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Environmental Monitoring of Smog in Lahore Metropolitan Area Using GIS Technology.

Original Article

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Smog, a combination of polluted gasses or smoke with fog, brings a harmful breathing environment that mostly exists during the pre-winter season in Lahore. The smog episodes are prevailing over the city which are getting aggregated by smoky fumes, impurities, and dust particles. Severe smog episodes were observed over Lahore mainly during November and December 2019, resulting in adverse environmental conditions e.g., eye irritation, breathing difficulty, and creating very low visibility in and around Lahore. This study is based on eighty-five sample sites from all over Lahore city, to measure the Particulate Matter during smog season. In this study, the risk zones are demarcated based on land use and land covers during pre-winter seasons. It has been revealed through geospatial technology and the evaluation of weather data that local pollution has a greater contribution towards deteriorating the quality of air as compared to the contributions which are regionally active during the smog season. Spatial dispersion of smog has shown the local industrial and vehicular emissions as the major contributor of smog rather regional diffusion of pollutants.

Keywords: Smog, Particulate Matter, Land use, Land cover.
Project details. Nil
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Author's Contribution. All authors contributed significantly to the study.

Introduction

Environmental quality has been worsened due to a rapid increase in population growth resulting in rapid urban expansion causing a higher amount of energy consumption. Environmental pollution has been aggravated by excessive industrialization, increased use of fossil fuels (especially of poor quality), and a higher level of vehicular emissions[1]. A higher level of energy consumption is causing a high level of air pollution to reach its epidemic level. The effects of air pollution are very harmful to humans, as well as plants. Air pollution can be linked to many health-related issues, as it is one of the main reasons behind pulmonary, respiratory, and skin diseases across the globe [2].

Most of the Pakistan lies in the tropical and temperate zones; it experiences four seasons in which summers are usually extended than winters. Areas near to the coast experience mild summers and mild winters. Temperature variations are also found all over Pakistan[3]. Pakistan contributes less to greenhouse gas emissions worldwide but faces negative impacts of climate change and very high vulnerability [4]. Smog has been added as a fifth season in Pakistan, which comes every year in October and ends in February [5].

Smog, a major hazard which is caused by air pollution, has disastrous impacts on the environment, health, transportation, and educational sectors. The word "smog" comes from the combination of two different words, "fog" and "smoke". It holds a meaning of fog that contains smoke in it. The burning of fossil fuel brings out numerous amounts of invisible carbon particles, which, when combined, form smoke[6]. It is mainly because when fossil fuels do not get enough amount of oxygen to burn, many tiny and unburned particles are released into the environment in the form of ash particles. These suspended particles are known as smoke [7]. Various environmental and meteorological factors support the smog phenomena. Mainly the automobile emissions and burning of leftovers of the harvested crops, especially wheat, cotton, maize, and sugarcane plants, as well as industrial emissions are the main cause of smog. Every year, the crops are harvested in Indian and Pakistani Punjab during the post-monsoon season, and the residues of these crops are burnt. The fumes of these burnt crops produce smoke, and this smoke is then transported to other parts of the regions through wind which eventually produces smog [8].

Smog affects human health and our day-to-day life and is directly proportional to low temperature, less wind speed, and less amount of sunlight. It has a chemical composition of Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), and Nitrogen monoxide (NO) with water vapors[9]. During the daytime, sunlight heats the gasses near the earth's surface. The less-dense heated air tends to raze, but due to less wind or no wind, it gets stagnant. These stagnant gasses react with emissions in the presence of sunlight and create smog phenomena [10].

In recent years we have seen disastrous phenomena related to air pollution, which have increased in intensity and severity with time. On the 2nd to 5th of November 2016, an event associated with smog occurred in Lahore [11]. As a result, the visibility was very low which has restricted the human mobility. The study was conducted to assess the comparison of ambient air measured in the first week of November 2016 and the ambient air quality measured during the same period of the previous year[12]. The results were higher than the previous year, *i.e.*, NOx was assessed to be almost 17 times higher than the previous year's value. SO_2 and O_3 were 4 times higher[13]. CO, VOC, and $PM_{2.5}$ were two times, and PM_{10} was six times higher than the previous year. Studies revealed that there was a 60 % increase in the number of patients reported with ocular surface diseases (dry eyes, irritation, lid erosion, corneal diseases, conjunctival diseases, uveitis, and lacrimation) during periods of smog as compared to baseline conditions. During the smog event, the temperature was cool,

with calm wind, and a high rate of humidity that boost the photochemical reaction, which caused the smog [14].

