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Spatial-temporal Variation of Ground Level Particulate Matter ($PM_{2.5}$) at the North-East Coast of Peninsular Malaysia

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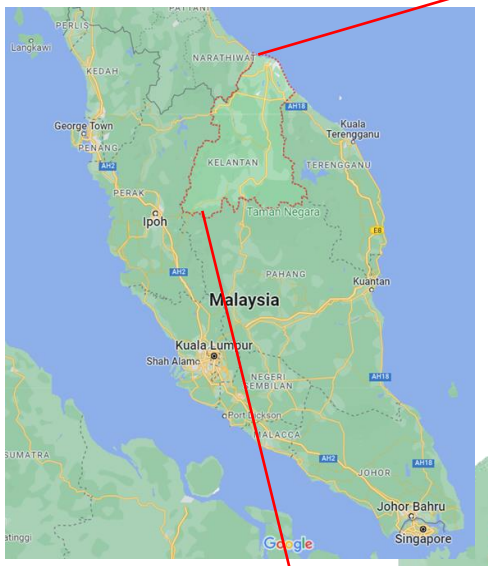
Background: Research Motivation

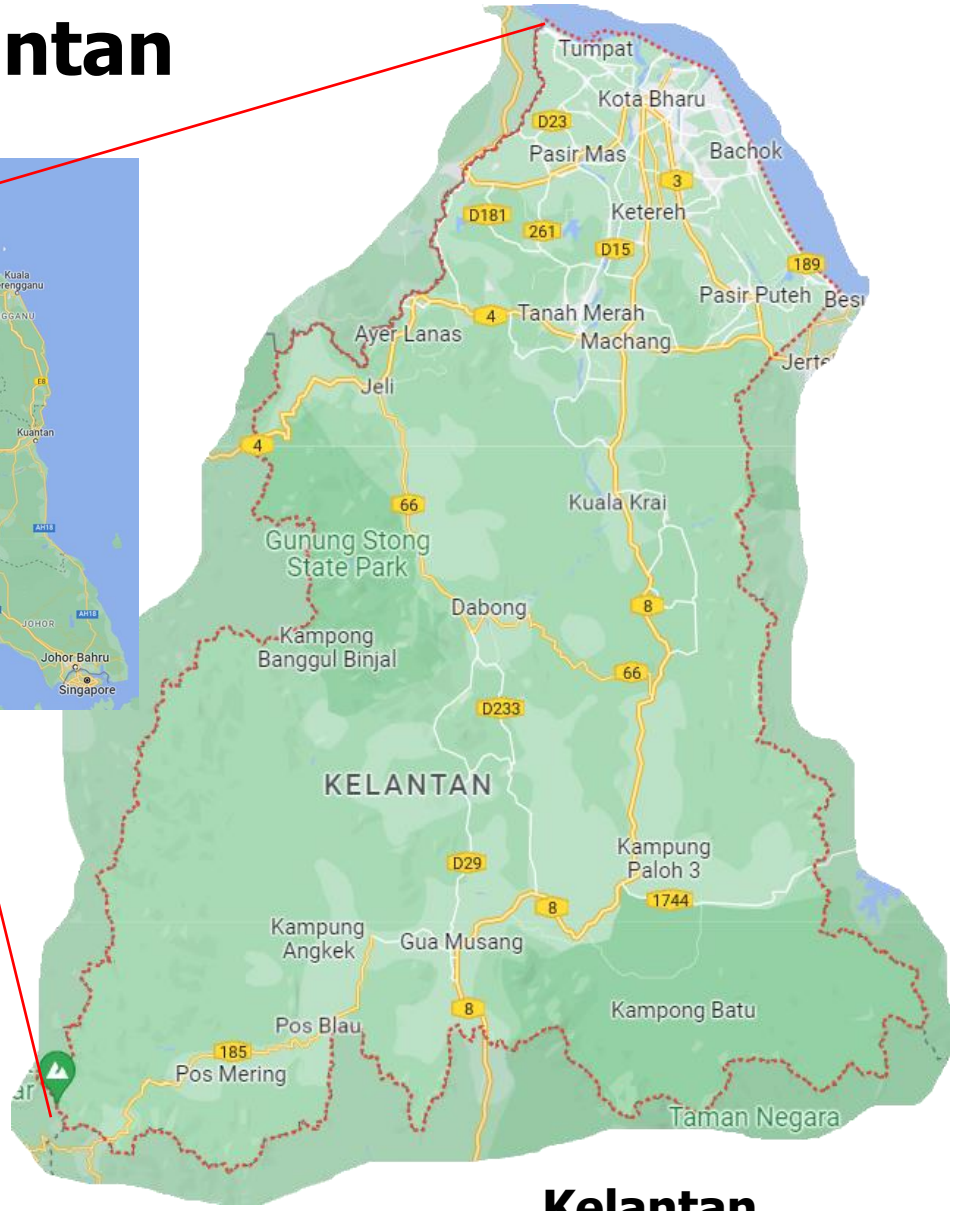
- Kelantan is one the states that experienced emerging risks of weather and climate extremes under Global Warming 1.5 °C and 2.0 °C according to climate projection data based on CORDEX-SEA (25 km x 25 km).
- Less air quality research on the spatial-temporal variation in Kelantan (low economically backward region, less industry, slower urbanization rate).
- Lack of long-term research on $PM_{2.5}$ as the Malaysian Department of Environments (DOE) only starts monitoring $PM_{2.5}$ in mid-2017.
- Therefore, is a need to study the long-term particulate matter ($PM_{2.5}$) and to exhibit the spatial-temporal trend variation, the meteorological variables influencing factors on the $PM_{2.5}$ distribution, and the potential sources.

Background: Kelantan

- Kelantan is a state located on the North East-Coast of Peninsular Malaysia, 15 040 km^2
- Less urbanized, low economically backward state than Kuala Lumpur.
- Total population (1.9 mil, 2020).
- Annual population growth is 1.1%.
- Main economical activities: Agricultural and fisheries



Peninsular Malaysia



Kelantan

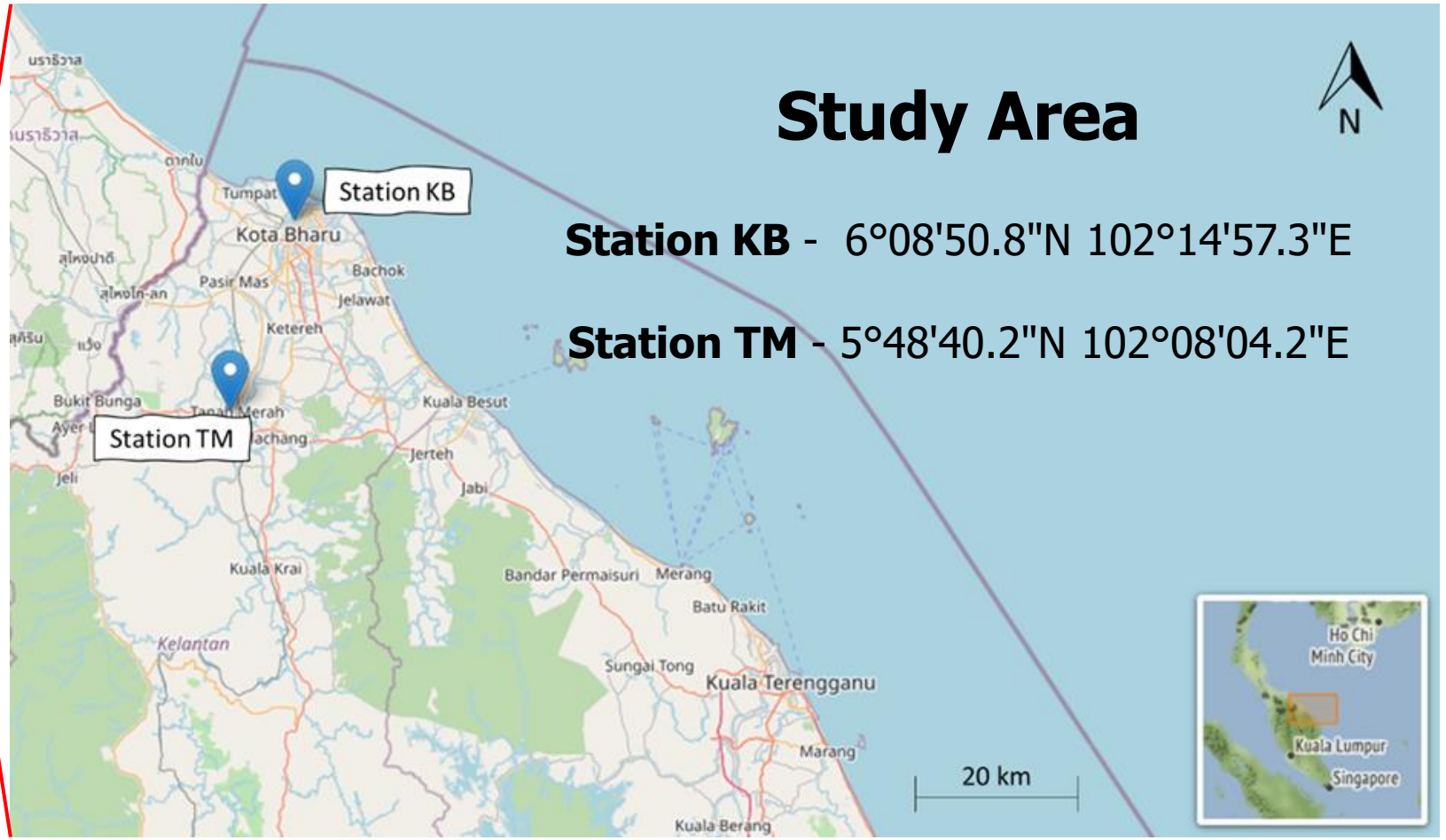
Northeast Monsoon (**NEM**) – Early November to ends in March, wind flow steady easterly or north-easterly (10 – 30 knots prevails).

