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Comparative Assessment of Air Pollutants and Associated Health Impacts in Urban and Rural Mardan

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Abstract

This study conducts a comparative assessment of ambient air pollutants and associated health impacts across urban and rural areas of Mardan, Pakistan. Rapid urbanization, increased vehicular emissions, industrial expansion, and biomass burning have contributed to deteriorating air quality in the region. Using field-based measurements and the study examines concentrations of $PM_{2.5}$, PM_{10}, CO, and NO_2, along with health effects. Air sampling results reveal significantly higher pollutant concentrations in urban areas, with $PM_{2.5}$ averaging 583.19 µg/m³ and PM_{10} 742.73 µg/m³—far exceeding WHO and NEQS standards. Rural concentrations, although lower, also surpassed safe limits, largely due to biomass burning and brick kiln activities. CO and NO_2 levels were substantially higher in congested urban zones, reflecting direct links to traffic and combustion sources. One-way ANOVA confirmed statistically significant differences ($p < 0.05$) between urban and rural pollutant levels. Reported health issues included respiratory irritation, coughing, eye redness, and reduced lung function, particularly among roadside vendors with prolonged exposure.

The study concludes that urban Mardan faces more severe air quality challenges and emphasizes the need for enhanced monitoring, public awareness programs, green infrastructure, and policy interventions to reduce pollutant emissions and mitigate long-term health risks.

Keywords ; Air pollution; Health impacts; Mardan; Particulate matter; Urban–rural comparison; Vehicular emissions

Introduction

Air is a blend of various gases that cover the earth and play imperative role in the life existence. Human survival requires constant supply of clean air in the range of 10- 20 m 3/day (Park, 2005). Air pollution is any short-lived or persistent changes in the Earth atmospheric structure that are brought about by polluting agents of anthropogenic and natural nature that result in environmental alteration that ultimately creates an impact to the living organisms (Painter, 1974). The global population growth and urbanization has been a reason behind a noticeable increase of sources and types of air pollutants in the world coupled by subsequent surge of energy demand and resulting automobile surges (Gurjar et al., 2008). The loss of agricultural land, crowded metropolitan areas, and complicated urban layouts are all consequences of population increase. Additionally, it can result in adverse meteorological conditions (Habitat, 2016). This increases the amount of pollution that exceeds the airborne dispersion's carrying capacity and the air's diffusion, resulting in atmospheric pollution. The transportation sector contributes over 80% of the pollutants to the environment, and anthropogenic activities are a major contributor to the cumulative pollutant emissions created by heavy industries and power plants (Moller et al., 1994).

Ambient air quality is the natural, uncontaminated state of the surrounding air (Khwaja and Shams, 2020). Point and nonpoint, indoor and outdoor, air pollution can be classified as main or secondary, hazardous or non-hazardous, based on its origin and characteristics (Singh, 2024).Air pollution of the ecosystem is enhanced by heavy industrial activities, increase in population and the developing transportation industry (Hopke et al., 2008). Owing to their dependence on fossil fuels to provide energy to their industries, industries are part of the

economic development of a given country but their energy consumption releases different pollutants in the atmosphere (Sarker, 2024).

The CO, SO2, NO2, PM, Pb and O3 are the pollutants of high interest as far as the causes of air quality problems as well as health effects are concerned. Nevertheless, there are other air pollutants that can be detrimental to living beings (Khwaja and Khan, 2005). Since the Industrial Revolution began, the amount of carbon dioxide in the atmosphere has grown. The processing of H and NH3 and the buffering of limestone are examples of industrial activities that are the primary cause of CO2 emissions. They believe that one of the natural sources of CO2 in the atmosphere is volcanic eruptions, which occur when carbon-containing minerals react with lower-pH water (Cicerone and Oremland, 1988).

The tasteless, odorless, almost invisible carbon monoxide (CO) is one of the primary pollutants. Because of its oxidation to CO2, it is less persistent within the atmosphere and has a higher density than air (Pope III and Dockery, 1992). Fossil fuels are highly ranked as air pollutants since they burn completely unevenly in power plants, automobile engines, and heating industries. Deforestation, crop residue burning, and wildfires all emit significant amounts of CO (Godish, 2003). Automobile emissions are one of the primary sources of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) that worsen outdoor air quality because of incomplete burning of fossil fuels including coal, gasoline, and diesel (Sahlberg et al., 2013).

When emissions from various sources, such as coal-burning plants, automotive exhaust, and industrial facilities, are exposed to sunlight, they go through a photochemical process that creates nitrogen oxides which are ozone precursors and troposphere ozone (O3). Due to environmental conditions and significant precursors in the atmosphere, ground-level ozone is one for the second pollutants that require attention (Geddes and Murphy, 2012).

Problem Statement

Air quality is an important challenge in both developed and developing world. One of the biggest challenges encountered by a developing South Asian nation such as Pakistan would be atmospheric pollution, among other environmental concerns. The health problems caused by polluted air bring about severe complications both in town and countryside. This is especially true in urban centers where automobile emissions together with industrial and energy production are very large. Those pollutants may cause severe health disorders, which might be respiratory and cardiovascular diseases, and influence the overall quality of life greatly. The level of pollution has been found to be excessively high in most cities. Large urban centers have been given a fair share of air quality oversight and control, but small cities and those in the country have been immune to the same.

The second largest city of Khyber Pakhtunkhwa province is called Mardan. It is also a rapidly developing city of Khyber Pakhtunkhwa. Air pollution in the city is caused by various sources that include vehicle emission, industrialization and burning of biomass in the countryside. Continuous air quality monitoring is deficient which affects the ability to monitor the trends of pollution. The comparative studies on the ambient air quality of urban and non-urban settings have not yet been done in place, and there is lack of sufficient information on pollution rates amid these conditions.

