Cloud and PM2.5 Spatiotemporal Monitoring using the PM2.5 IoT and AirLink sensors in Krabi, Thailand

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Abstract

In this study, we compared (1)the PM2.5 dust sensor PMS3003 with the AirLink PM2.5 sensor to evaluate using a low-cost sensor for PM2.5 measurement at (1) Boon Siam Hotel and (2) Chao Fa Pier, Krabi Province, Southern Thailand and (2) examined the relationship of PM2.5 to air temperature, relative humidity, cloud type, and percentage of cloud cover using the GLOBE Observer: Cloud app. Our results show that the higher the air temperature, the more pm2.5 dust, and the higher the temperature, the better the pm2.5 dust can be distributed, reducing the chance that pm2.5 will fall to the ground. The higher the humidity, the less pm 2.5 will be because dust will stick to the water. Especially if it is a thick cloud with high humidity, pm 2.5 will be low because the cloud collects dust and disperses rainwater, causing the dust to fall to the ground. The higher the percentage of cloud cover, the less pm 2.5 will be because the higher the percentage of clouds that collect dust and disperse rainwater, the more dust will fall to the ground.

Keywords: Particulate Matter; PM 1; PM 2.5; PM 10; IoT; Iot Sensors; Arduino IDE; Globe observer app: Cloud Protocol; Clouds; Temperature; Relative Humidity;

Introduction

Air pollution is the contamination of the environment by any biological, physical, or chemical means that modify the characteristics of the atmosphere. Chronic exposure to particulates has been associated with increased rates of bronchitis and other respiratory ailments, loss of lung function, and increased risk of lung cancer (Schwartz, 1993). Therefore, air quality measuring equipment must be installed to reduce air pollution at traffic intersections and industrial areas. These monitoring stations track PM_{10} and $PM_{2.5}$ on a 24-hour basis (Nagendra et al., 2007). An extensive literature review was conducted to learn more about the various air quality devices developed in the published articles (Zhuang et al., 2015), including embedded sensors like GPS, accelerometer, and dust sensor, which only measure $PM_{2.5}$.

The primary data to assess PM exposure could be emission data or observations from different monitoring devices. Emission data are essential for air quality modeling, which simulates the transport and reaction of pollutants. A comparison study found that the methods using observations are more accurate than those using models (Yu et al., 2018). Air quality observations have been widely used in mapping the distribution of air pollutants. Most mapping studies rely on fixed sites of air quality monitors. Several studies have also used the measurements of mobile detectors or low-cost sensors to improve spatial resolution.

The data quality and duration of low-cost sensors are still not as good as that of standard air quality stations (Mak and Lam, 2021). The accuracy and reliability of microsensors must be validated under laboratory conditions and through field evaluations of the quality of data used in exposure assessments (Huang et al., 2018; Zamora et al., 2019). Air pollution is a severe global problem, especially in developing countries. A central air pollutant in urban environments is delicate particulate matter (PM_1, $PM_{2.5}$, PM_{10}), which negatively affects human health. However, the traditional existing air quality monitoring networks are sparsely deployed and lack measurement density because installing and maintaining air quality monitoring instruments is expensive. Low-cost air quality sensors are promising supplements to regulatory monitors for PM_1, $PM_{2.5}$, and PM_{10} exposure assessment. Low-cost sensors have been used to collect real-time high-density air pollution data.

Low-cost PM1, PM 2.5, and PM10 sensors were developed from the Internet of Things (IoT). Investigators can also deploy additional sensors to increase spatial coverage of the air quality monitoring network. Moreover, low-cost sensors can gather real-time air quality information about the community at any location. The sensors are potentially accessible to use and maintain because they require less energy and space. Low-cost sensors have been proposed to stand alone or as complementary components of existing air quality monitoring regulatory networks, which measure air pollution concentrations. In this study, we compared a PM2.5 dust sensor PMS3003 with the AirLink PM2.5 sensors to assess the applicability of low-cost sensors for measuring PM2.5 at (1) Boon Siam Hotel and (2) Chaofa Pier in Krabi province, Southern Thailand, and how PM2.5 was associated with air temperature, relative humidity, cloud types, and the percentage of cloud cover using the GLOBE Observer: Cloud App.

Research Questions:

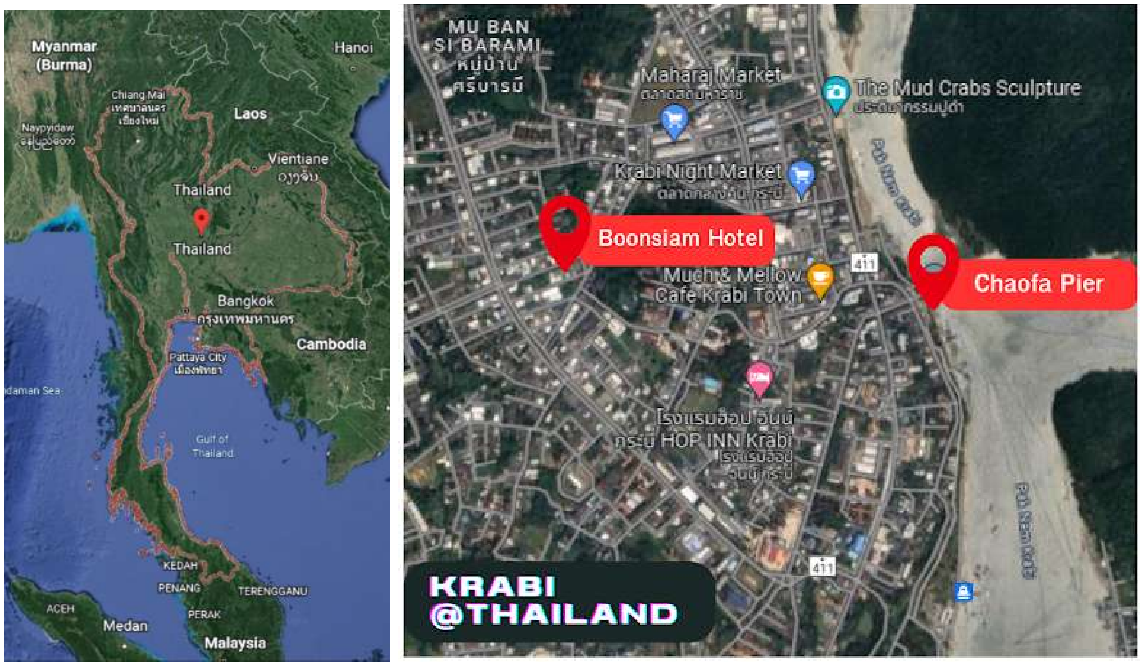
This research aims to answer the following questions:

1. How does air temperature and relative humidity affect PM 2.5?
2. How do cloud types and amounts of clouds relate to the increase or decrease of PM2.5 in the air?
3. Is the Low-cost IoT dust sensor PM30003 able to detect PM 2.5 data accurately compared to the Davis Airlink PM 2.5 sensor?

Materials and Research Methods

A. Study sites

The study was conducted at (1) Boon Siam Hotel (8.063299, l.910576) and (2) Chaofa Pier (8.06456, 98.91771) in Krabi province, Southern Thailand. The Plantower Laser PM2.5 dust sensor PMS 3003 low-cost sensors and a Davis AirLink reference tool were installed at both sites.



