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A Comprehensive Study on Air Quality Detection Using ML Algorithms

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***Abstract*—An indicator of the air's condition, an air quality index (AQI) is a metric. It evaluates an air pollution's immediate health effects. The combustion of fossil fuels (like Wood, coal and natural gas), as well as industrial processes and automobile emissions, are major contributors to air pollution. Among the many air pollutants are NO, CO, and CO2. Air pollution is a leading source of serious health problems, including cancer of the lungs and brain, and in extreme cases, death. After calculate an AQI, machine learning methods are useful. The AQI's mission is to inform people about the dangers of breathing polluted air in their area. The study summarises the, including its main points. This study delves into a growing issue of air pollution and a crucial need for efficient air quality monitoring and evaluation, with a focus on cities that are undergoing fast industrialisation and population expansions. The research delves into several methods for forecasting air quality using machine learning algorithms, taking into account aspects like pollution concentrations, spatio-temporal dynamics, and the effects on both human and environmental health. The paper summarises previous research on methods for predicting air quality, with an emphasis on statistical approaches and basic machine-learning models.**

Keywords—Air pollution, Air quality prediction, machine learning

I. Introduction

A proliferation of technological advancements, substantial population expansion, and the rising quantity of vehicles will engender an innumerable array of critical environmental issues, including but not limited to acid rain, deforestation, air and water pollution, and the emission of hazardous substances. Significant air pollution issues are afflicting urban regions worldwide as a result of industrialisation that has accelerated in response to the demands of a growing population. This progress may result in the emission of hazardous gases into the atmosphere from diverse sectors. As a consequence, the air that individuals or the environment themselves breathe is deemed polluted, devoid of cleanliness, due to the presence of numerous hazardous gases and particulate that impair human health. The air quality deteriorates as a result of pollution. When it comes to the majority of urban regions, air pollution becomes a major concern. Regarding the air they breathe, individuals ought to be informed. Data on a concentration of different air pollutants is produced by a National Ambient Air Monitoring Network; however, the average person may find this information difficult to comprehend [1]. A national AQI for cities in India is therefore established by the CPCB [4].

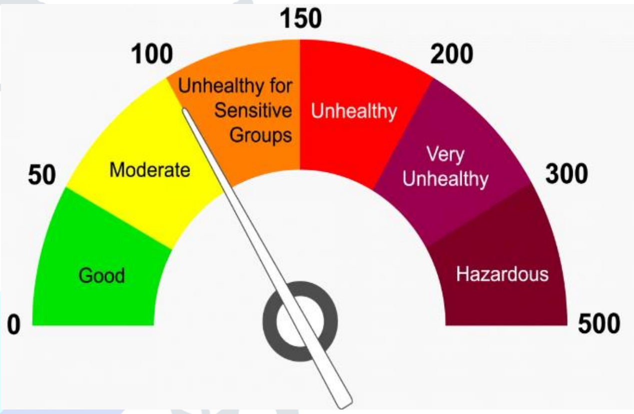

Fig. 1. Air Quality Index

The AQI is displayed in figure 1. AQI offers information regarding air quality or the degree to which the air in a specific area is polluted. Consequently, the AQI provides a qualitative representation of the surrounding air quality, which is associated with a variety of health effects. NO, CO, Particulate Matter (PM), SO2, and others are a most significant pollutants. The inadequate oxidation of propellants (petrol, gas, etc.) results in the production of carbon monoxide. Nitrogen oxide is generated as a result of thermal fuel combustion. Carbon monoxide induces vomiting and migraines; As a byproduct of smoking, benzene induces respiratory complications; nitrogen oxides induce vertigo and nausea. Particulate matter measuring 2.5 micrometres or smaller in diameter has a greater detrimental impact on human health. It is necessary to implement measures to reduce air pollution in the environment [2]. The AQI is a metric utilised to assess air quality. Formerly, air quality predictions were made using classical methods such as statistics and probability, which are now recognised for their exceedingly complex nature. Air pollutant data retrieval via sensors has become a straightforward process as an outcome of technological advancements. ML methods are the prevailing approaches utilised for air quality forecasting. The utilisation of ML algorithms guarantees the accurate prediction of future AQI, enabling the implementation of suitable measures [3] [4][5][6].

