ASSESSING THE EFFICIENCY OF SMOG CLEANING TOWER IN REDUCING AMBIENT PARTICULATE MATTER AT MEHMOOD BOOTI, LAHORE, PUNJAB

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ABSTRACT: Punjab Government is committed to take initiatives to control emerging problem of air pollution at Lahore, Punjab. Scientists, engineers and other stakeholders working on air pollution reduction technologies are encouraged to participate in pollution reduction. One of such research study was planned at Mehmood Booti to evaluate the effectiveness and efficiency of locally manufactured Smog Tower by Rapidiv Company, claiming the range of smog tower to capture and remove air particulate matter, especially PM 2.5 from 1km surrounded air of smog tower. For study purpose, EPA Installed four Air Quality Monitoring Stations at various distance to monitor ambient air PM2.5 concentration to report AQI. Data from six air quality monitoring stations were analyzed before and after tower installation. The analysis revealed a strong correlation between reduced $PM_{2.5}$ concentrations and increased wind speeds. Rainfall also played a significant role in improving air quality. These findings suggest that meteorological factors, particularly wind speed, rainfall, and humidity, have a more significant impact on air quality than the Smog Cleaning Tower (SCT). The observed improvement in air quality can largely be attributed to these natural atmospheric processes. Furthermore, the $PM_{2.5}$ monitoring conducted during the tower's operation indicated a substantial amount of particulate matter in the area, estimated at 373 Kg within a 1 km radius and 0.5 km height. However, the tower's $PM_{2.5}$ recovery rate was negligible, raising concerns about the efficiency of its electrostatic dust collection system.

Key words: Smog Cleaning Tower, Mehmood Booti, Rainfall, $PM_{2.5}$, Wind Speed.

INTRODUCTION

Lahore, one of Pakistan's largest cities, faces a severe air pollution crisis, with major contributors being vehicular emissions, industrial activities, construction dust, and the burning of crop residue in surrounding rural areas (Iqbal et al., 2022). Rapid urbanization, population growth, and lack of effective regulatory mechanisms exacerbate the situation, leading to consistently high levels of particulate matter ($PM_{2.5}$ and PM10), nitrogen oxides (NOx), sulfur dioxide (SO2), and carbon monoxide (CO) in the city's atmosphere (Ali et al., 2021).

Vehicular emissions are a dominant source of air pollution in Lahore, as the city hosts an increasing number of private vehicles with suboptimal emission standards. Older vehicles, particularly diesel-powered ones, contribute significantly to $PM_{2.5}$ concentrations (Rizwan et al., 2020). Additionally, the industrial zones surrounding Lahore release harmful pollutants such as volatile organic compounds (VOCs) and heavy metals, which further deteriorate air quality. Seasonal burning of agricultural waste, particularly during winter, results in the formation of smog, amplifying health risks for Lahore's population (Khan et al., 2023).

Lahore's geographic location and meteorological conditions also play a critical role in air pollution levels. During the winter months, low temperatures, high humidity, and limited wind speed contribute to the trapping of pollutants near the ground, resulting in prolonged exposure to harmful air (Ahmad et al., 2022). The combination of anthropogenic activities and natural factors has led to Lahore frequently ranking among the most polluted cities in the world, with average $PM_{2.5}$ levels far exceeding the World Health Organization’s recommended limits (WHO, 2021). The rapid growth of the city's vehicle fleet, coupled with a heavy reliance on outdated transportation technologies, leads to significant emissions of pollutants such as nitrogen oxides (NOx) and particulate matter ($PM_{2.5}$ and PM10) (Khan et al., 2018).

The burning of agricultural waste, a common practice in the surrounding areas, exacerbates the problem. During the winter months, the burning of crops and stubble releases large amounts of smoke and particulate matter into the air, further deteriorating air quality. Moreover, meteorological conditions, such as temperature inversions and low wind speeds, often trap pollutants near the ground, leading to the formation of smog and exacerbating the health impacts of air pollution (Shafique et al., 2017).

Meteorological factors significantly influence the dispersion and accumulation of air pollutants in Lahore. Temperature inversions, a common phenomenon during winter, trap pollutants near the ground, leading to increased concentrations. During these periods, the temperature increases with altitude instead of decreasing, creating a stable atmospheric layer that prevents the vertical mixing and dispersion of pollutants. This trapping effect contributes to the formation of smog and exacerbates air pollution levels (Shafique et al., 2017). Wind speed and direction also play a crucial role in air pollution levels. Low wind speeds limit the dispersion of pollutants, allowing them to accumulate in the atmosphere. Prevailing wind patterns can transport pollutants from surrounding areas, such as agricultural fields where crop burning occurs, into the city. Rainfall can help remove pollutants from the atmosphere through wet deposition. However, in Lahore, rainfall is often infrequent and insufficient to effectively cleanse the air (Khan et al., 2018).