Inter-monsoon Season 1 (**IMS1**) – Dry season, high temperature

Southwest Monsoon (**SWM**) – the latter half of May or early June and ends in September, wind flow southwesterly and light (<15 knots)

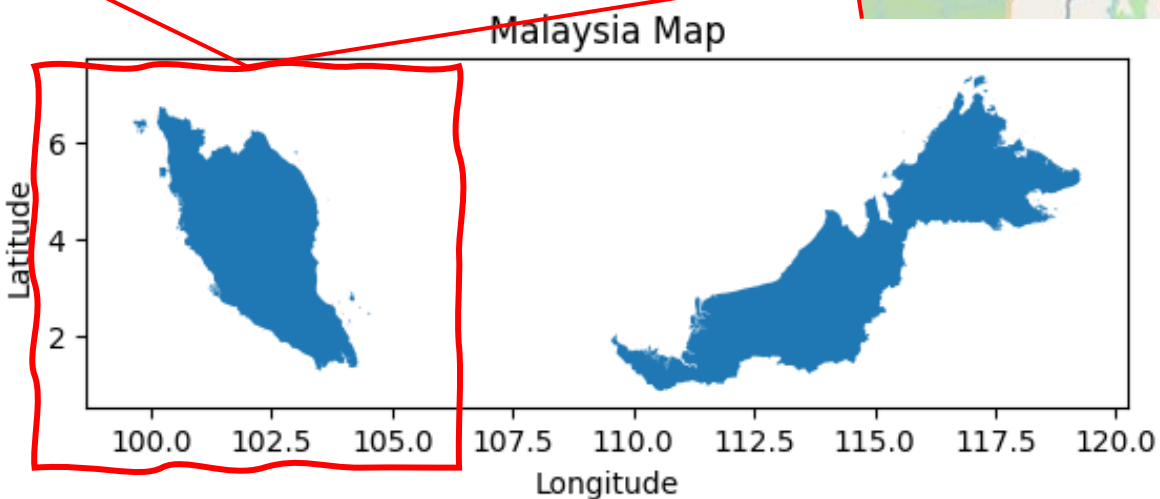
Inter-Monsoon Season 2 (**IMS2**) – Higher wind speed, thunderstorms, high rainfall

Kelantan (Marked with red-dotted boundary)



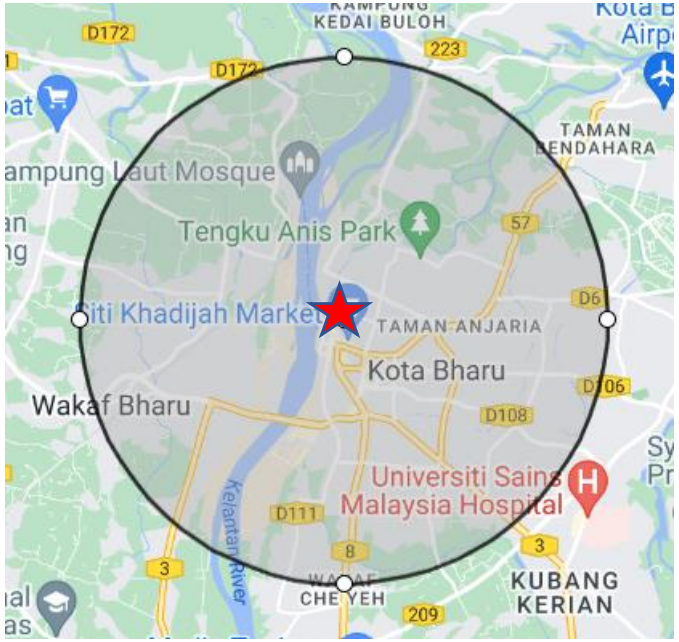
Station KB - 6°08'50.8"N 102°14'57.3"E

Station TM - 5°48'40.2"N 102°08'04.2"E



The two continuous air quality monitoring stations (CAQMS) in Kelantan are operated by the Malaysian Department of Environment (DOE)

Stations Descriptions



Station ID: CA47D (**Station KB**)
Location: Tanjong Chat National Secondary School
Description: Sub Urban, high traffic during early morning and evening, residential area, high volume of small and medium enterprises, fisheries activity, agricultural activity, cash crop

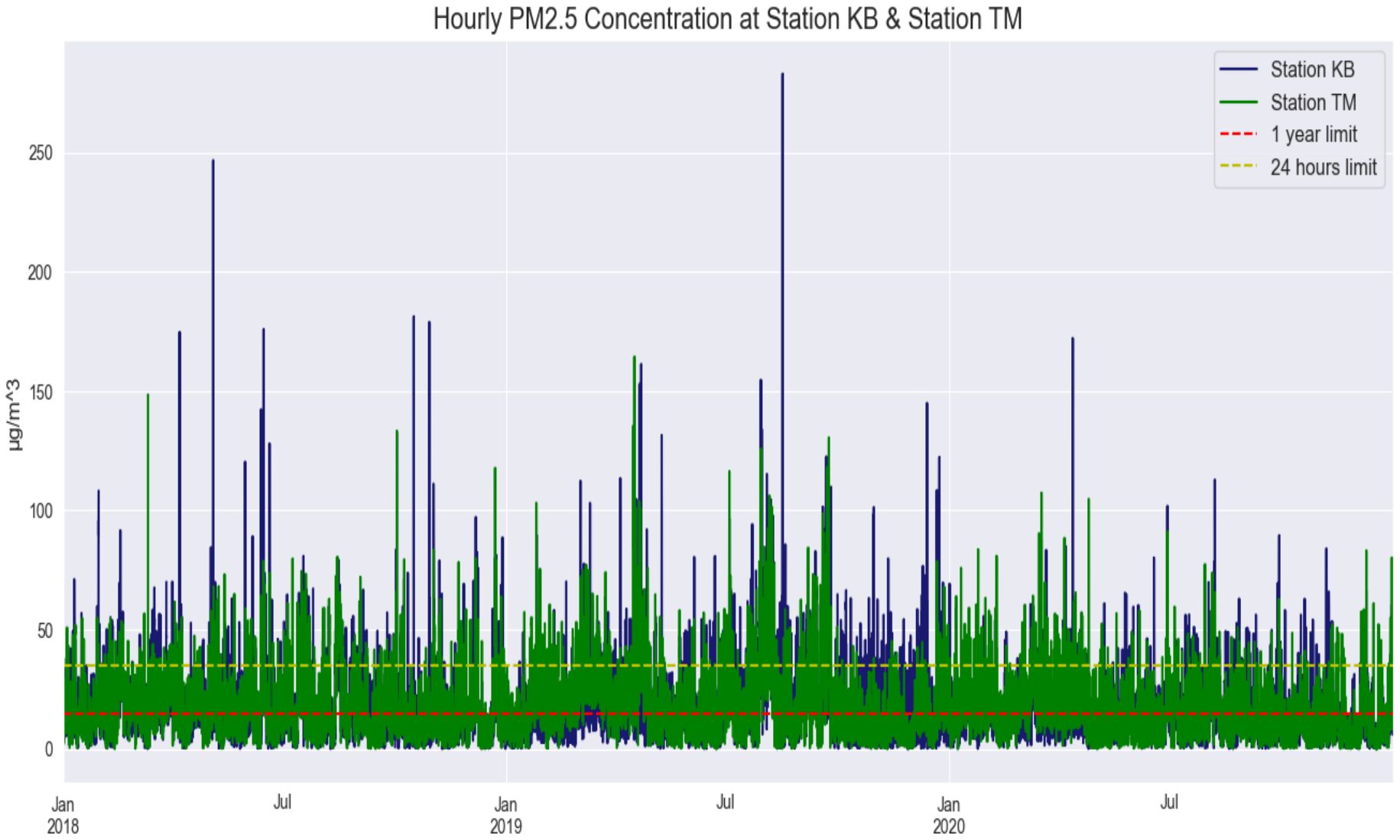
Station ID: CA46D (**Station TM**)
Location: Tanah Merah National Secondary School
Description: Sub-Urban, residential area, high traffic during day time, flat terrain, small and medium enterprise, rubber and palm oil, cash crop

