



Smart Monitoring and Prediction of Industrial Pollution Using IoT and ANN

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Abstract. The environment suffers greatly from industrial pollution, which emits harmful gases such as sulfur dioxide and carbon monoxide. These emissions lead to the formation of smog, acid rain, and global warming, besides adversely affecting the respiratory system. In comparison, the high concentration of carbon dioxide and other greenhouse gas emissions leads to rising temperatures due to ice caps melting and extreme and violent storms and drought which directly threaten terrestrial life. Its pollution also contaminates drinking water with toxic substances besides industrial machinery noise disrupting normal ecosystems. Chemical spills have also been known to raise environmental damage besides land deterioration that affects biodiversity and results in long- term ecological destabilization. This paper offers a solution for integrating Machine Learning and Internet of Things (IoT) technologies into the MATLAB platform to mitigate pollution monitoring and management. IoT-based technologies make it possible to monitor levels of pollutants in real-time, and comparison with established thresholds sends an alert in case limits are exceeded. Predictive algorithms of machine learning classify the diverse field parameters, identify trends, and forecast future events that may arise due to pollution. This approach will ensure timely prevention, maintaining pollution levels within acceptable limits. The system is intended to reduce overall pollution, safeguard biodiversity and public health, and promote long-term environmental sustainability.

Keywords: Internet of Things, Machine Learning, Embedded System, Artificial Neural Network

1 Introduction

Pollution is the introduction of harmful substances, and materials causing adverse effects on living organisms, ecosystems, and natural resources. These contaminants known as pollutants cause several health problems and respiratory issues, that cause major threats to human civilization. For example, Mining releases heavy metal ions, in the mixture of arsenic, cadmium, lead, mercury, and zinc. They affect soil, water, and human health [1][2]. There are various kinds of pollution water, air, and Soil Pollution. All this has various impacts on Human-Nature Coexistence. Focusing on air pollution that are tiny particles that are harmful when inhaled [2][3][4]. There are some methods for controlling pollution One of them is the "Novel Pollution Prevention Process" which is not just a pollutant concentration but it also reduces pollution to meet environmental compliance effectively. And the other method is the "Tree-Ring" which is a heavy metal analysis in tree rings. It is the historical impact of pollution and aids in monitoring changes over time [4][10][11]. Coming to noise pollution, an average of 75 dBA is an acceptable limit.

In noise pollution immediate zoning and mitigation measures are essential. High noise levels, up to 90 dBA were recorded from targeted urban planning. The monitoring system leverages IOT and ZigBee networks. This system facilitates open access to air. And it also helps in smart city infrastructure [11][12][13]. Also, we have "Indoor Air Pollution" which is a traditional receptor model that helps to identify the IAP. And it also has HEBIS that shows public health improvements and economic gains [12][16][17]. This system also uses IoT and ML to enable real-time water quality which is also used to monitor using sensors, and also collects data to predict patterns and improve decision-making. It also has a traditional water monitoring system in which there are of high costs which helps to provide continuous, real-time, and cost-effective solutions [17][9]. An IoT-Edge-Cloud platform is used to monitor PM levels to predict unsafe environments. By combining edge computing and cloud we can ensure a safe workplace.[7].

There are still more ways to predict the air pollution. It also makes use of AI models to detect and predict pollutant levels. This system effectively monitors various pollutants, including hexavalent chromium, VOCs, and particulate matter. AI models especially LSTM and Random Forest shows high accuracy. And this helps in improving workers safety [7][22]. There are various separation process and technologies available for treating air pollution, and industrial flue gases. These processes are used to control air pollutions like Co₂, Sox, Nox and trace metals. This also focuses on efficiency, Cost and the potential for improvement [27].The cost-effective air quality monitoring system uses multiple sensors like(MQ-2, MQ-7, MQ-8, MQ-135, DHT11) which helps to monitor various pollutants such as CO, CO₂, H₂, smoke and environmental conditions like temperature, humidity which helps in real-time and even in smart cities[27][31]. Focusing on water pollution, microplastic pollution in an urban lake in Northern Europe has many effects. There are research proved that there is a large amount of microplastic

concentration in summer compared to winter. The most abundant polymers were polyethylene, polystyrene, and polypropylene are present in water substance. We have to do filtering and sediment trapping to control these measures [23]. We should know the importance of water quality management to prevent contamination and ensure safe water supply. We first need to know about the importance of water quality, and we have to start identifying the contamination sources, and we should as know the suitable treatment methods and techniques to avoid health risks. And we also need to study about the metal species and their regulatory limits in drinking water [23][28].

