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RESEARCH ARTICLE

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# I-SOEWM: IoT Based Solar Energized Weather Monitoring System

**Parameswaran Ramesh**[1]*, **N Vidhya**[1], **P T V Bhuvaneswari**[2], **Shabana Parveen**[3]

**1** Ph.D Student, Department of Electronics Engineering, Madras Institute of Technology, Anna University, Chennai, India
**2** Professor and Director, Department of Electronics Engineering, Madras Institute of Technology, Anna University, Chennai, India
**3** Assistant Professor, Department of Electronics and Communication Engineering, Sri Sairam Engineering College, Chennai, India

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* **Corresponding author**.

parameswaran0789@gmail.com

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## Abstract

**Objectives:** To develop an IoT (Internet of Things) based Solar Energized Weather Monitoring System (I-SOEWM) that incorporates efficient mechanism to receive real-time weather reports both locally and remotely. **Methods:** Improved localized weather monitoring system powered by a renewable solar energy has been developed to provide continuous real-time monitoring of parameters namely temperature, humidity, pressure, air quality, etc., The developed device is GPS-enabled to provide geo-localized data. The significance of the developed work is that the parameters measured are stored simultaneously on two cloud platforms namely Thingspeak and Adafruit, thereby ensuring reliability and security of the developed system. From the literatures, it is found that several works have been carried out that are closer to the developed research. However continuous monitoring is ensured in the developed work through Solar energy based renewable energy harvesting mechanism. Further, new parameters namely UV Index, Air Quality Index (AQI), and Dew Point are also monitored when compared to existing systems. **Findings:** Through the inclusion of additional parameters namely UV Index, AQI and Dew Point, the air quality, intensity of sun and the temperature at which air cannot hold water vapors are measured which lacks in the existing WMS. These parameters are vital for well-being of living organism. **Novelty:** The proposed system is solar-powered and incorporates real-time analysis of additional parameters. It has a long battery life (2.5 years for Li-ion) because the controller uses less power and an added solar panel is built into it, and it is capable of real-time data monitoring. (It also provides interfaces for mobile and web applications for user interaction.

**Keywords:** Internet of Things; Weather monitoring System; GPS; Thingspeak; Cloud Platforms

## 1 Introduction

Several Weather Monitoring Systems (WMS) which provides real- time environmental weather condition exists in literatures[1,2]. Various controllers namely Raspberry Pi, Arduino Uno etc., used in the existing system[3] met out their power requirements through conventional power sources which when not available may lead to data loss. Remote monitoring of WMS can be achieved through Internet of Things (IoT) Technology[4]. When employing wireless communication technology, stochastic nature of wireless channel between transmitter and receiver induce connectivity impairment. Hence to address above two major challenges, (i) solar energy based harvesting mechanism, and (ii) NodeMCU having in-built Wi-Fi (Wireless Fidelity) communication module is used in this research. As a global fact to be agreed, Wi-Fi technology is the most promising technology, the connectivity issue is well addressed in this research. Further, envisioning the futuristic scope of the developed research, Thingspeak cloud platform is included for maintaining repository while Adafruit to provide visualization and Data Analytic mechanism.

In[5], the authors have made a system for monitoring and managing the environment that combines IoT with information systems. It also uses cloud computing on the saved database to figure out patterns in the weather. The data gathered with the help of multi sensors are fed to the perception layer. Both public and private networks are used by the network layer to access and exchange data. The application layer store, share, organize, and process the application data obtained from the environment.

The authors of[6] designed an environmental monitoring system for smart cities that allows efficient resource usage and improved service quality for inhabitants. It delivers services such as air quality control, weather monitoring and home and building automation. The fundamental factors considered are temperature, relative humidity, and Carbon dioxide level in air. An Android app is created to monitor the data sent from Lab VIEW to a smart phone.

In[7], the authors developed a wireless sensor network based weather monitoring system to keep track of fire detection, earthquake detection, temperature, humidity and rainfall level. The weather readings are displayed in real- time with a provision to track the historical readings on an hourly or daily basis.

By using IoT, the authors of[8] were able to make real-time data accessible to a significantly greater number of locations. The system measures temperature, humidity, wind speed, moisture, light intensity, UV radiation, and carbon monoxide levels in the air. Statistical visualization plots are made from these data to provide meaningful interpretation of the application. The system includes an application to send notifications indicating sudden change in weather condition.

