# Understanding the Rapid Change of $PM_{2.5}$ Using Low-cost Air Quality IoT Sensors

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**Abstract.** This paper presents an analysis of $PM_{2.5}$ monitoring using low-cost IoT sensors to understand the concentration change in relation to the meteorological data and demonstrate the benefit of the sensors toward air quality management. A case of rapid change of $PM_{2.5}$ from a high concentration (150 µg/m$^3$) in the morning to a low concentration (15 µg/m$^3$) in the noon was depicted in Bangkok, Thailand on 15 December 2020. This was an unusual phenomenon. $PM_{2.5}$ data were collected from SEA-HAZEMON platform during 8-16 December 2020 while vertical profiles of temperature and wind speed were collected from Bangna Agromet, Bangkok, Thailand from the on-line platform for the same period. Mixing layer height (MH) was estimated using temperature profiles for morning and noon periods. Correlation (R) analysis was used to explore relationships of estimated MH and $PM_{2.5}$, and wind speed (WS) and $PM_{2.5}$. Both MH and WS showed the inverse relationship on $PM_{2.5}$ with R for MH and $PM_{2.5}$ was -0.5495 and for WS and $PM_{2.5}$ was -0.4682. For 15 December 2020, rapid change of $PM_{2.5}$ in the noon was well explained by the strong wind above 500 m. height that help enhance $PM_{2.5}$ dispersion along with the expansion of MH. With a real-time data record and open data for download, IoT sensors enrich the understanding of air pollution behaviors for further improvement and enable identification of relevant air pollution events timely. IoT sensors could bring more benefits to the areas, particularly for low- and middle-income countries, where standard monitoring stations are unfeasible.

## I. INTRODUCTION

Particulate matters known as $PM_{2.5}$ (particulate matters with an aerodynamic diameter less than 2.5 µm) is one of the globally significant air pollutions. Its impacts have been well identified and related to various effects of human health, i.e. respiratory, pneumonia and cardiovascular symptoms [1-3]. High concentrations of $PM_{2.5}$ are commonly found in the low- and middle-income countries, particularly in mega cities where high density of population are observed that drives the economic growth in the area. Thus, the levels of $PM_{2.5}$ in the low- and middle-income countries directly link to combustion in energy sector (i.e. transportation, industry and power production) and open burning of crop residues from intensive agricultural activity [4]. Due to the lack of monitoring equipment of $PM_{2.5}$ and other air quality parameters, levels of air quality remain mysterious and may result in improper implementation of management strategies to tackle the air pollution problems.

With the advancement of digital technology, low-cost air quality sensors connecting to the IoT systems allow us to obtain and analyze the data in real-time manner with a much lower cost compared to the traditional standard equipment with a reasonably moderate accuracy [5]. Evaluation of low-cost $PM_{2.5}$ sensors have been carried out and found a significant relationship with standard equipment with $R^2$ around or above 0.8. $PM_{2.5}$ sensors have found to sensitive to high humidity and need further improvement [6,7]. However, with the strong relationship with the standard equipment, low-cost IoT sensors bring more benefits for monitoring and understanding the situation, and predicting the near-term concentrations for early warning.

For air quality management, IoT sensors have been applied in various areas [6,8,9,10]. For instance, [6] analyzed $PM_{2.5}$ data in relation to wind speed and direction, and forest fires in Mae Sot district, Tak province located in the northern region of Thailand. The results shown that higher wind speed blown the $PM_{2.5}$ from upwind to downwind locations while high levels of $PM_{2.5}$ were correlated well with a number of detected hotspots. The authors also proved that the IoT sensors were able to detect the plume movement and predict the $PM_{2.5}$ concentrations in the next 15 minutes providing early warning to nearby communities [6].

This paper presented and investigated a selected case of unusual situation of $PM_{2.5}$ concentrations in Bangkok, Thailand detected by IoT sensors. Together with other meteorological parameters, including temperature and wind profiles, the phenomenon was well explained and solutions can be used for further management. IoT sensors brings the benefits not only for this existing time, but also for the coming era.