Another main cause of water pollution is oil refinery industry which they contaminates water equally. This is proved by scientific investigation and effective monitoring [29]. We can also use IoT-based smart water quality monitoring systems, where it effectively measures the quality of the water undergo various processes and demonstrate its effectiveness through testing[29][30]. This also has a solar-powered, IOT-enabled system using LoRaWAN technology that captures real-time data on pH, TDS, turbidity, and temperature in rural areas. This helps us to demonstrate its effectiveness and reliability through field testing and laboratory validations [26]. Focusing on Machine learning plays a critical role in hybrid pollution and control systems, which also helps in enhance their efficiency, adaptability, and accuracy. The hybrid pollution control system combines multiple data sources, such as sensors, satellite imagery, and datasets that helps us to monitor air, water, and soil pollution. It helps in data collection and Integration, Pollution Prediction, Pollution Control, and Advanced ML Techniques in pollution and Control which focus on Supervised Learning, Unsupervised Learning, Reinforcement Learning, and Deep Learning. In helps in air pollution monitoring by estimating the pollutant's concentration. it also monitors water quality assessment to predict contamination events. It also helps the SI-powered systems and in creating pollution-aware city design using modeling that impacts traffic, infrastructure, and natural barriers [7][9].

2 Literature Survey

Pollution are harmful substances or contaminants into the environment, that cause adverse effects on living organism. It can occur in various forms and originate from numerous sources, both natural and human-made. There are lots of effects on pollution such as health impacts, environmental damage, economic consequences and social impact [1][2]. There are water, soil, and air pollution and many causes, such as industrial, transport, agriculture, and urbanization- related activities along with natural conditions. There is also evidence that has already been suggested that results from pollution cause respiratory illnesses, cancer, loss of biodiversity, climatic change, reduced agricultural yields, increased cost of remediation measures, and most importantly loss of quality of life [2][3][4]. There are some solutions to prevent pollution in which we can make our environment pollution some solutions are government regulations, renewable energy,

waste management, public awareness, technological innovations, and afforestation all this will help in making our environment pollution-free and gives us a healthy life [4][10][11]. Focusing on air pollution it is the contamination of the atmosphere by harmful substances, which is the mixture of harmful gases, particulates, and biological molecules. It also causes various risks to human health, the ecosystem, and also the climate [12][16]. Even in air pollution we have various types like Particular Matter (PM) in PM we have PM_{2.5} and PM₁₀ there are tiny particles that gets penetrate deep into the lungs and bloodstream the source for such kind of pollution is vehicle emissions, etc. The next type is gaseous pollutants such as Carbon Monoxide (CO), Sulfur Dioxide (SO₂), Nitrogen Oxides (NO_x), and Ozone(O₃) are this are also the main cause of air pollution where CO₂ is produced by the combustion of fossil fuel. SO₂ is by burning coal and oil. NO_x is by high-temperature combustions in vehicles and O₃ is the secondary pollutants that are formed from the reaction of sunlight with Nox [16][17]. Another significant factor to consider is Volatile Organic Compounds (VOCs), which encompass emissions from paints, solvents, and industrial processes. Furthermore, it is crucial to address Greenhouse Gases (GHGs), as they emit Carbon Dioxide (CO₂), Methane (CH₄), and Nitrous Oxide (N₂O), which are primary contributors to global warming, climate change, and acid rain. Additionally, pollution can originate from natural sources. These natural sources of pollution include events such as volcanic eruptions, forest fires, and dust storms [7][22]. Some major effects of air pollution are health impacts that cause respiratory diseases like asthma, bronchitis, and chronic obstructive pulmonary disease (COPD). The second is environmental damage such as acid rain caused by SO₂ and NO_x, and smog which reduces visibility, and ecosystem disruptions such as plant growth and animal habits. And also focuses on climatic changes that alternate weather patterns, rising sea levels, and extreme events [22][23].

