JCBI
Journal of Computing & Biomedical Informatics
ISSN: 2710 - 1606
Volume 06 Issue 02
2024
Research Article
https://doi.org/10.56979/602/2024

Air-Sense: Enhancing Crop Yield and Quality through Integrated IoT-based Air Quality Monitoring System

Faseeha Munir[1], Ayesha Hakim[1*], Sarfraz Hashim[2], and Shahid Iqbal[3]

[1]Institute of Computing, MNS University of Agriculture, Multan, 60000, Pakistan.
[2]Department of Agricultural Engineering, MNS University of Agriculture, Multan, 60000, Pakistan.
[3]Department of Plant Breeding and Biotechnology, MNS University of Agriculture, Multan, 60000, Pakistan.
[*]Corresponding Author: Ayesha Hakim. Email: ayesha.hakim@mnsuam.edu.pk

Received: January 09, 2024 **Accepted:** February 25, 2024 **Published:** March 01, 2024

Abstract: Air quality has a significant effect on crop production and quality. Crops are affected when they are exposed to certain air pollutants. The effect might range from visible spots on the leaves to reduced growth and yield, and plant's early maturity. The degree of the damage was determined by the concentration of the specific pollutants and several other variables. This paper presents Air-Sense that is an IoT-base real-time air quality monitoring system. It is not only monitoring the quality of air and weather parameters around the crop but also deter-mine its effect on the crop leaves. Air-Sense monitors four gases: hydrogen gas (H_2), Carbon Monoxide (CO), Ozone (O_3) and Carbon dioxide (CO_2). The dust particles (PM2.5), s air temperature, soil moisture and humidity are also determined with this system. The system has been evaluated on the cotton crop by measuring leaf chlorophyll concentration with the help of the image processing model with an average validation accuracy of 93.47% based on an image dataset of 2000 healthy and infected cotton leaves. This system will enable farmers to monitor their fields air quality and make timely decisions about the best suitable sowing location for crops to get better yield and quality.

Keywords: Greenhouse gases; Pollutants; Air quality index; Support vector machine; Image processing.

1. Introduction

Air quality has a significant effect on crop production and quality. According to the world air quality report (2022), Pakistan ranks third after Chad and Iraq as the most polluted country in the world in terms of dust particles with average 70.9 mg/m^3 PM2.5 concentrations [1]. The major reason of pollution in Pakistan includes industrial pollution, vehicular emissions, agricultural pollution, poor waste management, indoor air pollution, and natural disasters [2] [23]. This has significant negative impacts on agriculture, affecting both crop production and livestock health. This is challenging as Pakistan is an agricultural country and a major portion of its economy depends on crop yield and production. It is important to monitor and investigate how the main factors that contribute to the air quality index affect agriculture. There have been a few studies that use computer vision and IoT to monitor the effect of temperature, humidity, and air pressure on agriculture such as [3][4], however, monitoring greenhouse gases and particulate matter has acquired the least attention.

According to [5], persistent impacts of air pollutants like ground-level ozone are of particular importance in agriculture since they are caused by exposures that last few weeks, months, or even the whole crop lifecycle [16]. It is generally recognized that higher levels of pollutants in the air negatively affect the production of several crops, including wheat, rice, cotton, and soybeans. Mostly, farmers are unaware of the impact of air quality on crops at an early stage and they ignore this important factor while sowing crops in the field.

Crop health must be monitored on a regular and periodic basis in the field to protect from harmful effects [18]. The measurement of leaf chlorophyll is an essential metric that serves as a crop health indicator [8]. The chlorophyll concentration is significantly connected to the color of the leaf which reflects the plant's micronutrient intake and wellbeing state. Many researchers in the literature have used leaf color and size to predict chlorophyll and nutrient content. Handheld pollution measurement devices have recently been introduced by some manufacturers, including Aeroqual [6] and Alphasense [7]. However, these air quality monitoring devices are highly expensive and are not readily available in Pakistan.

