INSTITUTIONAL AQI FLAG HOISTING PROGRAM

A Project Report

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in Partial Fulfilment For the Award of

the Degree of

BACHELOR OF TECHNOLOGY

COMPUTER SCIENCE & ENGINEERING

Under the Guidance of

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PARUL UNIVERSITY

CERTIFICATE

This is to Certify that Project - 2 (203105400) of 7^{th} Semester entitled "INSTITUTIONAL AQI FLAG HOISTING PROGRAM" of Group No. PUCSE535 has been successfully completed by

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"The single greatest cause of happiness is gratitude."

-Auliq-Ice

I owe **ARUN CHAUHAN** for teaching me to love learning and strive for constant development in addition to providing knowledge. My academic and personal aspirations have greatly benefited from their mentoring, and I will always treasure the teachings I received both inside and outside of the classroom.

I appreciate you being such a great teacher and having such a significant good influence on my life.

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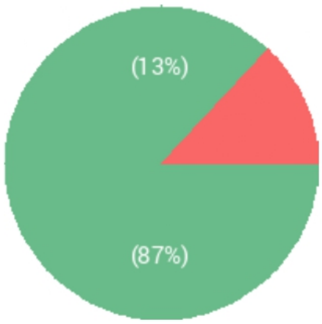
Abstract

Indian cities struggle with some of the highest ambient air pollution levels in the world. While national efforts are building momentum towards concerted action to reduce air pollution, individual cities are taking action on this challenge to protect communities from the many health problems caused by this harmful environmental exposure. In 2017, the city of Ahmedabad launched a regional air pollution monitoring and risk communication project, the Air Information and Response (AIR) Plan. The centerpiece of the plan is an air quality index developed by the Indian Institute of Tropical Meteorology's System for Air Quality and Weather Forecasting and Research program that summarizes information from 10 new continuous air pollution monitoring stations in the region, each reporting data that can help people avoid harmful exposures and inform policy strategies to achieve cleaner air. This paper focuses on the motivation, development, and implementation of Ahmedabad's AIR Plan. The project is discussed in terms of its collaborative roots, public health purpose in addressing the grave threat of air pollution (particularly to vulnerable groups), technical aspects in deploying air monitoring technology, and broader goals for the dissemination of an air quality index linked to specific health messages and suggested actions to reduce harmful exposures. The city of Ahmedabad is among the first cities in India where city leaders, state government, and civil society are proactively working together to address the country's air pollution challenge with a focus on public health. The lessons learned from the development of the AIR Plan serve as a template for other cities aiming to address the heavy burden of air pollution on public health. Effective working relationships are vital since they form the foundation for long-term success and useful knowledge sharing beyond a single city.



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Chapter 1

Introduction

1.1 Air Pollution as A Public Health Concern in India

Recent comprehensive analyses estimate that globally, exposure to ambient air pollution causes 4.1 million premature deaths each year, largely due to the impacts of small particles on the progression of cardiovascular disease [1]. Of this total, two-thirds of the burden falls in Asia, where ambient concentrations of fine particulate matter (PM2.5, particles of aerodynamic diameter 2.5 microns) are highest [2–7]. In India, exposure to PM2.5 causes more than half a million premature deaths each year [2,7], and a study of 2016 data found that 14 Indian cities ranked in the top 20 globally for the worst pollution levels [8]. Robust epidemiological research over the past two decades confirms that both acute and chronic exposure to ambient air pollution, especially PM2.5, causes many adverse health effects [9–13]. For example, chronic exposure to PM2.5 is associated with increased risk of premature mortality, stroke, heart disease, lung cancer, asthma, and other respiratory diseases [6,11,14–18]. Cities are increasingly working to disseminate information on air pollution levels and associated health risks with the aim of reducing harmful exposures at the population level [19–21]. One key tool to communicate such data is the air quality index (AQI), which summarizes air quality conditions in a single metric and distills information on associated health risks in a way that is accessible to the public [22,23]. Recent research indicates that AQI systems, when accompanied by emissions reductions on the most polluted days, could help cities achieve cleaner air and tangible health benefits [24]. In 2015, a steering committee organized by the Ministry of Health and Family Welfare issued a comprehensive report that examined India's air pollution problem from a public health perspective. The report recommended the deployment of both AQI systems and targeted health messaging at the local level as a strategy for addressing the significant health risks posed by polluted air [25]. At the state level, the Gujarat Pollution Control Board

(GPCB) is active in addressing air pollution and is developing a long-term clean air plan [26] in parallel with the Ministry of Environment, Forests, and Climate Change (MOEFCC) National Clean Air Programme on air pollution monitoring and control [27]. Complementing these efforts, the city of Ahmedabad is among the first cities in India where city leaders, state government, and civil society are proactively working together to address the air pollution challenge through an exposure mitigation plan centered upon an AQI [28–30].

1.2 Economic Growth and Climate Change

Continuing economic growth in India and associated demand for energy need not exacerbate the air pollution problem; indeed, cleaner air achieved through the deployment of both renewable energy sources (e.g., wind and solar power) and control technologies (e.g., flue gas desulfurization at thermal coal-fired power plants) improves worker productivity, health, and overall quality of life [31–36]. Air quality management requires appropriate control technologies and multi-pronged strategies deployed in targeted sectors. For example, the expansion of India's middle class is expected to increase the share of two-wheelers and private automobiles on already congested and highly polluted roadways [37–41]. Progressively strengthened vehicle fleet emission standards [42], in tandem with expanding public transportation systems [43,44] and active transportation options [45], can help reduce pollution emissions from the transportation sector [46]. Climate change is expected to directly and indirectly exacerbate already high concentrations of air pollution across India. In addition to PM2.5, ground-level ozone (O3) is a health damaging air pollutant [47–49]. The chemical formation of O3 in the troposphere is temperature-dependent, and higher average surface temperatures are generally expected to worsen O3 pollution at mid-latitudes worldwide [50,51]. The burning of solid biomass fuels to meet basic energy needs also contributes to high levels of both indoor and outdoor air pollution and exacerbates climate change [5,10,25,32,52,53]. The increasing frequency of extreme heat events driven by climate change [54,55] could also affect future energy demand [56] and air pollution levels [57]. Increasingly, the use of air conditioning is both a method to relieve exposure to oppressive heat and a status symbol of economic advancement in India [58]. Researchers estimate that sales of air conditioners are growing 20future electricity demands for cooling could exacerbate polluting emissions from coal-fired power plants [59]. Given the current toll of air pollution and the threat of this burden increasing in the future, forward-thinking planning is vital for safeguarding public health. In particular, improved monitoring and forecasting of air quality in Indian cities and communication of this information to the public can help motivate policies to achieve a cleaner energy future, improved air quality, and a reduction in rates of air pollution-related disease and premature death [25].

1.3 Leadership on Extreme Heat Preparedness

Efforts to better monitor regional air quality and communicate information about pollution and health risks in build on the foundation established by the Heat and Climate Study Group, which established an evidence-based Heat Action Plan (HAP) and extreme heat early warning system for the city [60]. This plan, developed in response to a 2010 heat wave linked to hundreds of deaths [54], has become a template for thirty other Indian cities and eleven states working to mitigate the health risks of extreme temperatures for vulnerable populations [61]. The HAP, supported by temperature forecasts from the India Meteorological Department (IMD), helps to coordinate government agencies and public outreach activities to reduce the health risks posed by extreme heat. In 2016, the group commenced discussions to establish a parallel monitoring and risk communication system for air pollution in the city. This manuscript describes efforts related to the air pollution work; for more background information on the establishment of the HAP.

1.4 Objectives

The overall goal of this project was to develop a health-based strategy for monitoring and communicating information about urban air pollution in the region and the new AQI, in the form of the Air Information and Response (AIR) Plan. Specifically, the goals of this project were to: (1) Assess the current state of the regional air pollution and health evidence base an AQI; (2) improve public awareness of the air pollution problem as it relates to health; (3) identify and protect especially vulnerable groups from the health threats posed by air pollution; (4) build capacity in the medical and public health sectors for promoting health-protective strategies on air pollution; and (5) identify the future mitigation and exposure control and reduction measures with key partners from leading local institutes. To help achieve these objectives, experts were consulted in New Delhi and other cities in India and internationally to engage in knowledge exchange and information sharing on air quality monitoring policies, epidemiologic methods, and communication strategies. The goals of this paper are to provide information on the first comprehensive air quality health risk communication and exposure mitigation plan in an Indian city, describe the challenges encountered, and highlight project aspects that may be adapted to other settings. The approach is outlined in the Methods section and project accomplishments to date are described in the Results section. The particular challenges of this work are analyzed in the Discussion section, as are the implications for other settings seeking to address the major threats to health posed by ambient air pollution.

Chapter 2

Literature Survey

2.1 Predict and Measure Air Quality Monitoring System Using Machine Learning (Turkish Journal of Computer and Mathematics Education Vol.12 No.2(2021), 2562-2571).

This article looks at how artificial intelligence can help expect the hourly consolidation of air toxinSulphur ozone, element matter (PM2.5), and Sulphur dioxide. As one of the most excellently procedures, AI can efficiently prepare a model on a large amount of data by using large-scale streamlining computations. Even thoughseveral works use AI to predict air quality, most of the earlier studies are limited to long-term data and easilyinstruct regular relapse designs (direct or nonlinear) to expect the hourly air pollution focus. This paper suggestsadvanced analysis to simulate the hourly environmental change focus based on previous days' weather-related data by calculating the expectation for more than 24 hours as an execute multiple tasks learning (MTL) issue. This allows us to choose a suitable model with a variety of regularization strategies. We suggest a useful regularization that maintains the assumption patterns of concurrent hours to be nearby to each other, and we evaluate it to a few common MTL expect completion such as normal Frobenius standard regularization, normal atomicregularization, and '2,1-standard regularization. Our tests revealed that the suggested boundary declining concepts and constant hour-related regularizations outperform open product relapse models and regularizations in terms of execution.