Current weather stations do not utilize renewable energy sources such as solar power, wind power, or hydrothermal power to activate the whole system. This is evident from the aforementioned literature assessment. Further, the number of weather parameters measured is limited to the sensors used. Hence, the proposed I-SOEWM system makes an attempt to use green energy sources to energize the weather monitoring station which measures all the basic weather parameters namely Temperature, Humidity, Air Quality, Pressure, Rainfall and intensity of Sun.

Table 1 illustrate presents the comparison of the proposed I-SOEWM with the above existing works to highlight the contribution claimed in the developed work. It is observed that new parameters related to weather are included in the developed work.

**Table 1.** Comparison of the Parameters

| S.No | Features | Proposed System (I-SOEWM) | Bharathy S Et.al (2022) | K. Sai Nikhilesh Et.al (2020) | Arpita Ghosh Et.al (2013) |
|---|---|---|---|---|---|
| 1. | Cloud Storage | ✔ | ✔ | ✖ | ✔ |
| 2. | Temperature | ✔ | ✔ | ✔ | ✔ |
| 3. | Pressure | ✔ | ✔ | ✖ | ✖ |
| 4. | Humidity | ✔ | ✔ | ✔ | ✖ |
| 5. | Altitude | ✔ | ✖ | ✖ | ✔ |
| 6. | UV index | ✔ | ✖ | ✖ | ✖ |
| 7. | AQI | ✔ | ✖ | ✖ | ✖ |
| 8. | Dew point | ✔ | ✖ | ✖ | ✖ |
| 9. | Rainfall | ✔ | ✖ | ✖ | ✔ |
| 10. | Solar panel | ✔ | ✔ | ✔ | ✖ |
| 11. | Battery | ✔ | ✖ | ✖ | ✔ |

# 2 Methodology

## 2.1 Proposed I-SOEWM

The presented system is an advanced weather monitoring solution that includes data sensing, data processing, and cloud enablement over the internet.

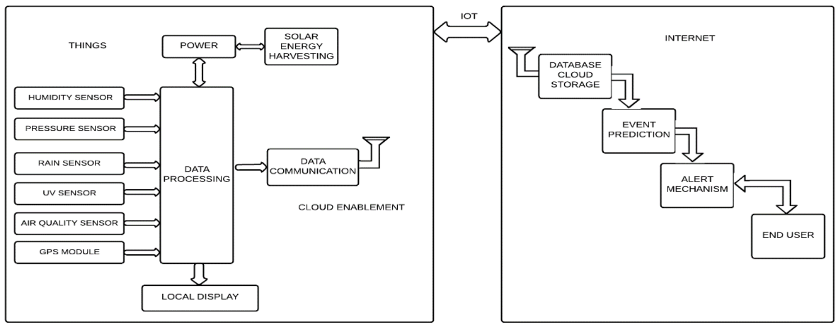


**Fig 1.** Proposed I-SOEWM System Architecture

Figure 1 shows the system architecture of the proposed I-SOEWM which consists of the following sub modules:

- Data sensing unit
- Data processing unit
- Cloud enablement unit
- Solar harvesting unit

## 2.2 Data Sensing Unit

A number of environmental sensors have been used to measure real time weather data on a given location as illustrated in Table 2.

**Table 2.** Sensors Parameters

| S.No | Make | Parameters |
|---|---|---|
| 1. | DHT22 Sensor | Temperature and Humidity |
| 2. | BM280 Sensor | Barometric Pressure, Altitude |
| 3. | MQ135 Sensor | Air Quality |
| 4. | FC36 Sensor | Rainfall |
| 5. | GY1145 Sensor | Ultraviolent |
| 6. | NEO-6MV2 GPS Sensor | Latitude, Longitude |

Each sensor measures a minimum of three weather parameters. Thus, the number of sensors used for measurement is minimized improving the efficiency of the system. Since the system is solar powered, it increases efficiency of the application by prolonging its lifetime.

## 2.3 Data Processing Unit

NodeMCU[9] controller is used for processing the application data. It is build based on the ESP8266[10], the open-source software and hardware development platform[11]. The in-built Wi-Fi protocol is used to connect devices and exchange sensed application data.

