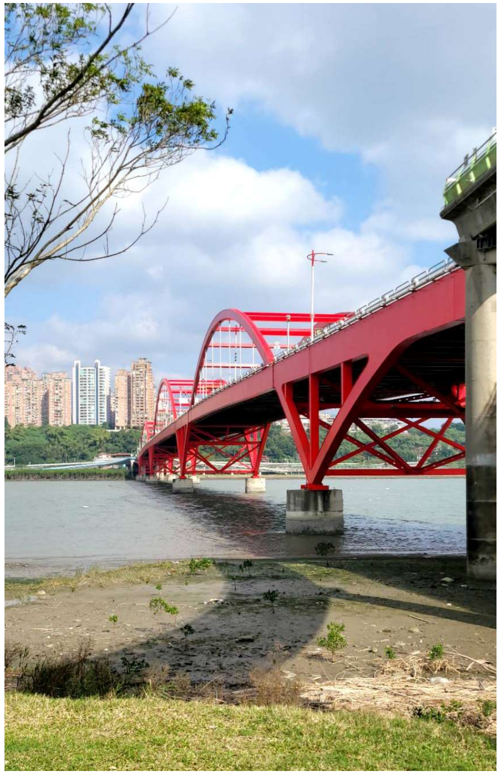
Using wind tunnel experiments to analyze the role of wetland vegetation in blocking air pollution

Yun-Ping Wu*, Jie-Yun Miao
FuDan High School, Taiwan
* yunping.julia@gmail.com



Research Motivation

Fig. 1 The mouth of Taipei's Tamsui River is the Guandu Plain. In the picture, you can see that the Guandu Plain has well-developed wetlands and vegetation. In the park with dense wetland vegetation, you can see a beautiful red bridge, which is the landmark of Taipei City: Guandu Bridge. The high mountain in the distance is Guanyin Mountain.

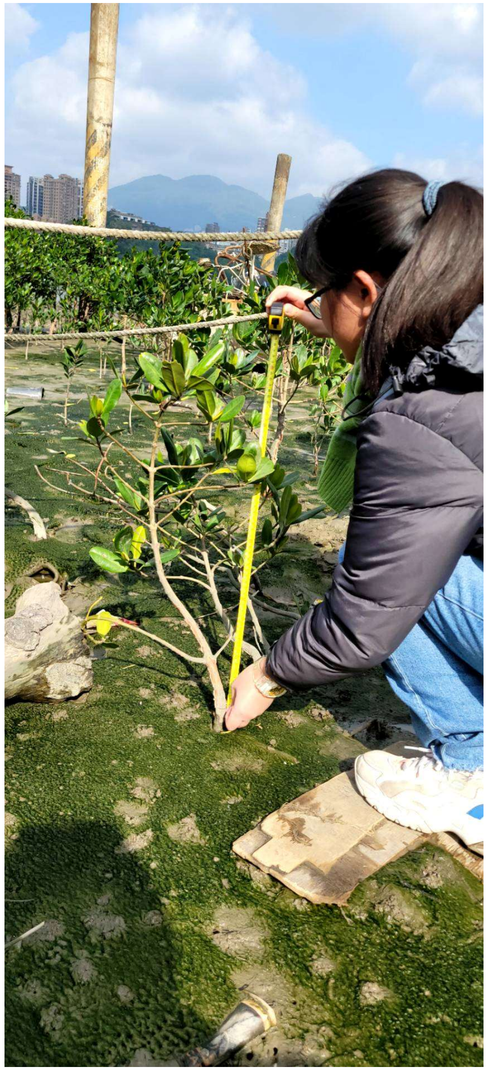
Research Motivation

Research Motivation

Fig. 4 The dense wetland vegetation in this image and the buildings in the background are the motivation for our project. We want to explore the effect of wetland vegetation on pollutant shielding and improve air quality.

Data Collection from and to GLOBE DATA

To study the impact of wetland vegetation on air pollution, we explored the GLOBE PROGRAM website for information on wetland ecology and air quality data. Since the school is far from the Guandu Wetland, we focused our research on the school area. Guided by our teacher, we used wind tunnel experiments to examine how vegetation placement affects airflow and air quality. The process involved a literature review, data collection, wind tunnel design, and analysis. We also hope to share our data and contribute to the GLOBE DATA database.



Main air quality monitoring instruments
(used in wind tunnel and field measurements)

PM2.5 air quality monitor: suspended particulate matter, air quality index, clean room monitoring, formaldehyc
(550-AQM+8) (Made in Taiwan, Precision Technology, Electrical Hardware Seat)

材質	ABS	顯示螢幕	2.8"LCD螢幕
尺寸	164*70*48(mm)	採樣時間	1.5秒
重量	179g	電源	5V DC USB充電
檢測項目	懸浮微粒(PM1.0/2.5/10) 甲醛(HCHO) 揮發性有機物(TVOC) 溫濕度(TEMP/HUM)	電量	2000 mAh
		工作溫度	-10°C~50°C

技術參數	
懸浮微粒 (PM1.0/2.5/10)	偵測技術:雷射散射傳感器 偵測範圍:0-999ug/m³
甲醛 (HCHO)	偵測技術:半導體傳感器 偵測範圍:0-1.999mg/m³
揮發性有機物 (TVOC)	偵測技術:半導體傳感器 偵測範圍: 0.000-9.999mg/m³
溫濕度 (TEMP/HUM)	偵測範圍:0-50 ° C/20%-85%RH 偵測精度: ±1 °C/±4%RH

