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

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Abstract

` Inspired by observations at the Guandu Wetland near the estuary of the Tamsui River in northern Taiwan, this study investigates the relationship between wetland vegetation density and its effectiveness in mitigating air pollution, particularly in relation to the location of nearby buildings. By participating in the GLOBE Program, we compared air quality data from within and outside the school campus with GLOBE data. We also contributed to the program by installing pollution monitoring instruments.

Focusing on the blocking effects of wetland vegetation on air pollution, we specifically explored the location and density of dense vegetation. To gather data, we designed wind tunnel experiments to identify the optimal placement of wetland vegetation for improving air quality. Using a self-constructed acrylic wind tunnel, we conducted 40 experiments, considering factors such as pollutant emission times, vegetation location, and vegetation density.

The experimental results demonstrated consistency and reproducibility, ensuring the reliability of the findings. The analysis revealed that denser wetland vegetation, placed farther from pollution sources and closer to residential buildings, significantly improved air quality, highlighting the potential of wetlands to enhance urban environmental conditions.

Introduction

The outlet of the Taipei Basin in Taiwan is the Guandu Plain, where the beautiful Tamsui River meanders through. On it stands a beautiful red arch bridge called the Guandu Bridge. Fig. 1 When we passed the Guandu Bridge, we not only admired the beauty of the bridge, but also the lush wetland ecosystem under the bridge. (Fig. 1) (Fig. 2) (Fig. 3)

In addition, we also saw that many beautiful buildings often have huge wetlands and green belts in front of them (Fig. 4). At this time, an interesting question comes to mind: Can wetland vegetation reduce air pollution? If so, how to reduce it? Should it be related to the density of wetland vegetation? Is the building close to wetland vegetation for the best air quality? Or should it be a little further away? How do wetlands block or capture pollutants in the air?

In order to find the answer, our teacher suggested that we go to the GLOBE DATA database to find the answer. We found a lot of information on the GLOBE PROGRAM website, including photos and data shared by schools from all over the world, which made us more interested in wetland ecology.

In order to understand the impact of the location and density of wetland vegetation on the barrier of air pollutants, we proposed this project with the help and advice of teachers. We hope to conduct a systematic analysis through the collection of GLOBE DATA data, reading of literature, measurement of air pollution data around the school, and self-designed wind tunnel experiments. We hope that the results of this project can help us answer the above questions and provide useful suggestions for future wetland planning and urban planning.

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.

Fig. 2 Guandu Wetland has dense vegetation and rich ecosystems.

Fig. 3 From Yangmingshan in Taipei, you can overlook the entire Guandu Plain and Guandu Wetland.

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.

Methodology

In order to understand the location and density of wetland vegetation for the air pollution barrier effect, we first went to the GLOBE PROGRAM website to find information. We found that we can get a lot of information about wetland ecology and function from the GLOBE PROGRAM website. In addition, we also found the shared data of GLOBE Protocols, which includes professional data provided by NASA and data shared by students from all over the world. In addition, we also collected data provided by the government to understand the air quality around Guandu Wetland and the school.

Since the school is quite far from Guandu Wetland, we do not have enough time and space to measure there for a long time. Therefore, under the teacher's suggestion, we will conduct pollutant-related research around the school. We also plan to use wind tunnel experiments to understand the impact of plant planting locations on the flow of ambient air and the improvement of air quality. Among them, the key point is whether wetland vegetation should be arranged close to the pollution source or close to the residential area to achieve the most efficient improvement of air quality.

The process we implemented includes a literature review, environmental background data collection, campus air quality monitoring, wind tunnel experiment design and construction, wind tunnel experiment data collection and analysis, results and discussion, and presentation writing. The following is a detailed description of each implementation process:

Literature Review

We collected relevant academic journal articles from the past to understand the analysis methods and key results of each journal article, and the current research progress of the academic community on this issue. Simultaneously, we collected literature and relevant air quality textbooks to understand the current research progress of the academic community on this issue and help us establish a comprehensive viewpoint for our experiments.

As air pollution in urban environments has received increasing attention, pollution caused by traffic emissions has attracted particular attention. Recent studies have shown a close relationship between the planting of street trees and the diffusion and deposition of pollutants. Gromke et al. (2008) used wind tunnel experiments and numerical simulations to explore how the configuration of trees in the street affects the diffusion of pollutants. They found that properly configured trees can effectively reduce the concentration of pollutants, thereby improving the air quality in pedestrian areas. This shows the importance of trees' geometric configuration and density for air circulation.

Janhäll (2015) conducted a comprehensive analysis of urban vegetation and particulate pollution, pointing out that vegetation can not only settle particulate matter but also capture particles suspended in the air through its leaves, thereby improving air quality. In places with high traffic volume, planting street trees can effectively reduce particulate matter in the air.