Research Objectives

1. To determine the concentration of air pollutants in urban and rural areas in Mardan
2. Comparative analysis of the health impacts of air pollution among highly exposed populations

Significance of the study

Air pollution is one of the current global environmental problems. One of these things however is the absence of adequate monitoring stations and regulatory mechanism in third world countries. This research will seek to present real-time information of air pollution and its effect on the so-called vulnerable populations that are the roadside vendors, and the perspectives of the people of urban and rural Mardan. The paper provides a comprehensive

understanding of the impacts of air pollution on health through the synthesis of scientific facts and the opinions held by the citizens.

This research will be very beneficial to policy makers, environmental organizations and health authorities to develop specific interventions to reduce air pollution. The comparative study of urban and rural areas will aid to trace the location-specific patterns of pollution and health risk in order to respond to the addressed problem regionally. There are a high societal and environmental benefits of study. Awareness of the people and sellers regarding the issue of air pollution and its potential impact on health will facilitate the promotion of preventive measures such as the use of masks and the improvement of city structure. These findings could be formed at the basis of the future research, particularly in the regions where there is a lack of information about air quality.

Literature Review

A major problem in the most populated cities is air pollutants, as many of the urban and suburban regions remain polluted with air, exposing people to air pollution. In urban areas, fuel combustion at home is the greatest contributor of air pollution although automobiles considerably rise the total number of emissions. In order to reduce the population's exposure, the main causes of poor air quality should be identified (Sharma et al., 2017).

Air Pollution in Pakistan

Over twenty thousand brick kilns are contributing to the air pollution in the environment in Pakistan. The burning in these brick kilns frequently involves the use of rubber that emits PM, CO and other harmful emissions that worsen the quality of air (Idrees et al., 2023). In rural territories, the level of air pollution is extremely high because of an overload of the air with particulate matter during winter periods because of the burning of biomass and the activities of the brick kilns. A report in India shows that the emission of PM 2.5 in the air by brick kilns contributes 15 percent to the pollution in Delhi (Patel, 2023).

Two twin cities in Pakistan, Rawalpindi and Islamabad, had high PM10 levels of 184 µg/m3 and 121 µg/m3, respectively, according to an air quality survey. Additionally, the CO2

concentrations in Islamabad and Rawalpindi were 385 and 409 parts per million, respectively. On the contrary, it was discovered that the levels of NOx and O3 were below what was permitted (Shahid et al., 2019). In a study conducted in Islamabad, Pakistan, throughout the winter, the PM2.5 concentration was tracked by Rasheed et al. (2015). Between 2007 and 2011, the highest concentrations were 303 µg/m3, 495 µg/m3, and 379 µg/m3. Even yet, the average yearly concentration was 98 0 3 in Islamabad, 150 0 3 in Lahore, and 104 0 3 in Peshawar.

A rise in the concentration of PM2.5 in the ambient air has been detected by an air quality measurements exercise carried out in Lahore, Pakistan of carbonaceous species of PM2.5 and this is an extreme danger to health. Much higher amounts of organic and elemental carbon on the PM2.5 were found above the allowable limit. Carbon containing PM 2.5 was actually greater in the winters because of the stationary circumstances within the atmosphere compared to the summers (Ahmad et al., 2022).

A separate research done in various other cities in Punjab in Pakistan such as Lahore, Faisalabad, Rawalpindi, Multan and Gujranwala had shown that the primary reason from poor air quality in major urban centers are traffic and industrial pollution. PM10 concentrations were found to be higher than the established limits, but NOx and CO concentrations were lower than the specified limits. Gujranwala had the highest PM10 levels, whereas Lahore had the highest levels of CO, NO2, and SO2. They anticipated the use of green fuels and environmentally friendly technology as an alternative to the present ample requirements, in addition to these pollutants staying under the limits or air pollution would exceed the thresholds (Tabinda et al., 2020).A comparison of the air quality of Chinese and Pakistani cities revealed that Faisalabad had higher PM10 levels than Dalian, China, with mean scores of 45.9 Ag/m3 and 148.3 A, respectively (Niaz et al., 2016).

Alam et al. (2015) state that a portable GRIMM device was used to measure the PM levels in Peshawar, Pakistan. According to the findings, the highest concentrations of PM10 and PM2.5 were found to be 553/101/m3 and 187/19/m3, respectively. Due to the intense traffic, large aerosol particles had been seen in this morning and early evening. The outcomes surpass the PM increases recommended by the WHO, which are around six to nine times

higher than the permissible limit. According to Anjum et al. (2021), PM2.5 concentrations in Pakistani cities were alarmingly high, with Lahore, Gujranwala, and Okara having the highest concentrations at 170 µg/m3, 163 µg/m3, and 139 µg/m3, respectively.

An evaluation of the ambient environment along Haripur, Khyber Pakhtunkwah, using a Youngteng YT-HPC 3000a sensor found that the Hattar Commercial Estate has resulted in high concentrations of PM2.5 and PM10 at twenty-three locations that surpass the EPA's established criteria. Additionally, PM10 and PM2.5 levels have been observed to positively correlate (Asghar et al., 2022). Similarly, the highest SO2 values were recorded between five and eight in the morning. According to Al-Rashidi et al. (2018), winter rather than summer had the highest concentrations of NO2 and O3.

Air Quality and its influence on human health

One of the most significant topics of public health in the developing world is the pollution of the atmosphere. It is seen as the second contemporary planet issues after climatic change (World Health Assembly, 2018). Diseases which are the leading cause of death in the contemporary world are non-communicable. The second time around, exposure to the air pollution is the greatest environmental risk factor across the globe in terms of the NCDs, following tobacco use (Organization, 2019). The problem of air pollution has been one of the primary sources of illnesses and deaths (Cohen et al., 2017). An estimate of a report by WHO indicates that nearly 99% of the total world population both at home and at work breathes polluted indoor and outdoor.