【尺寸為單批測量，每批製造可能略有±3%誤差，請以實際收到商品為準。】

產品包裝

空氣品質監控儀*1、說明書*1、充電線*1

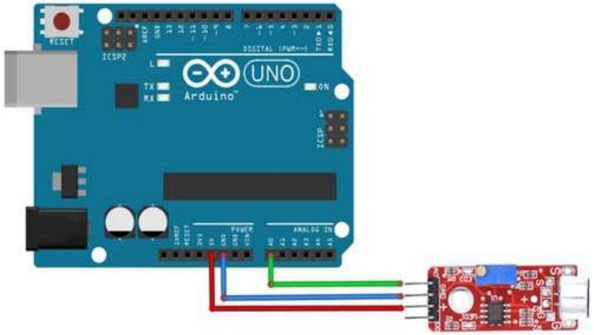
Air quality monitoring equipment

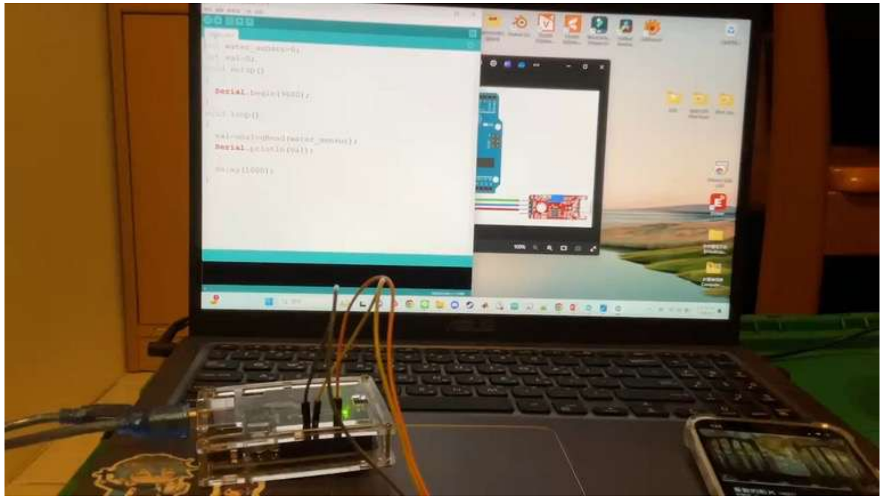
Anemometer

Sound Level meter

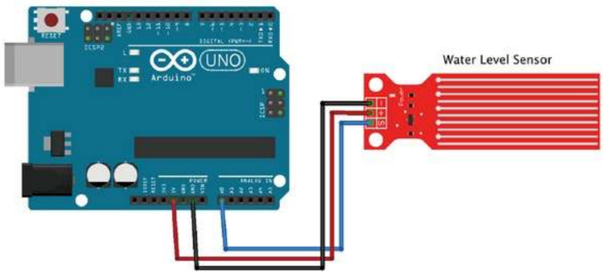
Thermo-hygrometer

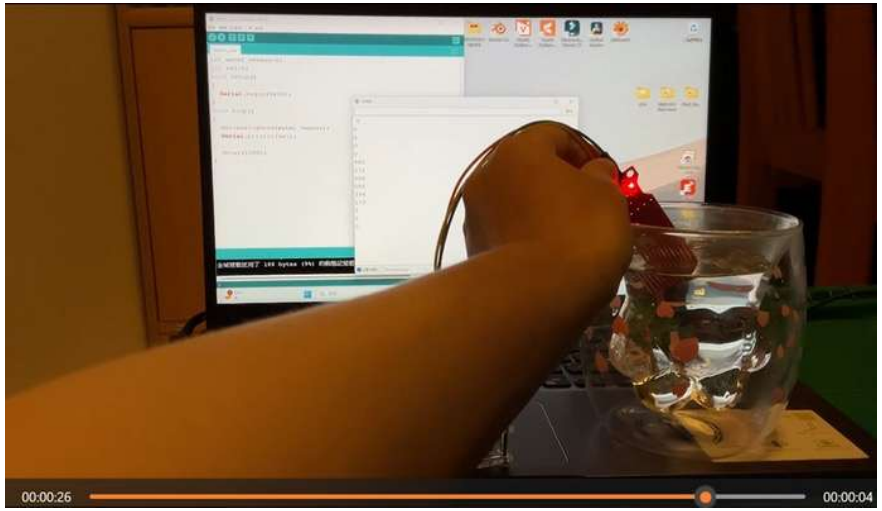
Sound Sensor





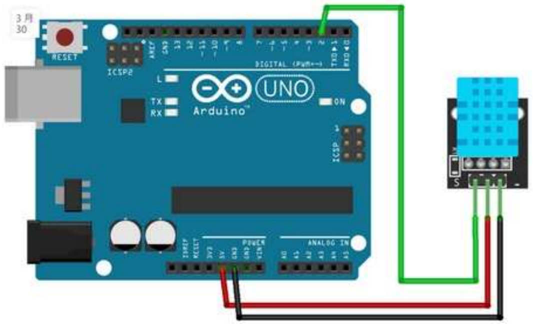
Water level meter

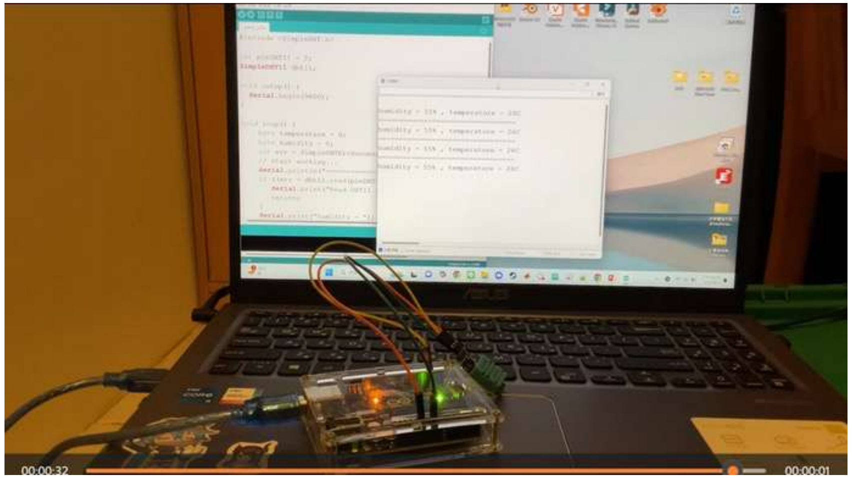




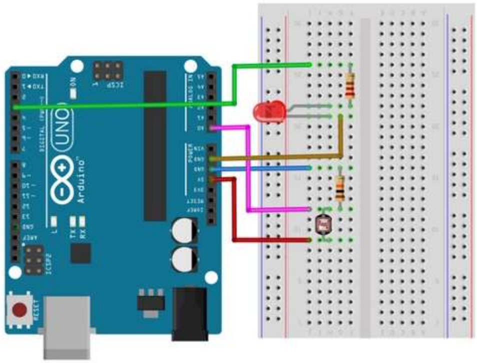
Building Arduino Monitoring Instrument: Sound Sensor and Water level meter.

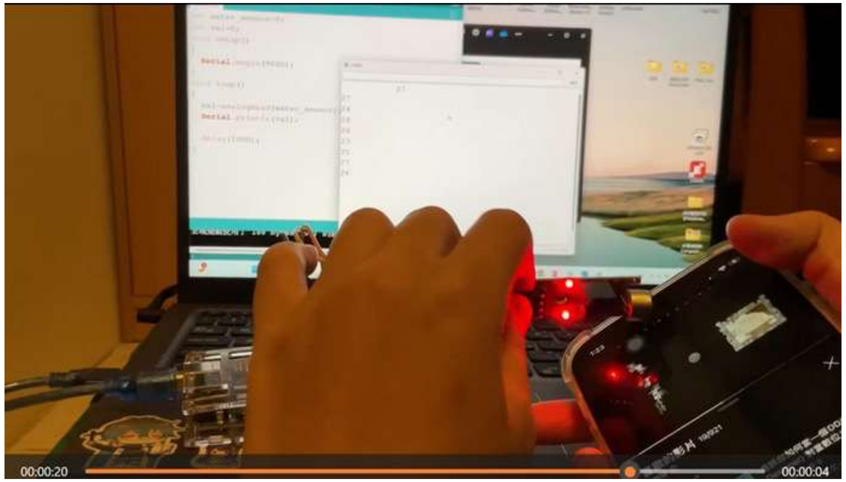
Temperature and humidity





Photoresistor





Building Arduino Monitoring Instrument: Temperature and humidity, and Photoresistor.

Daytime air quality monitoring around campus

Date：9/17 (二)

Time：13:00

Measurement data ：

- PM2.5：7 ug/m3
- PM1.0：4 ug/m3
- PM10：8 ug/m3
- HCHO（Formaldehyde）：0.027 mg/m3
- TVOC（Volatile organic）：0.154 mg/m3
- Wind Speed：1.58 m/s
- Temperature：35.6 °C
- Humidity ：46.4 %

Nighttime air quality monitoring around the campus

Date：9/17 (二)

Time：19:00

Measurement data ：

- PM2.5：11 ug/m3
- PM1.0：4 ug/m3
- PM10：8 ug/m3
- HCHO（Formaldehyde）：0.049 mg/m3
- TVOC（Volatile organic）：0.275 mg/m3
- Wind Speed：3.31 m/s
- Temperature：29.7 °C
- Humidity：63.2 %
- Decibel ：89 db

Measurement on campus (small wetland on campus)

Date：10/1 (Monday)

Time：17:00（Rush Hours）

Measurement：

- PM2.5：27 ug/m3
- PM1.0：15 ug/m3
- PM10：34 ug/m3
- HCHO（Formaldehyde）：0.040 mg/m3
- TVOC（Volatile organic）：0.222 mg/m3
- Temperature：26.6 °C
- Humidity：89.0 %

Measurement outside campus (at school gate)

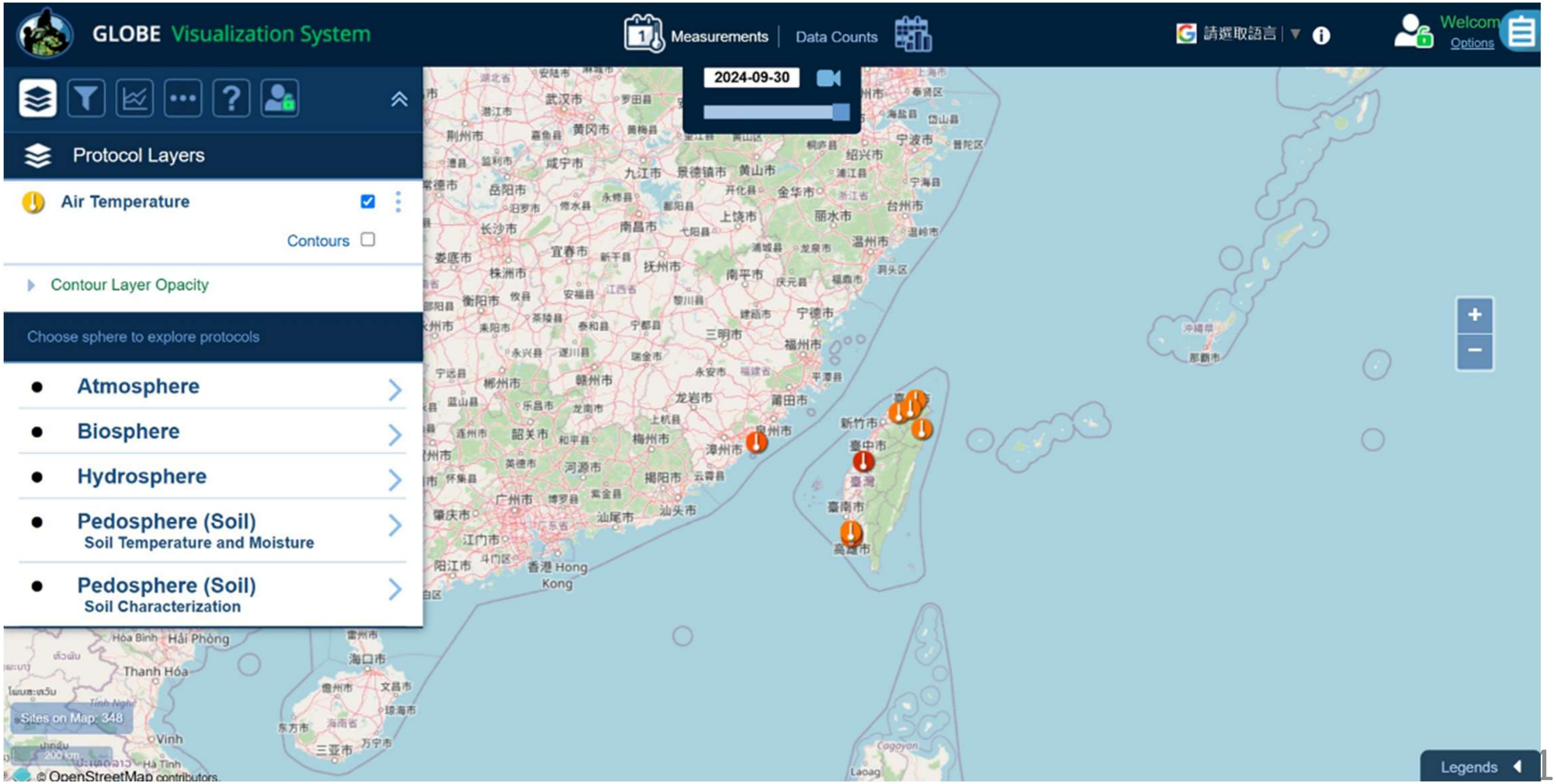
Date：10/1 (Monday)