Kimbrough et al. (2017) analyzed the transformation process of nitrogen oxides (NOx) in the air and explored the impact of this process on the pollutant diffusion model. The study pointed out that in places close to roads, the configuration of trees will affect the conversion rate of NO to NO2, further affecting the concentration of pollutants in the air. This reminds urban planners that when choosing the location for tree planting, they must consider the impact of traffic emissions on air quality.

Hagler et al. (2010) used mobile monitoring technology to study the concentration of carbon monoxide and ultrafine particulate matter near roads and found that the concentration of pollutants increased significantly during heavy traffic, but this situation was improved under the protection of trees. The presence of trees reduced the concentration of these harmful substances to a certain extent, especially when the traffic volume was heavy.

Karner et al. (2010) emphasized that urban planning and design should fully consider the relationship between traffic emissions and the location of roadside trees. They suggested that introducing appropriate vegetation configuration in urban design can effectively improve the air quality near roads and reduce the impact of traffic emissions on health.

Environmental background data collection

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. (Fig. 5) (Fig. 6) (Fig. 7) (Fig. 8)

Air quality monitoring equipment
(for campus measurement)

Anemometer | **Decibel meter** | **Thermo-hygrometer**

Fig. 5 Air quality monitoring equipment (for campus measurement)

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

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

Fig. 6 Main air quality monitoring instruments (used in wind tunnel and campus measurements)

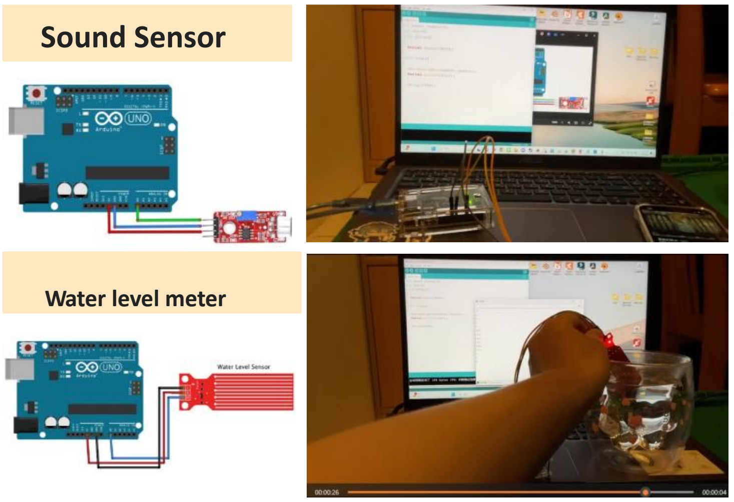


Fig. 7 Building Arduino Monitoring Instrument: Sound Sensor and Water level meter.

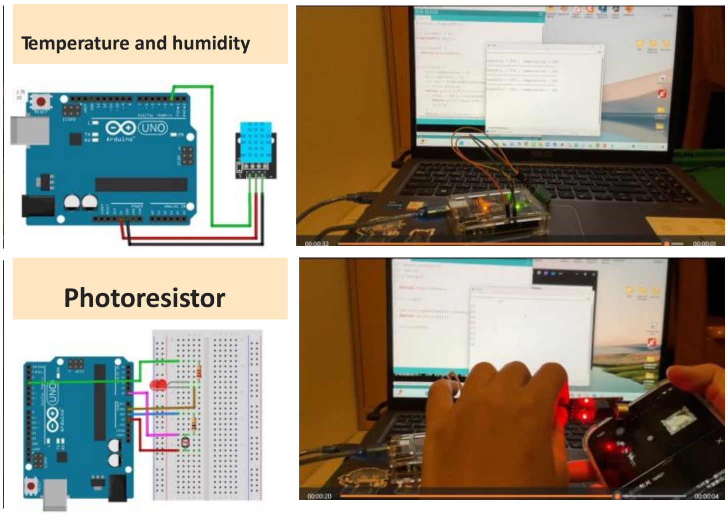


Fig. 8 Building Arduino Monitoring Instrument: Temperature and humidity, and Photoresistor.

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

Fig. 9 Daytime and nighttime air quality monitoring around campus.

Monitoring of campus environmental pollutant concentrations

Using the Arduino system, we made our own air pollution monitoring equipment (sensing components such as CO2, temperature, humidity, PM2.5, and cup anemometers), and chose the campus as the research detection site. We installed several sets of equipment at two locations, one near the road and one near the classroom, to detect, record, and collect data. (Fig. 9)

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 %

Fig. 10 Measurement on campus (small wetland on campus)

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 %

Fig. 11 Measurement outside campus (at school gate)