Particulate air pollution refers to the presence of tiny solid particle suspended in the air. These particles, often invisible to the naked eye, can originate from various sources such as vehicle exhaust, industrial emissions, construction activities, and natural events like wildfires and dust storms (World Health Organization, 2022). Studies have shown that air pollution in Lahore significantly contributes to respiratory illnesses, particularly among children and the elderly (Siddiqui et al., 2016).

Efforts to control air pollution have included government policies to promote cleaner fuels, regulate industries, and monitor air quality, but enforcement remains inconsistent. The Punjab Environmental Protection Agency (EPA) has implemented measures such as issuing challans to vehicles with excessive emissions and enforcing the installation of emission control systems in industries. However, consistent enforcement of these measures remains a challenge. Public awareness campaigns and the deployment of air quality monitoring systems have highlighted the urgent need for long-term solutions to mitigate this environmental and public health crisis.

Recognizing the severity of the issue, particularly during winter months (October to December) when air pollution levels peak, Government is focusing on new interventions by scientists and researcher to develop new technologies to control pollution one of which is smog cleaning tower. These large-scale systems aim to mitigate particulate matter by drawing in polluted air and passing it through filters or other cleaning mechanisms. Smog cleaning towers, also known as air purifiers or air scrubbers, are large-scale systems designed to mitigate particulate air pollution. They operate by drawing in polluted air, passing it through a series of filters or other cleaning mechanisms, and subsequently releasing cleaner air back into the atmosphere. Common technologies employed in smog cleaning towers include electrostatic precipitators, baghouse filters, and wet scrubbers (U.S. Environmental Protection Agency, 2023).

While smog cleaning towers can effectively reduce particulate pollution in specific areas, their efficacy can vary based on factors such as the type and concentration of pollutants, the tower's size and design, and the surrounding environmental conditions. Moreover, the mechanical design and mode of operation of the smog cleaning towers plays a significant role in pollution control efficiency and operational cost (National Renewable Energy Laboratory, 2022).

METHODOLOGY

The EPA Punjab has welcomed the installation of a Smog Cleaning Tower (SCT) by Rapidiv Company in Lahore as a positive step towards combating the city's severe air pollution. Rapidiv claims the tower covers a 1 km radius area. To evaluate the tower's effectiveness, four air quality monitoring stations have been strategically placed at distances of 0 km, 0.5 km, 0.7 Km and 1.5 km from the tower. Station 5 at Punjab university (20 Km away) and Station 6 at Town Hall (08 Km) away were taken as background stations.

Continuous $PM_{2.5}$ Monitoring:

- Utilize the three AQMS stations strategically placed:
  - **Station 1:** Immediately adjacent to the smog cleaning tower.
  - **Station 2:** 0.5 km away within Mahmood Booti.
  - **Station 3**: 0.7 km away at Hill Park.
  - **Station 4**: 1.5 km away in Sagian.
  - **Station 5**: 20 km away at Punjab University (As Background Station)
  - **Station 6**: 08 km away at Town Hall (As Background Station)

Continuous $PM_{2.5}$ data were collected from four strategically placed air quality monitoring stations (AQMS). Station 1 was located directly adjacent to the tower, Station 2 was 0.5 km away within Mahmood Booti, Station 3 was located at 0.7 Km and Station 4 was situated 1.5 km away in Sagian. Station 5 at Punjab University and Station 6 at Town Hall were taken as background stations. Concurrent meteorological data, including temperature, wind speed, wind direction, and humidity, were collected from a nearby weather station to account for their influence on air quality.

The collected data were analyzed using various statistical techniques. Temporal analysis involved examining $PM_{2.5}$ trends over time at each station, comparing periods with and without the tower operating. Spatial analysis focused on comparing $PM_{2.5}$ levels across the all stations to assess the spatial extent of the tower's impact. Statistical methods such as time series analysis, regression analysis, and spatial interpolation were employed to determine the statistical significance of any observed $PM_{2.5}$ reductions and to understand the relationship between $PM_{2.5}$ levels, tower operation, and meteorological factors.

The tower's performance was evaluated based on the collected and analyzed data. Key performance indicators included the comparison of $PM_{2.5}$ levels at Station 1 during tower operation compared to background levels, the spatial extent of the tower's impact as determined by $PM_{2.5}$ reductions at Stations 2 and 3, the volume of air cleaned by the tower, and an estimate of the tower's $PM_{2.5}$ removal efficiency.