A. Problem statement

The imperative to maintain and regulate air quality has emerged as a critical concern in densely populated areas with numerous industries, businesses, and individuals. Population growth is accompanied by increased transportation, electricity, and fuel consumption. The presence of a substantial amount of refuse deposited on the land is common knowledge. In addition, the air is extremely polluted, which poses an even greater danger to all forms of life on Earth. This necessitates surveillance and evaluation of air quality; consequently, the government should be notified so it can implement the required measures. This research endeavours to conduct a comprehensive analysis of the primary studies conducted in this field through the utilisation of ML algorithms.

B. *Motivation of the study*

Air pollution is a significant concern due to the escalating levels of pollutants caused by technological advancements. The exacerbation of adverse health and climate consequences results from the ongoing degradation of air quality. Due to this rationale, a multitude of researchers examine the mechanisms governing pollution; however, the implementation of diverse chemical substances results in the exacerbation of air pollution. Monitoring air quality is important for reducing the usage of certain compounds, which helps to preserve air quality. A multitude of researchers are engaged in the development of automated air quality forecasting systems by employing efficient machine learning and data mining methods. The accuracy of the introduced techniques in predicting air pollutant levels is compromised due to the daily fluctuations in pollutant concentrations. As a result, greater attention must be paid to the recognition process when analysing air pollutants. In addition to this, the traditionally introduced air pollutant prediction techniques do not yet have the highest recognition results. Hence, the optimised and hybridised classification techniques are applied to meteorological data to forecast an air quality recognition result.

C. *Organized of this paper*

The rest of this paper follows: Sections II and III provide the overview of text sentiment analysis and sentiment analysis. Section IV gives the analysis of machine learning and their types then section V provide the machine and deep learning techniques VI section provide the literature review on text sentiment analysis on movie review. Last section provides the conclusion and future work of this work.

II. Air Quality Index (AQI)

An AQI is a quantifiable metric utilised for a consistent recording and reporting of air quality pertaining to different constituents with respect to human health [7]. The AQI is a daily reporting tool for air quality. It indicates a degree to which they are inhaling pure oxygen. The AQI is being implemented as a benchmark for air quality. This AQI provides the public with information regarding the environment in which they reside [8][9]. This information provides crucial insights into the pollution resulting from industrial emissions and can serve as a feedback mechanism to encourage industry-specific emission reductions. Additionally, it facilitates the allocation of financial resources to air pollution control boards. This AQI facilitates the ranking of various locations according to their pollution levels, thereby emphasising the most polluted regions and a frequency of potential dangers. The AQI facilitates the assessment of changes in air quality over a designated duration, allowing for the forecasting of air quality and the execution of pollution mitigation strategies. This AQI has been determined using air pollutants with significant concentrations.

There are hundreds of sources of air pollution in many locations, but the following are the most significant contributors: stationary power generation, automobile emissions, industrial and agricultural processes, surface re-emissions, manufacturing, chemical use, and natural processes. India is presently facing deteriorate in air quality, and forthcoming economic progress will lead to face a challenge in the management of air quality. The effects of emission of PM2.5 concentration had surpassed the national PM2.5 annual standard (40 µg m-3) in most of the cities in India. The majority of the PM2.5 exposure that is now occurring is due to sources that are associated with human activities. While the rest are from other natural sources [10]. Figure 2 depicts the various sources of pollution that cause toxics to air which cause health impacts.