## II. METHODOLOGY

During the morning (07:00-08:00) of 15 December 2020, high concentration of $PM_{2.5}$ around 150 μg/m$^3$ was reported by the IoT sensors deployed in Bangkok area, Thailand. However, the concentration of $PM_{2.5}$ was rapidly dropped to around 15 μg/m$^3$ in the afternoon (14:00-15:00) of the same day (see Fig. 1). This phenomenon is unusual for the rapid change of a substantial high concentrations from morning to noon. Understanding the situation correctly could help prepare the appropriate measures and strategies for short- and long-term air quality management.

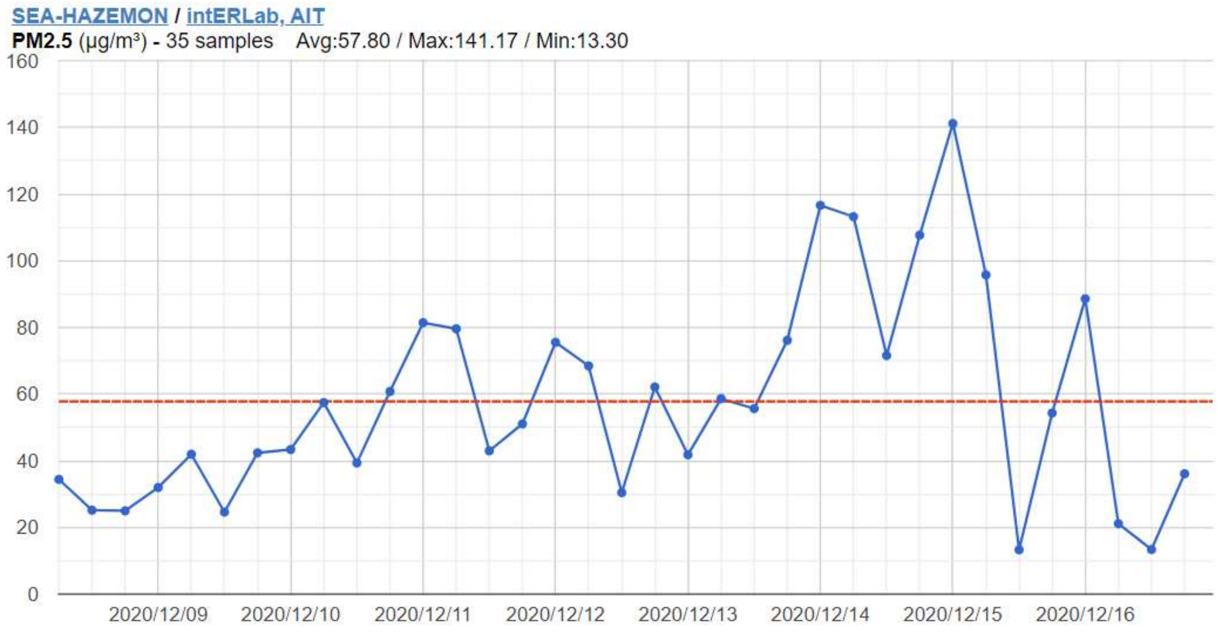
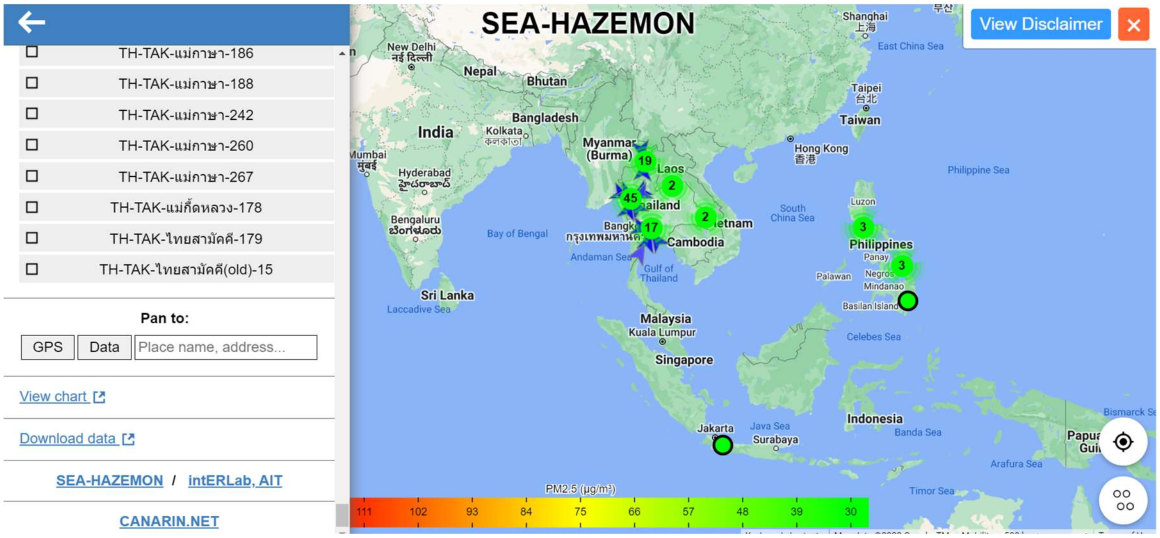