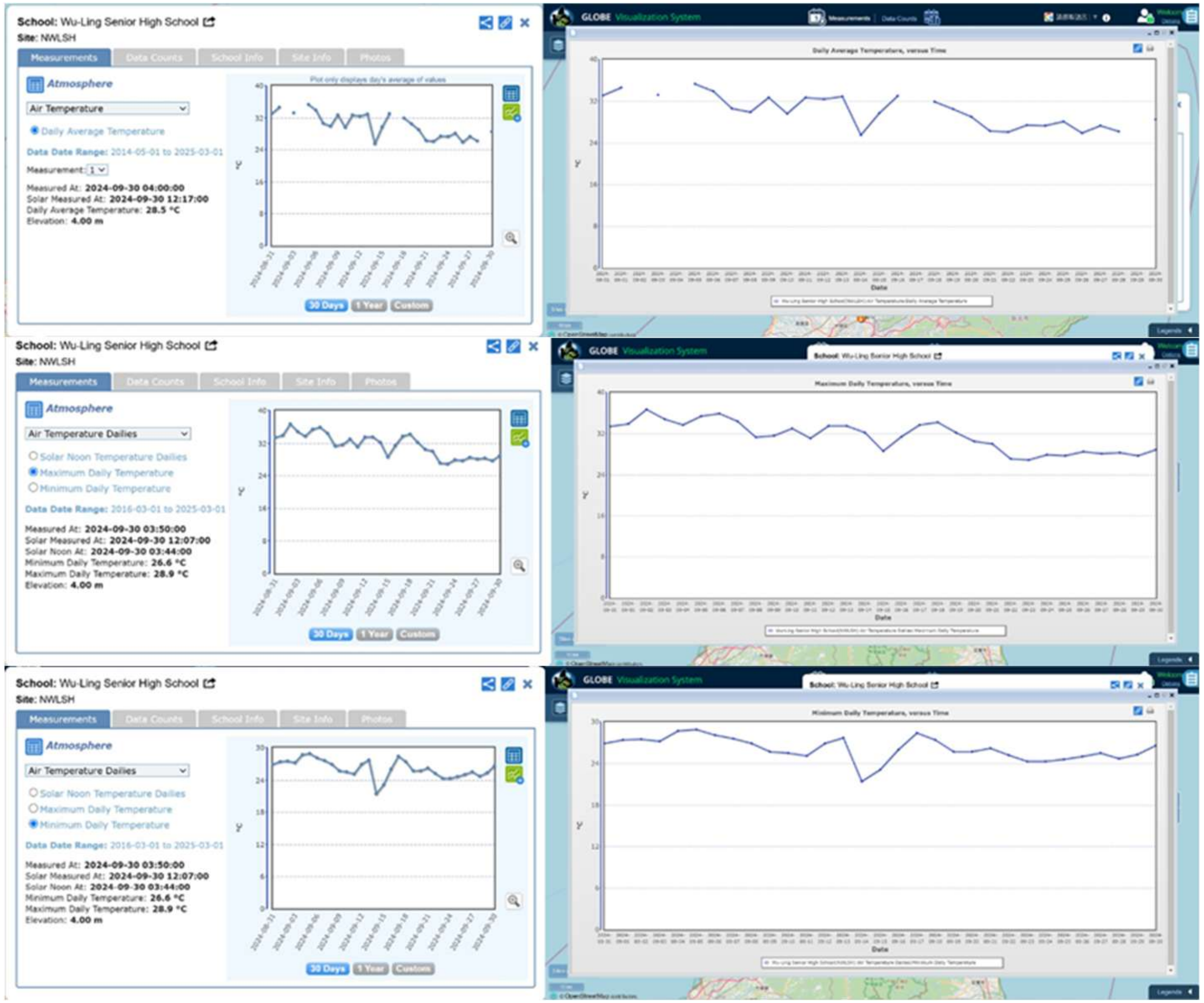
Time：17:00（Rush Hours）

Measurement：

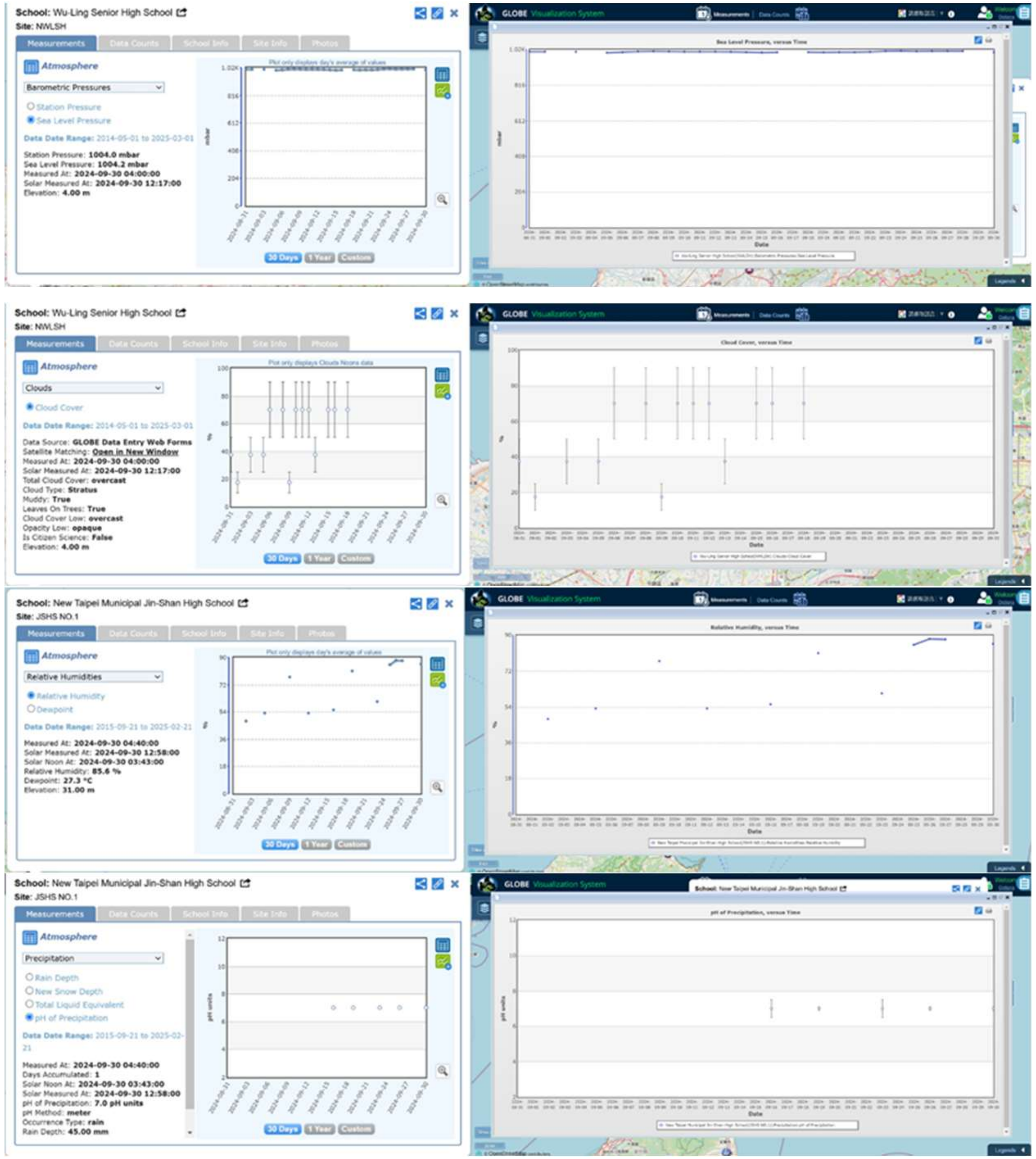
- PM2.5 ：33 ug/m3
- PM1.0 ：19 ug/m3
- PM10：42 ug/m3
- HCHO（Formaldehyde）： 0.024 mg/m3
- TVOC（Volatile organic） ：0.137 mg/m3
- Temperature：27.7 °C
- Temperature：90.0 %

Using GLOBAL DATA



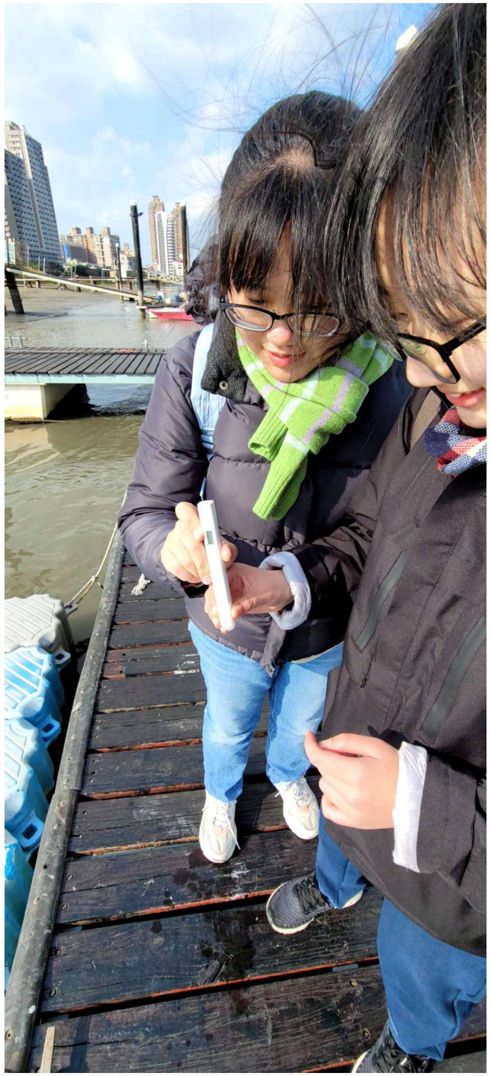


GLOBAL Up to down: Data. Site location; Daily averaged air temperature; Maximum daily averaged air temperature; Minimum daily averaged air temperature

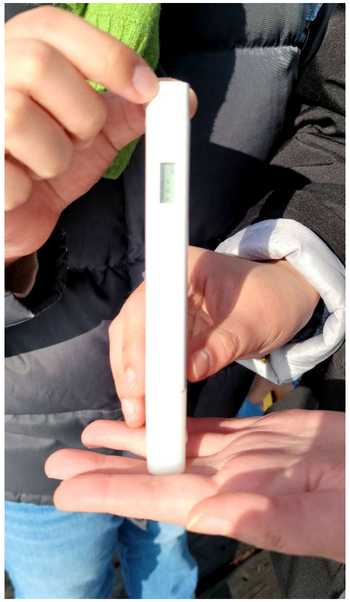

School: Wu-Ling Senior High School
Site: NWLSH
Measurements
Data Counts
School Info
Site Info
Photos
Atmosphere
Barometric Pressures
Station Pressure
Sea Level Pressure
Station Pressure: 1004.0 mbar
Sea Level Pressure: 1004.2 mbar
Measured At: 2024-09-30 04:00:00
Solar Measured At: 2024-09-30 12:17:00
Elevation: 4.00 m
30 Days
1 Year
Custom
GLOBE Visualization System
Clouds
Cloud Cover
Data Source: GLOBE Data Entry Web Forms
Satellite Matching: Open in New Window
Measured At: 2024-09-30 04:00:00
Solar Measured At: 2024-09-30 12:17:00
Total Cloud Cover: overcast
Cloud Type: Stratus
Muddy: True
Leaves On Trees: True
Cloud Cover Low: overcast
Opacity Low: opaque
Is Citizen Science: False
Elevation: 4.00 m
School: New Taipei Municipal Jin-Shan High School
Site: JSHS NO.1
Relative Humidities
Relative Humidity
Dewpoint
Measured At: 2024-09-30 04:40:00
Solar Measured At: 2024-09-30 12:58:00
Solar Noon At: 2024-09-30 03:43:00
Relative Humidity: 85.6 %
Dewpoint: 27.3 °C
Elevation: 31.00 m
Precipitation
Rain Depth
New Snow Depth
Total Liquid Equivalent
pH of Precipitation
Measured At: 2024-09-30 04:40:00
Days Accumulated: 1
Solar Noon At: 2024-09-30 03:43:00
Solar Measured At: 2024-09-30 12:58:00
pH of Precipitation: 7.0 pH units
pH Method: meter
Occurrence Type: rain
Rain Depth: 45.00 mm

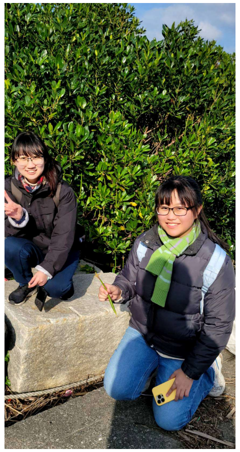
Environmental background data collection from GLOBE DATA and Government websites

