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An Investigation Study on $PM_{2.5}$ in Ambient Air: A Case Study of Karachi, Pakistan

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Abstract

The susceptibility of ambient air quality is due to particle pollution from $PM_{2.5}$, which is a great alarm when levels in the air are unhealthy. Inhalation in unhealthy levels of $PM_{2.5}$ can raise the risk of health problems and also decrease visibility and cause the air to appear obscure. This research investigates the continuous accumulation of $PM_{2.5}$ at hourly interval using an automated air monitoring instrument in 50 distinct locations' in the five districts of Karachi, Pakistan. Data were collected over a period, from January 1st until June 30th, 2022. During the research study duration, the $PM_{2.5}$ concentration exhibited variability within the range of 2 to 374 $\mu g/m^3$. The results revealed that the minimum and maximum $PM_{2.5}$ concentrations in District South was 3 $\mu g/m^3$ and 374 $\mu g/m^3$ respectively followed by District Central (3 $\mu g/m^3$, 337 $\mu g/m^3$), District West (3 $\mu g/m^3$, 349 $\mu g/m^3$), District East (2μ g/m^3, 343 $\mu g/m^3$) and District Malir (2 $\mu g/m^3$, 199 $\mu g/m^3$) correspondingly. The entire sampling data 24-hours average was 114.88 $\mu g/m^3$ compared to the permissible limits of Sindh Environmental Quality Standards (SEQS-2016) 75 $\mu g/m^3$ and World Health Organization (WHO) air quality guidelines 25 $\mu g/m^3$. The outcomes emphasize the necessity for implementing strict emission control protocols and promoting cleaner energy sources to mitigate the health risks associated with $PM_{2.5}$ exposure. This research work underscores the urgency of air quality management strategies in Karachi, aiding policy makers and stakeholders in devising effective mitigation measures. Addressing the challenges posed by high-level $PM_{2.5}$ can lead to significant improvements in the overall well-being and quality of life of the city's inhabitants.

Keywords: Inhaling Air, Air Pollution, Particulate Matter, $PM_{2.5}$ estimations, Karachi

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Introduction

Rapid industrialization, population explosion, and extraordinary increases in land and aerial transportation are some of the major contributors to urban air pollution [1-4]. It is revealed that air pollution has grown to be a foremost environmental issue in metropolitan cities globally with more than four million life losses in 2016, near about 91 percent of these causalities happening in emergent nations, and it is envisioned to become the notable environmental provenance of global fatality rate by 2050 [5-6]. Moreover, there is an increasing feeling of anxiety that high pollution concentration of air will be attributed to an upsurge in the usage of obsolescent version road vehicles. As stated by the World Health Organization (WHO) 2014, there were 90 million motor vehicles officially documented in Pakistan, and studies have implied that Karachi encapsulates predominant health-related issues from colossal proportions of total suspended particulates (TSP) [7-9].

Primarily, various pollutants in the air contribute significantly to deprived air quality and are known to have far-reaching effects on human health in the urban environment [10-14]. Airborne Particulate Matter (PM) is not a solitary pollutant, but conversely is an assortment of many chemical genres. It is a composite combination of solids and aerosols conjunction of small droplets of aqueous, dehydrated solid fragments, and dense cores with liquid coatings. Constituents vary in shape, size, and chemical configuration, and may include elemental carbon, inorganic ions, organic compounds, metallic compounds, and compounds from beneath the earth. $PM_{2.5}$ has garnered significant attention due to its adverse health impacts. These tiny particles have a knack for infiltrating deep into our respiratory system, posing serious risks. From aggravating cardiovascular diseases and even shortening lifespans, the health hazards associated with $PM_{2.5}$ pollution are undeniable [15-16]. Thus, unraveling the intricate relationship between $PM_{2.5}$ exposure and health outcomes is not just a scientific pursuit but a vital step toward safeguarding public health in our increasingly urbanized world. Policy intermediations are immediately required in metropolitan cities to develop the quality of inhaling air and assessments of hazards are desired for assistance to commence these efforts at the local, regional, and global levels. The divergent health effects and advanced methodologies for air quality in understanding pollutant $PM_{2.5}$ are critical [17].