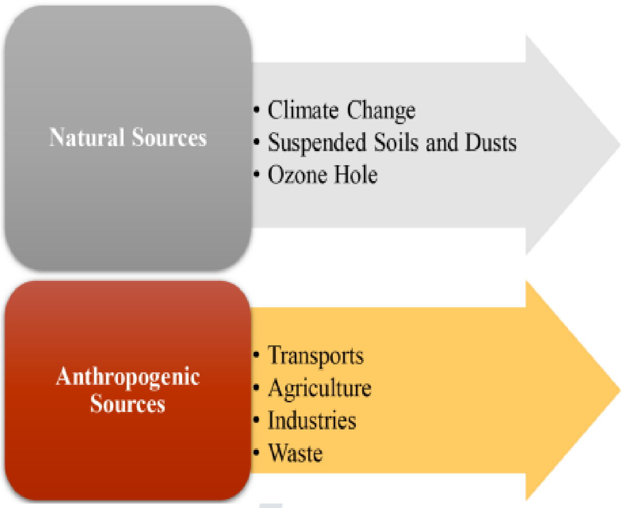

Fig. 2. Sources of Air Pollution

A. *Natural Sources*

Natural sources of air pollution include vegetation, dispersed sediments, seawater, and dust, including that which originates from the Sahara. Subsequent to volcanic eruptions and forest fires, additional natural sources emit gas. Even in remote locations, the emission of substantial quantities of smoke and hazardous substances can result in a prolonged escalation of ambient pollution levels. Ozone is one such instance of a pollutant.

- **Climate change:** Climate change is connected with Air pollution. The outcome of variations in weather would affect the local air quality. The burning of fossil fuels leads to increase in CO_2 and, in turn, releases greenhouse gases which cause global warming [11][12].
- **Suspended Soils and Dusts:** Dust from soil plays an important role in air quality. Wind is the main natural mechanism in the generation of soil dust. Wind erosion occurs when the air travels over the earth surface and suspend particulates in the atmosphere. Dust storm leads to inject a large quantity of soil dust into the atmosphere in a short period of time.
- **Ozone Hole:** Ozone is present in a stratosphere in relatively high concentrations; its principal function is the absorption of ultraviolet radiation. One of its numerous advantageous functions is to shield plants, animals, and humans from ultraviolet radiation of short wavelengths. Ground level Ozone is a dangerous pollutant of air which causes special effects on the public and the surroundings.

B. *Anthropogenic (Man Made) Sources*

Human actions are liable for world's man-made air pollution. Most anthropogenic contaminants are volatilised trace elements or released as very fine aerosols as a result of high-temperature combustion activities. The Anthropogenic sources lead to hazardous conditions in cities of huge residents. It is not possible to avert air pollution caused by nature, but it is possible to reduce air pollution and its effects caused by humans.

- **Transport - Roads and Rails:** The more powerful the vehicle, the more pollution it releases. Trains produce much less pollution when compared to cars on the same journey. However, trains still produce pollution. Electric trains run on power generated at power stations. In the usage of these fuels, PM, NO, and SO_2 are released into an atmosphere [13].
- **Agriculture:** The dust particles enter the air from heavily fertilised fields and animal waste. Hence most of the aerosol ingredients that affect the quality of air are from farming. The Environmental Protection Agency assessed that the agricultural zone plays a major role in US global warming emissions. Air quality that affected by agriculture mainly originates from ammonia which reacts with other contaminants in the air to produce fine particles that disturbs social breathing.
- **Industry and Power Generation:** Numerous factories were constructed in close proximity to major urban centres and villages. Present-day industrial centres are also situated in rural regions. The primary pollutants produced by industrial processes are nitrogen dioxide and sulphur dioxide. Power plants generate electricity through the combustion of fuels like gas, coal, and oil. These fuels have the potential to emit greenhouse gases, nitrogen oxides, sulphur dioxide, and particulate matter, all of which have the potential to contribute to climate change.
- **Waste:** Air pollution is caused due to gasses and matter dispersing from the junk waste. In the process of decomposing waste from agriculture and livestock, people release methane into the atmosphere, which leads to global warming. Plastic waste in the exposed space is also a major source of air pollution.

