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GEO-SPATIAL ANALYSIS OF AIR QUALITY FROM PRE TO POST-COVID-19 PANDEMIC LOCKDOWN: A CASE OF KARACHI-PAKISTAN

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ABSTRACT:

Air quality holds paramount importance in the realm of sustainability, as it exerts a significant influence on diverse facets of human existence. Therefore, air particulate matter levels are key focus in the United Nations' Sustainable Development Goals (SDGs) 3, 7, and 11. The study examines the variations of Particulate Matter 2.5 (PM2.5) and Nitrogen dioxide (NO_2) in the air before, during, and after the implementation of the COVID-19 lockdown in Karachi, Pakistan's largest metropolitan city. While the pandemic disrupted socioeconomic and political dominion, it inadvertently brought environmental benefits by curbing human activities, such as traffic volume and industrial production, leading to improved air quality. Continuous online data was collected, sorted, tabulated, and then imported into ArcGIS for spatial analysis. The resulting maps illustrate the variation in spatial distribution of PM2.5 and NO_2. Statistical analysis, including linear regression, was applied to demonstrate monthly variations and predict future trends. PM2.5 and NO_2 records from the pre-pandemic period indicated 210 µg/m³ and 208 ppb in February 2020. While in June 2020, during lockdown, local air showed very low PM2.5 concentration and 50 ppb for NO_2. After lockdown, PM2.5 levels increased to 175 µg/m³, and NO_2 dropped to 49 ppb in October 2020. Results also revealed an inverse relationship between PM2.5-NO_2 and COVID-19 cases in Karachi. Study concludes that maintaining healthy air quality is directly linked with intensity of anthropogenic activities and is crucial for an enhanced quality of life. It is recommended to regulate urban activities rigorously for a safe environment. Effective implementation of air quality control devices, laws and regulations will be instrumental in promoting sustainability in Karachi.

KEYWORDS: PM2.5, NO_2, Covid-19 lockdown, GIS, SDGs, Karachi.

1. INTRODUCTION

Air pollution, characterized by atmospheric chemistry disturbances, poses significant threats to environmental quality and public health (Hashmi et al., 2005). With the rapid and haphazard development of urban areas in developing countries, air pollution has become a major and evolving life-threatening issue, causing an estimated 4.6 million loss of healthy years and 800,000 deaths worldwide annually (WHO, 2006). The adverse effects of air pollution are wide-ranging and include pulmonary and respiratory illnesses such as stroke, lung cancer, bronchitis, and cardiovascular diseases (Analitis et al., 2006; Peng et al., 2009; Zanobetti & Schwartz, 2009).

Among the various types of air pollution, particulate matter has been found to have the highest impact on acute and chronic illnesses globally. The toxicity of particulate matter varies depending on its size suspended in the air, with particulate matter of aerodynamic size 2.5µm (PM2.5) posing a greater risk than particulate matter of size 10µm (PM10) (Fu et al., 2020). Recent studies have indicated that the pollution caused by PM2.5 particles, including sulphate, carbon, nitrate compounds, and heavy metal particles, depending on the emission sources, has led to increased hospitalizations (Arsalan et al., 2020). These sources of pollution include increased vehicular traffic, combustion processes, open waste dumps, construction projects, power plants, and various industrial sectors (Bank, 2016).

Recognizing the importance of air quality, the United Nations has formulated 17 Sustainable Development Goals (SDGs) to incorporate sustainability in all sectors of countries. Three specific SDGs address the maintenance of healthy air quality levels. Goal 3, Indicator 3.9.1, targets a decrease in premature death rates caused by hazardous chemicals in the atmosphere. Goal 7, Indicator 7.1.2, focuses on reducing harmful emissions by implementing cleaner technologies. Goal 11, Indicator 11.6.2, emphasizes the need to control the annual mean levels of PM2.5 based on the resident population (Menne et al., 2020; Longhurst et al., 2018).

The COVID-19 pandemic has shed light on the relationship between air pollution and the spread of the virus. Studies have reported a strong correlation between COVID-19 transmission and the amount of particulate matter in the air (Mehmood et al., 2021; Sipra et al., 2021). PM2.5 particles have been found to act as carriers for toxic elements due to their carbon core and outer organic layer, providing an ideal surface for adhering biological components such as bacteria, viruses, and fungi (Conticini et al., 2020). These smaller particles have a high probability of causing chronic respiratory and cardiovascular diseases due to their ability to penetrate deeply into the lungs. On the other hand, PM10 particles primarily cause irritations in the upper respiratory tract (Mehmood et al., 2020). PM2.5 particles have also been observed to act as vectors for the COVID-19 virus, with an increase in their concentration associated with a rapid rise in COVID-19 mortality rates in metropolitan regions worldwide (Xie & Zhu, 2020; Wu & McGoogan, 2020). The respiratory system is the major target of the virus. Individuals from sensitive groups, such as those with allergies, asthma, pneumonia, cancer, and compromised immune systems, have shown a higher percentage of COVID-19 cases (Mehmood et al., 2020).

