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Air Quality Predicting System for Colombo City using Machine Learning Approaches

MDCM Wijethunga#, WMKS Ilmini

Faculty of Computing, General Sir John Kotelawala Defence University, Sri Lanka

#chamithmayura1995@gmail.com

Abstract Air pollution is one of the biggest threats to the environment and human beings. Because of the meteorological and traffic factors, the burning of fossil fuels, industrial activities, power plant emissions acts as major effects for air pollution. Therefore, the governments of the developing countries like Sri Lanka are majorly focused on the effects of air pollution and they create the rules & regulations to minimize the level of air pollution. The main purpose of this study is to design a Machine Learning approach to predict air pollution status and levels in Colombo city by analyzing the previous dataset of $PM_{2.5}$ air pollutants. This paper presents, how previous researches predict the air quality level using different types of technologies and data collection methods used to analyze the air quality. And also, it demonstrates the design and implementation of an air quality predicting system, named as Air Quality Predicting System for Colombo City using Machine Learning Approaches. A simple Linear Regression-based supervised machine learning algorithm is using for the predicting process and it gives 8.578 average Root Mean Squared Error (RMSE) value with higher accuracy. This system will implement in both web and mobile platform and it will provide a better user experience. In Sri Lanka, there is no way to predict the air quality based on the above scenario. Most of the researchers have used PM2.5 air pollutant concentration levels as the main feature of their approaches due to the higher relationship to the Air Quality Index value. And also those researches are mostly based on supervised machine learning algorithms like Linear regression, FFNN, & SVM algorithms.

Keywords Machine Learning approach, PM2.5 air pollutant, air quality, Root Mean Squared Error

Introduction

Air pollution is one of the most highly affected environmental issues in any country. Definition of Air pollution is the contribution of one or many pollutant elements polluting the air in various quantities and periods which may affect human, and animal life cycles directly or indirectly.

Colombo, the capital city of the Western province as well as the commercial capital of Sri Lanka is one of the coastal cities with degenerate air quality and condition. Most of the studies have recorded, that air pollution levels in Colombo is increasing during the last few years with the increase of traffic index, development of industries both public and private sector, domestic and commercial activities inside the city. These types of air pollutant levels are highly effective for the weather and climate condition of the city. Therefore, the wind direction and water cycle will be changed due to the results of these air pollutant levels. Fine particulate matter ($PM_{2.5}$) acts as a major role along with other Air pollutant elements such as NO_2 and SO_2. Because it highly affects the humans' and animals' health when its level in the air is relatively high. $PM_{2.5}$ means tiny particles in the air that reduce visibility and cause the air to appear hazy when levels are elevated (Wei, 2014.). According to WHO" More than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed WHO limits"("Air pollution levels rising in many of the world's poorest cities," n.d.).

In Sri Lanka, according to the statistics of the National Building Research Organization (NBRO) measured results in 2017 show that pollutant levels are comparatively high in major traffic areas than in surrounding areas in the Colombo city ("National Building Research Organization (NBRO), 2017"). And it further tells annual average pollutant levels have increased rather than the recommended WHO guideline values for NO_2 and SO_2 within the Colombo city. For measuring these air pollutant elements, NBRO selected 19 sampling locations around the Colombo city and they monthly collect average levels of NO_2 and SO_2 gases and they collect data about 24-hourly average levels of $PM_{2.5}$.

According to the statistical results of NBRO, incrementally increased pollutant levels are recognized by the WHO. Therefore, the need for the Air quality Predicting System is to implement predictive air pollution levels in the future by analyzing the present results. By using these types of systems, authorities of the relevant fields can get decisions about future planning without any hesitation about the air pollution issues.

Therefore, this paper presents a way to predict air quality details from using previous air pollutant data and machine learning approaches. By implementing the "Air Quality Predicting System for Colombo city", users can able to understand the effectiveness of the air pollutants in Colombo city and authorities can able to adapt to the situation by introducing a different type of rules and regulations.

The rest of this paper is created as follows. Section 2 describes related works and existing systems regarding the field. Section 3 describes the structure and the processes of the proposed Air Quality Predicting System for Colombo city. Section 4 describes the conclusion of the paper and section 5 describes the future work of the ongoing system.

