Air Quality Monitoring of Bangladesh (AQM): Data Driven Analysis System

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Abstract: Air pollution is a major concern for countries around the world. According to World Health Organization (WHO), seven million people die worldwide every year caused by air pollution. Bangladesh has not only serious pollution problems but also it is ranked first among the world's most polluted countries with a PM2.5 reading of 76.9 microgrammes per cubic meter (µg/m^3) in the year 2021 (AQI Bangladesh, 2021). In this paper, we propose to develop a data-driven software system for monitoring the air quality of Bangladesh. Our proposed system will provide atmospheric maps and charts for monitoring the current and future Air Quality Index (AQI) of any area. We conducted an experiment for 1-year time span to observe the concentration level and data patterns of PM2.5 in our country focusing on the transportation routes and industrial zones. The data is collected from the sensors and satellites of different stations covering multiple areas. The results are analyzed in the context of divisions, transportation stations, industrial zones, and time. For a variety of air quality indicators, the experimental results were compared to IQAir AirVisual Pro and showed good results, with very small differences between our obtained result and IQAir AirVisual Pro. Our goal is to mainly monitor the industrial zones, power plants, divisions, and transportation routes as most toxic compounds are formed there.

1 INTRODUCTION

Air pollution is a worldwide crisis with limited solutions because of the presence of compounds in the atmosphere that are detrimental to the wellness of habitats or pose a hazard to the ecosystem or objects. Bangladesh is a densely populated country struggling with serious air pollution. According to the most recent World Health Organization data, Dhaka's air quality averages 90 μg/m3 of PM2.5 concentration per year. Dhaka, having a yearly Air Quality Index of 168, is considered to be unhealthy and is indicated only as a warning since air pollution can reach significantly up to 300 plus dangerous higher levels.

The World Bank began a 7-year investment of USD $62.20 million in the Clean Air and Sustainable Environment (CASE) project in 2009. The goal of this project was to install 11 Continuous Air Quality Monitoring Stations (CAMS) among 8 cities to monitor air pollutants and create real-time air quality data including an air quality index for important cities. Under this project, Air Quality Research and Monitoring Center (AQRMC) has been established at Dhaka University, Bangladesh. According to the CASE project report, $10 millions USD have already been used but the progress is not visible (Air Pollution, 2021).

We have collected data from different areas of Bangladesh using sensors and compared the result with the data obtained by an industrial-graded device called AirVisual Pro by IQAir. This comparison is performed to determine the data compatibility and it has been observed that the data we yielded had good results. We have also implemented multiple machine learning algorithms for predicting the AQI on AOD 550 nm data. However, in this paper, we propose to develop a data-driven solution to monitor the air quality that will collect data from IoT-based devices, Aqua satellite, and geospatial weather data bank. The Aerosol Optical Depth (AOD) data is determined to be collected from satellites for those areas which are not covered by AQM devices. Our system will generate atmospheric maps and various charts with the help of different MLAs which will display the AQI, PM1.0, PM2.5, PM10, CO, CO_2, NO_2, VOCs of different areas of Bangladesh. The AQI forecast will

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help the government to make significant decisions for maintaining the air quality.

The rest of this paper is organized as follows. Literature reviews have been discussed in section 2 while the research problem is stated in section 3. Our proposed solution to solve the research problem is presented in section 4. The experimental results have been presented in section 5 and finally, in section 6 we have drawn the conclusion along with future research scope.

2 RELATED WORKS

Around the world, in different countries, many systems have been developed to monitor air quality. So far in Bangladesh, very few works have been done related to Air quality monitoring systems. In this research work, A number of conference papers and journal articles related to air quality monitoring systems have been studied for a deeper understanding.

An air quality monitoring system was designed by (Gu and Jia, 2019). The system's modular architecture allows it to carry a variety of air pollution sensors and integrate data from all of them with geo-location information in real-time. The prototype's preliminary field tests show that the onboard devices had no effect on the UAV's power consumption or flight time. A similar kind of system is also developed by (Kannaki et al., 2020), the entire operation is controlled by a microcontroller, which receives input signals and sends output signals to components such as the DC Brushless Fan and LED lamps. (Sung et al., 2019) also developed a system where PM1, PM2.5, PM10, CO, CO_2, VOCs, temperature and humidity have been monitored. They used short and long-distance communication modules such as Bluetooth, Wi-Fi, and Lora to communicate with a developed smartphone application.