2.2 Development of Ahmedabad's Air Information and Response (AIR) Plan to Protect Public Health (International Journal of Envirnomental Research and Public health).

In 2017, the city of Ahmedabad launched a regional air pollution monitoring and risk communication project, the Air Information and Response (AIR) Plan. The centerpiece of the plan is an air quality index developed by the Indian Institute of Tropical Meteorology's System for Air Quality and Weather Forecasting and Research program that summarizes information from 10 new continuous air pollution monitoring stations in the region, each reporting data that can help people avoid harmful exposures and inform policy strategies to achieve cleaner air. This paper focuses on the motivation, development, and implementation of Ahmedabad's AIR Plan. The project is discussed in terms of its collaborative roots, public health purpose in addressing the grave threat of air pollution (particularly to vulnerable groups), technical aspects in deploying air monitoring technology, and broader goals for the dissemination of an air quality index linked to specific health messages and suggested actions to reduce harmful exposures. The city of Ahmedabad is among the first cities in India where city leaders, state government, and civil society are proactively working together to address the country's air pollution challenge with a focus on public health. The lessons learned from the development of the AIR Plan serve as a template for other cities aiming to address the heavy burden of air pollution on public health. Effective working relationships are vital since they form the foundation for long-term success and useful knowledge sharing beyond a single city

2.3 Air Quality Monitoring and IoT- Past and Future(2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO) Amity University, Noida, India. June 4-5, 2020).

Air quality index is a key discussion area in today's time in concern with human health and environmental hazards. It directly impacts the human health. In the current scenario, mobile and other wireless based smart devices are playing an important role in day to day life. Hence, it is important and evident that the same must be used efficiently to tackle our daily problems. One common issue related to quality of surrounding environment is to know about whether the air in surrounding is under the danger level index. Intelligent devices with the help of Internet of Things (IoT) will help in pulling of the idea of equipping every device with a measuring chip or a component that is capable of checking the quality of air on its own. Every electronic equipment with mobility can be embedded with the smart device or the smart device can itself be used externally whenever and wherever required. There exist various traditional approaches those measure the level of air quality index accurately but the problems with these are that they are located or stagnant at a particular area. Hence the real time information and the real time change is not recorded. This paper proposes an architecture using IoT for measurement of air quality index through sensor and NFC in movable devices. The proposed smart architecture will help to record the quality of air data at the current location. It is also capable of helping in collection of the wide range of data for the future solution to the problem.

2.4 Prediction of Air Quality Index Using Machine Learning Techniques: A Comparative Analysis (International Journal of Envirnomental Research and Public health Volume 2023 — Article ID 4916267).

An index for reporting air quality is called the air quality index (AQI). It measures the impact of air pollution on a person's health over a short period of time. The purpose of the AQI is to educate the public on the negative health effects of local air pollution. The amount of air pollution in Indian cities has significantly increased. There are several ways to create a mathematical formula to determine the air quality index. Numerous studies have found a link between air pollution exposure and adverse health impacts in the population. Data mining techniques are one of the most interesting approaches to forecast AQI and analyze it. The aim of this paper is to find the most effective way for AQI prediction to assist in climate control. The most effective method can be improved upon to find the most optimal solution. Hence, the work in this paper involves intensive research and the addition of novel techniques such as SMOTE to make sure that the best possible solution to the air quality problem is obtained. Another important goal is to demonstrate and display the exact metrics involved in our work in such a way that it is educational and insightful and hence provides proper comparisons and assists future researchers. In the proposed work, three distinct methods—support vector regression (SVR), random forest regression (RFR), and CatBoost regression (CR)—have been utilized to determine the AQI of New Delhi, Bangalore, Kolkata, and Hyderabad. After comparing the results of imbalanced datasets, it was found that random forest regression provides the lowest root mean square error (RMSE) values in Bangalore (0.5674), Kolkata (0.1403), and Hyderabad (0.3826), as well as higher accuracy compared to SVR and CatBoost regression for Kolkata (90.9700) and Hyderabad (78.3672), while CatBoost regression provides the lowest RMSE value in New Delhi (0.2792) and the highest accuracy is obtained for New Delhi (79.8622) and Bangalore (68.6860). Regarding the dataset that was subjected to the synthetic minority oversampling technique (SMOTE) algorithm, it is noted that random forest regression provides the lowest RMSE values in Kolkata (0.0988) and Hyderabad (0.0628) and higher accuracies are obtained for Kolkata (93.7438) and Hyderabad (97.6080) in comparison to SVR and CatBoost regression, whereas CatBoost regression provides the highest accuracies for New Delhi (85.0847) and Bangalore (90.3071). This demonstrated definitely that datasets that had the SMOTE algorithm applied to them produced a higher accuracy.

2.5 Intelligent Forecasting of Air Quality and Pollution Prediction Using Machine Learning(International Journal of Envirnomental Research and Public health Volume 2023 — Article ID 9861680).

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

2.6 A Multiple Kernel Learning Approach for Air Quality Prediction (International Journal of Envirnomental Research and Public health Volume 2018 — Article ID 3506394).

Air quality prediction is an important research issue due to the increasing impact of air pollution on the urban environment. However, existing methods often fail to forecast high-polluting air conditions, which is precisely what should be highlighted. In this paper, a novel multiple kernel learning (MKL) model that embodies the characteristics of ensemble learning, kernel learning, and representative learning is proposed to forecast the near future air quality (AQ). The centered alignment approach is used for learning kernels, and a boosting approach is used to determine the proper number of kernels. To demonstrate the performance of the proposed MKL model, its performance is compared to that of classical autoregressive integrated moving average (ARIMA) model; widely used parametric models like random forest (RF) and support vector machine (SVM); popular neural network models like multiple layer perceptron (MLP); and long short-term memory neural network. Datasets acquired from a coastal city Hong Kong and an inland city Beijing are used to train and validate all the models. Experiments show that the MKL model outperforms the other models. Moreover, the MKL model has better forecast ability for high health risk category AQ.

2.7 Ambient Air Quality Monitoring In Pune City (May 2015 International Journal of Science and Research (IJSR) 4(5):2909-2913).

This is especially true in the developing world, mainly due to high proportion of old, poorly maintained vehicles and poor fuel quality. On 9th May, 2002 the Supreme Court of India issued order in W.P. No. 13029 of 1985 directed that a scheme be prepared for improvement of air environment with special reference to vehicular pollution. The Supreme Court of India directed to include Pune City, as one of the four cities. The Air quality of the Pune city day by day will change and goes on the benchmark of pollution. Presently MPCB and IMD monitored air quality of Central Pune city on continuous and intermittent basis. This paper and study has main aims to develop effective monitoring mechanism to monitor the concentration of CO and NOX at existing and new monitoring stations and includes scenario of gaseous air pollutants due to vehicular emission in different areas of Pune city and surroundings so that the station wise air quality and its respective parametric concentrations will analyzed.

Chapter 3

Analysis / Software Requirements Specification (SRS)

3.1 Planning

Effective stakeholder outreach and community engagement were essential for planning the intervention in India. The research team convened several planning sessions to clarify the project goals, scope, and plans for implementation. The main aim was to support the AMC and IITM-SAFAR with the new monitoring and AQI system. To inform these goals, several informal meetings and a two-day workshop on "Air Pollution Health: Laying the Foundation for Effective Use of India's Air Quality Index" were held in 2016 [62,63,72]. The workshop included local groups as well as national and international experts, as discussed in Section 2.4. After this workshop, an issue brief entitled "Protecting Health from Increasing Air Pollution in India" was published, which documented air quality conditions in India and highlighted international best practices on AQI system coordination and health risk communication [64]. The issue brief, coupled with information from the community needs assessment and background research described below, served as the scientific evidence base for eventual development of the AIR Plan.

3.2 Intervention Implementation

The review of the existing air quality policy landscape, available air quality data, and AQI systems operating in India and other cities worldwide informed the development the AIR Plan. Synthesizing the issue brief research and stakeholder discussions, the mayor of India released a draft AIR Plan at a stakeholder workshop in February 2016 [72], making it available for a three-month public comment period [73]. With the national government and coalition partners, the AIR Plan and AQI were launched jointly in May 2016 by the MOEFCC Minister [150,151]. This plan serves as the first effort in Ahmedabad to comprehensively monitor air quality and communicate information about air pollution to the public to mitigate exposures and ultimately protect health. The plan describes a health-based governance framework designed to increase awareness, reduce exposure risk, and motivate longer-term policy action to reduce air pollution. With the IITM-SAFAR AQI as the focal point, the plan aims to facilitate information sharing on air quality, increase population preparedness for acute air pollution episodes, and improve response coordination to reduce the health impacts of air pollution on vulnerable populations

3.3 Five Strategic Elements

1. Pilot Health-Based AQI Warning and Interagency Coordination—robust interagency coordination to pilot a color-coded AQI alert system that makes air quality data from new IITM-SAFAR air quality stations in Ahmedabad available to the public.

2. Enhanced Public Awareness and Communication Outreach—an expansive program that communicates the AQI and protection strategies to local communities through a range of tools, including 12 new LED light board displays, hoardings and billboards; the IITM-SAFAR web portal; cellular phone text messages (SMS) and smartphone mobile application; traditional media engagement; and information, education and communication (IEC) materials translated into the local language (Gujarati).

3. Focused Activities on Children's Health—development of a school flag program with local elementary schools to display colored flags corresponding to daily forecast AQI levels [101,152].

4. Targeted Capacity Building for Medical Professionals—engagement with private and public medical professionals to build awareness of the AQI and promote protection strategies on air pollution [66].

5. Supporting Research on Future Exposure Reduction and Mitigation Pathways—application of the AQI for identification of exposure mitigation and pollution source reduction measures by key academic partners from leading local institutes [152].