With the rapid development of the Machine Learning (ML) approaches, most of the manual systems are turned into the ML-based automated systems due to the accuracy of the ML approaches. Therefore, most of the manual air pollution systems are turned into the ML-based air pollution monitoring systems with containing prediction features. For the study about the usage of ML approaches in the above systems, this paper focused on nine ML algorithms namely Support Vector Machine, Support Vector Regression, Logistic Regression, Autoregression and Autoregressive nonlinear neural network, State of Art machine algorithm with the linear regression algorithm, Alternating Decision Tree, Random Forest algorithm, Feedforward Neural Network, Extreme Learning Machine for both data classification and prediction parts.

Dan Wei (Wei, 2014.) has implemented the Air pollution prediction system using the machine learning approaches in Beijing, China. The aim of the project was the prediction of air pollution levels in Beijing city with the ground data set. According to the paper, it performed machine learning techniques such as Support Vector Machine (SVM) and Neural Network, to predict the air pollutant level of the $PM_{2.5}$ based on a dataset containing Temperature, Wind Speed, Relative Humidity, Traffic index, the Air quality of previous day. The training data set has 322 observation points and the test data has 55 points. output data was categorized as one or zero. One refers to the high pollution level and zero refers to the low pollution level. The total number labelled as zero is 103, while the remaining 274 points are labelled as 0. They measured these levels, based on the values of the $PM_{2.5}$ and he simplified the $PM_{2.5}$ level into a binary digit to classify the $PM_{2.5}$ level into "High" (> 115 ug/m3) and "low" (<=115 ug/m3). The value is chosen based on the Air Quality Level standard in China, which set 115ug/m3 to be mild level pollution. To measure these levels, he used three supervised learning algorithms were used: logistic regression, Naïve Bayes Classification & Support Vector Machines (SVM). Among these algorithms, he selected SVM as the best classifier for this case based on the prediction results. And also, he mentioned, "the data set in that project is not large enough, Because of the Air quality is a long-term formed problem and it is better to use a large data covering a variety of years and locations".

Aditya C R and others (Vidya Vikas Institute of Engineering and Technology et al., 2018) have introduced the Air Pollution monitoring system with both detection and prediction functions to predict $PM_{2.5}$ level and detect air quality based on a dataset consisting of daily atmospheric conditions in a specific city. As they said in the paper, "there are applications that display the real-time $PM_{2.5}$ levels, while some show the forecast of a particular day. However, $PM_{2.5}$ levels for dates after a week is not forecasted". Therefore, they proposed this system to do both two tasks (detection and prediction) based on the $PM_{2.5}$ level by using the dataset that contained Temperature, Wind Speed, Dewpoint, Air pressure, $PM_{2.5}$ Concentration(ug/m^3), and previous results. According to the paper they have selected two machine learning algorithms to detect and predict the Air pollution level; (i) Logistic Regression Algorithm used to detect the levels of $PM_{2.5}$ based on the data values and, (ii) Autoregression is used to predict future values of $PM_{2.5}$ based on the previous $PM_{2.5}$ readings. As they mentioned in the paper, the reason behind selecting these algorithms, results depict Logistic Regression best for that system with the mean accuracy and standard deviation accuracy to be 0.998859 and 0.000612 respectively. Finally, they think this system will provide common people as well as those in the meteorological department to detect and predict pollution levels and take the necessary action following that.

C.S. Elvitigala and B.H. Sudantha (Elvitigala and Sudantha, 2017.) have developed another system for monitoring Air pollution by using datasets they collected using IoT devices with a sensory array. This system is proposed to use in the city of Colombo, Sri Lanka. They aim is to give a complete solution for monitoring and analyzing air pollution. Because of this, still, this process is done by using the manual procedure and it cannot forecast the air pollution level of the future with evidence. First, they have categorized air pollutants into three sections; (i) Primary pollutants, (ii) Secondary pollutants, and (iii) Minor Air pollutants. After that, they analyzed those pollutants and selected Carbon monoxide (CO) as the air pollutant for measuring the level of air pollution in Colombo city. The proposed system includes four main parts; (i) The microcontroller with module connection slots, (ii) The wireless communication device through the WiFi module. (iii) The data classifying and storing server. (iv) Machine learning and graphing software. They collect data about CO concentration by using multiple IoT devices which are in the different locations around the Colombo. They have done the prediction part of the system by using a linear regression algorithm. Finally, these predicted data are visualized by using the graph that was created from the TensorFlow (TensorFlow Core | Machine Learning for

