VERTICAL PROFILING OF PARTICULATE MATTER (PM2.5 AND PM10) AND METEOROLOGICAL FACTORS AT THE URBAN ATMOSPHERIC BOUNDARY LAYER (UABL) USING AN AIR QUALITY INTEGRATED SYSTEM

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PRESENTATION OUTLINE

- RESEARCH BACKGROUND
- **AIR QUALITY INTEGRATED SYSTEM DEVELOPMENT**
- PILOT FIELD EXPERIMENT
- FURTHER WORK
- CONCLUSION

BACKGROUND

6.5 million death cases

92%

people inhale dirty air

From

Respiratory and cardiovascular issues

Source: World Health Organization

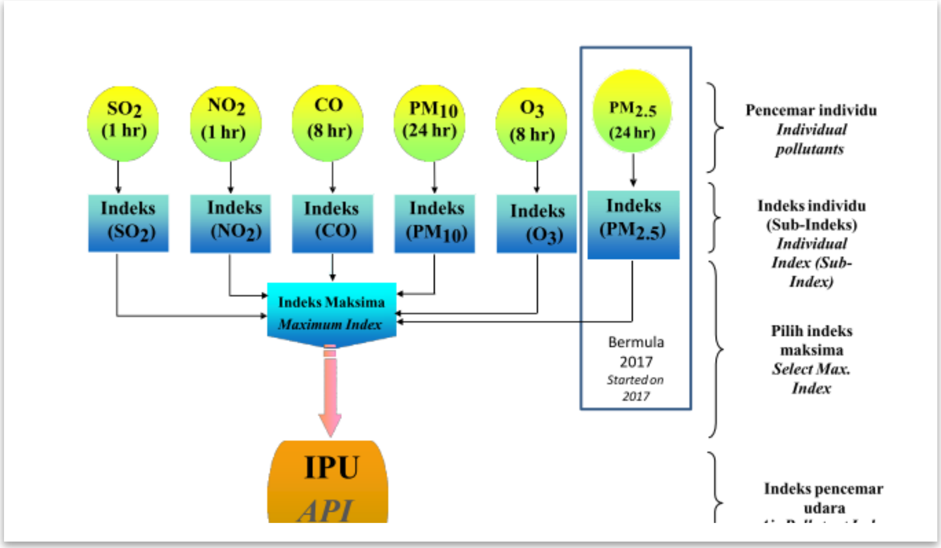


Figure 1 Six pollutants will indicate the air pollution level based on the sub-index of pollutants.
Source: Department of Environment Malaysia, n.d.).

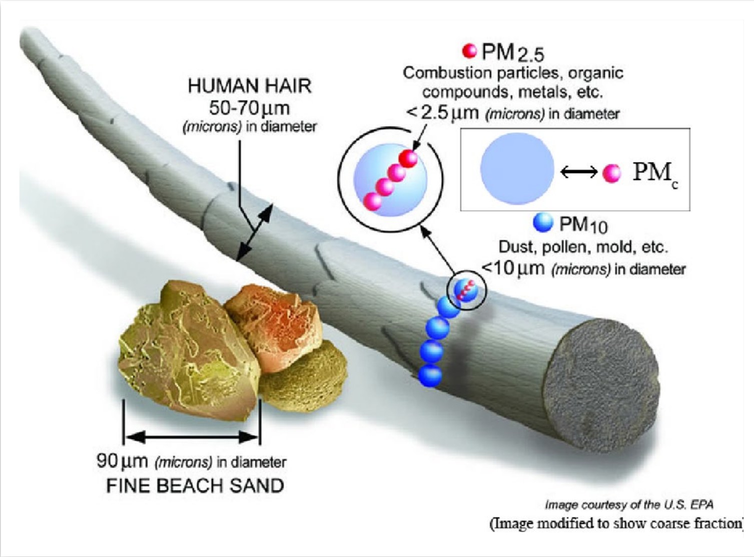


Figure 2 Three size fractions of PM.
Source: Jennings (2013)

- Between July and September, the direction of the wind from the southwest (Sumatra) caused higher particulate matter distribution to Klang Valley (Shaadan et al., 2015)
- During the northeast monsoon (wet season), the air quality is getting better due to the precipitation that carries pollutants to the earth from the atmosphere. However, during the southwest monsoon (dry season), the air quality was exacerbated since the pollutants become unstable from shifts of warm air to higher regions of the earth (Barmpadimos et al., 2011; Mohd. Odli, 2009)

Cont...

Urbanization Vs. Meteorological factors

Due to industrialization, developments, high population.

(Rostam et al., 2010). PM2.5 concentration has a positive relationship with temperature and a negative relationship with relative humidity and wind speed Babaan et al., (2018)

High rise buildings

5.5 million people in Malaysia with vertical livings until June 2014.

(New Straits Times, 2016) There is a significant difference in increasing latitude and decreasing latitude with the changes of height. The pollutant PM2.5 concentration data is different in the vertical distribution of PM2.5 near the ground Li et al., (2018)

Point based measurement Air Quality data

- Not accurately represent exposure on a small scale, very few, uneven geographical intervals (Tian, 2008)
- Vertical distribution of PM (Gautam et al., 2021; Lu et al., 2019) and (Bates et al., 2013)
- PM distributions and meteorological factors (Gautam et al., 2021; Peng et al., 2015; Lu et al., 2019)

Current Vertical Profiling Measurement of Air Quality Data

Methods	Advantages	Limitations
 Satellite-Based Remote Sensing	• Efficient in measuring changes of the tropospheric air pollution temporally and spatially at multiple scales (Peng et al., 2015).	• Consider each layer of surface to the atmospheric as a layer without considering the measurement of vertical gradient (Peng et al., 2015). • Low accuracy due to the insufficient data validation (Peng et al., 2015).
 Tethered Balloons	• Able to reach extreme height altitude even up to the upper stratosphere (Lu et al., 2019). • Possesses ability to monitor pollutant and meteorological parameters in troposphere with a high spatial resolution (Bisht et al., 2016; Li et al., 2015; Renard et al., 2009).	• Insufficient sampling frequency and coarse resolution to resolve the detailed ABL structures and their evolutions (Lu et al., 2019). • Limited to horizontal measurement range (S.-J. Lu et al., 2019).
 Piloted Aircrafts	• Managed to acquire continuous data directly from various atmospheric heights (Peng et al., 2015).	• High-cost (Peng et al., 2015).
 Light Detection and Ranging (LiDAR)	• Able to determine the vertical aerosol dispersion easily (Li et al., 2015; Wang et al., 2015).	• High-cost technology and lack of data within the 200 meters of height (Li et al., 2015; Wang et al., 2015).

URBAN ATMOSPHERIC BOUNDARY LAYER (UABL)

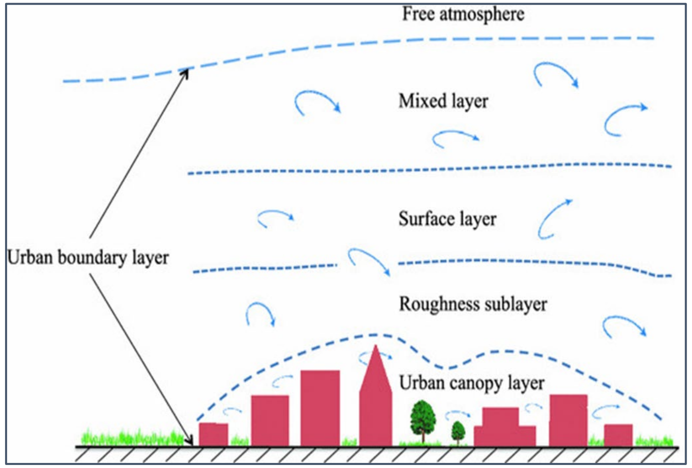


Figure 3 Different sublayers of an urban boundary layer (following the classification of Oke 1988)
Source: Wang et al., (2014)