This multi-faceted approach provided a comprehensive understanding of the smog cleaning tower's effectiveness in mitigating air pollution in Mehmood Booti, Lahore

In this scenario, estimating the total $PM_{2.5}$ within a 1 km radius area with a 0.5 km height as shown in Figure 1, involves making assumptions and simplifications:

- **Uniform Distribution:** The calculation assumes that the measured $PM_{2.5}$ level at the single monitoring point is representative of the average $PM_{2.5}$ level throughout the entire volume of air within the defined area and height. This is a significant simplification as $PM_{2.5}$ levels can vary considerably within a given area due to factors like local emissions sources, wind patterns, and atmospheric conditions.

- **Simplified Geometry:** The calculation treats the polluted area as a simple cylinder with a radius of 1 km and a height of 0.5 km. This ignores any irregularities or variations in the shape of the polluted area.

Calculation:

1. **Determine the volume of the polluted area:**
   - Volume of a cylinder = π * radius² * height
   - Volume = π * (1 km)² * 0.5 km = 1.57 km³
2. **Calculate the total** $PM_{2.5}$**:**
   - Total $PM_{2.5}$ = $PM_{2.5}$ level * Volume
   - Assuming an $PM_{2.5}$ level of 100 units (this value would need to be replaced with the actual measured $PM_{2.5}$ level):
     - Total $PM_{2.5}$ = 100 units/km³ * 1.57 km³ = 157 units

- **The chosen height of 0.5 km is arbitrary.** The actual height of the polluted layer can vary significantly depending on meteorological conditions and the nature of the pollutants

- **The Flow Rate Analysis:** The flow rate of the Tower was also analyzed as compared to total volume of the air in the area of 1 Km radius and 0.5 Km height.

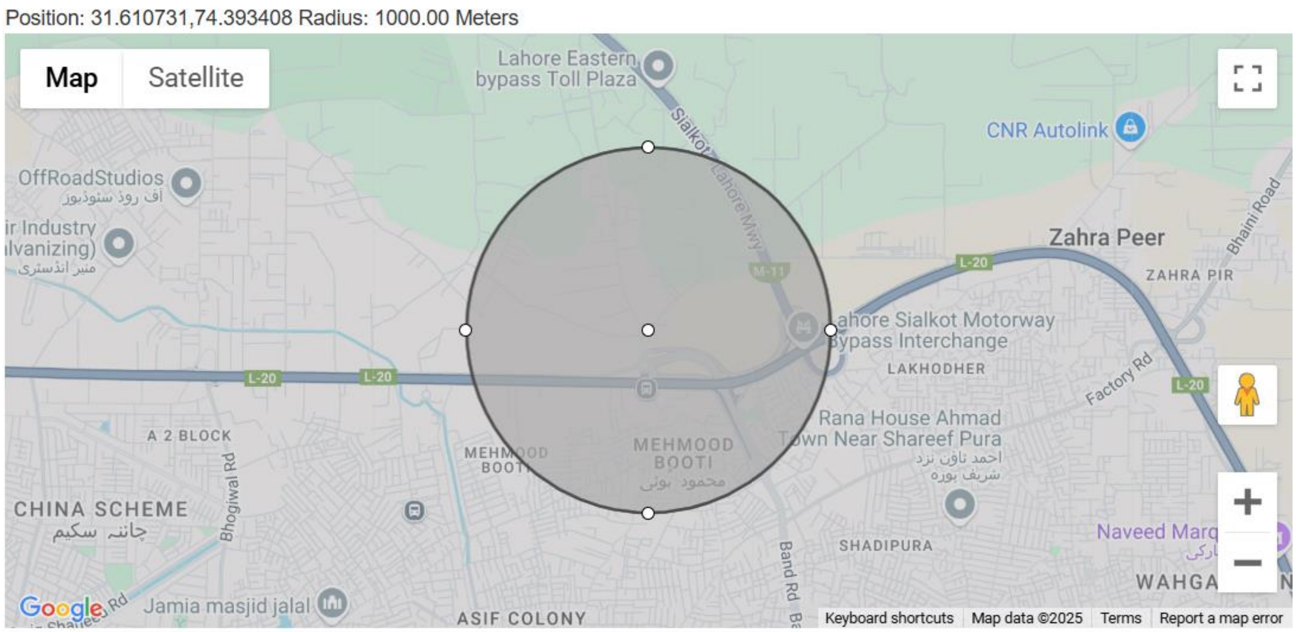

Figure 1: Study Area: Google Map showing area in 1 Km radius around Smog Cleaning Tower at Mehmood Booti Lahore

Table 1 describes the physical dimensions and Specifications of Smog Cleaning Tower. The Figure 2 shows SCT and AQMS. 1.

Table 1: Physical dimensions and Specifications of Smog Cleaning Tower.