Beginners and Experts, 2020) machine learning packages. As they said in the paper, "The system is a complete low-cost solution to monitor the environment pollution as the sensor devices are low cost to buy and easy to set up in a given environment". And also, they think, this system will help the government to develop the Colombo city with environmentally friendly in the future.

Mahmoud Reza Delavar and others (Delavar et al., 2019) have proposed the Air pollution prediction system for Tehran, Capital of Iran intending to predict the density of air pollutants (Carbon monoxide (CO) and Nitric oxide (NO_x) in industrial locations around the city. And also, they used $PM_{2.5}$ and PM_{10} air pollutant elements used as an input for the machine learning algorithms. According to the paper, they used two types of datasets for predictions; first dataset, the refined meteorological data, and unrefined pollutant data, and in the second dataset, refined meteorological data and pollutant data with the attributes, air pressure, temperature, humidity, rainfall and wind speed. Datasets have been created using satellite imagery and ground sensors. They have been used artificial neural network (ANN), the nonlinear autoregressive exogenous Neural Network, geographically weighted regression (GWR), and support vector regression (SVR) were used to prediction process. By using the results, for each of these algorithms they selected autoregressive nonlinear neural network as a prediction model for the above system. Because it is the most reliable and accurate algorithm for the project. They mentioned in the paper errors can be occurred when the modeling and analysis processes. Therefore, they used the Savitzky–Golay filter to reduce the noises and errors.

Gaurav Pandey (Pandey et al., 2013) has implemented another air pollution predicting approach which is used in Hangzhou, China. The study aims to analyze the collected data from the observations of weather and traffic variables and using machine learning techniques for the prediction of submicron-sized ambient air pollutants like $PM_{1.0}$ and Ultra Fine Particles (UFP). According to the journal paper, "this paper is the first study on predicting levels of submicron particles based on weather and traffic factors using a systematic classification approach". They processed these collected data by using twenty-five classification techniques to predict discrete levels of UFP and $PM_{1.0}$ concentrations. They used a wide variety of classifiers, such as Neural Network, Bayesian Network, SVM, and Decision Trees (and their parameters). According to the results of the project, Tree-based classifiers such as Alternating Decision Tree (ADTree) and Random Forests (RFs) produced the most accurate predictions for $PM_{1.0}$ and UFP air pollutants.

Ilias Bougoudis and others (Bougoudis et al., 2016) have introduced a slightly different approach called, "Easy Hybrid Forecasting (EHF)". It can predict the level of air pollutants without using real-time measurements from sensors or any other devices. The paper aims to develop an innovative, cost-effective, accurate air pollution predicting system with an extreme air pollutant value. Data for datasets were collected from four measurement stations. Datasets contained hourly measurements of the following air pollutants: CO, NO, NO_2, O_3, SO_2 for the period of 2000–2012. They used Fuzzy C means, Neural Gas Artificial Neural Networks (NGANN), Unsupervised Self Organizing Maps (UNSOM), and Semi-Supervised Self Organizing Maps (SEMSOM) for the clustering the data. After that they tried several algorithms for regression analysis of the system such as Random Forests, k-Nearest Neighbor (k-NN), Feed Forward ANN(FFANN), Radial Basis Function ANN and Support Vector Machines like e-SVR) and Linear Regression. By considering the results of each of these regression algorithms, the FFANN algorithm gave the most reliable results for the input variables. As they said in the paper, this system can provide highly accurate predictive details of air pollution levels in a specific city by using the mobile phone without using any expensive device or software.