Karachi, a megacity and economic hub of Pakistan, has widespread and various industries based across the metropolis together with coal and oil-fired electric power generation plants, steel mills, scuffle metal reprocessing plants, cement plants, chemical industries, and refineries, among others [18]. Incineration of solid waste and burning debris openly is a general exercise in the city. The trend of $PM_{2.5}$ in selected areas in the city was reported by many researchers but limited data is available in district-wise distribution to evaluate implications of air pollution in the city [19]. Since Karachi is a coastal city therefore, it is also threatened by climate change challenges in the form of urban heat waves etc. According to the 2017 census, Karachi inhabits 14.9 million people and the city population is increasing exponentially which is coupled with the effect of rural population migration to urban centers for more livelihood opportunities. An increase in population not only puts dwellers' lives under pressure but also depletes ambient air quality as well.

The research study aims to address significant gaps in existing research by highlighting recent trends regarding the concentration of $PM_{2.5}$ in different districts of Karachi, providing localized data on $PM_{2.5}$ levels, identifying sources of pollution, assessing possible health impacts specific to Karachi, offering tailored policy recommendations to address air quality concerns in the city, and drawing the attention of authorities to scrutinize the PM regulatory plans. This research work demonstrates the outcomes of a comprehensive daily and hourly study of $PM_{2.5}$ concentration recorded in 5 districts of the metropolitan city of Karachi during the study period. Several reasons have led us to conduct this research work, primarily the high $PM_{2.5}$ concentration reported in the city [20] and the significant awareness of air pollution among the residents of Karachi, Pakistan. Therefore, examinations of $PM_{2.5}$ concentration pollutants across the metropolitan city of Karachi are deemed essential.

Material and Methods

Sampling Sites and Instrumentation

The city of Karachi is the metropolitan and 3rd largest city in the world [11-13], situated on the shore of the Arabian Sea in the south direction of Pakistan, having 24°51’N 67°02’E geographic coordinates. By way of 2013, it has assessed inhabitants of over 23.5 million, having an estimated area of 3,527 km^2, causing 6,000 people per square kilometer population density. Karachi is the economic center of Pakistan producing over 70% revenue and lodging over 70% of the varied industries. International companies also have a preference to locate their businesses in Karachi for its deep water harbor and low-cost toil in great quantity. The concentration of $PM_{2.5}$ was measured in five districts of Karachi, i.e. Malir, South, East, West, and Central (Fig. 1). To select the 50 locations in five districts of Karachi, meticulous sampling methodology was employed to ensure a representative depiction of the city's diverse land-use patterns. Firstly, Karachi's geographical area was stratified into distinct zones. Based on land-use categories such as residential, commercial, and industrial. Within each zone, potential sampling sites were chosen using a stratified random sampling technique, considering factors like population density, industrial activity, traffic volume, and proximity to measure roadways. This approach guaranteed that each land-use type was proportionately represented in the sampling framework. By employing this systematic approach, the sampling methodology aimed to provide an accurate portrayal of $PM_{2.5}$ levels across the city's diverse urban landscape. Instrument HT9600 HTI Meter $PM_{2.5}$ Air Quality Dust Humidity Detector was used through an accurateness of ±1.5 $\mu g/m^3$ and ±0.5 $\mu g/m^3$ for hourly and 24-hour average values, respectively. Data accuracy was ensured by rigorous quality control measures and timely calibration of the instrument. To address variation in pollution level hourly measurements of $PM_{2.5}$ were recorded.

Objectives and Study Design

The primary objective of this study was to investigate the levels of $PM_{2.5}$ in the ambient air of Karachi, Pakistan. The study aims to test the hypothesis that certain areas within Karachi exhibit $PM_{2.5}$ levels that exceed the WHO's recommended limits. The study was conducted over six months, from January to June 2022. A stratified random sampling technique was employed to select 50 locations within Karachi, representing various land-use patterns such as residential, industrial, and commercial zones.