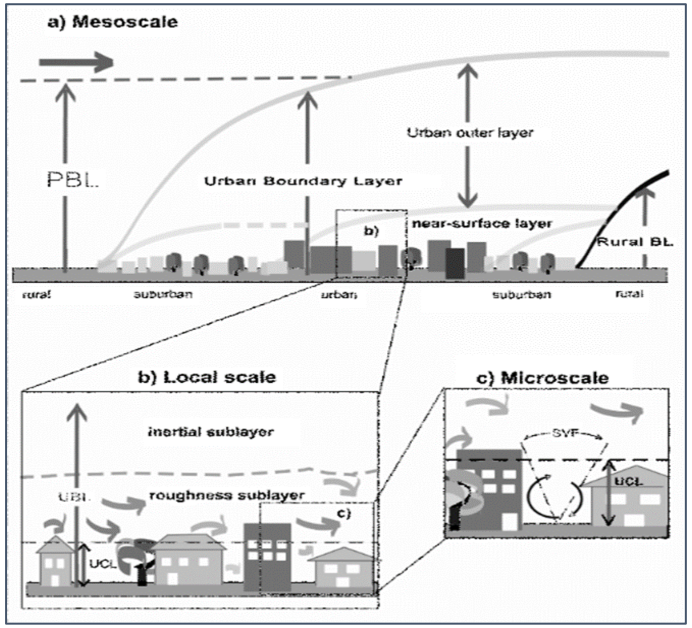
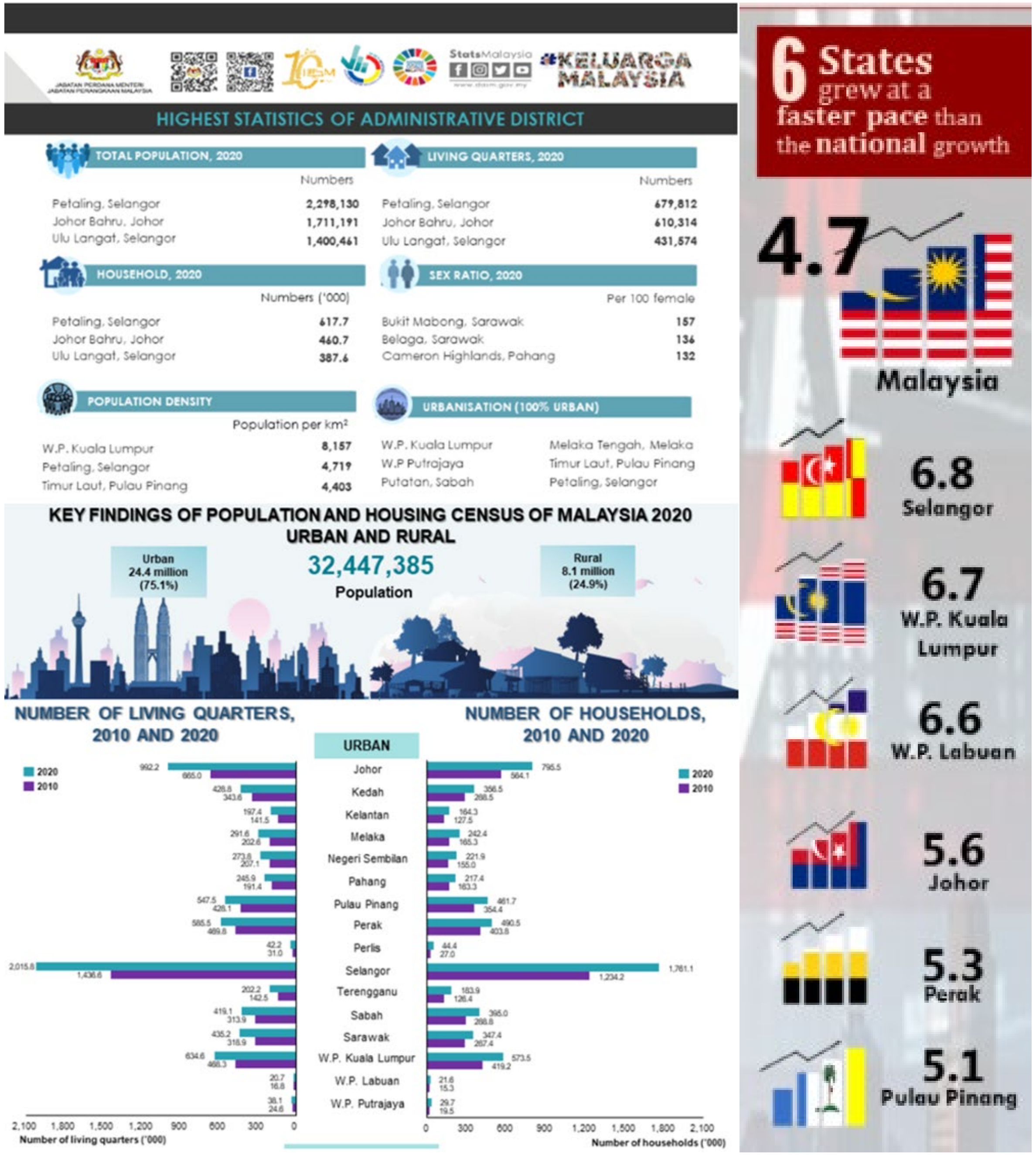


Figure 4 Sketch of the urban boundary layer structure indicating the various (sub)layers and their names (modified after Oke, 1987). In c) SVF stands for sky view factor.
Source: Rotach et al., (2005)

- The UABL is the layer of the atmosphere that houses the majority of the world's population. It is known as the most complicated and poorly understood microclimates (Barlow, 2014). From 0 to 450 m
- Consists of surface layer, planetary boundary layer and urban boundary layer.
- During day : convective boundary layer (CBL)
  During night : stable boundary layer (SBL) (Sun et al., 2018).

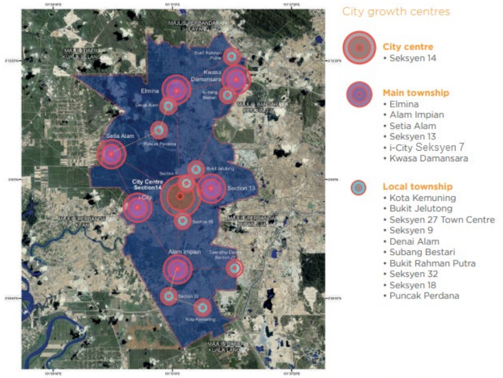
The Highlight of SDG Local Review of Shah Alam



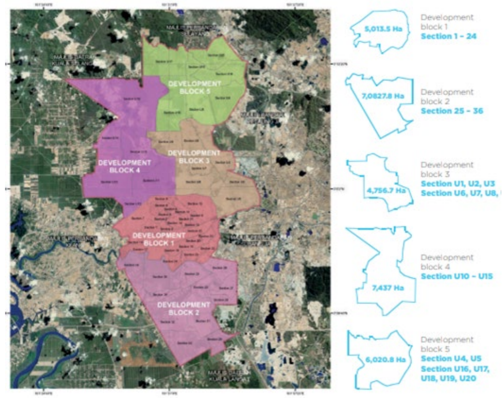
Source: Department of Statistic Malaysia

Source: Urbanice Malaysia and

SHAH ALAM, SELANGOR



Shah Alam's city growth centres as determined in the Shah Alam 2035 Draft Local Plan, MBSA, 2020.


Development and planning

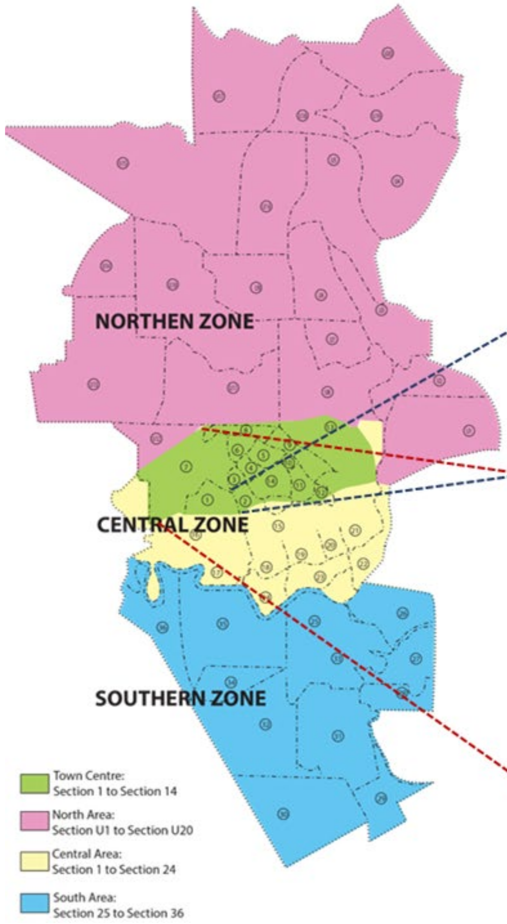
To guide orderly development, Shah Alam's 56 Sections are spatially divided into five development blocks as shown below.

Within the five development blocks, a differentiation is being made between development and non- development areas. The largest proportion of developed land is currently assigned to transportation (20%), followed by residential (16.8%) and industrial (10.3%) uses.

Shah Alam in the context of Malaysia, the state of Selangor, and the district of Petaling and Klang.

Source: Urbanice Malaysia and MBSA (2021).

STUDY AREA



- House Development
- Residential Area

Figure 5 Nearby the Akademi Pengajian Bahasa (APB) and the Main Entrance of Seksyen 2.