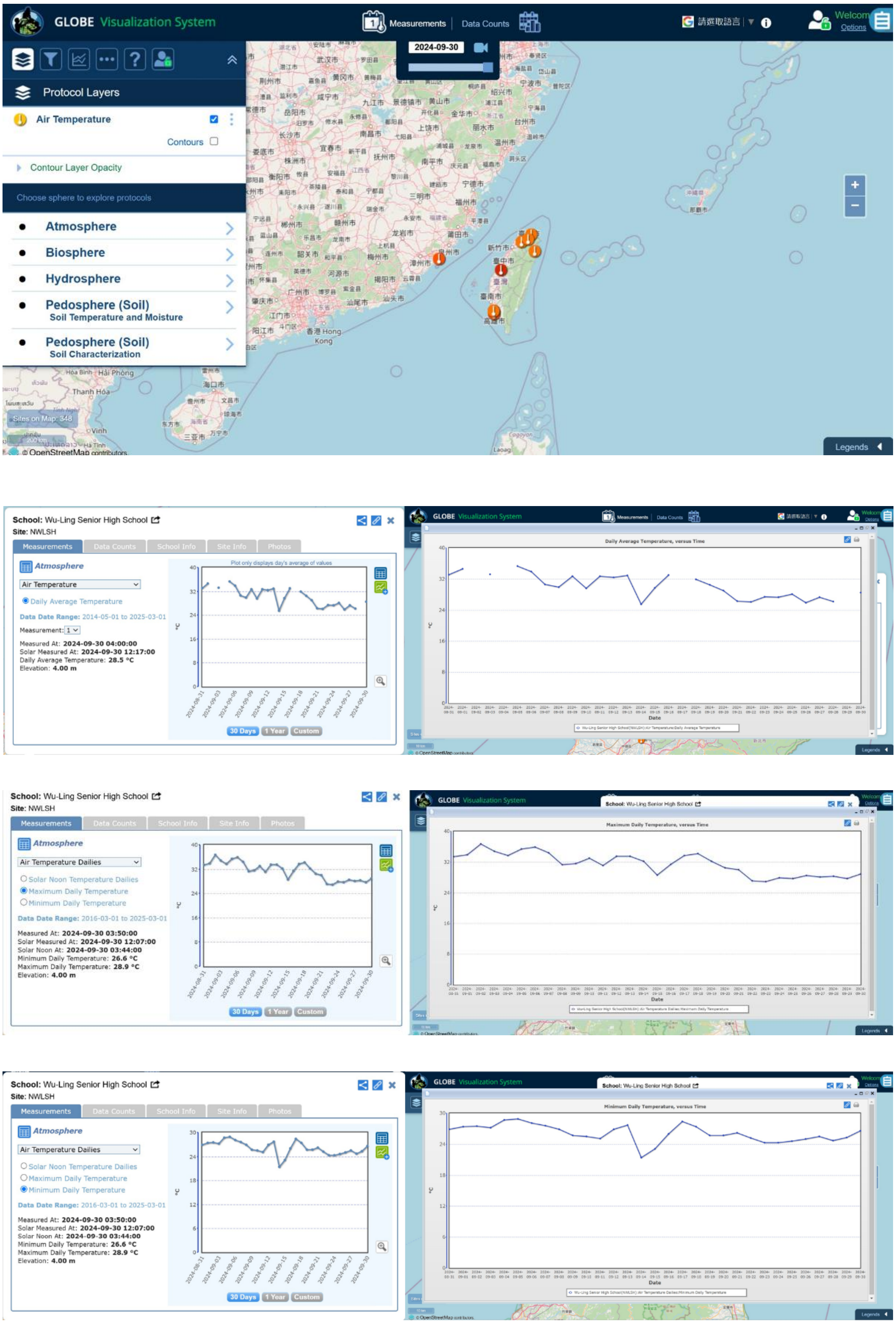


Fig. 12 (a) GLOBAL Up to down: Data. Site location; Daily averaged air temperature; Maximum daily averaged air temperature; Minimum daily averaged air temperature