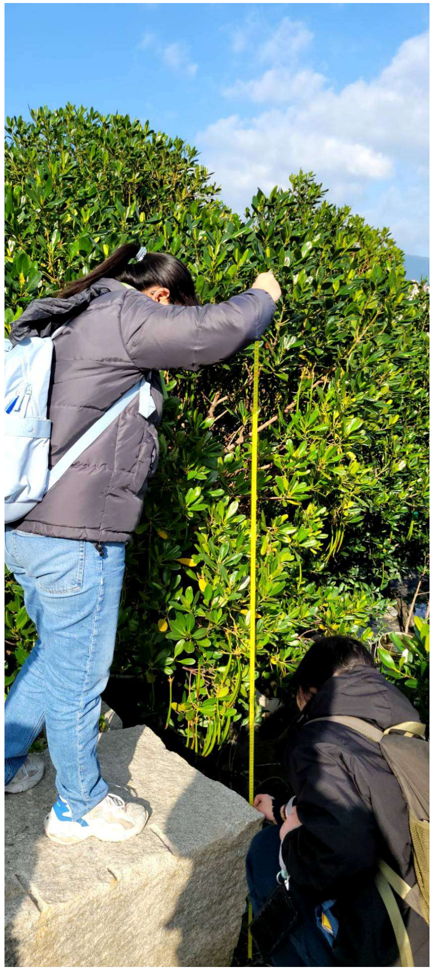
We collected environmental data around the school as background data, which will be revised to a wider area or larger spatial scale depending on the analysis situation. The relevant data include CO_2, CO, O_3, SO_2, NO_2, temperature, humidity, AQI value, PM10, PM2.5, wind speed, wind direction, rainfall, traffic volume and other monitoring data.



Data Collection from and to GLOBE DATA







Outline

This presentation is followed by:

- Research Background

- Observations from the Guandu Wetland near the Tamsui River estuary in northern Taiwan
- Investigating the relationship between wetland vegetation density and air pollution reduction, especially in relation to nearby buildings

- Research Methods

- Participating in the GLOBE Program, comparing air quality data from inside and outside the school campus
- Installing pollution monitoring instruments to collect air quality data

- Research Focus

- Exploring how wetland vegetation blocks air pollution
- Specifically studying the location and density of vegetation

- Wind Tunnel Experiments

- Designing wind tunnel experiments to identify the best placement of vegetation for improving air quality
- Conducting 40 experiments using a self-constructed acrylic wind tunnel
- Factors considered: pollutant emission times, vegetation location, and density

- Experimental Results

- Denser vegetation placed farther from pollution sources and closer to buildings significantly improved air quality
- Emphasizing the potential of wetlands to enhance urban environments

Literature

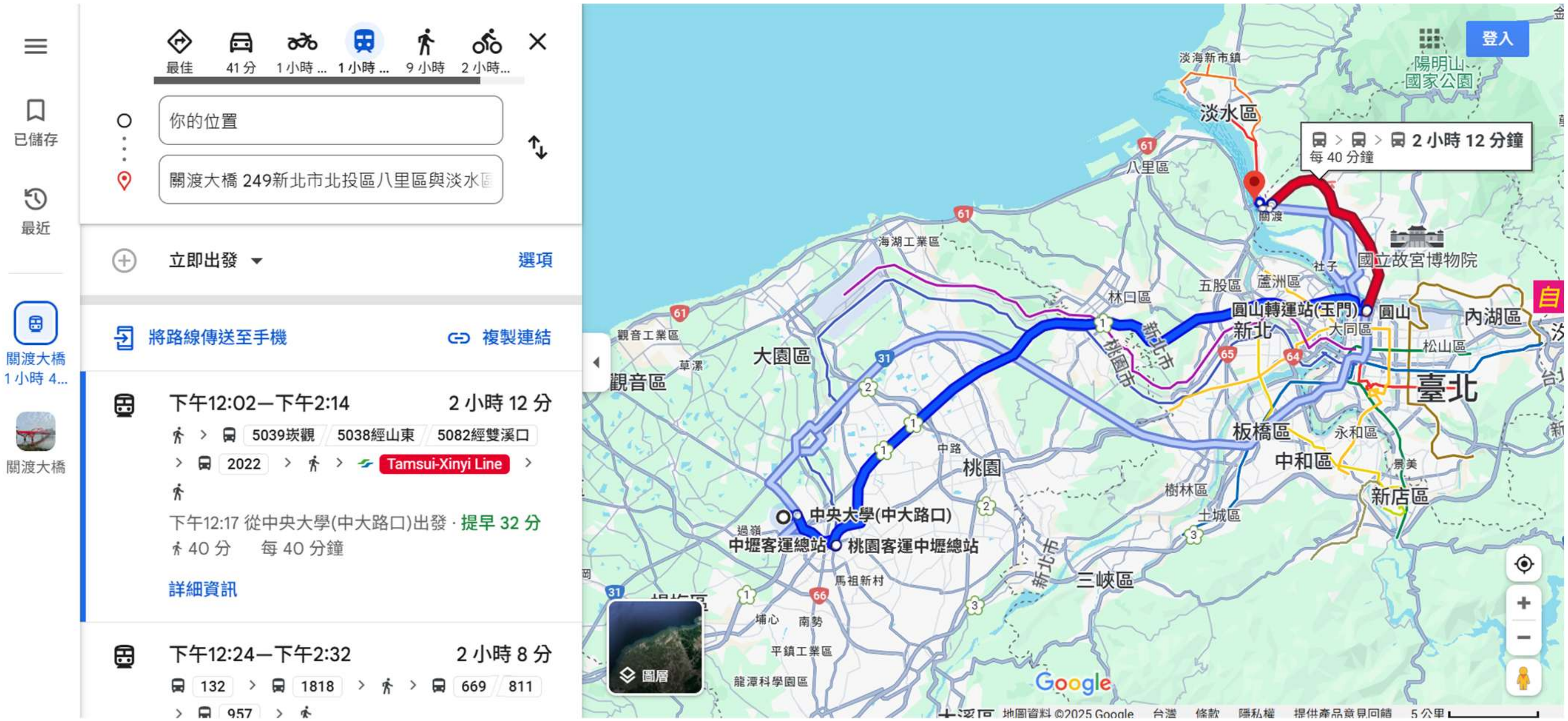
We read five SCI papers regarding the water quality and vegetation

1. Gromke, C., Buccolieri, R., Di Sabatino, S., & Ruck, B. (2008). Dispersion study in a street canyon with tree planting by means of wind tunnel and numerical investigations—evaluation of CFD data with experimental data. Atmospheric Environment, 42(36), 8640-8650. DOI: 10.1016/j.atmosenv.2008.08.019
2. JANHÄLL, S. (2015). REVIEW ON URBAN VEGETATION AND PARTICLE AIR POLLUTION—DEPOSITION AND DISPERSION. ATMOSPHERIC ENVIRONMENT, 105, 130-137. DOI: 10.1016/J.ATMOSENV.2015.01.052
3. KIMBROUGH, S., OWEN, R. C., SNYDER, M., & RICHMOND-BRYANT, J. (2017). NO TO NO2 CONVERSION RATE ANALYSIS, AND IMPLICATIONS FOR DISPERSION MODEL CHEMISTRY METHODS USING LAS VEGAS, NEVADA NEAR-ROAD FIELD MEASUREMENTS. ATMOSPHERIC ENVIRONMENT, 165, 23-34. DOI: 10.1016/J.ATMOSENV.2017.06.027
4. HAGLER, G. S. W., THOMA, E. D., & BALDAUF, R. W. (2010). HIGH-RESOLUTION MOBILE MONITORING OF CARBON MONOXIDE AND ULTRAFINE PARTICLE CONCENTRATIONS IN A NEAR-ROAD ENVIRONMENT. JOURNAL OF THE AIR & WASTE MANAGEMENT ASSOCIATION, 60(3), 328-336. DOI: 10.3155/1047-3289.60.3.328
5. KARNER, A. A., EISINGER, D. S., & NIEMEIER, D. A. (2010). NEAR-ROADWAY AIR QUALITY: SYNTHESIZING THE FINDINGS FROM REAL-WORLD DATA

Literature Review

The literature shows that planting wetland vegetation can beautify urban areas and significantly reduce air pollution, improving public health and quality of life. However, while it highlights the importance of wetland vegetation, it doesn't specifically address how tree planting locations affect air quality, indicating the need for further research.

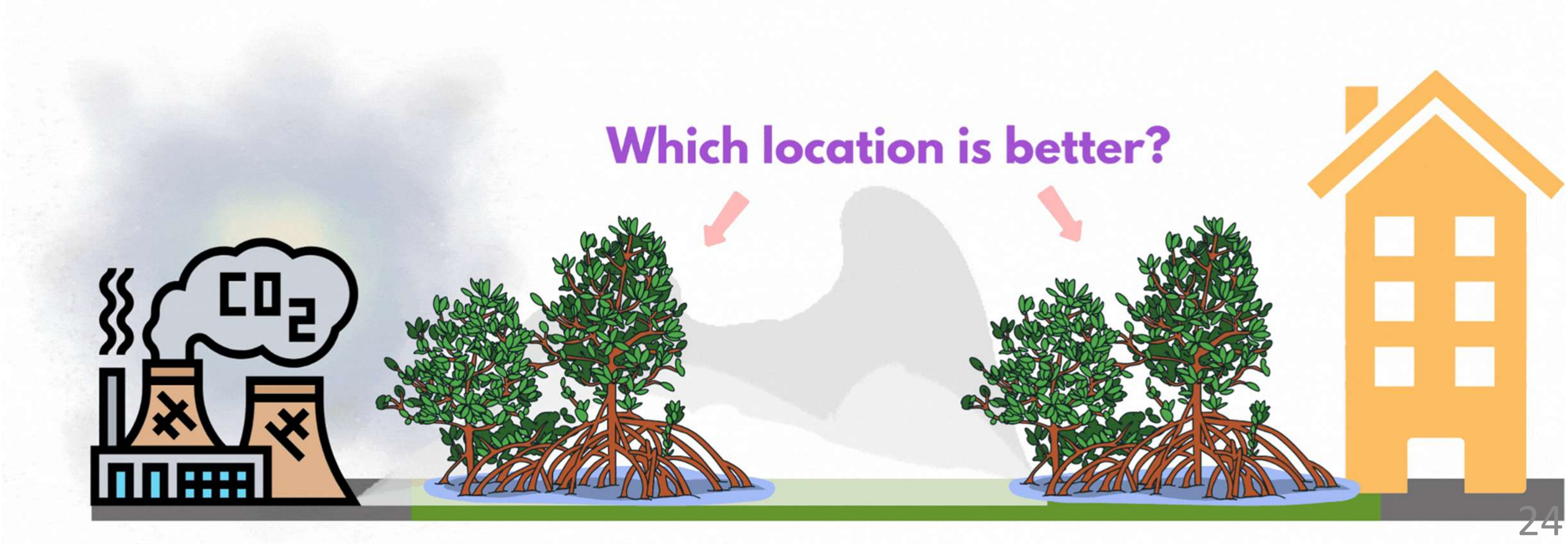
However, the travel time between Guandu Bridge and our school is over two hours, which is too long, so our teacher suggested that we conduct wind tunnel experiments in the lab and collect data from our school.