Method

- The hourly concentration of $PM_{2.5}$ are extracted between January 2018 and December 2020.
- The hourly PM_{10} and $PM_{2.5}$ concentrations are collected using Thermo Scientific Model TEOM 1405-DF (Thermo Fisher Scientific, USA) through continuous and simultaneous particulate collection through tapered element oscillating microbalance which contains the sample inlet for PM_{10} and $PM_{2.5}$, respectively.
- The SO_2 concentration is collected using Thermo Scientific Model 43i through pulsed UV fluorescence, NO_2 (Thermo Scientific Model 42i, Chemiluminescence), CO (Thermo Scientific Model 48i, Gas Filter Correlation), and O_3 (Thermo Scientific Model 49i, UV Photometric).
- The hourly meteorological data (ambient temperature, relative humidity, solar radiation, wind speed, wind direction) were also retrieved from DOE which was recorded using Climatronic AIO 2 Weather Sensor (Climatronics Corporation, USA)

Example of Continuous Air Quality Monitoring System (CAQMS)'s cabin operated by Malaysian DOE

Result



The Daily Hourly Average trends of $PM_{2.5}$ concentration during the measurement campaign in the year 2018-2020.

- The World Health Organization (WHO) guidelines set annual mean concentration <10 µg/m^3. The recorded $PM_{2.5}$ concentration above 10 µg/m^3 is 64.78 % for Station KB and 68.38% for Station TM.
- The measurement recorded above the 24-hour limitation of $PM_{2.5}$ for Station KB is 9.48% and TM is 8.62%.

Hourly $PM_{2.5}$ Concentration in Station KB and Station TM

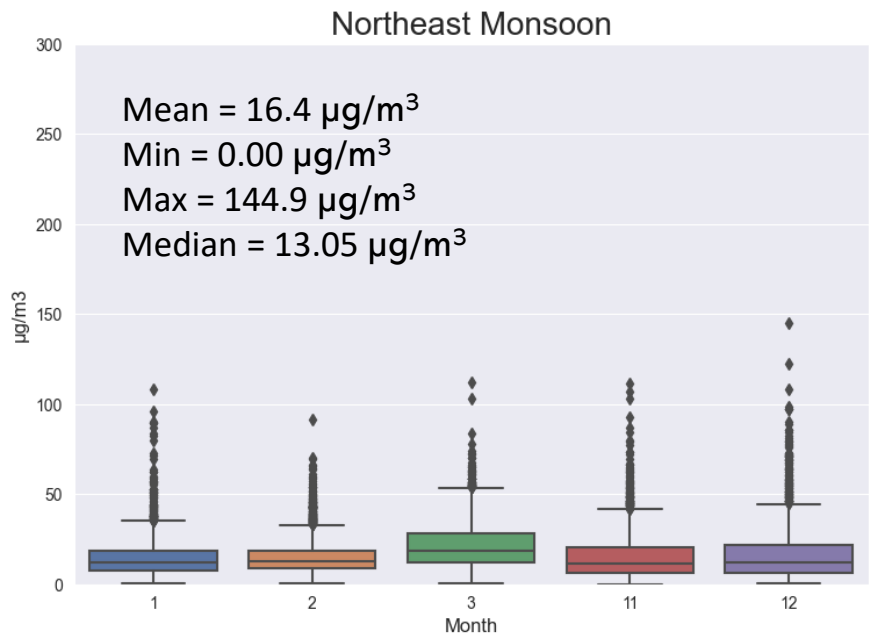
Mean hourly $PM_{2.5}$ concentration in Station KB and Station TM

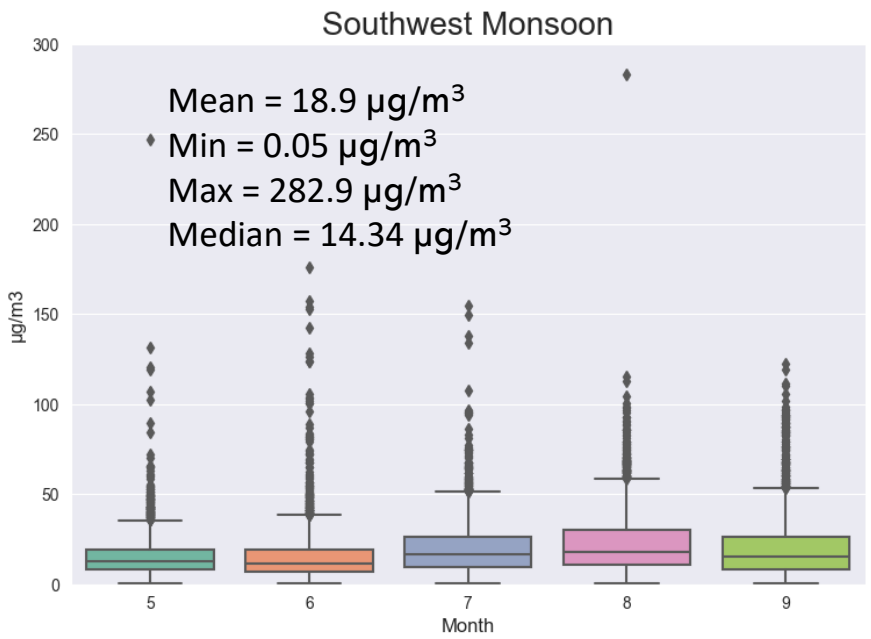
- $PM_{2.5}$ showed a decreasing trend until 7 am before a slight increase until 9 am in both stations.
- Higher traffic in the morning.
- Both stations showed an increasing trend after 5 pm and the highest peaks were recorded at 9.00 pm (Station KB) and 8.00 pm (Station TM).
- Low wind speed and stagnant air at night cause $PM_{2.5}$ to accumulate.

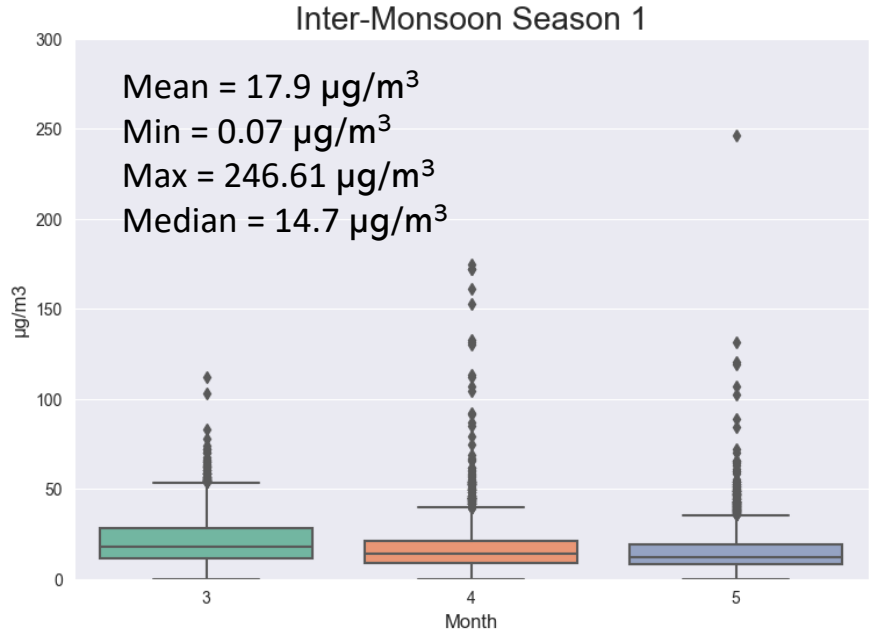
Results: Highest Hourly $PM_{2.5}$ Concentration