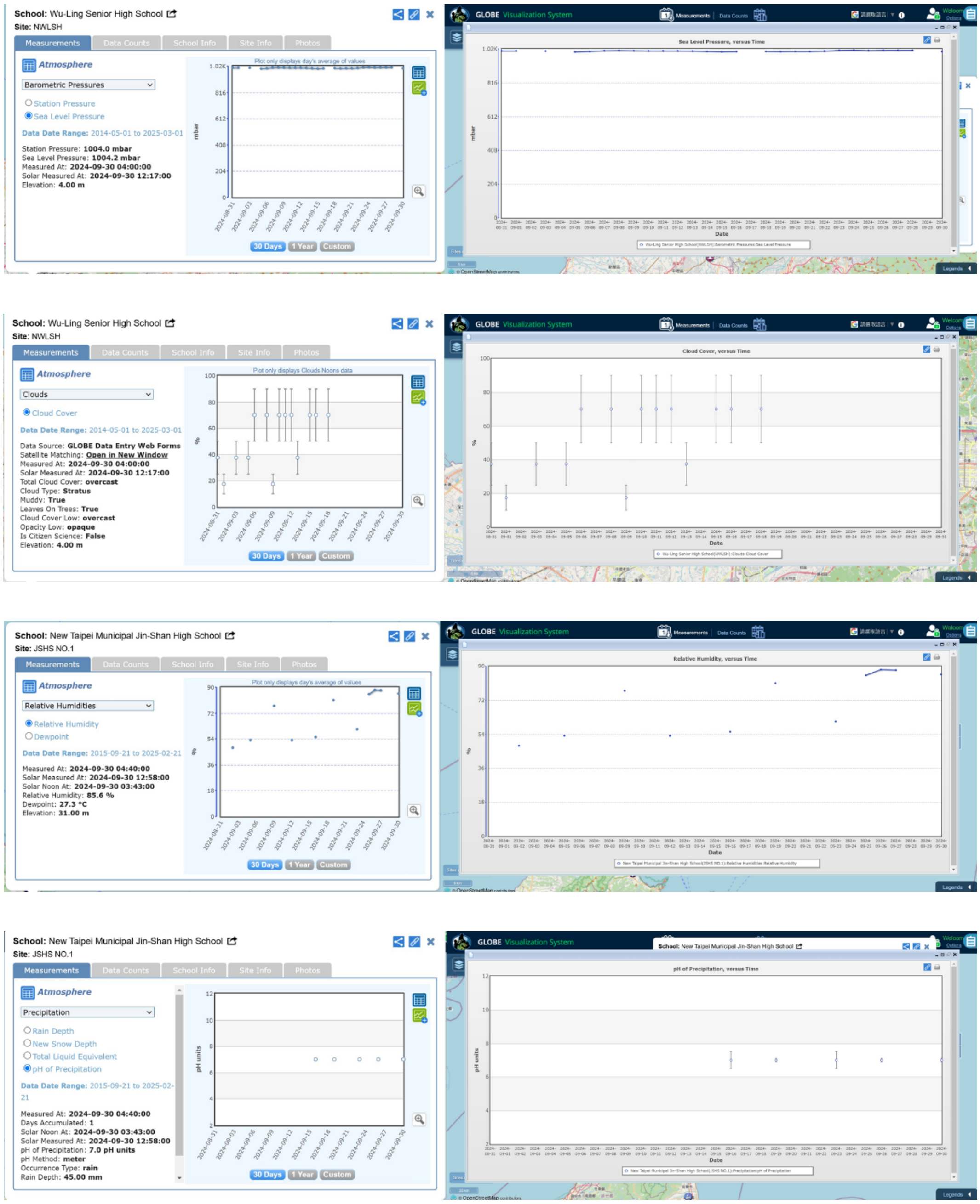


Fig. 13 (b) GLOBAL Up to down: Barometric Pressure at sea level; Cloud Cover; Relative humidity; pH of Precipitation.

Fig. 14 (c) Field measurements. Including sparse and dense mangroves, length of water pens, wetland water quality values, temperature, humidity, wind speed, PM2.5, and CO_2.

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. We hope to use the GLOBAL DATA database to understand the weather conditions and air quality around the school and also use the data we collect to verify the data. The data collected from the GLOBAL website includes Site location, Daily averaged air temperature, Maximum daily averaged air temperature, minimum daily averaged air temperature, Barometric Pressure at sea level, Cloud Cover, Relative humidity, pH of Precipitation (錯誤! 找不到參照來源。 (a))(Fig. 12 (b)).

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. The field measurement data including sparse and dense mangroves, length of water pens, wetland water quality values, temperature, humidity, wind speed, PM2.5, CO_2.

Summary of field tests inside and outside the campus

The air quality during peak traffic hours and non-peak traffic hours is very different. (Fig. 11) (Fig. 12). The first measurement was during the Mid-Autumn Festival when there were few vehicles, and the air quality was significantly better. This data can be used to provide background data on air quality.

The second measurement was during everyday get-off work and school hours when there were many vehicles, and the air quality was significantly worse.

From the measurements at the school gate and on campus, it can be seen that street trees improve air quality, but it is not easy to quantify.

This difference gave us the motivation for research. We hope to quantify the impact of the location of street tree planting on improving air quality through experiments.

Wind tunnel experiment design and construction

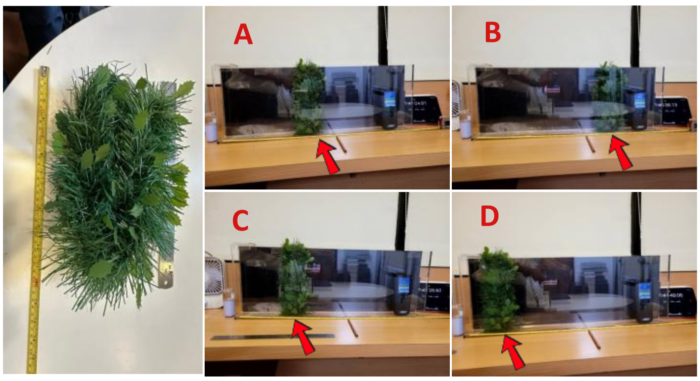
A self-made small wind tunnel model was used. This study used a sprayer as a visualized pollution source, model trees as analogs for wetland vegetation, and air quality monitoring equipment at the location of the building. The entire practical design hopes to observe whether the wetland vegetation size will significantly impact airflow and pollution source diffusion. The actual data obtained in the middle will also be analyzed to obtain effective supporting data to verify the configuration of wetland vegetation in the environment and the specific impact on the concentration of pollutants in the residential environment, hoping to find a more ideal configuration method. (Fig. 15) (Fig. 16)