### *2.3.1 Proposed I-SOEWM Schematic diagram*

Proposed I-SOEWM system is designed using EasyEDA PCB designing tools as shown in Figure 2. Each of the components in the schematics is converted into footprints and then a Gerber file is generated. The Gerber files are used to describe the PCB images: copper layers, solder mask, legend, drill data, etc. using which the final hardware PCB layout is created.

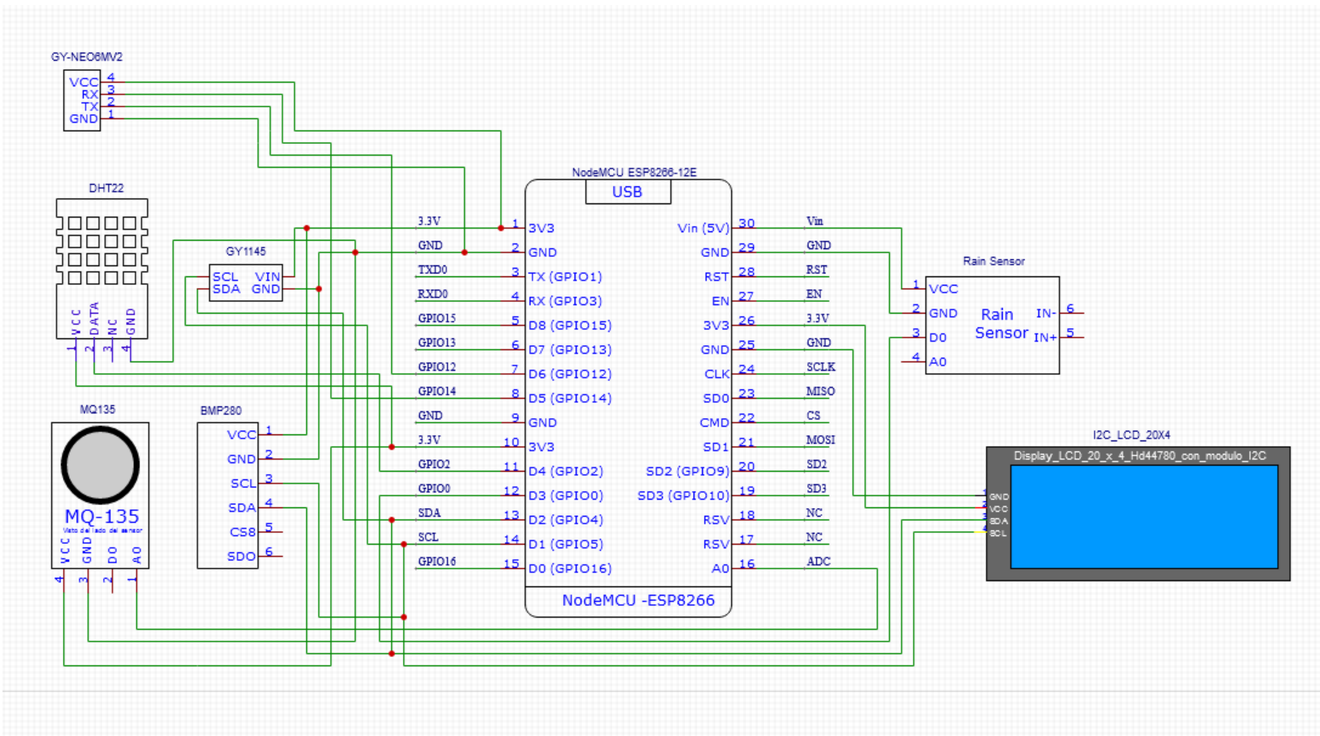


**Fig 2.** PCB schematics of Proposed I-SOEWM

The notation used in developed algorithms is described in Table 2.

### *2.3.2 Algorithms used in Proposed I-SOEWM*

The proposed I-SOEWM system uses two algorithms namely (i) Data Sensing and Processing and (ii) User Authorization. Notations used in the developed algorithms are given in Table 3.