The extreme smog effected human health, the flora and fauna, and transportation sectors. This research highlights that a decrease in individual wastage, awareness about the use of public transport, and creating an awareness in farmer community for not burning stubble play a vital role to decrease smog level [15]. On the way round, smog creates vital impacts in term of various diseases e.g., exacerbation of asthma, eye infection, and cardiac pathologies, which ultimately lead to death. Many stern recommendations are given through which the extreme effects could be minimized; first, prudent measures are needed to improve air quality; secondly, provision of specialized equipment, standardized protocols, and acquisition of trained personnel. Finally, the Government should allocate appropriate funds to educate people to protect themselves amid hazards through rigorous awareness campaigns [16].

The burning of coal released black carbon eventually becomes a part of our atmosphere. It absorbs the radiations coming from the sun and increases the atmospheric temperature that lead to decrease the air quality. It causes many health problems like respiratory and cardiovascular problems [17].

Problem statement

Lahore is considered one of the most polluted cities in the world due to the heavy blanket of smog during the winter season [18]. Urbanization and industrialization also contributed a lot to contaminating the air quality, which is becoming worsen day by day. Smog which is one of the factors in polluting the air quality also involves many health-related issues. The main objective this was study to explore the pattern of pollutants dispersion and to identify the major contributors of this menace.

Study Area

Lahore is one of the largest cities in Pakistan, having a population of 11.12 million as per recent population census of 2017. The central area is comprised of generally poor and middle-class residential use and some commercial land use. Besides, other areas are ill planned areas comprised of uncontrolled and mixed land use related to residential and commercial activities. The outskirts of Lahore are comprised of many planned societies that are located outside the Ring Road. Along with these planned societies, many villages are also located. The outer zone comprises of higher-class income group that lives in planned societies, whereas the lower-class income group lives in the adjacent villages.

Lahore is the second largest city in Pakistan experienced smog season in 2019 from October to February. Its Air Quality Index (AQI) reached 598, and vacations were announced as it was dangerous for kids to go to school. Air Quality is considered morbid when it reaches 100, and at 300 and above, it is hazardous. One should wear a mask while going out in such a condition. Smog in Lahore is mainly due to traffic pollution, dust coming from deserts, domestic and industrial level coal consumption, and fossil fuel burning [19].

Air quality is determined by the measure of $PM_{2.5}$ and PM_{10} concentrations in the sample air given in g/m^3 [12]. The transport and industrial sectors are mainly the cause of ambient air pollution in Lahore. The climate of the city remains semi-arid throughout the year, and it allows the pollutants to submerge in the air easily. Urbanization and rapid increase in the automobile industry led to harmful effects on the air quality of the city.

Data and Its Sources

The main objective of this study is to measure the concentration of pollutants like PM_{10}, $PM_{2.5}$, and other environmental variables during pre-winter months [12]. This will eventually draw a comparison with the air quality standards. In this duration, the variables were collected from eighty-five (85) sample sites that belong to nine (9) different land uses.

The unchecked economic development, as well as the population increase, will damage the natural resources and have a strong impact on the environment. This study will access the concentration of pollutants from which the air quality of this city becomes deteriorated.

The monitoring site represents the concentration of particulate matter over a large area that shows the true picture of the environmental characteristics of the city. The air quality monitoring was done over different geographical areas, *e.g.*, residential, commercial, main road crossing, main road and commercial, residential and commercial, hospitals, parks, education, and water bodies. Together, these are nine different land uses that belong to the major Central Business District (CBD).

Conceptual Framework

For sustainable development of the city or urban center, it is important to know the need for an improved attitude and mindset. We need to know the real data that shows the environmental conditions of the area in which we are interested. For this, the data were collected seasonally, *i.e.*, during the pre-winter season. Samples were collected twice a month, and the duration of data collection is from 1st November 2019 to 15th December 2019. Most of the smog saturation points were gathered through a topographical sheet, pictorial data, and field observation to set the sample stations in Lahore city. For this, a complete set of land use/cover was under consideration that meets the requirement of the study. This allow covering the required areas in which we witnessed smog contamination. Pollutants like $PM_{2.5}$ and PM_{10} were studied along with their relationship with temperature, humidity, wind speed, and wind direction. These sites were identified to experience a clear picture of the situation during pre-winter.

With the help of weather data, areas that face smog contamination will be identified and will be classified according to urban, semi-urban, rural, roadside, and remote rural sites. Secondly, for the special spread of smog, each area will be observed twice a month, and finally, the mapping will be done through the GIS techniques. Each targeted site have been assessed according to the contaminants that were found in the air. Recommended Dust Particle Counter device was used to collect the primary data ($PM_{2.5}$ and PM_{10}) from the selected eighty-five (85) sites.