Researchers and extension workers utilize devices such as SPAD-502 meters to measure the chlorophyll rate which is expensive for farmers and needs proper training to handle properly. There are a few attempts to develop an automated chlorophyll rate detection system, for instance, [9] used a back-propagating (BP) neural network architecture based on chlorophyll fluorescence for predicting rice leaf chlorophyll content, and their results show that the predicted chlorophyll content was highly correlated with that measured by SPAD-502 meter. SPAD-502 meters are used to monitor leaf chlorophyll concentration, however, the impact of air pollutants and environmental variables on leaf health remain unknown [20]. The proposed study covers three aspects: *first*, the development of Air-Sense: the air quality monitoring system; *second*, analysis of the effect of air quality on crops based on specific parameters recorded by Air-Sense, and *third*, monitoring the leaf chlorophyll rate using image processing and machine learning models. The development of Air-Sense was carried out using wireless sensors networks connected through a central server (Figure 1).

Four gases including hydrogen gas (H_2), Carbon Monoxide (CO), Ozone (O_3), and Carbon dioxide (CO_2), as well as dust particles (PM2.5), air temperature, humidity, and soil moisture are monitored through various sensors [21]. Low-cost wireless sensors have been used to reduce the cost of the system to make it affordable by the local farmers. Based on the sensor readings, the system analyses the effect of air pollution on cotton crop leaves using an image processing model based on the rate of chlorophyll using cotton RGB images [17].

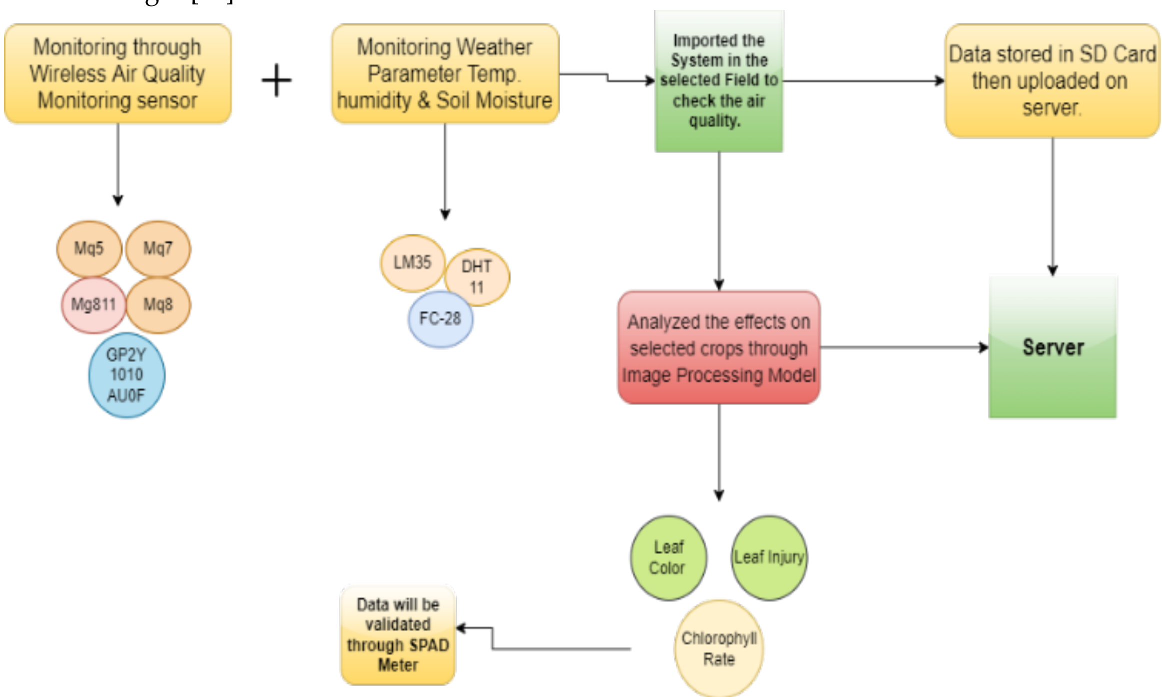


Figure 1. Flow diagram of the proposed air quality monitoring system.

2. Materials and Methods

In this proposed study, Proteus (8.0) is utilized as simulation software for microcontroller circuit design, EasyPC is used to make schematic and printed circuit board design system, and Arduino IDE is used for coding. For the cotton leaf health monitoring model, we used the TensorFlow Python library on Google Collab. To take readings of air quality and weather parameters, MQ series wireless sensors have been used that are easily available in Pakistan and are cost-effective. DHT11, LM35, and FC-28 sensors have been used to monitor air humidity, temperature, and soil moisture respectively. Other hardware components like Arduino Mega, LCD 324, Buzzer, LEDs, RTC, SD card Module, Power Supply, Transformer, Bridge rectifier, Filter capacitor, Resistance/LED, and Voltage regulator have been used to design the operating system.