Experimental equipment

PM2.5 meter | Sprayer | Tape measure | artificial tree strips | Iron Ruler

Fig. 15 Experimental equipment. From the left, PM2.5 meter: Records the concentration of pollution sources; Sprayers: as a source of pollution; Tape measure: Confirm the position of the artificial tree strips; Artificial tree strips: Simulating wetland vegetation; Ruler: Move the artificial tree strips.

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

Fig. 16 Wetland vegetation model establishment method. Folding strips of artificial trees create the wetland vegetation. Dense vegetation: 1.0-meter artificial tree strips folded in half to 0.25 meters. 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: mA：30 cm; B：50 cm; C：40 cm; D：20 cm

Experiment Setup

The experiment was conducted in a self-made acrylic wind tunnel. The top and left side of the acrylic wind tunnel are open, and there is a 5-cm opening on the right side to simulate a group of buildings. The sprayer is placed on the left side of the wind tunnel, spraying water mist as a pollution source. The background is made of black cardboard to facilitate the observation of the movement of water mist. A tape measure is set on the outside of the bottom of the wind tunnel to confirm the position of the fake tree strips. The fake tree strips are placed at four designated locations in the tank. A PM2.5 detector is set on the right side of the wind tunnel 60 cm away from the pollution source to record the concentration changes of the pollution source. A stopwatch is set outside of the wind tunnel to track the time course. The concentration change process is recorded by mobile phone recording. A stopwatch is set outside the screen to control the sprayer delivery time. (Fig. 17)

Fig. 17 The experimental setup. The white object on the left is a sprayer that can emit tiny water droplets as a source of pollutants. In the middle is a small wind tunnel. Fake tree strips are set up in the wind to bring up surface wetland vegetation. A pollutant sensor is set up on the right side of the wind tunnel, mainly to observe changes in PM2.5 concentration. On the right is a timer, which records the time of the experimental process.

Results

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 significantly reduces the pollution level. (Fig. 18)

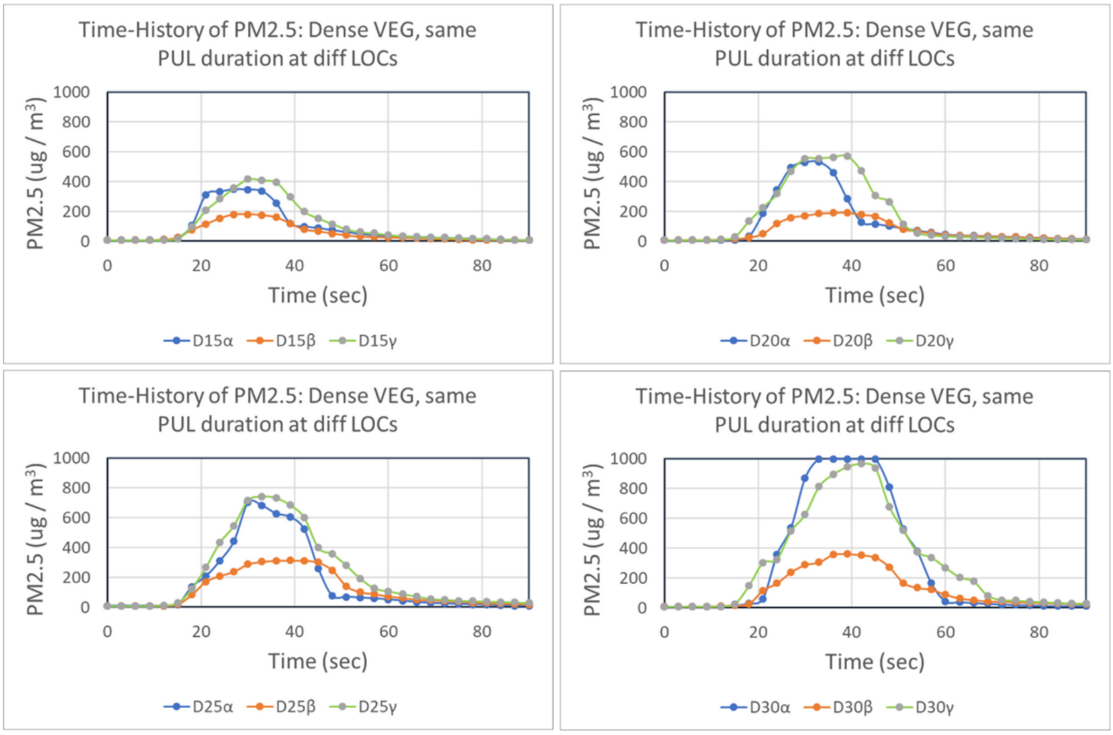


Fig. 18 Time-history of PM 2.5. Dense vegetation. Four images represent different levels of pollution. Three lines represent different locations