Development of PM takes place in the troposphere as the result of chemical processes of different air pollutants. These tiny and microscopic particles are the ones that are inhaled by the human beings and enter the lungs (Wilson and Suh, 1997). As the results of a study revealed, an increment of 10 µg/m3 in PM 2.5 concentrations correlates with a 17% increment of the ratio of casualties (Jerrett et al., 2005). In China, fine PM has been associated with several deaths associated with lung carcinoma (Hou et al., 2010). Cerebrovascular disease (CVD) is a critical social problem which is gaining an increased interest. Except in the risk factors such as diabetes, hypertension and hyperlipidemia,

epidemiology has shown that PM 2.5 has a correlation with CVD. Due of its small volume, large number, high activity, and delayed settling rate, PM2.5 can carry a variety of chemicals, bacteria, and viruses (Fu et al., 2022). Long-term illness prevalence and mortality are caused by exposure to PM, O3, and dust in automobiles and factories, which increases the respiratory system's susceptibility to chronic pulmonary obstructive disorder (COPD) (Jiang et al., 2016). Coal cooking and heating increases the likelihood that children will get asthma (Zheng et al., 2002). High levels of PM, sulfur, and nitrogen oxides have been linked to pneumonia and bronchitis in children, according to a study conducted by Australians (Barnett et al., 2005).Male reproductive system is affected especially by poor air quality especially PM10, SO2 as well as NO2. The quality of semen of the rural residents is superior to those of the urban citizens due to higher exposure to air pollutants in urban regions (Zhou et al., 2014).

Partial burning of fossil fuel produces carbon monoxide gas. Health complications caused by exposure to CO are headache, unconsciousness, dizziness, vomit, nausea (Manisalidis et al., 2020). There is a 10-15% incidence of the development of allergies and heart related problems in the Iranians caused by the CO in the air (Salehpour et al., 2010). The level of carboxyhemoglobin below 2 percent has not been proved to impact human health in any manner, whereas above 40 percent can be fatal. They have established that the inherent processes of CO poisoning are ischemia, hypoxia, and apoptosis (Ghorani-Azam et al., 2016). CO emission has been kept to a minimum by initially introducing catalytic converters to automobiles. A rise of transportation is linked with a direct rise of ambient CO (Chen et al., 2007).

Nitrogen oxide is one of the typical releases of air pollutants emitted by automobile engines Richmond-Bryant et al., (2017). According to Liu et al. (2014), children in China are at a 25% higher risk of developing asthma for every 10 micrograms of NO2 per meter cube. A Danish study by Brunkum-Hansen et al. (2018) found that NO2 in the air may shorten the life expectancy of urban residents. According to the research, the projected life expectancy will increase by two years if the concentration of NO2 is lowered to the level found in rural areas. According to (Ghorani-Azam et al., 2016), excessive exposure to NO2 causes left and right

ventricular hypertrophy. It interferes with normal functioning of the male reproductive system, high dose of NO2 in the working environment has been associated with reduction in the number of sperm counts among the male in studies established by Lafuente et al., (2016) but has not been investigated among general population. In a different study in China (Zhou et al., 2014), it was concluded that NO2, SO2 and PM had adverse effects on the male reproductive system since they reduced the quality of sperm of men who lived in urban areas.

With a threshold of 0.03 parts per million, sulfur dioxide acts as a gaseous pollutant released into the atmosphere by fossil fuels and industry (Manisalidis et al., 2020). In addition to having detrimental effects on human respiratory, cardiovascular, and neurological systems, sulfur dioxide also causes diabetes type 2 and unintentional fatalities.Although there have been certain evidences that sulphur dioxide in some levels does not impose any adverse health effects, they can exhibit great synergies at a combination with other air pollutants (Khalaf et al., 2024). Also, skin redness, the destruction of mucous membranes and eyes (lacrimation and corneal opacity), the aggravation of the underlying cardiovascular disease have been reported (Manisalidis et al., 2020). Hydrogen sulphide, a colorless and poisonous gas. This combustible gas is taken into the human respiratory system. Because it is somewhat heavier than air, exposure to high concentrations can result in olfactory fatigue and occasionally cause mortality in enclosed areas (Shah and Arooj, 2019).

Effects of the Air pollution on the roadside vendors

Research also indicates that a significantly greater percentage of air pollutants are exposed in places where individuals remain beside the roads as compared to their indoor counterparts or communities that are farther away from roads (Ghosh et al., 2021). Occupational exposure of hawkers caused by heavy traffic along the roadside leads to adverse pulmonary health of the roadside vendors as well as exposes them to higher risks of pulmonary illnesses (Amaran et al., 2016). Health problems employees at the brick kiln are reported to experience respiratory problems, coughing, reddening of eyes and skin problems (Hamid et al., 2023).

Street sellers are more at risk from coarse particulate matter than retailers (210 µg/m3 and 130 µg/m3, respectively), according to a study done in Hong Kong by Jones et al. (2008).

The majority among the hawkers had health issues, including lung inflammation, tuberculosis, heart problems, skin and eye problems, and respiratory tract infections, according to Thapa and Karki (2024). A study carried out in Malaysia established the existence of causal relationship between hours of work of street vendors with phlegm production. It was also found that there was a correlation between the shortness of breath and the service hours (Yi et al., 2022).

Atmosphere also has the agents that can bring about toxicity on cellular level. The exposure in urban areas to genotoxic substances to long term and high level of exposure to traffic emissions presents invaluable information regarding the health risk to urban workers, in this case, the street vendors (Benbrahim-Tallaa et al., 2012). The findings of another experiment conducted in Brazilian cities on how air pollution effects can impact street vendors have shown that the primary cause of genotoxicity harmful to the selected tissues in the target group, that is, the street-vendors, but the others who work in polluted environment too are constantly exposed to air pollution (Domingues et al., 2018).

Research Methodology

Study area

The Mardan District is part of the Peshawar Valley, with lies between directions 34 05 as 34 32N and latitude 71 11 48 and 72 25W. To the north is Buner district; to the east is Swabi district; to the south is Nowshera district; and to the west are Charsadda and Malakand. The district's area is 1632 km². It is further separated into two areas: the hilly region towards the northeast and the plains towards the southwest, which feature fertile land excellent for agriculture (DCR, 1998).The overall population of Mardan District is 2,744,898, according to the Khyber Pakhtunkhwa Population Welfare Department's 2023 census report. This is much more than the 2,373,399 population reported by the Department in 2017.The total number of households is 400,904 with the average household size being 6.85. Tehsil Mardan contains 1,403, 002 people, 359, 024 of them are urbanized, and 1043978 are rural (Kamran et al., 2023).