Results and Discussion

During the period from 1st December 2019 to 29th February 2020, the wind blows from the Northwest and Northeast at 0800PST. Whereas, North-west and West at 1700PST. The average wind speed is 1.58 knots, and 64.84% of the wind speed is calm at 0800PST. Similarly, the average wind speed is 2.06 knots, and 19.78% of the wind speed is calm at 1700PST. (PMD, 2021) During this season (1st November to 15th December 2019), the data related to $PM_{2.5}$, PM_{10}, temperature, and relative humidity was gathered from eighty-five (85) different sites, which represent nine (9) different land uses.

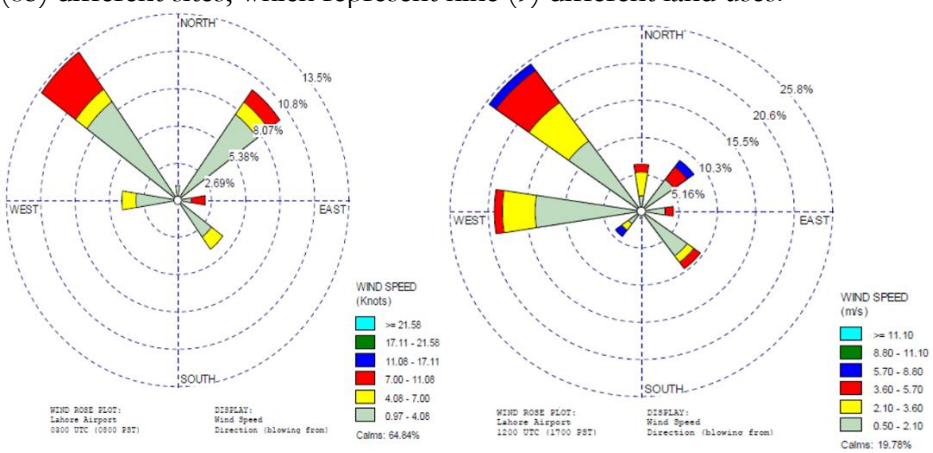

Figure 1: Wind Rose of Winter Lahore at 0500PST & 1700PST 2019-2020 (PDM, 2021)

Residential Areas

In the residential type of land use, Wahdat Colony (average 155 μgm^3) has the lowest concentration, and Township (average 416 μgm^3) has the highest concentration of $PM_{2.5}$. Similarly, Gulshan-e-Ravi Block "A"(average 322 μgm^3) has the lowest concentration, and Township (average1342 μgm^3) has the highest concentration of PM_{10}. The average temperature ranged from 26.9^0 C to 15^0 C, whereas the relative humidity was between 63% to 47.8%.

Main Road Crossings

In this category, Campus Bridge (average 143 μgm^3) has the lowest concentration, and Shalimar G.T Road (average 408 μgm^3) had the highest concentration of $PM_{2.5}$. Similarly, Campus Bridge (average 588 μgm^3) had the lowest concentration, and Babu Sabu (average 1897 μgm^3) had the highest concentration of PM_{10}. The average temperature ranges from 27.8^0 C to 16^0 C, whereas the relative humidity ranged between 67% to 45.7%

Main Roads and Commercial Land use

This important land use of the Lahore City showing Metrology Department Jail Road (average 174 μgm^3) had the lowest concentration, and Yateem Khana (average 299 μgm^3) had the highest concentration of $PM_{2.5}$. Similarly, Meteorology Department Jail Road (average 686 μgm^3) had the lowest concentration, and Yateem Khana (average 1099 μgm^3) has the highest concentration of PM_{10}. The average temperature ranges from 26.89^0 C to 13.38^0 C, whereas the relative humidity stays between 54.8% to 45.03%.

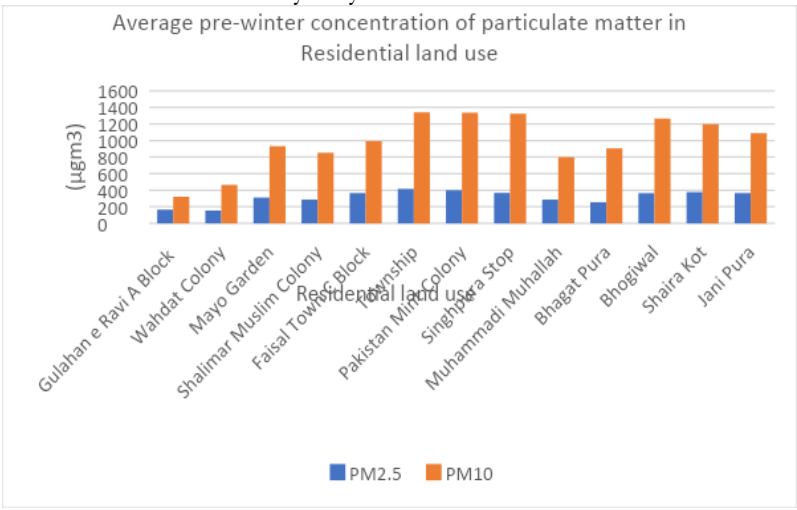

Figure 2: Average pre-winter concentration of PM10 & PM2.5 in Residential Land use, Lahore