The solutions in this regard include policies and regulations, technological improvements, urbanization, and public awareness; besides these international endeavors to combat air pollution consist of the Paris Agreement on reducing the overall level of greenhouse gases in the entire world. The World Health Organization provides guidelines on air quality standards. UN Initiatives also consist of movements like Clean Air for All [23][6]. Water pollution, it involves the introduction of harmful substances into various water sources, including rivers, lakes, oceans, aquifers, and groundwater. This contamination renders these water bodies unsuitable for drinking, recreational activities, agricultural use, and the well-being of aquatic ecosystems [23]. There are some ways in which water is getting polluted such as chemical pollution such as industrial chemicals such as heavy metals like lead, mercury, and arsenic. Pesticides and Herbicides from agriculture runoff and oil spills that are leakage of oil into oceans and seas. There is also some biological pollution also which is the presence of pathogens such as bacteria, viruses, and parasites which all come from untreated sewage and agricultural waste. Some of the physical pollution such as sediment pollution such as soil particles washed into water bodies, reduces light penetration. And Eeben we have nutrient pollution in which there is excess nitrogen and phosphorus from fertilizers causes algal blooms, which leads

to oxygen depletion (eutrophication)[28]. Some global measure taken for this is UN Sustainable Development Goal 6 which focuses on ensuring the availability and sustainable management of water and sanitation for all. MARPOL Convention which helps in regulating marine pollution that is caused by ships.

The Global Plastic Action Partnership (GPAP) strives to decrease plastic pollution in marine environments [29]. Additionally, the application of the Internet of Things (IoT) and Machine Learning (ML) technologies is revolutionizing industries by facilitating the creation of intelligent, interconnected systems. IoT describes a network of internet and responding to data [30]. Key elements of IoT include data-collecting sensors and devices, connectivity protocols such as Wi-Fi, Bluetooth, or cellular networks for data transmission, and cloud-based IoT platforms for data storage and processing [7]. Machine Learning, a branch of Artificial Intelligence (AI), empowers systems to recognize patterns within data and make autonomous predictions or decisions without explicit programming instructions. Some of the main components of ML include data, which are obtained from IoT devices, and Algorithms that help in supervised learning, unsupervised learning, and reinforcement learning, and then there are the models-trained algorithms that help in predictions or decisions. We can use this ML for Image Recognition, Predictive Maintenance, Fraud detection, and Personalization. This will integrate both, help generate a massive amount of data, and provide the tools to analyze it and extract actionable insights from it [1][4][10][21].

3 Experimental Methodology

The described system employs various sensors to gather environmental data, including sound, air quality, water pH, turbidity, and temperature. These sensors continuously monitor conditions and transmit readings to an ESP32 controller, which serves as the central processing unit. The ESP32 aggregates and sends this information to the Thing Speak IoT platform for remote access and visualization, while also comparing sensor readings to predetermined thresholds for comprehensive pollution monitoring. This setup utilizes a hybrid approach, combining real-time monitoring with predictive analytics. The ESP32 controller constantly evaluates sensor data, triggering immediate alerts via a buzzer and LCD screen display if any parameter exceeds its set limit. The LCD screen functions as a local interface, showing current values and identifying parameters that have surpassed safe thresholds, ensuring prompt notification of on-site personnel Figure 1. Complementing the real-time alerts, the system incorporates predictive analytics using MATLAB and an Artificial Neural Network (ANN). The ANN model is trained on the initial half of the collected data to forecast future pollution levels. By examining historical patterns, the ANN predicts the probability and intensity of upcoming pollution events. This forward-looking feature is crucial for proactive environmental management, allowing users to anticipate potential risks and implement preventive measures before pollution reaches hazardous levels. The ANN integration enables the system to provide

valuable insights beyond immediate responses, offering stakeholders a tool for long-term planning and mitigation strategies.