STUDY SITE 1

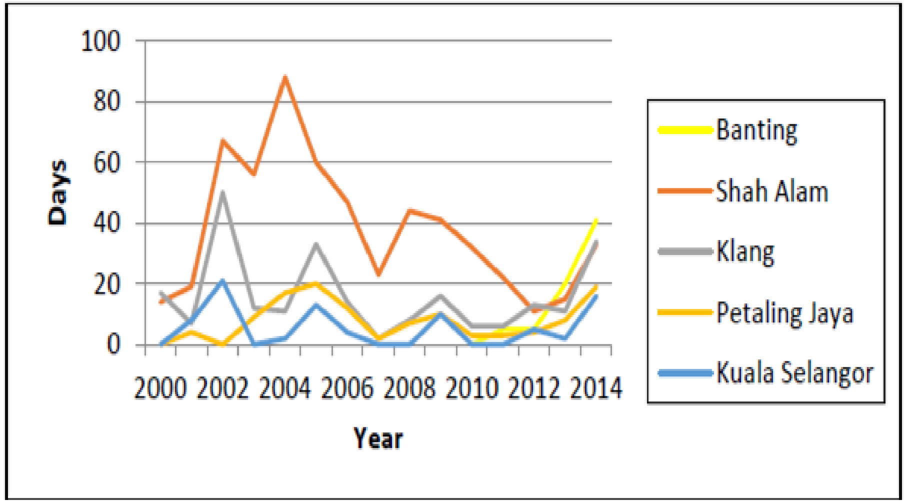
N 3°04'14" E 101°30'14"

Figure 6 Nearby the Entrance of Seksyen 7.

STUDY SITE 2

N 3°04'35" E 101°29'29"

- Commercial Areas
- Residential Areas
- Development of Light Rail Transit (LRT3) Station
- Industrial
- Major Highway



The Number of Unhealthy Days in Five Sub-Areas of Selangor Between 2000 to 2014 Due to Air Pollution. Source: Mabahwi et al. (2018)

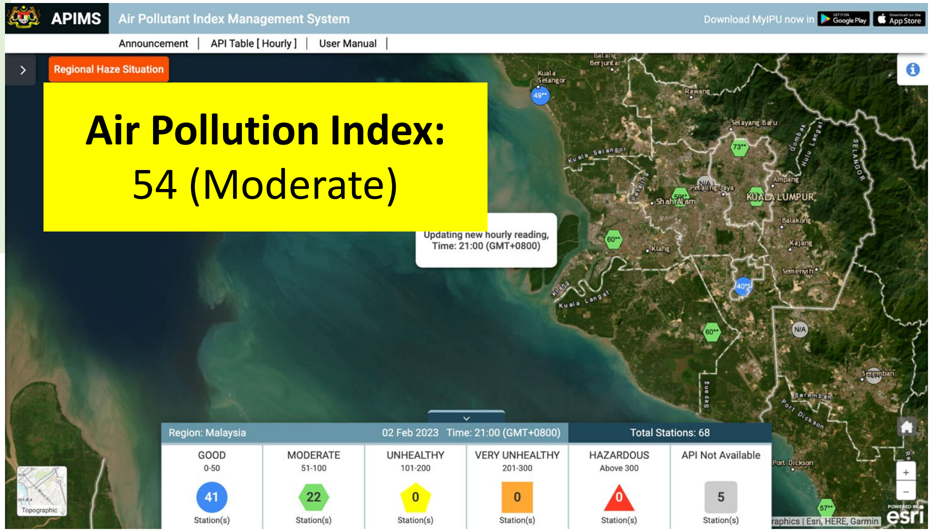


Figure 5 The subset of Location Two Study Areas from the Shah Alam Map

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OBJECTIVE

1

To develop Air Quality Integrated System.

2

To measure vertical profile of Particulate matter ($PM_{2.5}$ and PM_{10}) and meteorological factors (temperature and humidity.

3

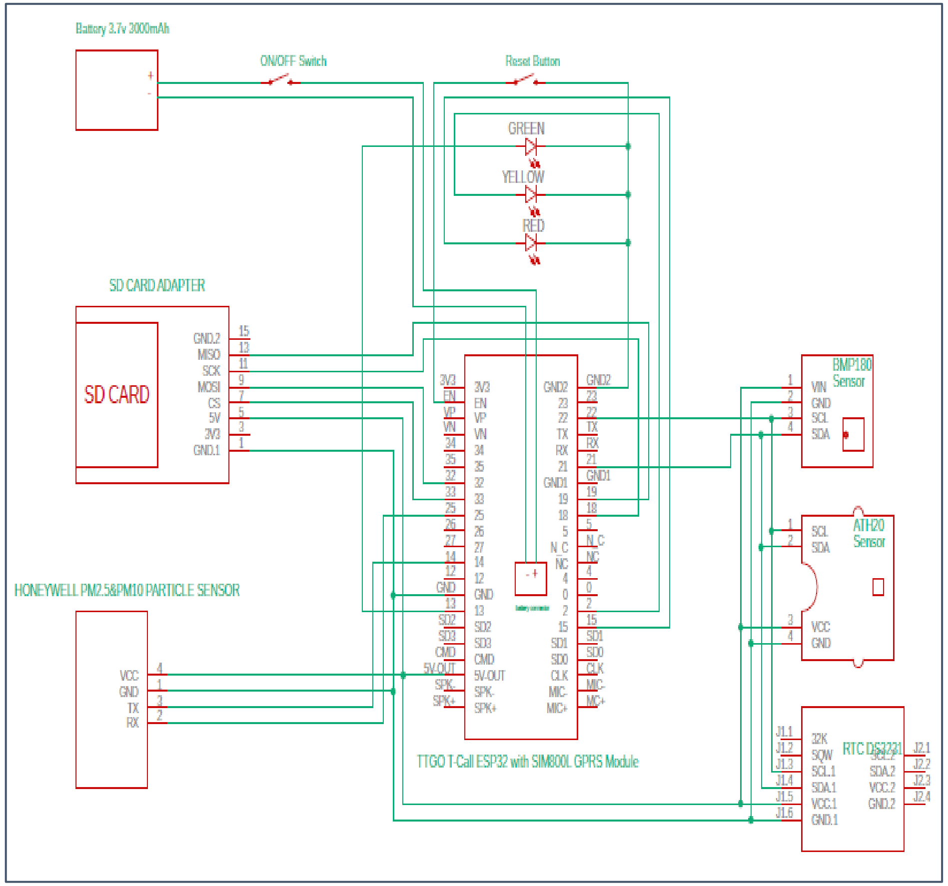
To analyse the vertical profile particulate matter ($PM_{2.5}$ and PM_{10}) and meteorological factors (temperature and humidity).

SCOPE OF STUDY

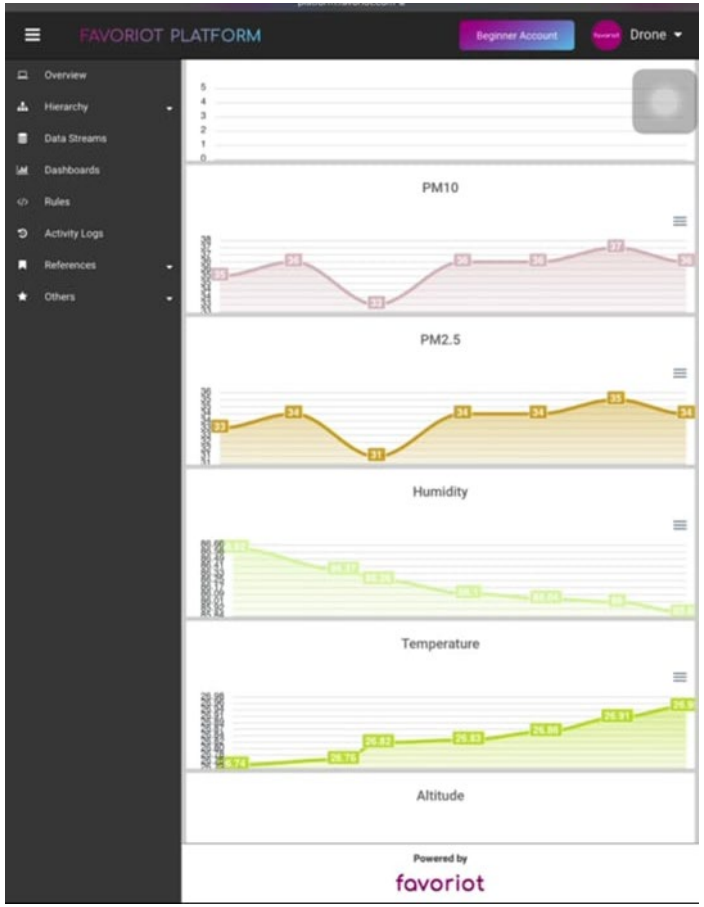
- This study is focusing on the vertical profiling of Particulate Matters (PM2.5 and PM10)distributions based on meteorological factors (humidity and temperature)
- Selected areas of Shah Alam have been chosen to represent urban areas (Section 2 and Section 7)
- The UAV fly at height (0 - 120 m)