2.1. Sensor Configuration and Readings

The MQ-7 sensor is used to detect carbon monoxide (CO) concentrations, which are quantified in parts per million (ppm). It is a toxic gas that cannot be smelled, seen, or tasted. The MQ-8 sensor is used to detect hydrogen gas (H_2) concentrations, with a range of 100 to 10,000 ppm, making it highly sensitive and resistant to other gases. The MQ-131 sensor detects surface ozone gas (O_3) and has high sensitivity to ozone and strong oxides such as NO_2. The MG-811 sensor is used to detect carbon dioxide (CO_2) concentrations and is highly sensitive to CO_2 with a conditioning circuit that amplifies the output signal. The GP2Y1010AU0F sensor detects airborne dust particles of 2.5mm diameter and is highly sensitive to minute particles such as dust in combination with smoke and other gases. The LM35 temperature sensor generates an analog output signal proportional to the measured temperature with a sensitivity of 10 mV/degree Celsius. The DHT11 humidity sensor is a low-cost sensor that detects temperature and humidity in the air with excellent accuracy and long-term stability. The FC-28 soil hygrometer sensor is used to measure the moisture content of the soil, which is important for plant growth, and consists of two electrodes that measure the amount of moisture present when current travels from one electrode to the other [22].

Table 1. Measured and expected values of sensors. The "measured values" represent average sensor values recorded from Air-Sense in the field and the "expected values" represent weather parameters and air quality index of Multan region taken from [10]

Sensor	Measured Value	Expected Value
CO (ppm)	467	500
PM 2.5 (ppm)	52	90
Relative Humidity (percentage)	40	55
LPG (ppm)	160	300
H_2 (ppm)	152	200
CO_2 (ppm)	772	900
Soil Moisture (percentage)	40	50
Temperature (Degree Celsius)	39	32

All the sensors have been calibrated by spraying gas into the glass jar and placing the respective sensor inside the jar. To measure the functionality, the gas level has been altered with a syringe, and variations in sensor values have been recorded. The Arduino Mega 2560 board based on the ATmega2560 microprocessor has been used to configure sensors [25].

The proposed system was installed at two separate locations in the cotton field, one near the main roadside, and the second in the middle of the field where there is less exposure to traffic pollution. The cotton plants were irrigated regularly, and the data was collected in three months from June-August 2022 during day and night with varying air temperature levels. The gas sensors readings were recorded in units of ppm, air humidity and soil moisture sensors readings were recorded in percentages, and air temperature is recorded in degree Celsius. All sensors have been programmed to take readings after every hour. The comparison of average values recorded from different sensors and the expected values is shown in Table 1.

Figure 2. Data acquisition through a camera and SPAD-502 meter.

2.2. Data Acquisition and Pre-processing

The dataset [19] of 2000 cotton leaves on the main stem of the plant were collected from cotton field of MNS-University of Agriculture, Multan. All images were captured using a 16-mega pixel camera in RGB (Red, Green, Blue) format during daylight between 12:00 pm to 2:00 pm in June, July, and August 2023. All images were labelled as 'healthy' or 'injured' by agricultural experts. The dataset [19] is accompanied by a text file containing data of chlorophyll content of leaf taken from SPAD-502 meter. The process of recording chlorophyll content of the lead using SPAD-502 meter is shown in Figure 2. Chlorophyll content of leaf was recorded at three distinct locations: the top leaf, the centre leaf, and the bottom leaf of the main cotton plant stem.