**FIGURE 1.** Observed rapid change of $PM_{2.5}$ in Bangkok on 15 December 2020
(Source: https://www.hazemon.in.th/v2/map.html)

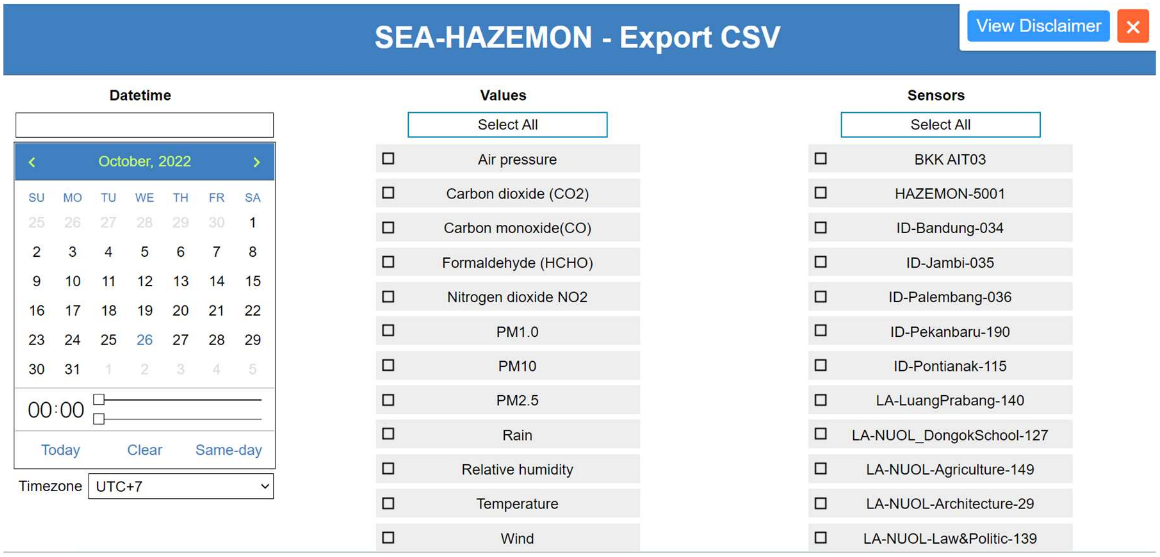
The data were collected from the SEA-HAZEMON platform which provides the open data for air quality and meteorological parameters. The platform covers several areas in Thailand and neighboring countries by collecting the data from low-cost IoT sensors which are open publicly. These open data are available at: https://www.hazemon.in.th/v2/map.html (Fig. 2) which can be downloaded for a specified period and location selecting from each sensor location.

In addition, vertical profiles of temperature and wind speed were collected from the Bangna Agromet, Bangkok Thailand. The data were obtained from the on-line platform developed by the University of Wyoming (http://weather.uwyo.edu/upperair/sounding.html). Both data of IoT sensors, and temperature and wind profiles were collected for a period of 8 to 16 December 2020 to explore the changes of $PM_{2.5}$ in relation to meteorological data prior to the phenomenon.

For data analysis, mixing layer height (MH) which is used to determine a vertical distribution of air pollutants from ground level was estimated. If MH is high (few kilometers), vertical ventilation of the atmosphere is high resulting in potentially lower air pollutant concentrations. In contrast, if mixing layer is lower (few hundred meters), vertical ventilation of the atmosphere is low resulting in potentially higher air pollutant concentrations [11].