Method: Air Quality Integrated System Development

Component 1
Air Quality Sensor



Component 2:
Real time IOT dashboard



Component 3:
UAV Quadrotor

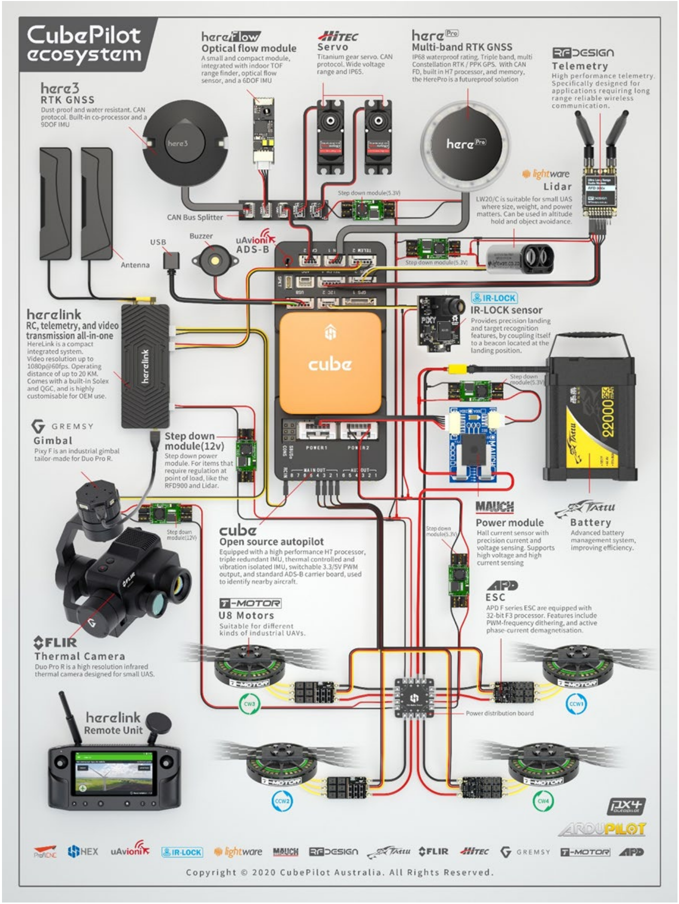
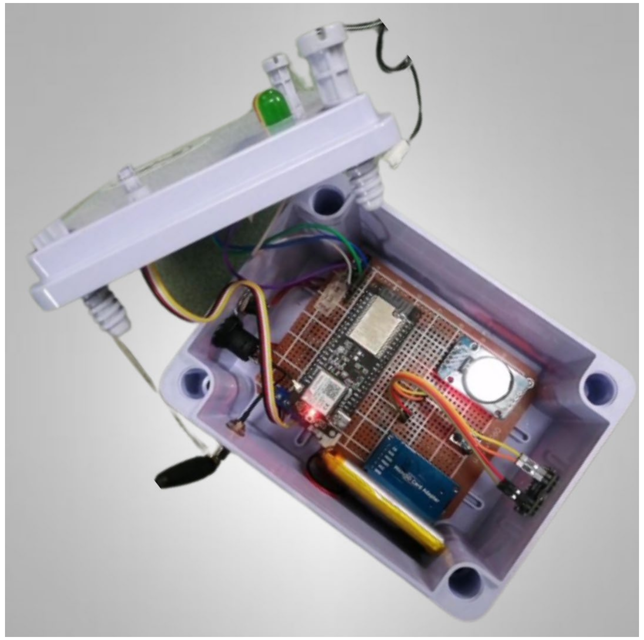


Figure 6 The Schematic Diagram of The Air Quality Integrated System

i. Air Quality Sensor



- **Total weight**
  0.396kg
- **Dimension**
  L x W x H (154.5mm x 115.0mm x 77.6mm)
- **The components of the air quality sensor:**
  i. Arduino UNO R3 board
  ii. Dust Sensor Module DSM501A
  iii. Temperature and Humidity Sensor
  iv. GPS Module model NEO-6M compatible with Arduino UNO R3
  v. Real-Time Module DS3231
- **Battery Life**
  30 minutes
- **Data storage:** Real time IOT Favoriat and SD Card inserted in the sensor
- **Sensor interval measurement**
  i. SD Card: 1 second
  ii. Real time IOT Favoriot: 10 seconds