(a) Thailand Map (b) Study sites

Figure 1 (a) Map of Thailand and (b) Boon Siam Hotel and Chaofa Pier in Krabi

B. Materials

1. **Jump wires (Male-Female)** -Jumper wires are wires or terminals that connect between a remote electronic circuit and a panel. Male ends have a pin protruding and can plug into things, while female ends do not and are used to plug things into. Male-female starts with a male and ends with a female.
2. **Jump wire (Female-Female)** starts with the female and ends with the female.
3. **Using laser scattering theory, PM 2.5 sensor (PMS3003) - PMS3003** can get in the air-suspended particulate matter concentration of 0.3 to 10 microns, and reliable data; built-in fan, digital output, and high integration.
4. **Node MCU** - NodeMCU is a low-cost open-source IoT platform. It initially included firmware that runs on the ESP8266 Wi-Fi SoC from Espressif Systems and hardware based on the ESP-12 module. Later, support for the ESP32 32-bit MCU was added.
5. **Breadboard** -A breadboard, or protoboard, is a construction base for prototyping electronics. In the 1970s, the solderless breadboard became available. Nowadays, the term "breadboard" is commonly used to refer to these.

6. **Micro-USB** - Micro USB is a miniaturized version of the Universal Serial Bus (USB) interface developed for connecting compact and mobile devices such as smartphones, MP3 players, GPS devices, photo printers, and digital cameras.
7. **Notebook or Computer** - connect to IoT device and measure pm 2.5
8. **Arduino IDE** - A program that uses an open-source style in which the Arduino IDE acts as an interface between the computer and the Arduino board. This program is designed to make it easy to write code and upload the program that we write to the Arduino board.

C. PM 2.5 Iot Sensor Construction and Operation

1. Place the NodeMCU on the breadboard.
2. Connect the jumper wire to the PM 2.5 sensor. The second pin of the DHT 22 should connect to D2, D3 on the MCU, 3v3, or Vin on the MCU. The last pin of the PM 2.5 sensor should be connected to a ground (GND).
3. Connect the Micro-USB to the MCU and PM 2.5 sensor and connect it to the computer.
4. Open ARDUINO IDE software and set up the SoftwareSerial library.
5. Open the Arduino IDE and use the following codes. (Figure 2):

```
const char* ssid     = "TVOWalailak2021"; //ชื่อwifiโรงแรม ริมน้ำ
const char* password = "TVOwifi@007"; //password


const int analogInPin = A0;
int sensorValue = 0;

#define DHTPIN D4
#define DHTTYPE DHT22

DHT dht(DHTPIN, DHTTYPE);

SoftwareSerial mySerial(D2,D3); // RX, TX
unsigned int pm1 = 0;
unsigned int pm2_5 = 0;
unsigned int pm10 = 0;

void setup() {
  Serial.begin(9600);
  while (!Serial) ;
  Serial.println(F("IoT AI Module v 1.0"));
  Serial.println(F("CoE for Ecoinformatics, Walailak Universit
  Serial.println(F("(c) 2023 Krisanadej Computing"));
  Serial.println(F("DHTxx test!"));
```

Figure 2. Arduino Code for Laser Dust Sensor

6. Open the data repository with a browser to see the data (Figure 3):

{"T":"{2023,11,27,00,06,46}","Temp":"26.20","Humid":"76.00","CO":"218","TimeStamp":"6420522","PM1":"1","PM25":"4","PM10":"5"},
{"T":"{2023,11,27,00,16,56}","Temp":"26.30","Humid":"75.30","CO":"214","TimeStamp":"7030695","PM1":"1","PM25":"7","PM10":"7"},
{"T":"{2023,11,27,00,27,07}","Temp":"26.10","Humid":"76.40","CO":"211","TimeStamp":"7640865","PM1":"1","PM25":"5","PM10":"7"},
{"T":"{2023,11,27,00,32,12}","Temp":"26.10","Humid":"76.90","CO":"192","TimeStamp":"7946025","PM1":"0","PM25":"7","PM10":"7"},
{"T":"{2023,11,27,00,37,17}","Temp":"26.10","Humid":"76.80","CO":"188","TimeStamp":"8251193","PM1":"1","PM25":"10","PM10":"10"},
{"T":"{2023,11,27,00,42,22}","Temp":"26.20","Humid":"76.10","CO":"208","TimeStamp":"8556360","PM1":"1","PM25":"7","PM10":"8"},
{"T":"{2023,11,27,00,47,27}","Temp":"26.10","Humid":"75.80","CO":"204","TimeStamp":"8861519","PM1":"1","PM25":"6","PM10":"8"},
{"T":"{2023,11,27,00,52,32}","Temp":"26.20","Humid":"75.70","CO":"199","TimeStamp":"9166687","PM1":"1","PM25":"7","PM10":"7"},
{"T":"{2023,11,27,00,57,38}","Temp":"26.20","Humid":"76.50","CO":"207","TimeStamp":"9471848","PM1":"4","PM25":"11","PM10":"11"},
{"T":"{2023,11,27,01,02,43}","Temp":"26.20","Humid":"76.90","CO":"205","TimeStamp":"9777105","PM1":"0","PM25":"4","PM10":"5"},
{"T":"{2023,11,27,01,07,48}","Temp":"26.20","Humid":"77.10","CO":"204","TimeStamp":"10082270","PM1":"4","PM25":"7","PM10":"8"},
{"T":"{2023,11,27,01,12,53}","Temp":"26.20","Humid":"76.60","CO":"196","TimeStamp":"10387511","PM1":"0","PM25":"5","PM10":"5"},
{"T":"{2023,11,27,01,17,58}","Temp":"26.10","Humid":"76.10","CO":"201","TimeStamp":"10692673","PM1":"5","PM25":"11","PM10":"13"},
{"T":"{2023,11,27,01,23,04}","Temp":"26.20","Humid":"75.90","CO":"199","TimeStamp":"10997841","PM1":"1","PM25":"7","PM10":"8"},
{"T":"{2023,11,27,01,28,09}","Temp":"26.10","Humid":"76.60","CO":"199","TimeStamp":"11303008","PM1":"0","PM25":"2","PM10":"2"},
{"T":"{2023,11,27,01,33,14}","Temp":"26.30","Humid":"77.20","CO":"200","TimeStamp":"11608167","PM1":"0","PM25":"4","PM10":"4"},
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{"T":"{2023,11,27,03,04,47}","Temp":"26.10","Humid":"78.10","CO":"185","TimeStamp":"17101070","PM1":"2","PM25":"8","PM10":"8"},
{"T":"{2023,11,27,03,09,52}","Temp":"26.10","Humid":"77.50","CO":"181","TimeStamp":"17406272","PM1":"5","PM25":"11","PM10":"11"},

Figure 3. PM Sensor Data Generated from the Server

Research Method

Figure 4 presents the flowchart of the research methodology. The research started with the construction of the low-cost IoT PM sensor. Hardware constructions and software coding are done inside the Center of Excellence in Ecoinformatics (CoE) Laboratory, School of Science, Walailak University. After this, calibration of the IoT PM sensor was done to check the reliability and accuracy of the device using machine learning (ML). The calibration process was also done inside the laboratory of CoE. The compared calibration result is used as the basis for fielding or not fielding the device. The IoT PM sensor is then compared to the data gathering of the Davis Airlink standardized device to calibrate the data collection before fielding further. After calibrating the device, the IoT PM sensors are installed together with Davis airlink to the designated location outside the laboratory of CoE for data air quality data collection.

Furthermore, the collected data are tested for errors and gaps by cleaning and spotting errors using Google Sheets. The result of the cleaned data allows the researcher to field the device in a broader area. The IoT sensors with Davis Airlink were brought to Krabi Province, Southern Thailand, for fielding and data gathering on a broader scale. Two IoT PM 2.5 sensors were installed in different locations in Krabi to check the air quality index of the Area.