Parameter	Description
Physical Dimensions	
Form Factor	Hexagon
Height	20 feet
Length x Width	10 feet x 10 feet
Specifications	
Material	Galvanized Iron (Structure), Stainless steel (Outer Fins)
Airflow Capacity	12,000 m^3/hour and maximum upto 50,000 m^3/hour
Fan Speed	450 RPM max
Fan Diameter	6 feet
Input Power Consumption	600 Watt-Hour
Cleaning Mechanism	Though Ionization

Figure 2: Air Quality Monitoring near Smog Tower at Mehmood Booti Lahore

RESULTS

This study aimed to evaluate the effectiveness of a newly installed smog-cleaning tower in mitigating $PM_{2.5}$ levels in the Mehmood Booti area of Lahore, Pakistan. Data from 06 air quality monitoring stations were collected before and after the tower's installation to assess its impact on ambient air quality. More over SMP level in the study area was calculated to check the efficiency of SCT in an additional way.

During the evaluation of the Smog Cleaning Tower (SCT), several observations and concerns were raised. It was noted that background data from controlled environment or laboratory trials of the SCT was not available, which the RAPIDEV team requested to be presented for review. Additionally, there was no visible collection of Particulate Matter observed along the SCT on the polythene sheet, raising doubts about its efficacy. Concerns were also highlighted regarding the potential generation of secondary pollutants, which could pose environmental risks. Furthermore, the technological measures to assess the magnitude of ionized particles and to prevent their re-introduction into the environment from the SCT were found to be lacking, pointing to a critical gap in the system's design and functionality

The Figure 3 provide comparative data on $PM_{2.5}$ levels recorded by 06 air quality monitoring stations (AQMS) before and after the installation of a smog-cleaning tower. The variations in $PM_{2.5}$ concentrations suggest that wind speed plays a crucial role in determining the levels of particulate matter in the ambient air, more so than the impact of the smog-cleaning tower.

Before Installation of the Smog-Cleaning Tower (16–22 December 2024): Table 2 shows PM2.5 data of 06 AQMSs before and after installation of Smog Cleaning Tower. During this period, $PM_{2.5}$ levels were high across all monitoring stations. At AQMS.1, $PM_{2.5}$ levels peaked at 648 µg/m³ on 18 December. AQMS.2 recorded a maximum of 379 µg/m³ on 19 December, and AQMS.3 had its highest reading of 408 µg/m³ on 18 December. Wind speeds during this time were relatively low, ranging from 1.59 Km/h to 6.85 Km/h. The low wind speeds likely contributed to stagnant air conditions, preventing the dispersion of pollutants and causing an accumulation of $PM_{2.5}$ in the atmosphere. The lack of rainfall further compounded the issue, as there was no natural cleansing mechanism to reduce particulate concentrations.

After Installation of the Smog-Cleaning Tower (23–29 December 2024): A closer analysis of the meteorological data reveals that these improvements in air quality were strongly influenced by changes in wind speed. At AQMS.1, concentrations dropped from 252 µg/m³ on 23 December to 155 µg/m³ on 29 December. Similar trends were observed at other AQMSs. During this period, wind speeds were higher, ranging from 3.05 Km/h to 11.9

Km/h, peaking on 29 December. Higher wind speeds aid in dispersing pollutants, reducing their concentration at ground level. Additionally, rainfall occurred on multiple days after the installation, with a notable 1.7 mm on 27 December, further helping to cleanse the air by settling airborne particulates. The AQMS.1, which is near SCT consistly showed high $PM_{2.5}$ level comparative to other AQMSs.

Role of Precipitation and related Wind Speed: The Figure 3 shows rainfall on 23, 27 and 29 November. The data strongly suggests that rainfall and increased wind speed is a critical factor in the fluctuation of $PM_{2.5}$ levels. During periods of low wind speed before the installation, $PM_{2.5}$ concentrations remained high, indicating limited pollutant dispersion. Conversely, after the installation, higher wind speeds coincided with reduced $PM_{2.5}$ levels, suggesting that the improved air quality was primarily driven by meteorological conditions rather than the smog-cleaning tower.

The role of wind speed and other meteorological factors (e.g., humidity, rainfall) appears to be far more significant in influencing air quality. The effectiveness of the smog-cleaning tower remains questionable, and the observed improvement is likely due to natural atmospheric processes.