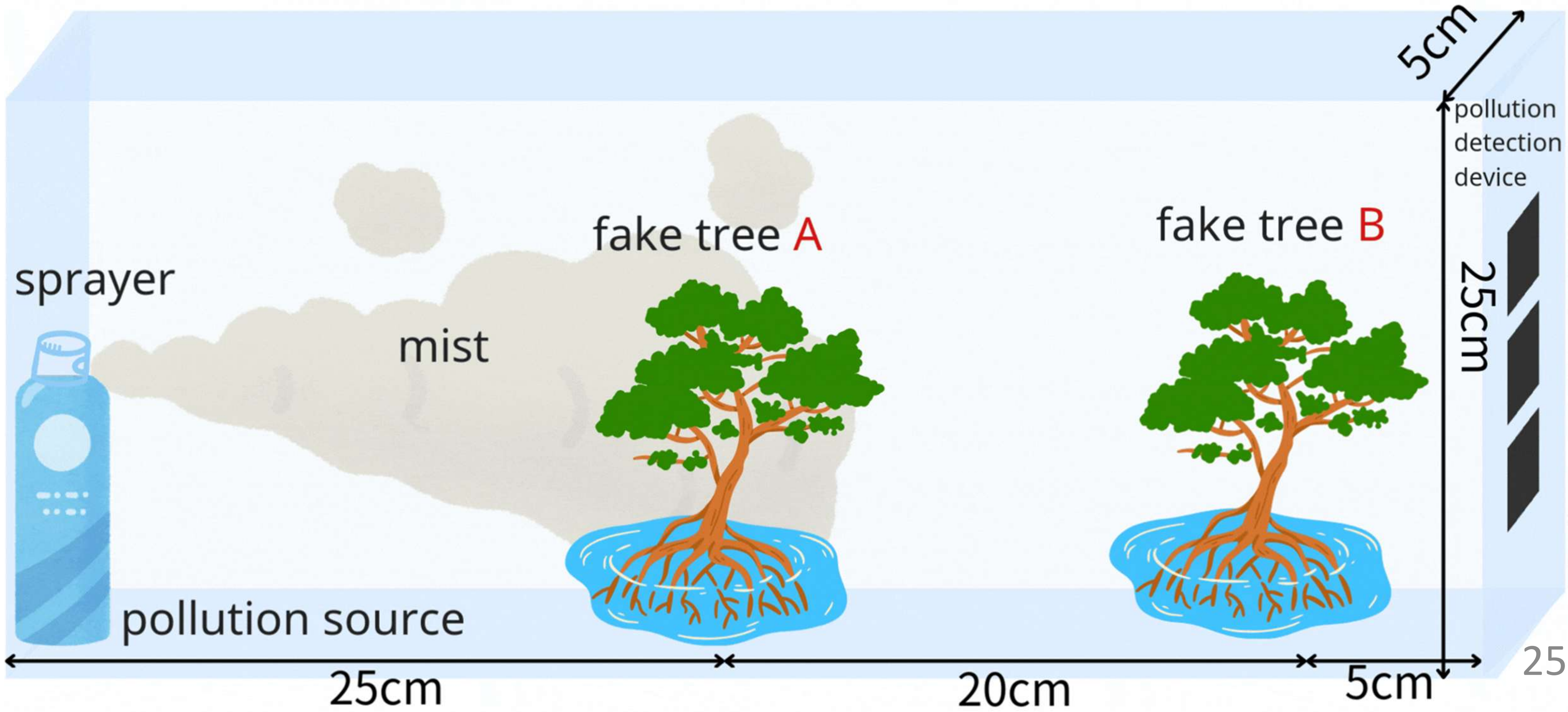
Wind tunnel experiment

Concept sketch

We want to know which is better for reducing air pollution and improving air quality? Planting wetland vegetation near pollution sources or near houses?



Wind Tunnel Experiment



Experimental equipment

PM2.5 Meter
Record pollution source concentration

sprayer
As a source of pollution

tape measure
Confirm the location of the artificial tree strips

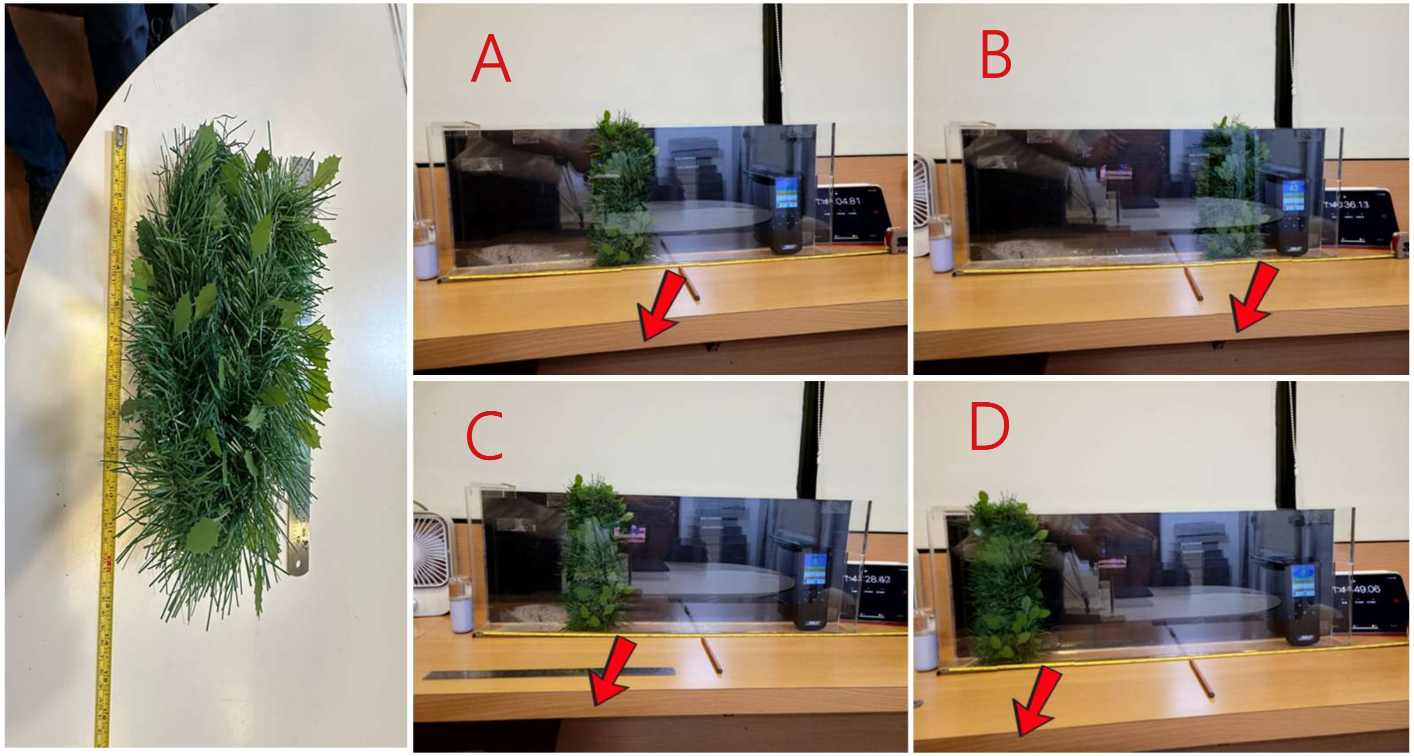
Fake tree strips
Simulate trees

Iron Ruler
Push and move fake tree strips

Experiment Setup

The experiment used a custom-built acrylic wind tunnel with a sprayer releasing water mist as a pollution source. Fake tree strips were placed at different positions to study their impact on air quality. A PM2.5 detector monitored pollutant concentration, and timing was controlled with stopwatches and recorded via mobile phone.

Wetland vegetation model establishment method



B: closest to buildings, D: closest to pollution sources

The wetland vegetation is created by folding strips of artificial trees.

1. Dense vegetation: 1.0 meter artificial tree strips folded in half to 0.25 meters.
2. Sparse vegetation: 0.5 meter strips of artificial trees folded into 0.25-meter strips.

The distance between the artificial tree strips and the pollution source:

- A：30 cm
- B：50 cm
- C：40 cm
- D：20 cm

Experiment Video

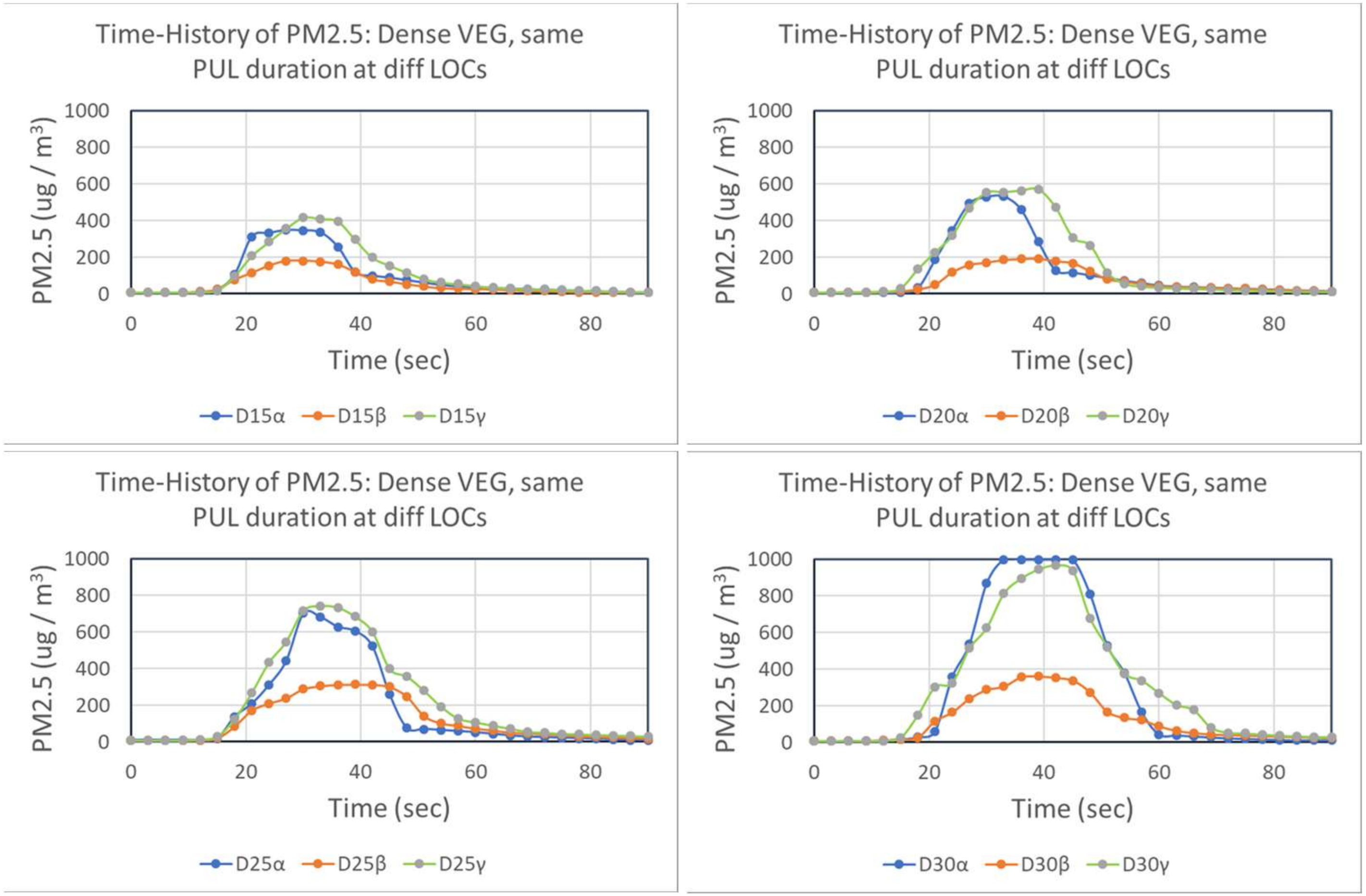
The sprayer on the left releases water mist as pollution, while the black device on the right detects pollutants. The black background helps us visualize the pollutants' advection.

Experimental Data (40 experiments)

	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
1	D15δ	X05χ	X10χ	S05α	S10α	S15α	S05β	S10β	S15β	S05γ	S10γ	S15γ	S05δ	S10δ	S15δ
2	9	8	9	9	9	9	9	9	8	8	9	9	8	10	9
3	8	8	10	9	9	8	9	8	8	8	8	8	8	9	10
4	8	57	67	10	8	8	9	8	8	8	9	8	9	9	9
5	8	641	683	31	16	10	21	32	22	12	14	27	15	38	12
6	15	999	999	85	104	118	386	265	314	116	316	267	47	194	155
7	195	999	999	182	518	632	505	754	716	346	811	713	160	578	841
8	585	999	999	205	761	999	533	999	999	441	999	999	229	999	999
9	937	999	999	212	999	999	548	999	999	462	999	999	237	999	999
10	999	999	999	220	999	999	554	999	999	522	999	999	242	999	999
11	999	477	999	203	999	999	350	966	999	430	999	999	239	999	999
12	999	124	999	127	895	999	128	680	999	278	999	999	172	999	999
13	999	35	492	72	650	999	91	322	999	227	647	999	109	847	999
14	878	30	165	64	352	999	80	148	999	138	518	999	99	607	999
15	643	25	19	55	150	999	72	103	542	83	303	999	89	358	999
16	295	22	17	45	103	830	59	96	317	67	167	650	76	300	690
17	188	19	14	39	90	507	46	73	142	57	104	302	60	237	425
18	98	16	12	34	79	78	35	58	106	44	85	132	46	110	277

Statistics

Time-history of PM 2.5. Dense vegetation. Four images represent different levels of pollution. Three lines represent different locations

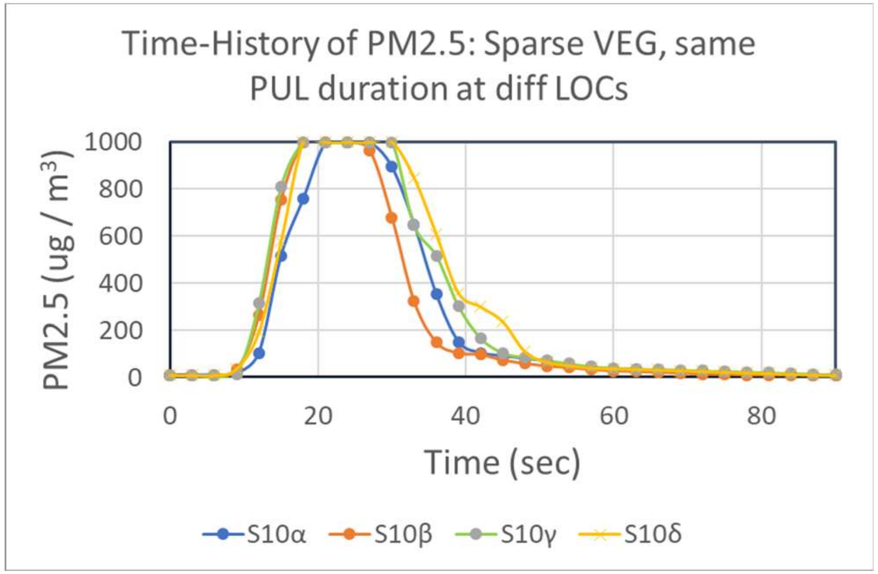


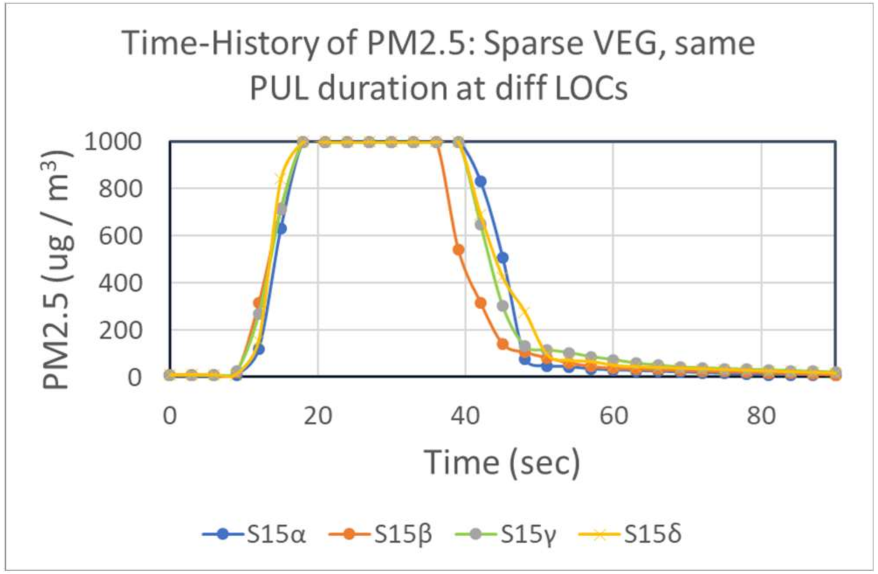
Based on the above data, under the same vegetation density, no matter whether the pollution emission time is 15, 20, 25, or 30 seconds, the pollution level is lighter at position B. Position A is 30 cm away from the pollution source, while position B is 50 cm. In other words, when the vegetation is far away from the pollution source and close to buildings, wetland vegetation has a significant effect on reducing the pollution level.

Statistics

Time-history of PM 2.5. Sparse vegetation. The two images represent different levels of pollution. Each line represents a different location.

From the two experimental data below, we can see that sparse wetland vegetation has limited ability to block air pollution, and the PM2.5 concentration rises rapidly and soon exceeds the limit of the instrument. However, it can still be seen from the rate of pollutant dissipation that planting wetland vegetation at position B has the best effect in reducing PM2.5 concentration, and it can be seen that the closer the vegetation is to the building, the better the effect of improving air quality.





Statistics

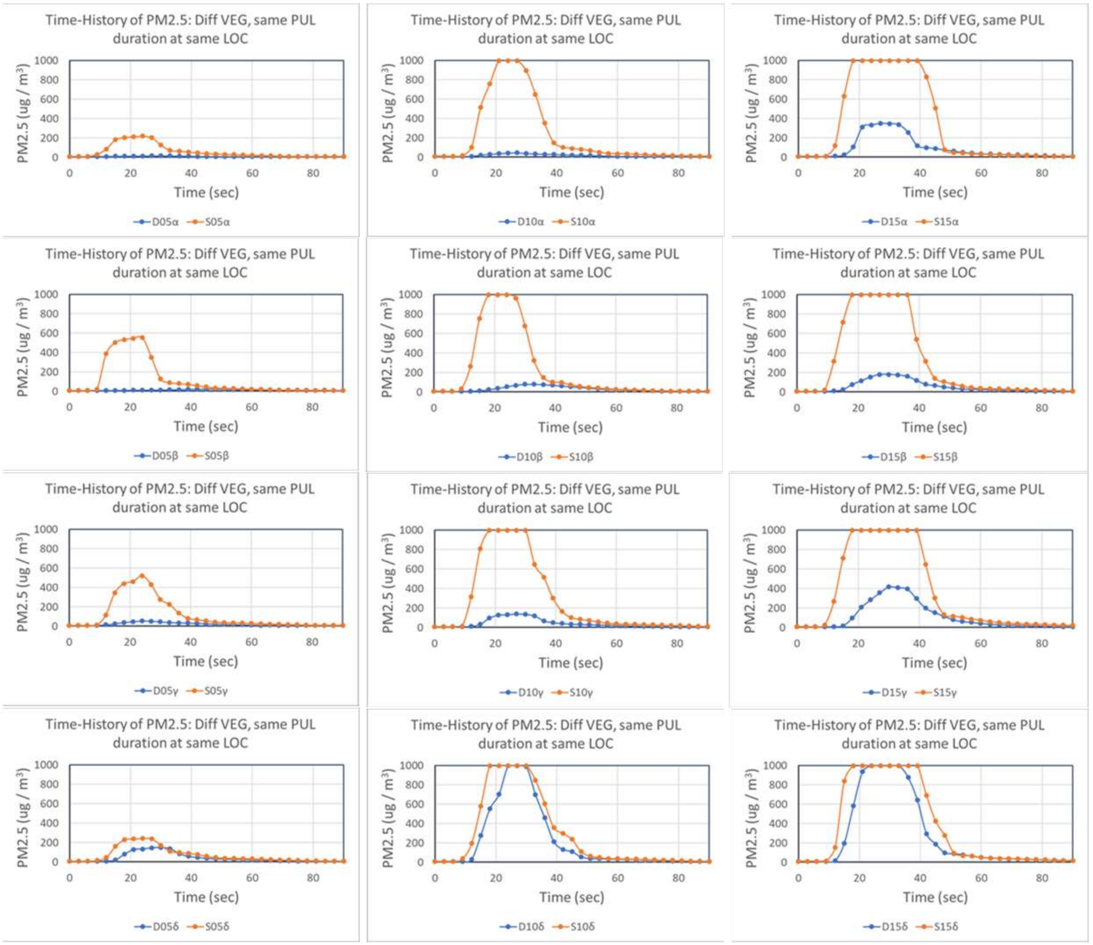
Time-history of PM 2.5. Dense (blue line) vs. sparse (orange line). A, B, C, and D represent different locations. Three sets of lines represent different pollution levels