1

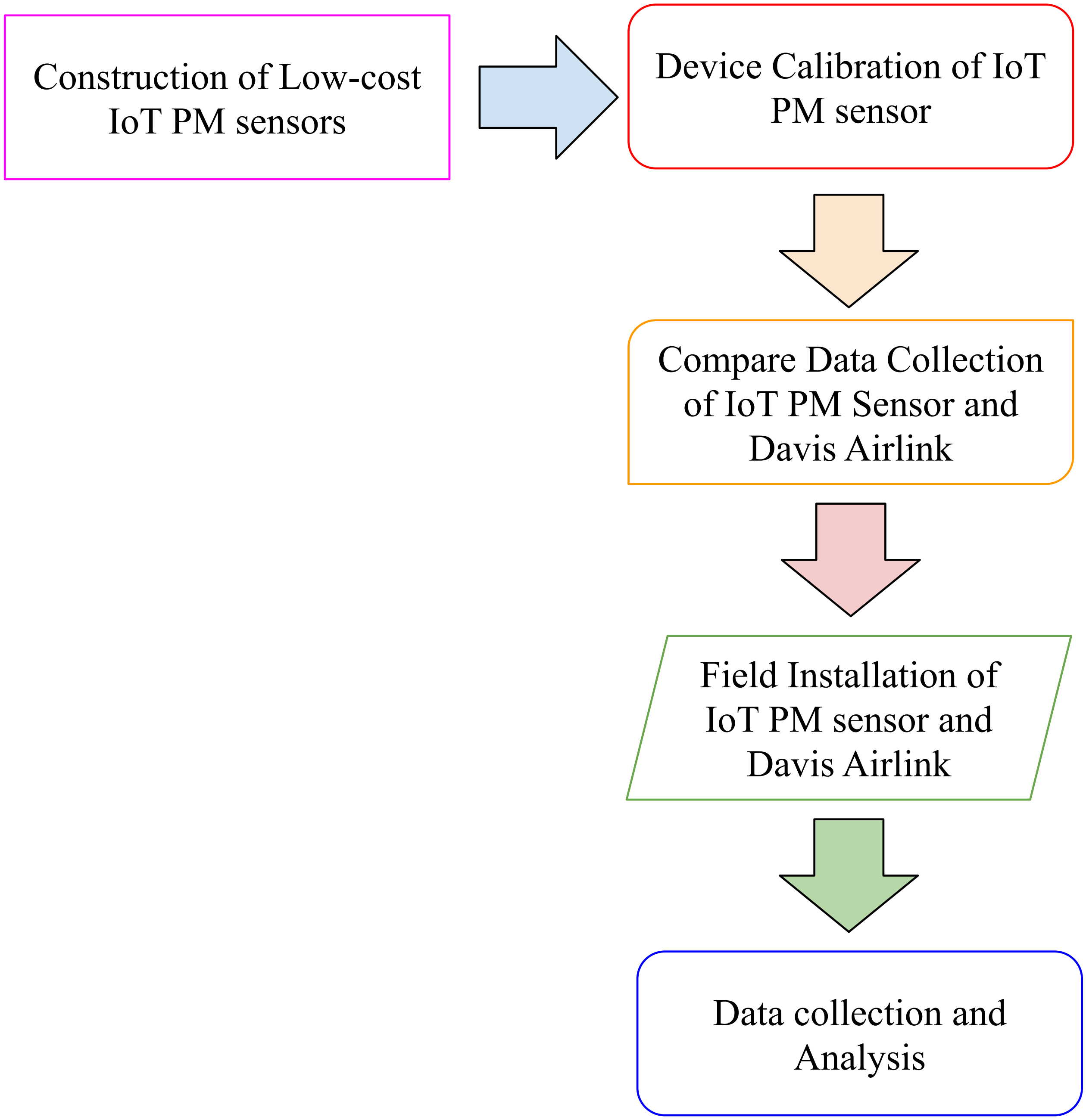

Figure 4. Flowchart of the research study

Data Collection

A. Globe Observer Application: Cloud Protocol

This Globe application cloud protocol tells a big picture of climatic cloud effects on the phenomena happening at the earth's surface by providing a detailed analysis of what is happening in specific locations (https://www.globe.gov/web/s-cool). The researchers used the application to collect cloud information, specifically the percentages of Cloud Cover, Cloud Types, Sky Clarity, and Sky Color, to establish a relationship with the amount of PM 2.5 in the atmosphere.

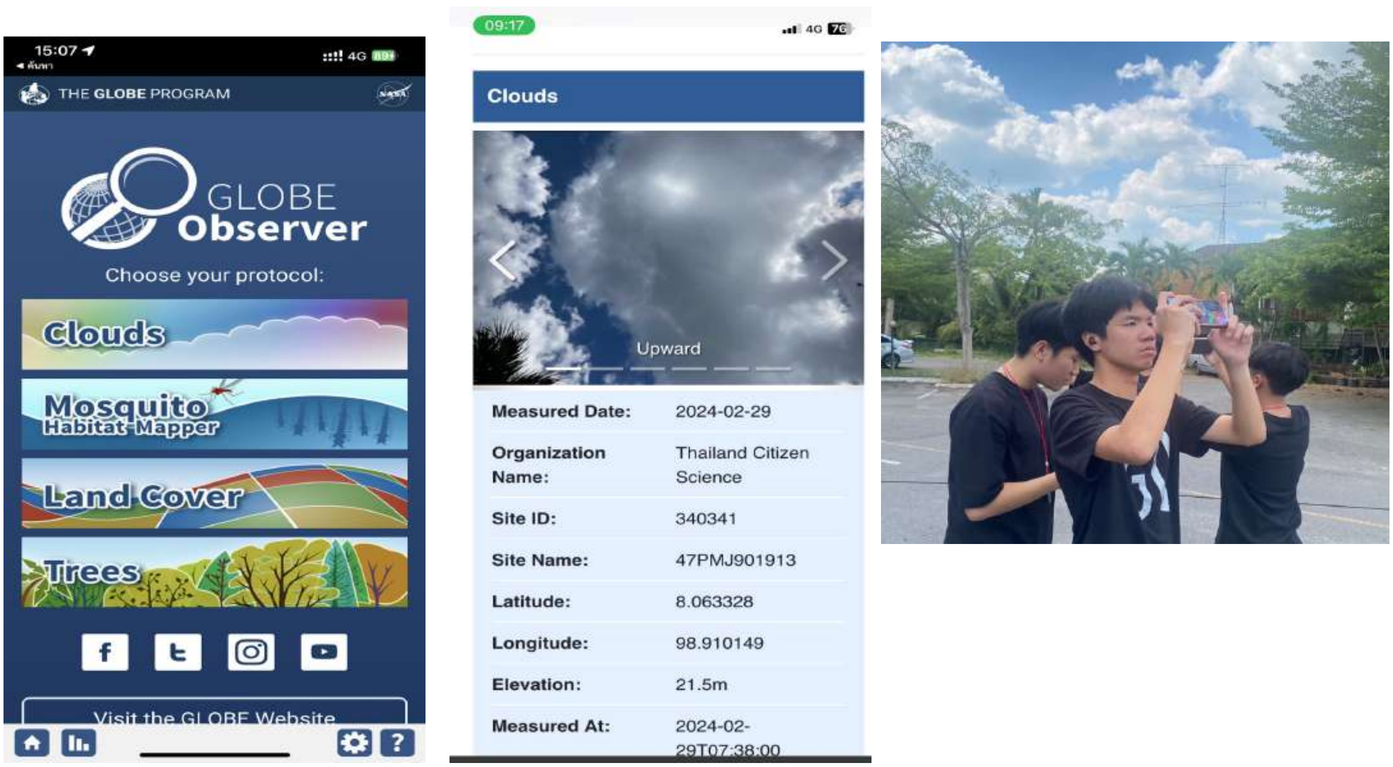

Figure 5. Cloud data was collected using the GLOBE Observer: Cloud application.

B. Low-Cost IoT PM 2.5 Sensors and Davis Airlink

Data from the IoT PM sensors and Davis Airlink sensors are extracted in real-time from 02/28/2024 to 03/2/2024. The metadata from IoT PM sensors is exported from the device server using Google Sheets and cleaned for errors and data analysis. In contrast, the data from the Davis Airlink were exported in real-time by downloading from the device's website called weatherlink.com. Figure 6 shows the snippets of data collection from both devices.