A big data driven urban healthcare system was proposed by (Chen et al., 2018) where a method was introduced for combining multi-source air quality data which help to prepare data for AI based smart urban services. A testbed was also established by them, including the deployment of air quality aware healthcare applications. Similar kind of system was presented by(Meli et al., 2020) where the system enables the deployment of many low-cost nodes throughout a building, yielding considerable location-based indoor air pollution data. A new concept of a portable system named GASDUINO which enables the users to detect air quality via IoT was introduced by (Karar et al., 2020). Their technology can warn users about harmful levels of air quality index (AQI) values ranging from 0 to 200 PPM. It detects the AQI with the MQ-135 sensor and visualizes the data using the Remote XY Arduino cloud. A low-cost air quality measurement system was developed by (Arroyo et al., 2019) where volatile organic substances such as benzene, toluene, ethyl benzene, and xylene are detected by the system.

A study describes the evaluation of a smart indoor air quality and health system conducted by (Patil et al., 2019) , which aims to allow the users to monitor oxygen level and provide alerts when the environmental atmosphere breaches the safe limit threshold. A Wireless Sensor Network (WSN) based system has been developed by (Purwanto et al., 2019) that can be accessed through smartphone and internet. With the capability to measure air pollution environmental factors like temperature, humidity, wind speed, S_2, NO_x. Air quality monitoring via an array of sensors which transmit their toxic gas readings through Bluetooth to the nearest smartphone introduced by (Yang and Li, 2015). The readings get updated every time the application is installed in the smartphone and clicked. WSN based air pollution monitoring system was proposed by (Suganya and Vijayashaarathi, 2016). This system used a Mobile Ad Hoc Network routing algorithm, where 28 moving vehicles cover a large area. Each vehicle covers 300 meters and collects the data using air pollutant detecting sensors.

A real-time air monitoring system has been developed by (Holovatyy et al., 2018) where real-time toxic gas data has been extracted with an array of sensors to determine the concentration of deadly gases and vapours in air. Similarly, a system developed by (Kiruthika and Umamakeswari, 2017) where a set of data is extracted from multiple sensors which had some threshold values set by the system. While the collected value exceeds the threshold value, the message alert has been sent by the communication module to the client. An air pollution Geo-sensor network has been modelled by (Al-Ali et al., 2010) to obtain the AQI (Air Quality Index) where sensors are taking 24/7 real-time readings of CO, NO_2 and SO_2 components and transmit the pollutant data to a database through a server. (Dhingra et al., 2019) developed a system to observe the concentration of Carbon Monoxide (CO), Methane (CH_4) and Carbon dioxide (CO_2) gases to measure the AQI. A platform has been developed by (Zaldei et al., 2017) to monitor air pollution and traffic movements which captures CO, NO_2, and C_2 concentrations using open-source Arduino technology.

3 PROBLEM STATEMENT

The average annual PM 2.5 concentrations in Bangladesh were 76.9 microgrammes per cubic meter (µg/m3) which is seven times higher than the WHO exposure guidelines. Dhaka the capital of Bangladesh stands second among all cities around the world (AQI Dhaka, 2021). To eliminate the climate change crisis, we are proposing to develop an air quality monitoring system which will forecast AQI using AOD data from the satellite along with a device to detect the concentration of pollutants and monitor the data patterns in real-time. Our proposed AQM system, in combination with the device, will help in forecasting AQI in remote places where the devices cannot be deployed. The forecast model of the AQM system will also greatly reduce the cost of a large-scale implementation of the air quality detection system by reducing the quantity of device implementation. Our collected data showed promising results with respect to the industrial-approved device called AirVisual Pro by IQAir. Therefore, we believe that our data-driven air quality monitoring software system can be developed to monitor the air quality of Bangladesh and help to take appropriate measures for decreasing air pollution.

4 PROPOSED SOLUTION

Inspired by the success of data-driven solutions, we propose to develop a data-driven software system that will be used to monitor and ensure the air quality of Bangladesh. The main purpose of the proposed AQM system is to improve air quality and to establish a low-cost solution for improving AQI by monitoring the air standard. A high-level diagram of the proposed AQM system is presented in Figure 1.