Table 1: Represents the site locations in urban Mardan

S No:	Location	Abbreviations	Latitude	Longitude
1.	Pakistan Chowk, Bank Road	U-PC	34.198522	72.045332
2.	Gujjar Ghari, Baghdada	U-GG	34.211300	72.035563
3.	Malakand Chowk, Mardan	U-MC	34.198573	72.031782
4.	Par Hoti Neher Chowk, Mardan	U-PH	34.201548	72.069657
5.	Nowshera Road, Toru CNG, Sheikh Maltoon, Mardan	U-TC	34.141841	72.027598
6.	College Chowk, Mardan	U-CC	34.192296	72.034613
7.	Sabzi Mandi, Mardan	U-SM	34.199922	72.046460

Table 2: Represents the site locations in rural Mardan

S No:	Location	Abbreviations	Latitude	Longitude
1.	Lund Khwar Bazar	R-LB	34.391896	71.976742
2.	Lund Khwar	R-LK	34.399655	71.989256
3.	Gulshan Abad Road, Lund Khwar	R-GA	34.389830	71.950371
4.	Hathian Chowk, Shergarh	R-HC	34.393029	71.899025
5.	Hathian Bazar	R-HB	34.385138	71.921245
6.	Jalala Bazar	R-JL	34.331242	71.908833
7.	Jalala Baray Shah	R-JB	34.336156	71.905178

Air Quality data collection

HAZ dust particle air monitoring instrument EPM-5000 is a portable instrument, with the help of which the measurement of the particulate matter (PM10, PM2.5) was carried out. The PM analyser was continuously used to measure air after 24 h and identify it with a given filter. Automatically, the EPAM-500 stored the particles within the given time. The average data is considered when all the tests have been completed (Subhanullah et al., 2022). The

samples of NO2, CO and CO2 were also sampled using a portable multi-gas Nova 600 series ambient air monitoring analysers (NOVA Model 600-2-3-4-5-7-10, Canada). Air was drawn into the device by a 2 m long pipe, then analysed by a number of sensors. Several measurements of different gases, among them NO2, CO and CO 2.

Health Impact Assessment

The vendors/hawkers were used as a target population to conduct the survey in order to determine the health effects of air pollution among roadside people due to their increased exposure to air pollution.

The pulmonary lung function was assessed by the aid of a peak flow meter. The figures are indicated on the sides of the peak flow meter in mg per liter indicating the exhalation rate (Shahzad et al., 2021). Peak flow measurements are often grouped into three zones of measurement, which are green, yellow and red (Association, 2007).

Sample Size

A total of 100 street hawkers were surveyed equally from both urban and rural areas.

Procedure

The target respondents were asked about their age, number of hours worked, history of smoking, and any respiratory conditions they may have had. First, the individuals' weight and height were recorded. The peak flow meter was calibrated before a sample was taken. To maintain hygiene, mouthpieces were stored in a disposable way. One was shown how to position the marker at the bottom of the scale, 0, and place the meter in the horizontal position. Hold your breath deep and press your mouth firmly round the mouthpiece and expel the air as expeditiously as you are able. Every participant was given the opportunity to read on three occasions, and the best reading was noted as their personal record. The chart containing the collected data was compared against a chart to identify the height, age and what the peak flow of the person was supposed to be to determine his or her health.

Data Analysis

The data were analyzed to provide a comparison of the air quality between the urban and rural zones, research the health effects of air pollution that may impact a specific population group, like roadside hawkers. The information was tabulated and divided in to individual datasets of each region. The comparison of the levels of pollutants, the level of awareness and health conditions at the urban and rural areas were compared with data visualizations in the form of pie charts and bar graphs. Data gathered was evaluated in SPSS and Microsoft Excel. Simple statistics like mean and standard deviation were applied. The correlation coefficient and one-way ANOVA were implemented to analyze the variability of the pollutants between the urban and the rural population by comparing them.

RESULTS AND DISCUSSION

Health Impact Assessment

The process of knowing the degree of exposure or dosage, risk recognition, surveillance and preventive actions comprises the environmental health risk assessment. The mean peak expiratory flow rate (PEFR) of the urban and rural hawkers was 465126.4l/min and 526106.6l/min respectively. The age category of survey population is between 20-65. Normal, mild and severe expiratory peak forced expiratory rate was found in 48, 36 and 16 percent respectively of urban hawkers as indicated in Figure: but among the rural hawkers, the PEFR was normal, mild and severe at 70, 24 and 6 percent respectively. The overall findings suggest that there is a low peak flow rate of the urban hawkers than the rural vendors. The present research is consistent with the review conducted by (Singh et al., 2024) in urban rural comparative research. The standard deviations show a medium difference, which shows that there is a similarity in the variability of the two groups. Correspondingly, another study in Peshawar; Pakistan found harshly PEF among 33 percent of urban shopkeepers whereas reduced peak flow rate was reported among 13 percent of the rural shopkeepers (Shahzad et al., 2021).