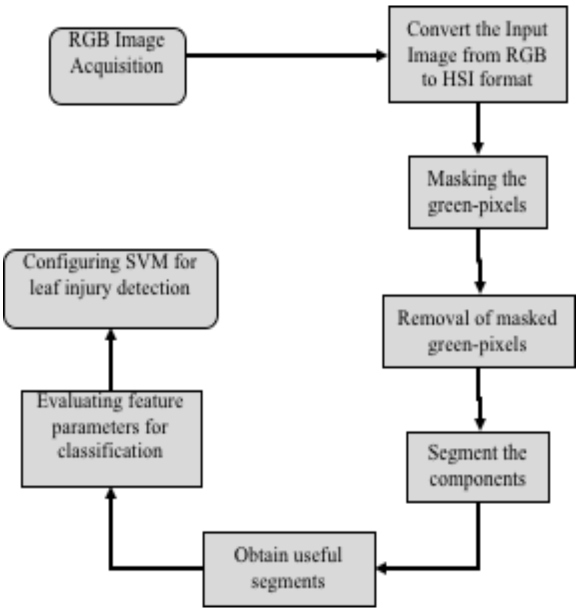
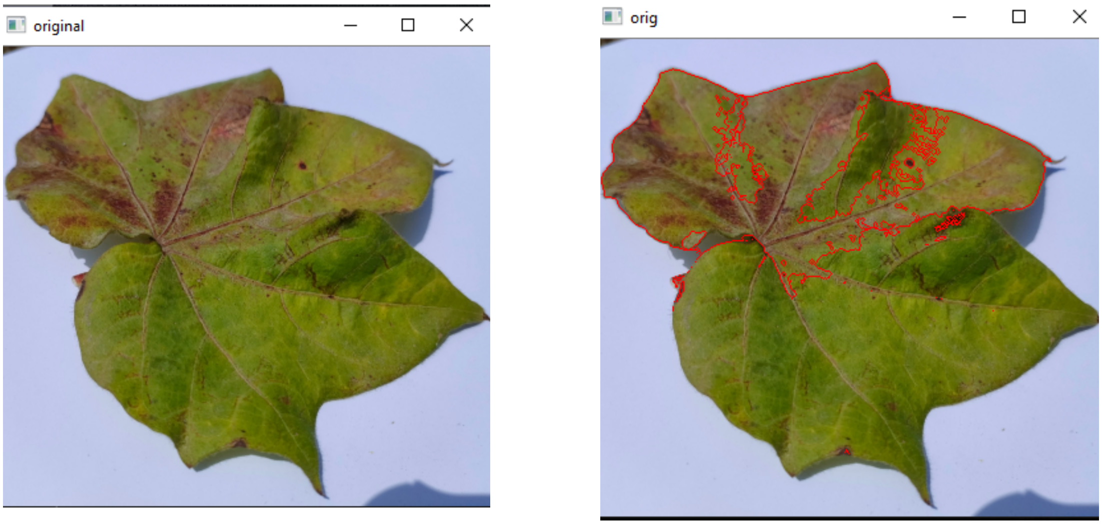


Figure 3. Data flow diagram of the proposed methodology

The dataset was pre-processed, and the image processing model was trained by following the steps as shown in Figure 3. All images were converted from RGB (red, green, blue) to HSI (hue, saturation, intensity) format. Only the H (hue) component of the HSI color space has been used after transformation because it contains all the necessary information. The conversion was performed to highlight the green color pixel that represents the leaf's healthy region. Green pixels were masked based on the specified threshold values. After color transformation, segmentation of images was performed. The injured component of the leaf was removed by segmenting the selected area by comparing it with green pixels.



(a) (b)

Figure 4. Contouring for Leaf Injury Visualization.

2.3. Classification

After data acquisition and pre-processing, we used Support Vector Machine (SVM) to classify healthy and injured leaves based on the features: chlorophyll rate, area of injury (other than green pixels), and leaf colour. SVM is a supervised machine learning technique that was used for the classification of images into two classes: healthy leaves and injured leaves. Contouring was performed using OpenCV to visualize the leaf injury as shown in Figure 4.

3. Results

The results of the SVM classifier were compared with that of ground truth annotated data giving an average accuracy of 98%. It has been observed that there were more injured leaves in the field towards the main roadside as compared to the middle of the field where there was comparatively less exposure to air pollution. The results of chlorophyll rate obtained through image processing was validated by comparing with SPAD-502-meter values giving 93.47% validation accuracy. The range of chlorophyll value obtained through image processing was 45-55 $\mu g\ cm^2$, and that obtained through SPAD-502 meter was 50-60 $\mu g\ cm^2$.

Table 2. Correlation of different gases in the air

Correlation	Values
Dust & O_3	-0.005
O_3 & CO	+0.590
Air temperature & air humidity	-0.702
Air humidity & soil moisture	+0.478
CO_2 & H_2	+0.290

This comparison shows that the accuracy of image processing model.