1) Environmental Impact of Air Pollution

The environmental condition in which they reside is being adversely affected by air pollution [14]. The subsequent points delineate the most significant environmental impacts.

a) Acid rain

The term "acid rain" refers to precipitation that contains potentially harmful amounts of nitric and sulfuric acids, whether it is moist (snow, fog, or rain) or dry (gas and particles). In addition to harming trees and plantations, they may also degrade soil and water quality, which in turn can destroy man-made buildings, outdoor artwork, and sculptures.

b) Haze

Haze is produced when minuscule particulates disperse within the atmosphere, thereby obstructing the line of sight to the sky. It is brought about by the functioning of factories, power plants, cars, and other vehicles that release gases into the environment.

c) Ozone

On the contrary, ground-level ozone is a pollutant and detrimental to human health. Regrettably, ozone-depleting substances—including chemicals, pesticides, and aerosols—degrade stratospheric ozone over time. The depletion of the protective stratospheric ozone layer could potentially expose Earth to UV radiation, which has the potential to induce harm to crops and human life, including skin cancer [15]. The infiltration of ozone into plant stomata induces their closure, impeding the transfer of CO_2 and consequently leading to a reduction in photosynthesis [16].

d) climate change

Climate change on a global scale is a significant concern for all of humanity. It is common knowledge that the "greenhouse effect" maintains a constant global temperature. This protective temperature effect has been sadly obliterated by human activities through the emission of vast quantities of greenhouse gases; as a result, global warming is intensifying, posing a threat to agriculture, human health, animals, forests, wildlife, and the aquatic environment. According to one report, global warming exacerbates the health dangers faced by the impoverished[17] [18].

e) Wildlife

Wildlife is adversely affected by toxic pollutants originating from the atmosphere, soil, or aquatic environment; consequently, prolonged exposure to such pollutants can lead to adverse health effects in animals. Birth complications and reproductive failure have been documented.

f) Eutrophication

Eutrophication transpires when heightened nutrient concentrations, particularly nitrogen,promote a proliferation of aquatic vegetation, leading to an imbalance in fish diversity and subsequent death.

Indirectly related to the capacity of an ecosystem to neutralise acidity, there is unquestionably a minimum concentration of pollution that it can withstand before it is annihilated. Ozone-exposed plants exhibit a discernible disruption in both photosynthetic rhythm and metabolism [19][20].

2) Challenges and Limitations of air quality

- The levels and varieties of pollutants will differ between locations. Additionally, the origins of pollutants vary, including natural and manmade.
- Every pollutant is capable of causing detrimental effects on human beings.
- The monitoring stations shall provide quantitative data on a diverse array of pollutants. The prevailing data availability is typically a 24-hour average.
- The AQI calculation for a specific location necessitates the inclusion of all pollutants. The majority of pollutants fluctuate over time. Managing an enormous quantity of data will be a challenging endeavour.
- A greater amount of research has been devoted to the prediction of specific pollutants, but not the AQI.
- The information may not be provided for a statutory purpose, as it is provided directly to the public without any scrutiny from the analysers for real-time AQI.
- The process of monitoring and reporting AQIs subsequently encompasses a multitude of procedures, which comprise the functioning of sensors and analysers, their calibration, acquisition of data by a local server, transmission to a central database via the Internet, and more. Monitoring station functionality may also be impacted by a variety of operational and technical factors, including extended power outages and maintenance problems [21].

Considering these limitations, there is a possibility that the uninterrupted flow and distribution of information may be disrupted. Nevertheless, in the case of malfunctions, prompt measures are implemented to reinstate the system to functioning status within a rational timeframe. Machine learning algorithms were analysed and evaluated to prediction of air quality forecasting.

III. Machine And Deep Learning

ML is a subfield of computer algorithms that involve the construction of learning rules based on previous experience using data that already exists. ML is a subfield of AI concerned with determining how to interact with data so as to extract information that can be applied to future decision-making. Implementing statistical, logical, and mathematical learning strategies on the data may impede the acquisition of principles [22][23]. The dataset consisting of data examples utilised to assess the learning model's performance is known as the testing dataset, whereas the training dataset comprises the data examples utilised in the construction of the learning model. Machine learning (ML) techniques are implemented in various domains, shown in Figure 3, including but not limited to computer science. In addition to bioinformatics, health informatics, computer vision, and voice recognition, these disciplines consist of cyber-security, industrial engineering, traffic systems, and object recognition. This investigation is preoccupied with the utilisation of ML algorithms in the field of bioinformatics.[24].