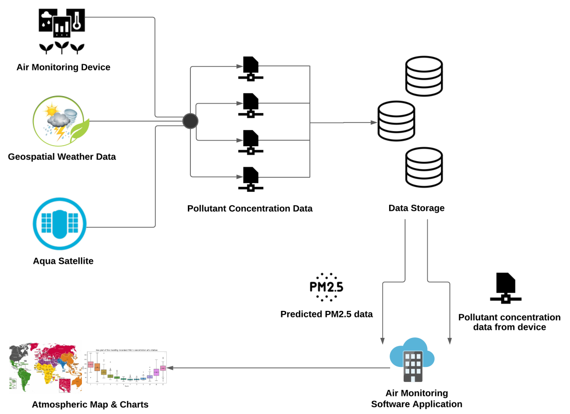

Figure 1: High-level Diagram of AQM.

Our proposed AQM system will collect data through different sensors which have been set in different regions of Bangladesh. Since it is not feasible to set the sensors in every single place, therefore, the system will also collect Aerosol Optical Depth (AOD) 550 nm data from Aqua Satellite for those areas which are not covered under sensors and geospatial weather data from Visual Crossing weather data bank. All the data collected from the sensors, Aqua Satellite, and the weather data banks will be stored in the cloud.

Data collected from different sensors are real-time data whereas we get the previous day's data from aqua satellite and the weather data banks. Atmospheric maps and charts will be generated based on the stored real-time data collected from different sensors. On the other hand, machine learning algorithms and techniques will be applied on the data collected from the aqua satellite, weather data banks and prediction analysis will be performed. After prediction analysis, atmospheric maps and charts will be generated and shown on the AQM system.

Figure 2 depicts the software system architecture of our proposed AQM system where the air quality data will be gathered from various sources i) Pollutant data from IoT based air quality monitoring device ii) Aerosol Optical Depth (AOD) 550 nm data from Aqua satellite iii) Geospatial weather data from Visual Crossing weather data bank. Data obtained from the IoT devices and the Geospatial Weather Data along with the satellite data will be stored in a Apache Cassandra NoSQL database. The real time data from the AQM devices will be stored in the database using MQTT protocol and Kafka connector whereas, the weather and satellite data in CSV files will be imported directly using Apache Cassandra. Real time data will be preprocessed using the real time stream processing of the Apache Spark and generate atmospheric maps and charts for different areas such as distinctive states, industrial zones, transportation routes. Similarly, our proposed system will operate a batch processing on the data collected form AQM devices, weather, and satellite using the batch processing tool of the Apache Spark. We will use Apache Spark MLib tool to obtain prediction analysis based on the preprocessed data and fit the machine learning models to forecast air quality index (AQI). Finally, the system will generate AQI-based atmospheric maps and charts for the betterment of polluting areas and route monitoring.

Figure 3 shows the communication overview of the MQTT and Kafka Connector used in our proposed AQM system. In the AQM system the AQM Devices will use MQTT protocol to feed sensor data to the MQTT Broker, then using Kafka MQTT connector

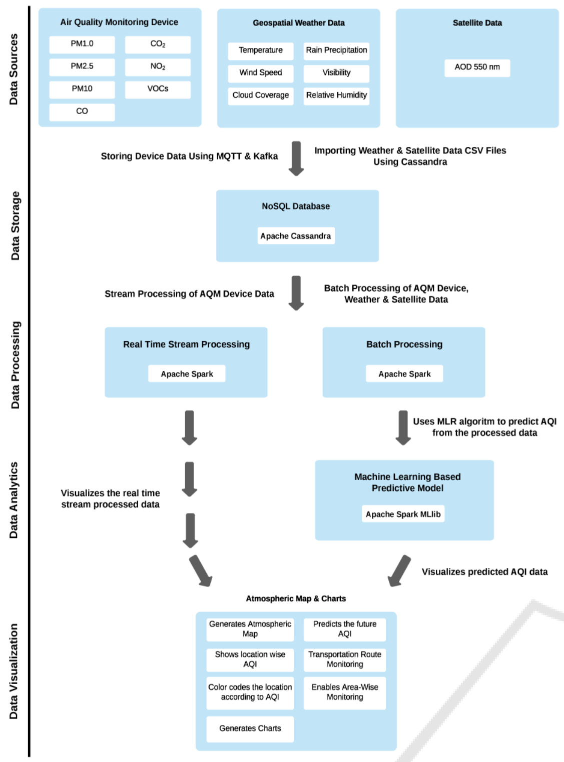

Figure 2: Software System Architecture of AQM.