**Table 3.** Description of the Notation

| S.No | Notations | Description |
|---|---|---|
| 1. | S | The Number of sensors, such that S varies from 1 to n |
| 2. | $\tau$ | Data fetch time |
| 3. | $\delta$ | Time required displaying the sensed data in LCD |
| 4. | $\varepsilon$ | Transfer time required to upload sensed data in both Thingspeak and Adafruit cloud platform |
| 5. | $\lambda$ | Cloud processing time |
| 6. | P | GPS sensor |
| 7. | LLA | Latitude, Longitude, Altitude data |
| 8. | Na | Thing speak cloud Registered users |

The algorithm 1 (Figure 3) developed for data sensing, displaying and uploading of weather parameters in IoT cloud is detailed in below.

**ALGORITHM 1** DATA SENSING AND PROCESSING

Step 1: Start
Step 2: Initialize Si, Pi, Wij, where i- 1 to N and j- 1 to k, Si –Weather stations. Pi- Position of Weather Station, Wij-Weather parameters
Step 3: Create channels in Thinkspeak Cloud to store Pi and in Adafruit cloud to store Wij
Step 4: Sense the parameter Pi and upload in Thinkspeak Cloud.
Step 5: Sense the parameter Wij periodically with an interval of τ where τ varies from 1 to n sec.
Step 6: Display the Wij locally with an interval of ε seconds
Step 7: Upload Wij in Adafruit cloud with an interval of λ seconds
Step 8: Repeat the process from step 4 to 7 for all S (i-1)
Step 9: Stop

**Fig 3.** Algorithm 1

Thingspeak cloud provides permission to the registered users (Nu) only to access the weather parameters. Hence, it stores the registered user login credentials and access details of time and location of the users as explained in algorithm 2 (Figure 4).

**ALGORITHM 2** USER AUTHORIZATION

Step 1: Start
Step 2: Initialize Nu where u – 1 to U
Step 3: Execute User Registration
Step 4: Create Channels for registered Users
Step5: Provide access to the weather parameters for the registered authenticated users
Step 6: Repeat step 3 to 5 for all N (u-1)
Step 7: Stop

**Fig 4.** Algorithm 2

## 2.4 Cloud Enablement Unit

Cloud enablement in this research is essential to store the sensed weather parameters and to provide statistical data and accessing data over the Internet instead of using them locally. It allows the sharing of data across devices through centralised storage. This information could be utilised in weather forecasting.

### *2.4.1 ThingSpeak cloud*

Thing Speak is an IoT Cloud platform that allows sensors to send weather parameters such as temperature, humidity, air quality and pressure to the cloud. This cloud-based tool allows users to aggregate, visualise, and analyse real-time data streams.

### *2.4.2 Adafruit cloud*

The weather monitoring system uses the following cloud databases to store time-series weather data. Adafruit IO supports MQTT protocol for device communication in a secured manner. The MQTT library is used to send and receive fed data, as well as to post and conform to feeds. The monitored parameters are stored in cloud platforms in real-time and further visualization is performed. The output obtained from the Adafruit dashboard is visualized.

Each parameter is displayed in a widget. The maximum and minimum range is set and the units are marked for each parameter. By clicking on the feed name, each parameter can be graphically visualized. Rain indicator changes from red to blue while the droplets are sprinkled. This indicates that real time weather updates can be easily visualized using an Adafruit cloud. The monitored parameters can be downloaded from the Adafruit cloud and can be further used for analysis of weather predictions.

## 2.5 Solar Harvesting Unit

The solar harvesting unit comprises of the following blocks as shown in Figure 5. In the solar characteristics, time vs. voltage measured, time vs. current drawn and time vs. temperature of the solar panel are studied graphically.

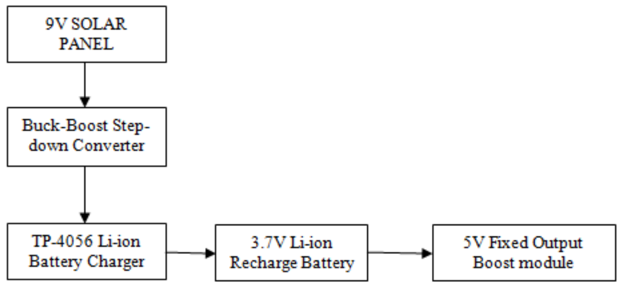


**Fig 5.** Solar Harvesting Unit

The power budget Analysis is performed to determine the lifetime of the application. The power consumed per hour and the energy dissipated by each sensor is computed as illustrated in Algorithm 3 given in Figure 6.