3.4 Project Evaluation

Qualitative evaluation of the AIR Plan has been conducted since its launch in 2016. Ongoing evaluation entails assessing performance of the AQI in reporting and forecasting pollution levels. It also includes assessing the effectiveness of the AIR Plan in reducing exposure of citizens to air pollution, promoting greater awareness of the health impacts of air pollution, and lowering rates of

Table 2. Key aims of the AIR Plan and corresponding evaluation methods.

AIR Plan Aim [151]	Evaluation Method
1. Health-Based AQI Warning and Interagency Coordination	Meetings with AMC and IITM-SAFAR staff and development of a draft internal AIR Plan User Guide and Standard Operating Procedures to standardize and strengthen interagency coordination practices.
2. Communication and Outreach	Community roundtable meetings to qualitatively gauge the success of communication and outreach efforts. Development additional public outreach materials and engagement of local media on the AQI and AIR Plan.
3. Focused Activities for Vulnerable Groups	Roundtable discussions with school administrators participating in the school flag program to assess student understanding and engagement [152].
4. Capacity Building of Medical Professionals	Conversations with leading medical professionals [152,186].
5. Research on Exposure Reduction and Mitigation Pathways	Local expert working group discussions of IITM-SAFAR AQI data and the Emissions Inventory to inform emission reduction efforts [24,152,158].

Figure 3.1: Key aims of AIR plan

air pollution-related health problems. Over the long term, it is also important to analyze air pollution trends to understand the success of the project from a pollution mitigation standpoint [81,180]. Evaluation of the plan's first year included assessment of two main target groups: organizations and individuals directly involved in the AIR Plan response to air pollution, and the people most vulnerable to high levels of air pollution. Impact assessment of preparedness activities in the public health community included roundtable discussions and surveys with key personnel involved in forecasting, reporting, and responding to high air pollution episodes. Specifically, understanding of AIR Plan roles and responsibilities, familiarity with preparedness and response activities, recognition of respiratory illnesses, and thoughts on barriers to implementation were evaluated. Key personnel included IITM-SAFAR experts, AMC Health Department staff, hospital administrators, urban health center staff, and administrators of emergency medical services. Table 2 describes the completed evaluation efforts corresponding to each of the AIR Plan's five major aims.

Chapter 4

System Design

4.1 Piloting a Health-Based AQI through Streamlined Interagency Coordination

To develop an inclusive communication framework, the agencies already involved in responding to air-related health emergencies were visually mapped. Figure 1 shows the array of stakeholders involved in efforts to document and communicate the AQI. As the lead (Nodal) agency, the AMC Health Department has the overarching responsibility for coordination and outreach on activities related to the AQI and AIR Plan. This includes monitoring the daily AQI and disseminating public health messages to local departments and community service providers. Because air pollution sources can affect large geographic areas and encompass different sectors, city and statewide coordination of government agencies is an important mechanism to effectively combat air pollution [153]. AIR Plan efforts have supported positive interagency working relationships, cooperation, and consultation. The coordination process has also created a functional framework for fostering better working relationships, improving general understanding of the work of each agency, and identifying key roles and responsibilities of each agency early in the process. Overall, coordination efforts have improved trust and understanding among agencies.With India , IITM activated the IITM-SAFAR network that includes 10 air pollution monitoring stations in and around the city each monitoring local conditions. Each IITM-SAFAR monitor reports pollutant-specific AQI levels based on the benchmarks specified in Table 1 for the present day (based on continuously monitored conditions), and a pollutant-specific AQI forecast for one and two days into the future. On days when levels of multiple pollutants are measured to be high, the site-level AQI is designated as the highest AQI for any specific pollutant at that site.

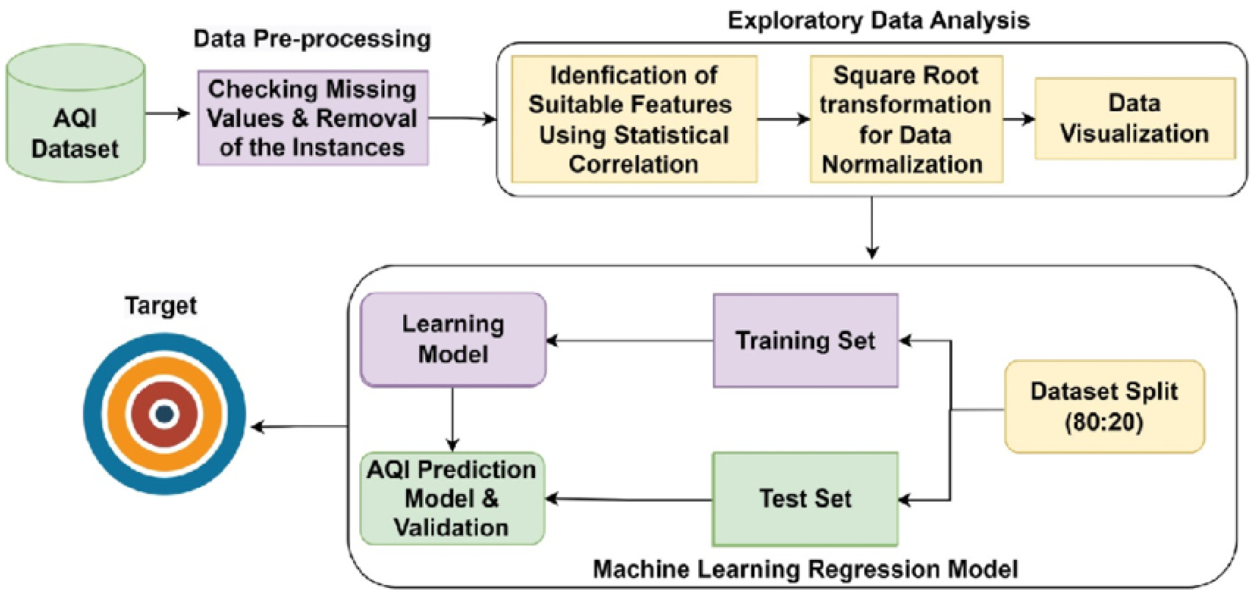


Figure 4.1: Machine-learning-DFD-for-the-prediction-of-AQI

4.2 Conducting Effective Communication Outreach to Enhance Public Awareness

Essential elements for effective risk communication are information quality, transparency, simplicity, and timeliness [74,93,95,154]. In Ahmedabad, IITM-SAFAR and the AMC publicize the city-wide and site-specific AQI values through multiple channels, including online, an automated phone hotline, a mobile phone application, and a network of digital display boards that communicate the daily AQI and next-day forecast, shown in Figure 3A [140]. These display boards can help reach the considerable portion of the population for whom the internet may be unavailable, inaccessible, or unaffordable [155]. The AMC directly engages local media on the importance of air quality as a public health concern and the role of the AQI in helping to inform the public about environmental health risks. A key element of the AIR Plan's communication strategy is the development of tailored IEC materials to explain the AQI and provide more general information about the health risks of air pollution to the residents of Ahmedabad. For example, Figure 4 shows a flyer prepared in Gujarati that helps to raise awareness about air pollution from the city's thermal coal-fired power plants.

4.3 Enhanced Public Awareness and Communication Outreach

IITM-SAFAR also calculates a city-wide average AQI based on each of the site-level AQI values, upon which Health Warnings and Alerts are based. Figure 2 displays the IITM-SAFAR air quality descriptors, AQI ranges, and associated health messages for the city-wide AQI. As part of the AIR Plan, the AMC Nodal Officer issues a Health Alert when the next day's city-wide AQI is forecast to