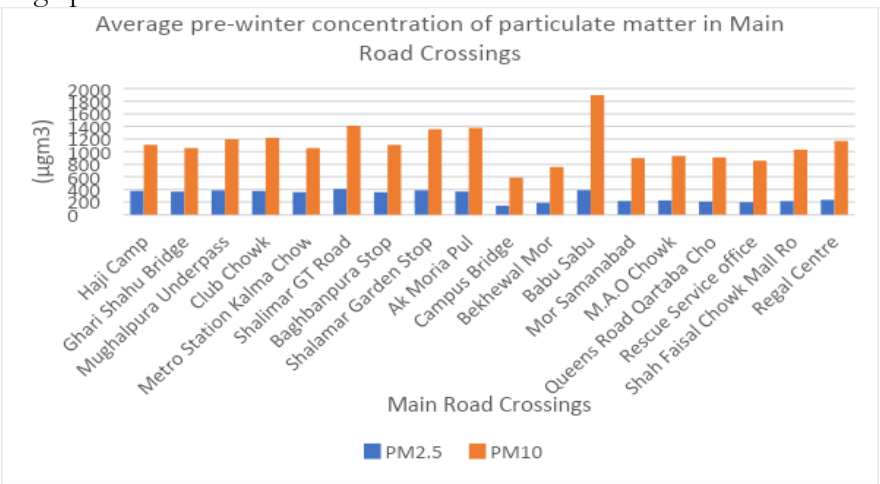

Figure 3: Average pre-winter concentration of PM10 & PM2.5 near main road crossings, Lahore

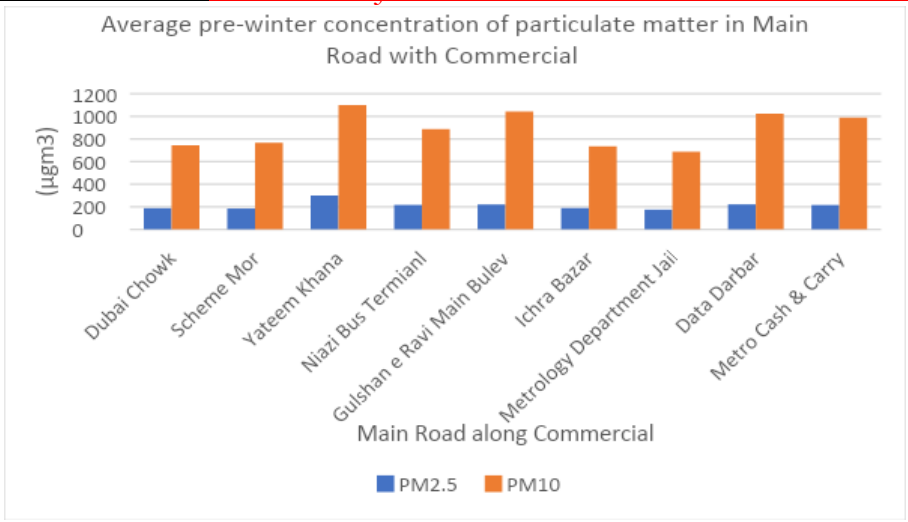

Figure 4: Average pre-winter concentration of PM2.5 & PM10 in main roads with commercial land use, Lahore

Residential and Commercial (Mixed Land Uses)

Muslim Town (average 198 µgm^3) had the lowest concentration, and Nabipura Gulberg (average 357 µgm^3) had the highest concentration of $PM_{2.5}$. Similarly, ACRO Paints Bund Road (average 1198 µgm^3) had the lowest concentration, and Muslim Town (average 826µgm3) had the highest concentration of PM_{10}. The average temperature ranges from 26.62^0 C to 19^0 C, whereas the relative humidity stays between 63% to 48.6%.