Figure 3: Overview of the MQTT and Kafka Connector in our proposed AQM system.

the data will be sent to the Kafka Broker from the MQTT Broker. Finally, the sensor data will be stored in the Apache Cassandra Database from the Kafka Broker.

4.1 Data Collection

For the detection of contaminating toxic gases, it is necessary to outsource the sensors with greater accuracy that is available and inexpensive, keeping in mind the budget-friendly factor. After sourcing the sensors, it is vital to narrow down the suitable methodologies that will lead the proposed system to its outcome. To determine the most-fitted procedure, it is better to do a literature review to execute the goal and fix the steps. The stated process above will be executed according to the proposition.

According to the proposition design, the sensors will be mounted to multiple cars as nodes. When the car is in motion, the device takes readings from sensors every minute and uploads the data to the cloud storage with the location and time stamp. It will use in-built GSM module to upload the sensor's data to the cloud database server, then all the data will be processed and published on the AQM system portal along with temperature, relative humidity data and GPS information. We will collect data also from Aqua Satellite of Aerosol Optical Depth (AOD) 550 nm data for those places which are not covered by sensors. We will use the NASA Giovanni data visualization tool to get the satellite AOD 550 nm data. The available AOD 550 nm data which we will obtain are preprocessed using the Aqua Satellite's MODIS (Moderate Resolution Imaging Spectroradiometer) instrument. Aqua satellite travels from the South to the North Poles. The AOD 550 nm data is essentially the level-3 atmosphere daily global product (MYD08 D3), which is produced from four level-2 MODIS AQUA atmosphere products (MYD04 L2, MYD05 L2, MYD06 L2, and MYD07 L2). And, the geospatial weather data will be collected from Visual Crossing weather data bank.

4.2 Data Preprocessing

In our experiment, we started with data cleaning during the data preprocessing phase. Initially, we identified all the missing data, noisy data, and global outliers caused due to equipment malfunction and have inconsistencies with other recorded data using One-Class Support Vector Machine (SVM). One-Class SVM is used in one-class problems, in which all data belongs to the same class. In One-Class SVM, the algorithm knows the pattern of normal data therefore, when new data comes it can identify whether the data is normal or not. If not, the new data is classified as anomalous. After identifying, we removed all missing data, noisy data and global outliers. To accomplish the data integration, the acquired AOD 550 nm data from the Aqua Satellite, PM2.5 data from the ground station, and geospatial weather data were merged into a single coherent csv file. Data value conflicts such as different scales were removed during the extraction of the data as all the data were extracted in British Units. Later on, the data were split into a 70:30 ratio respectively for training and testing datasets.

Finally, data transformation was performed. Except for the AOD 550 nm data, all the integrated data was normalized by decimal scaling to two decimal points. Decimal scaling the AOD 550 nm impacted heavily in the prediction model thus it was discarded from decimal scaling. Similarly, in our proposed system we will be implementing the aforementioned data preprocessing procedure.

4.3 Reporting

One of the most important parts of our proposed data-driven air quality monitoring software system (AQM) is to generate atmospheric maps or graphical reports. The overall air quality and other pollutant data will be calculated and displayed in the form of atmospheric maps and charts which will help the decision-makers to analyze air quality and to take initiatives for improving the air quality. Our proposed AQM system will generate atmospheric maps for divisions, industrial areas, and transportation routes for both land and marine which are presented below. Using real data, we have generated multiple atmospheric maps and charts. Our generated atmospheric map for all the divisions of Bangladesh is presented in Figure 4.

In Figure 4, air quality index (AQI) is shown for all the divisions of Bangladesh such as Dhaka, Sylhet, Chittagong, Barisal, Khulna, Rajshahi, and Rangpur. All the divisions were color coded according to their individual mean AQI. We have also generated a demo atmospheric map for Tongi industrial area of Dhaka City which is presented in Figure 5.