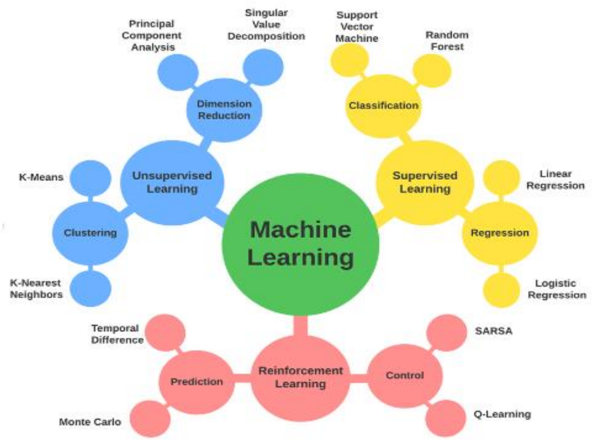

Fig. 3. Machine learning

Methods for ML can be categorised into one of three distinct approaches based on the utilisation of labels or not. The subsequent enumeration delineates every category:

A. Supervised Learning

Supervised learning algorithms generate a mathematical model by utilising a dataset comprising the intended outputs and inputs, as shown in Figure 4. Typically, a subset of the entire dataset, referred to as training data or a set of training examples, is chosen at random. A desired output, known as a supervisory signal, is integrated with one or more inputs in the training data. Each feature vector, which is an array or vector, is utilised to represent a training dataset within the mathematical model [25]. In order to represent training data, a matrix is utilised. Supervised learning algorithms learn from a model using a function that may be used to predict the result given fresh inputs by repeatedly optimising an objective function. The algorithm accurately calculates the result for non-training data inputs by utilising an optimal function.

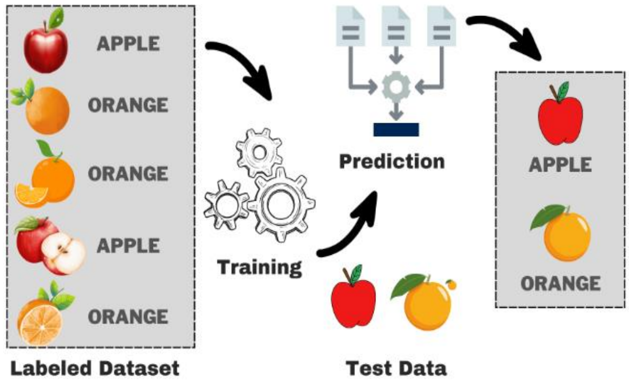

Fig. 4. Supervised learning

B. Unsupervised learning

Unsupervised learning methods categorise data without labels into similar subsets shows in Figure 5. It's a strategy used by machine learning programmes. Information that is not tagged nor classed is ignored.[26]. This frees the system from acting on the data without intervention from a human. Grouping unsorted data according to patterns, differences, and similarities is the work at hand in unsupervised learning, which requires no preexisting knowledge of the data. In unsupervised learning, a computer is not given any training data or human direction. As a result, machines like ours can't unearth the underlying structure in unlabeled data. A further subdivision of unsupervised learning is clustering or association. The system might, for instance, group information together based on the frequency with which particular words or word combinations appear. Unsupervised learning methods like labels and clustering are unavailable during the training phase. Opinions are expressed and classified utilising a set of established syntactic patterns. [27].

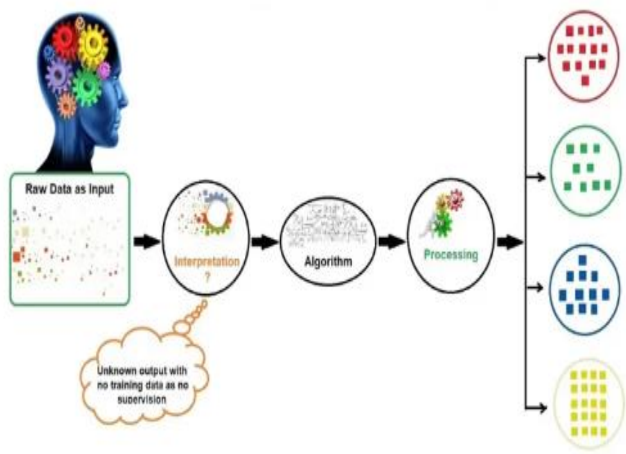

Fig. 5. Unsupervised learning

C. Reinforcement learning

Learning through a system of action-reward as seen in animals or humans, is the basis for reinforcement learning shows in figure 6. When a newborn first learns to walk, he is driven by instinct to explore his environment and discover all of its potential. Children learn by experiencing the positive and negative outcomes of their behaviour [28][29].

