IOT ENABLED WASTE FIRE POLLUTION MAPPING

Aligned with SDG 11: Sustainable Cities and Living

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Vikram Jirgale

Second Year, BTech (Computer Science with AI & ML)

Vishwakarma Institute of Technology Pune, 411037

Maharashtra, India

The goal of this project is to create an Internet of Things (IoT) enabled device that can identify and analyse the amounts of harmful gases generated during waste fires. This understanding of the amount of pollution caused by garbage burning in areas of a town helps real-time monitoring and mapping using GIS software.

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1. ABSTRACT

The escalating frequency of wastefires poses a significant environmental threat, deteriorating air quality and increasing global pollution levels. This project focuses on developing an advanced IoT-enabled device to detect wastefires and analyze the concentration of gases released during combustion. The primary goal is to predict the extent of pollution caused by wastefires in specific localities, providing real-time data monitoring.

Given the critical nature of increasing pollution as a global issue, wastefires are substantial contributors. The IoT device is strategically deployed in fire-prone areas, continuously monitoring concentrations of key air pollutants such as CO, CO_2, CH4, and PM2.5. The collected data undergoes comprehensive analysis to forecast potential pollution increases, with accuracy validated by nearby Air Quality Monitoring (AQM) stations.

Using free and open-source GIS software such as QGIS, the data is mapped to provide a spatial context for pollution levels and impact analysis.

2. INTRODUCTION

India, a developing nation faces the harmful effects of wastefires on air quality. Although wastefires are not the topmost contributor to air pollution, they contribute significantly towards local air quality degradation in urban and rural areas of India.

This project idea stems from an empathetic approach toward the problems observed in the surroundings and a motivation to develop sustainable solutions to target them. The project aims to develop a low-cost pollution mapping device to measure the local air quality degradation.

Simply detection cannot suffice, however, mapping the wastefires and extracting patterns and insights contribute towards a more holistic approach. These can help the local authorities to closely monitor, control, and take action to mitigate the waste fire pollution issue. For a global issue such as air pollution, local-level insights can help understand the problem better and develop sustainable solutions to the problem.

This research focuses on developing an advanced IoT-enabled device designed to detect wastefires and analyze emitted gases, and pollution levels in specific areas, all while providing real-time data monitoring. Strategically deployed in waste fire-prone zones, the IoT devices monitor key pollutants such as CO, CO_2, CH4, and PM2.5. Data collected is validated by nearby Air Quality Monitoring stations and undergoes comprehensive analysis, enhanced by GIS mapping. This integration significantly enhances the clarity and efficacy of the findings, offering valuable insights into pollution distribution and extent in various locations.

The integration of GIS-based mapping with an IoT-based waste fire monitoring system is a groundbreaking initiative, marking a pioneering effort in this field. This innovative approach provides continuous and immediate data on wastefires, revealing a distinct correlation between wastefires and local air quality degradation. The project has a broader impact potential, as it will be shared as an open-source resource. This openness facilitates replication and enables future citizen-science projects to leverage and enhance this technology for better environmental monitoring.

3. METHODOLOGY

Materials

The project encompasses the integration of two distinct components that seamlessly interface with each other: Software and Hardware.

A. Hardware

The hardware component comprises essential elements such as the Arduino MKR Zero board, an MQ-7 Carbon Monoxide(CO) sensor, an MQ-135 AQI and Carbon Dioxide(CO_2) sensor, a PM2.5 dust sensor, and a MQ-4 methane sensor.

1) Arduino MKR Zero
   The Arduino MKR Zero microcontroller board provides a good prototyping platform for data acquisition and storage capabilities, owing to its seamlessly integrated features. Featuring a microSD card slot, the MKR Zero facilitates a smooth integration with external memory, specifically designed for the purpose of data recording. This capability proves especially beneficial in the context of this research, where it plays a crucial role in collecting and storing data gathered by sensors. The information stored serves as a comprehensive dataset, later retrieved for detailed analysis and mapping, enhancing the versatility of the MKR Zero in applications requiring robust data management.

2) MQ-7 Sensor
   The MQ-7 sensor is a gas detection module renowned for its efficiency in sensing carbon monoxide (CO) concentrations in the surrounding environment. Employing a semiconductor gas sensor, the MQ-7 is highly sensitive to CO, making it a vital component in various safety and monitoring applications. Its compact design and straightforward interface make the MQ-7 sensor a reliable choice for projects requiring real-time detection and alerting capabilities in the presence of carbon monoxide.

3) MQ-135 sensor
   The MQ-135 sensor is a compact and versatile component designed for the detection of various gases, including CO_2. Employing advanced semiconductor technology, the MQ-135 provides a reliable solution for measuring CO_2 levels in diverse environments. Its sensitivity to carbon dioxide makes it an essential tool in applications such as air quality monitoring, ventilation control, and environmental sensing in the context of wastefires. The MQ-135 sensor's compact design, accuracy, and ease of integration make it a valuable asset for projects aiming to gauge and regulate carbon dioxide concentrations.

4) PM2.5 sensor

   PM2.5 refers to particulate matter with a diameter of 2.5 micrometres or smaller, which is a key indicator of air quality. These fine particles, often emitted from sources like wastefires can penetrate deep into the respiratory system, posing health risks. Monitoring PM2.5 levels is crucial for assessing air pollution and its potential impact on human well-being and the environment.