ii. Favoriot Platform for Real time

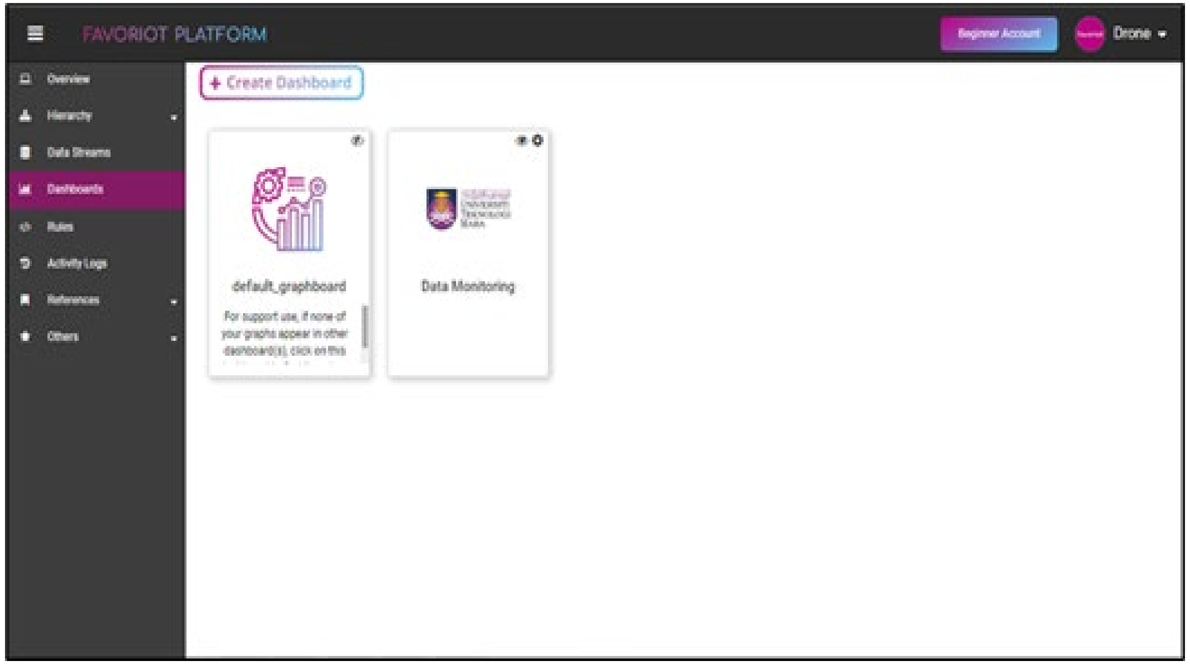


Figure 8 The User Interface (UI) of Favoriot Platform

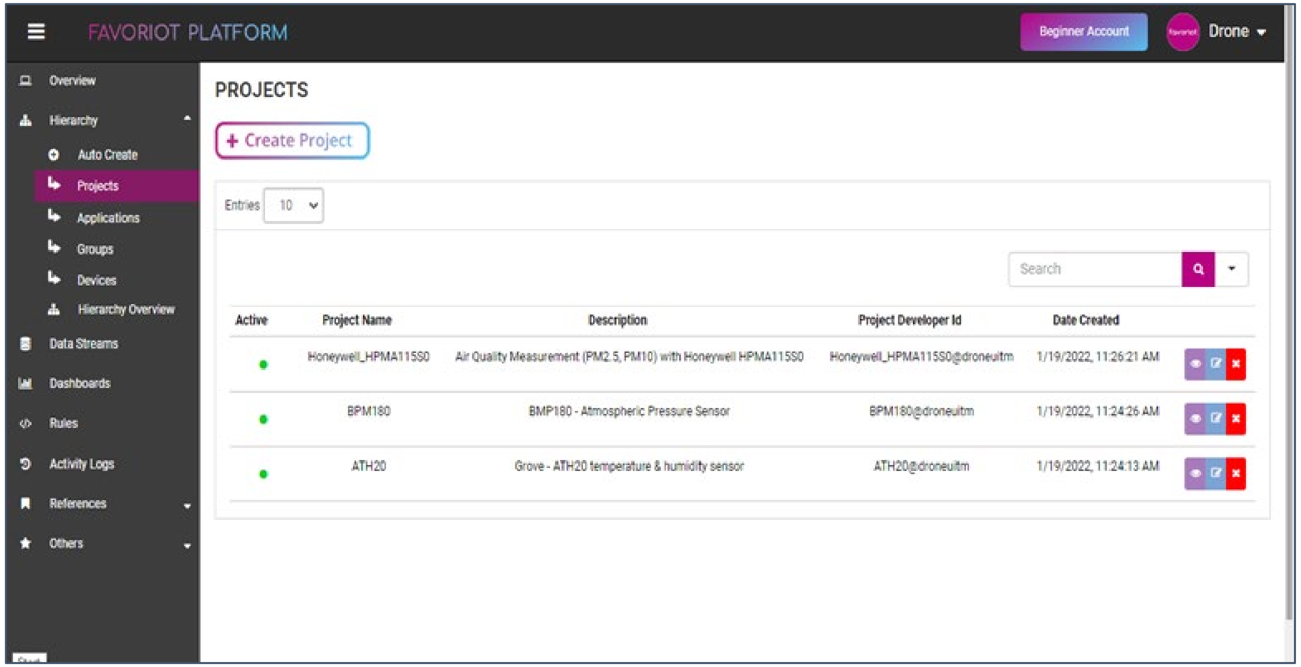
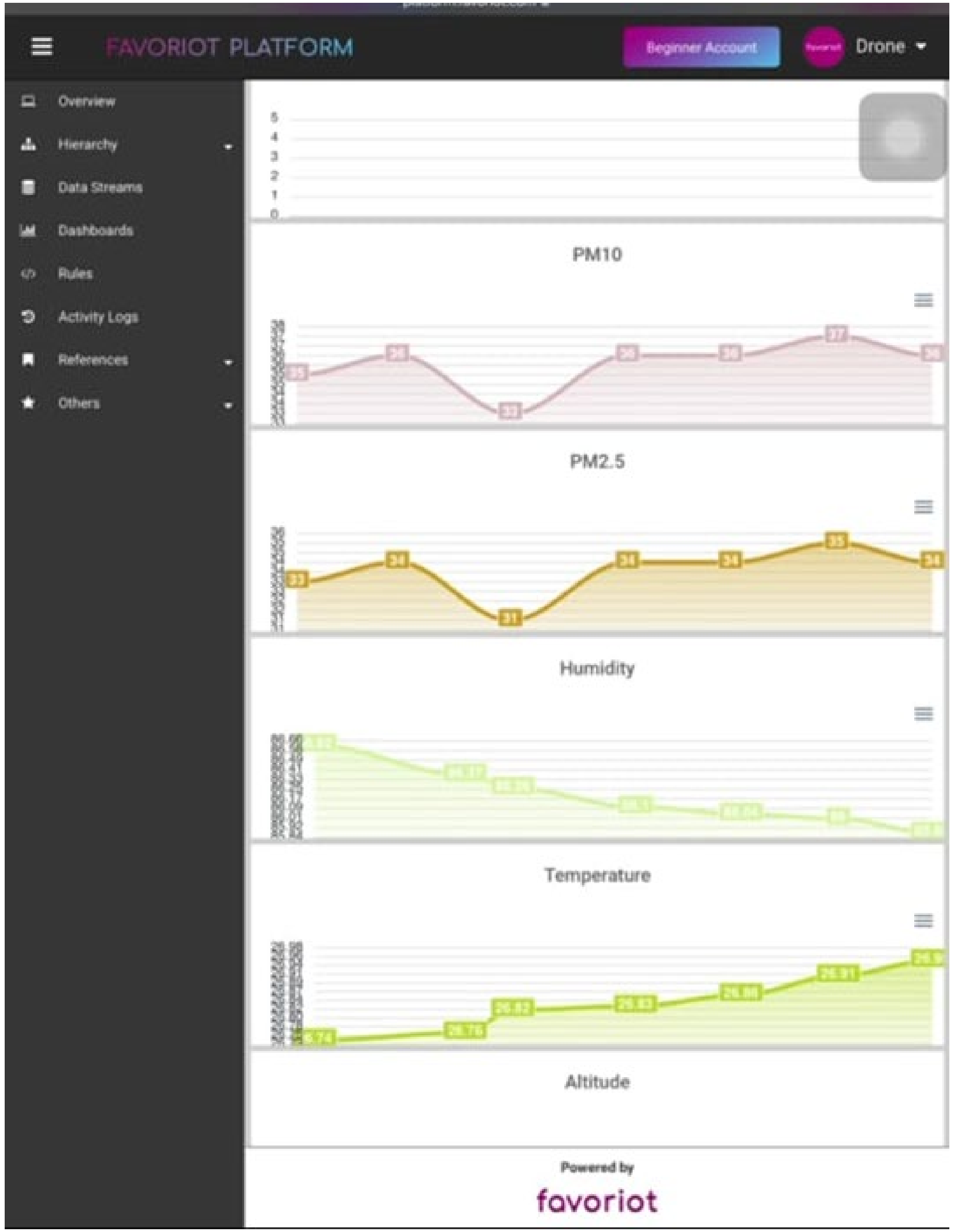


Figure 9 Three categories of data involved in data monitoring by using the sensors of; (i) Honeywell HPMA 115S0 ($PM_{2.5}$ and PM_{10} data measurement) (ii) BMP180 (Atmospheric Pressure and Altitude Measurement) (iii) ATH20 (Temperature and Humidity Data Measurement).



Favoriot Platform for Real time Dashboard

Display of Real time graph:

- PM2.5 concentration (ug/m3)
- PM10 concentration (ug/m3)
- Altitude (m)
- Humidity (%)
- Temperature (°C)

Figure 10 The graph shown in dashboard of IoT platform which includes the variables of the study.

iii. UAV Quadcopter

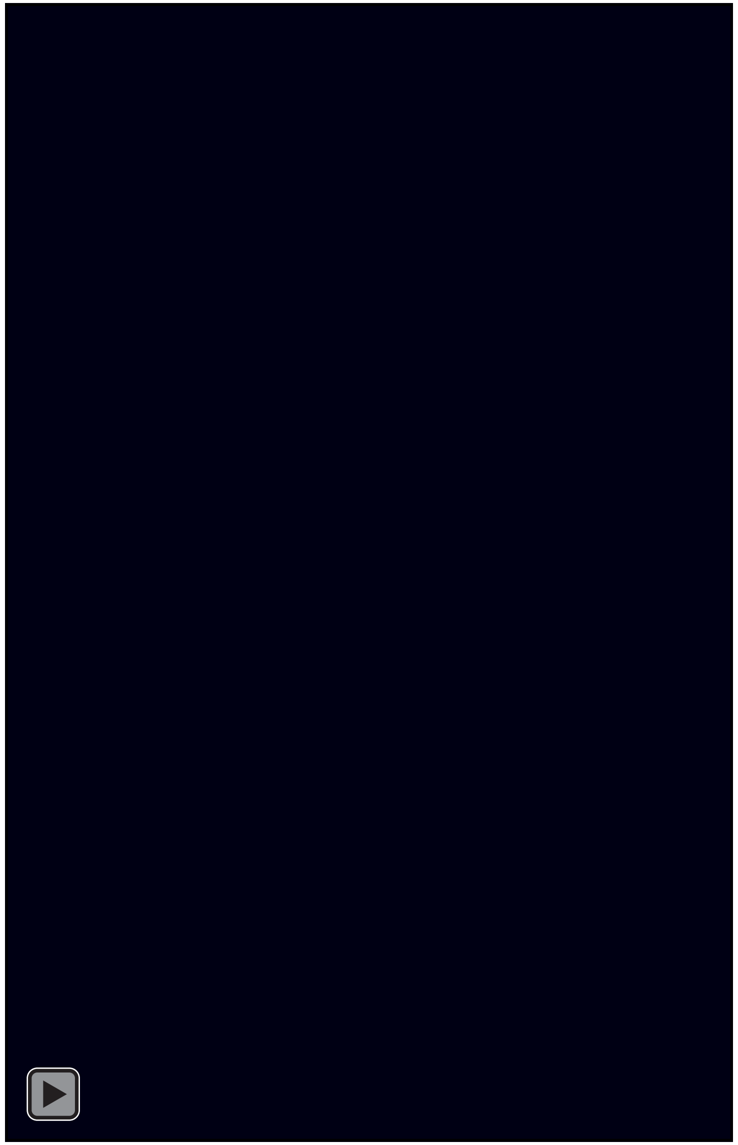
- Weight: 1.8 kg
- Payload : 500 g
- Estimation: Fly for around 15–20 minutes
  - For safety reasons, the drone was flown for approximately 7 minutes.
- Flown 120 metres in a vertical manoeuvre.
- Safety features to ensure stable and reliable flight performance
  - Fail safe mode
  - A built-in vibration damping system

Figure 11 The Quadcopter Used to Fly The Sensor.

OBJECTIVE 2:

To measure vertical profile of Particulate Matters ($PM_{2.5}$ and PM_{10}) and meteorological factors (temperature and humidity).

Figure 12
The Integrated UAV at Study Site 1.



Field Measurement

Table 3 The Details During The Data Acquisition.

Field Experiment	Monsoon Season	Season	Date	Time	API (Based on DOE)
First	Southwest Monsoon	Dry Season (March - September)	2 June 2022	9 am - 12 pm	54 (Moderate)
Second	Northeast Monsoon	Wet Season (November - March)	24 December 2022	8 am - 11 am	57 (Moderate)

Collected during morning time zone from 8.00 a.m. to 12noon(Gautam et al., 2021; Liu et al., 2018)

PM10, PM2.5 POINT MEASUREMENT FOR VALIDATION

Figure 13 The Air Quality Detectors Used During Ground-based Measurement.