From the two experimental data below, we can see that sparse wetland vegetation has a limited ability to block air pollution, and the PM2.5 concentration rises rapidly and soon exceeds the instrument's limit. 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. (Fig. 19)

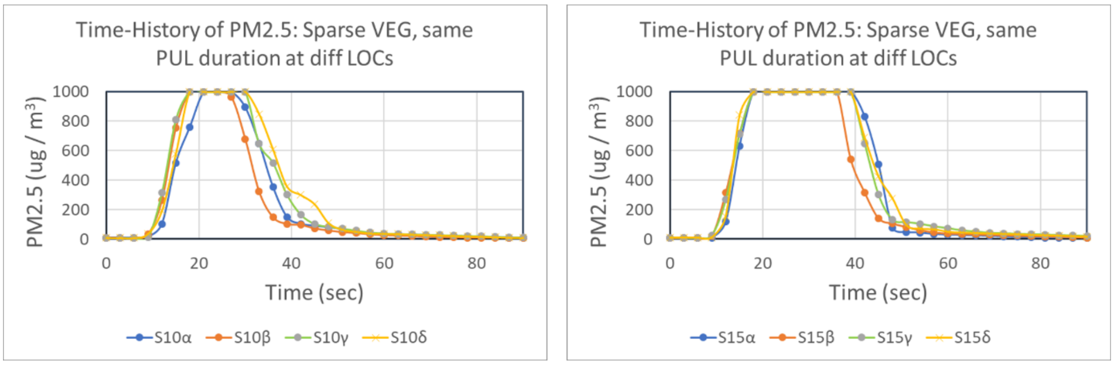


Fig. 19 Time-history of PM 2.5. Sparse vegetation. The two images represent different levels of pollution. Each line represents a different location

This data set compares the effect of different densities of wetland vegetation planted at locations A, B, C, and D on improving air quality. It is evident from the data that dense vegetation is more effective in blocking pollution than sparse vegetation. (Fig. 20)

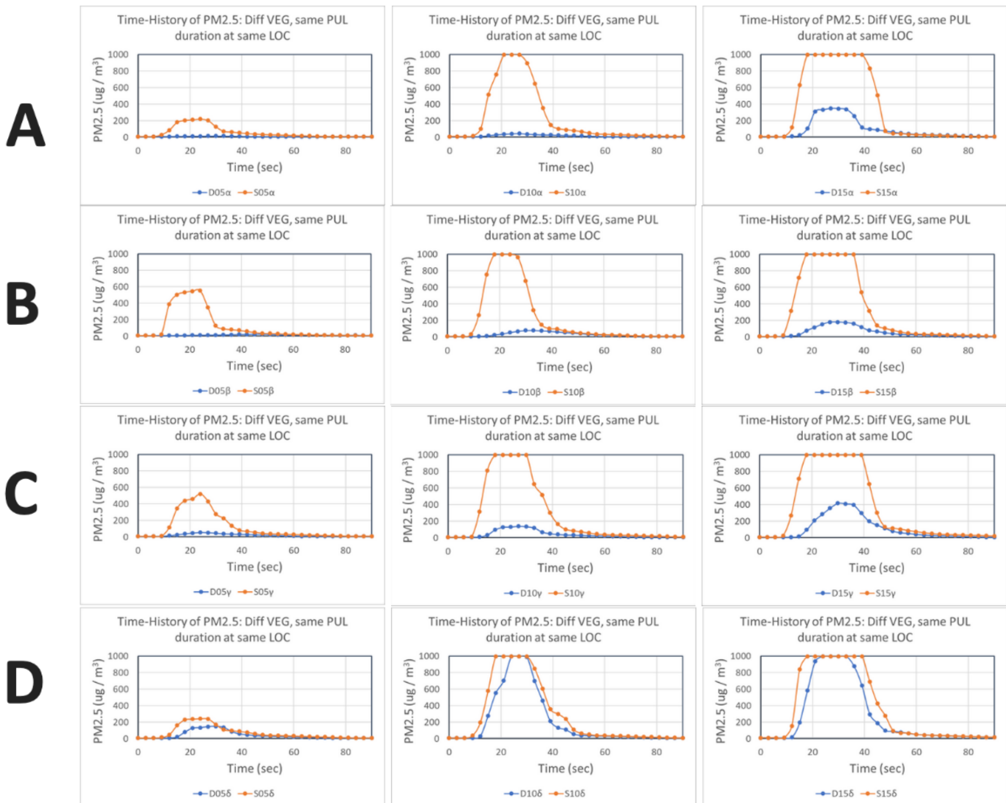


Fig. 20 Time-history of PM 2.5. Dense (blue line) vs. sparse (orange line). A, B, C, and D represent different locations. Three sets of lines represent different pollution levels