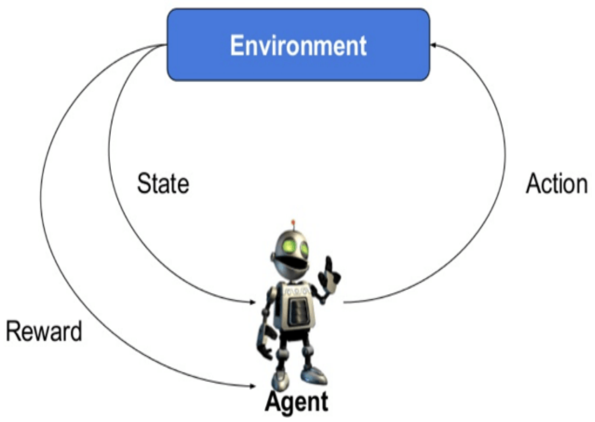

Fig. 6. Reinforcement learning

When applied to large Markov decision processes, when accurate approaches become impractical, reinforcement learning algorithms vary significantly from traditional dynamic programming techniques because they do not require prior knowledge of anexact mathematicalmodel of the Markov decision process.

IV. Literature Review

The current body of research in this domain predominantly employs statistical techniques and rudimentary ML models to tackle a challenge of forecasting air quality.

In this research, Saikhu et al., (2023) a solution is found by developing an air pollution forecast that makes use of spatio-temporal data. This research implementation employed a variety of deep learning methodologies, including Bi-LSTM, GRU, and LSTM. By obtaining the lowest MAPR value of 1.25% and the highest R2 value of 0.998, LSTM outperforms other models when applied to spatiotemporal data to predict air pollution[30].

This paper, Li, Deng and Tang, (2021) applies data mining techniques to the fullest extent possible, including neural networks, intelligent optimisation algorithms, and mutual information theory. The fundamental data utilised as both the training set and test set are long-term air quality predictions from open monitoring points. Prior to analysing the correlation between various monitored pollutants, the SOM neural network model is applied to relevant pollutant data for unsupervised clustering. In order to address the challenges presented by the algorithm's lengthy calculation time and the volume of data, an NSGA-II optimised neural network is suggested for predicting future pollution conditions in conjunction with the clustering results. The experimental findings indicate that the accuracy of pollutant predictions can exceed 90%[31].

This paper, Tran et al., (2022) presents a proposal for an IoT-integrated air quality monitoring and forecasting system that aggregates multiple pollution factors totrack and forecast airpollution in a designated region. For a number of months, air quality data was gathered. Regarding execution time, RMSE, MSE, MAE, and R-squared, the KNN model exhibited superior performance compared to all others. Future air quality is then predicted utilising the ARIMA and LSTM algorithms. The result indicates that, at 96%, our system predicts air quality factors for the following hour with the maximum degree of accuracy of any system. An air quality monitoring and forecasting web interface was ultimately devised[32].

In, Kekulanadara, Kumara and Kuhaneswaran, (2021) utilised the dataset, which comprises hourly measurements of multiple air pollutant categories collected from various stations in numerous Indian cities. Hourly data commenced on January 15, 2015, and concluded on July 1, 2020. A total of sixteen attributes existed. The DT, SVM, and RF were implemented. A random forest classification algorithm produces the most precise classifications. Compared to the alternative methods, it achieved a peak accuracy of 74%. These findings will aid in the advancement of current research and provide direction for future investigations[33].