A

B

C

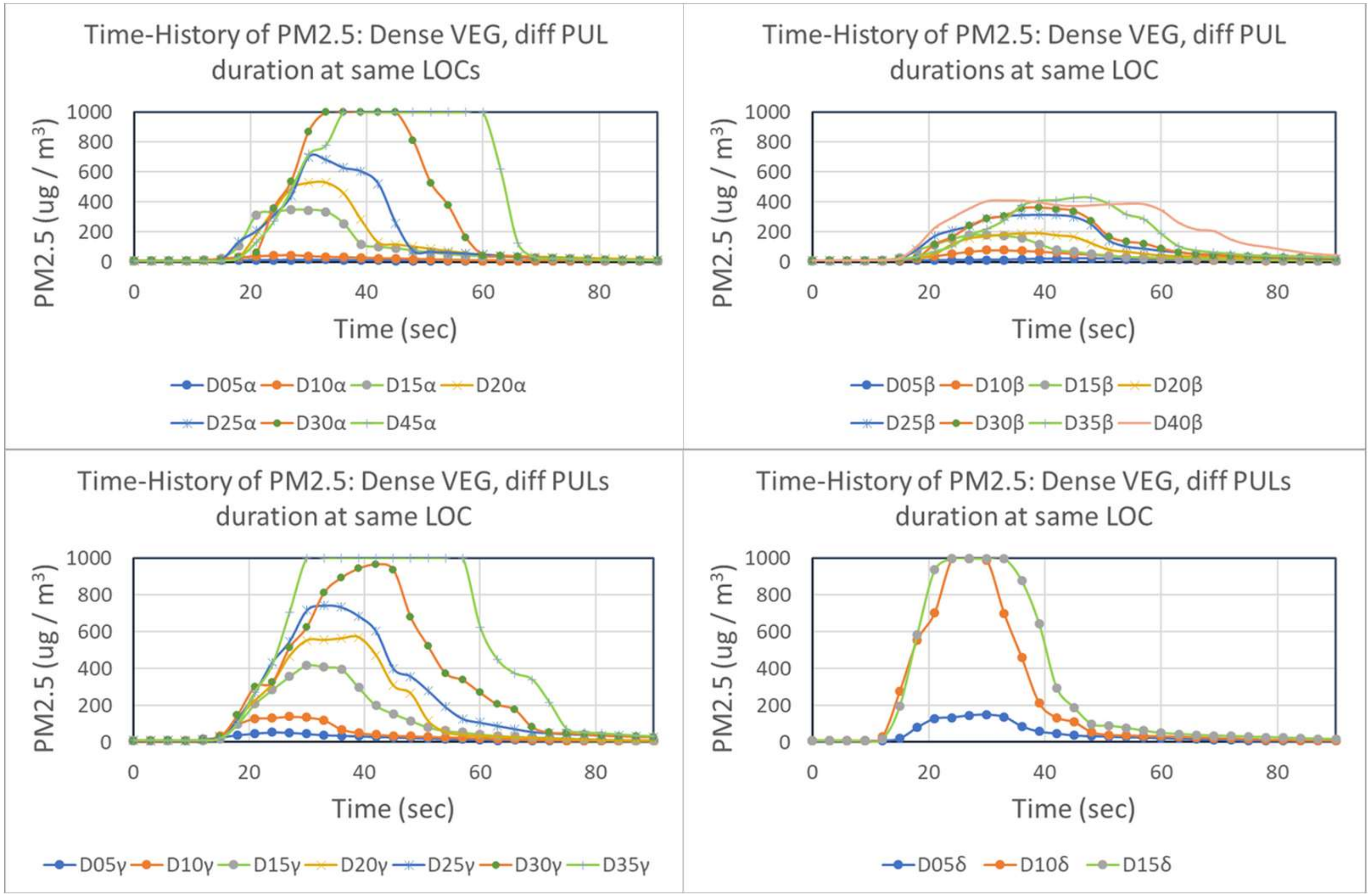
D



This set of data compares the effect of different densities of wetland vegetation planted at locations A, B, C, and D on improving air quality. It is obvious from the data that dense vegetation is more effective in blocking pollution than sparse vegetation.

Statistics

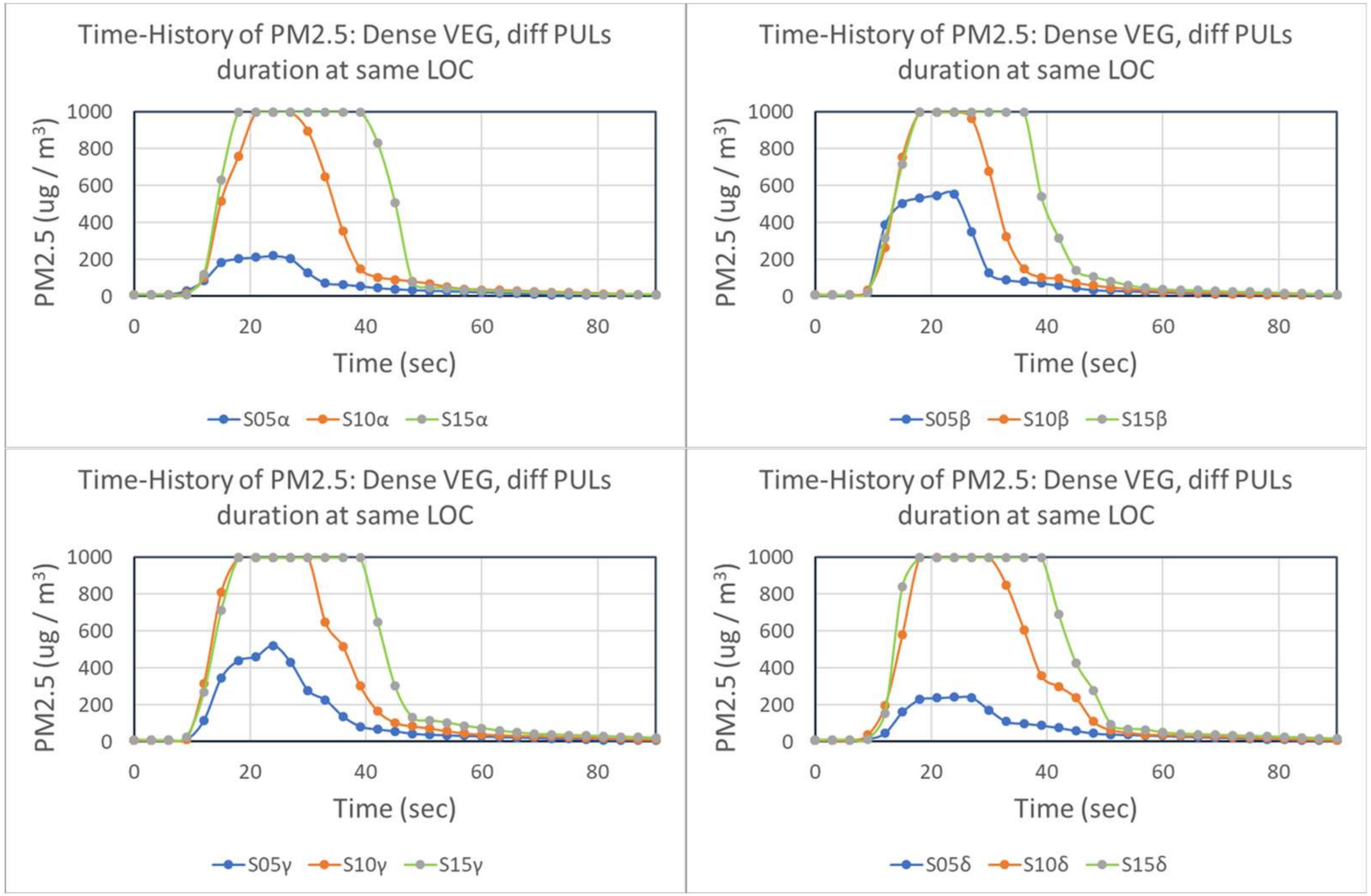
Time-history of PM 2.5. Dense vegetation. The four images represent different locations. Each line represents a different level of pollution.



This data is a time series history chart of PM2.5 concentration of dense vegetation wetland vegetation at positions A, B, C, and D for different pollutant emission times. It can be clearly seen that wetland vegetation at position B, which is the position closest to the building, has the best effect in improving air quality. That is, the PM2.5 concentration at position B is the smallest among all pollutant emission times. From the figure, it can be seen that the pollutant concentration is approximately proportional to the emission time. In addition, this experiment belongs to a two-dimensional diffusion experiment.

Conclusion

Time-history of PM 2.5. Dense vegetation. Four images represent different locations. Three lines represent different levels of pollution.