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. 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. (Fig. 21)

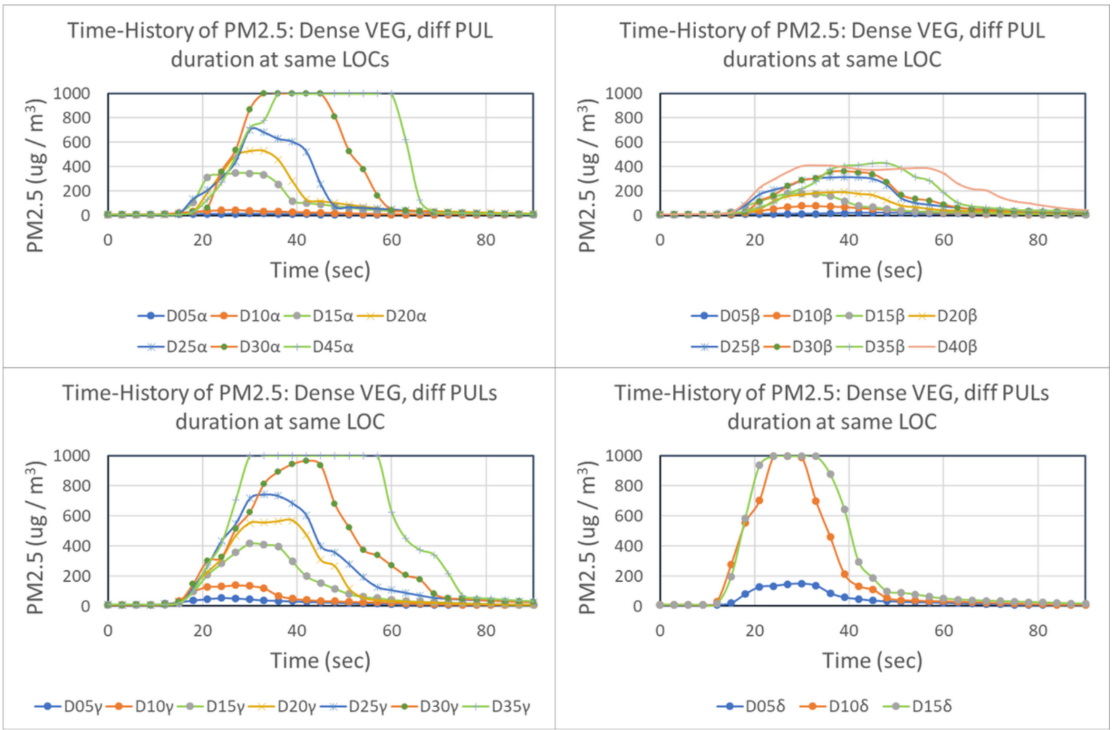


Fig. 21 Time-history of PM 2.5. Dense vegetation. The four images represent different locations. Each line represents a different level of pollution.

This data set 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 pollutants will increase rapidly under sparsely vegetated wetland vegetation.

However, the rate of decrease in pollutant concentration is the fastest at location B. (Fig. 22)