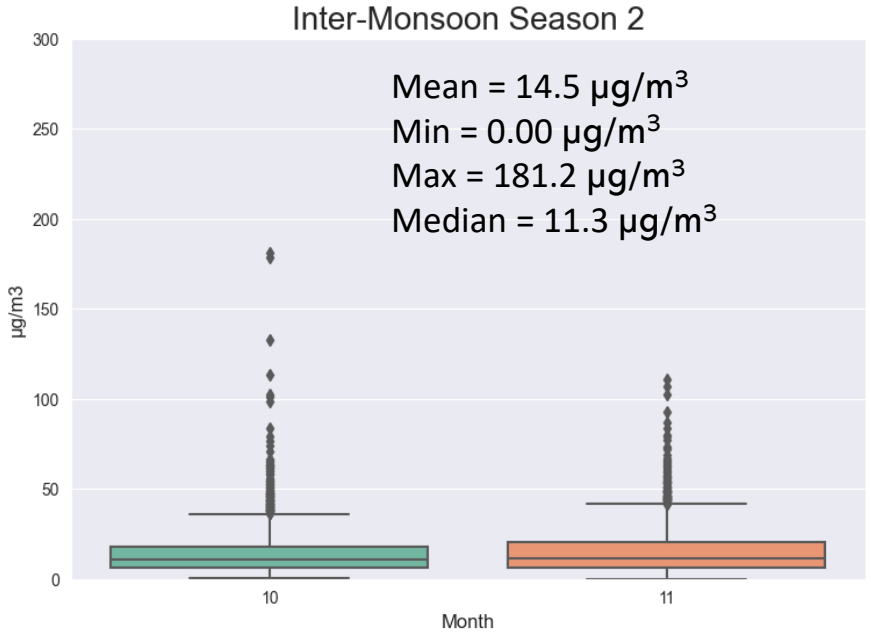
CAQMS Station KB		
Date	**$PM_{2.5}$ (µg/m3)**	**Season**
2019-08-16 19:00:00	**282.9**	**SWM**
2018-05-04 13:00:00	246.6	**SWM**
2018-10-16 20:00:00	181.2	IMS2
2018-10-29 16:00:00	178.9	IMS2
2018-06-15 03:00:00	175.9	**SWM**
2018-04-06 21:00:00	174.7	**IMS1**
2020-04-11 22:00:00	172.1	**IMS1**
2020-04-11 21:00:00	172.0	**IMS1**
2019-04-22 05:00:00	161.2	**IMS1**
2018-06-15 04:00:00	157.1	**SWM**
2019-07-29 21:00:00	154.6	**SWM**

CAQMS Station TM		
Date	**$PM_{2.5}$ (µg/m3)**	**Season**
2019-04-16 18:00:00	164.4	**IMS1**
2018-03-11 19:00:00	148.4	NEM
2019-04-16 17:00:00	140.0	**IMS1**
2019-04-15 18:00:00	135.4	**IMS1**
2018-10-02 22:00:00	133.3	IMS2
2019-09-23 23:00:00	130.5	IMS2
2019-07-29 21:00:00	125.9	**SWM**
2018-10-02 21:00:00	123.0	IMS2
2019-09-22 15:00:00	118.0	IMS2
2018-12-22 21:00:00	117.7	NEM
2019-09-22 16:00:00	117.5	IMS2





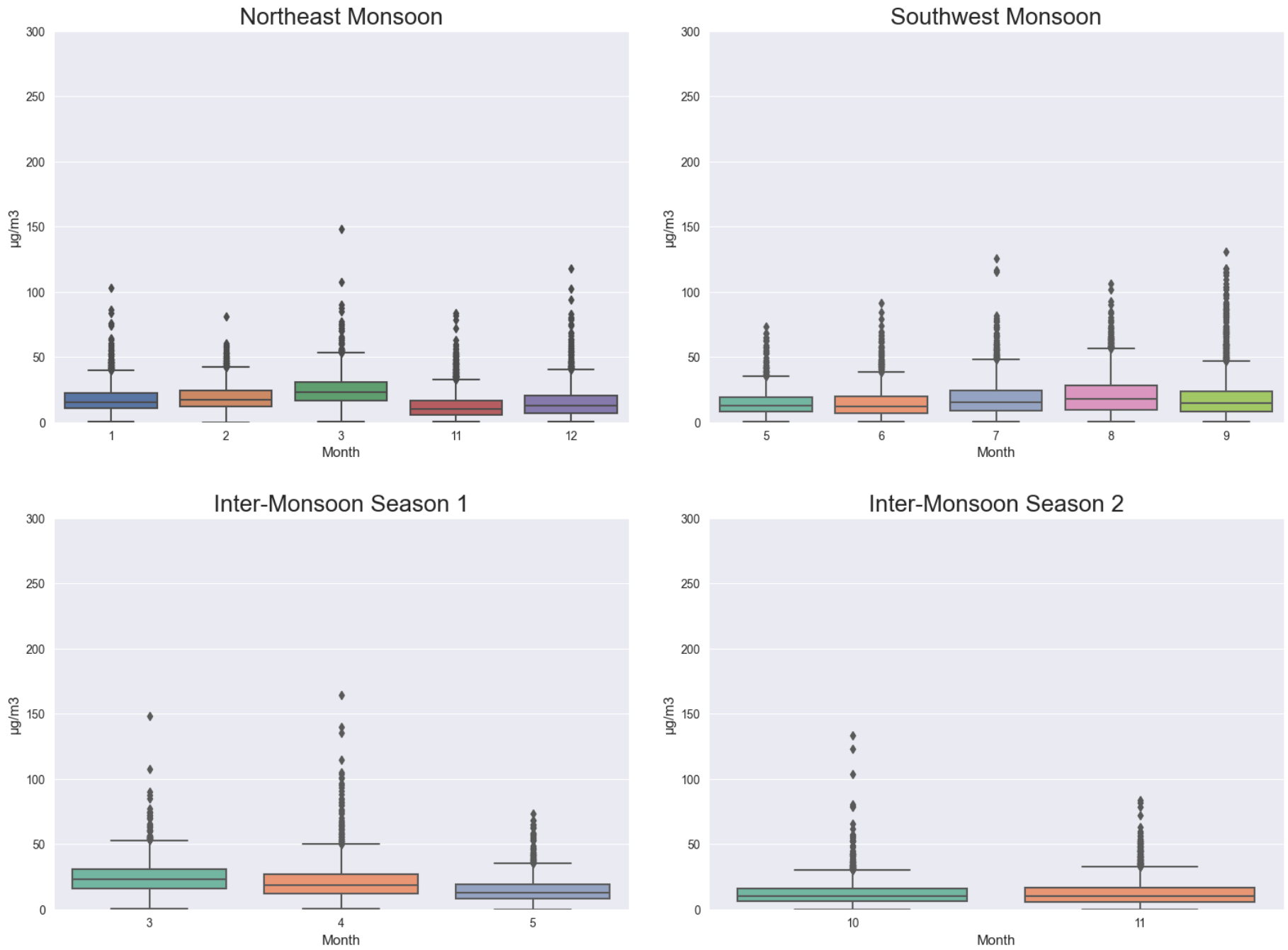




Boxplot of Average Daily $PM_{2.5}$ by Month in Kota Bharu (2018-2020)

Results: Seasonal Variation (S. KB)

- The highest average $PM_{2.5}$ concentration in Station KB was recorded during the SWM (282.9 µg/m3), followed by the IMS1 (246.6 µg/m3).
- The lowest average $PM_{2.5}$ concentration was recorded during the NEM (0.058 µg/m3).
- During SWM, Malaysia experienced haze due to biomass burning and peatland fires[1].
- During IMS1, Malaysia experienced a dry season with less rainfall, high temperature, wildfires, and peatland fires.
- During the NEM, Kelantan experienced higher rainfall and higher wind speed.