Ayaskanta Mishra (Mishra, 2018.) has introduced another air pollution forecasting system with using IoT device to discover the best prediction and forecasting model for analyzing the effect from the air pollutants like O_3, NO_2, SO_2, and CO. This proposed IoT device used to collect real-time data, to expand the Machine Learning model. And also, they used authorized open-source datasets from the US government to train the model for giving better prediction results. They have used three machine learning algorithms, such as Linear Regression, Random Forest, and XGBoost for predictive modeling and Autoregressive integrated moving normal (ARIMA) model for time-series forecasting to find out the best algorithm for calculating Air Quality Index (AQI) for the above air pollutants. According to the results of the performance analysis, the Random Forest algorithm gave the most reliable results.

Jan Kleine Deters and others (Kleine Deters et al., 2017) introduced a new model to analyze the air quality of the Quito, the capital of. According to the paper, they planned to predict the concentrations of $PM_{2.5}$ by using machine learning approaches based on six years of meteorological and pollution data. They collected data from two air quality monitoring sites located in Quito (Cotocollao and Belisario). And also, they collected data about wind speed and direction in 6 years to create the classification model with more reliability. They have used Supervised learning algorithms (Boosted Trees (BTs) and Linear Support Vector Machines (L-SVM)) to create models for the classification task. All computational and visualization parts are done by using Matlab. BT, L-SVM, and Neural Networks (NN) are used to process regression analyses for both sites. After that, they have used the Convolutional Generalization Model (CGM) for optimizing the regression. Results are shown, CGM performs it's best in the regression analyses by comparing it with other algorithms in both sites.

Bing-Chun Liu and others (Liu et al., 2017) have discussed another approach to check out the urban air quality of China. It is aimed to present a new model for the Air Quality Index (AQI) forecasting using collaborative multiple city air quality data as input. They selected Beijing, Tianjin, and Shijiazhuang in China for their research area. They have collected raw data such as daily air pollutant concentration data from the China Environmental Monitoring Center and daily weather conditions and meteorological data from the China Meteorological Administration. These collected data categorized into 12 characteristic variables including the six air pollutants concentration namely "$PM_{2.5}$", "PM_{10}", "SO_2", "CO", "NO_2" and "O_3"; five variable weather conditions namely "minimum temperature", " maximum temperature "," weather ", "wind direction " and " wind power "; and the last day's observed AQI values. They have used one single machine learning algorithm called Support Vector Regression (SVR) for predicting AQI and regression analyses. According to the results, SVR is less prone to overfitting than Artificial Neural Networks (ANNs) due to the presence of regularization parameters.

Jiangshe Zhang and Weifu Ding (Zhang and Ding, 2017) have proposed another approach to predict the Air pollutant concentration level in Hong Kong. They have used the Extreme Learning Machine (ELM)

Table 1Classification of Researches based on Technology/Algorithm

No.	Research paper	Used Technologies/ Algorithms	Comments
1	(Wei, 2014.)	SVM	lowest test error, 9.09%, and the 0.722 precision
2	(Vidya Vikas Institute of Engineering and Technology et al., 2018)	Logistic Regression Algorithm (detection process) & Autoregression Algorithm (prediction process).	mean accuracy-0.998859, standard deviation-0.000612 and Mean Squared Error (MSE) to be 27.00
3	(Elvitigala and Sudantha, 2017.)	Linear regression algorithm	Only uses the Linear regression algorithm, because they use linear type data from IoT devices & sensor arrays.
4	(Delavar et al., 2019)	Autoregressive nonlinear neural network (NARX)	NARX- 40% increase in R2 and a 94% decrease in RMSE occurs.
5	(Pandey et al., 2013)	ADTree and Random Forests	Accuracy rate-98.6%
6	(Bougoudis et al., 2016)	FFANN algorithm for regression	comparing the Coefficient of Determination (R^2) values the is much high effort in FFANN
7	(Mishra, 2018.)	Random Forest algorithm	Avg. MAE: 0.0083 Avg.RMSE: 0.0316
8	(Kleine Deters et al., 2017)	BTs, L-SVM for classification & CGM for regression	CGM performs best in the regression analyses
9	(Liu et al., 2017)	SVR	MAPE and RMSE value less than 12
10	(Zhang and Ding, 2017)	ELM	RMSE-14.3, R^2 0.71

algorithm for predicting the Air pollutant levels by analyzing data from eight quality parameters in two monitoring stations (Sham Shui Po and Tap Mun) in Hong Kong for six years period. As well as they have tested other supervised algorithms (Combined Machine Learning Algorithm, PCA-RBF, Neurocomputing, and Feedforward Neural Network Based on Back Propagation (FFANN-BP)) by training datasets, but due to the drawbacks of each of these algorithms ELM performs well in training datasets both quantitatively and qualitatively with minimum root mean square error values.