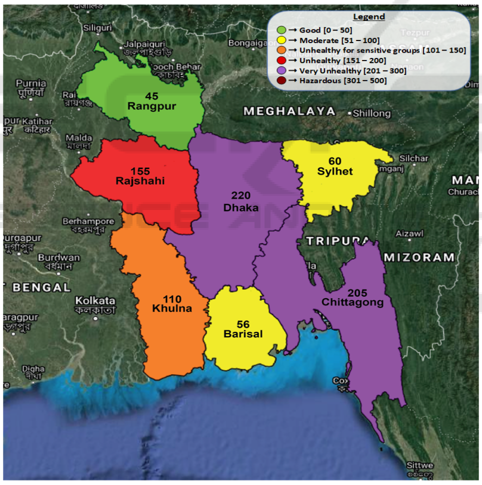

Figure 4: Overall Monitoring of Bangladesh.

The AQM system will also monitor the industrial areas which will greatly help to reduce the pollution in the environment. Figure 5 represents the Industrial area monitoring. In Figure 5, R1 represents the center of the industrial area where the level of pollution is highest, R2 represents the minimum distance from the center where all the sensor nodes are inside the industrial area, R3 represents the maximum distance from center where most of the sensor nodes are outside the industrial area, and R4 represents the $+\delta$ distance away from the center where all the sensor nodes will be outside the industrial area. We have divided the industrial area into circular areas and plan to place three sensor nodes in every single circle which will be used to read the AQI.

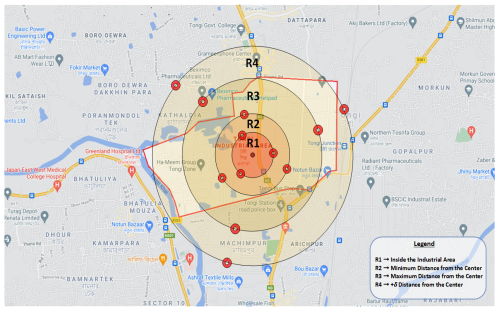

Figure 5: Industrial Area Monitoring.

Figure 6 depicts the mean AQI per station radius for the industrial area which is shown in Figure 5. The AQI is highest in the center R1 which means the concentration of pollution is highest in R1 and the AQI is falling as distance increases, indicating that air quality is improving.

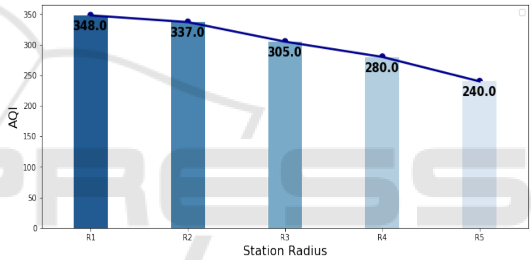

Figure 6: Bar Chart of Mean AQI Per Station Radius.

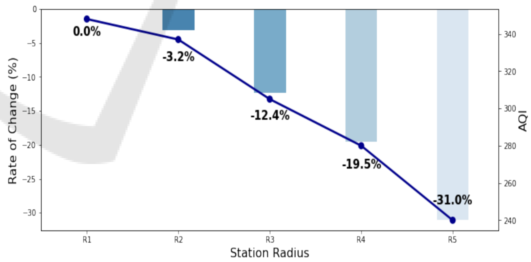

Figure 7: Change of Rate of AQI Per Station Radius.

Figure 7 shows the rate of change in the AQI per station radius for the industrial area depicted in Figure 5. The rate of change in the AQI increases negatively as distance increases.

5 RESULT AND DISCUSSION

The purpose of making the IoT-based device is to present a cheaper option and easily accessible to the citizens of the country, so that they become alert of the alarming situation which is not being addressed yet.

Our IoT-based device detects many of the pollutants like PM1.0, PM2.5, PM10, CO, CO_2, NO_2, Volatile Organic Compounds(VOCs), and helps us keep track of temperature and humidity.