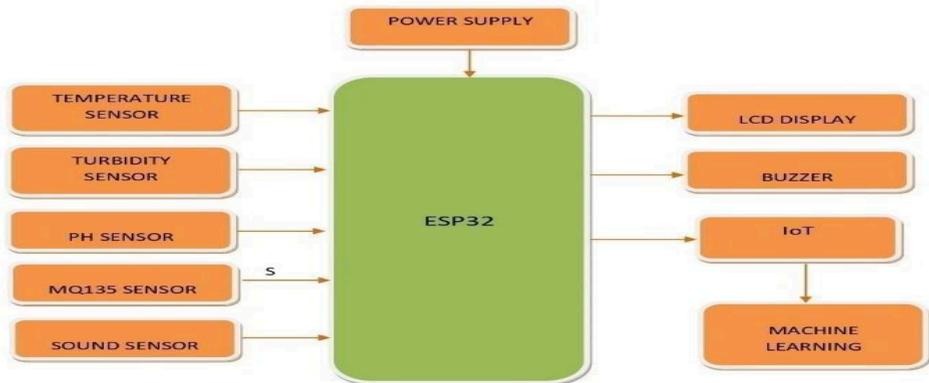


Fig. 1. Pollution Monitoring Block Diagram

All sensor data is continuously uploaded to the Thing Speak IoT platform, a cloud-based system that enables real-time visualization, data storage, and advanced analytics. This platform allows remote access to pollution data through user-friendly dashboards, providing insights into both current and historical pollution levels. The combination of local monitoring via the LCD and global accessibility through Thing Speak enhances the system's scalability and user-friendliness. By combining the ESP32 controller, IoT technology, and ANN-based predictive analytics, this system presents a robust and cost-effective solution for pollution monitoring. The inclusion of audible and visual alerts ensures timely action during critical events, while the ANN's predictive capability offers a clear view of future challenges. This adaptability makes the system suitable for various applications, such as industrial pollution control, urban air, and water quality management, and environmental monitoring for smart cities. The seamless integration of real-time monitoring with predictive analytics establishes the system as an effective tool for addressing both environmental and health risks associated with pollution.

4 Proposed System

This system depicts a holistic approach that integrates the use of IoT-enabled sensors, continuous monitoring capabilities, and predictive analytics to monitor the levels of pollution and develop actionable alerts. The framework employed in this context incorporates an assortment of sensors that are comprised of Sound Sensors, MQ135 devices for assessing air quality, pH Sensors for testing water quality, Turbidity Sensors for measuring the clarity of water, and DS18B20 units for temperature monitoring. These sensing instruments are strategically located to collect data on critical environmental parameters. Acting as the central processing component of the system, the ESP32 microcontroller handles and analyzes data collected by various sensors.