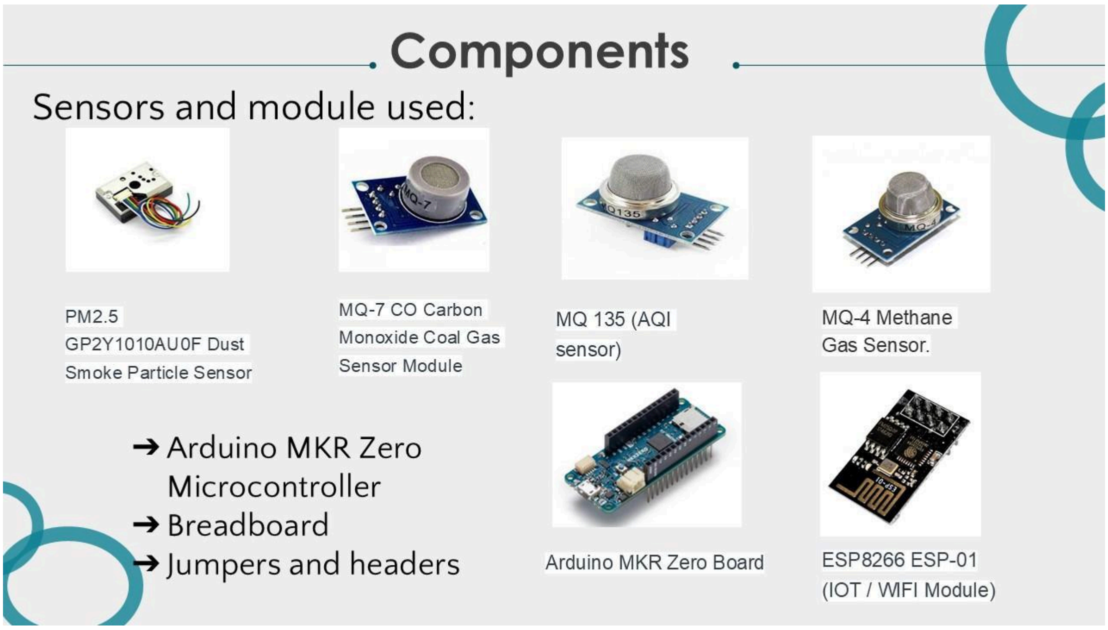
5) MQ-4 sensor

The MQ-4 sensor is a highly specialized gas sensor designed to detect methane in the air. With its sensitive and responsive nature, the MQ-4 sensor is a key component in gas detection systems. TheMQ-4 sensor operates based on its ability to change electrical conductivity in the presence of methane, offering a reliable and efficient solution for collecting the concentration of methane which is a characteristic gas in a waste fire.

6) ESP8266 Iot module

The ESP8266 is a budget-friendly Wi-Fi microchip with built-in microcontroller capabilities, perfect for IoT projects. It offers reliable wireless connectivity, low power consumption, and ample memory for various applications. Programmable via Arduino IDE and Lua script, its affordability and extensive community support make it a top choice for this project.

Fig 3.1 Hardware module components



B. Software

The open-source Arduino software was used to develop the necessary software to run the hardware. Data preparation and preprocessing was done using LibreOffice tools and the data analysis was done using Python. Furthermore, the free and open source QGIS software was used to map and visualize the collected data. It facilitates the creation of detailed maps and assists in making informed decisions based on spatial information. Its versatility and ease of use make it a valuable asset for students, amateurs and professionals working with geographic data across various fields.

C. Structural Design

The proper integration of all the sensors mentioned in the hardware section and MKR Zero board along with ESP8266 Iot module was successfully done in a circuit diagram as shown in Fig 3.1. Later actual circuit was made as shown in Fig 3.2 based on the circuit diagram.

Fig 3.2: Circuit diagram of the module

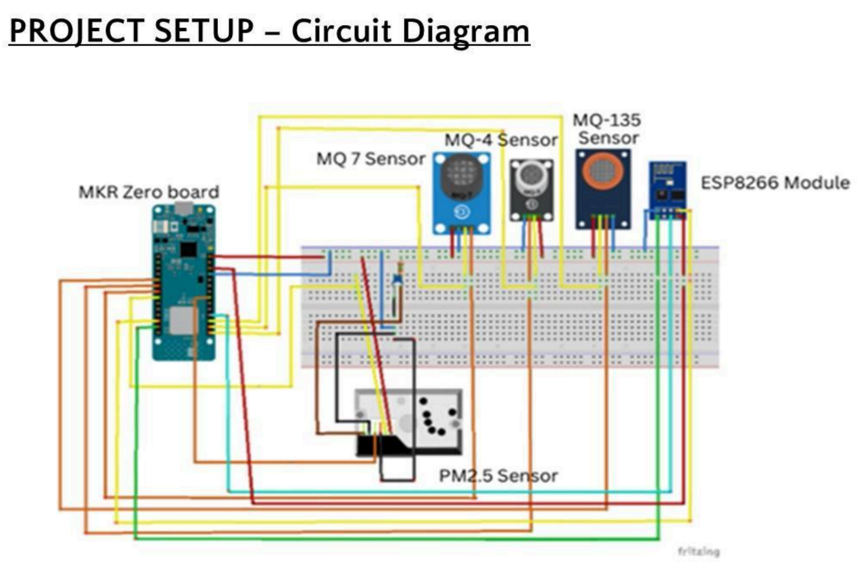
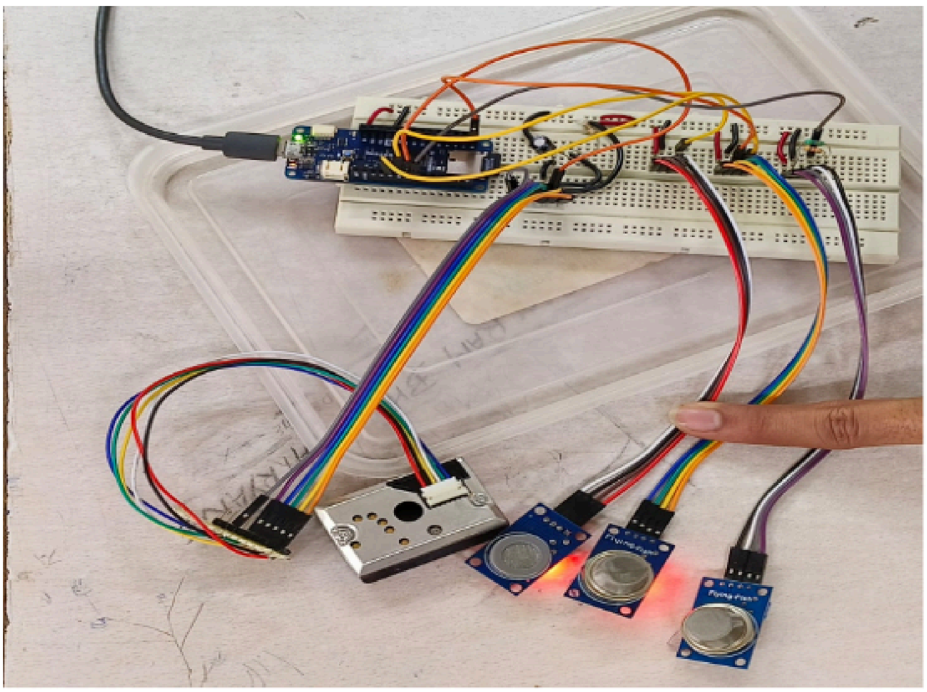