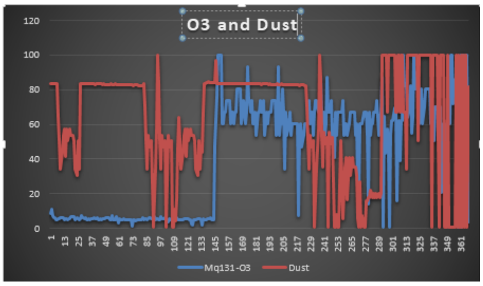


Figure 5. Co-relation Between O_3 and dust particles (PM 2.5mm)

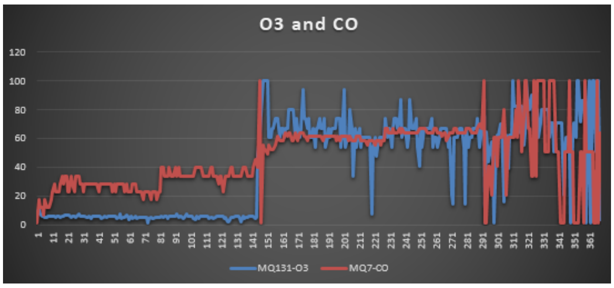


Figure 6. Co-relation Between O_3 and CO

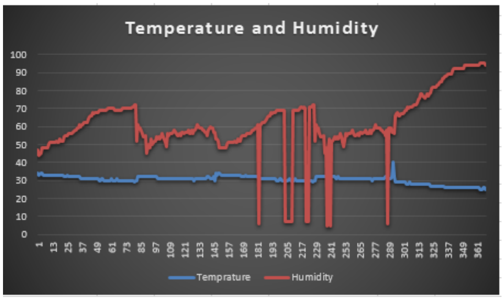


Figure 7. Correlation Between Air Temperature and Air Humidity

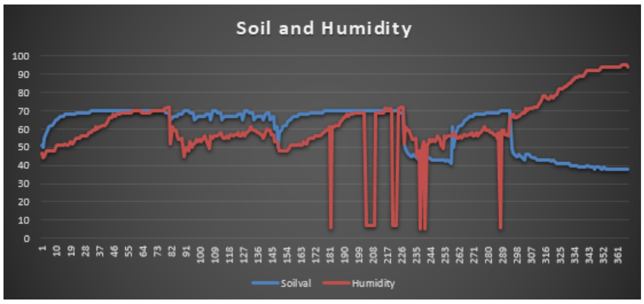


Figure 8. Co-relation Between Soil Moisture and Air Humidity

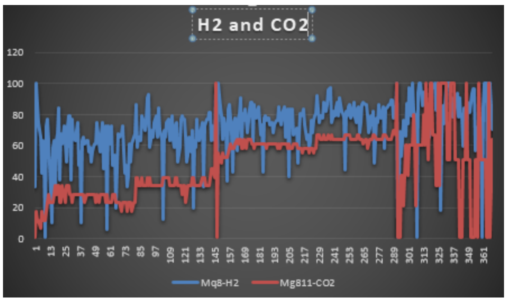


Figure 9. Co-relation Between H_2 and CO_2

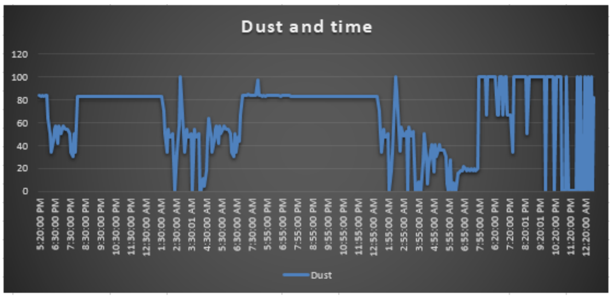


Figure 10. Co-relation Between Dust and Time

We analyzed the correlation between different gases based on sensor readings of Air-Sense and found interesting results (Table 2). The effect of the Ozone layer on crops depends on its occurrence with other greenhouse gases. The graph in Figure 5 shows that there is no correlation between ozone (O3) and dust particles. This has been validated through the literature that the occurrence of dust particles and ozone are not related to each other, however, their combined exposure cause significantly more effect on crop and human health than either ozone or dust particles individually [11]. Figure 6 shows a positive correlation between ozone (O3) and carbon monoxide (CO). This has been validated through the literature that carbon monoxide when exposed to sunlight produces a chemical reaction to create ground-level ozone [12].