**ALGORITHM 3** POWER BUDGET ANALYSIS

Step 1: Start
Step 2: Initialize Capacity of battery(C), charging time ($T_{ch}$), Discharging time ($T_{dh}$), Battery charging current($I_c$), Current drawn ($I_j$)
Step 3: Compute battery charging current charging time and discharging time
Step 4: Compute the power consumption of each sensor
Step 5: End

**Fig 6.** Algorithm 3

Relation of the battery charging time and discharging time is obtained. Li-ion batteries are used in this research and given in Equation 1 and 2.

Battery charging Time ($T_{ch}$):

$$T_{ch} = \frac{Capacity\ of\ Battery\ (C)}{Charging\ Current\ (I_c)} \tag{1}$$

Battery discharging Time ($T_{dh}$):

$$T_{dh} = \frac{Capacity\ of\ Battery\ (C)}{Current\ drawn\ (I_j)} \tag{2}$$

## 2.6 Link Budget Analysis

The proposed system I-SOEWM is wireless enabled where the reliability of data communication is dependent on the link between the transmitter and the receiver. Transmitting point of the NodeMCU and receiving station point data to the cloud. The quality of the link will be determined based on the kind of environment in the Transmitter and the receiver separation. Hence link budget analysis is performed to determine the wireless channel characteristics as illustrated in Algorithm 4 given in Figure 7.

From the aforementioned section, the novelty claimed through the developed research is that continuous remote seamless monitoring is realizable with the employment of Solar based renewable energy resource and Wi-Fi based connectivity establishment. The necessary link budget and power budget analysing algorithms are developed to substantiate the above claim. Further, inclusion of new parameters namely UV index, AQI and Dew point provide additional details on the weather condition

**ALGORITHM 4** LINK BUDGET ANALYSIS

```
1: x and y: positions of wireless access point
2: β: signal strength
3: P1, P2, P3… P10 be the effective positions of the station
   points.
4: procedure Position Detection (Pn)
5:        for each n=1 varies to 10 do
6:        move the y position to get the β
7:        if β >=threshold
8:                  place the y position as pn
9:        else change the y position and check the step 6
10:       end for
11: end procedure
```

**Fig 7.** Algorithm 4

that are vital for well-being of living organisms. The developed I-SOEWM is enabled with GPS sensor to provide geo-tag based real-time data. As a futuristic scope, when multiple numbers of such developed systems are integrated through IoT, weather prediction can be made possible, hence to support this, two cloud platforms are used in the developed research.

## 3 Results and Discussion

### 3.1 Experimental Setup

During daytime, the complete setup is powered using solar energy which is the most abundant renewable energy. The input from the solar panel is stepped down to 5V using buck-boost convertor and is fed to the TP4056 module from which the battery is charged and the setup is powered simultaneously. The monitored parameters are displayed in an LCD screen in a loop-back format.

During nighttime, the solar panel and Buck-boost convertor are kept idle. The setup is powered using the charge stored in the battery as illustrated in Figure 8. The output is displayed in an LCD screen and is graphically visualized in Thingspeak and Adafruit cloud.

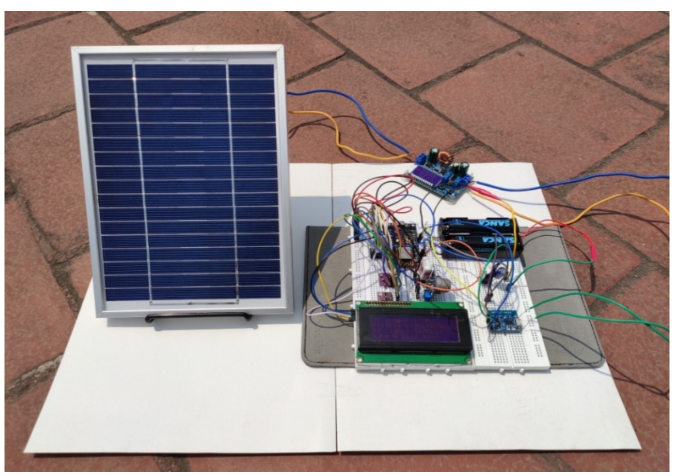

**Fig 8.** Remote Weather Parameter Monitoring in proposed I-SOEWM System

### 3.2 Performance Analysis

The results obtained from various weather sensors are analysed in this section.