Table 2: PM2.5 data of 06 AQMSs before and after installation of tower

Date	AQMS-1 (Mehmod Booti 1) (0Km)	AQMS-2 (Mehmod Booti 2) (0.5Km)	AQMS-3 (Hill Park) (0.7Km)	AQMS-4 (Sagian road) (1.5Km)	AQMS-5 (PU) (Approx. 20Km)	AQMS-6 (Town Hall) (Approx. 08 KM)	Temp (˚C)	Hum. (%)	Wind Sp. (Km/h)	Prec. mm
Before Installation of Tower										
16.12.2024	365				379	452	21	59.7	2.89	0.0
17.12.2024	455	371		295	407	413	21	65.7	4.18	0.0
18.12.2024	742	467	353	283	424	448	21	70.0	3.14	0.0
19.12.2024	556	374	473	434	390	464	20	72.8	5.00	0.0
20.12.2024	467	381	368	240	394	368	20	66.4	6.85	0.0
21.12.2024	382	418	379	305	324	346	20	59.9	4.81	0.0
22.12.2024		374	417	316	428		20	68.9	1.59	0.0
Average AQI	**495**	**398**	**398**	**312**	**392**	**415**	**20**	**66**	**4**	**0**
Max AQI	**742**	**467**	**473**	**434**	**428**	**464**	**21**	**72.8**	**6.85**	**0**
Min AQI	**365**	**371**	**353**	**240**	**324**	**346**	**20**	**59.7**	**1.59**	**0**
After Installation of Tower										
23.12.2024	303	297	294	253	256	295	20	77.9	9.26	0.30
24.12.2024	320	279	315	193	252	278	19	70.4	8.7	0.0
25.12.2024	433	293	385	226	337	352	19	71.1	4.18	0.0
26.12.2024	433	278	345	279	300	374	18	63.1	3.05	0.10
27.12.2024	561	377	514	397	403	509	17	89.3	4.82	1.7
28.12.2024	208	203	183	161	189	210	17	82.1	5.47	0.2
29.12.2024	206	-	169	153	180	182	16	85.2	11.90	1.1
30.12.2024	345	-	245	246	207	237	14	78	4.6	0.0
31.12.2024	310	-	307	277	302	351	13	80	5.0	0.0
Ave.	**347**	**288**	**306**	**243**	**270**	**310**	**17**	**77**	**6**	**0**
Max.	**561**	**377**	**514**	**397**	**403**	**509**	**20**	**89.3**	**11.9**	**1.7**
Min.	**206**	**203**	**169**	**153**	**180**	**182**	**13**	**63.1**	**3.05**	**0**

Figure 3.(a): Before the Installation of the Smog-Cleaning Tower

- **R^2 = 0.69**: This high R^2 value (closer to 1) indicates a strong relationship between $PM_{2.5}$ levels and wind speed. It suggests that wind speed plays a significant role in determining $PM_{2.5}$ concentrations in the air. Higher wind speeds likely disperse particulate matter, reducing $PM_{2.5}$ levels, whereas lower wind speeds allow pollutants to accumulate.

Figure 3.(b): After the Installation of the Smog-Cleaning Tower

- **R^2 = 0.60**: This lower R^2 value still indicates a strong but slightly weaker relationship compared to before the tower's installation. The data implies that wind speed continues to significantly influence $PM_{2.5}$ levels, but the impact of other factors (e.g., the smog-cleaning tower or other environmental influences) might slightly affect the dispersion patterns

The smog-cleaning tower's effectiveness appears negligible, as the observed improvement in air quality can largely be attributed to favorable meteorological conditions rather than the tower itself. Wind dispersion, higher humidity, and precipitation were the dominant factors reducing $PM_{2.5}$ levels in the ambient air. This highlights the importance of addressing the root causes of air pollution, such as vehicular and industrial emissions, rather than relying solely on isolated technological interventions.