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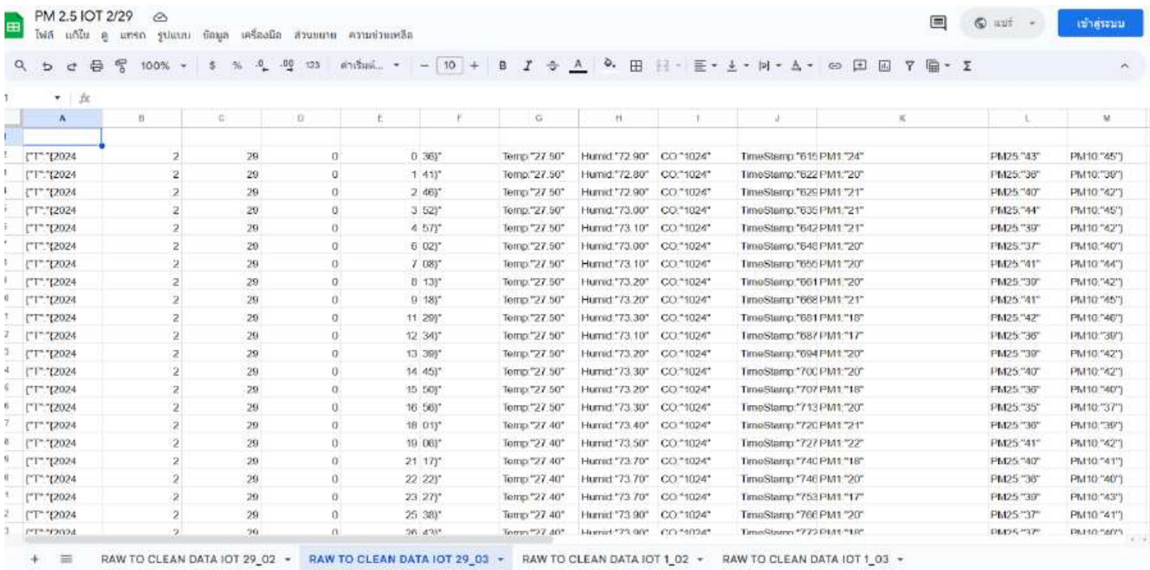


Figure 6a. Google Sheet Snippet

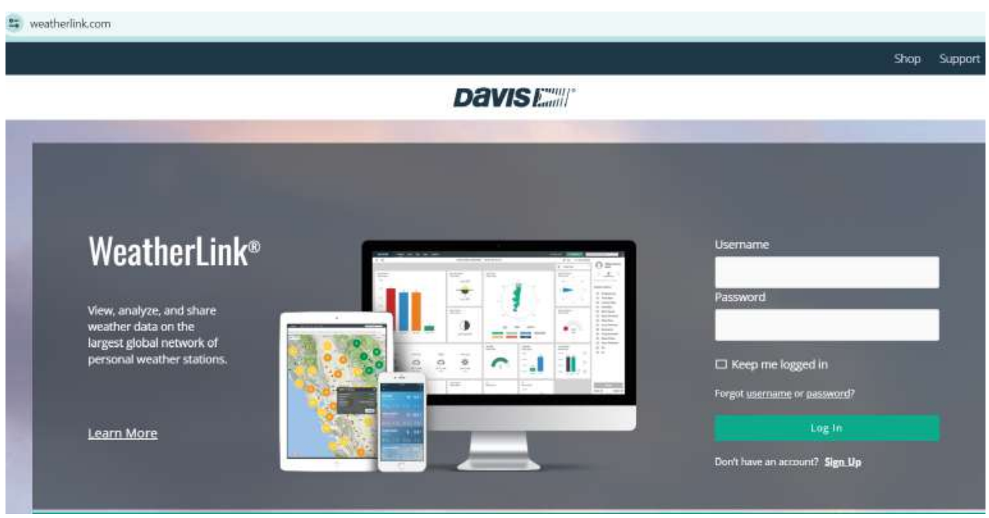


Figure 6b. Davis Airlink Website

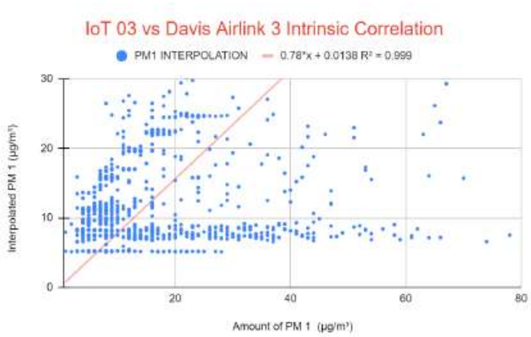
Data Analysis

The low-cost IoT PM sensor's data collection and accuracy were assessed through a correlational analysis with a reference instrument, Davis Airlink. In addition, we used simple linear regression analyses to assess relationships showing the association between PM concentrations measured by the low-cost sensors and the Davis AirLink reference instrument at two areas in Krabi and (2) the daily PM_1, $PM_{2.5}$, and PM_{10} concentrations. Subsequently, Globe Application using Cloud Protocol was used to establish relationships between cloud type, cloud cover percentage, and amount of PM 2.5.

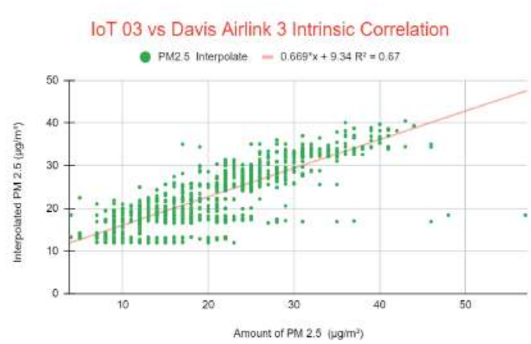
Results and Discussion

A. Intrinsic Correlation of PM Sensors in Krabi Province

For Low-Cost IoT PM Sensor set 1 at Boon Siam Hotel and PM sensor set 2 at Chaofa Pier, PM_1, $PM_{2.5}$, and PM_{10} sensor data with IoT were positively associated with the Davis Airlink sensor using Simple linear regression test: Set 1 in Figure 7(a-c) : PM_1: $R^2 = 0.999$, $P < 0.001$, $y = 0.78x + 0.0138$; $PM_{2.5}$: $R^2 = 0.67$, $P < 0.001$, $y = 0.669x + 9.34$; PM_{10}: $R^2 = 0.69$, $P < 0.001$, $y = 0.766x + 9.58$,. For Set 2 in Figure 7(d-f) PM_1: $R^2 = 0.599$, $P < 0.001$, $y = 0.637x + 8.5$; $PM_{2.5}$: $R^2 = 0.756$, $P < 0.001$, $y = 0.542x + 10.3$; PM_{10}: $R^2 = 0.767$, $P < 0.001$, $y = 0.682x + 8.09$. It can be inferred that the Low-cost IoT PM sensor's performance and accuracy in data collection are almost the same as the reference instrument. The positive correlation results showed that the low-cost IoT PM sensors can be used in PM data gathering because they can give accurate PM concentration data similar to the standardized and well-calibrated Davis Airlink device.