Data Collection

At each of the 50 predetermined sampling locations scattered across Karahi, Pakistan, the instrument was strategically positioned to capture the ambient air quality accurately. Measurements were recorded at hourly intervals, resulting in a rich dataset comprising multiple readings for each day at every location. The codes of L1-L50 were given to each dataset which were collected daily. To compute the hourly $PM_{2.5}$ concentration, the average reading from the instrument during each hour was calculated. Subsequently, to drive the 24-hour average $PM_{2.5}$ concentration, the hourly measurements for each location on a given day were aggregated, and the mean value was determined. By transparently documenting the methodology for data collection and analysis, including the calculation of hourly and daily averages, the study promotes reproducibility and facilitates validation by fellow researchers, enhancing the credibility and reliability of the findings.

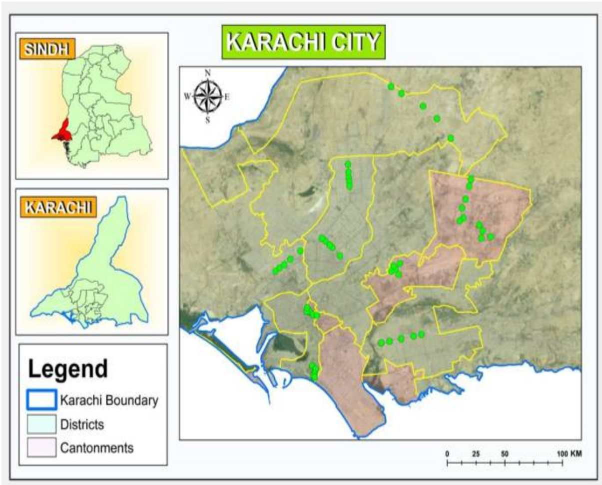

Figure 1. **Districts-wise sampling location of Karachi city**

Protocols and Strategies

The $PM_{2.5}$ standards have been recognized by varied entities to defend the environment and community health (Table 1). These standard values ascertain the permissible concentration of $PM_{2.5}$ in inhaling air, which must not go beyond a definite intermission. United States Environmental Protection Agency (USEPA) and National Environmental Quality Standards (NEQs) guidelines are similar values of $PM_{2.5}$ for 24 hrs. (average). The WHO and Sindh Environment Quality Standards (SEQS-2016) were employed to measure $PM_{2.5}$ concentrations at hourly intervals during the period of this research work.

Table 1. **Permissible limits of ambient air quality for $PM_{2.5}$.**

Indigenous and International Standards	$PM_{2.5}$ (µg/m^3)		
	Yearly Average	*24-Hour Average*	1-Hour
Sindh Environmental Air Quality Standard (SEQS)	40	75	-
National Ambient Air Quality Standard (NEQS)	15	35	15
WHO Air Quality Guidelines	10	25	1
US-EPA	15	35	-
European Union	25	-	-

Statistical Analysis

Statistical analysis of this research work data was executed using SPSS and Microsoft Excel. Pareto charts were used to represent bins which are structured from highest to lowest frequency and also comprise a line that shows commutative frequency.

Results and Discussion

$PM_{2.5}$ Concentration Data

In this study, we conducted a detailed analysis of $PM_{2.5}$ concentration levels across different districts of Karachi, Pakistan. The average concentration of $PM_{2.5}$ per day was calculated after 12 hours of data collection. The $PM_{2.5}$ occurrence days have higher daily mean concentration than SEQS ($PM_{2.5} \geq 75$ µg/m^3) permissible limit while those days that have less than SEQS ($PM_{2.5} \leq 35$ µg/m^3) are called non-occurrence days. The descriptive statistical analysis of hourly $PM_{2.5}$ concentrations gained through this research work period is shown in Table 2.