Fig 3.3: Actual Circuit Module (prototype)



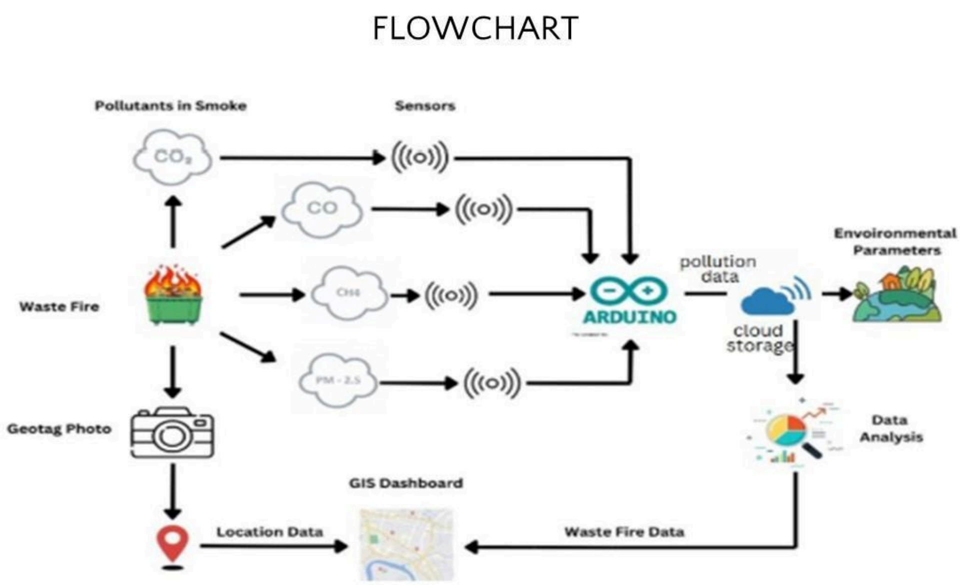
D. Method

In the course of this project, a comprehensive methodology for environmental monitoring was designed, utilizing a model equipped with sensors specifically designed for the precise measurement of CO, CO_2, AQI, and PM2.5 levels. Employing the MKR Zero board facilitated direct data collection, storing the information in CSV format on the SD card mounted on the board. The ESP8266 empowers real-time data monitoring and seamless cloud storage integration within IoT systems. To streamline and automate the data collection process, we transitioned the entire module to an Internet of Things (IoT) framework.

This eliminated the reliance on manual data retrieval from the SD card, significantly enhancing real-time monitoring and responsiveness. The IoT based system optimized data collection, contributing to the overall efficiency and autonomy of the monitoring module. Following successful data acquisition, a thorough analysis was conducted.

To validate the findings, a comparative study was undertaken by comparing the collected data with pre-existing data from the Maharashtra Pollution Control Board (MPCB). This comparative analysis allowed to identify and quantify variations in pollution levels. Subsequently, the QGIS software was harnessed to visually represent the spatial distribution of their collected data, enabling the creation of detailed maps. The utilization of GIS software not only enhanced their comprehension of the data but also provided a visual context that proved invaluable in elucidating the project's outcomes. The integration of this mapping component significantly contributed to the overall efficacy and lucidity of the research findings.

Fig 3.4: Project flowchart



Errors and problems faced:

Gas sensors such as the MQ-135 and MQ-7 were utilized. These sensors operate based on the principle of ionizing the surrounding air to measure specific gas concentrations. It should be noted that these sensors necessitate a preliminary heating phase to achieve accurate readings. The heating process plays a vital role in ensuring optimal performance by facilitating the stabilization of the sensors' internal resistance, thereby enhancing the precision of gas measurements.

To achieve this, the sensors must be powered and operational for an extended period, typically ranging from 6 to 12 hours. During this duration, the sensors undergo a calibration process where their internal components reach a thermal equilibrium, resulting in a stable resistance value. This calibrated state is imperative for the sensors to provide reliable and accurate readings of the targeted gases.

Therefore, the careful consideration and adherence to the recommended operational duration allow the sensors to achieve their requisite heated and calibrated state. This meticulous approach contributed significantly to the reliability and accuracy of the data obtained from the sensors, ensuring the validity of the research findings.

C. Testing

Hypotheses

Experiments were designed to test the hypotheses:

1.In areas with AQI less than the city average, wastefires act as one of the major causes of pollution.