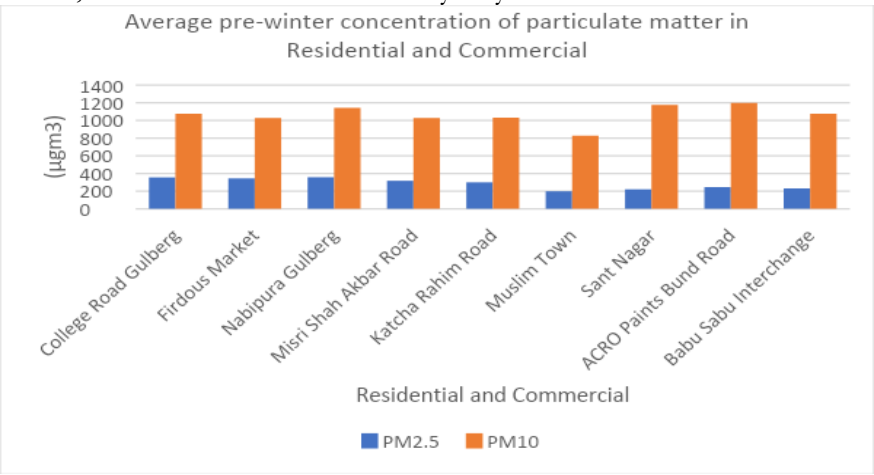

Figure 5: Average pre-winter concentration of PM2.5 & PM10 in residential & commercial land use, Lahore

Hospitals

In this category, Jinnah Hospital (average 201 µgm^3) had the lowest concentration, and United Christian Hospital (average 376 µgm^3) had the highest concentration of $PM_{2.5}$. Similarly, Jinnah Hospital (average 832 µgm^3) had the lowest concentration, and Sir Ganga Ram (average 1208µgm^3) has the highest concentration of PM_{10}. The average temperature ranged from 26.63^0 C to 16^{0}C, whereas the relative humidity was between 59% to 45.3%.

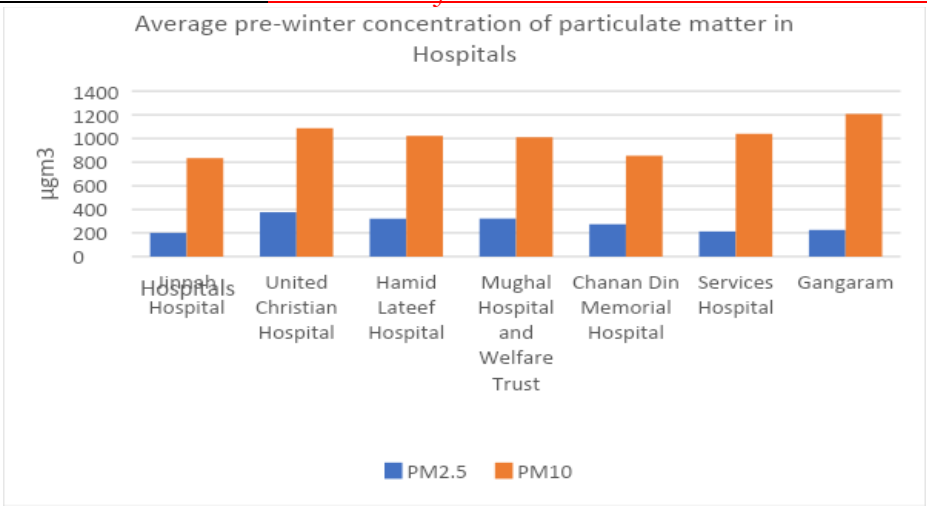

Figure 6: Average pre-winter concentration of PM2.5 & PM10 near hospitals, Lahore

Educational Institutes

Educational Institutes category showing Gulberg College (average 105 µgm^3) had the lowest concentration, and Superior Shalimar Campus (average 342 µgm^3) had the highest concentration of $PM_{2.5}$. Similarly, CIMR (average 731 µgm^3) had the lowest concentration, and UVAS (average 1050 µgm^3) has the highest concentration of PM_{10}. The average temperature ranged from 26.76^{0}C to 15^{0}C, whereas the relative humidity was between 42.2% to 65%.

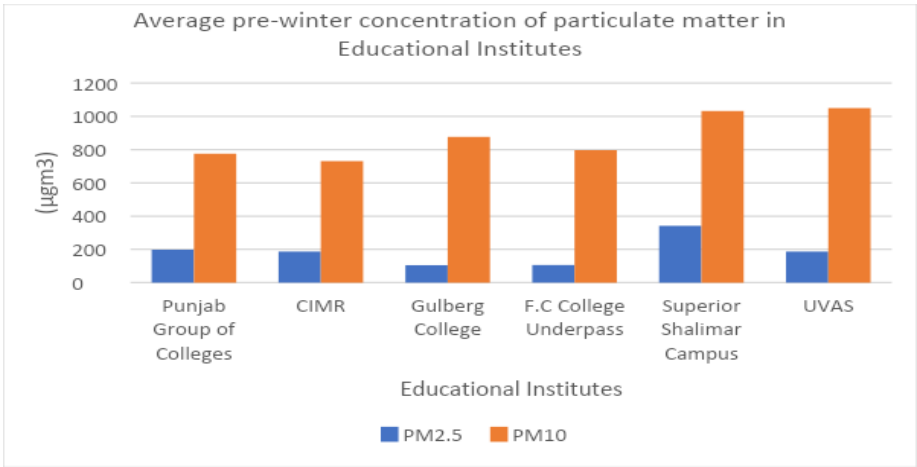

Figure 7: Average pre-winter concentration of PM2.5 & PM10 near educational institutes, Lahore