Table 2. **Descriptive statistics of hourly concentration of $PM_{2.5}$ from Jan-June 2022 (24 hrs).**

Districts	$PM_{2.5}$ (µg/m^3)				
	Min	*Max*	*Minimum Mean*	*Maximum Mean*	*Std. Dev*
West	03	349	90.3	121.4	74.67977
Malir	02	199	65.5	76.2	45.67915
South	03	374	102.7	127.1	74.0290
Central	03	337	91.1	115.6	66.0376
East	02	343	97	109.7	64.2823

As revealed in Fig. 2, raised hourly concentrations were detected for $PM_{2.5}$ and minimum mean values in Malir Districts, South District, East, West District, and Central were 65.5 µg/m^3, 102.7 µg/m^3, 97 µg/m^3, 90.3

μg/m^3 and 91.1 μg/m^3, respectively. Most of the values of $PM_{2.5}$ exceeded the permissible limits and trends are well supported by Pareto charts mentioned in Fig. 3. Our findings revealed significant variations in $PM_{2.5}$ labels throughout the city, with some districts exhibiting higher concentrations than others. This variation may be attributed to differences in land-use patterns, anthropogenic activities, traffic density, sea spring, increased oil burning, resuspension of urban dust, and other environmental factors across the districts.

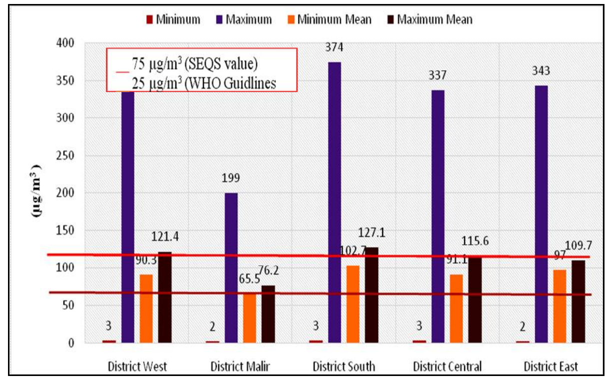

Figure 2. **District-wise values of $PM_{2.5}$ comparisons with WHO guidelines and SEQS value**