- Conducted prior each flight.
- Random sampling method.
- 40 random points
- The coordinates of the selected points are determined by using the Global Positioning System (GPS).
- Data collected by Air Quality Detectors:
  - PM concentrations
  - temperature and
  - Humidity

Site Section 2

- **Table 5:** Vertical profile particulate matter (PM2.5 and PM10) and meteorological factors (temperature and humidity during Dry Season (June 2022)

HEIGHT (m)	AVERAGE							
	HUMIDITY (%)		TEMPERATURE (°C)		PM2.5 Concentration (ug/m3)		PM10 Concentration (ug/m3)	
	F1	F2	F1	F2	F1	F2	F1	F2
0-20	63.24	71.03	32.50	31.50	14	9	15	10
21-40	66.37	66.39	32.91	32.85	14	15	15	16
41-60	58.81	59.42	34.00	34.18	30	66	31	68
61-80	**61.98**	**60.76**	**32.83**	**33.21**	**15**	**79**	**16**	**81**
81-100	54.19	56.82	33.88	35.72	15	72	16	74
101-120	52.99	53.58	35.14	35.30	15	72	16	74

Site Section 7

- **Table 6:** Vertical profile particulate matter (PM2.5 and PM10) and meteorological factors (temperature and humidity during Dry Season (June 2022)

HEIGHT (m)	AVERAGE							
	HUMIDITY (%)		TEMPERATURE (°C)		PM2.5 Concentration (ug/m3)		PM10 Concentration (ug/m3)	
	F1	F2	F1	F2	F1	F2	F1	F2
0-20	61.87	61.20	33.64	33.71	19	21	20	23
21-40	55.14	59.81	33.21	33.34	19	67	20	70
41-60	57.44	58.18	34.27	33.49	58	43	59	45
61-80	**55.74**	**57.15**	**33.75**	**33.62**	**83**	**40.1**	**85**	**41.5**
81-100	54.85	59.65	34.01	33.18	90	13	92	14
101-120	54.62	57.41	33.71	33.59	14	7	15	8

Site Section 2

- **Table 7:** Vertical profile particulate matter (PM2.5 and PM10) and meteorological factors (temperature and humidity during Wet Season (December 2022)

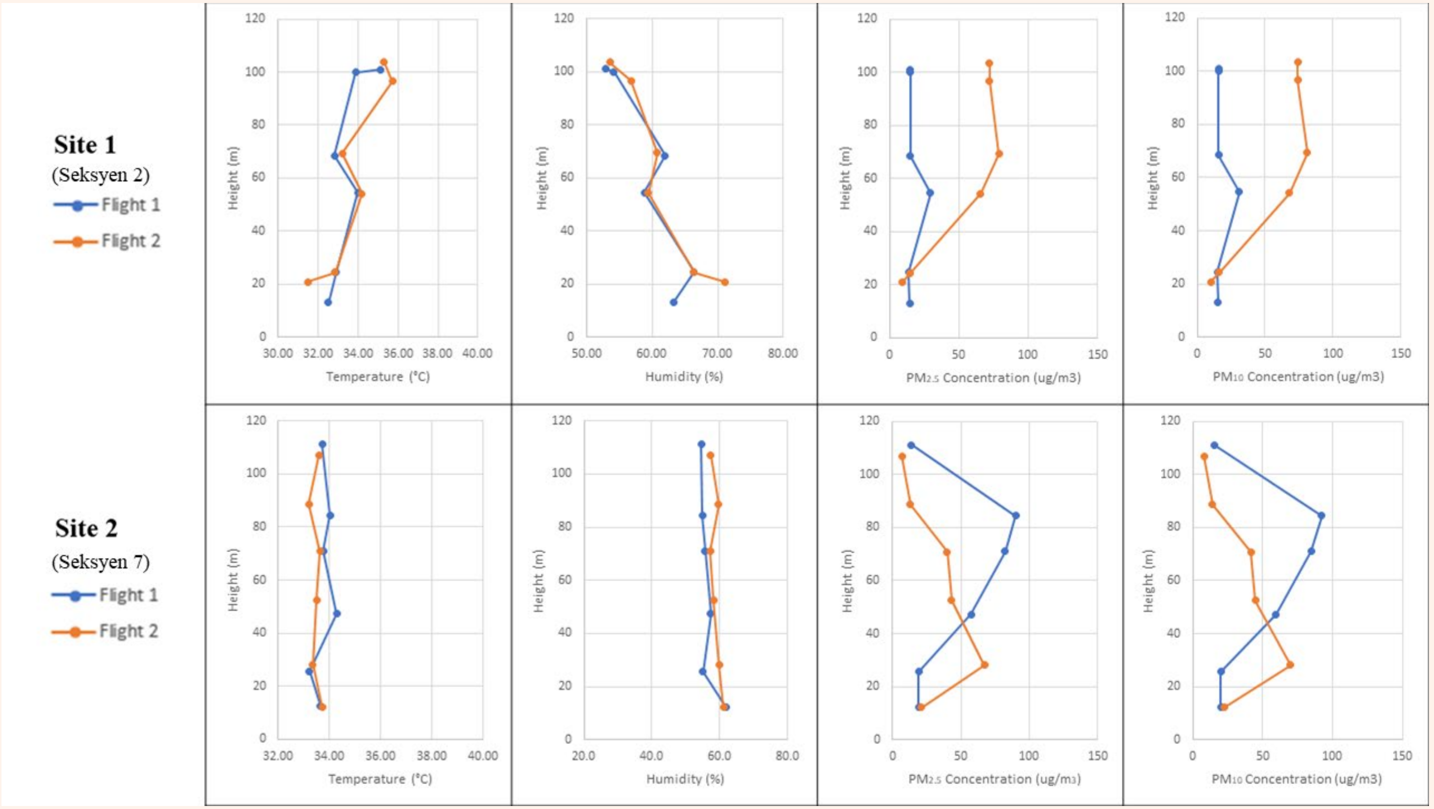
HEIGHT (m)	AVERAGE							
	HUMIDITY (%)		TEMPERATURE (°C)		PM2.5 Concentration (ug/m3)		PM10 Concentration (ug/m3)	
	F1	F2	F1	F2	F1	F2	F1	F2
0 - 20	68.90	58.63	29.72	32.43	42	25	44	26
21 - 40	67.80	58.31	29.64	32.33	38	25	41	27
41 - 60	67.31	58.32	29.73	32.33	40	27	42	31
61 - 80	**67.40**	**57.97**	**29.84**	**32.38**	**42**	**29**	**44**	**31**
81 -100	66.66	57.48	29.75	32.63	34	30	36	32
101 - 120	67.00	56.69	29.85	32.70	33	28	35	30

Site Section 7

- **Table 8:** Vertical profile particulate matter (PM2.5 and PM10) and meteorological factors (temperature and humidity during Wet Season (December 2022)