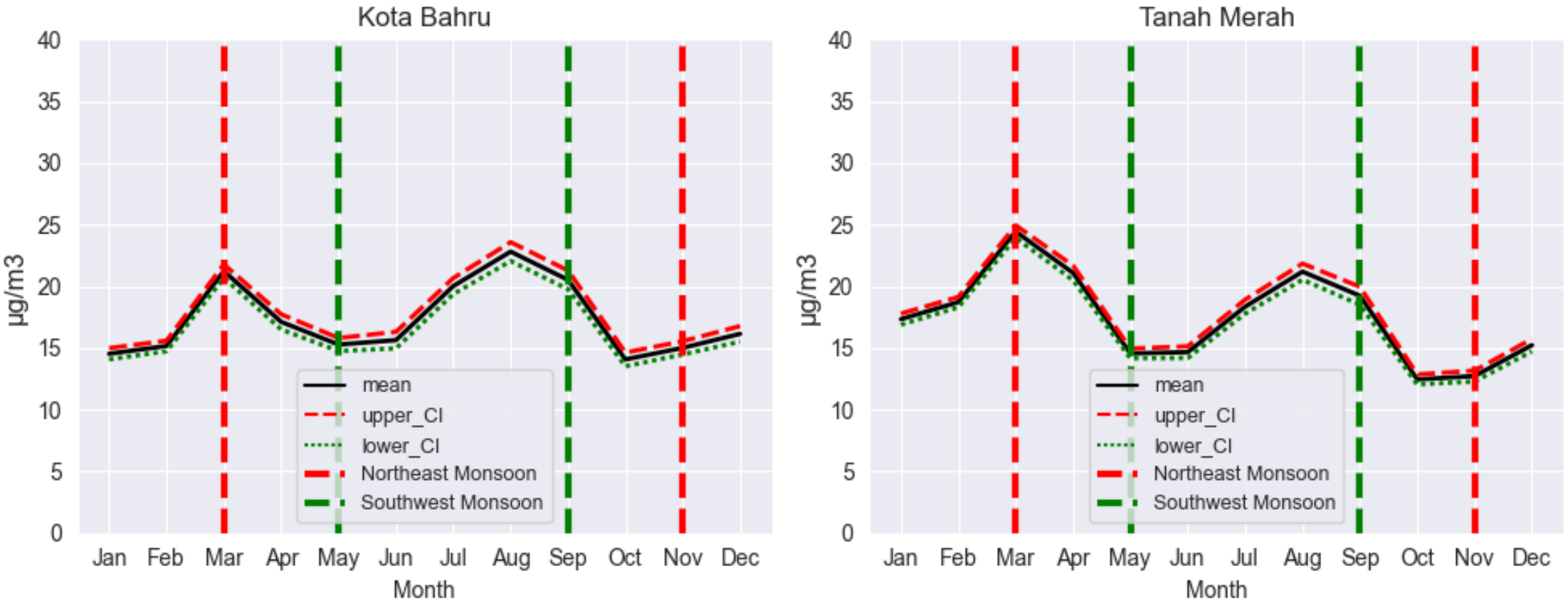


Boxplot of Average Daily $PM_{2.5}$ by Month in Tanah Merah (2018-2020)

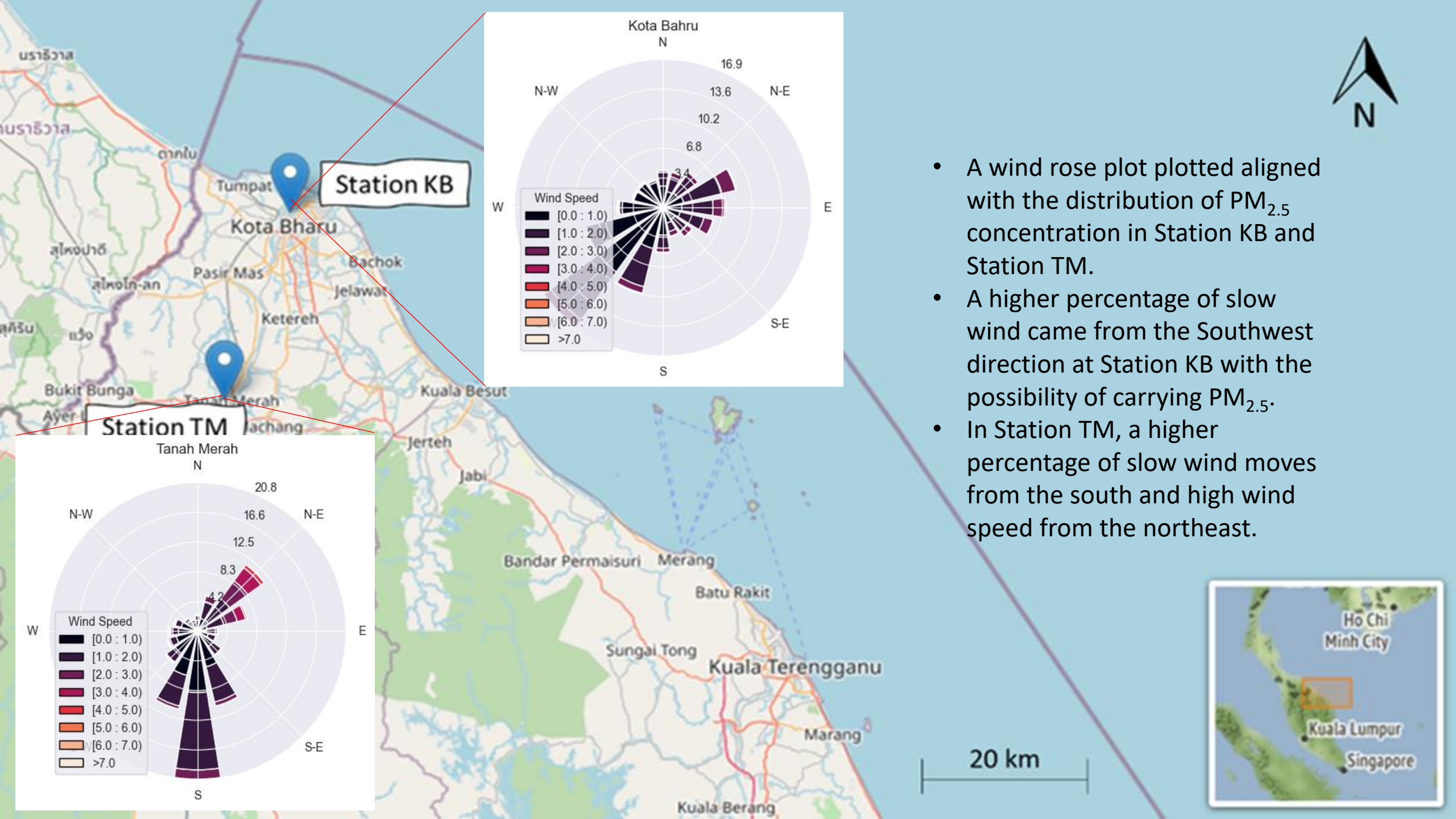
Results: Seasonal Variation (S. TM)

- The highest average PM2.5 concentration in Station TM was recorded during IMS1 (164.36 µg/m^3) and during NEM (148.4 µg/m^3).
- The lowest average concentration was recorded during the NEM (0.015 µg/m^3).
- During the IMS1, the prolonged dry season increases the chances of fires occurring and persisting.
- Transboundary haze and biomass burning worsen the haze situation.

Monthly $PM_{2.5}$ Concentration in Station KB and Station TM



- The $PM_{2.5}$ concentration in Station KB and Station TM shows bimodal peaks during the early Inter-Monsoon Season 1 (IMS1) and during the Southwest Monsoon period.
- During paddy harvesting season (March, September), there mass agricultural waste burning occurs.



- A wind rose plot plotted aligned with the distribution of $PM_{2.5}$ concentration in Station KB and Station TM.
- A higher percentage of slow wind came from the Southwest direction at Station KB with the possibility of carrying $PM_{2.5}$.
- In Station TM, a higher percentage of slow wind moves from the south and high wind speed from the northeast.