Observing each of the above-mentioned research studies, most of them give a higher successful accuracy rate for their systems by using ML approaches. Table 1.0 shows the summarized classification of researches based on technology.

According to Table 1.0, most of the researchers are interested in using the SVM/SVR algorithm, Regression analysis, and Random Forest algorithm for their predictions due to the accurate results.

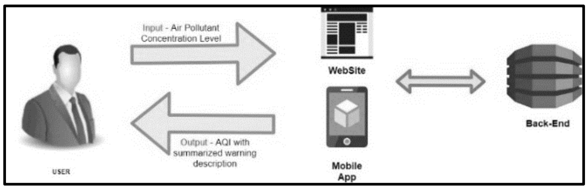

Figure 1. overall workflow diagram

Anatomy of Air Quality Predicting System for Colombo City

This section discusses the design and implantation of the Air Quality Predicting System up to now. Because at this moment the system is in its development stage. The proposed system aims to predict the future Air Quality Index (AQI)/Level and provide the summarized warning description by considering the present & past data of the air pollutants. The system can predict the quality of the air by getting $PM_{2.5}$ air pollutant concentration levels as input. After providing those data through web or mobile interface to the system, the back-end of the system analyzes inputs and provides summarized air quality warning description with Air Quality Index (AQI) value to the user as an output. Figure 1 shows the overall workflow diagram of the system to understand the surface structure of the system.

The inside operations and technologies which are used to develop the system can be explained by identifying 5 major development phases namely Data collection and analyzing phase, Back-end development phase, Front-end development phase, Back-end & Front-end connection establishment phase, and User notification method development phase. The integration of these development phases can demonstrate the overall structure of the system and its functionality. The following sections give a brief description of each development phase.

A. Data Collection and Analyzing Phase

First, $PM_{2.5}$ and AQI values have been collected from the US Embassy of Sri Lanka and the National Building Research Organization. $PM_{2.5}$ dataset contains 20789 of raw data without any null values. And those collected data have to do correlation analysis to check the relationship between air pollutant concentration data with AQI value. So that provides a basic explanation about how well those data relate to another. At this moment, only did the correlation analysis for the $PM_{2.5}$ dataset with AQI value and it gives a higher value for the relationship. Figure 2 shows the result of that analysis study.

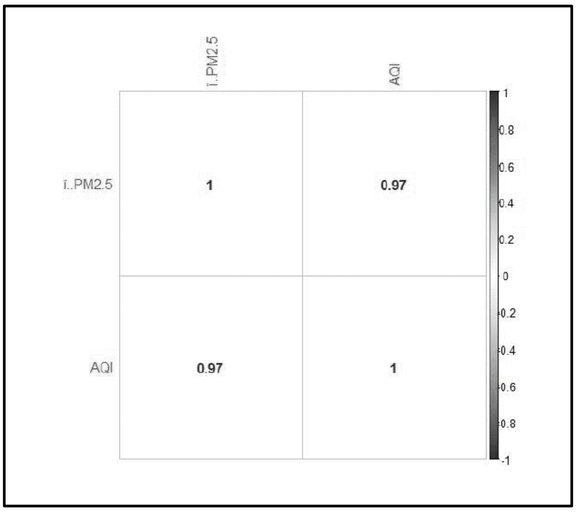

Figure 2. correlation analysis for $PM_{2.5}$ dataset and AQI value

B. Back-end development phase

In the back-end development stage, Simple Linear Regression-based supervised machine learning algorithm is using for the predicting process combining with sklearn (Getting Started — scikit-learn 0.23.1 documentation, 2020) and Pandas (Getting started — pandas 1.0.5 documentation, 2020) libraries. It predicts AQI value based on the $PM_{2.5}$ concentration value. Firstly, train the model with preprocessed data and test the model using those data. According to the study of related systems, the Simple Linear Regression algorithm has provided the highest accurate prediction results for those types of input data. Figure 3 shows the high-level architecture of the back-end part of the system.