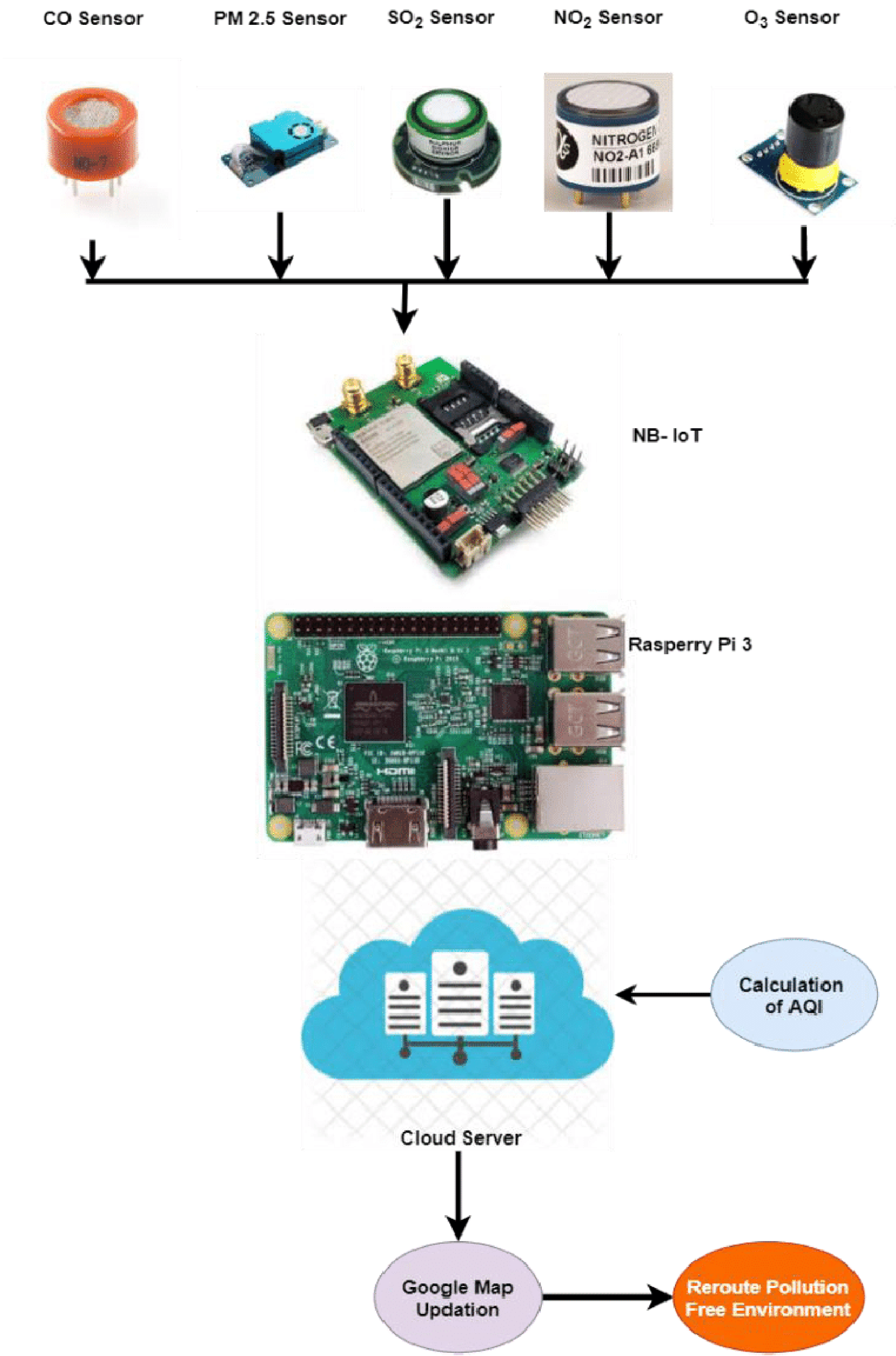


Figure 4.2: Sequence of events for Air Quality Monitoring System

Air Quality Descriptor	AQI Value	$PM_{2.5}$ (µg/m^3) 24-hr Average	PM_{10} (µg/m^3) 24-hr Average	O_3 (ppb) 8-hr Average	NO_2 (ppb) 24-hr Average	CO (ppm) 24-hr Average
Good	0–100	0–60	0–100	0–50	0–43	0–1.7
Moderate	101–200	61–90	101–250	51–84	44–96	1.8–8.7
Poor	201–300	91–120	251–350	85–104	97–149	8.8–14.8
Very Poor	301–400	121–250	351–430	105–374	150–213	14.9–29.7
Severe	401–500	251–350	431–550	375–450	214–750	29.8–40

Figure 4.3: I
ITM-SAFAR air quality descriptors, AQI numeric values, and corresponding air pollution concentration thresholds and temporal averaging periods [95,140].

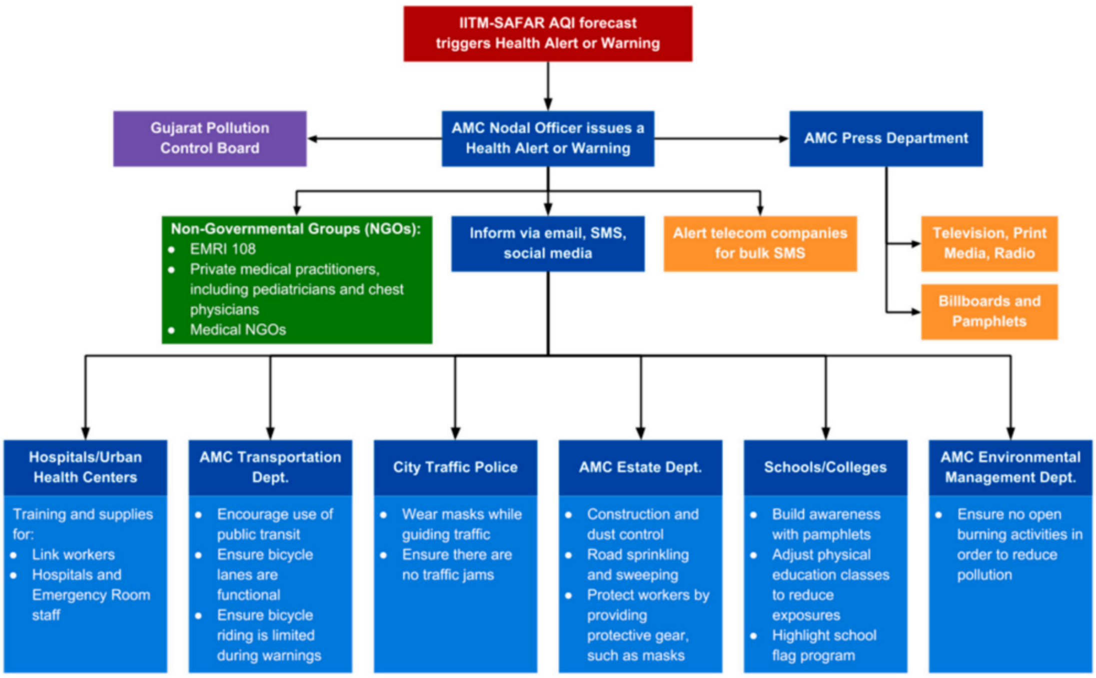


Figure 4.4: Flowchart.

Figure 4.5: (A) Digital display board of IITM-SAFAR forecast city-wide AQI (one of 12 in Ahmedabad), and (B) A yellow flag at Zebar School for Children indicates an IITM-SAFAR AQI forecast of Moderate air quality (yellow category, AQI 101-200) for the coming day.

be Very Poor (red, AQI levels 301–400) and a Health Warning when the city-wide AQI is forecast to be Severe (maroon, AQI levels 401–500). The AMC also issues a Health Advisory bulk mobile phone text message (SMS) communication when the city-wide forecast is Poor (orange, AQI levels 201–300). Each AQI category is associated with a health advisory message, and as air quality deteriorates from the Good level, health advisory messages provide specific information about risks to public health. For example, an AQI level of 201–300 is associated with a Poor level of air quality, and indicates that sensitive populations (such as children, adults who are active outdoors, and people with respiratory disease) will experience unhealthy conditions outside. An AQI level of 301–400 (Very Poor) or 401–500 (Severe) represents a public health risk that applies to the entire population. While the AIR Plan's first phase focused on the dissemination of critical air quality information to the public, a longer-term effort will be required to familiarize the general population with the wide range of health effects associated with even relatively moderate levels of air pollution. Equipping the population of Ahmedabad with AQI information is the first step towards research and policy measures to better understand and eventually mitigate harmful exposures to air pollution [152].

Figure 4.6: . IITM-SAFAR AQI air quality descriptors, index value ranges, and associated health messages [64]. AQI levels 301–400 activate a Health Alert in Ahmedabad, while levels 401–500 activate a city-wide Health Warning

4.4 Initiate Research on Future Exposure Reduction and Mitigation Pathways

Ahmedabad's work on reducing extreme heat vulnerability through its HAP has also shown that developing local scientific studies to build an evidence base on environment-health connections provides a foundation for creating and implementing effective policies [54,156]. The AIR Plan aims to support future air pollution research in the city with a focus on emissions sources, air quality trends, and epidemiologic investigation. These efforts are coordinated by the local expert working group on air pollution, which meets regularly to assess the progress of the AIR Plan and consider recommendations for longer-term air quality management in the region [157]. While some prior research has made progress towards identifying the key sources of air pollution in Ahmedabad, new monitoring efforts enabled by IITM-SAFAR allow for a better understanding of spatial variation in pollution. Upon launching the AIR Plan, the IITM-SAFAR program released its comprehensive emissions inventory assessment of the city [158]. This report showed that the top three sources of PM2.5 in 2016–17 were transportation (36(21and informs ongoing policy efforts at the city level to understand and mitigate exposure to pollution from key sectors [159]. The wealth of data recorded by the IITM-SAFAR monitors allows for a more complete understanding of air quality conditions in the region. For example, spatial variation in pollution levels can be better characterized by analyzing data from the 10 monitoring stations throughout the region. Moreover, because these monitors document conditions every five minutes, stakeholders can better ascertain trends in pollution over multiple time horizons (e.g., hourly, daily, weekly, monthly, seasonally, and annually) [160,161]. As a result, the city is better equipped to understand air quality on a historical basis and potentially identify localized "hot spots" of elevated pollution levels on which to base future emission reduction and exposure mitigation actions. Such actions include concerted efforts to expand vegetated areas within the city [162], which have been shown to reduce air pollution and extreme temperatures in urban areas [163–165] and could also improve mental health outcomes [166,167]. Specifically, planting certain tree species can achieve substantial reductions in biogenic VOCs relative to known high-emitting species [168]. The new air quality data available in Ahmedabad can also be utilized for regional environmental health research that characterizes the risks to local citizens as a result of their exposures to pollution, particularly for PM2.5 [25]. As a first step, IIPH-G is planning a cross-sectional study that seeks to identify the associations between PM2.5 and respiratory function in children. While studies analyzing air quality and health data measured in India are underrepresented in the global air pollution epidemiology literature, improved monitoring data helps to expand the exposure evidence base for health research and environmental policy [25,70,88,98,99,111,127–134,136,169,170]. Given the unique genetic and environmental risks in the region and dose-response relationships for PM2.5 that are being better quantified regionally, the newly-available air pollution data collected in cities like Ahmedabad could be useful for efforts to better understand local epidemiologic risk [6,7,171–173]. IIPH-G also plans to apply IITM-SAFAR data in epidemiologic research examining the relationship between air quality exposure and population-level risk for hospitalization and emergency department visits.Additional scientific studies that could serve to build the in-country evidence base include exploration of the long-term effects of air pollution exposure amongst pregnant women and newborns [174,175], the effects of fossil fuel combustion on health risks in children [97,176], and the long-term health effects and financial costs to society of chronically polluted air [3,177–179]. Exposure assessment research could better quantify the range of air pollution exposure among highly exposed outdoor workers (such as traffic police) and track how policy efforts to reduce emissions affect air quality exposures experienced over time [180,181]. Furthermore, air pollution data from IITM-SAFAR could improve the study of the health effects of air pollution related to heat waves in Ahmedabad, because while effects of heat on mortality have been robust to confounding by air pollution, the possibility exists for effect modification [182–185]

Chapter 5

Methodology

5.1 Planning and Conceptual Model Development

The Ahmedabad AIR Plan builds on the effective heat action plan that the city and partnering institutions, led by the Indian Institute of Public Health-Gandhinagar (IIPH-G) and the Natural Resources Defense Council (NRDC), developed and implemented beginning in 2013 [60]. Both IIPH-G and NRDC are knowledge partners for the air and heat programs, with two separate memoranda of understanding with the city. The conceptual model was developed based on domestic and international expert input and research documented in a comprehensive technical issue brief, which established a scientific evidence base for the eventual development of the AIR Plan [62–64]. Based on the background literature review, roundtable discussions, and a participatory workshop documented in the issue brief, the conceptual model is premised on several factors: Air pollution poses a significant public health risk [50]; this risk is under-recognized by the public; air pollution is inadequately monitored and managed [65]; and documenting air quality through an AQI and communicating specific exposure mitigation strategies can improve public health and facilitate long-term improvement of air quality [25,51,66]. Another underlying premise is that certain populations are at greater risk to air pollution-related health effects because of relatively high exposures (e.g., occupational exposures among outdoor workers, including traffic police, construction workers, and street vendors, among others [42,67,68]) or low coping capacity (e.g., school children, patients with pre-existing respiratory illnesses [69–71]). The model also posits that strategies for conveying risk information and corresponding exposure mitigation recommendations would reduce the population health risks related to air pollution [66].