NOAA HYSPLIT MODEL
Backward trajectories ending at 1900 UTC 16 Aug 19
GDAS Meteorological Data

The highest PM2.5 (282 µg/m^3) concentration was recorded at Station KB during Southwest Monsoon in 2019

Source ★ at 6.15 N 102.25 E

Meters AGL

Job ID: 173503 Job Start: Wed May 31 04:30:52 UTC 2023
Source 1 lat.: 6.147444 lon.: 102.249236 hgts: 100, 500, 1000 m AGL

Trajectory Direction: Backward Duration: 150 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 15 Aug 2019 - GDAS1

NOAA HYSPLIT MODEL
Backward trajectories ending at 1300 UTC 04 May 18
GDAS Meteorological Data

Highest PM2.5 concentration

Meters AGL

Job ID: 173625 Job Start: Wed May 31 04:34:17 UTC 2023
Source 1 lat.: 6.147444 lon.: 102.249236 hgts: 100, 500, 1000 m AGL

Trajectory Direction: Backward Duration: 150 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 1 May 2018 - GDAS1

NOAA HYSPLIT MODEL
Backward trajectories ending at 1800 UTC 16 Apr 19
GDAS Meteorological Data

Source ★ at 5.81 N 102.13 E

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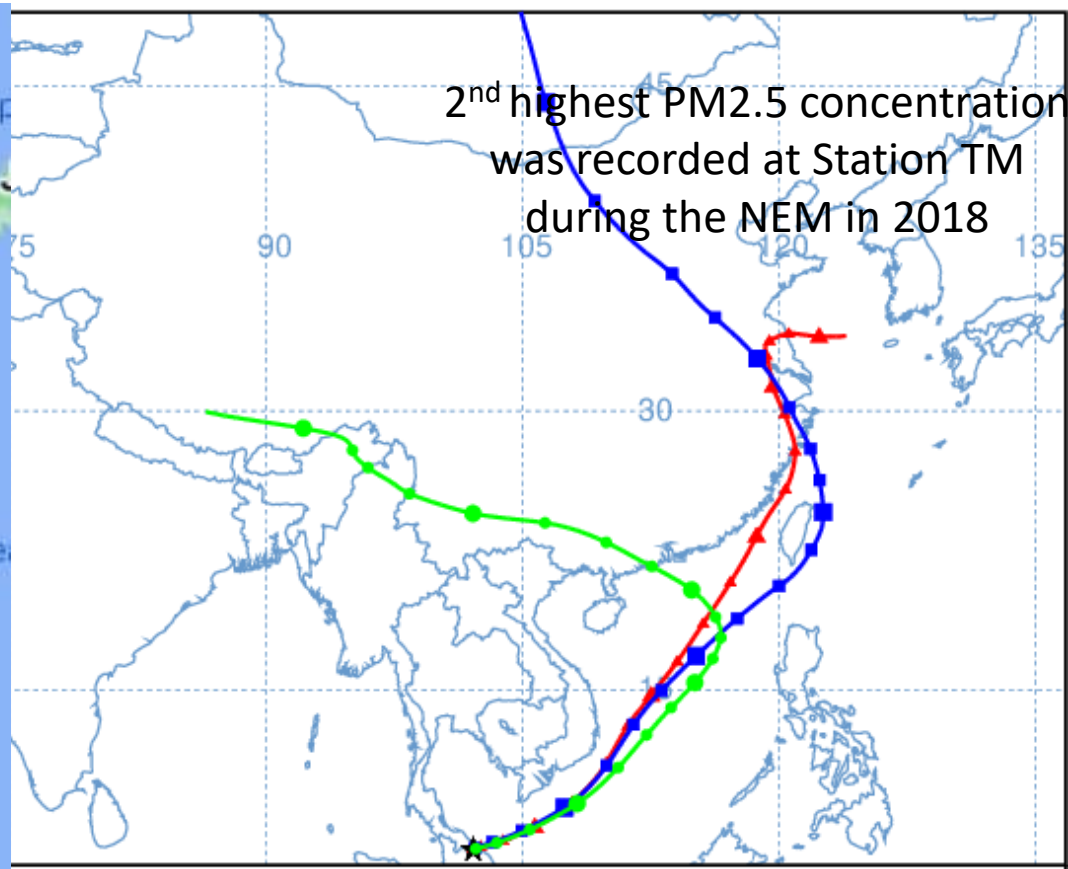
Job ID: 173783 Job Start: Wed May 31 04:47:01 UTC 2023
Source 1 lat.: 5.811167 lon.: 102.134500 hgts: 100, 500, 1000 m AGL

Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 15 Apr 2019 - GDAS1

NOAA HYSPLIT MODEL
Backward trajectories ending at 1900 UTC 11 Mar 18
GDAS Meteorological Data



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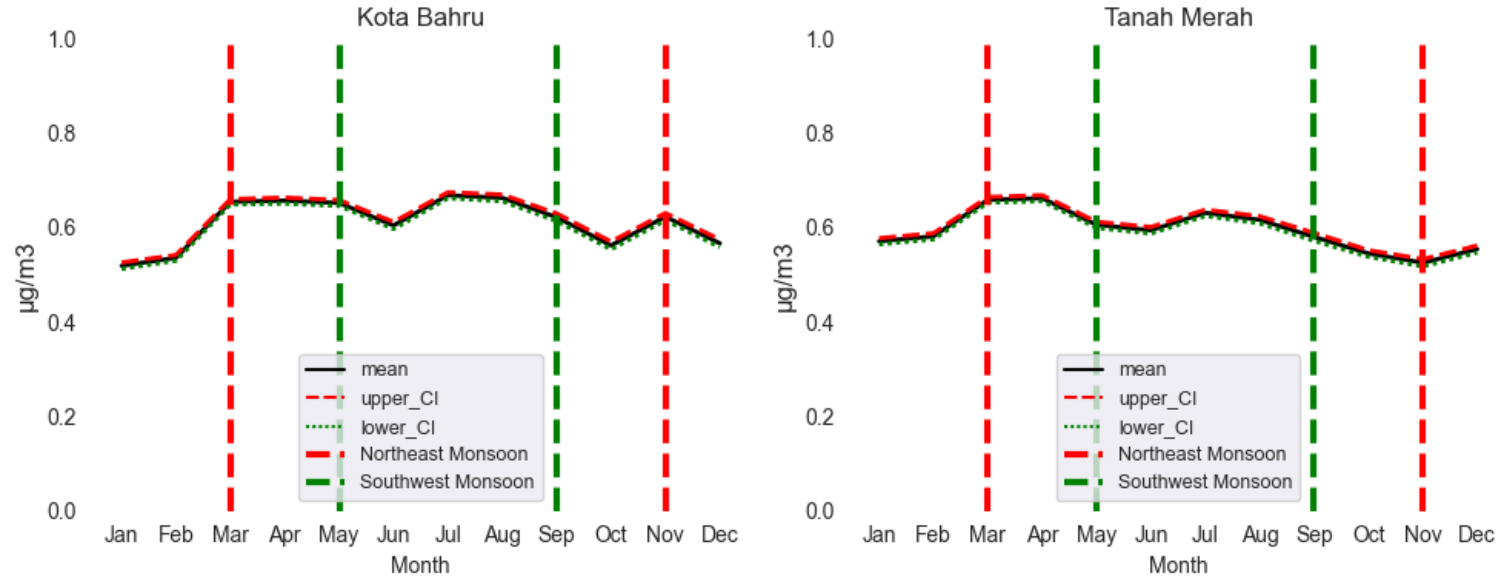
03/11 03/10 03/09 03/08 03/07

Job ID: 173815 Job Start: Wed May 31 04:48:53 UTC 2023
Source 1 lat.: 5.811167 lon.: 102.134500 hgts: 100, 500, 1000 m AGL

Trajectory Direction: Backward Duration: 120 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 8 Mar 2018 - GDAS1