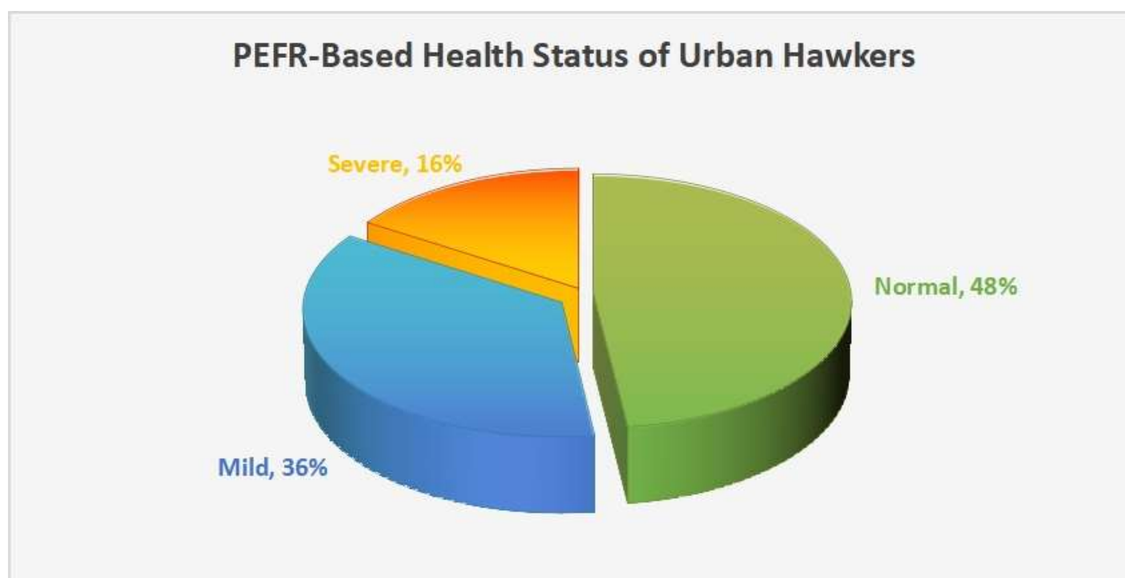

Figure 1: Health status of urban hawkers based on Peak expiratory flow rate

Table 3: Urban Peak Flow Rate categorization based on gender and occupational exposure

Gender	Age Group (20-65)	Outdoor Exposure (6-8 hours)	Outdoor Exposure (>8 hours)	Green Zone (>80%)	Yellow Zone (50-79%)	Red Zone (<50%)	Frequency (n)
Male	20-29	05	11	12	04	00	16
Male	30-39	04	12	09	06	01	16
Male	40-49	03	05	03	03	02	08
Male	50-59	01	04	00	02	03	05
Male	>60	02	03	00	03	02	05
Total	-	**15**	**35**	**24**	**18**	**08**	**50**

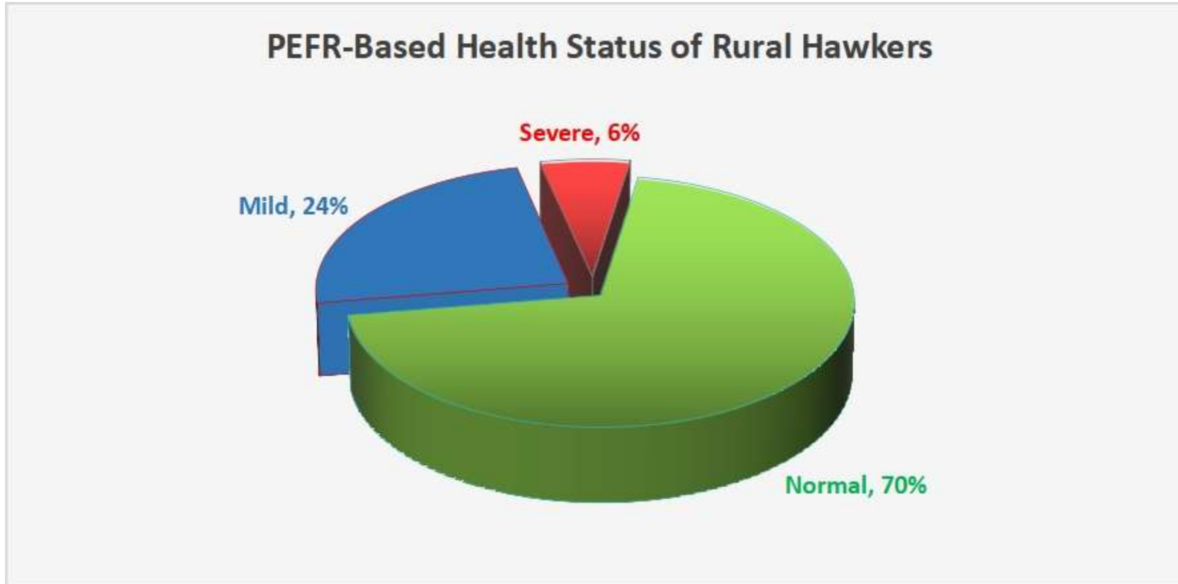

Figure 2: Health status of rural hawkers based on Peak expiratory flow rate

Table 4: Rural Peak Flow Rate categorization based on gender and occupational exposure

Gender	**Age Group (20-65)**	**Outdoor Exposure (6-8 hours)**	**Outdoor Exposure (>8 hours)**	**Green Zone (>80%)**	**Yellow Zone (50-79%)**	**Red Zone (<50%)**	**Frequency (n)**
Male	20-29	06	09	14	01	0	15
Male	30-39	04	06	07	03	0	10
Male	40-49	06	05	06	04	01	11
Male	50-59	03	06	05	03	01	09
Male	>60	01	04	03	01	01	05
Total		**20**	**30**	**35**	**12**	**03**	**50**

A one-way ANOVA was conducted to compare the mean peak flow measurements among participants from urban and rural areas. The results indicated a significant effect of living area on peak flow, $p = 0.010$ which shows a higher peak flow readings among rural population compared to urban.

Table 5: A one-way ANOVA results for PEFR among rural and urban survey participants

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*

Between Groups	94249	1	94249	6.756	0.010782	3.938
Within Groups	1367002	98	13949			
Total	1461251	99				

*Significance at $P<0.05$

4.12 Correlation between PM and PEFR

The researcher compared the correlation of PM 2.5 levels and peak flow rates in an urban and rural population. The correlation coefficient (r) between PM2.5 levels and the peak flow rates between urban and rural regions is equal to -1 which implies that the linear relationship between the two variables is negative and strong. Peak flow rates are gradually declining among the survey population as the concentration of PM2.5 adds.