However, in this experiment, the PM2.5 data were separately monitored to determine the pollutant's concentration level in our country for one year time span. To observe the data, we incorporated multiple PM2.5 detecting sensors by mounting them over the local transports which travel only through that specific route throughout the day. The recorded data is later uploaded to the cloud for each transportation stop, also known as stations. In the following parts of the discussion, the results are examined and user interfaces have been developed for analyzing station-wise, hourly, monthly, and season-wise data patterns. Like every other experimental result, some outliers have been distinguished into the data patterns which we will be covering in the following research below.

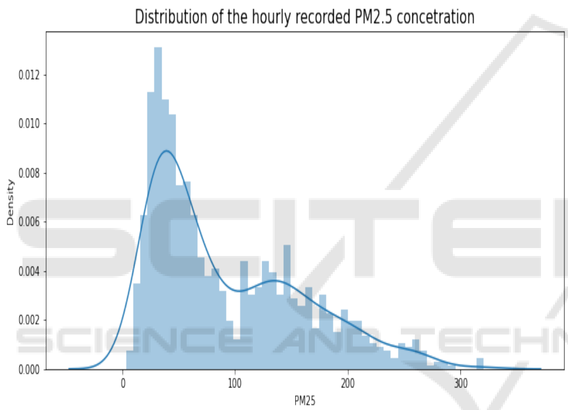

Figure 8: Data Distribution of PM2.5.

We have identified the data patterns in PM2.5 concentration readings. Figure 8 shows the data patterns in PM2.5 concentration readings found in the busy transportation route. The data was taken for one year continually round the clock. We may deduce from the distribution of PM2.5 data that the data is positively skewed. The majority of the PM2.5 concentration data falls on the lower bound in this positively skewed distribution, although a rise in PM2.5 concentration during the daytime leads the distribution to skew positively.

In our proposed system user interfaces will be available so that users can observe the data with respect to different times. Figure 9 presents the user interface for the Box Plot diagrams portraying the PM2.5 concentration behaviour in Bangladesh. The drop-downs depend on the time chosen by the user on the day, night, hourly, or monthly basis and the users are independent to choose the season of their choices

Figure 9: Box Plot User Interface.

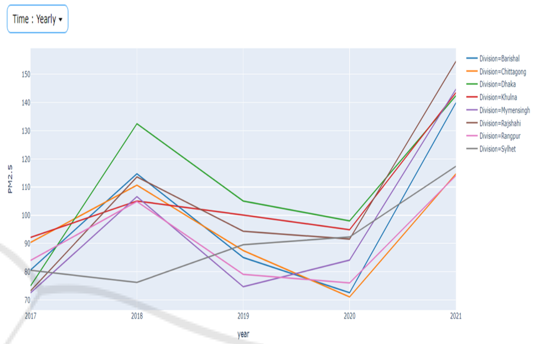

Figure 10: Division-Wise Time Based User Interface.

such as Winter, Spring, Summer, Autumn, or All Season.

There are different divisions in Bangladesh and different divisions have a different levels of PM2.5 concentration since the population, the number of transports, and factories are different. A division wise time-based user interface for PM2.5 concentration behaviour in Bangladesh has been presented in Figure 10. This user interface displays PM2.5 for eight divisions such as Dhaka, Khulna, Barishal, Chittagong, Rangpur, Rajshahi, Sylhet, and Mymensingh over the year. Since the PM2.5 data are being updated to the cloud according to the station, a station-wise box plot diagram demonstrated in Figure 11 has the most upper extreme and upper quartile in the most busy routes.

Figure 12 presents the hourly box plot diagram against PM2.5 and it has come to a surprise that the most generation of PM2.5 occurs at the earliest time of the day, evening and night-time. In the morning time, the routes are mostly used by citizens, during the evening working citizens take the road and at night-time, the paths are mostly occupied by trucks and pickup vans for carrying goods.

The monthly box-plot diagram of PM2.5 data in Figure 13 explains that the maximum production of PM2.5 occurs during January, February, March, November and December since the winter and au-

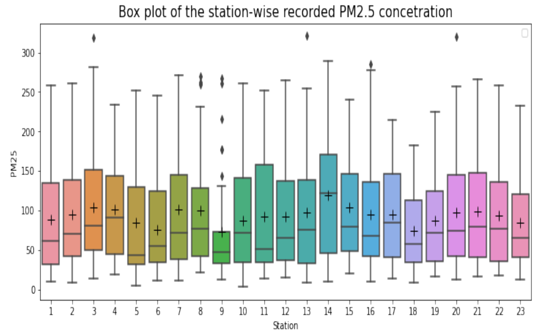

Figure 11: Box Plot of Station-Wise PM2.5 Data.