(a) SEA-HAZEMON website



Timezone UTC+7

(b) Download options

**FIGURE 2.** SEA-HAZEMON open data of low-cost sensors for air quality monitoring: (a) SEA-HAZEMON website and (b) Download options
(Source: https://www.hazemon.in.th/v2/map.html)

In this study, estimation of MH was done using traditional and graphical method (Holzworth's Method) for the morning and afternoon [12] for all selected days (8 to 16 December 2020). The relationships of $PM_{2.5}$ and MH and wind speed at 500, 1,000 and 1,500 m were analyzed using statistical correlations.

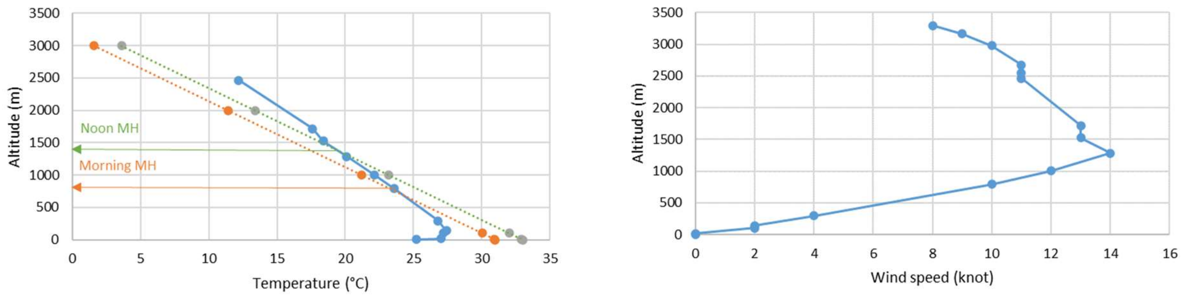
## III. RESULTS AND DISCUSSION

Morning and noon $PM_{2.5}$ concentrations were calculated for 6-hr average from 6:00-12:00 and 12:00-18:00, respectively to compare with the estimated morning and noon MH during 8-16 December (see Table 1). Selected wind speeds in 3 vertical levels closed to the estimated MH were also presented in Table 1. $PM_{2.5}$ was observed to tentatively continue rising from 8 - 15 December 2020 (see also Fig. 1) and dropped suddenly on 15 December 2020 from morning to noon times. For MH, it was found that morning MH was lower and around 700 m. except on 13 and 14 December, morning MH was 1,400 and 1,500 m., respectively. This is due to the higher minimum surface temperature on these days comparing to others. For noon MH, it was higher and around 1,500 m. every monitoring day. Noon MH brings a good ventilation that help reduce $PM_{2.5}$ concentrations. For WS, it changed and fluctuated from day to day. On 15 December 2020, it was found that WS was high in the upper layer of 1,000 m. and 1,500 m. Estimated MH and wind profile on 15 December 2020 are in Fig. 3.

**TABLE 1.** Morning and noon $PM_{2.5}$ concentrations with MH and selected wind speed profiles

| Date | Morning MH (m) | Noon MH (m) | Wind speed (knot) at 7:00 | | | 6-hr Average $PM_{2.5}$ (μg/m$^3$) | |
|---|---|---|---|---|---|---|---|
| | | | 500 m | 1000 m | 1500 m | Morning (6:00-12:00) | Noon (12:00-18:00) |
| 8-Dec-2020 | 600 | 1,700 | 4 | 6 | 4 | 34 | 25 |
| 9-Dec-2020 | 600 | 1,700 | 15 | 7 | 4 | 42 | 25 |
| 10-Dec-2020 | 400 | 1,500 | 2 | 4 | 5 | 57 | 39 |
| 11-Dec-2020 | 400 | 1,500 | 6 | 8 | 8 | 80 | 43 |
| 12-Dec-2020 | 700 | 1,700 | 4 | 8 | 10 | 68 | 30 |
| 13-Dec-2020 | 1,400 | 1,700 | 5 | 3 | 6 | 59 | 56 |
| 14-Dec-2020 | 700 | 1,600 | 4 | 5 | 6 | 113 | 72 |
| 15-Dec-2020 [a] | 700 | 1,400 | 7 | 12 | 13 | 96 | 13 |
| 16-Dec-2020 | 1,500 | 1,500 | 12 | 16 | 14 | 21 | 13 |