Parks

This land use depicting, Race Course Park (average 177 µgm^3) had the lowest concentration, and Shalamar Park (average 377 µgm^3) had the highest concentration of $PM_{2.5}$. Similarly, in forested areas, Shahdara (average 649 µgm^3) had the lowest concentration, and Shalamar Park (average 1396 µgm^3) had the highest concentration of PM_{10}. The average temperature ranged from 26.9^0 C to 16^0 C, whereas the relative humidity was between 47.4% to 63.1%

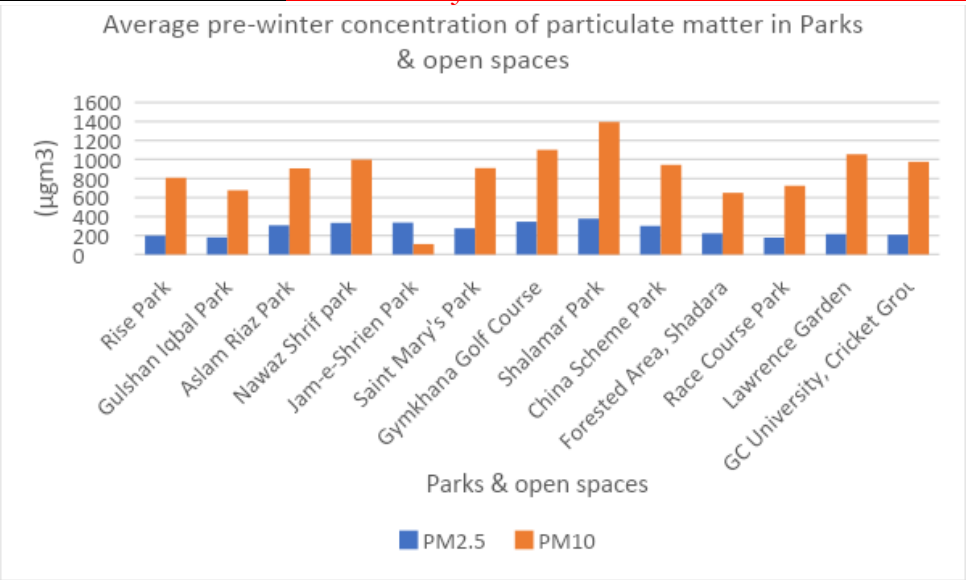

Figure 8: Average pre-winter concentration of PM2.5 & PM10 near parks & open spaces, Lahore

Commercial

Commercial concentration areas such as Karim Block (average 216 µgm^3) had the lowest concentration, and Mini Market (average 357 µgm^3) had the highest concentration of $PM_{2.5.}$ Similarly, Karim Block (average 867 µgm^3) had the lowest concentration, and Mini Market (average 1156 µgm^3) had the highest concentration of PM_{10}. The average temperature ranges from 15 ºC to 26.76 ºC, whereas the relative humidity remained between 51.9% to 61%.

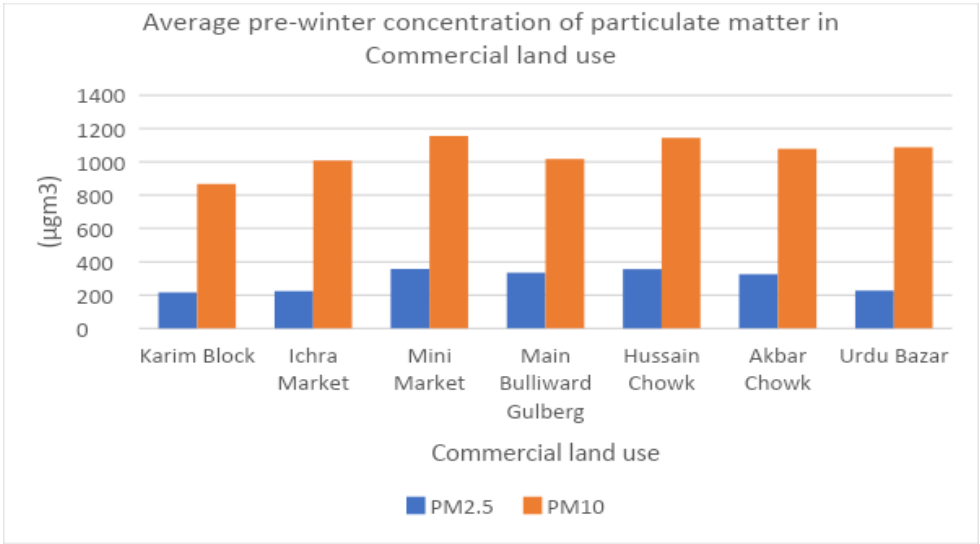

Figure 9: Average pre-winter concentration of PM2.5 & PM10 in commercial land use, Lahore