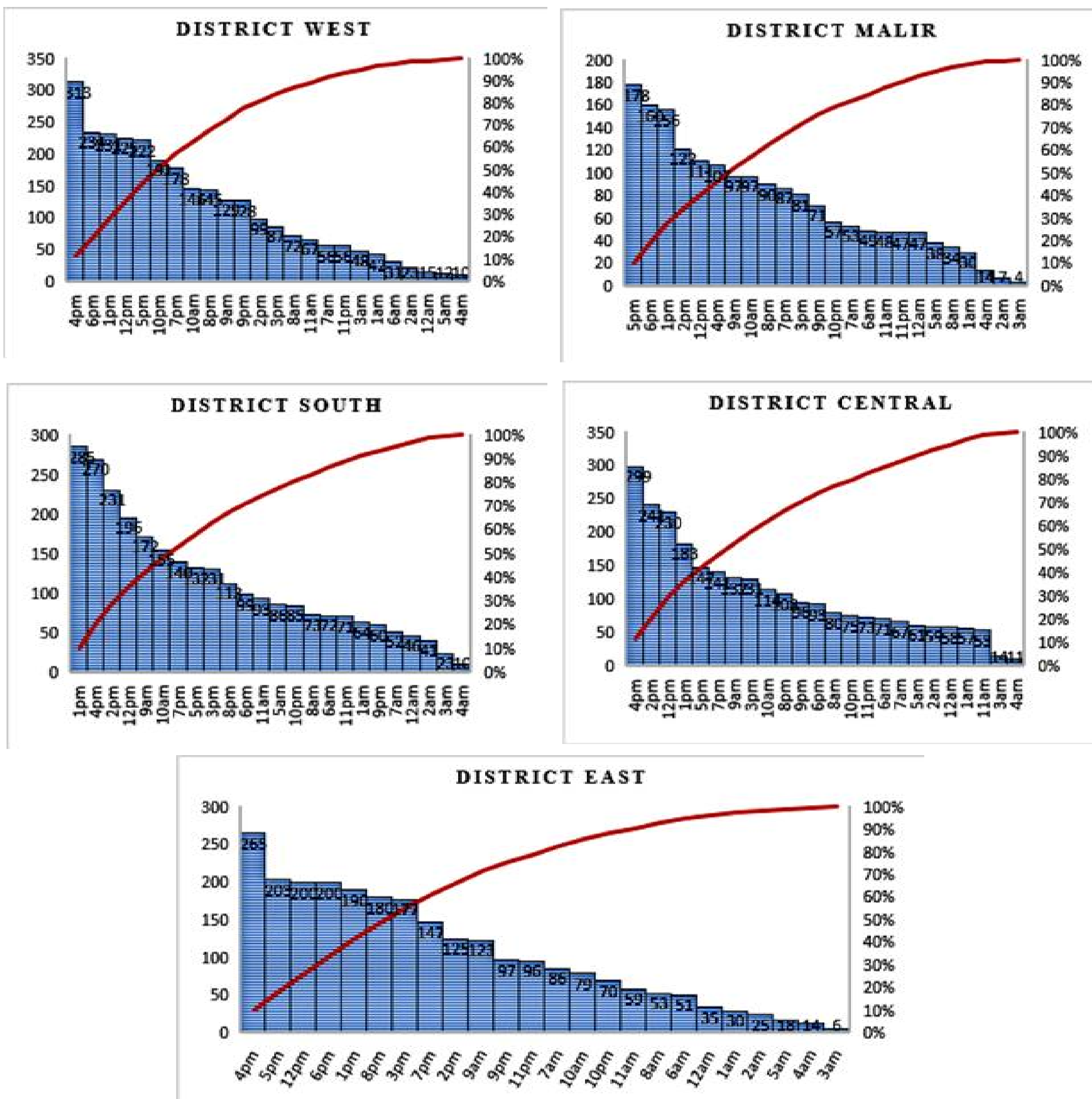

Figure 3. **Pareto chart showing $PM_{2.5}$ values in 5 districts of Karachi**

Pareto charts shows, the mass concentration indicators $PM_{2.5}$ values for the research study in five districts of Karachi city. The average minimum value of $PM_{2.5}$ was found almost high in all districts with an average value of WHO guidelines and SEQS-2016 standard values; only district Malir shows a lower value of $PM_{2.5}$ with an average concentration of SEQS-2016 standard value of 75 $\mu g/m^3$. Increased concentration of $PM_{2.5}$ in the district south which is 102.7 $\mu g/m^3$ associated with exhaust emission from transportation, construction works, and industrial and commercial activities.

Comparing our findings with established air quality standards, we found that $PM_{2.5}$ concentrations in certain districts exceeded permissible limits set by regulatory bodies. This indicates potential health risks associated with long-term exposure to elevated $PM_{2.5}$ labels in these areas. According to Fig. 2, maximum mean concentration of District West was 1.6 times greater than the SEQS-2016, 3.46 times greater than the NEQS, 4.9 times higher than the WHO limit. Similarly, the maximum mean concentration of District Malir was 1.01 times higher than SEQS, 2.17 times higher than NEQS, and 3.048 times higher than WHO limits. In District South Maximum mean concentration was 1.7 times higher than SEQS, 3.63 times higher than NEQS, and 5.084 times higher than the WHO limit. District Central's maximum mean concentration was 1.54 times higher than SEQS, 3.3 times higher than NEQS, and 4.62 times higher than WHO limits. East District's maximum mean concentration was 1.46 times higher than SEQS, 3.13 times higher than NEQS, and 4.388 times higher than WHO. As a study by Khawaja et al., 2012 [28] reported (2008-9), 24 hrs. mean concentration of Korangi was 3.5 times higher than WHO, 1.16 times of SEQS limit, and 2.5 times of NEQS meanwhile the Tibet Center's mean concentration was lower than SEQS limit but 2.09 times higher than NEQS and 2.92 times higher than WHO. It's quite clear that the maximum mean concentration of this study was significantly higher than the 2008 and 2009 studies. According to 2012-2013 $PM_{2.5}$ values in the context of intra-city comparison the mean concentration was 1.49 times higher than the recommended limits of SEQS, 3.2 times higher than NEQS, and 4.48 times higher than WHO, meanwhile in Meo et al., [26] the 2020-2021 mean values were 1.47 times higher than SEQS, 3.15 times higher than NEQS and 4.416 times higher than WHO limits.