Similarly, Figure 7 shows the negative correlation between air temperature and air humidity that is according to the air properties. When the temperature increases the air becomes drier causing a decrease in relative humidity. The graph in Figure 8 shows positive correlation between soil moisture and air humidity. When the soil is moist, it releases moisture into the air through evaporation. This increases the amount of moisture in the air, leading to higher levels of air humidity. Figure 9 presents a weak positive correlation between hydrogen and carbon dioxide gas. The co-occurrence of these two gases forms methane in the air which is very harmful to plants and the environment as it increases ground-level ozone causing leaf injury [13].

Figure 10 presents a correlation between dust particles and time of the day. The graph shows an increase in dust particles during the daytime that decreases in the night-time. The correlations listed in Table 2 presents the co-occurrence of different gases in the air. The co-occurrence of ozone and dust, as well as ozone and carbon monoxide, harms the cotton leaf by affecting the chlorophyll rate.

4. Discussion

The study's findings offer valuable insights into the intricate relationship between air quality and crop health, particularly focusing on cotton crops in Pakistan. The Air-Sense monitoring system, with its low-cost sensors, revealed significant correlations between different gases and environmental factors, providing farmers with actionable information for informed decision-making. The high accuracy of the SVM classification model in identifying healthy and injured cotton leaves validates the effectiveness of image processing in real-time crop health assessment. The observed implications underscore the practical significance of this research for local farmers and policymakers, emphasizing the need for targeted interventions to address the impact of air pollution on agriculture.

Future research directions include the exploration of real-time monitoring and alert systems to enable dynamic responses to changing air quality conditions. Expanding the study to encompass a broader range of crops and geographical locations, along with collaboration with agricultural extension services, could enhance the applicability and adoption of monitoring systems. Additionally, investigating the long-term effects of air pollution on soil health and microbial communities is crucial for a comprehensive understanding of the holistic impact on agroecosystems, guiding the development of sustainable agricultural practices.

5. Conclusions

Based on the sensor readings and analysis presented in this study, farmers can get useful information about the air quality on and around the fields. This would help them to make informed decisions about the best-suited location for growing specific crops that are sensitive to air quality. Air-Sense provides precise information about the local farms that are more useful than the information received through satellite weather stations. The system is cost-effective and affordable for local farmers in developing countries [24]. It can also be used at homes and offices to monitor the air quality and weather parameters.

