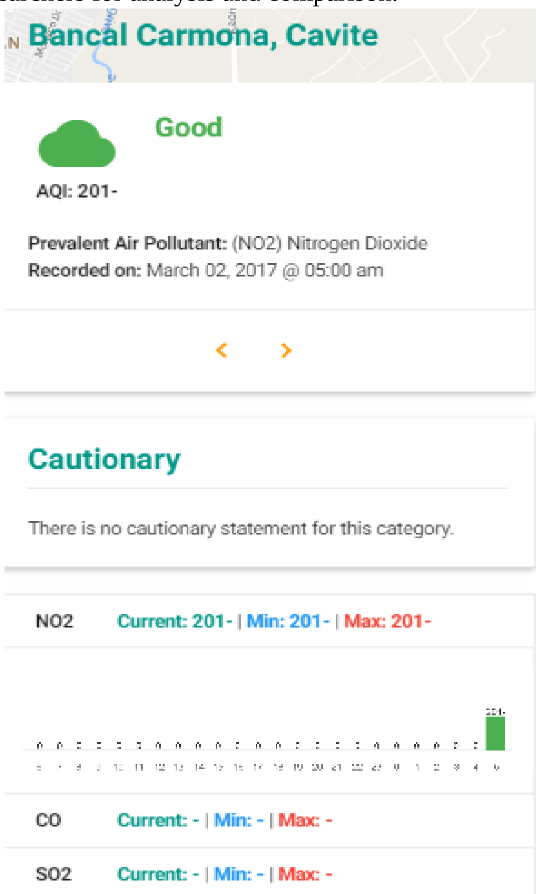


Fig. 9. The air quality monitoring system mobile view for citizen and researchers.

IV. Conclusions and Recommendations

The study was able to design and develop an IoT based surface air quality monitoring system that is placed in two distant key areas/zones of a target municipality. This can help in determining if standards provided in the National Ambient Air Quality Guidelines are met by the collection of concentration values of air pollution. The web application (with a mobile friendly feature) for the municipality, citizens, and researchers, that collects and displays air pollution data, generates raw air pollution data reports, and provides indications when certain amount of levels of air pollution has been reached, that helps in the improvement of the implementation of standards and policies provided in the Clean Air Act, and compliance with the provisions set in the Municipal Environment. The IoT device that enables real-time collection of the air pollution concentration data in distant zones and retrieval whenever it is needed to help experts in their investigation. The experts from the municipality have verified that the data provided by the AQMS system is reliable, and acceptable based from the Philippine Clean Air Act. The MENRO officer has accepted the system and is now able to test it in monitoring air pollution in the two key areas of the target Municipality. Real time collected and validated data can be set as source and their basis in the implementation and compliance with the Clean Air Act which could lead to greater impact in the environment on a local and national scale. Also, citizens of the target municipality are now enabled to view real-time air pollution data that will help them become more aware of the possible health effects that air pollution can inflict.

The study can be extended by allowing an optimized network farm of WiFi board Modules, given that the WiFi Board used in the study can be configured to connect to more network infrastructure, thereby extending also the sensory in a bigger environment. One key feature that can be included is a time-based prediction of air quality in order to know interesting patterns of the air quality data. With this, the company would be prepared for possible actions and future mitigations. Also, to further improve the study, it is also recommended to use additional sensors with Arduino to monitor different kinds of gaseous elements other than sensory devices used in this study. This could provide a better grasp of the level of gaseous elements produced in a surface air. The study would also like to direct the future researchers to consider mathematical proportionality computation of the effect of external factors including temperature and humidity indices, which have direct impact to the accuracy of the readings in the sensory system.

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