(a)



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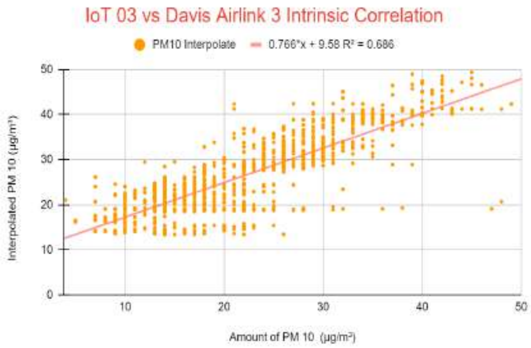
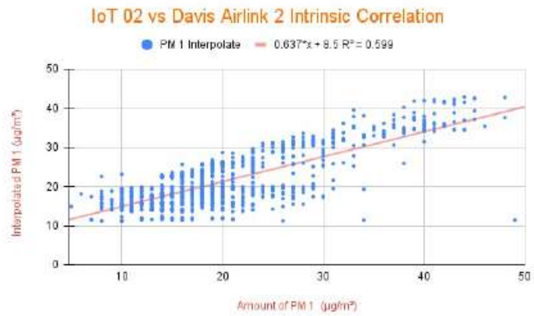
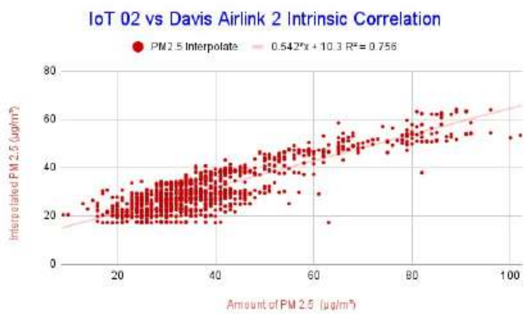
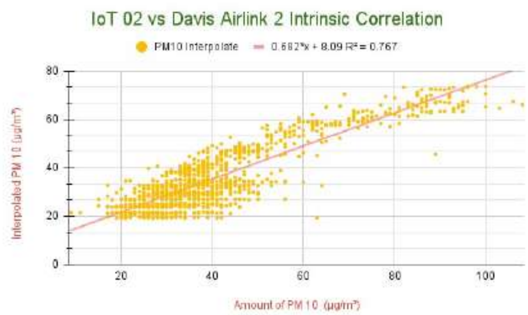




(d)

(c)



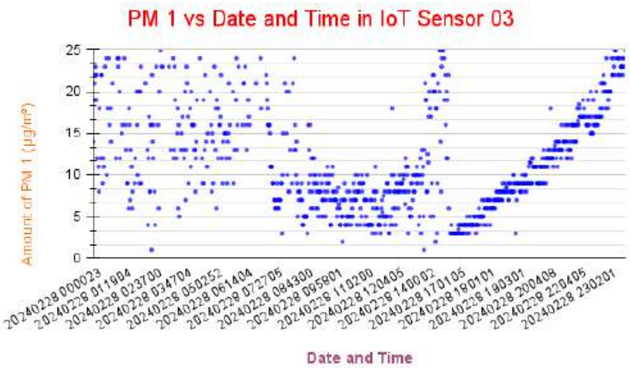


(e) (f)

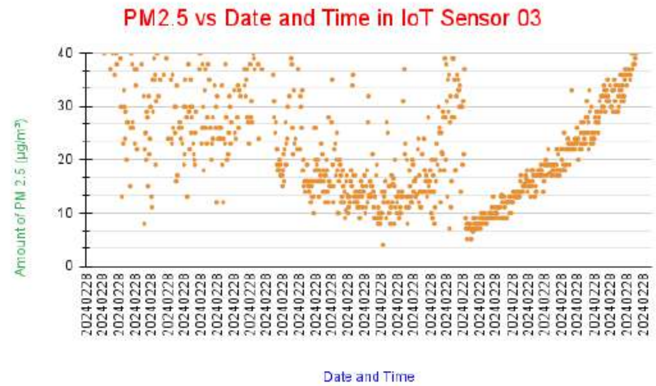
Figure 7(a-f). Intrinsic Correlation of PM sensors at Boon Siam Hotel.

B. Three-day Concentration of Particulate Matters

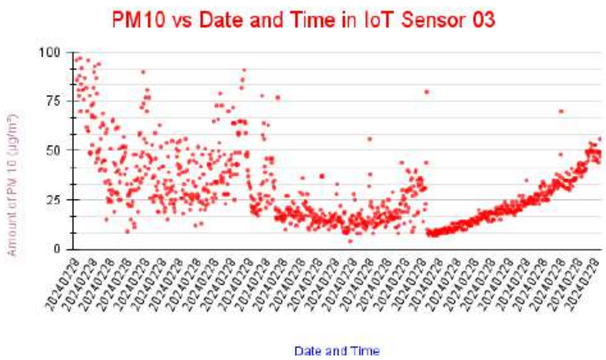
The daily concentration of PM_1, $PM_{2.5}$, and PM_{10} for the IoT sensor set 1 installed in Boon Siam Hotel from 28/02/2024 to 01/03/2024 is shown in Figures 8 (a-i). The graph shows that the highest PM concentrations were recorded during the morning because the Hotel is located at the center of a busy road from North to West. Many vehicles use the service road in the morning, which passes the hotel's front and sides, compared to the afternoon and evening. Apart from the vehicular exhaust, the hotel is surrounded by the houses of locals who are primarily active in doing their household chores in the morning.


PM 1 vs Date and Time in IoT Sensor 03
Amount of PM 1 (μg/m³)
Date and Time

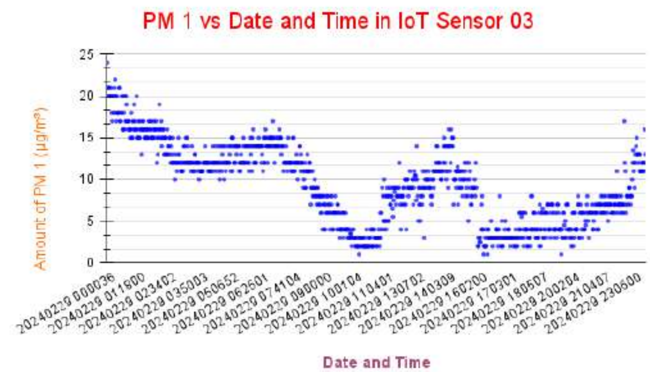
(a)


PM2.5 vs Date and Time in IoT Sensor 03
Amount of PM 2.5 (μg/m³)
Date and Time

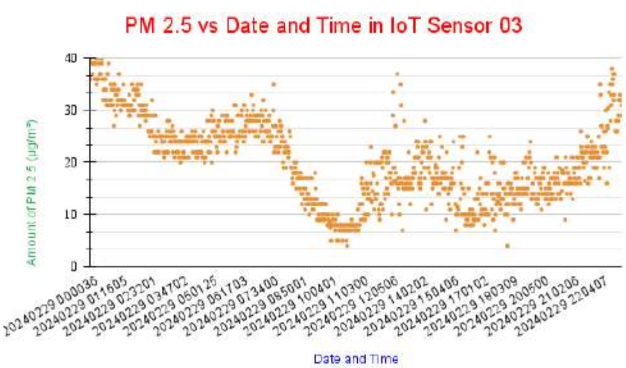
(b)


PM10 vs Date and Time in IoT Sensor 03
Amount of PM 10 (μg/m³)
Date and Time

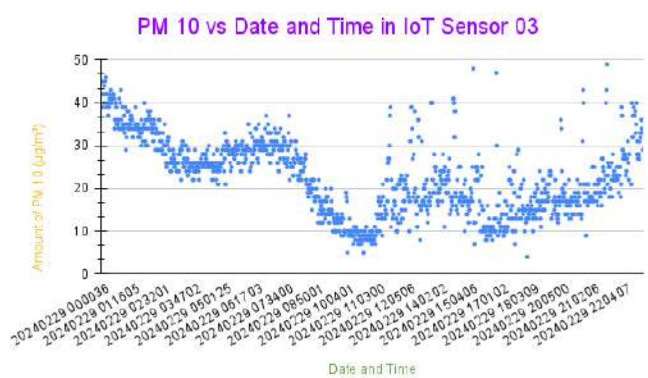
(c)