2. wastefires near residential areas are one of the major causes of local air-quality degradation

The wastefires comprised organic and inorganic waste, including dry leaves, plastic wrappers, waste papers, and plastic bottles. To conduct the testing for the project, several types of waste was collected from homes, college, and a nearby waste dump land to burn a small amount of it for testing. The experiment aimed to study the ignition of wastefires, the process of locating and recording pre-existing fires, and the analysis of the composition of wastefires. It was divided into two categories to ensure a comprehensive analysis of the results.

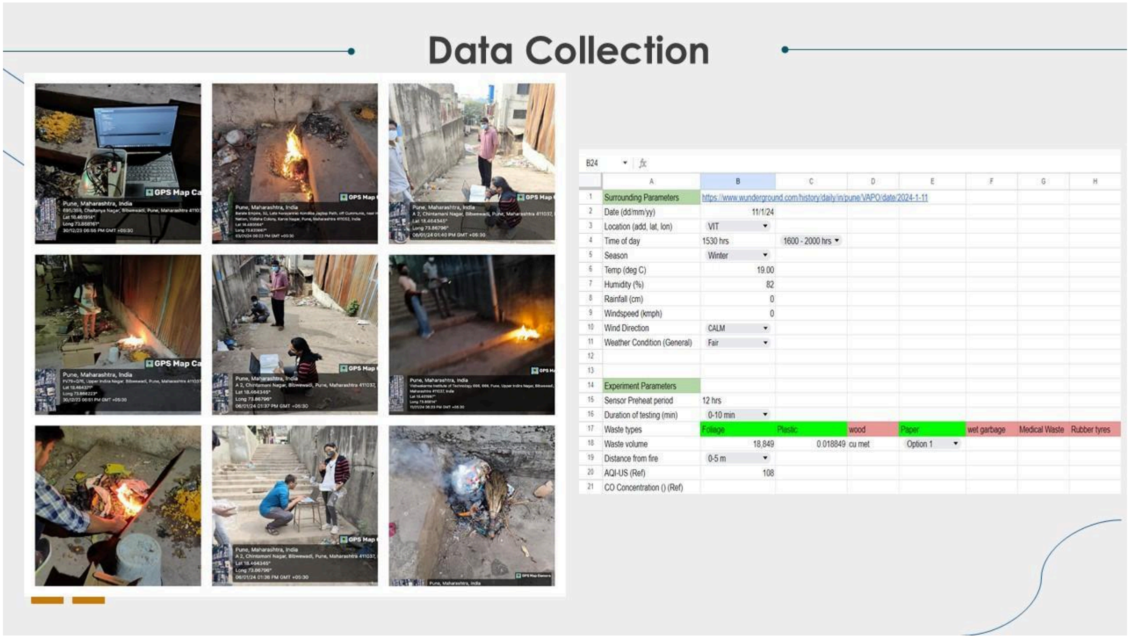
The first category involved the ignition of wastefires by the research team and focusing on finding and recording pre-existing fires. Areas for experimentation in the second category were selected by the team, involving planning, studying the environment, and choosing random areas. This approach enabled the researchers to gather data from various environments, including those with different waste compositions, humidity levels, and temperature ranges. For the known wastefires, different components like plastic wrappers, plastic bottles, dry leaves, fruit peels, papers, etc., were collected, and the fire was ignited for the experiment. For unknown wastefires, the garbage was collected from nearby areas, and the components were unknown to the researchers. This detailed analysis allowed for more accurate conclusions to be drawn from the experiment results.

Testing Parameters

Show the details of testing parameters, a datasheet was created to insert the data. The parameters were categorized into two types, surrounding parameters, and experiment parameters. The surrounding parameters included location, date, time, season, temperature, and general weather conditions in the area of testing. On the other hand, the experiment parameters included duration of testing, types of waste, amount of waste in cubic meters, distance maintained from the fire, etc.

Approximately 1 cubic foot of waste was utilized in each test, and a noteworthy rise in the quantity of pollutants in the smoke emitted by the waste was observed. A comparison was made between the local Air Quality Index (AQI) measurement and the AQI of the city ward average, with results duly recorded. The experiments were replicated at different locations, and a Geographic Information System (GIS)-based dashboard depicting these wastefires was also created.

Fig 3.5 Data Collection

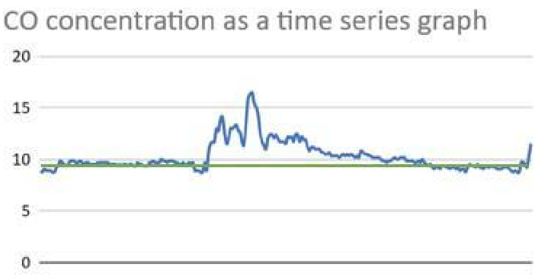


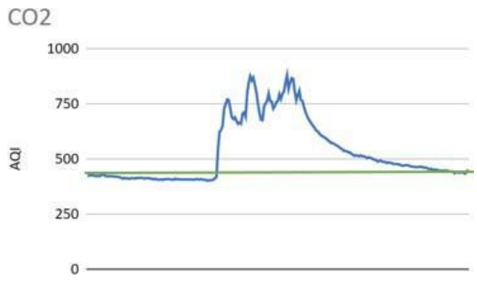
4. RESULTS AND DISCUSSIONS

The following graphs show the variations in local pollutant concentrations during the experiment. It shows a clear spike in pollutant levels due to waste fire instances. This validates the hypotheses.

Fig 4.1(A): Graph showing the concentration of CO with time

Fig 4.1(B): Graph showing concentration of CO_2 with time





The Fig 4.1(A) shows the concentration of CO measured by the model plotted with respect to time at the time of a waste fire. Similarly, Fig 4.1(B) shows concentration of CO_2 with respect to time for the same waste fire. The lines in green shows the data collected by Maharashtra Pollution Control Board (MBCB). The data collected by the model is similar to the data by MPCB, later at the time of waste fire the concentration of CO and CO_2 increases. The difference in the concentrations can be seen before and after the occurrence of waste fire.