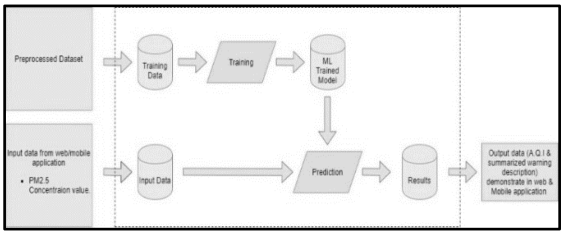

Figure 3. high-level architecture of the back-end part of the system

In the Simple Linear Regression algorithm, it used Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE) as a performance measurement of the trained algorithm to identify the accuracy of the algorithm. Table 2 represents those results for the given dataset.

Table 2. Performance measurements

performance measurement	Result
MAE	4.231920905485698
MSE	73.5694107009268
RMSE	8.577261258754266

According to the above performance measurements it produces more acceptable predicted values for given input values rather than other types of models. To prove that statement, It used,20% of data from the dataset for test the trained algorithm, and those results are shown in Figure 4.

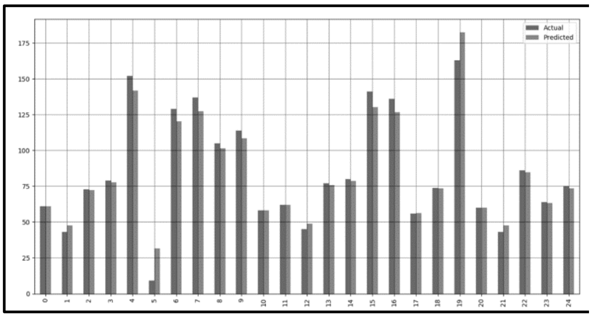

Figure 4. comparison of Actual and Predicted values of the first 25 data attributes

C. Front-end development phase

The front-end development stage mainly uses an Angular framework for developing the web interface of the system using a firebase realtime database (Firebase, 2020) for implementing the user authentication process. So the system provides a role-based access control process to control access of admin and on the website. The website contains four main webpages namely "Home", "Inputset", "Dashboard", "About US". According to the role-based access control process, Admin can only access the "Inputs" webpage to the input Air pollutant concentration values. "Dashboard" page shows the AQI value and the summarized warning description to the users to understand the air quality of the present time.

The Android mobile application of the system has been developed by using the Flutter framework with the use of the Webview concept (The Power of WebViews in Flutter, 2020). Webview concept provides web applications to run inside the android application. Figure 5 shows the implementation of the dashboard page of the Android mobile application.

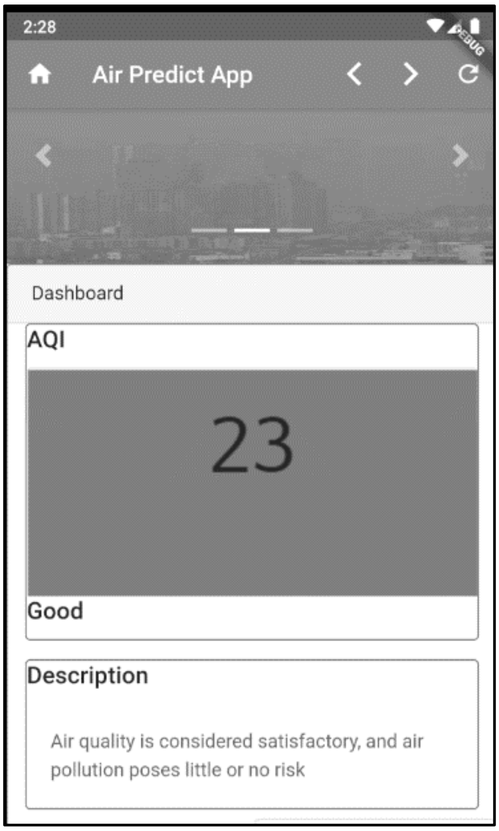

Figure 5. Dashboard page of Android mobile application

D. Back-end & Front-end connection establishment phase

In this phase of the development process, the Flask (Welcome to Flask — Flask Documentation (1.1.x), 2020) web framework is proposed to establish the connection between the back-end and the front-end of the system.