Hourly and Seasonal Variation of $PM_{2.5}$ to PM_{10}

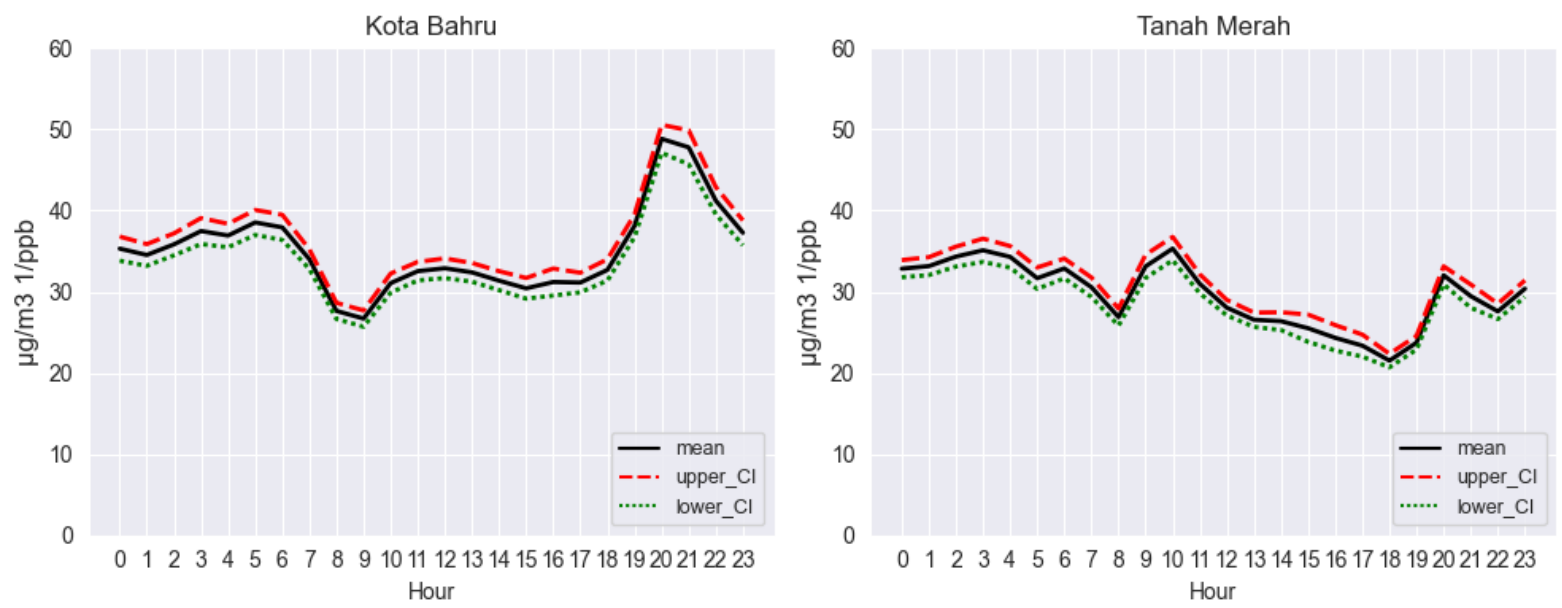
Hourly $PM_{2.5}$ to PM_{10} Ratio in Station KB and TM



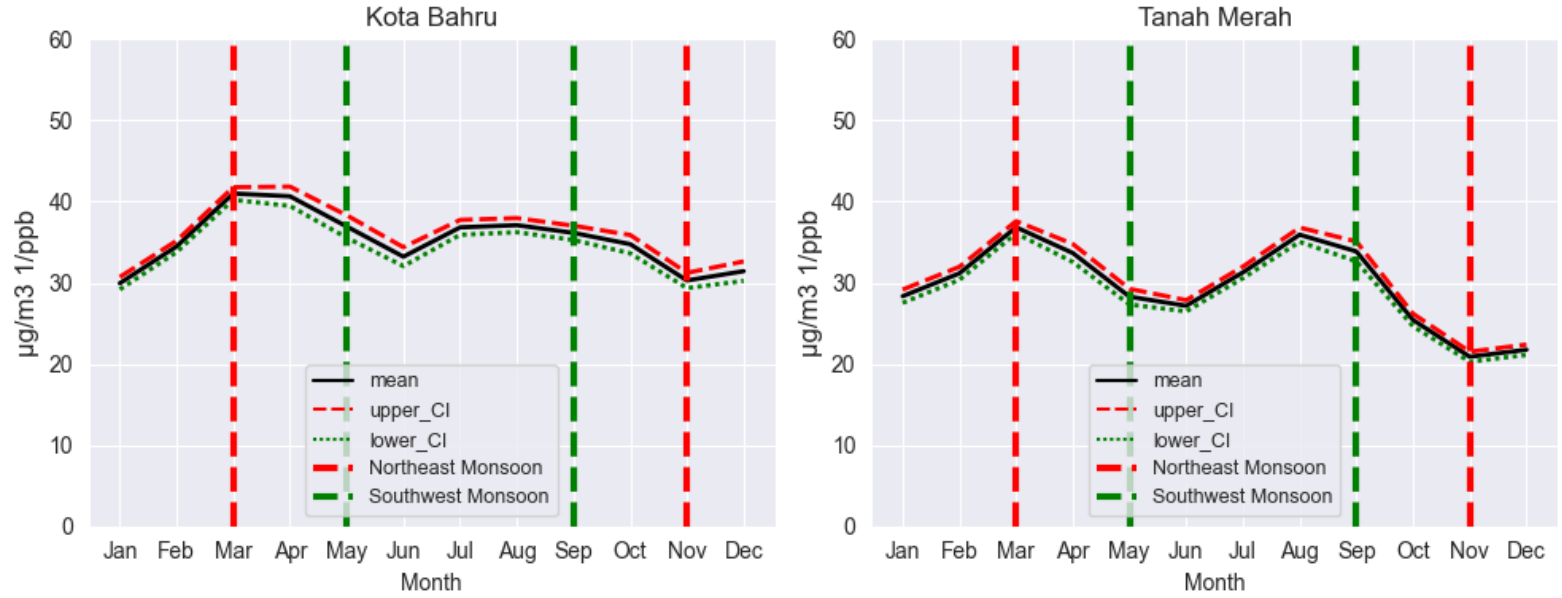
Monthly $PM_{2.5}$ to PM_{10} Ratio in Station KB and TM

- The hourly average of the $PM_{2.5}$ to PM_{10} ratio was above average in both stations. This indicates the emission of greater fine particles and potential sources are vehicle emissions, combustion processes, and biogenic[1].
- The slightly increasing ratio after 7 am indicates the source originates from vehicle exhaust and people activities.
- The bimodal peaks of the $PM_{2.5}$ to PM_{10} ratio indicates an increased level of $PM_{2.5}$ implies the sources from biomass burning or haze during the dry seasons and Southwest monsoon, respectively[4].