PM 1 vs Date and Time in IoT Sensor 03
Amount of PM 1 (μg/m³)
Date and Time

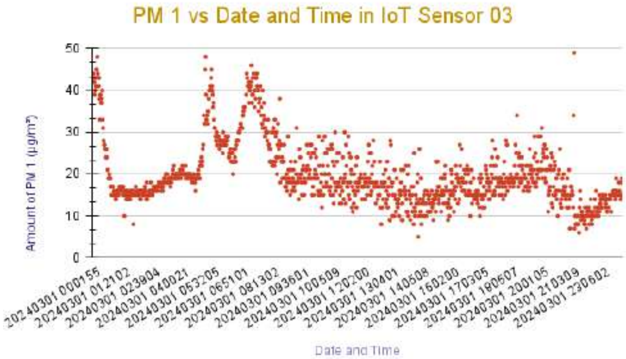
(d)


PM 2.5 vs Date and Time in IoT Sensor 03
Amount of PM 2.5 (μg/m³)
Date and Time

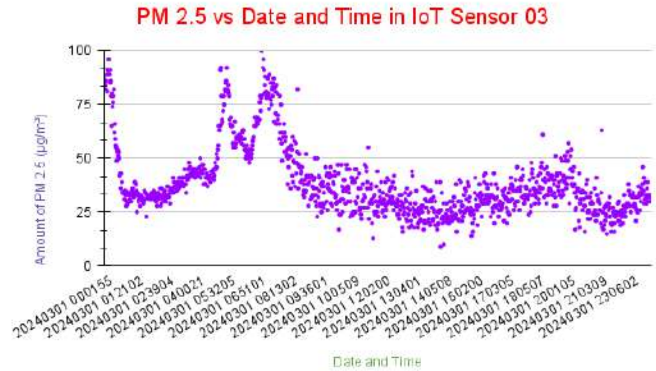
(e)


PM 10 vs Date and Time in IoT Sensor 03
Amount of PM 10 (μg/m³)
Date and Time

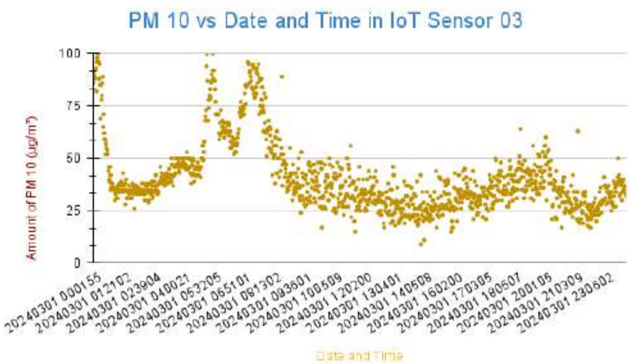
(f)



(g)



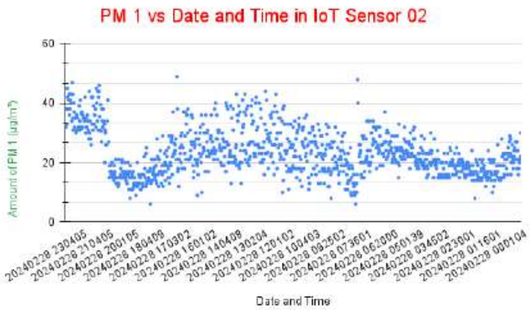
(h)



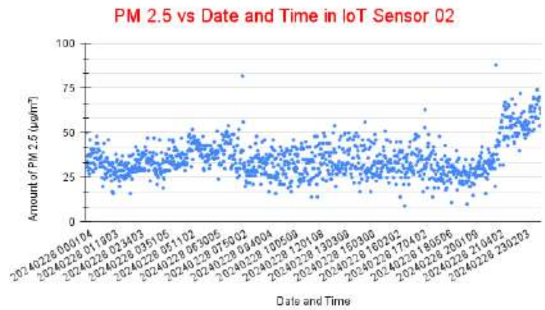
(i)

Figure 8(a-i). Daily PM Concentrations at Boon Siam Hotel

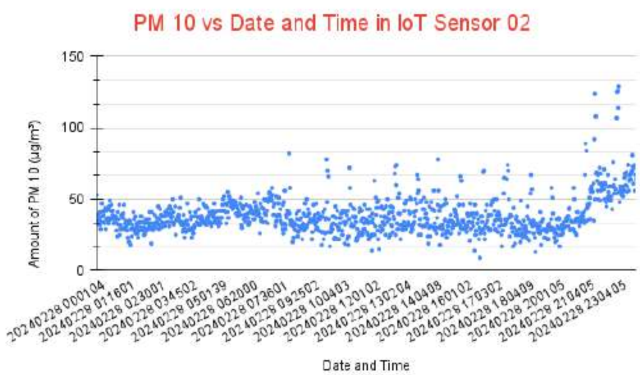
Figure 9 shows the daily concentration of PM_1, $PM_{2.5}$, and PM_{10} for the IoT sensor set 2 installed at Chao Fa Pier from 28/02/2024 to 01/03/2024. The graph shows that the PM concentration is at its highest in the morning compared to the afternoon and evening. The amount of PM in the area is due to car parking lots, people exercising, burning to cook some street food, and local settlers surrounding the area.


PM 1 vs Date and Time in IoT Sensor 02
Amount of PM 1 (μg/m³)
Date and Time

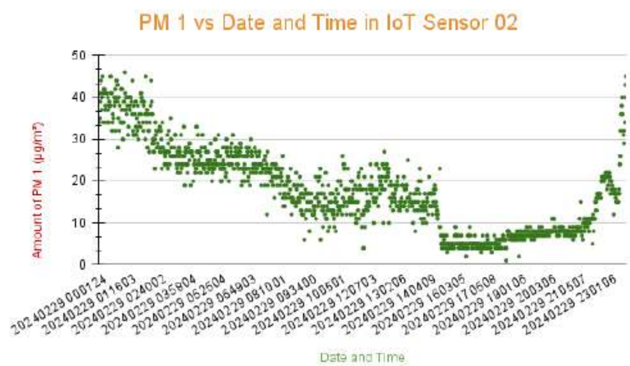
(a)


PM 2.5 vs Date and Time in IoT Sensor 02
Amount of PM 2.5 (μg/m³)
Date and Time

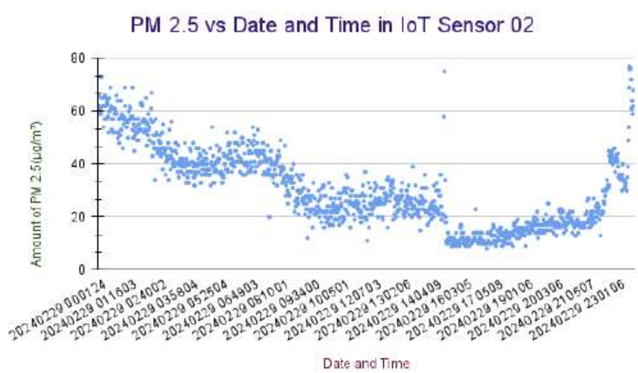
(b)


PM 10 vs Date and Time in IoT Sensor 02
Amount of PM 10 (μg/m³)
Date and Time

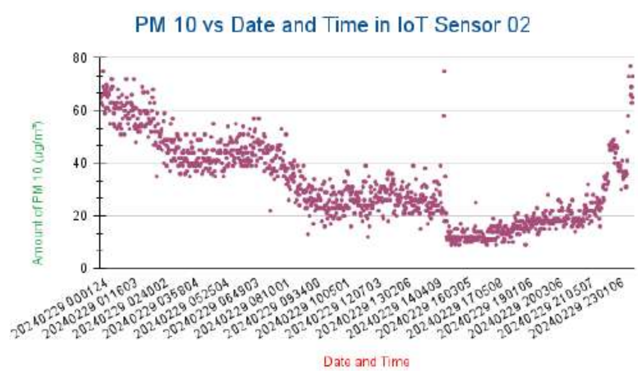
(c)