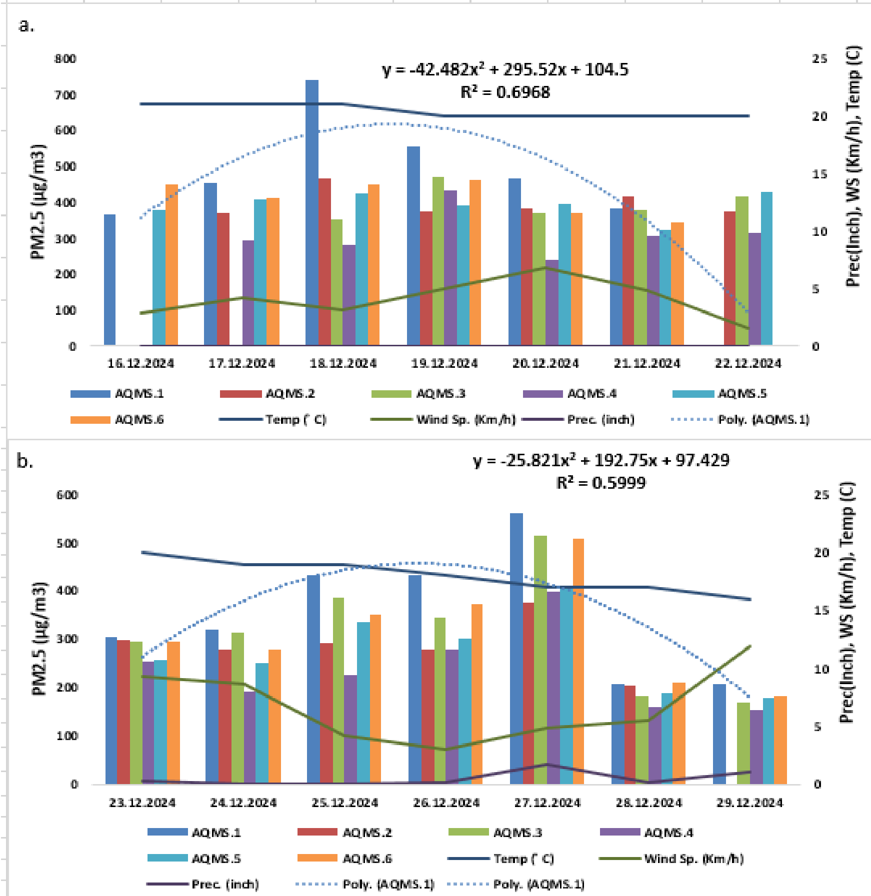

Figure 3: Polynomial expression of $PM_{2.5}$ data near Smog Cleaning Tower (AQMS 1) showing comparison with other AQMSs along with relationship with meteorological parameters: a. before operation of Smog Cleaning Tower, b. During Operation of Smog Cleaning Tower

Air Quality Monitoring network across the Lahore: EPA Punjab has been monitoring air quality with 14 AQMSs across the Lahore. Four AQMSs have been deputed temporarily near the SCT to monitor its efficiency. Figure 4 shows air quality data of 14 AQMS across the Lahore on December 25, 2024. EPA Punjab's air quality monitoring network across Lahore recorded elevated AQI levels at all 14 monitoring sites, indicating widespread air pollution. Notably, the station near Mehmood Booti exhibited the highest AQI among the four stations specifically installed to assess the smog cleaning tower's effectiveness. While this suggests a localized area of particularly high pollution near Mehmood Booti, it's important to note that high AQI values were observed across the city, highlighting the pervasive nature of the air pollution problem in Lahore. Figure 4 shows that average AQI of Lahore is 330, while AQI at Mehmood Booti is 433 on 25, December, 2024. This observation raises questions about the tower's immediate impact on reducing AQI levels in the vicinity and necessitates further investigation into the factors contributing to the elevated pollution levels at Mehmood Booti, such as localized emission sources or specific meteorological conditions.