### *3.2.1 DHT22 Temperature and Humidity sensor*

The DHT22 is a digital temperature and humidity sensor that doesn't cost much. The ambient air is measured via a capacitive humidity sensor and a thermistor.

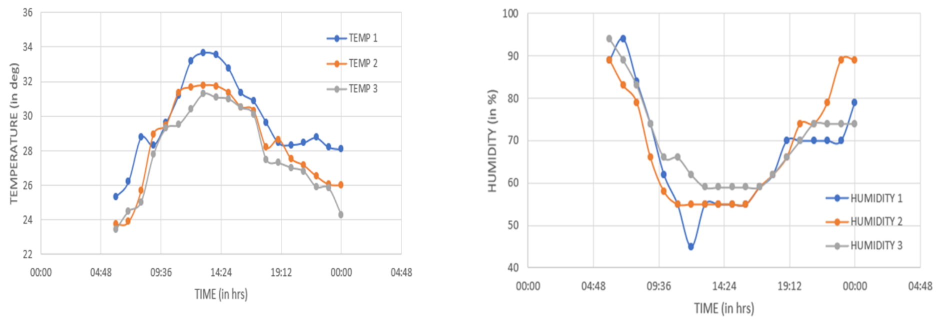


**Fig 9.** a. Temperature characteristics, b. Humidity characteristics

The characteristics of temperature and humidity sensors are presented in Figure 9 a and b. The parameters are monitored for a span of 5 days under three different temperature. The average value is represented in above Figures. From the Figure 9 a, it is observed that increase in atmospheric temperature is found when radiation energy of photons from the sun is increased. The increase in UV radiation from the sun results in an increase in UV Index.

$$Temperature\ \alpha\ \frac{1}{Relative\ Humidity} \tag{3}$$

It is observed that from 12.00 noon to 2.00 pm, the atmospheric temperature reaches its peak. According to the ideal gas law, when the air's temperature rises, it can retain more water molecules, and its relative humidity falls. Temperatures close to dew point cause high relative humidity in the atmosphere. Thus, at 12:00 noon to 2 pm as the temperature spikes, a sharp drop at relative humidity percentage value is observed in Figure 9 b.

Relative humidity and air temperature combine to produce the heat index, which is sometimes referred to as "apparent temperature" by meteorologists is represented as equation 3. This has significant implications for the wellness of the human body. When the body becomes overheated, it starts to perspire or sweat in an effort to cool down. Heat index characteristics of DHT22 are as shown below in Figure 10.

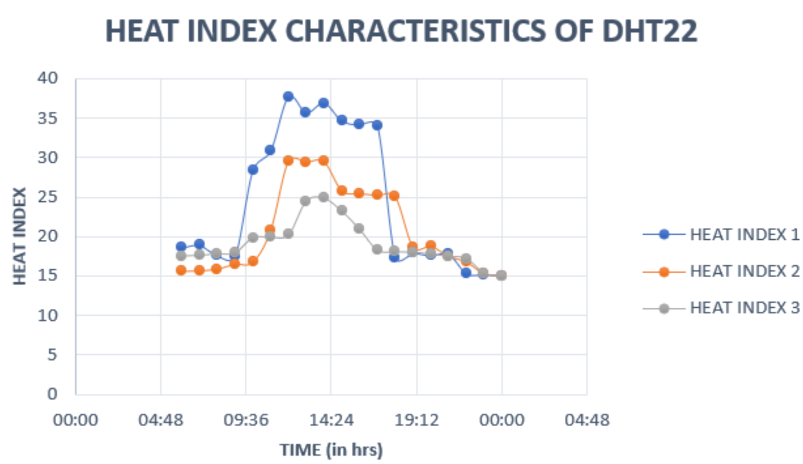


**Fig 10.** Heat index characteristics of DHT22

### *3.2.2 BMP280 Pressure sensor*

BMP280 is an ultimate barometric pressure sensor that is made for mobile use. Because it is tiny, low power consuming, it can be used in devices that run on batteries, such as cellular phones, GPS modules, and watches. Figure 11 a and b shows Pressure and Altitude characteristics of BMP280 pressure sensor.