In the same manner, the correlation coefficient (r) between PM10 concentration and peak flow rates was found to be -1 which suggests that there is a strong negative linear relationship between two variables within the two settings. It implies that with the increase of PM10 rates, the peak flow rates are continuously declining both in urban and rural settings. It means that lowering the peak flow rates is a consequence of exposure to higher levels of PM2.5 and PM10 in the urban and rural environments that could influence the respiratory health in some geographical locations. Ghosh et al., (2021) also established higher rates of PM association with a resultant decrease in pulmonary functionality in the roadside hawkers.

Particulate Matter (PM2.5)

It was observed that PM2.5 was more when there were urban areas than when there were rural areas. The research environment had an average PM2.5 concentration of 405.18+217.3 ug/m3. The highest mean PM2.5 in urban areas was U-CC 731+15.55 -15.55 = -15.55 µg/m3. A research conducted in Dhaka, Bangladesh, likewise found a PM2.5 concentration of 660 0g/m3 (Hossain et al., 2022). U-GG 321.35+81.10 31 ug/m3 had the mean lowest concentration. On the other hand, in rural regions, the lowest average PM2.5 levels were 74.751.75 in R-LB and the highest average was 366.60264 25 in R-GA. The mean levels of PM 2.5 are greater than the NEQS in Pakistan, the research is also in agreement with

(Rasheed et al., 2014). The results of the analysis show that PM2.5 concentration exceeds the recommended limit of 15 µg/m3 (24-hour average) in the WHO AQGs of 2021.

Increased concentration of PM2.5 in cities can be explained by various factors including automobile emissions because of the increased traffic, smoke sources like restaurants and vendors, use of winter fog. Karagulian et al. (2015) indicated a concentration of PM2.5 in the urban centers because of the road traffic. A quarter of the global PM particles found in the atmosphere is caused by traffic emissions, with domestic fuel emissions & industrial activity coming in second and third, respectively, at 20% and 15%. On the other hand, the usage of biomass burning, brick kilns, and vehicle emissions can partially account for the somewhat elevated PM2.5 concentrations in rural areas. Short-term exposure to abrasive particles can cause heart problems and respiratory disorders that increase the risk of dying young (Peng et al., 2008).

A one-way ANOVA was used to assess PM2.5 levels in urban and rural settings. The results showed that there was actually significant variation (P less than 0.05) within the two regions and that PM2.5 concentrations were greater in urban areas as opposed to rural areas, as shown in the table.

Table 6: A one-way ANOVA results for $PM_{2.5}$ among urban and rural locations

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	848,180.46	1.00	848,180.46	45.35	0.000000381	4.23
Within Groups	486,309.95	26.00	18,704.23			
Total	1,334,490	27.00				

*Significance at P<0.05

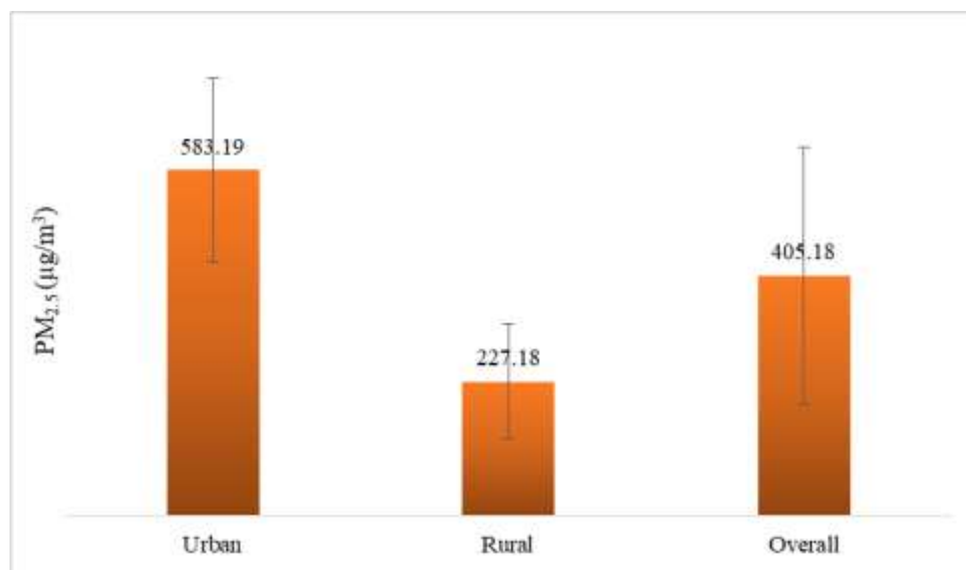

Figure 1: $PM_{2.5}$ levels in urban OR rural Mardan

Particulate Matter (PM_{10})

It was discovered that urban regions have a higher percentage of PM10 than rural ones. The average PM10 concentration was 463.37±238 µg/m3 in both urban and rural areas. PM10 concentrations range from 74.75 to 818.5 µg/m3 in both urban and rural locations. Seismic PM10 values varied from 158 to 733 µg/m3, according to another study done in Lahore, Pakistan (Zhang et al., 2008).

PM10 levels in urban and rural areas were 656.40-172.5 µg/m3 and 270.33-95.7 µg/m3, accordingly. In U-TC, PM10 levels were 815±9.19 µg/m3, while in U-GG, they were 294.85±62 µg/m3. Similarly, R-LB had the lowest PM10 concentration, averaging 74.75 µg/m3, while R-GA had the highest, averaging 410.95 µg/m3. These results show that average PM10 levels are higher than the Pak-EPA's highest permitted level of 150 µg/m3 in both urban and rural areas. The WHO AQGs 2021 of 45 µg/m3 (24-hour average) are exceeded by the PM10 concentration.