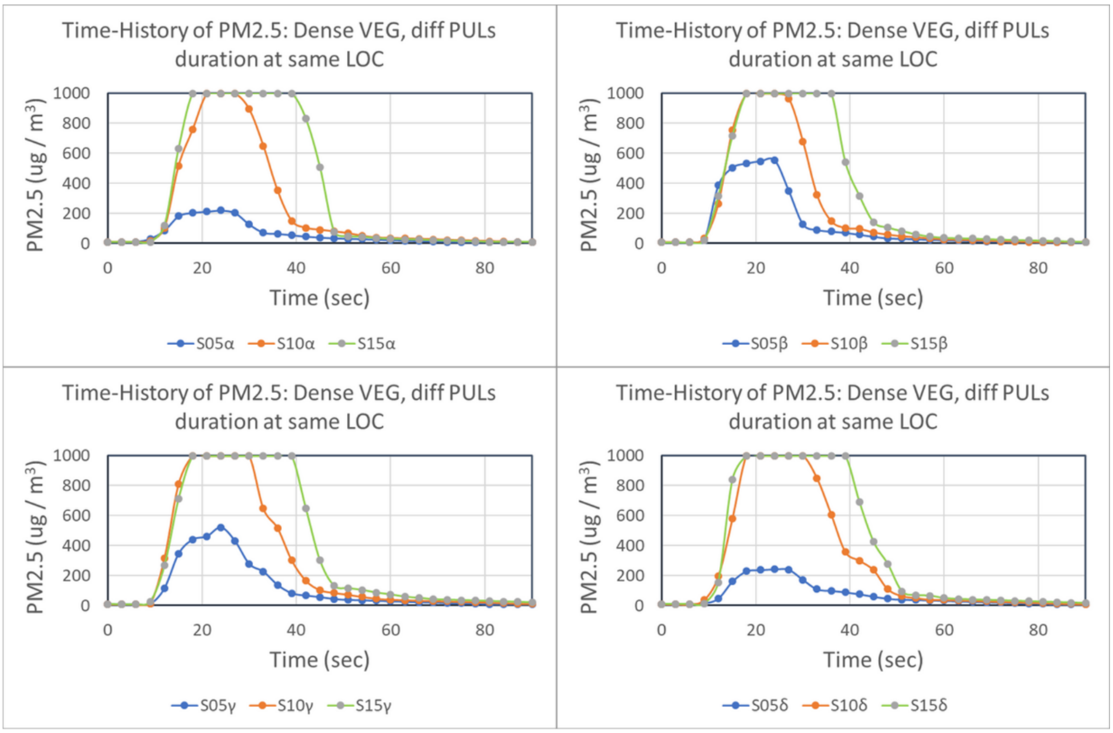


Fig. 22 Time-history of PM 2.5. Sparse vegetation. Four images represent different locations. Three lines represent different levels of pollution.

Conclusion and Recommendations

Finally, to summarize the above analysis results, this study believes that to improve the wetland vegetation to the best effect, the following key points should be taken:

1. The tree species of wetland vegetation should be densely leafed as much as possible.

2. The location of wetland vegetation should be as close to buildings as possible and away from pollutants.

3. If the pollution source is too severe or the pollution source discharges for too long, the function of wetland vegetation will no longer exist.

If it is not possible to plant dense wetland vegetation, then at least plant general wetland vegetation because, as seen from the figure, if wetland vegetation is not planted, the pollution source will immediately reach a PM2.5 concentration that exceeds the instrument range. (Fig. 23)

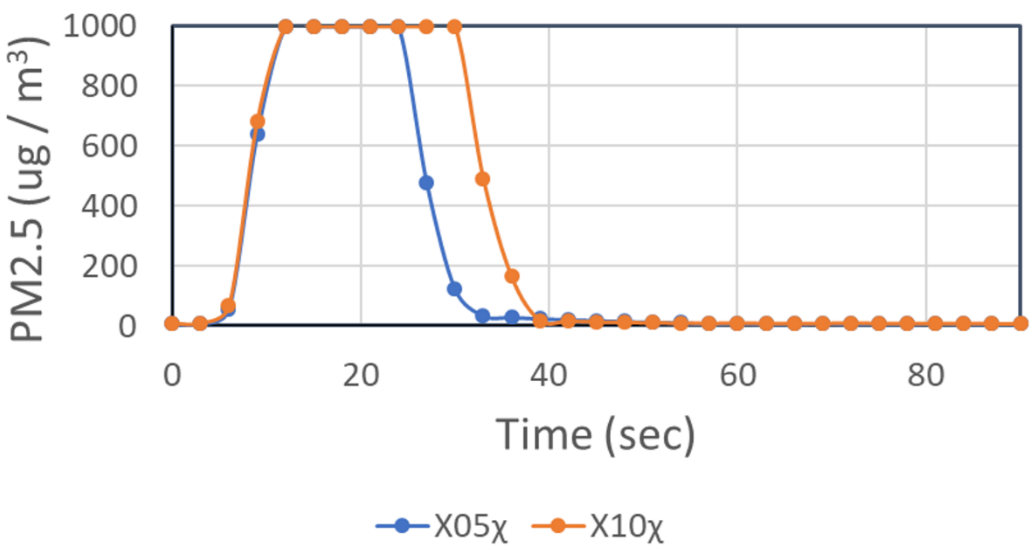


Fig. 23 Time-history of PM 2.5. No vegetation. Two lines represent different levels of pollution.

In this project, we first read the articles related to pollutant concentration in the GLOBE PROGRAM and read 5 SCI air quality-related papers. We also set up pollutant concentration monitoring equipment that can measure PM2.5, PM1.0, PM10, HCHO, TVOC, and other indicators.

In addition, we collected pollutant concentration data around the school and historical data from the past three years through the GLOBE PROGRAM website. We also personally measured pollutant concentration data around and inside the campus and conducted a detailed comparative analysis.

In the experimental part, we used a small wind tunnel made of acrylic and conducted 40 experiments using sprayers, fake tree strips, and pollutant concentration monitors. Finally, we conducted a cross-analysis of these 40 sets of data. The experimental results showed consistency and repeatability, ensuring the integrity and reliability of the research results.

The study found that the denser the wetland vegetation, the farther away from the pollution source and closer to residential buildings, the more significant the effect of improving pollutant concentration. Based on this research result, we suggest that the government should prioritize planting denser tree species and low shrubs when planning sidewalks and wetland vegetation in the future. Wetland vegetation should also be set up on the side close to residential areas to achieve the best effect of improving air quality.

Fig. 24 The process of our experiment

The above is the process of our experiment. The process is very hard, but the harvest is also very significant. Thank you, GLOBE PROGRAM, for providing DATA and the opportunity to participate in the competition. (Fig. 24)

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