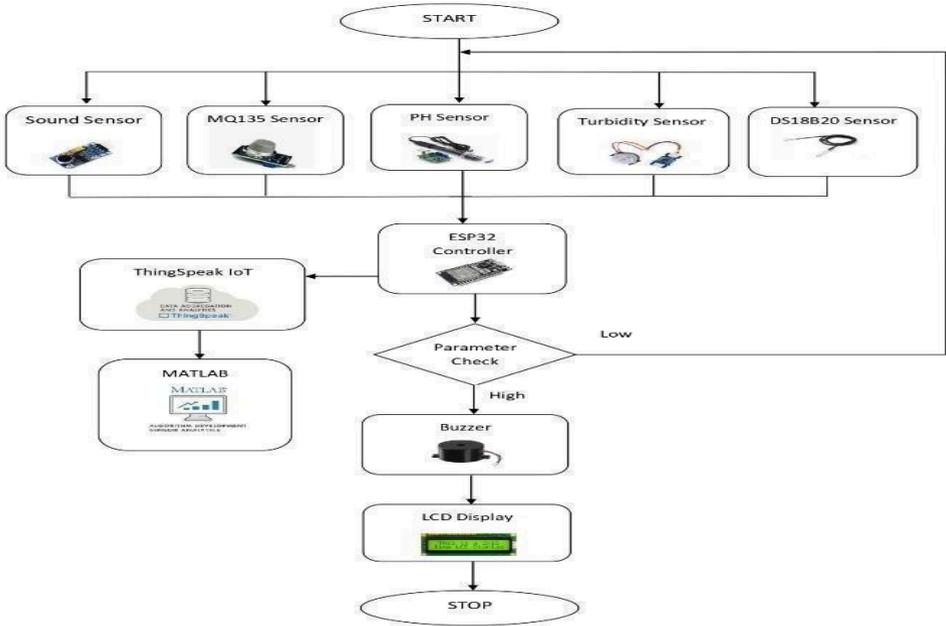


Fig. 2. Machine learning Module-Monitoring Module

The ESP32 aggregates sensor data and processes it before sending it to the Thing Speak IoT platform for further analysis and visualization. The system uses a threshold-based approach where every parameter is cross-checked against set point Figure 2. When the

measured values go below the thresholds, it records the data and shows them on an LCD screen; then, it transmits data to the Thing Speak IoT platform for remote monitoring. The moment any parameter exceeds the threshold, the system gives a signal by activating a buzzer that alerts the people present in the nearby region. The LCD screen shows the critical value in an obvious manner so that the user can quickly identify and respond to abnormal situations (Figure 3). This immediate feedback system allows for a quick response to possible environmental risks, thus reducing the dangers of pollution.

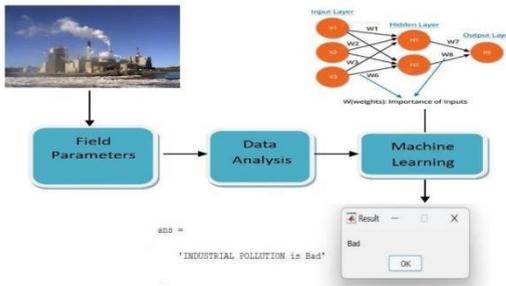


Fig. 3. Sensor Data Acquisition via ESP32

This system is suited to industrial pollution control applications, monitoring of urban air and water quality, and environmental management in smart cities. This system gives instantaneous alertness to critical events due to pollution and provides trends with ANN-based forecasting so that interventions can be undertaken well in advance to mitigate adverse environmental and health effects. This system ensures both usability and scalability by integrating remote access through Thing Speak with local monitoring in real-time by using LCDs. Its cost-effectiveness, flexibility, and scope for dealing with different environmental issues make it a practical and efficient solution

5 Results and Discussion

The architecture and working of the ANN are well depicted in Figure 4, where the MATLAB implementation has been done. Thus, the ANN model with multiple layers such as input, hidden, and output layers contributes to an efficient classification of pollution levels. Data preprocessing is ensured along with normalization. In that case, the error rate minimization of the algorithm has been trained in advance. MATLAB simulations indicate the effectiveness of ANN over real-time data and ensure its reliable predictions with negligible deviations.