Water Bodies

Among the major water bodies of Lahore city, Waris Shah Underpass Canal (average 187 µgm^3) had the lowest concentration, and Faiz Ahmad Faiz Underpass Canal (average 235 µgm^3) had the highest concentration of $PM_{2.5}$. Similarly, Waris Shah Underpass Canal (average 698 µgm^3) had the lowest concentration, and Faiz Ahmad Faiz Underpass Canal

(average 1032 µgm^3) had the highest concentration of PM_{10}. The average temperature ranged from 16.3ºC to 24.9ºC, whereas the relative humidity was between 64.2% to 48.5%.

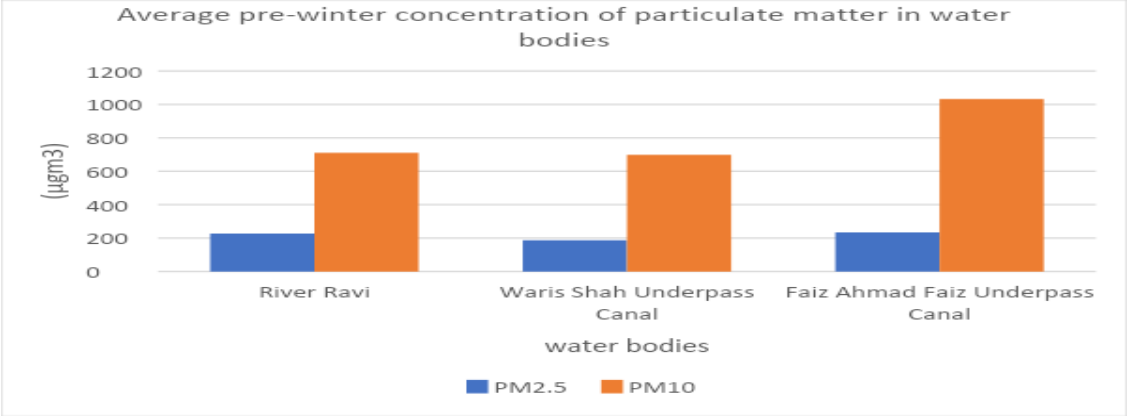

Figure 10: Average pre-winter concentration of PM2.5 & PM10 near water bodies, Lahore

Conclusion

It has been revealed from this study that a significant association between smog and land use and land cover has been established (or $PM_{2.5}$ and PM_{10} concentration). The smog episodes and fine particulate air pollution had bigger and more detrimental impacts on residents, especially those living close to high to moderate risk zones.

Risk Zones

Based on the facts derived from the statistics of Particulate Matter concentration, weather variables, and visual surveying, risk zones are identified, which have demarcated the areas of very high concentration to very low concentration. The mean value was taken out from all the sample sites, and a total risk zone of $PM_{2.5}$ and PM_{10} was derived. Following is the graphical description of the total average $PM_{2.5}$ and PM_{10} concentrations.

Very Low-Risk Zone

This is the zone of very low concentrations of $PM_{2.5}$ and PM_{10}. Areas that include in the $PM_{2.5}$ zone are usually in the center, western, and southwestern sides of the city. These areas face a very low concentration of $PM_{2.5}$ throughout this duration. Areas include Canal Road, Gulbarga, Jail Road, Shadman, some areas along Ferozepur Road, and parts of Mall Road. The concentration of $PM_{2.5}$ is very low in this risk zone and is considered safe and favorable for the population. Similarly, areas that are very low in PM_{10} concentration are located in the city center. It was observed that there are big parks and open spaces in the city center like Racecourse Park, Lawrence Garden, Nawaz Sharif Park, and open spaces of Punjab University. This will minimize the $PM_{2.5}$ and PM_{10} concentrations.

Low-Risk Zone

Areas that include in the $PM_{2.5}$ zone are usually around or in the surroundings of the city center to the western side and southern sides of the city (Map 9). These areas face low concentrations of $PM_{2.5}$ throughout the season. The concentration of $PM_{2.5}$ is low in this risk zone and is considered as not vulnerable to the population concentration. Similarly, areas that are low in PM_{10} concentration (Map 10) are located around the city center and in the southern parts of the city. These areas include parts of Model Town, Kot Lakhpat, Faisal Town, Johar Town, Mughal Pura, and some patches of G.T Road.