In this study, Li, Deng and Tang (2021) To improve the predictive model for air quality in the Wuling mountain area, ML techniques are implemented to forecast air quality in that region. Exams involving air quality prediction utilise deep backpropagation neural networks, random forests, or decision trees. A comparison was made among the forecasted and observed values using the MSE (MAE). MSE (MAE) values for the deep back propagation neural network, RF, and DT at the Huaihua station in the Wuling mountain area are 3.54 (1.28), 8.35 (1.92), and 5.01 (1.61, respectively). Furthermore, in terms of performance, random forest outperformed both deep back propagation neural networks and decision trees[31].

TABLE I. COMPARATIVE ANALYSIS OF AIR QUALITY PREDICTION USING VARIOUS METHODS AND TECHNIQUES

Ref	Methodology	Data set	Performance	Limitations & future work
H. Liu [34]	RFR, SVR	California	RMSE, R-SQUARE, Correlation Coefficient (r)	Predicting pollutants and AQI with high accuracy using SVR with RBF kernel.
Wang et al. [35]	Forecasting using ANN algorithm	Real-time sensor data of downtown Toronto, Canada	ANN provides flexible modeling; better accuracy with increased dataset size.	Prone to overfitting with large datasets; computational complexity.
Ke et al. [36]	Integration of diverse data sources with ML models	Meteorological data, pollutant concentrations, emissions data	ML models combined with ensemble method predict six common pollutants; hyperparameter optimisation.	Dependency on data quality and availability; computational demands.
(Wood, 2022) [37]	Regression modelling using SVR algorithm	Dallas County (Texas, USA)	SVR achieves good prediction performance for combined air quality benchmarks (CLAB).	Sensitivity to parameter tuning; computational demands.
Masmoudi et al. [38]	Regression modelling with Random Forest	UCI dataset	Combination of methods improves prediction of multiple pollutants.	Vulnerable to overfitting; complexity increases with the number of targets.
Chang et al. [39]	LSTM extension incorporating regional sources	Various locations	ALSTM integrates regional pollution sources for early forecasting.	Complexity increases with the number of integrated sources; data dependencies.
Liu and You [40]	Time series analysis model for forecasting	Beijing, China	ARIMA performs comparably to LSTM for short-term AQI prediction in Beijing.	Limited by historical data; assumes stationarity in time series.
Gopu et al. ,[41]	Time series analysis model for forecasting	Various locations	ARIMA effectively forecasts pollution levels based on historical data.	Limited ability to capture non-linear relationships; sensitive to outliers.

A. *Research gaps*

Although a lot of progress has been achieved in air quality prediction using different machine learning and statistical methods, there are still a lot of unanswered questions and problems. Improving prediction models to account for the complicated spatio-temporal dynamics of air pollution is a key area where knowledge is lacking. There is a lack of generalizability across varied geographical areas or models that do not capture the full complexity of pollution interactions since existing research frequently concentrate on specific locations or use restricted datasets. The complexity of trustworthy and scalable prediction frameworks is even further magnified by issues of the deep learning model computational needs, the reliance on data availability and quality, the fitting danger, and the parameter adjustment sensitivity. Overcoming these limitations and bridging the gaps requires cooperation between researchers from various fields, development of new algorithms and access to large-scale high-quality data to generate more accurate, scalable and beneficial air quality models.

V. Conclusion And Future Work

Air pollution poses detrimental effects on both the natural environment and human life. Air pollution occurs when the concentration of specific substances in the atmosphere surpasses a specified threshold. Air quality and PM2.5 forecasting is one of the most effective pollution management measures. Thus, a conclusion is that the research leads to the understanding that a regular air pollution monitoring is important as well as in making the air quality forecasts. Advances in air quality forecasting, health risk evaluation, and decision-making on policy have been all resulting grounds of machine learning applications utilisation. However, it is not complete removal of the hurdles is still there despite a lot of approaches and new technologies. Among the many challenges encountered in the process of model development are those pertaining to the disentanglement of pollutant interactions, the improvement of the generalizability over varied geographical areas, and the resolution of concerns related to data quality, model overfitting, and model parameter sensitivity. Technical improvements in prediction models, wider availability of large-scale and highly accurate data sets, and more interdisciplinary collaboration should become a research priority in the future. Gaps of the environmental management and public health can be filled up and the problems they caused can be fixed with the air quality prediction models to be more accurate.

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