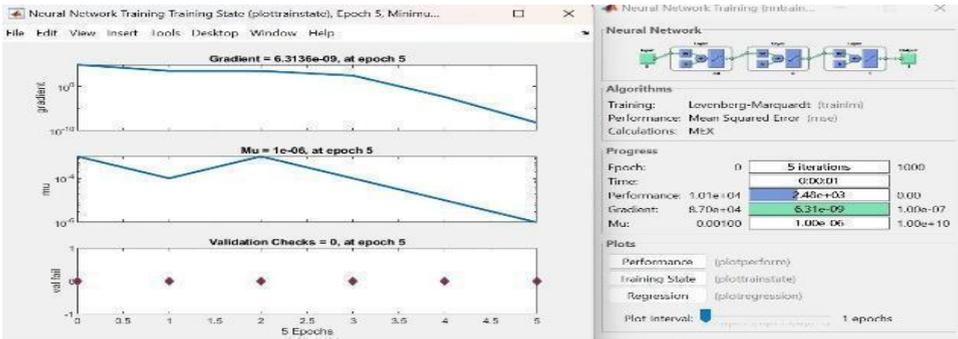


Fig. 4 ANN Algorithm in MATLAB

The functionality of the IoT-based monitoring system is well represented in the data visualized in Figure 5, showing the trends of air pollution through real-time data collected from ESP32 and displayed on the Thing Speak platform. This Figure captures the essence of the system's remote monitoring of air quality while offering critical insights to its stakeholders regarding the levels of pollution. The graphical information depicts a consistent monitoring mechanism and offers actionable information regarding environmental management.

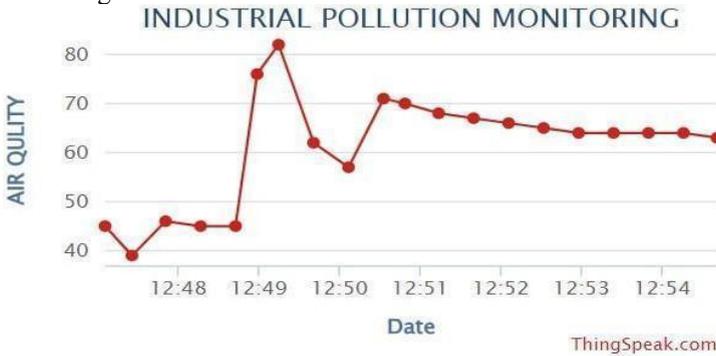


Fig. 5 Air Pollution Monitoring Data

Another important parameter in monitoring pollution is the quality of water, expressed as pH levels in Figure 6. The real-time data presented highlights the system's accuracy in measuring the changes in pH, which may be a sign of contamination from industrial discharge. The outcome depicts continual monitoring, thus maintaining ecological balance in water bodies. This notwithstanding, pH is one criterion; the clarity of the water is shown as indicated by turbidity in Figure 7. This outcome is set to show how sensitive sensors are to changes in a turbidity level and what this may indicate. The graph validates

the system's role in identifying water quality issues promptly, aiding in swift intervention.

INDUSTRIAL POLLUTION MONITORING



Fig. 6 PH Monitoring Data

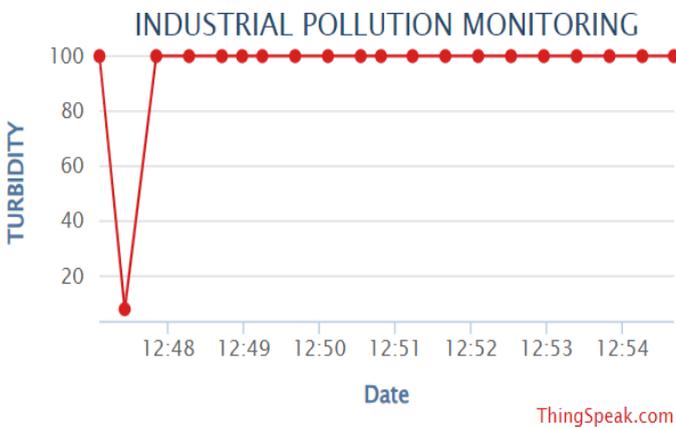


Fig. 7 Turbidity Monitoring Data

This is mainly the monitoring of thermal pollution, and Figure 8 will show temperature data captured through the field sensors. There's an indication of fluctuation of temperatures over time, signifying that the system does well in anomaly detection. That is the feature useful in identifying and mitigating some potential sources of thermal pollution in industrial areas.