5.2 Community Needs Assessment

the need for a comprehensive air quality and health risk communication program in the region was assessed through several measures. To gather opinions from city residents, a series of community meetings, workshops and roundtables with local stakeholders (including physicians, environmental professionals, health scientists, city staff, and other community leaders) were conducted from August 2016 to May 2017. Roundtable sessions and workshop interviews were conducted with national and international air pollution experts, local municipal administrators, and key academic institutions [62,63,72,73]. Soliciting input from members of the public as key stakeholders was critical to establish effective communication channels, mutual trust, and the reciprocal exchange of information. This approach was also conducive to forming innovative solutions, in contrast to one-way communication models [74].

5.3 Baseline Data

To inform efforts on improved air quality monitoring and communication, it was necessary to ascertain the information already available from prior work in the city. The peer-reviewed literature and publicly-available government reports were consulted to gauge the degree to which quantitative air quality information was available, and the epidemiological literature was surveyed for research conducted in the Ahmedabad region and the state of Gujarat. This baseline data research involved a literature review into four aspects of air pollution data and policy: (1) India's National Ambient Air Quality Standards (NAAQS) and the authority of the government to monitor air pollution and regulate polluting sources; (2) the extent of existing air quality monitoring systems in Ahmedabad; (3) prior research on key pollution sources and health impacts of pollution in the region; and (4) information on the operation and efficacy of other AQI systems, both in India and in other countries, with a focus on key international cities (Beijing, Los Angeles, and Mexico City).

5.4 India's Air Quality Standard

All AQI reporting systems relate air quality monitoring data to anticipated public health impacts by assessing monitored levels of pollution relative to health-based air quality benchmarks [23,75]. To assess the appropriate benchmarks for different AQI levels and associated public health warnings, information about India's NAAQS was reviewed [51,76] along with documentation about the various government jurisdictions involved with monitoring, reporting, and managing air quality [25,77–82].

5.5 Health Impacts of Air Pollution

The peer-reviewed public health literature was surveyed to better understand the burden of air pollution in Ahmedabad, as well as the need for improved air quality monitoring data at higher spatial and temporal resolution. The focus was on the quantification of health effects in vulnerable sub-populations in the city, including children [69,84], the elderly [85], people with pre-existing medical conditions [70,86–88] and those exposed to especially high levels of pollution due to their socioeconomic status [89,90] or occupation [67,68,91].

5.6 Best Practices from Other AQI Systems

Best practices and fundamental elements for establishing an effective AQI system were also identified. To distill information on the key elements of effective AQI systems worldwide, the peer-reviewed academic literature, documentation from air quality management agencies, and online media sources were surveyed [22–24,51,66,74,92–94]. In particular, several dimensions of AQI systems were reviewed: Stakeholder coordination, system planning and implementation processes, communication aims and modes, system role in local capacity building, and the application of air quality monitoring data for further research. The review of other AQI systems operating in India and in other countries highlighted best practices to adapt to Ahmedabad. AQI programs started in the 1970s and now operate in over 100 cities across Asia, Australia, Europe, North America, and South America. In 2013, IITM and the IMD developed SAFAR, which provides location-specific AQI in near real-time and forecasts the daily AQI up to two days in advance. IITM-SAFAR was conceived as a major national initiative for greater metropolitan cities in India to provide local information on air quality, in collaboration with the National Centre for Medium Range Weather Forecasting [95]. IITM-SAFAR monitors are deployed in accordance with Central Pollution Control Board and World Meteorological Organization standards [95,117] and continuously collect data at 5-min intervals. IITM-SAFAR has also adopted the U.S. Environmental Protection Agency (U.S. EPA) Standard Operating Procedures for instrument calibration and maintenance [95]. IITM-SAFAR deploys state-of-the-art monitoring instruments, manufactured in France by Environnement SA [138], that are ISO standard compliant [139] and certified by U.S. EPA for their PM10 and PM2.5 sampling technology. The IITM-SAFAR monitors represent the first network in India that continuously monitors and forecasts air pollution levels [95,140]. Monitors sample air at a height of three meters from the ground and characterize air quality for the entire city by incorporating information from sites in industrial corridors, residential areas, urban centers, agricultural zones, and areas that represent background level concentrations [95]. The monitors measure small particles (PM2.5 and PM10), O3, NO2, and carbon monoxide. The stations also monitor key meteorological parameters (ultraviolet radiation, rainfall, temperature, humidity, wind speed and direction). IITM-SAFAR publishes an AQI based on its raw monitoring data that largely corresponds to the CPCB AQI calculation methodology [51,95]. Air monitoring also informs a comprehensive, computationally intense modeling apparatus that is used to develop dynamic air quality forecasts for one and two days in advance. Section 3.4.1 further explains how IITM-SAFAR forecasts are used by the AMC Nodal Officer. CPCB established a national AQI system in 2015 in 14 cities, and that index now summarizes air quality in 57 cities [27,112]. In addition to AQI systems administered by the CPCB and IITM, other countries have implemented their own systems to protect their citizens working in the country. For example, the U.S. embassies and consulates in New Delhi, Mumbai, Kolkata, Hyderabad, and Chennai have deployed the U.S. EPA-certified instruments and calculation methods to convert raw PM2.5 readings into an AQI value that helps to inform the public about air quality-related health risks [141,142]. These AQI data and health effects advisories are continuously updated online [143]. Three other cities (Beijing, Los Angeles, and Mexico City) offer experiences with AQI systems that are instructive in protecting public health and improving air quality. Beijing and many cities in China are plagued by poor air quality. To protect public health, Beijing's AQI has been a central means for notifying communities and driving action [144]. The city's AQI system delivers information to the public over radio, print media, hourly online reports, and a smartphone application. In tandem with better quantification of air quality, China and Beijing have instituted measures to reduce air pollution such as decommissioning and retrofitting coal-fired boilers and banning dirty cars from the road [145,146]. In California, the Los Angeles AQI is a key tool for the city's air quality program [147]. The system facilitates health alerts on poor air quality days, broad public outreach (via television, radio, and print media), medical professional engagement, and community-based programs to raise awareness. For example, local schools operate a school flag program announcing the AQI via color-coded flags on a daily basis. In 1992, WHO identified Mexico City as the most polluted city in the world [148]. Since then, the city has made tremendous progress in understanding the polluting sources and geographic characteristics that led to particularly high air pollution levels. Mexico City's AQI warns at-risk populations about future acute air pollution episodes and associated health risks, and was designed to generate reliable data that advances local clean air strategies [149]. In sum, effective AQI systems require strong foundations of robust air pollution monitoring, effective communication of health risk information, and robust interagency coordination. The dual goals of protecting public health from air pollution in the near-term and improving air quality over a longer time horizon are strengthened by effective AQI systems, which provide the evidence base for municipal, state, and national agencies to take policy actions to reduce air pollution.

Chapter 6

Implementation

6.1 Background Information

The background information that needs to be collected includes details of sources and emissions, health status, demography, population growth, land use pattern, epidemiological studies. Such prior information will provide immense help to identify the likely effects and in particular health impacts resulting from population exposure to air pollutants.

6.2 Sources and Emissions

Sources in a city include vehicles, industries, domestic etc. In an industrial area, information should be obtained on the type of industries including their number, fuel used, composition of fuel, pollutants emitted etc. Information on number and distribution of sources should be collected. This information will help in identifying which pollutants can be expected in an area and thus should be measured. In case of industrial stacks, locations of maximum ground level concentrations should be determined by modeling. The stations should be located at locations where maximum ground level concentrations are expected. Information on type and number of vehicles should be obtained. Information on domestic fuel that is used in household should be obtained. Pollution load emanating from these sources should be estimated so as to identify sources that are generating significant amount of pollution.

6.3 Health and Demographic Information

Investigations shall be carried out based on the public complaints received from an area related to air pollution. If the results of such investigations reveal that the levels are high that area can be considered for ambient air quality monitoring. Areas where population density is high (more than one million) can be considered for locating monitoring stations. Information on age and socio-economic status of population is also important for making a decision on initiation of ambient air quality monitoring. Location of monitoring station in such areas will help in finding exposure levels to population which can be used further in epidemiological studies to evaluate health effects of air pollutants.