Remark: [a] 15 December 2020 is the date of rapid change of $PM_{2.5}$

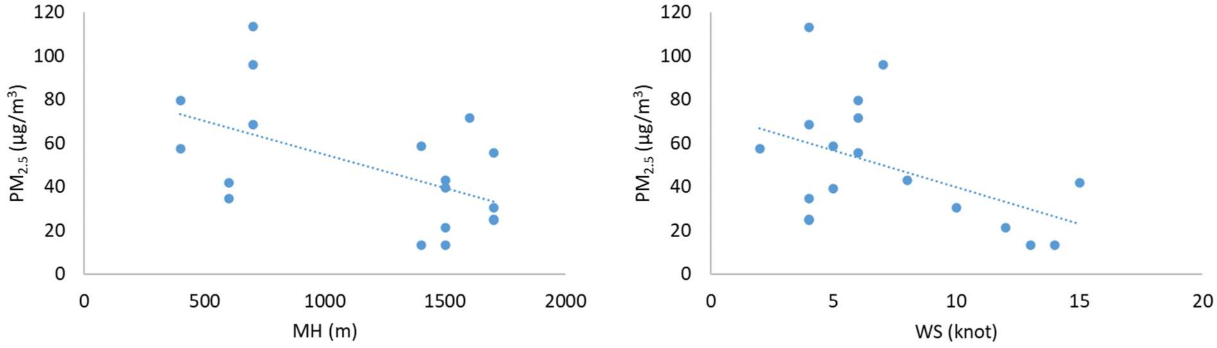


(a) MH estimation

(b) Wind profile

**FIGURE 3.** Mixing layer height (MH) estimation and wind profile on 15 December 2020

To understand the phenomenon, scatter plots of MH and $PM_{2.5}$, and WS and $PM_{2.5}$ were examined as shown in Fig. 4. Both MH and WS exhibited the inverse relationship on $PM_{2.5}$. From correlation (R) analysis, R for MH and $PM_{2.5}$ was -0.5495 ($p < 0.05$) and R for WS and $PM_{2.5}$ was -0.4682 ($p < 0.05$).



(a) MH and $PM_{2.5}$

(b) WS and $PM_{2.5}$

**FIGURE 4.** Scatter Plots of MH and $PM_{2.5}$ and WS and $PM_{2.5}$

From the analysis, on 15 December 2020, morning MH was low that was similar to the previous day resulting in high $PM_{2.5}$ in the morning. In the noon time, MH was increased that was also similar to the previous day; however, with a strong wind above 500 m. that help enhance $PM_{2.5}$ dispersion. This strong ventilation happened vertically (high MH) and horizontally (high WS) at the noon of 5 December 2020. Thus, $PM_{2.5}$ dropped rapidly.

From the presented case study, we envisage that existing open data and IoT sensors, together with the corresponded meteorological information enhance the understanding of air pollution behaviors. As IoT sensors are now with a low-cost and a reasonably moderate accuracy, this would help the low- and middle-income countries where financial support to establish the standard monitoring stations are unfeasible to comprehend the situation of air pollutions and drive the appropriate measures and policies toward cleaner and better air quality. In this existing age, IoT sensors for air quality monitoring are now attainable. However, in the coming age, other IoT sensors or instruments for advance measurement of meteorological related parameters, i.e. MH and vertical profile of WS are anticipated.

## IV. CONCLUSION

During the study period (8-16 December 2020), morning MH was generally lower and around 700 m while noon MH was higher and around 1,500 m in Bangkok, Thailand. Higher noon MH brings a good ventilation for $PM_{2.5}$ reduction resulting in generally lower $PM_{2.5}$ in the noon. For WS, it changed and fluctuated from day to day. From analysis, MH and WS had significant relationship on $PM_{2.5}$ in the negative direction. R for MH and $PM_{2.5}$ was -0.5495 ($p < 0.05$) and R for WS and $PM_{2.5}$ was -0.4682 ($p < 0.05$). With estimated MH and WS profiles, rapid change of $PM_{2.5}$ concentrations on 15 December 2020 were well explained with strong WS in addition to MH expansion in the noon.

## ACKNOWLEDGEMENT

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