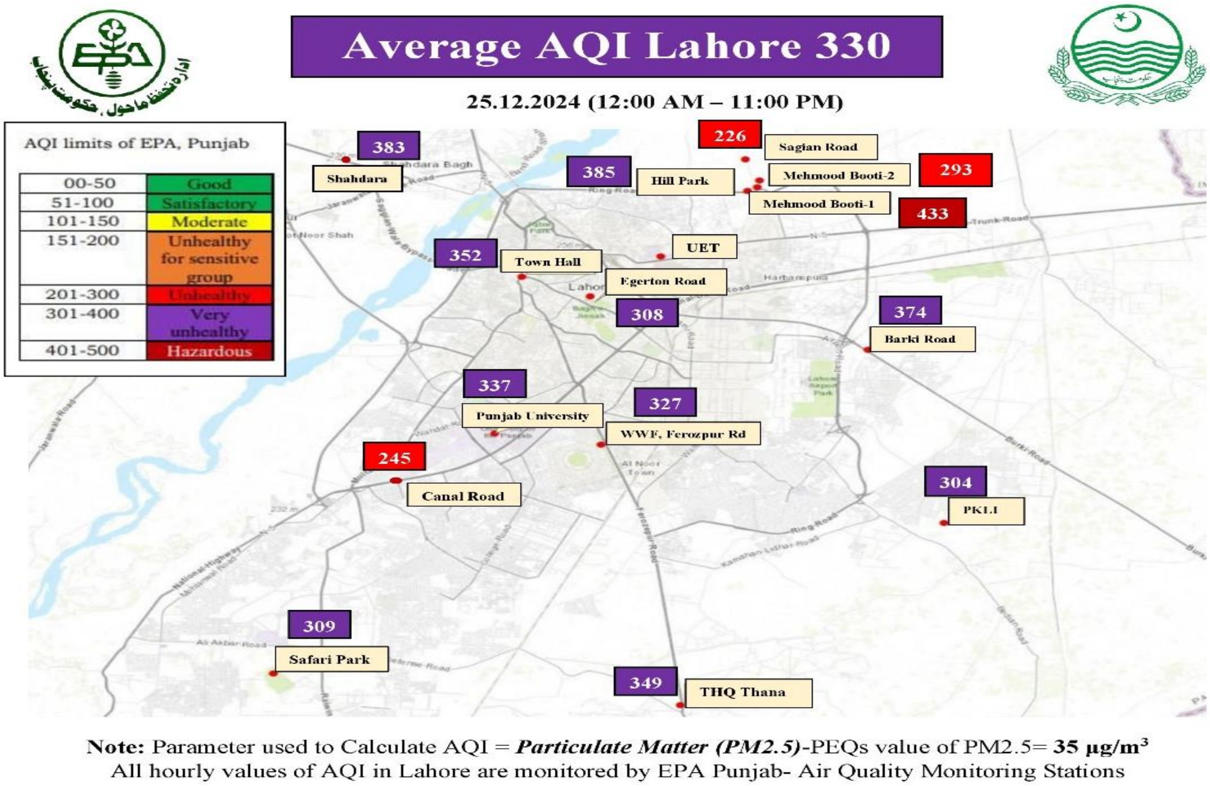

Figure 4: Ambient Air Quality Monitoring by EPA Punjab at 14 points across the Lahore

$PM_{2.5}$ Load in the Area: Table 3 shows the calculated $PM_{2.5}$ in the study area with 1 Km radius and 0.5 Km height. The average $PM_{2.5}$ monitored by four AQMSs installed in the Mehmood Booti area during operation of Smog Cleaning Tower, was measured at 237 µg/m³, translating to an estimated 373 Kg of $PM_{2.5}$ within a 1 km radius and 0.5 km height. However, the smog cleaning tower, utilizing electrostatic recovery of $PM_{2.5}$, demonstrated an extremely low recovery rate. This stark discrepancy highlights a significant shortcoming in the tower's dust minimization and collection system. The observed low recovery rate suggests inefficiencies in the electrostatic precipitation process, potentially due to inadequate voltage, improper electrode design, or insufficient collection surface area. These findings necessitate a thorough evaluation and optimization of the tower's design and operational parameters to enhance its effectiveness in capturing and removing $PM_{2.5}$ from the ambient air

$PM_{2.5}$ Calculation:

1. **Volume of the polluted area with 1 Km radius and 0.5 Km height:**

- Volume of a cylinder = π * radius² * height
- Volume = π * (1 km)² * 0.5 km = 1.57 km³= 1.57×10^{09} m³

2. **Calculate the total $PM_{2.5}$:**

- $PM_{2.5}$ = 237 µg/m³
- Total $PM_{2.5}$ = $PM_{2.5}$ level * Volume
- Total $PM_{2.5}$ in 1.57 Km³ = 237 * 1.57×10^{09}
- = 3.73×10^{11} µg
- = 3.73×10^{08} mg
- = 3.73×10^{05} g
- = 373 kg
- = 0.373 ton

3. The Table 4 illustrates the stark difference between the total volume of air within the 1 km radius and 0.5 km height (1.57×10^9 m³) and the smog cleaning tower's airflow capacity of 12,000 m³/hour. The tower can only process approximately 12000 m³ of the total air volume in an hour and 288000 m³ in 24 hour, which is only 0.018% of total air mass in 1Km radius and 0.5 Km height volume.

Table 3: $PM_{2.5}$ load in the study Area with 1 Km radius and 0.5 Km Height

Parameter	Value	Unit
$PM_{2.5}$ Concentration	237	µg/m³
Radius	1	Km
Height	0.5	Km
Volume of Area	1.57	km³
Total $PM_{2.5}$	3.73×10^{11}	µg
Total $PM_{2.5}$	3.73×10^{08}	mg
Total $PM_{2.5}$	3.73×10^{05}	G
Total $PM_{2.5}$	373	Kg

Total $PM_{2.5}$	0.373	Tons

Table 4: Air Suction Flow Rate of Smog Cleaning Tower.

Metric	Value	Unit	Relative to air volume within 1 Km radius
Total Air Volume in 1 Km radius with 0.5 Km height	$1.57x10^{09}$	m³	
Tower Airflow (per hour)	12000	m³/hour	0.0008%
Tower Airflow (per 24 hour)	288000	m³/24hour	0.018%

Conclusion: The comparative data on $PM_{2.5}$ levels was recorded at 06 air quality monitoring stations (AQMS) before and after the installation of a smog-cleaning tower. The variations in $PM_{2.5}$ concentrations suggest that wind speed and rainfall plays a crucial role in determining the levels of particulate matter in the ambient air, more so than the impact of the smog-cleaning tower.