6.4 Meteorological Information

Meteorological data with respect to temperature, relative humidity, wind speed and direction should be collected. Predominant wind direction plays an important role in 10 determining location of monitoring stations. Due to effects such as land and sea breezes, valley effects etc. it is important to collect local meteorological data specific to the site. The monitoring stations should be located in areas that are downwind from the sources. Mixing height data should also be collected. Mixing height data can be collected from Indian Meteorological Department. Information on duration of various seasons in a year is also important. Measurement frequency should be such that monitoring is done in all the seasons so that all seasonal variations are included in computing annual average.

6.5 Topographical Information

Local winds and stability conditions are affected by topography. In river valleys there is increased tendency of developing inversions. More number of monitoring stations should be located in areas where spatial variations in concentrations are large. Mountains, hills, water bodies also affect dispersion of pollutants.

6.6 Previous Air Quality Information

Any previous information collected on ambient air quality can serve as a basis for selecting areas where monitoring should be conducted and previous studies may include data collected for any health studies etc. Previous studies can be used to estimate the magnitude of the problem. Once the background information is collected, the ambient air quality monitoring is to be initiated and selection of type of pollutant to be measured, number and distribution of monitoring stations etc. should be made.

6.7 Number and Distribution of Monitoring Locations

Knowledge of existing air pollutants levels and pattern within the area are essential for deciding number and distribution of stations. Isopleths distribution of ambient concentrations determined from modeling or previous air quality information can be used to determine number and distribution of stations. When isopleths maps are not available information of emission densities and land use

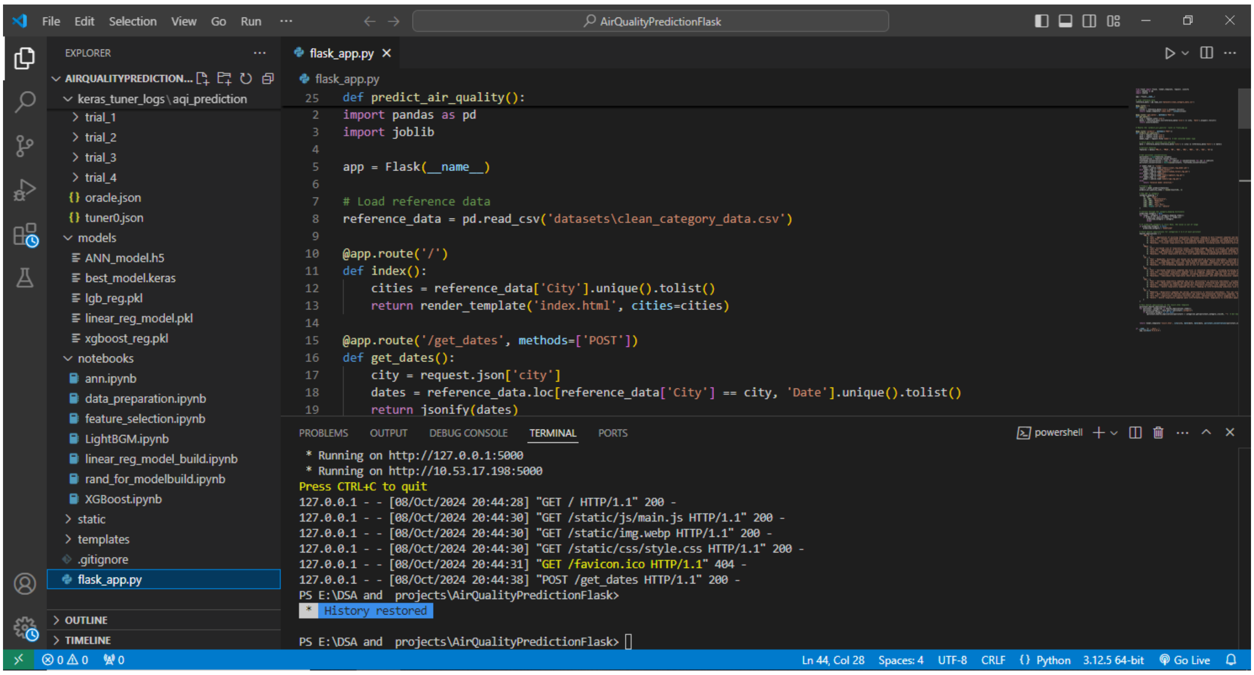


Figure 6.1: Project Structure and Files

pattern may be used with wind-rose data to determine areas of expected higher concentrations. The number of monitoring stations in a city can be selected based on background information collected on sources and emissions, Population figures which can be used as indicators of region variability of the pollutants concentration.

6.8 Selection of Pollutants

Prior to selection of pollutants, an emission inventory study or modeling results can be carried out or used if available. The pollutants expected from the sources present should be monitored. For monitoring in metropolitan cities and urban areas, the common urban air pollutants such as carbon monoxide, SO2, NO2, SPM and RSPM should be measured on a regular basis. Resource availability can play a very important role in determining the pollutants to be measured in an area.

6.9 Project Implementation

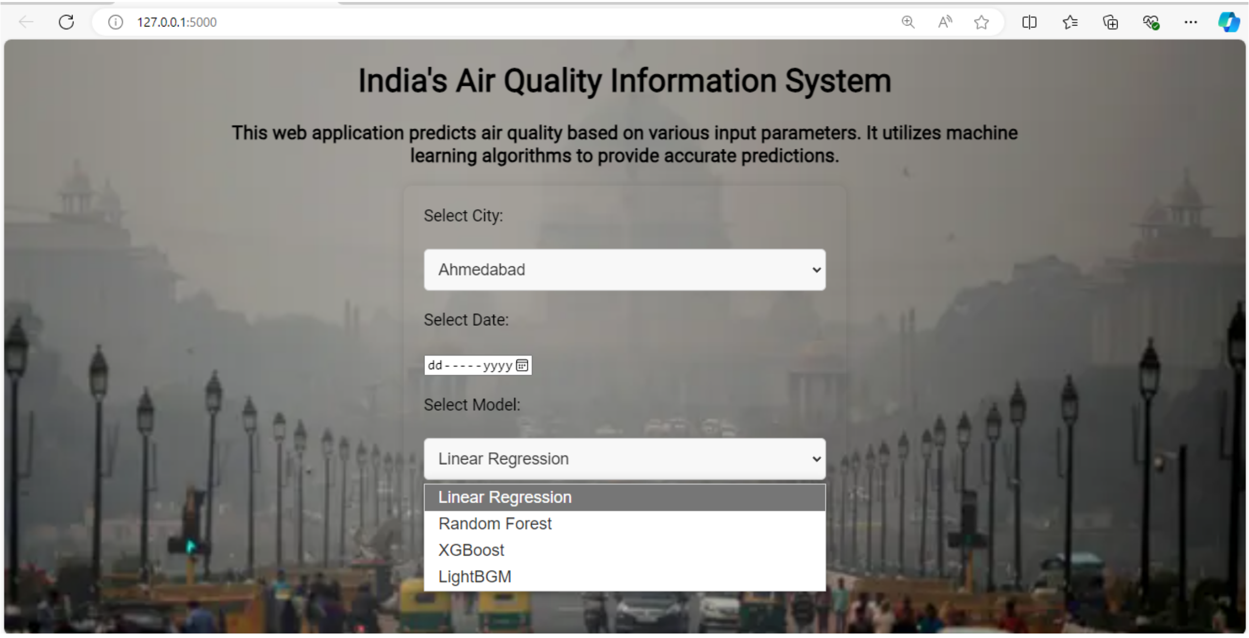


Figure 6.2: Home Page

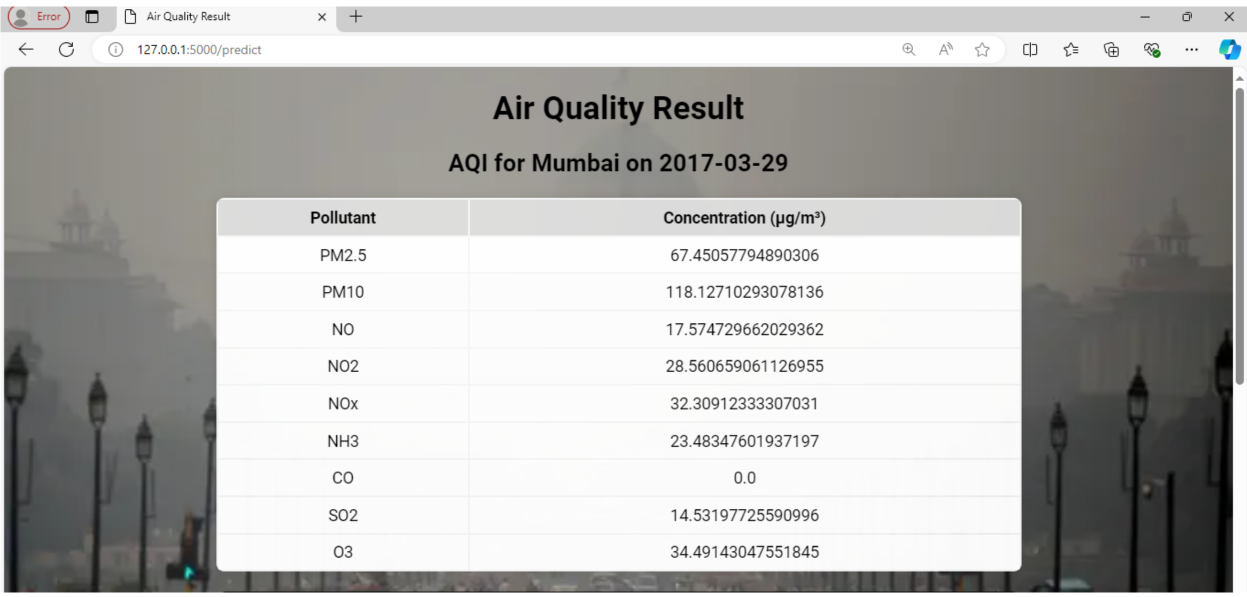


Figure 6.3: ML Model Prediction

Chapter 7

Testing

7.1 Machine Learning model testing

Machine learning testing is the process of evaluating and validating the performance of machine learning models to ensure their correctness, accuracy, and robustness. Unlike traditional software testing, which mainly focuses on code functionality, ML testing includes additional layers due to the inherent complexity of ML models. It ensures that ML models perform as intended, providing reliable results and adhering to industry standards. As ML models are involved in critical decision-making like approving loans, steering autonomous vehicles, or diagnosing patients, there could be chances of errors. This is why ML testing is a crucial process that every business needs to implement. It ensures that the ML models operate responsibly, accurately, and ethically.