The observed variation in $PM_{2.5}$ concentration labels across different districts of Karachi highlighted significant health risks associated with fine particulate matter exposure. Districts with higher $PM_{2.5}$ concentrations for increased health hazards, underscoring the need for targeted pollution management strategies. Moreover, the exceedance of air quality standards in certain districts emphasizes the necessity for stricter environmental regulations and monitoring of pollutant sources. Addressing sources such as industries, vehicular emissions, and biomass burning is crucial for mitigating $PM_{2.5}$ pollution and safeguarding public health in urban areas like Karachi.

It is noteworthy to mention that our analysis revealed distinct fluctuations in $PM_{2.5}$ concentrations between weekdays and weekends in Karachi, with higher concentrations observed during weekdays compared to weekends and weekends showing a slight decrease in $PM_{2.5}$ levels. The pattern reflects differences in human activities and associated emissions, such as increased vehicular traffic and industrial operations during weekdays. Understanding these weekday-weekend variations provides valuable insights for targeted pollution reduction strategies and regulatory intervention to mitigate $PM_{2.5}$ pollution in the city. By addressing sources of pollution and minimizing public health risks associated with $PM_{2.5}$ exposure, particularly during peak pollution periods on weekdays, policymakers can effectively improve air quality in Karachi.

The intra-city comparison is a glaring example that for decades and even more the outdoor $PM_{2.5}$ average concentrations (Table 2) have violated the said limits of all three standards which means that Karachiites are under constant threat of air pollution of PM which would invariably give rise to long term and acute illnesses associated with it. As shown in Table 3, intercity comparison nationally and internationally to draw out a broader spectrum understanding of $PM_{2.5}$ air pollution as in Dalian city's (China) mean concentration being 29 µg/m^3 meaning it is lesser when compared with national environmental quality standards limit of 35 µg/m^3 but it is 1.19 times higher than world health organizations designated limit. Dalian City's average concentration is lesser than max average concentration of the four districts of Karachi. While Dalian showed one of the lowest average concentrations of $PM_{2.5,}$ Beijing showed one of the highest mean concentrations of $PM_{2.5}$ which is 148 µg/m^3, which is 4.22 times higher than the NEQS and 5.92 times higher than WHO limit. Southeast Asia showed prevalent $PM_{2.5}$ mean concentrations which were some of the highest, with Manila, Philippines having 391 µg/m^3 which was 11.17 times higher than NEQS, and 15.64 times higher than the WHO limit. Badung, Indonesia had 72 µg/m^3 which was 2.05 times higher than NEQS and 2.88 times higher than WHO guidelines, Hanoi, Vietnam had one of the lowest mean concentrations which was 48 µg/m^3 which was 1.37 times higher than NEQS, and 1.92 times higher than WHO limits. Chennai, India in 2013 had 46.5 µg/m^3 mean concentration of $PM_{2.5}$ which was 1.32 times higher than the NEQS limit and 1.86 times higher than WHO limits, meanwhile in Agra (2011) had 90 µg/m^3 which was 2.57 times higher than NEQS and 3.6 times higher than WHO, Udaipur in 2010 had 32 µg/m^3 mean concentration of PM $_{2.5}$ which was lower than NEQs but 1.28 times higher than WHO. In 2013 city of Rabigh, Saudi Arabia recorded 37 µg/m^3 which was 1.05 times higher than NEQs and 1.48 times higher than WHO limits. In 1999, Bueno Aires, Argentina had 41 µg/m^3 which was 1.71 times higher than NEQS and 1.64 times higher than WHO. Although data on $PM_{2.5}$ is limited [21]; according to various studies shown in Table 3, high levels of Particulate Matter due to natural and human activity causes are responsible for generating $PM_{2.5}$ directly or gas-phase reaction in the atmosphere. $PM_{2.5}$ can be a mixture of secondary aerosols, heavy metals, water, crustal dust, carbon-based and elemental carbon [17, 22-23], while primary sources of $PM_{2.5}$ comprise motor vehicle emission, bio-mass burning, combustion of oil and coal, and industrial processes [24]. Furthermore, it is reported [25] that inorganic dust containing coarse particles of PM_{10} is also a source of $PM_{2.5}$.