Author Contributions: Ayesha Hakim conceived the idea for the study, while Faseeha Munir conducted the experiments. Shahid Iqbal contributed to dataset collection, and Sarfraz Hashim assisted in the design of the system. All authors collaborated in refining the methodology, interpreting the results, and drafting the manuscript. Additionally, all authors reviewed and approved the final version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IQAir, World Most Polluted countries, 2022, https://www.iqair.com/world-most-polluted-countries
2. Anjum, M.S., Ali, S.M., Subhani, M.A., Anwar, M.N., Nizami, A.S., Ashraf, U. and Khokhar, M.F., 2021. An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan; a critical review. *Journal of Hazardous Materials*, *402*, p.123943.
3. Kumar, Somansh and Ashish Jasuja. Air quality monitoring system based on IoT using Raspberry Pi, In Proc. The 2017 International Conference on Computing, Communication and Automation (ICCCA), 2017, pp. 1341-1346.
4. N. V. Raju and P. Ravikumar. (2020). Automated crop health monitoring system using computer vision and IoT. International Journal of Engineering and Technology, 12(5), 382-387.
5. Wahid, A., Influence of atmospheric pollutants on agriculture in developing countries: a case study with three new wheat varieties in Pakistan. Science of the Total Environment, 2006, 371(1-3), pp.304-313.
6. Aeroqual. 2022. https://www.aeroqual.com/
7. Alphasense. 2022. https://www.alphasense.com/
8. Pavlovic, D., Nikolic, B., Djurovic, S., Waisi, H., Andjelkovic, A. and Marisavljevic, D., 2015. Chlorophyll as a measure of plant health: Agroecological aspects. Pestic. Phytomed. (Belgrade), 2015, 29(1), 21–34 UDC 581.132:632 DOI: 10.2298/PIF1401021
9. Ban, S., Liu, W., Tian, M., Wang, Q., Yuan, T., Chang, Q. and Li, L., 2022. Rice Leaf Chlorophyll Content Estimation Using UAV-Based Spectral Images in Different Regions. *Agronomy*, *12*(11), p.2832.
10. Accuweather, 2022, https://www.accuweather.com/en/pk/multan/260624/air-quality-index/260624
11. Mølhave L, Kjaergaard SK, Sigsgaard T, Lebowitz M. Interaction between ozone and airborne particulate matter in office air. Indoor Air. 2005 Dec;15(6):383-92. doi: 10.1111/j.1600-0668.2005.00366.x. PMID: 16268828.
12. NASA, Carbon Monoxide, Fires, and Air Pollution. 2022. https://earthobservatory.nasa.gov/images/7033/carbon-monoxide-fires-and-air-pollution
13. EPA. United States Environmental Protection Agency. 2022. https://www.epa.gov/ghgemissions/overview-greenhouse-gases
14. Lordwin Cecil Prabhakar, M., R. Daisy Merina, and Venkatesan Mani. 2023. "IoT Based Air Quality Monitoring and Plant Disease Detection for Agriculture." Automatic Control and Computer Sciences 57(2): 115–22.
15. Morchid, Abdennabi, Rachid El Alami, Aeshah A. Raezah, and Yassine Sabbar. 2024. "Applications of Internet of Things (IoT) and Sensors Technology to Increase Food Security and Agricultural Sustainability: Benefits and Challenges." Ain Shams Engineering Journal 15(3).
16. Aashiq, M. N. M., Kurera, W. T. C. C., Thilekaratne, M. G. S. P., Saja, A. M. A., Rouzin, M. R. M., Neranjan, N., & Yassin, H. (2023). An IoT-based handheld environmental and air quality monitoring station. *Acta IMEKO*, *12*(3). https://doi.org/10.21014/actaimeko.v12i3.1487
17. Singh, N., Sharma, A. K., Sarkar, I., Prabhu, S., & Chadaga, K. (2024). IoT-based greenhouse technologies for enhanced crop production: a comprehensive study of monitoring, control, and communication techniques. *Systems Science and Control Engineering*, *12*(1). https://doi.org/10.1080/21642583.2024.2306825
18. Vijayalakshmi, K., Al-Otaibi, S., Arya, L., Almaiah, M. A., Anithaashri, T. P., Karthik, S. S., & Shishakly, R. (2023). Smart Agricultural–Industrial Crop-Monitoring System Using Unmanned Aerial Vehicle–Internet of Things Classification Techniques. *Sustainability (Switzerland)*, *15*(14). https://doi.org/10.3390/su151411242
19. "Munir, Faseeha (2024), 'Air-Sense ADS Data', Mendeley Data, V1, Doi: 10.17632/7jhnzrmddz.1."
20. Buelvas, J., Múnera, D., Tobón V, D. P., Aguirre, J., & Gaviria, N. (2023). Data Quality in IoT-Based Air Quality Monitoring Systems: A Systematic Mapping Study. Water, Air, and Soil Pollution, 234(4). https://doi.org/10.1007/s11270-023-06127-9
21. Aashiq, M. N. M., Kurera, W. T. C. C., Thilekaratne, M. G. S. P., Saja, A. M. A., Rouzin, M. R. M., Neranjan, N., & Yassin, H. (2023). An IoT-based handheld environmental and air quality monitoring station. Acta IMEKO, 12(3). https://doi.org/10.21014/actaimeko.v12i3.1487
22. Kumar, Tarun, and Amulya Doss. 2022. "AIRO: Development of an Intelligent IoT-Based Air Quality Monitoring Solution for Urban Areas." Procedia Computer Science 218: 262–73.

23. Guerrero-Ulloa, G., Andrango-Catota, A., Abad-Alay, M., Hornos, M. J., & Rodríguez-Domínguez, C. (2023). Development and Assessment of an Indoor Air Quality Control IoT-Based System. Electronics (Switzerland), 12(3). https://doi.org/10.3390/electronics12030608
24. Ghosal, A., Chowdhury, R., Karmakar, R., Kundu, S., Bhattacharya, S., Chatterjee, S., & Debnath, R. (2023). A very simple and cost effective IoT based Air Quality Monitoring System. 10(1), 139–142.
25. Buelvas, Julio H., Danny Múnera, and Natalia Gaviria. 2023. "DQ-MAN: A Tool for Multi-Dimensional Data Quality Analysis in IoT-Based Air Quality Monitoring Systems." Internet of Things (Netherlands) 22.