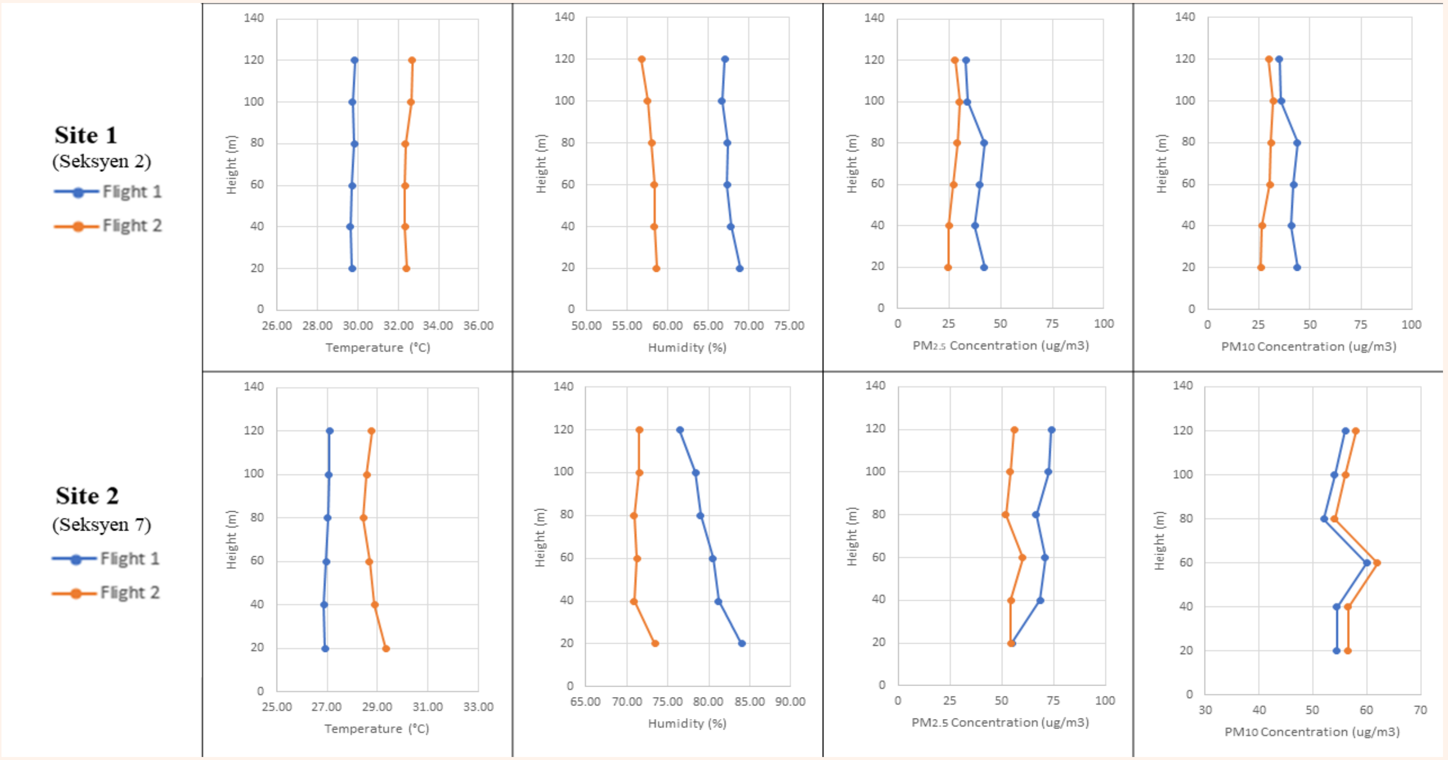
HEIGHT (m)	AVERAGE							
	HUMIDITY (%)		TEMPERATURE (°C)		PM2.5 Concentration (ug/m3)		PM10 Concentration (ug/m3)	
	F1	F2	F1	F2	F1	F2	F1	F2
0 - 20	83.98	73.40	26.91	29.34	55	55	55	57
21 - 40	81.19	70.89	26.88	28.89	69	55	55	57
41 - 60	**80.52**	**71.22**	**26.97**	**28.67**	**71**	**60**	**60**	**62**
61 - 80	79.02	70.90	27.02	28.44	67	52	52	54
81 -100	78.37	71.54	27.08	28.58	73	54	54	56
101 - 120	76.45	71.52	27.10	28.76	74	56	56	58

PM2.5, PM10, Temp & Humidity During Dry Season



- **Highest PM2.5 Concentration Vs. Height :**
- 61 ug/m3 at **61-80 m** (Section 7)
- **Highest PM10 Concentration Vs. Height :**
- 63 ug/m3 at **61-80 m** (Section 7)
- **Height with highest concentration of PM Concentration Based on Study SIte**
  - Section 2: **41 - 60 m**
  - (PM2.5: 48 ug/m3, PM10: 49 ug/m3)
  - Section 7: **61 - 80 m**
  - (PM2.5: 61 ug/m3, PM10: 63 ug/m3)

PM2.5, PM10, Temp & Humidity During Wet Season



- **Highest PM2.5 Concentration:**
  - 66 ug/m3 at **41-60 m** (Section 7)
- **Highest PM10 Concentration:**
  - 61 ug/m3 at **41-60 m** (Section 7)
- **Height with highest concentration of PM Concentration Based on Study SIte**
  - Section 2: **61 - 80 m**
  - (PM2.5: 36 ug/m3, PM10: 38 ug/m3)
  - Section 7: **41 - 60 m** in Seksyen 7 (PM2.5: 66 ug/m3, PM10: 61 ug/m3

Discussion

Table 9 The Correlation Analysis During Dry Season

Variables	p-value	r-value	r-value Descriptor
PM2.5 Vs. Altitude	<0.05*	0.133	Extremely Low Positive Correlation
PM2.5 Vs.Humidity	0.000**	-0.220	Low Negative Correlation
PM10 Vs. Altitude	<0.05*	0.122	Extremely Low Positive Correlation
PM10 Vs. Humidity	0.000**	-0.223	Low Negative Correlation

**p* is significant when <0.05

- **Positive correlation between PM concentration and altitude;** As pollutants can accumulate in the atmosphere due to less mixing of air mass and dilution.
- The air is often cleaner and less polluted at higher altitudes, particulate matter can still be transported from lower altitudes, leading to increased concentrations (Su et al., 2018).

- **Negative correlation between PM concentration and humidity;** The PM becomes dry and light in low humidity. As a result, the dry loose soil is easily blown by the wind and the particle will be suspended in the air and can promote the formation of particulate matter
- High humidity can increase the efficiency of removal mechanisms such as deposition and scavenging, leading to lower PM concentrations in the atmosphere.
- Increasing humidity, moisture particles eventually, grow in size to a point where 'dry deposition' occurs, reducing PM10 concentrations in the atmosphere (Hernandez et al., 2017)

Discussion

Table 10 The Spearman Correlation Analysis During Wet Season

Variables	p-value	r-value	r-value Descriptor
PM2.5 Vs. Humidity	<0.05*	0.727	High Positive Correlation
PM2.5 Vs. Temperature	<0.05*	-0.818	Extremely High Negative Correlation
PM10 Vs. Altitude	<0.05*	-0.750	High Negative Correlation
PM10 Vs. Humidity	<0.05*	0.802	Extremely High Positive Correlation
PM10 Vs. Temperature	<0.05*	-0.750	High Negative Correlation

*p is significant when <0.05

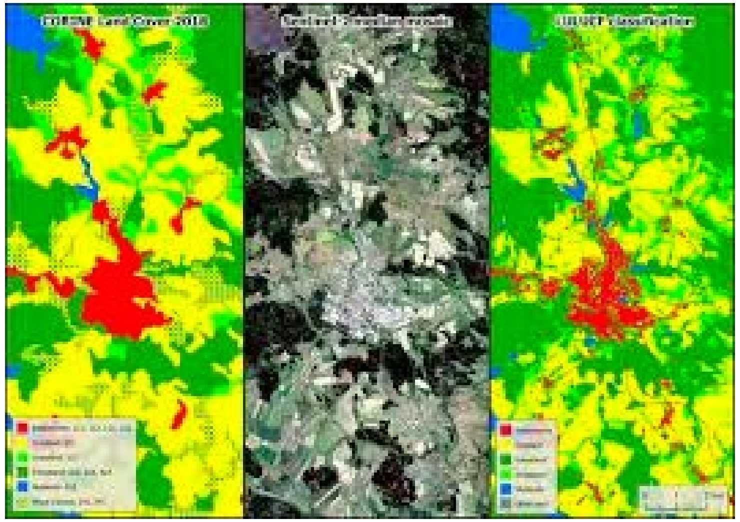
- **Negative correlation between PM concentration and altitude**; As emissions from human activities can contribute to higher levels of air pollution. At lower altitudes, the air is often more polluted due to increased emissions and reduced mixing, leading to increase of PM10 concentrations (Su et al., 2018).

- **Positive correlation between PM concentration and humidity;** Increased atmospheric stability, which can reduce the mixing of air masses and increase the accumulation effect of PM concentrations (Lou et al., 2017).
- Humidity has an impact on the way that PM naturally deposits, when moisture particles adhere to PM, it accumulates the atmospheric PM concentration. Consequently, the PM concentration increased (Hernandez et al., 2017).

- **Negative correlation between PM concentration and temperature;** Because intense radiation heats city underlying surface.
- The lower atmosphere is not unstable and turbulent strengthens, which is advantageous to the diffusion of pollutants. Therefore, the probability of atmospheric pollution decreased with the increase of air temperature in summer (Li et al., 2015)

Further work

Data validation and interpretation with other sources of dataset



Land Use classification and urban change detection

To analyse urban expansion through time at the study area

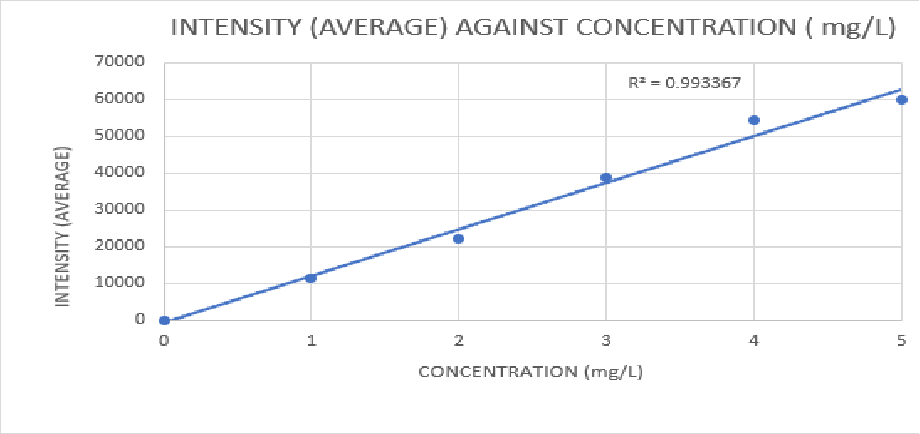
Chemical Characterization

Simultaneous particle sample we collected and chemical characterization has been conducted using Mini Volume Sampler and Heavy metal was determined are Mercury (Hg) Iron (Fe), Cadmium (Cd), Plumbum (Pb) using an Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES).