PM 1 vs Date and Time in IoT Sensor 02
Amount of PM 1 (μg/m³)
Date and Time

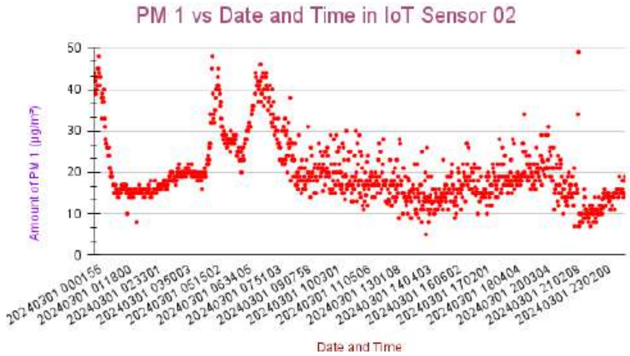
(d)


PM 2.5 vs Date and Time in IoT Sensor 02
Amount of PM 2.5 (μg/m³)
Date and Time

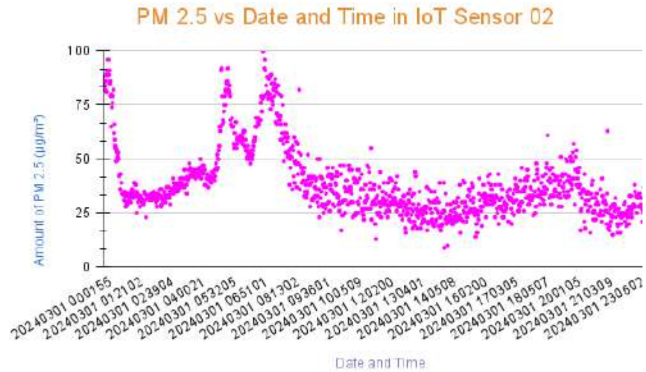
(e)


PM 10 vs Date and Time in IoT Sensor 02
Amount of PM 10 (μg/m³)
Date and Time

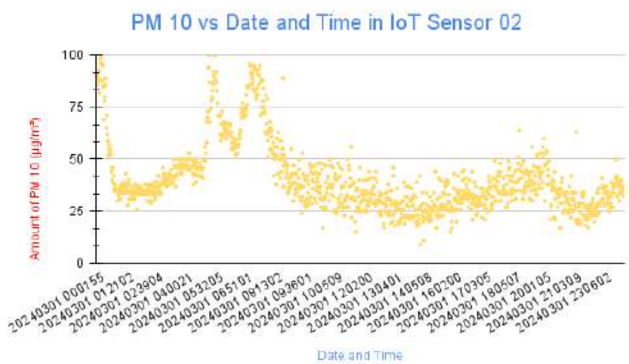
(f)



(g)



(h)



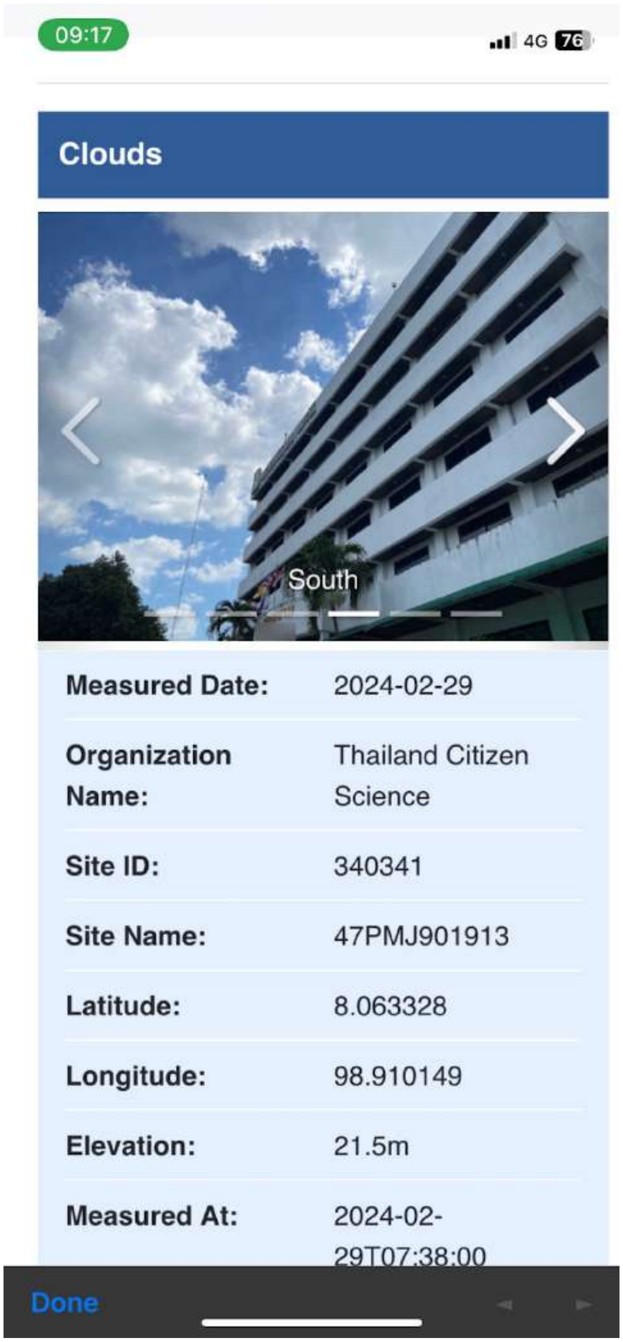
(i)

Figure 9(a-i). Daily PM Concentrations at Chao Fa Pier

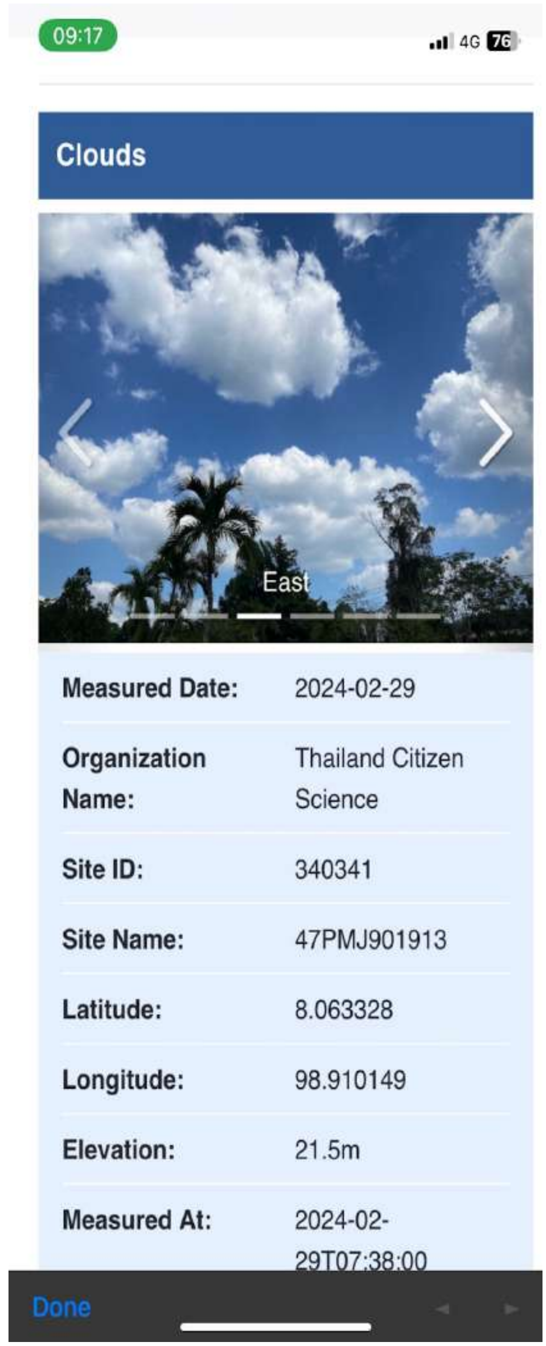
C. Globe Application: Cloud Protocol

Cloud types and cloud cover percentage were collected using the GLOBE Observer application to evaluate the cloud data's relationship to the particulate matter in the atmosphere. Clouds can affect air quality in many ways, and clouds act as cover, which reduces the amount of sunlight that hits the earth's surface and affects air pollutants like ground-level ozone, a component of smog. Clouds or floating masses of condensed water vapor affect the composition of gasses and particles in the air. Air temperature, humidity, and even wind speed may vary according to the vertical and horizontal size of the cloud. Figure 10 (a-b) shows the cloud type and cover at Boon Siam Hotel, while

Figure 10 (c-d) shows the data collected at Chao Fa Pier. The clouds recorded mainly during the cloud protocol survey are cumulus to altocumulus clouds in both areas, especially during the morning hours when the highest PM concentration is recorded. It could be inferred that cumulus-type clouds indicate rising air pollutants in the atmosphere. Furthermore, the amount of clouds covering the sky and the type of clouds at the moment of the cloud survey may have a direct or indirect relationship to the amount of PM concentration in the air due to factors like parking lots in the area and a busy street.