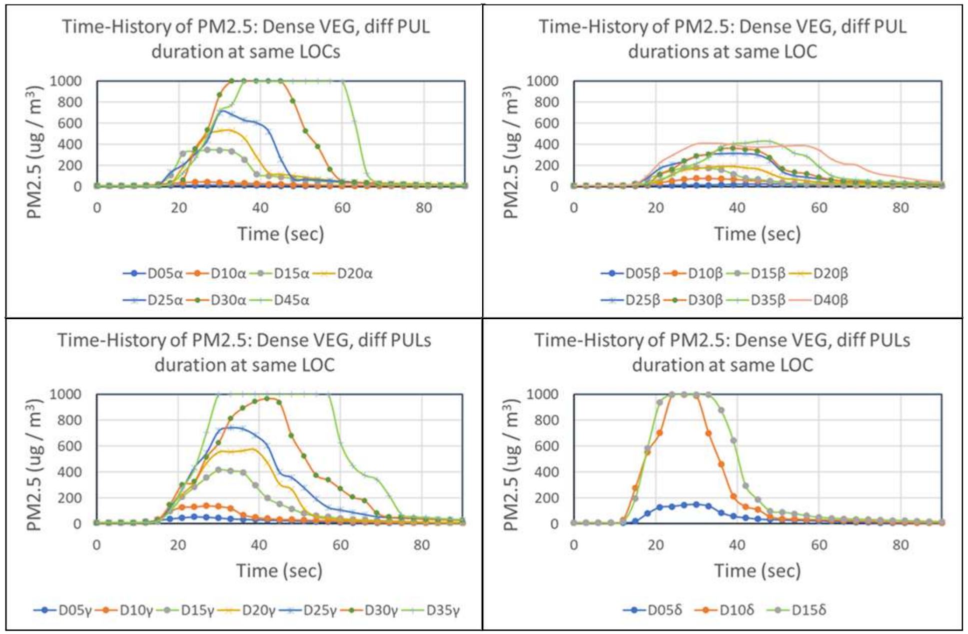


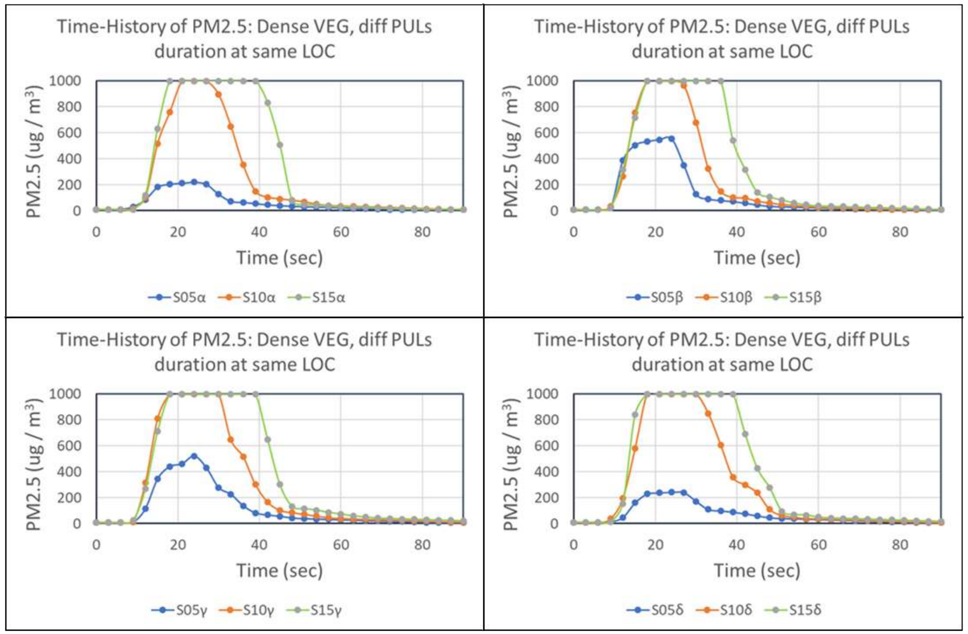
This set of data is a time series of PM2.5 concentrations at different pollutant emission times for sparsely vegetated wetland vegetation at locations A, B, C, and D. It can be seen that under the conditions of sparsely vegetated wetland vegetation, pollutants will increase rapidly. However, the rate of decrease in pollutant concentration is the fastest at location B.

Conclusion and implementation points

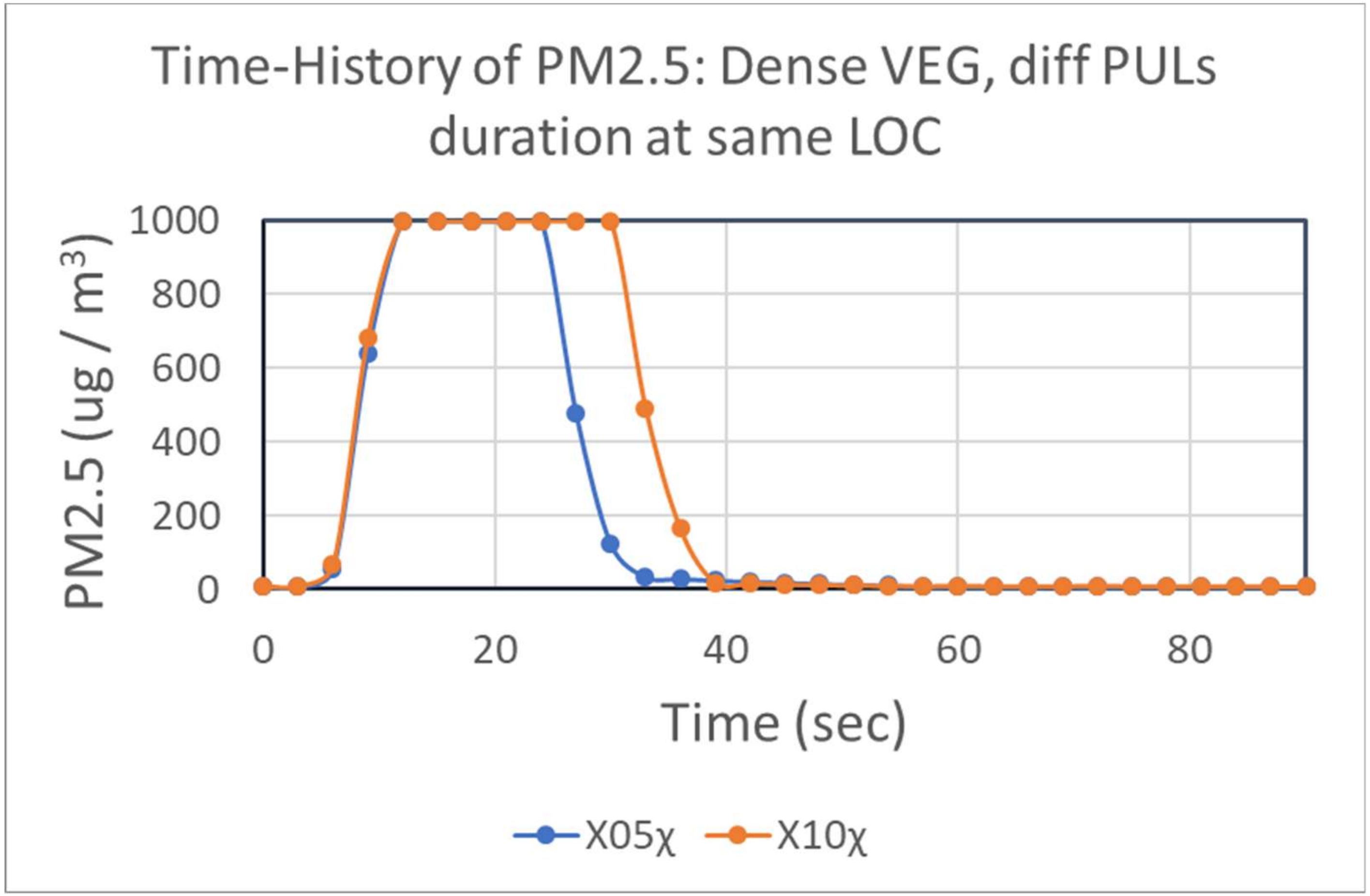
In summary, to maximize the effectiveness of wetland vegetation, the following points should be considered:

1. Choose mangroves with dense leaves and plant shrubs underneath them.
2. Position wetland vegetation close to buildings and away from pollutants.
3. If pollution is too severe or prolonged, wetland vegetation’ s effectiveness will be reduced.





Conclusion and implementation points



If dense wetland vegetation cannot be planted, at least plant general wetland vegetation. As shown in the figure, without any wetland vegetation, the pollution source quickly leads to a PM2.5 concentration that exceeds the instrument's range.

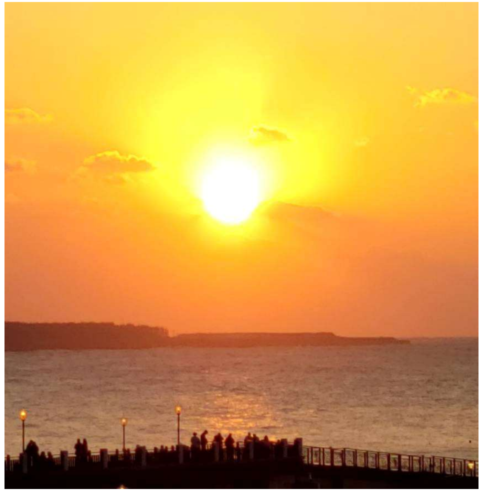
Conclusion and Recommendations

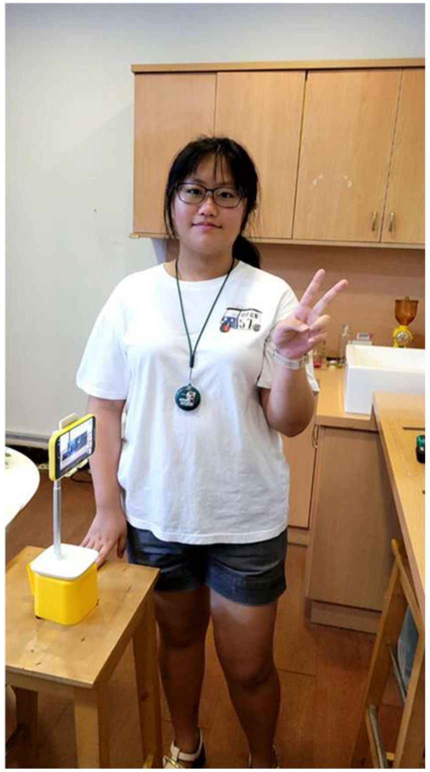
Conclusion and Recommendations

- In this project, we reviewed GLOBE PROGRAM articles and 5 SCI papers on air quality, and set up monitoring equipment for PM2.5, PM1.0, PM10, HCHO, TVOC, and other indicators.
- We collected pollutant data around the school and from the past three years via GLOBE, as well as measuring pollutant concentrations on campus for comparative analysis.
- For experiments, we used a small acrylic wind tunnel and conducted 40 trials with sprayers, fake tree strips, and pollutant monitors. The results showed consistency and repeatability, ensuring the reliability of our findings.

Conclusion and Recommendations

The study found that denser wetland vegetation, placed farther from pollution sources and closer to residential buildings, significantly improves pollutant concentration. Based on these findings, we recommend that the government prioritize dense tree species and low shrubs when planning sidewalks and wetland vegetation, with vegetation placed near residential areas for optimal air quality improvement.





Thanks for listening

Yun-Ping Wu*, Jie-Yun Miao
FuDan High School,
Taiwan