Table 7: A one-way ANOVA results for PM_{10} among urban and rural locations

Source of	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*

Variation						
Between Groups	1043358.03	1	1043358.0	49.78462	0.00000017	4.225
Within Groups	544893.281	26	20957.433			
Total	1588251.31	27				

*Significance at $P<0.05$

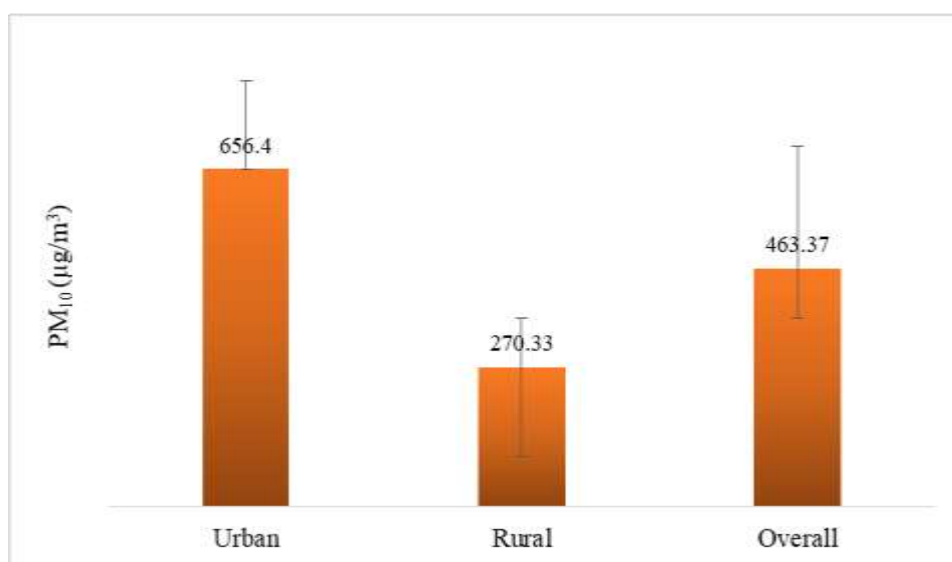

Figure 2: PM_{10} levels in urban and rural Mardan

PM2.5 and PM10 levels are significantly positively correlated in both urban and rural areas, having a correlation value (r) of 1. PM2.5 concentrations increase in synchrony with PM10 levels, and vice versa.

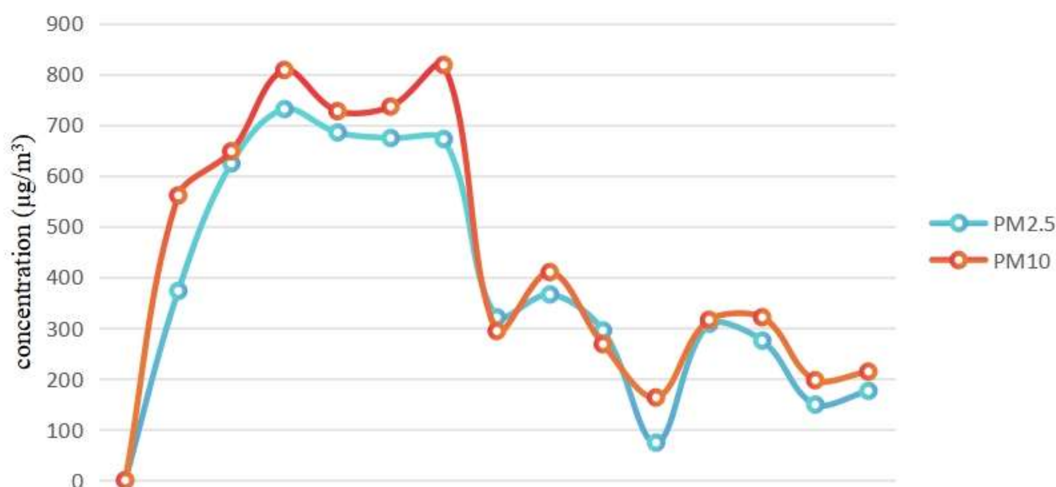

Figure 3: Correlation between $PM_{2.5}$ and PM_{10} levels in urban and rural Mardan

The increased concentration of PM2.5 in cities can be explained by various factors including automobile emissions since the cities bear a high traffic volume, restaurant smoke, and the existence of winter fog. Conversely, the biomass burning, the existence of brick kilns and automobile emissions to a degree can be considered as the cause of moderately higher concentrations of PM2.5 in rural settings.

PM2.5/PM10 ratio

The PM2.5/PM10 ratio is crucial for assessing health risks since it is designed to generate an appropriate concentration of airborne particles. In cities, PM2.5 is 0.5–0.6 about PM10 (Majid et al., 2012). PM2.5/PM10 ratios were 0.8 in urban and 0.8 in rural areas, respectively. This shows a greater ratio (>0.5), which is usually caused by vehicle emissions and implies a larger percentage of tiny particulates in the air. The PM2.5/PM10 ratio in Chinese cities has decreased to 0.7, according to Qian et al. (2001).

Carbon monoxide

In rural as well as urban settings, the average CO level was 6.95±7.8 ppm. The mean CO concentrations in rural and urban areas were 1.9 2 ppm and 11.9 8 ppm, respectively. On the other hand, Bangladesh's wintertime atmospheric concentrations of carbon was below the recommended threshold of 9 ppm, according to a study by Hossain et al. (2022). R-JL and R-

LK obtained the smallest level of 0 ppm, while U-CC recorded the highest figure of 24.66 ppm. According to Shahid et al. (2015), 23.50 percent of CO emissions in metropolitan areas come from the transportation sector.On the other hand, using agricultural waste includes bagasse and rice fiber as fuel pollutes the environment with dangerous gaseous emissions like CO and NO2 of about 80 Gt and 3 Gt, respectively, according to Irfan et al. (2014).