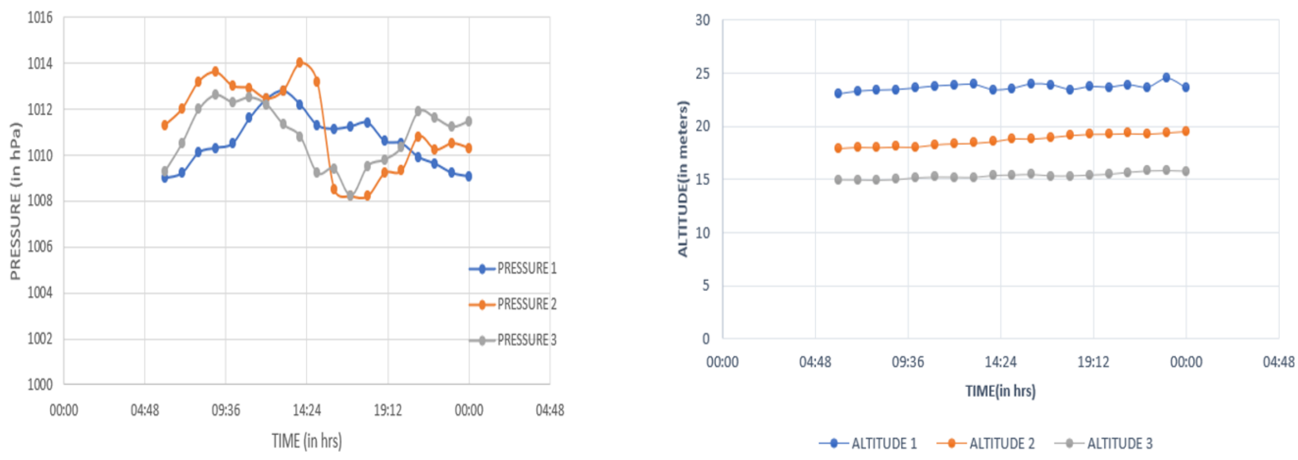


**Fig 11.** a. Pressure characteristics, b. Altitude characteristics

The Ideal gas law [12] states that

$$PV = nKT \tag{4}$$

Where P = absolute pressure of measured gas, V = Volume, N = Number of atoms/molecules,
T = Temperature, k = ideal gas constant. It is represented in Equation 4.
As the altitude goes up, the air gets less dense, which makes the pressure goes down.

$$Temperature \ \alpha \ Pressure \tag{5}$$

Temperature is directly related to pressure as represented in Equation 5, thus when pressure falls, so does the temperature.

The dew point is the temperature where the atmosphere wants to just be kept cool until it is completely saturated, or reaches 100% relative humidity.

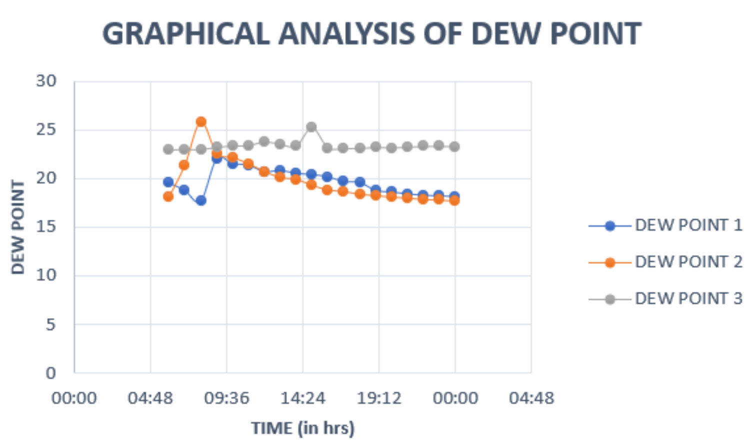


**Fig 12.** Analysis of Dew point

From Figure 12, it can be observed that the dew point is almost constant for a particular day. The UVI measures the amount of ultraviolet radiation It ranges from 0 to 1, with higher UVI values indicating increased risk of skin and eye damage and quicker time to harm initiation.