Hourly and Seasonal Variation of $PM_{2.5}$ to CO

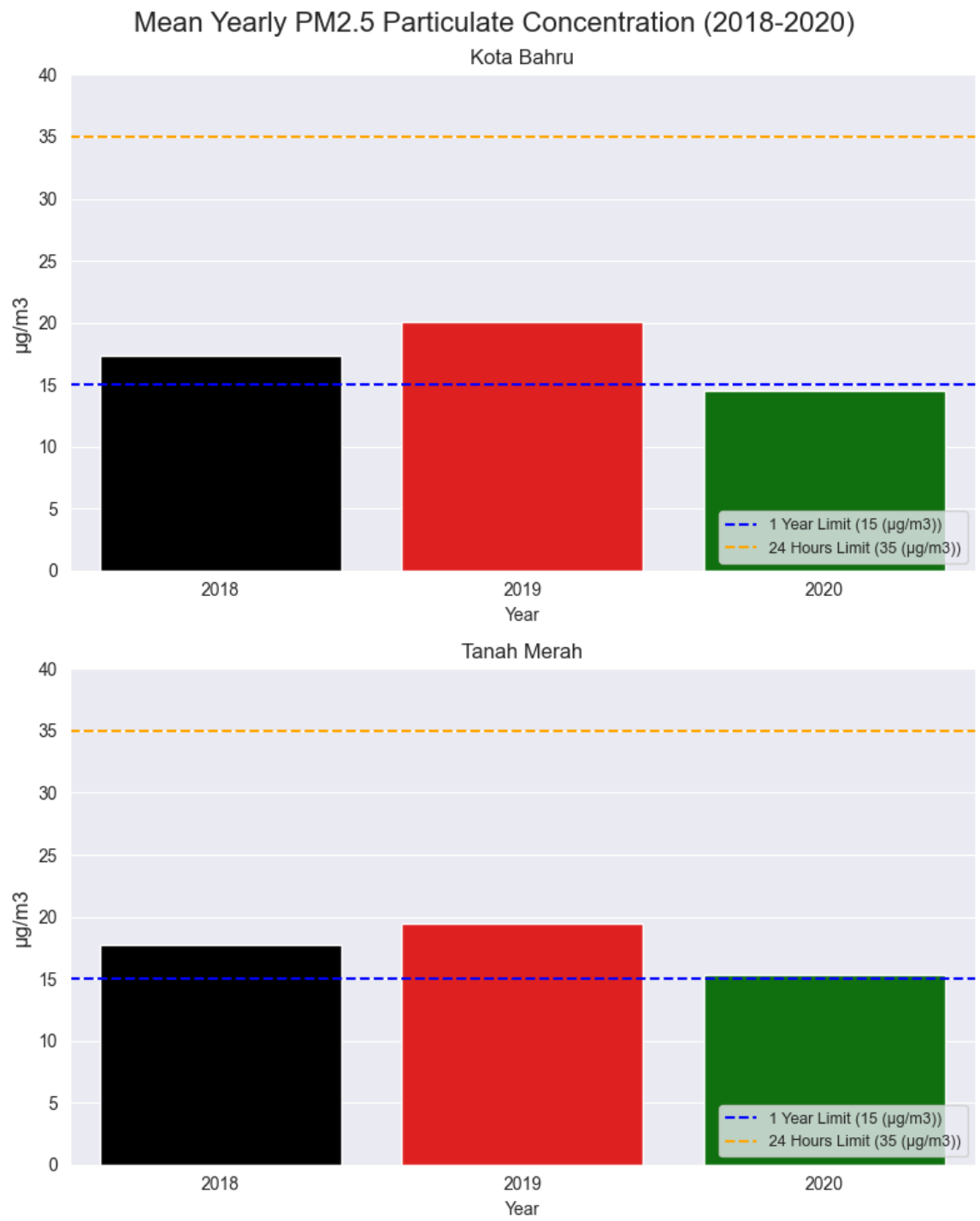


Hourly $PM_{2.5}$ to CO Ratio in Station KB and TM



Monthly $PM_{2.5}$ to CO Ratio in Station KB and TM

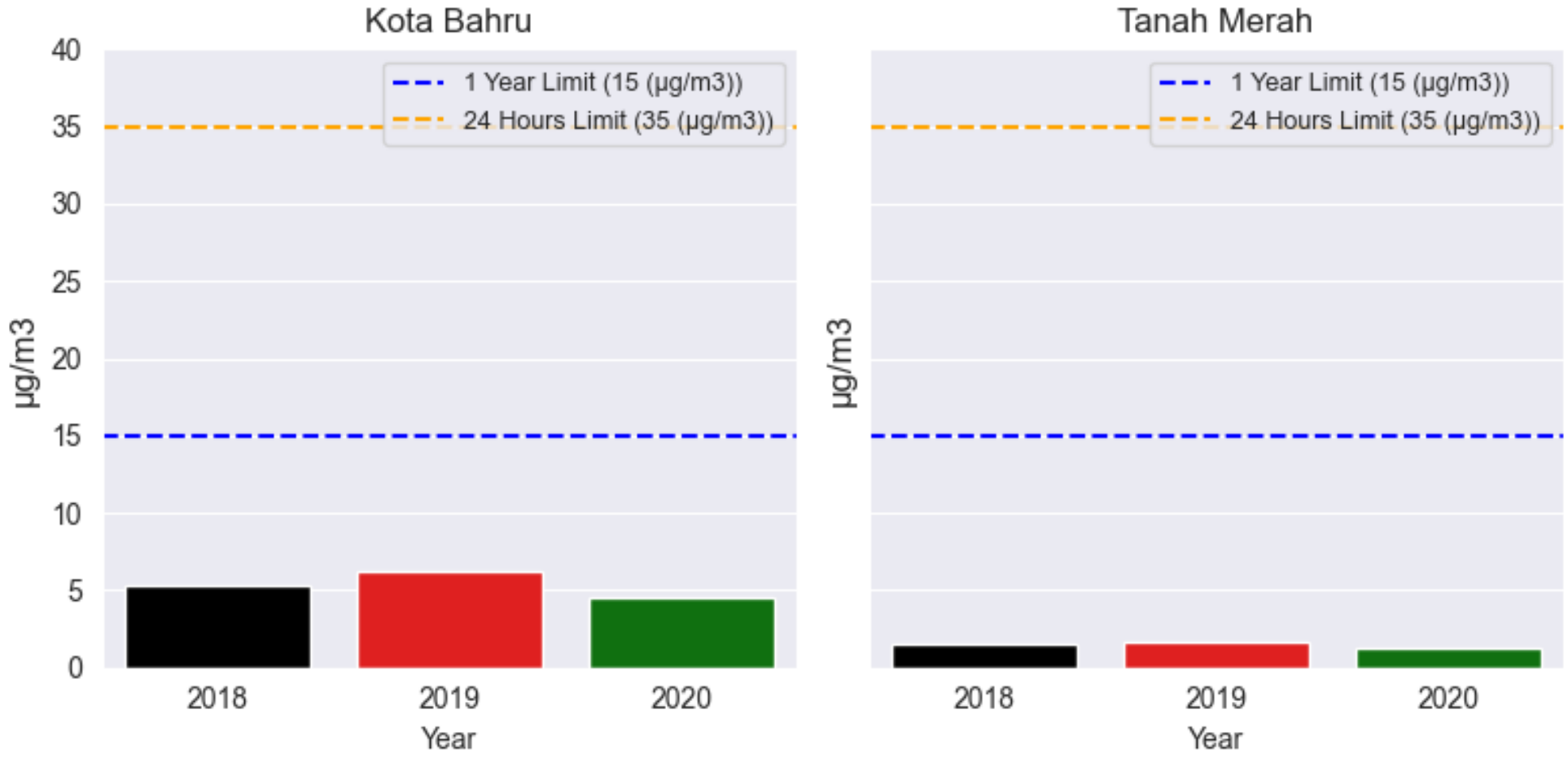
- The hourly ratio of $PM_{2.5}$ to CO is showing a higher ratio than the usual urban emission pollutants.
- This indicates the potential sources were from combustion sources such as biomass burning, peatland fires, and vehicle emissions [1].
- A slight increase from 11 am to 12 pm showed a potential of secondary pollutants forming with help from solar radiation[3].
- The bimodal peaks during the IMS1 and SWM in line with the potential sources were from biomass burning, peatland fires, and vehicular emissions[4].



The Yearly Variation of $PM_{2.5}$ in Station KB and Station TM

- Malaysia experienced the worst haze event in 2019 and this explained why the $PM_{2.5}$ concentration at both stations is the highest compared to 2018 and 2020.
- Covid-19 pandemic caused nationwide lockdown. No industrial activities and other anthropogenic activities, caused the $PM_{2.5}$ concentration in 2020 to be the lowest in three years.

Population-weighted Annual Mean $PM_{2.5}$



- This indicates the average concentration of $PM_{2.5}$ in the air taking into account the population distribution is lower than the recommended level sets by Malaysian authorities.
- It implies that the health risk associated with long-term exposure to $PM_{2.5}$ are lower and do not pose significant health concerns.
- But there are still localized areas or specific populations experiencing higher levels of $PM_{2.5}$ pollution.

Study Limitation

- Ground observation cannot reflect the spatial variability of $PM_{2.5}$ over large areas and highly populated areas.
- There are only two ground observation stations to monitor the main criteria air pollutants & meteorological variables in Kelantan.
- The mean value may lead to systematic error in assessing the population exposure and health effect.

Future Suggestion

- Incorporate the satellite remote sensing data as the satellite can continuously obtain the PM2.5 concentration over a large surface area.
- Therefore, the understanding of the $PM_{2.5}$, other pollutant levels, and meteorological variables in no-ground monitoring station locations can be established.

Acknowledgment

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Thank you to the Malaysian Department of Environment (DOE) for providing air quality and meteorological data.

Reference

[1]Othman, M., Latif, M. T., Hamid, H. H. A., Uning, R., Khumsaeng, T., Phairuang, W., ... & Lung, S. C. C. (2022). Spatial–temporal variability and health impact of particulate matter during a 2019–2020 biomass burning event in Southeast Asia. Scientific Reports, 12(1), 7630.

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[3]Jaffe, D. A., Schnieder, B., & Inouye, D. (2022). Use of PM 2.5 to CO ratio as a tracer of wildfire smoke in urban areas. Atmospheric Chemistry & Physics Discussions.

[4]Mohtar, A. A. A., Latif, M. T., Baharudin, N. H., Ahamad, F., Chung, J. X., Othman, M., & Juneng, L. (2018). Variation of major air pollutants in different seasonal conditions in an urban environment in Malaysia. Geoscience Letters, 5(1), 1-13.

Q & A Session