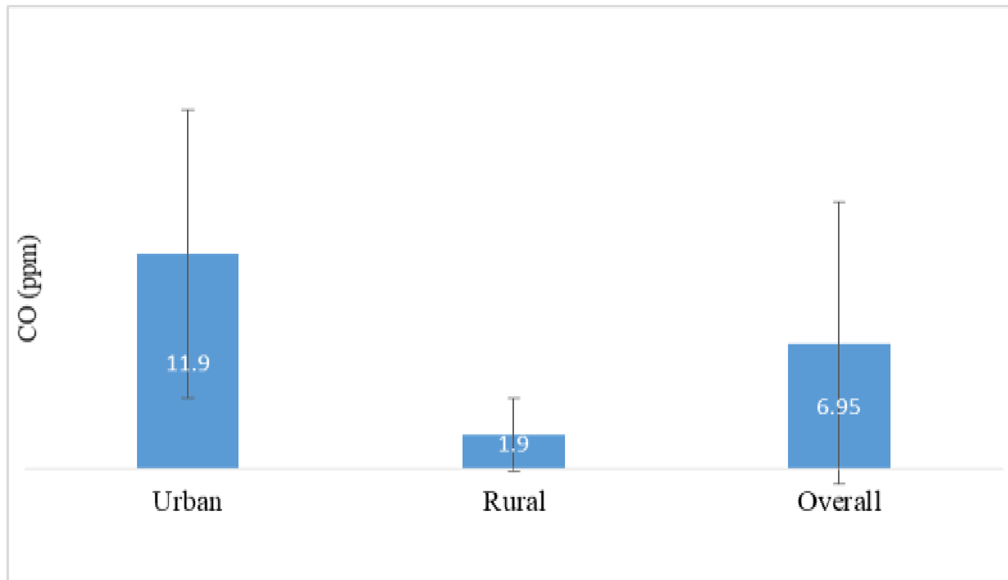

Figure 4: CO concentration in urban and rural Mardan

There is a substantial difference (P<0.05) between the concentrations of CO in urban and rural areas, with urban areas having greater concentrations than rural areas, according to the results of a one-way ANOVA.

Table 8: A one-way ANOVA results for CO levels among urban and rural locations

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1050	1	1050	27.16856	0.0000060	4.084746
Within Groups	1545.905	40	38.64762			

Total	2595.905	41

*Significance at $P<0.05$

Nitrogen dioxide (NO_2)

The average NO2 content in the study area was 0.033 parts per million. In the urban and rural sampling areas, the average NO2 content was 0.058 ppm and 0.008 ppm, respectively.U-MC had the highest mean NO2 content (0.107 ppm), whereas R-LK had the lowest (0.002 ppm). There is a significant difference (P<0.05) in the concentration of NO2 between urban and rural areas, with the concentration of NO2 in urban areas being higher than in rural areas, according to the findings of a one-way ANOVA.

Table 9: ANOVA single factor results for NO_2 levels in urban and rural areas

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	21	1.237	0.058905	0.00133
Column 2	21	0.171	0.008143	6.19E-05

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.027056	1	0.027056	38.87596	0.00000022082712	4.084746
Within Groups	0.027838	40	0.000696			
Total	0.054894	41				

*Significance at $P<0.05$

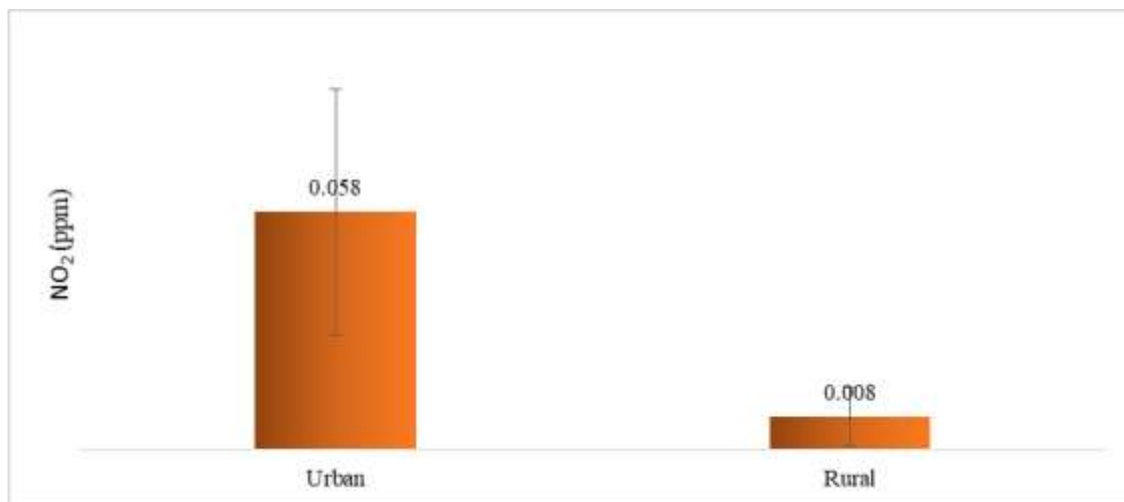

Figure 5: NO_2 concentrations in urban and rural areas

Conclusion

Finally, the findings show that rural regions have a relatively good quality of air compared to urban regions because of the reduced traffic, industrialization and population. The concentration of air quality parameters was higher than that of the urban focusing points that had more air quality problems than the rural areas. Both the PM2.5 and PM10 concentration are a matter of huge concern in the region that is higher than the set standards of EPA-Pak. The amount of CO and NO2 was also more in urban areas and the amount of CO was significantly different in the urban places where people sampled. CO was also high in congested areas where there was high traffic load. The research found that there was an increased awareness of the urban population about the air pollution. Results of the findings revealed that majority of the urban respondents are aware of the impact of air pollution on human health as harmful compared to the rural respondents of about 26 who agreed to be quite dangerous to human health implying a perception difference.

Recommendations

Metropolitan areas should be equipped with proper air quality surveillance stations which monitor the trends of pollution and give out health warnings to the population. Mass transportation should be used to encourage the use of public transport to reduce congestion in the automobiles. More studies should be done on how to assess the possible health effects of

air pollutants on road-side vendors in Mardan in terms of biomarkers. Group with high exposure should also be made to undergo routine health checks. It is suggested to consider the influence on the air quality of the city of changing climatic factors. Plantation drives and green areas in the cities to encourage better health in the population, reduce rising temperatures in urban areas, and enhance air quality. Stimulate the development of the latest pollution control systems and explore the environmentally friendly urban design variants.

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