09:17
4G 76
Clouds
South
Measured Date:
2024-02-29
Organization Name:
Thailand Citizen Science
Site ID:
340341
Site Name:
47PMJ901913
Latitude:
8.063328
Longitude:
98.910149
Elevation:
21.5m
Measured At:
2024-02-29T07:38:00
Done

(a)


09:17
4G 76
Clouds
East
Measured Date:
2024-02-29
Organization Name:
Thailand Citizen Science
Site ID:
340341
Site Name:
47PMJ901913
Latitude:
8.063328
Longitude:
98.910149
Elevation:
21.5m
Measured At:
2024-02-29T07:38:00
Done

(b)

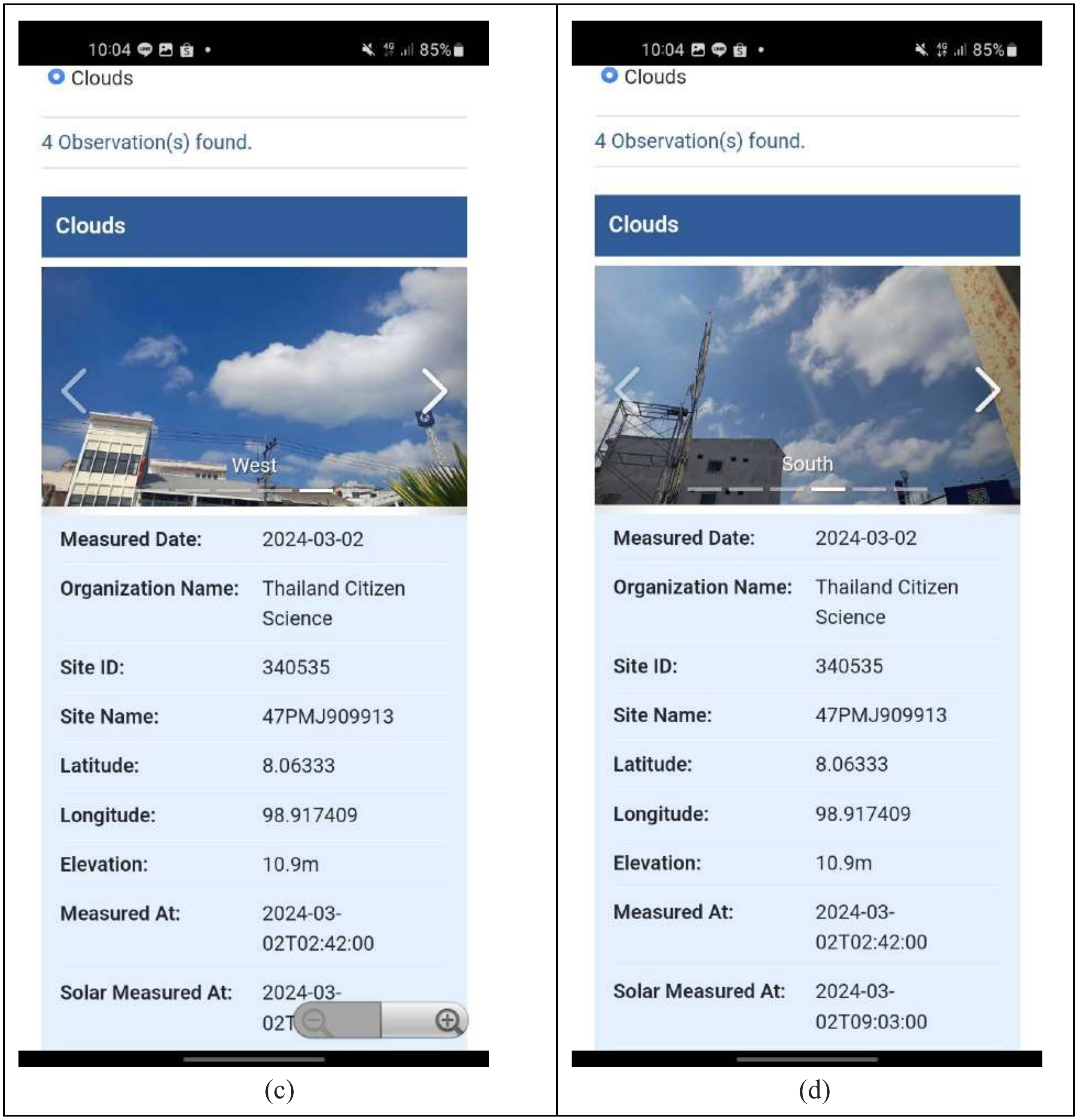


Figure 10. (a-b) Cloud Data recorded at Boon Siam Hotel, (c-d) Cloud Data recorded at Chao Fa Pier

Conclusion

Based on the results, it could be concluded that Figure 7 (a-f) shows that the Low-cost IoT PM sensor is accurate and reliable in measuring and gathering the PM concentration as compared to the referenced instrument Davis Airlink, in which the intrinsic correlation showed almost near to 1 or at least more than 0.5. However, some calibration methods could be suggested to reduce the error of the IoT device. Moreover, The IoT device could record the daily concentrations of PM in both areas without much interruption. It was found out that PM concentrations in both areas are at the highest during the morning due to active human activities like traveling, selling, and cooking street foods and daily household activities surrounding the area compared to night when. Furthermore, cumulus clouds are primarily seen during the cloud survey. When PM is the highest, cumulus clouds cover the sky.

IVSS: Badges

1. I am a STEM professional.

   The report effectively outlines the collaboration with a STEM professional, detailing how this collaboration enhanced research methods, improved precision, and facilitated more sophisticated analyses and interpretations of results. In this study, regression analysis is employed to analyze the findings. Additionally, the results highlight discrepancies between field measurements and drone-based data processing, indicating the potential for refining a quicker method for measuring PM2.5 data in the future.

2. I am a data scientist.

   The report incorporates a thorough examination of both the students' collected data and data from other sources. Students critically evaluate the limitations of these datasets, draw inferences about past, present, or future events, and utilize the data to address questions or solve problems within the system under study. This includes considering data from other schools or databases. Specifically, this study's regression analysis between field measurements and PM2.5 data assesses the validation of PM2.5 data. The limitations of drones and a comparison to findings from other studies are discussed in the later part of the report.

3. I make an impact.

   The report clearly describes how a local issue led to the research questions or makes connections between local and global impacts. The students must clearly explain or show how the research positively impacted their community by making recommendations or taking action based on findings. This study indicates that Fine particulate matter (PM2.5) is an air pollutant that concerns people's health. PM2.5 can travel deeply into the respiratory tract, reaching the lungs. Exposure to fine particles can cause short-term health effects such as eye, nose, throat, and lung irritation, coughing, sneezing, runny nose, and shortness of breath.

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