### *3.2.3 GY1145 UV sensor*

The amount of ultraviolet (UV) light emitted is measured by UV sensors. UV sensors are used in environmental situations to determine the exposure to ultraviolet radiation. From Figure 13, it is observed that during day and night, UV index falls in the range of 0-1.2. The UV index has a value of 1.5 around noon.

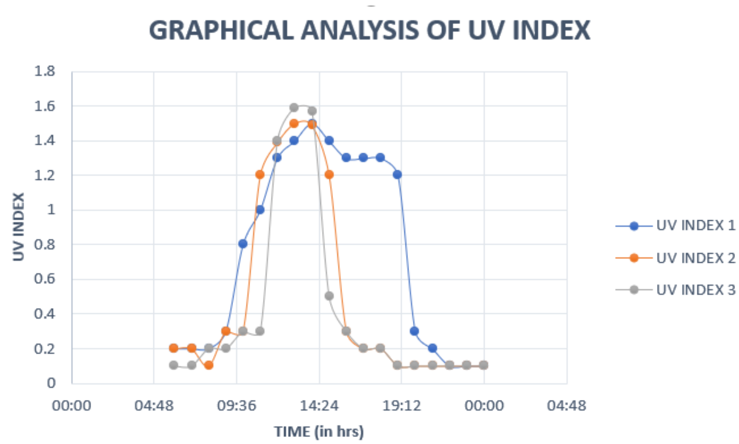


**Fig 13.** Analysis of UV index

### *3.2.4 MQ135 Air Quality sensor*

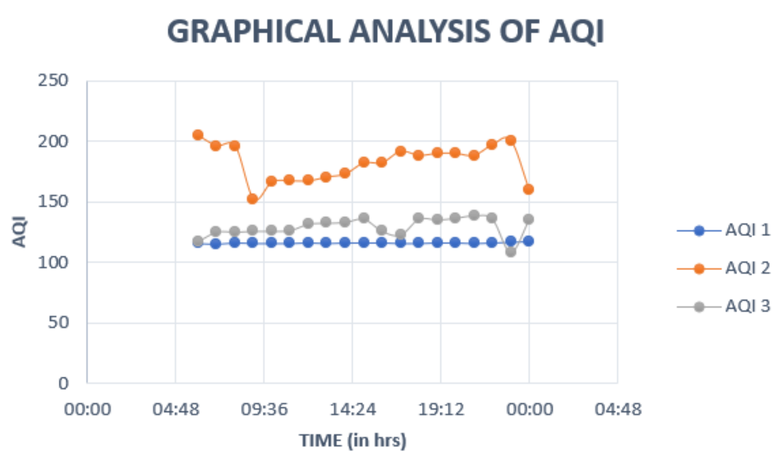


**Fig 14.** Analysis of AQI

AQI is used to measure air quality. It indicates the air pollutant level. The MQ135 gas sensor is very sensitive to ammonia, sulphide, and benzene series steam. Additionally, it can detect smoke and other hazardous substances. It can detect all types of hazardous gases and is a cheap sensor that may be used for this purpose.It can be observed from Figure 14, that air quality level is almost a constant value in a particular location. The AQI is designed to assist individuals understand how the local air quality affects their health. AQI readings over 900 (in PPM) are deemed hazardous to human health since they may induce respiratory difficulties.

## 4 Conclusion

The study exhibited a new solar based IoT enabled portable system (I-SOEWM) for continuous environmental weather monitoring. It is a cost-effective solution addressing long term energy requirements of the application. The GPS module used enable localized weather monitoring. The additional parameters namely AQI, UV Index and Dew Points differentiate the developed I-SOEWM from conventional WMS. The power budget and Link Budget Analysis ensures reliability of the system. The developed WMS can provide predictions on weather conditions that can guide farmers and gardeners to organize irrigation system. This model can be expanded to industrial zones for pollution monitoring. From the study made, the observations recorded are: AQI - 110–200, indicate unhealthy air. UV index - 0.2–1.8, Temperature - 22–34 degrees, Humidity - averages 82%.

The developed I-SOEWM allows remote access to sensed data via the cloud. Additionally, the whole system can be controlled via an Android application, which makes it more users friendly and convenient for weather monitoring purposes. This research will also predict weather conditions using a real-time dataset uploaded to Thingspeak cloud and a machine learning model in the future.

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