The Fig 4.2 is a graph showing concentration of CO, CO_2, PM2.5 and AQI with time. It showcases the increased levels of pollutant gases during the waste fire occurrence.

Fig 4.2: Graph showing concentration of CO, CO_2, PM2.5 and AQI with time

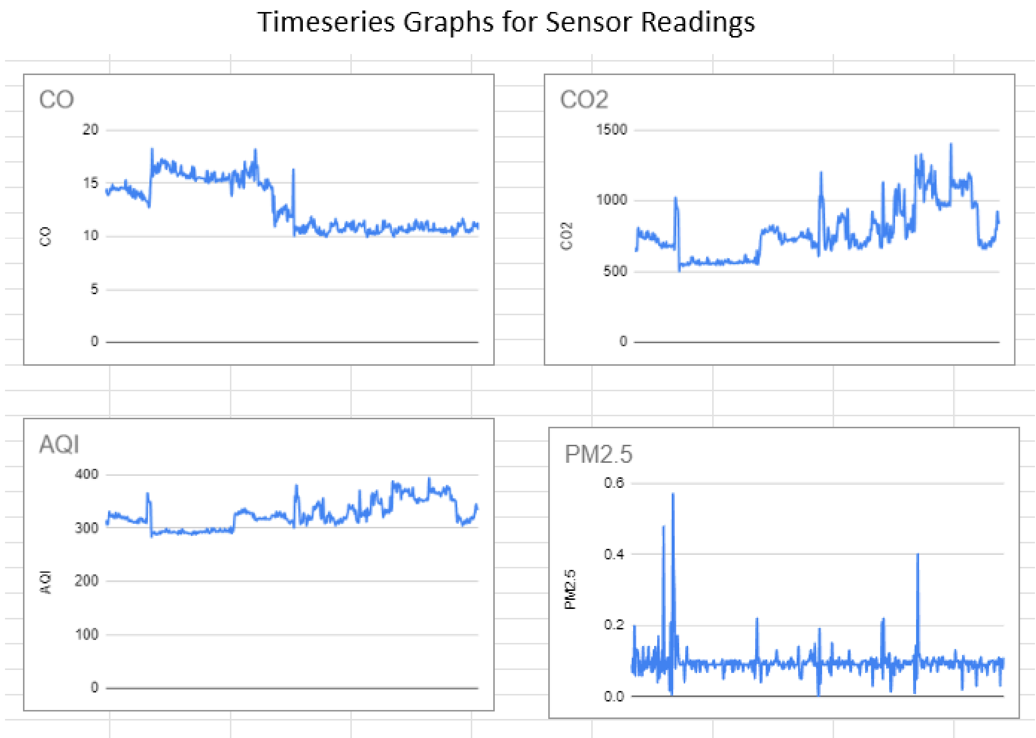
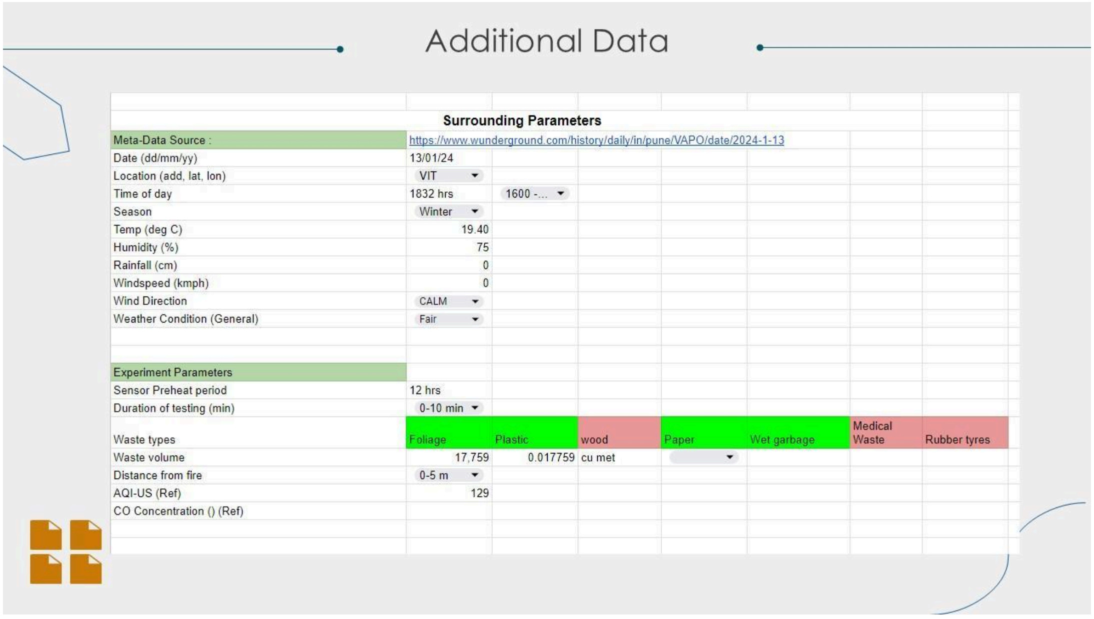