Test Case	Expected Outcome	Actual Outcome	Pass/Fail
Simple Prediction	Correct	Correct	Pass
Short Sentence Analysis	Accurate	Accurate	Pass
Known Failure Mode 1	Detected	Detected	Pass

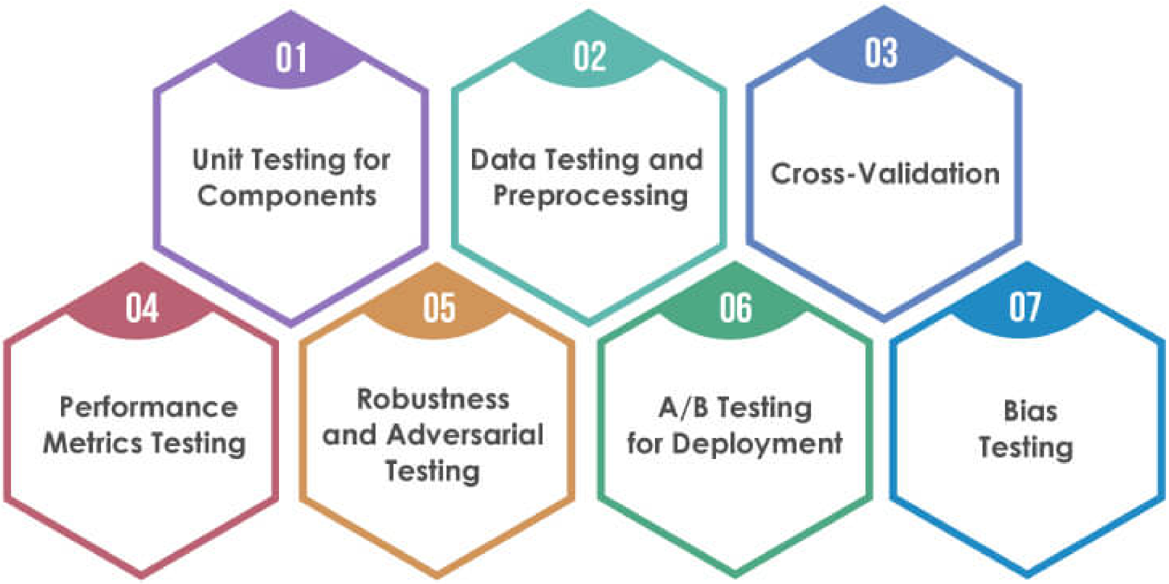


Figure 7.1: Stages of Testing performed on ML

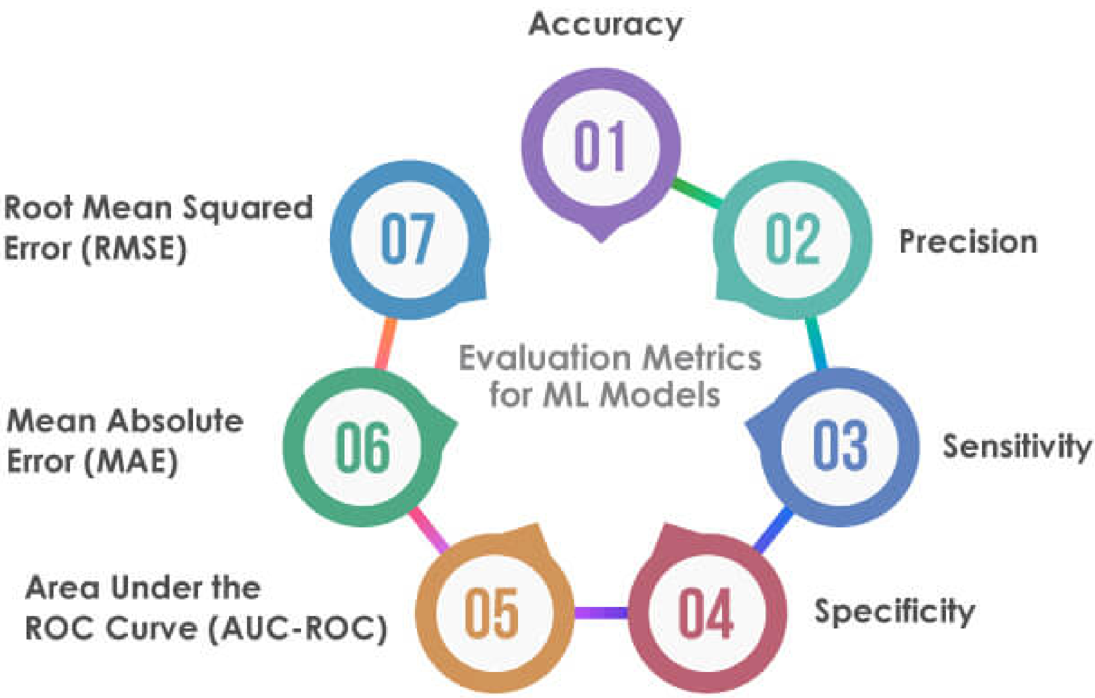


Figure 7.2: Evaluation Metrics for ML Models

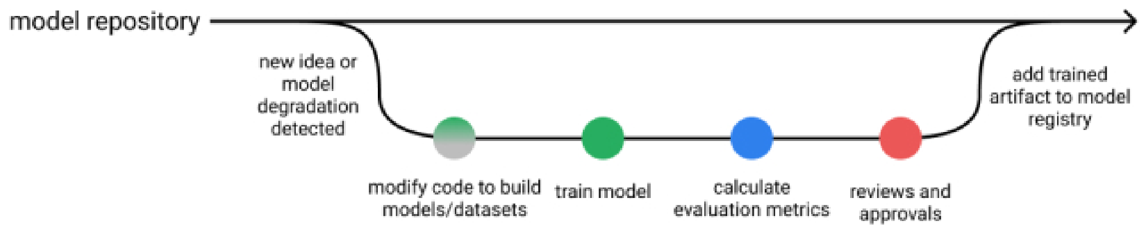


Figure 7.3: Typical ML development workflow with tests,

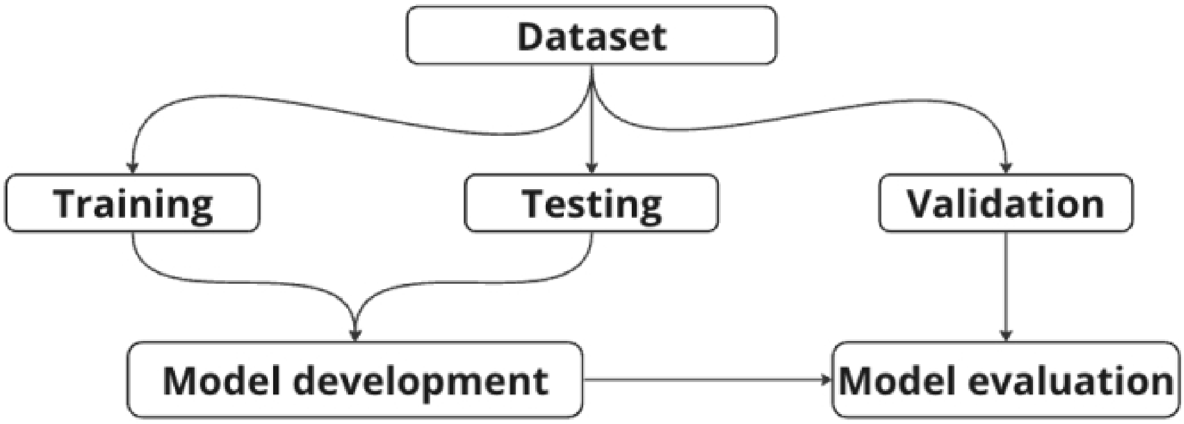


Figure 7.4: Model development and evaluation workflow

7.2 Testing Techniques

Many existing ML model testing practices follow manual error analysis (e.g., failure mode classification), making them slow, costly, and error-prone. A proper ML model testing framework should systematize these practices.

- Unit test: Check the correctness of individual model components.
- Regression test: Check whether your model breaks and test for previously encountered bugs.
- Integration test: Check whether the different components work with each other within your machine learning pipeline.