Moderate Risk Zone

Areas that include in the $PM_{2.5}$ zone are usually away from the city center and southern sides of the city (Map 9). These areas face moderate concentrations of $PM_{2.5}$

throughout the season. The concentration of $PM_{2.5}$ is moderately affecting population concentration with facts close to unhealthy air. These areas include Model Town, Faisal Town, Johar Town, and Cantonment. Similarly, areas that are moderate in PM_{10} concentration are located away from the city center. Mostly, the northern, southern, and western parts of the city are included in this zone. These areas include parts of Model Town, Kot Lakhpat, Johar Town, Mughal Pura, and its neighboring localities, and areas along the ring road in the north and the west.

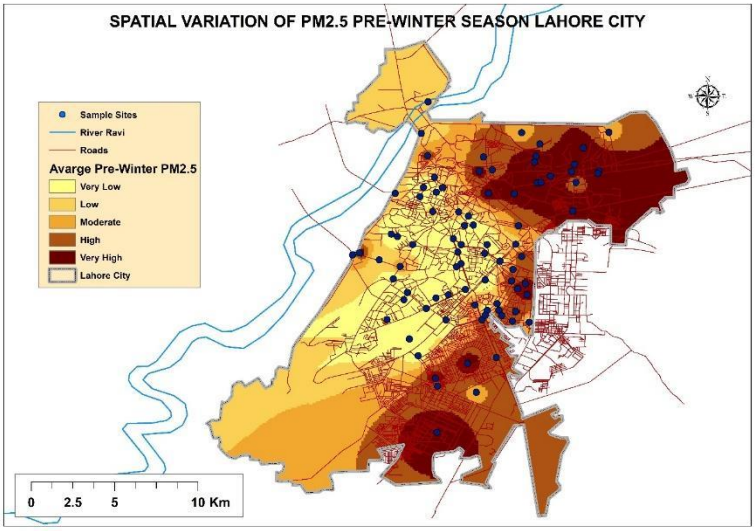

Figure 11: Spatial variation of the Concentration of $PM_{2.5}$

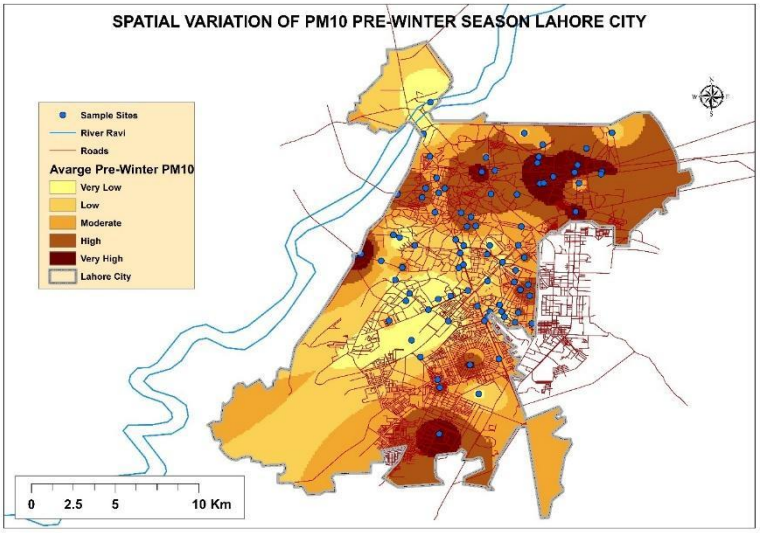

Figure 12: Spatial variation of Concentration PM_{10}

High-Risk Zone

Areas that include in the $PM_{2.5}$ zone are usually on the sides of the city center and mostly in spots. These sports are highly concentrated and are found in the city north to East and on the southeastern sides. These areas are at high risk which experiencing unhealthy air. Similarly, areas that are high in PM_{10} concentration are located in the north and south of the city center. The major concentration is found in the north of the city close to the ring road whereas sports are found in the west and south of the city. Sports in Model town are only found in the city center.

Very High-Risk Zone

This is the zone of very high concentrations of $PM_{2.5}$ and PM_{10}. Areas that include in the $PM_{2.5}$ zone are usually on the northeastern side city that remains concentrated through the season. Kot Lakhpat and its surrounding localities experience massive concentration. These areas are at very high risk and experiencing very unhealthy air. Similarly, areas that are high in PM_{10} concentration are located in the north and west of the city center. The major concentration is found in the west as well as in Kot Lakhpat and its surrounding localities.

It has been fond from this study that smog concentration has positive association with the human assembly and mobility. It has been recommended that high concentration of green areas may be able to mitigate the effects of smog in a Metropolitan City like Lahore.

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