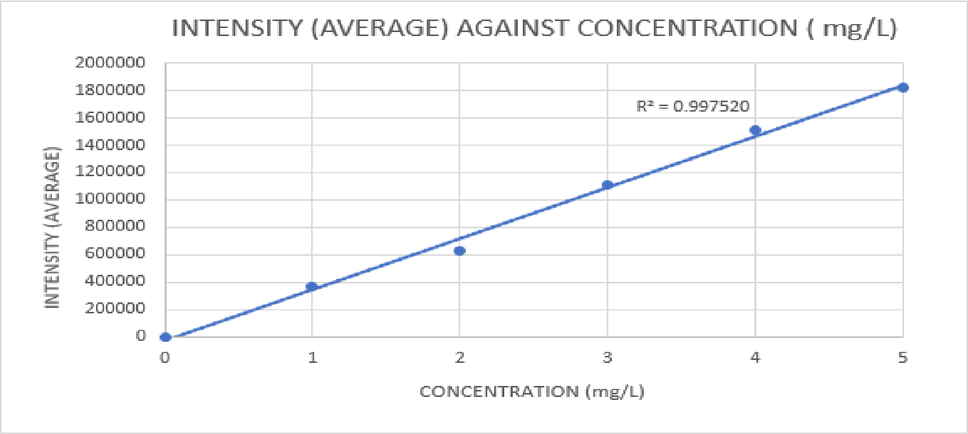
AiRBOX Sense

Ambient Air Quality Monitoring System with integrated sensors and software to measure the concentration of ambient pollution in urban environments such as PM2.5, PM10, CO, NOx, SOx, and O3.

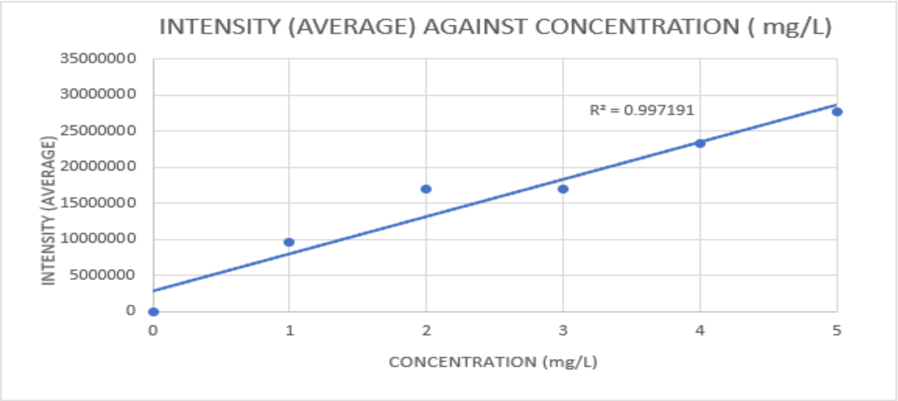
Heavy Metal	Locations	Average (mg/L)		Standard Deviation	
		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Hg	Seksyen 7	0.044	0.076	0.0008	0.0028
		0.070	0.054	0.0033	0.0022
		0.065	0.047	0.0030	0.0048
	Seksyen 2	0.071	0.061	0.0063	0.0027
		0.060	0.051	0.0031	0.0047
		0.061	0.042	0.0050	0.0023
Pb	Seksyen 7	0.068	0.069	0.0001	0.0002
		0.071	0.069	0.0002	0.0001
		0.075	0.068	0.0001	0.0001
	Seksyen 2	0.081	0.071	0.0001	0.0000
		0.067	0.072	0.0001	0.0002
		0.069	0.068	0.0001	0.0001
Fe	Seksyen 7	0.094	0.101	0.0003	0.0003
		0.105	0.095	0.0004	0.0003
		0.099	0.101	0.0012	0.0001
	Seksyen 2	0.106	0.102	0.0001	0.0003
		0.077	0.111	0.0001	0.0005
		0.179	0.095	0.0004	0.0000
Cd	Seksyen 7	-0.056	-0.053	0.0002	0.0000
		-0.051	-0.058	0.0000	0.0000
		-0.058	-0.059	0.0000	0.0000
	Seksyen 2	-0.058	-0.058	0.0000	0.0000
		-0.059	-0.056	0.0000	0.0036
		-0.059	-0.059	0.0000	0.0000



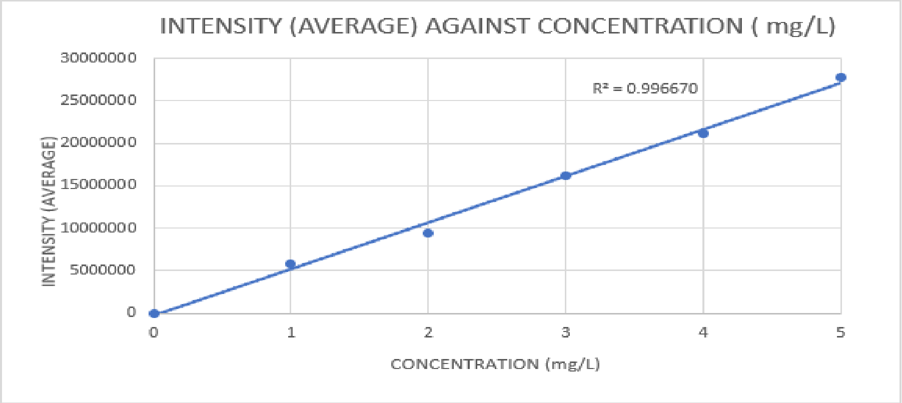
a) Mercury (Hg)



b) Plumbum (Pb)



c) Ferum (Fe)



d) Cadmium (Cd)

Analytical characteristics of ICP-OES method were studied using external standard method for calibration in the following concentrations range: 1.0, 2.0, 3.0, 4.0 and 5.0 ppm for Hg, Pb, Fe, and Cd shows high sensibility and linearity of the measurement in the concentration interval

LIMITATION OF STUDY

Weather conditions:

Adverse weather conditions such as strong winds, rain, or snow can affect the accuracy of sensor readings and also pose a risk to the UAV.

Line of sight:

UAVs require a clear line of sight to receive GPS signals and maintain stable flight, which can be impacted by tall buildings, trees, and other obstacles. Therefore, the SD card is compulsory

Maintenance:

Regular maintenance and calibration of sensors is required to ensure accurate readings and the longevity of the equipment.

Cost:

The cost of UAVs, sensors, and related equipment can be a barrier for some organizations.

Short flight time:

Limited battery life of UAVs can limit the duration of data acquisition. (Take 7 minutes to fly off and fly back to ground)

UAV design:

sensitive to payload weight

CONCLUSION

- The highest PM concentration is during the dry season within the area of Section 7 as residential areas, commercial areas and the development of the LRT3 station surround the area.
- Understanding atmospheric interactions could be enhanced as the particulate matter (PM2.5 and PM10), and meteorological factors can be analysed vertically.
- This study is also able to assist the authority and the decision makers to plan and implement the mitigation measures such as the guidelines, and environmental policy, and acts as the potential sources of pollutants emission could be determined vertically for high-rise buildings areas
- The system developed can be used for continual and long-term observation (Ding et al., 2005; Yang et al., 2005).

GRANT

GRANT PROVIDER	PROJECT TITLE	AMOUNT (RM)
GERAN INISIATIF PENYELIAAN (GIP) *(IN PROGRESS)*	THREE-DIMENSIONAL PARTICULATE MATTER VERTICAL CONCENTRATION DISTRIBUTION MODEL FOR URBAN ATMOSPHERIC BOUNDARY LAYER (ABL)	18,000
GERAN KHAS FRGS (UITM) *(IN PROGRESS)*	VERTICAL PROFILING OF PARTICULATE MATTER USING UAV SYSTEM	20,000

INTELLECTUAL PROPERTY

YEAR	IP TYPE	INVENTION INFORMATION	REFERENCE NO.
2022	COPYRIGHT	VERTICAL PROFILING OF PARTICULATE MATTERS ($PM_{2.5}$ AND PM_{10}), TEMPERATURE AND HUMIDITY AT URBAN ATMOSPHERIC BOUNDARY LAYER (UABL)	IP/CR/04669
2019	COPYRIGHT	$PM_{2.5}$ VERTICAL PROFILING USING INTEGRATED UAV	LCR201

Undergraduate and Postgraduate Students Under Air Quality Monitoring Research Group

The 16th IUAPPA Regional Conference 2023

The 6th IUAPPA Regional Conference is a joint conference between the Clean Air Forum Society of Malaysia (MyCAS) and the International Union of Air Pollution Protection and Environmental Associations (IUAPPA) to organize the 6th IUAPPA 2023 conference and the first IUAPPA regional conference in Southeast Asia

THANK YOU