The only city in Table 3, which was lower than NEQs and WHO limits was Shinjung, Taiwan, which had a mean concentration of 21.82 µg/m^3. When compared to previous studies conducted in the same geographical area, it was found that the $PM_{2.5}$ levels have shown a consistent increase over the years. This trend is alarming and calls for immediate intervention from both governmental and non-governmental organizations. While the study primarily highlights the alarming levels of $PM_{2.5}$, it catalyzes change by providing irrefutable evidence of the air quality crisis in Karachi. This could potentially lead to increased public awareness and advocacy, prompting policy changes and community-based initiatives aimed at improving air quality. The study also has social implications. The revelation of such high $PM_{2.5}$ levels could lead to public unrest, as citizens demand immediate action from authorities. Moreover, the healthcare system may face increased pressure due to a potential rise in respiratory illnesses linked to $PM_{2.5}$ exposure.

Table 3.**Comparative study of ambient air quality for $PM_{2.5}$.**

Reference	Location	Exposure type	Level (µg/m^3)
Meo et al. [26]	Karachi, Pakistan	Ambient, 24 hrs	110.4
	Lahore, Pakistan		174.0
	Islamabad, Pakistan		107.1
Niaz et al. [27]	Dalian City, China	Ambient, 24 hrs	29.8
	Bangkok, Thailand		143.0
	Beijing, China		148.0
	Chennai, India		46.5
	Badung, Indonesia		72.0
	Manila, Philippines		391
	Hanoi, Vietnam		48.0
Khwaja et al. [28]	Korangi, Pakistan	Ambient, 24 hrs	87.50
	Tibet Center, Pakistan		73.20
Nayebare, et al. [29]	Rabigh, Saudi Arabia	Ambient, 24 hrs	37.0
Pipal et al. [30]	Agra, India	Ambient, 24 hrs	90.0
Gugamsetty et al. [31]	Shinjung, Taiwan	Ambient, 24 hrs	21.82
Yadav et al. [32]	Udaipur, India	Ambient, 24hrs	32.0
Bogo et al. [33]	Buenos Aires, Argentina	Ambient, 24 hrs	41.0
Khan et al. [34]	Karachi, Pakistan	Ambient, 24 hrs	112.0

Conclusion and Recommendation

This research work sheds light relating to levels of $PM_{2.5}$ in the ambient air of Karachi, Pakistan. The five districts of Karachi practiced higher levels of $PM_{2.5}$, where the maximum allowable limits of SEQS and WHO were frequently disrupted. As a result, short and long-range policies must be applied to overcome the concentration of inhaling $PM_{2.5}$ thereby uplifting the environment that in sequence would improve the human life quality. The observed higher concentrations in specific districts, particularly during weekdays, emphasize the critical health risk caused by fine particulate matter pollution. To address this challenge effectively, policymakers and stakeholders should enforce strict emission standards for industries and vehicles, while promoting cleaner energy sources and green technologies. Implementing low-emission zones and congestion pricing can reduce vehicular emissions while enhancing urban green spaces that can absorb pollutants. Moreover, proactive public awareness campaigns and community engagement initiatives are essential to mobilizing residents to contribute to pollution reduction efforts. To see the dispersal of $PM_{2.5}$ in the inhaling air of Karachi city, a comprehensive exploration of the city for all weathers is desirable. Distant from indigenous pollution bases, there may be peripheral bases of pollution positioned outside the study zone.

All stakeholders must take a vital role in controlling the anthropogenic activities and level of $PM_{2.5}$ in inhaling air, which may be accomplished by governing the point source discharges, promoting eco-friendly transportation, supporting green culture, and educating the general public about problems of environmental humiliation. By swiftly implementing these measures based on our study findings, Karachi can mitigate the inverse health impacts of $PM_{2.5}$ pollution and pave the way for improved air quality and public health outcomes citywide.

Conflict of Interest Statement

The author affirms that the study was conducted in the absence of any viable or commercial interactions that could be interpreted as a prospective conflict of interest.

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