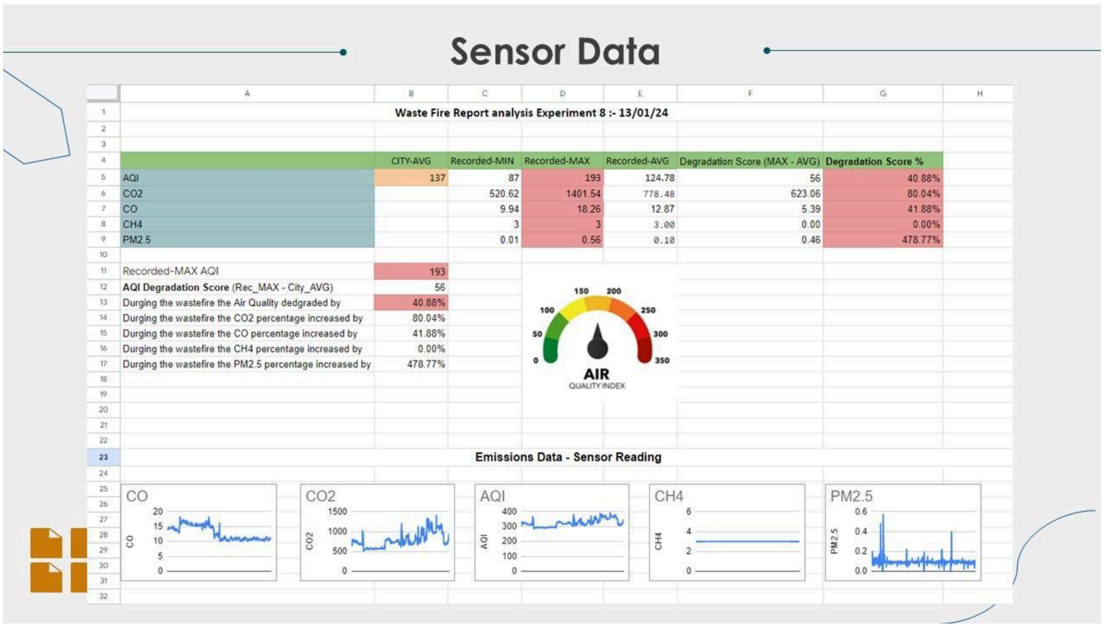
Fig 4.3 shows additional parameters studied during the waste fire event. They include environmental parameters such as temperature, windspeed, wind direction, rainfall etc. Meteorological datasets were referred for these values. Along with these values, the experiments also recorded parameters like waste volume, waste content type (foliage, wood, rubber etc.), and distance from fire.

Fig 4.3: Additional data: Environmental Parameters and Experiment Parameters



Meta-Data Source :	https://www.wunderground.com/history/daily/in/pune/VAPO/date/2024-1-13						
Date (dd/mm/yy)	13/01/24						
Location (add, lat, lon)	VIT						
Time of day	1832 hrs	1600 -...					
Season	Winter						
Temp (deg C)	19.40						
Humidity (%)	75						
Rainfall (cm)	0						
Windspeed (kmph)	0						
Wind Direction	CALM						
Weather Condition (General)	Fair						
Experiment Parameters							
Sensor Preheat period	12 hrs						
Duration of testing (min)	0-10 min						
Waste types	Foliage	Plastic	wood	Paper	Wet garbage	Medical Waste	Rubber tyres
Waste volume	17.759	0.017759	cu met				
Distance from fire	0-5 m						
AQI-US (Ref)	129						
CO Concentration () (Ref)							

Fig 4.4: Data Analysis of the data collected



	CITY-AVG	Recorded-MIN	Recorded-MAX	Recorded-AVG	Degradation Score (MAX - AVG)	Degradation Score %
AQI	137	87	193	124.78	56	40.88%
CO2		520.62	1401.54	778.48	623.06	80.04%
CO		9.94	18.26	12.87	5.39	41.88%
CH4		3	3	3.00	0.00	0.00%
PM2.5		0.01	0.56	0.10	0.46	478.77%

Recorded-MAX AQI	193
AQI Degradation Score (Rec_MAX - City_AVG)	56
Durging the wastefire the Air Quality dedgraded by	40.88%
Durging the wastefire the CO2 percentage increased by	80.04%
Durging the wastefire the CO percentage increased by	41.88%
Durging the wastefire the CH4 percentage increased by	0.00%
Durging the wastefire the PM2.5 percentage increased by	478.77%

Based on the extensive data collected, a detailed analysis was conducted to identify the minimum, maximum, and average values of the Air Quality Index (AQI) recorded throughout the study period, as illustrated in Fig 4.4. These statistical measures provided critical insights into the fluctuations in air quality, highlighting both the peaks and troughs in pollution levels.

With these values in hand, an air quality degradation score was calculated. This score is designed to offer a nuanced understanding of how air quality has deteriorated over time, taking into account not just the average pollution levels but also the extremes that were observed. The degradation score serves as a comprehensive indicator, summarizing the overall impact on air quality.

In addition to analyzing AQI, the same rigorous methodology was applied to the data for other pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and particulate matter (PM2.5 and PM10). For each of these gases, their respective minimum, maximum, and average concentrations were identified, as depicted in Fig 4.4. This consistent approach allowed for calculating degradation scores for each pollutant, providing a thorough and multi-faceted evaluation of air pollution.

The discernible degradation in air quality and the subsequent rise in pollution levels become evident through a meticulous comparison of the collected data with that of the Maharashtra Pollution Control Board (MPCB) during and after a waste fire incident. The observations reveal a sustained period of poor air quality persisting even after the fire has been extinguished. This temporal persistence highlights the lingering impact of such events on the local atmospheric conditions, underscoring the importance of continued monitoring and proactive measures to mitigate the aftermath of wastefires on air quality.

Based on this data a hypothesis was concluded, that in areas with AQI less than the city average, the waste fire acts as one of the major causes of pollution. The reason behind this is the burning of these wastefires that release several harmful pollutants into the atmosphere, causing the people residing in nearby areas to suffer from numerous health issues.