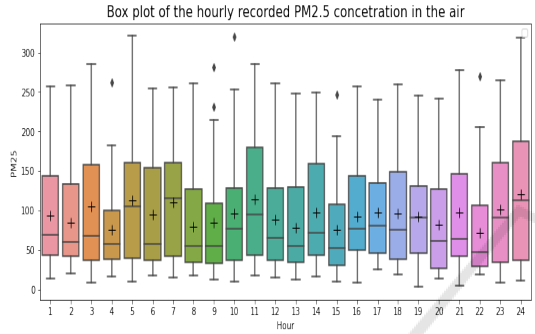

Figure 12: Box Plot of Hourly PM2.5 Data.

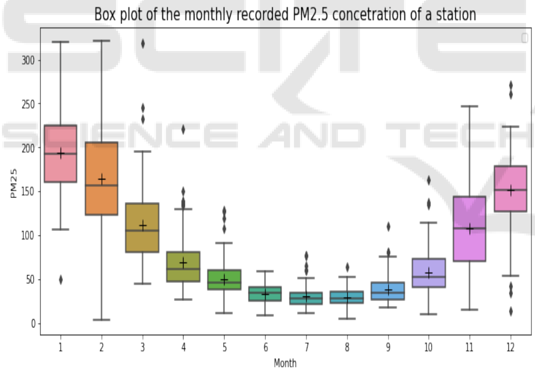

Figure 13: Box Plot of Monthly PM2.5 Data.

tumn seasons last within those months. The rest of the months has less concentration of this pollutant due to having the most amount of humidity and rain.

Figure 14 validates our point placed in Figure 13 where we justified how humidity and higher precipitation are responsible for less generation of PM2.5. The lower wind speed and shallower boundary layer height causes less substantial amount of PM2.5 as stated in (Dhaka et al., 2020).

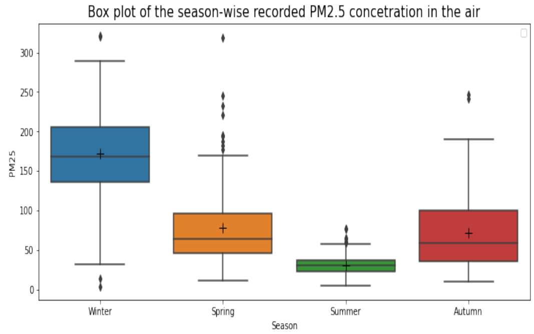

Figure 14: Box Plot of Season-Wise PM2.5 Data.

6 FUTURE WORK AND CONCLUSION

Bangladesh is a developing country, and it requires a massive amount of power, electricity, industrial usage with an uprising amount of infrastructure and technological advancement in the process of the country's establishment. With modernization, pollution comes in all kinds. Air pollution in Bangladesh is so high that a system is needed to monitor and control it. Our target is mostly to monitor the polluting areas like industrial zones, power plants and busy transportation routes. We are not against industrialization and modernization; our goal is to keep air pollution within a favourable amount.

The key concept highlighted in this research paper is air quality monitoring and assurance. We have performed an experiment for a year and our experimental results showed promising results. Therefore, we believe our proposed data-driven air quality monitoring software system (AQM) in this research work will help to monitor and ensure air quality. The proposed AQM system will monitor the air quality of different divisions, industrial areas, and transportation routes by showing atmospheric maps. We have presented different types of atmospheric maps in this paper that will be implemented in our proposed system.

We have collected air quality data for different areas of Bangladesh for one year period time from various sources and later analyzed them. Our experimental results have been compared to IQAir AirVisual Pro for different number of air quality indicators, including temperature, humidity, PM1.0, PM2.5, PM10.0, and CO_2 showed good results. Differences between our obtained result and IQAir AirVisual Pro are very low. In future, we will implement our proposed AQM software system in full fledged based on our current experiment. This AQM system will help to monitor and ensure the air quality of Bangladesh as well as decision-makers to take effective initiatives for improving and ensuring the air quality.

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