The operational mechanism of the Smog Cleaning Tower (SCT), including processes such as ionization or electrostatic precipitation, remained unclear during the review. The data available for assessing the efficiency of the SCT was inconclusive, as it was primarily based on changes in the Air Quality Index (AQI) without providing critical information regarding the generation of secondary pollutants or the fate of generated ions. Additionally, the effectiveness of the tower in large, open environments with varying air quality indices remains unverified, raising doubts about its scalability and practicality. The assessor committee suggested that the SCT should be considered a prototype project and further developed as a pilot initiative. However, the absence of available literature to support the effectiveness of this technology presents a significant challenge in validating its performance or benchmarking it against established standards, leading to concerns about its overall feasibility and scalability.

An analysis of PM2.5 levels at six Air Quality Monitoring Stations (AQMS) in Lahore before and after the installation of a smog-cleaning tower revealed that while PM2.5 levels fluctuated, wind speed appeared to be a more significant factor in influencing air quality than the tower itself. The tower's PM2.5 recovery rate was negligible, and its limited airflow capacity (processing only 0.018% of air mass daily) severely restricts its impact on overall air quality. Furthermore, AQMS.1, located closest to the tower, consistently recorded the highest PM2.5 levels. These findings suggest that the smog-cleaning tower should be based on international standards in terms of dust recovery, flow rate and quantum of pollution in the area.

Recommendation: To effectively address air pollution in Lahore, a multi-pronged approach is crucial.

- Enhancing the smog cleaning tower's efficiency is essential. This requires a thorough evaluation of the electrostatic precipitation system, including optimization of voltage, electrode design, and technological interventions for dust collection system. Regular maintenance and cleaning of the tower components are also vital.
- Enhance Airflow Capacity: Evaluate the feasibility of increasing the tower's airflow capacity. This could involve upgrading fan systems, optimizing airflow pathways within the tower, or exploring the potential for deploying larger-scale systems to process a greater volume of air.
- If the SCT is based on ionization principle, the ion neutralization and reabsorption of secondary pollutants should be ensured.
- To enhance the efficiency of the Smog Control Tower (SCT), additional technological interventions should be explored and incorporated. The prototype project must be upgraded to align with the standards of global pilot projects, ensuring reliable evaluation of its performance. The development of the SCT should prioritize the integration of internationally proven methods for particulate matter (PM) reduction. A comprehensive testing phase should be undertaken, starting with controlled lab-scale experiments. Subsequently, a pilot SCT should be deployed in an open environment, with the active involvement of the Environmental Protection Agency (EPA) or a similar regulatory authority.
- Any other technological interventions to improve the efficiency of Smog Control Tower.

REFERENCES

Ahmad, M., Nawaz, S., & Ali, T. (2022). Role of meteorological factors in the worsening air quality of Lahore. *Environmental Monitoring and Assessment*, 194(3), 112–118.

Ali, R., Khan, S., & Shafiq, M. (2021). Sources and health impacts of air pollution in Pakistan: A review. *Atmospheric Environment*, 244, 117870.

Iqbal, S., Fatima, A., & Saeed, S. (2022). Urbanization and air quality: A study of Lahore's evolving pollution patterns. *Journal of Urban Environmental Studies*, 18(2), 67–79.

Khan, I. A., Khan, M. A., & Khan, M. N. (2018). Air pollution in Lahore, Pakistan: A review. *Journal of Environmental Science and Technology, 11*(2), 235-248.

Khan, N., Tariq, H., & Aslam, F. (2023). Agricultural burning and its impact on smog formation in Punjab, Pakistan. *Journal of Environmental Sciences*, 29(5), 211–220.

National Renewable Energy Laboratory. (2022). Air pollution control technologies. https://www.nrel.gov/analysis/air-quality.html

Rizwan, M., Qadir, M., & Akhtar, N. (2020). Emission inventories and air quality challenges in urban Pakistan. *Asian Journal of Environmental Science and Technology*, 12(4), 453–461.

Shafique, M., Abbas, Q., & Khan, M. U. (2017). Air pollution in Lahore, Pakistan: A critical review. *Journal of Environmental Science and Pollution Research*, *24*(34), 26177-26190.

Siddiqui, T. H., Khan, M. A., & Khan, M. N. (2016). Impact of air pollution on human health in Lahore, Pakistan. *Journal of Environmental Health Science and Engineering*, *14*(1), 1-10.

U.S. Environmental Protection Agency. (2023). Particulate matter (PM) pollution. https://www.epa.gov/pm-pollution

World Health Organization. (2021). WHO global air quality guidelines: Particulate matter ($PM_{2.5}$ and PM10), ozone, nitrogen dioxide, sulfur dioxide, and carbon monoxide. *World Health Organization*

World Health Organization. (2022). Air pollution. https://www.who.int/health-topics/air-pollution.