7.3 Various Testing Stages

Figure 7.5: Failed Test Case

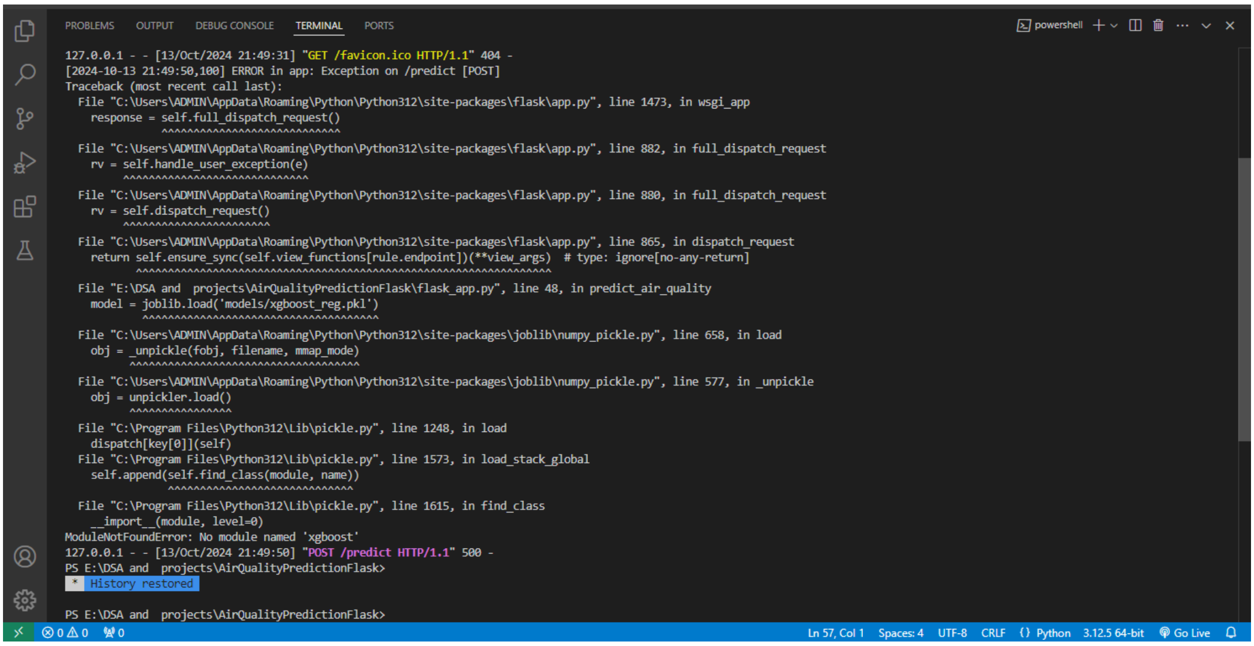


Figure 7.6: Error located and resolved

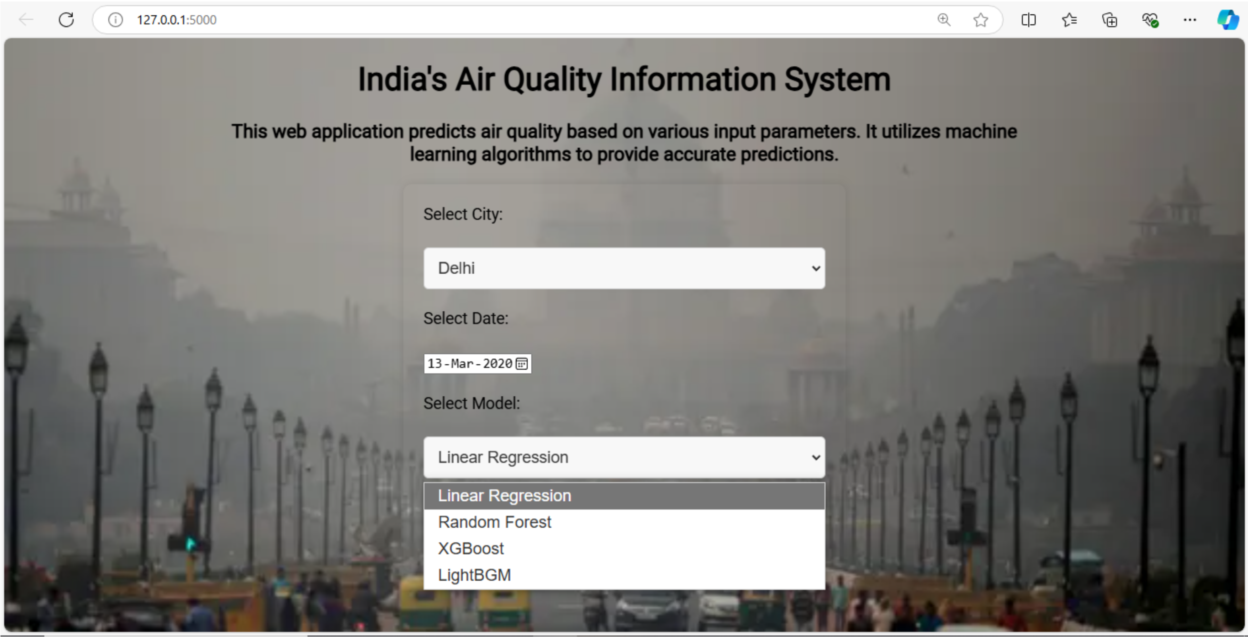
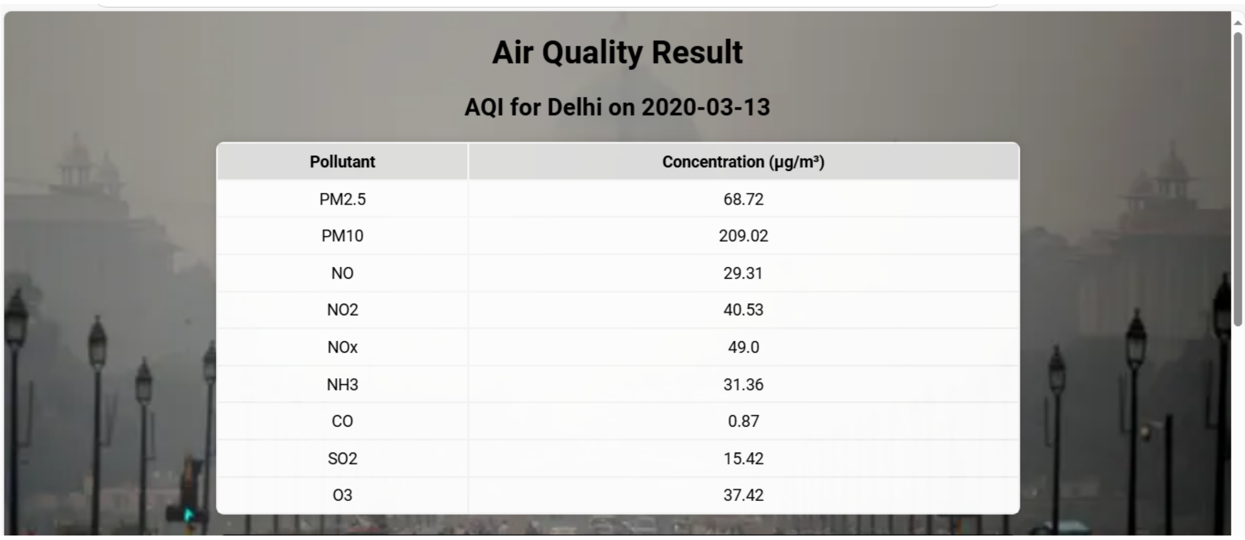


Figure 7.7: Test case passed



Pollutant	Concentration (µg/m³)
PM2.5	68.72
PM10	209.02
NO	29.31
NO2	40.53
NOx	49.0
NH3	31.36
CO	0.87
SO2	15.42
O3	37.42

Figure 7.8: Model Prediction test

Chapter 8

Conclusion

The experience of developing and implementing the AIR Plan in Ahmedabad offers a number of tangible lessons to other cities in India and other countries that are striving to address the problem of urban air pollution. First, strong partnerships and community engagement are paramount. Second, the reliance on transparent, tested technology for documenting and reporting air quality builds trust and allows for the establishment of a research base on which to craft informed air quality management policies. Third, it is important to design interventions that achieve near-term benefits while also laying the foundation for sustainable progress towards larger environmental and public health goals. Lastly, a sustained, stakeholder-focused approach that prioritizes community engagement at the outset is vital. As cities around the world strive to achieve healthy and sustainable conditions for their residents, Ahmedabad's leadership with the AIR Plan demonstrates that the combined efforts of government agencies, health professionals, academic leaders, and engaged community members can serve to effectively inform the public about major air pollution-related health risks. This project also lays a foundation for policy measures to improve the city's resilience to other complex environmental health threats. The lessons learned through the development and implementation of Ahmedabad's AIR Plan are instructive for other cities working to address the heavy burden of air pollution on the health of their citizens.

Chapter 9

Future Work

9.1 Prospects

AMC's launch of the AIR Plan in Ahmedabad was the culmination of a collaborative effort among an array of stakeholders. Because many Indian cities are suffering from the heavy burden of air pollution, it is important to acknowledge the local political dynamics that facilitated the planning and implementation of this plan. Locally, the AMC led the effort to make air pollution (and environmental health and resilience more generally) a municipal priority, and this proactive leadership was a major factor in the effectiveness of this work. City leaders have developed productive relationships with their counterparts in state and national government, enabling them to work collaboratively on technical and policy solutions. Because the sources of air pollution are so numerous, a similarly diverse and interdisciplinary team was required to address the problem from multiple perspectives;

9.2 Challenges

Fourth, numerous communication challenges were encountered in this work. Air pollution is a multidimensional topic, and the technical intricacies of pollution sources, ambient exposures, and health impacts can be difficult to navigate for any individual, regardless of training. Beyond the obstacles presented by these technical aspects, residents of Ahmedabad commonly speak multiple languages (dominantly Gujarati and Hindi) and approach the air pollution problem from distinct perspectives.

References

9.3 Abbreviations

AIR Ahmedabad Air Information and Response Plan

AMC Ahmedabad Municipal Corporation

AQI Air quality index

CPCB Central Pollution Control Board

GPCB Gujarat Pollution Control Board

HAP Heat Action Plan

IEC Information, education, and communication materials

IIPH-G Indian Institute of Public Health-Gandhinagar

IITM-SAFAR Indian Institute of Tropical Meteorology System of Air Quality and Weather Forecasting and Research

IMD India Meteorological Department

MOEFCC Ministry of Environment, Forests, and Climate Change

NAAQS National Ambient Air Quality Standards

NRDC Natural Resources Defense Council

NO2 Nitrogen dioxide

O3 Ozone

PM Particulate matter PM2.5 Fine particulate matter, aerodynamic diameter 2.5 microns

PM10 Coarse particulate matter, aerodynamic diameter 10 microns

SO2 Sulfur dioxide

SPCB State Pollution Control Board

U.S. EPA U.S. Environmental Protection Agency

VOCs Volatile organic compounds

WHO World Health Organization

9.4 References for numbers

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