E. User notification method development phase In this phase

The system uses a push notification method to implement the notification process. It works with the mobile application based on the push notification concept with flutter and the firebase database. The push notification method needs only a preinstalled android app on the mobile phone. Then if the mobile phone has an internet connection, the user gets a notification from the mobile app when the admin enters the above input values to the system. Figure 6 shows the implementation of the notification method using a mobile application.

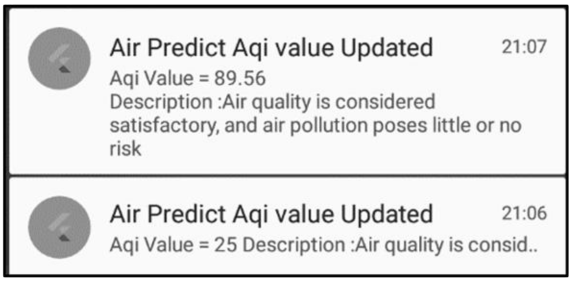

Figure 6. notification method using a mobile application

Results Discussion and Conclusion

This paper presented the design and implementation of the ongoing developing system of the "Air Quality Predicting System for Colombo city" with the reviewing of existing systems and other related works to find out the best ML model with a suitable data collection method to predict the air pollution level in a specific city. Most of them have collected meteorological data from the Meteorological Department of their countries and some of them used datasets, they collected through IoT devices. But, some of these studies have shown the drawbacks of this type of system are facing in practice. Some of the datasets in the above research works are not large enough to train the algorithm and the Unavailability of some data cause some errors in the final air pollution prediction. After reviewing these systems, PM2.5 air pollutant concentration level has been provided the higher accuracy for the prediction of the AQI value. Most of these PM2.5 datasets have used regression type algorithms to predict the AQI value. Therefore the "Air Quality Predicting System for Colombo city" system has been used those data as an input to the system to predict AQI. Previous studies like, Jiangshe Zhang and Weifu Ding (Zhang and Ding, 2017) have used the Extreme Learning Machine (ELM) algorithm for predicting Air pollutant levels by analyzing data from eight quality parameters. But they got RMSE value = 14.3 and in our machine learning model have recorded RMSE = 8.58. And also, Bing-Chun Liu and others (Liu et al., 2017) have aimed to present a model for the Air Quality Index (AQI) forecasting using collaborative multiple city air quality data as input and they used SVR algorithms for the predictions. They got RMSE and MAPE values less than 12. So, in our model, it has recorded RMSE and MAE values less than 9. Therefore, those points have shown, that our model is performed well on the PM2.5 air pollutant concentration dataset and the simple linear regression algorithm. According to the linear type relationship between PM2.5 value & the AQI value, it used a Simple Linear Regression type algorithm due to the lowest RMSE value with comparing to other types of machine learning approaches.

Future Works

Still, the "Air Quality Predicting System for Colombo city" system is in the development stage. Therefore, it has to make a connection between the back-end and the front-end of the system for getting user inputs from mobile or web application and implements predicted AQI value with the summarized warning description on the dashboard page. And finally, it should evaluate the predicted results with the actual values to confirm the creativeness of the system.

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Author Biographies

MDCM Wijethunga is a final year Software Engineering undergraduate of the Faculty of Computing, General Sir John Kotelawala Defence University.

WMKS Ilmini is a probationary lecturer of the Department of Computer Science, Faculty of Computing, General Sir John Kotelawala Defence University. Her research interests include Artificial Neural Networks, Deep Learning, Affective Computing, and Data Mining. She has produced more than 10 referred international and local publications to her credit. And also, she has won the Merit Award for Personality Detector in National ICT NBQSA 2019.