Fig 4.5 (A): GIS mapping of the collected data / Waste fire GIS Dashboard

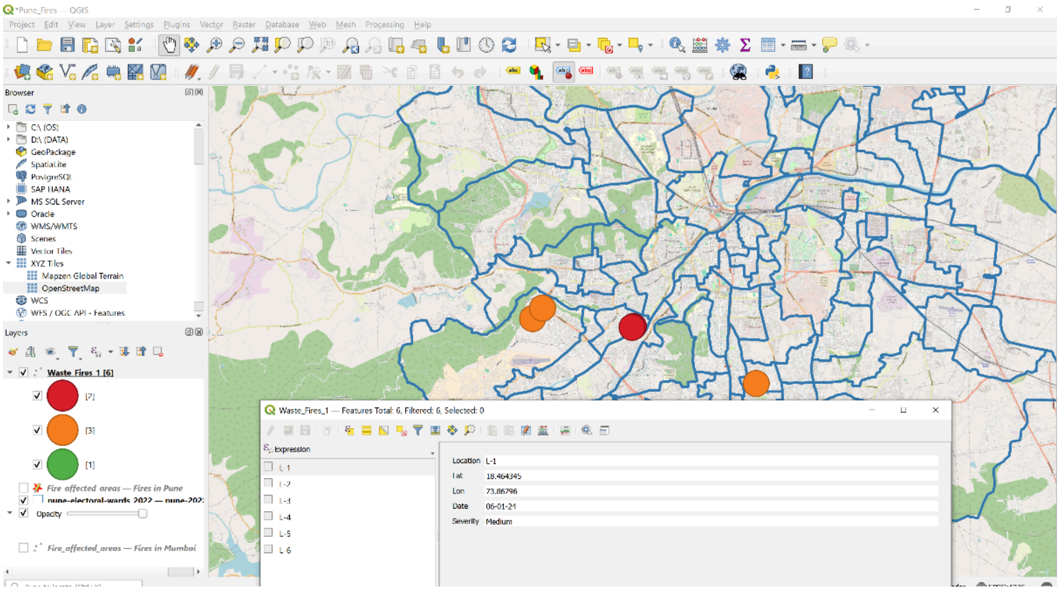


Fig 4.5 (B): GIS mapping of the collected data / Waste fire GIS Dashboard

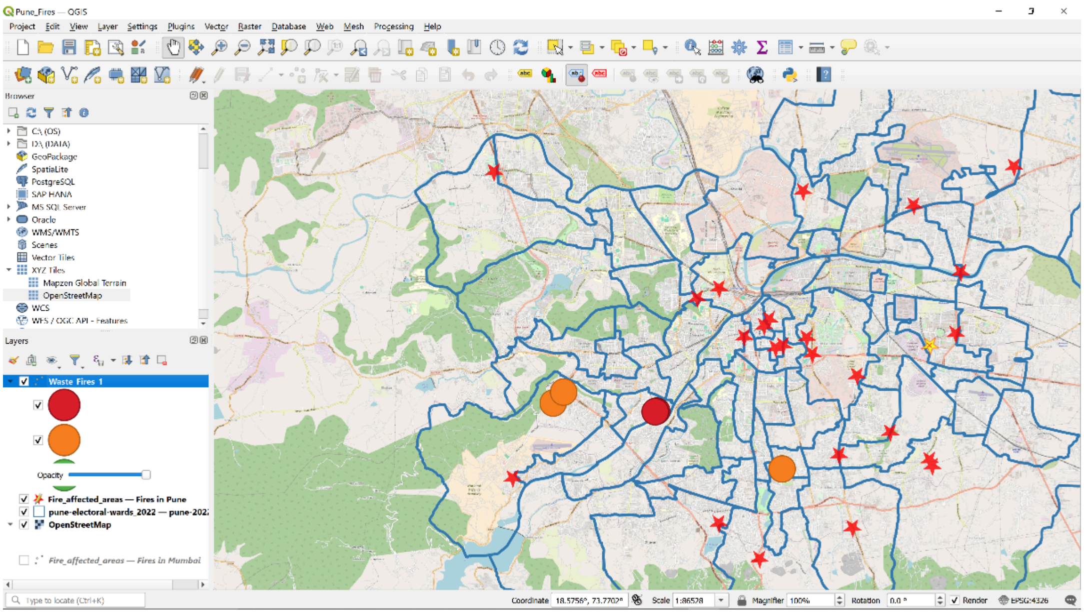
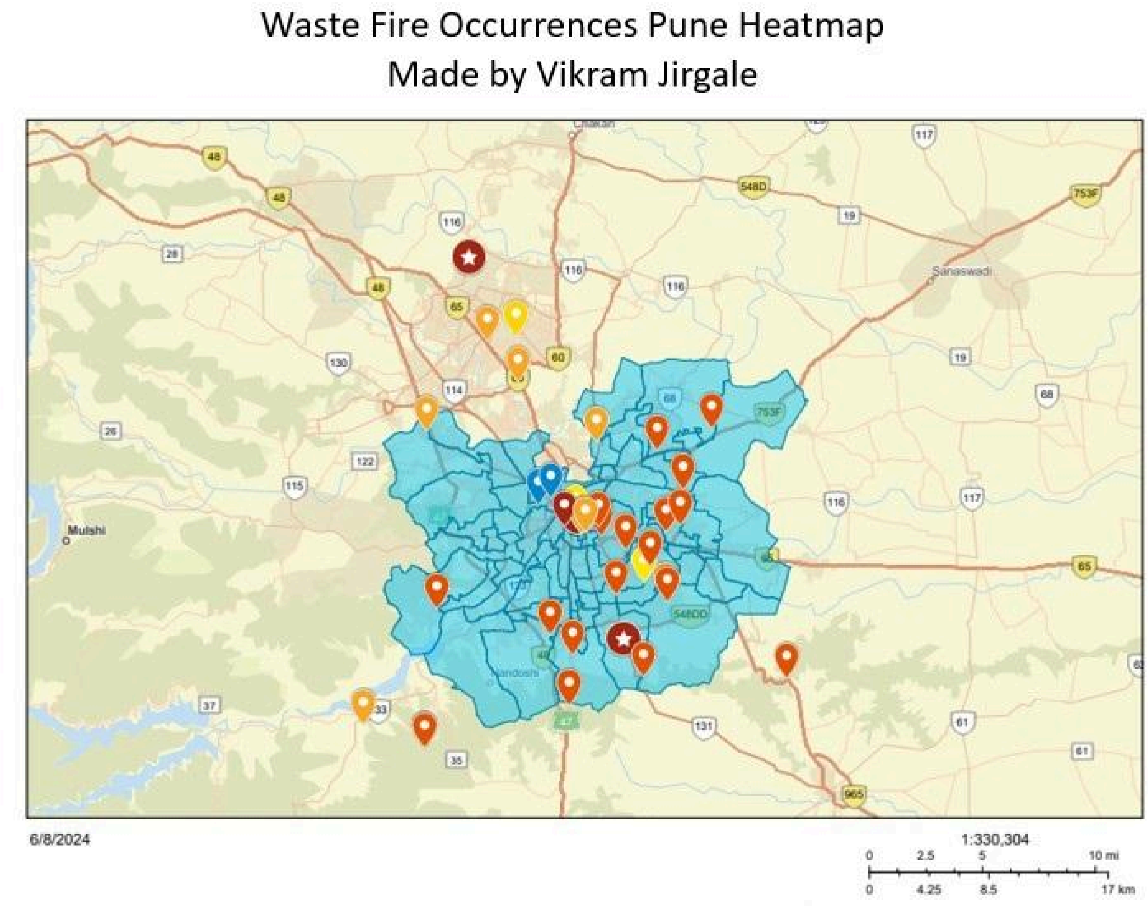