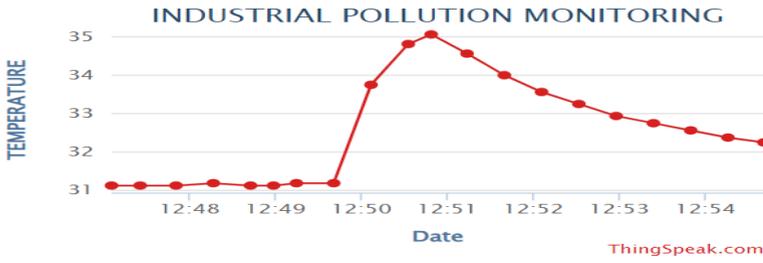


Fig. 8 Temperature Monitoring Data

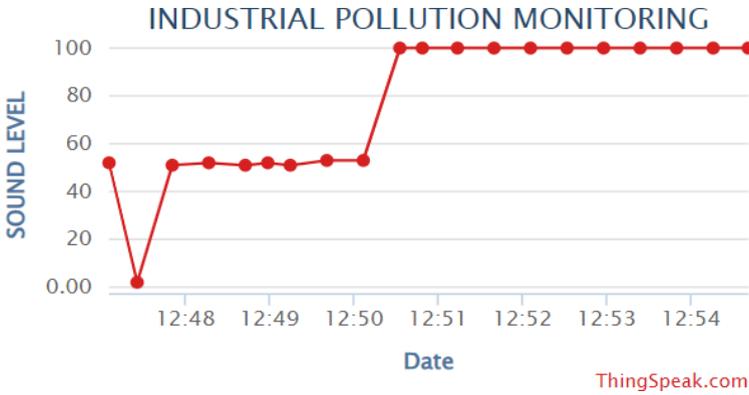


Fig. 9 Sound Monitoring Data

Figure 9 captures the monitoring of sound pollution. Real-time tracking of noise levels by the system is presented by data displayed on the LCD and uploaded to Thing Speak. When the noise crosses the predefined threshold values, the system initiates warning messages and a buzzer to alert personnel present nearby. This two-tier alerting mechanism will help immediately address harmful noise levels and thereby enhance the efficiency of the management of pollution.



Fig. 10 ANN Prediction Results

Figure 10 indicates the efficacy of the artificial neural network for environmental pollution forecasts. The algorithm predicts how bad or good the environmental scenario is through processing history data and sensors in real-time; thus, it enacts proactive decisions. Very accurate results of prediction and proof of its robust model ability to efficiently manage data are shown by the developed ANN model on industrial pollution data. Figure 10 indicates the efficacy of the artificial neural network for environmental pollution forecasts. The algorithm predicts how bad or good the environmental scenario is through processing history data and sensors in real-time; thus, it enacts proactive decisions. Very accurate results of prediction and proof of its robust model ability to efficiently manage data are shown by the developed ANN model on industrial pollution data.

6 Conclusion

This innovation introduces a novel approach to the monitoring of industrial pollution through IoT technology combined with machine learning in the form of an Artificial Neural Network (ANN) algorithm to deliver accurate, instantaneous, and forward-looking insights. Contrary to traditional systems of pollution monitoring, this project utilizes IoT-enabled sensors and the ESP32 microcontroller to gather data continuously and transmit it to remote platforms for observation through platforms such as ANN contributes significantly to the innovation by examining intricate, nonlinear data relationships and forecasting future pollution patterns and enabling stakeholders to implement preventive measures before they are surpassed by critical limits. A two-tiered alerting mechanism is a peculiar feature that integrates real-time data displayed on an LCD screen as well as an audible alert via a buzzer. This means that while action might be taken in the premises, the benefits of a remote access device are preserved. The adaptability of the system, which extends to monitoring other parameters in pollution, such as turbidity of water, pH, temperature, and levels of noise, demonstrates adaptability and expandability for general environmental applications. This project merges predictive analytics with real-time monitoring to not only enhance pollution management but to also present a scalable and cost-effective solution adaptable to various industrial environments. Such an integration of IoT and ANN technology underlines the potential for technology-driven sustainability in industrial operations.'

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