Fig 4.5 (C): Waste Fire Occurences Heatmap for Pune



Following data collection, the information is meticulously mapped utilizing QGIS software. This process not only deepens understanding of the data but also offers a visual representation of pollution levels in specific locations. The integration of this mapping component plays a pivotal role in elevating the overall effectiveness and clarity of the research findings. By visually contextualizing the data, the mapping component enhances the accessibility and interpretability of research outcomes, contributing to a more comprehensive and insightful analysis of pollution patterns across different areas. The GIS mapping of the data can be seen in Fig 4.5.

The map in Fig 4.5(C) shows waste fire occurrences plotted as a heatmap according to severity. The severity of these waste fires was calculated according to the following parameters:

1. Frequency of wastefire events in the locality
2. Population affected in the locality
3. Spread of pollutants in the locality

Wastefires near residential areas are one of the major causes of local air-quality degradation. The smoke and fumes from the wastefires in or near the residential cause respiratory issues, eye problems, skin problems, headaches, and other health issues. It not only causes health issues but can also become a cause of fires in the buildings and the houses of the people living in it posing a safety risk.

5. FUTURE SCOPE

The existing module is confined to monitoring four specific parameters, namely CO, CO_2, AQI, and PM2.5. To enhance the depth of investigation into wastefires, the integration of additional sensors capable of measuring the concentrations of various gases is recommended. This expansion would significantly enrich the dataset and contribute to a more nuanced understanding of the impact of wastefires on air quality.

Furthermore, employing machine learning techniques presents an exciting prospect. By leveraging the collected data, a machine learning model can be trained to identify regions with heightened pollution levels resulting from wastefires. This predictive capability can offer valuable insights and aid in proactive measures to address environmental concerns.

6. CONCLUSION

In regions where the Air Quality Index (AQI) falls below the city average, wastefires emerge as significant contributors to pollution. A comparative analysis was conducted, juxtaposing the local AQI measurements with the city ward average, while also taking into account various environmental conditions. The experimentation was replicated across diverse locations, leading to the development of a pioneering Geographic Information System (GIS) dashboard specifically dedicated to mapping these wastefires. The unprecedented insights gained from these endeavours will be disseminated to relevant authorities, empowering them to undertake essential measures for fostering a healthier environment that promotes overall well-being and sustainability.

7. REFERENCES AND CITATIONS

The project is being thoroughly guided throughout by Dr. Sachin Sawant, VIT Pune, and the authors express a vote of thanks for this excellent guidance.

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[3] E. Pangetsu et al. “Air Pollution Mapping Using Mobile Sensors Based on the Internet of Things”. The objective of this study is to develop a device employing mobile sensors for the detection of carbon monoxide pollution levels and their mapping on Google Maps. The system integrates MQ-7 sensors, GPS, GSM, a display module, an Arduino board, and a web server. Utilizing a distance-based sampling method, the system achieves improved data distribution and real-time functionality.

[4] R. Oleniacz et al. “Assessment of the impact of wastefires on air quality and atmospheric aerosol optical depth: A case study in Poland”. The research examined the influence of wastefires in Poland on both air quality and atmospheric aerosol optical depth. This investigation utilized data from the public Air Quality Monitoring (AQM) system and satellite observations. The findings revealed that significant wastefires dispersed pollutants over considerable distances, resulting in elevated concentrations of air pollutants at AQM stations located at greater distances. Additionally, the impact of the smoke on atmospheric aerosol optical depth was observable in the transported atmospheric layer.

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[6] K. Bot et al. “A Systematic Review of Applications of Machine Learning Techniques for Wildfire Management Decision Support”. This study examines recent instances of applying machine learning techniques to support decision-making in wildfire management. It specifically emphasizes case studies from the past four years. Analysing 135 documents, the review indicates that the utilization of machine learning methods contributes to improved decision support across various stages of fire management, thereby aiding in the prevention of the destructive impacts of wildfires.

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