Pakistan, located in South Asia with a population over 207.8 million individuals, is severely affected by air pollution due to anthropogenic activities, negligence, and the lack of implementation of air quality guidelines (Wazir and Goujon, 2019). Karachi, the largest mega city in Pakistan with a population exceeding 20 million, has been ranked under the top five most polluted cities in terms of particulate air pollution, according to a study by Gurjar et al. (2008). In November 2020, Lahore was ranked the most polluted city with an Air Quality Index (USAQI) of 258. Karachi ranked seventh with a USAQI of 161, according to IQAir's air quality and pollution city ranking. A research study conducted by the Center for Research on Energy and Clean Air analyzed the air quality before and after the COVID-19 pandemic in Pakistan. The study found that Pakistan had one of the worst air quality levels in Southeast Asia in 2019, but during the lockdown, there was a significant drop in particulate pollution, although NO_2 pollution persisted in Karachi due to ongoing industrial activities.

The first case of COVID-19 in Pakistan was recorded in Karachi on February 26, 2020. In response, provincial lockdowns were implemented as a measure to minimize the spread of the disease, with Sindh and Punjab provinces imposing complete lockdowns on March 24 and April 15, 2020, respectively (Covid statistics, Government of Pakistan 2021). Metropolitan areas with high concentrations of PM2.5 were found to have higher rates of active COVID-19 cases than smaller cities. Seposo et al. (2020) highlighted that PM2.5 and NO2 are potent air pollutants that increase the number of patients with acute and severe respiratory illnesses, thereby making the population more susceptible to COVID-19. Sipra et al. (2020) reported many COVID-19 cases in Lahore, attributed to high pollution and humidity in the city, whereas Karachi experienced lower risks due to coastal breeze and fluctuating humidity. Another research analysis by Ali et al. (2021) indicated that the spread of COVID-19 in Pakistan was accelerated by its proximity to China (the epicenter of the virus) and the country's poor air quality, which ranked second worst in South Asia. Both studies concluded that the implementation of lockdown measures, particularly smart lockdowns that isolated affected areas, was the most effective strategy for improving air quality and controlling the spread of the virus.

Despite the growing body of literature on air pollution and its health impacts, there is a research gap regarding the specific context of air quality in Karachi before and during the COVID-19 pandemic. Karachi, being the largest mega city in Pakistan with a high population density, is severely affected by air pollution resulting from anthropogenic activities and inadequate implementation of air quality guidelines. The present study aims to investigate the impacts of varying air quality throughout the COVID-19 pandemic. The research objectives include incorporating GIS techniques to determine the spatial distribution of PM2.5, statistical modeling to identify future trends in air pollution and reviewing the effective recommendations to control air pollution and improve air quality.

1.1. Study Area

Karachi, a coastal city, is classified as one of the most populated cities in the world and the largest city in Pakistan, with a population of more than 22 million. It encompasses a vast urban sprawl covering an area of 3,527 km^2. Geographically, Karachi is situated between 24°45" to 25°15" north latitude and 66°37" to 67°37" east longitude. The Arabian Sea borders it to the south, the Baluchistan province to the west, District Thatta to the southeast, and Dadu to the north.

Karachi's climate is arid, with mild hot and dry conditions prevailing throughout the year. The city experiences low precipitation, with an average annual rainfall of 250mm. The summer season extends from May to September, while winters are observed from November to February. March and April mark the spring season, and October represents the autumn month. The monsoon season, accompanied by increased humidity levels, occurs from June to August. The presence of a cool sea breeze mitigates the heat during the summer months (Hasan & Mohib, 2003; PQA 2021). Fig.1 depicts the study area of Karachi, illustrating its geographical location and extent.

Table 1: Division Based Distribution of Towns of Karachi.

KARACHI DIVISIONS	TOWNS OF KARACHI
Karachi Central	Jamshed Town, North Nazimabad, New Karachi, Gulberg and Liaquatabad.
Karachi East	Gulshan-e-Iqbal, Shah Faisal Town, Landhi, Malir, Faisal Cantt and Korangi.
Karachi West	Kemari, SITE, Gadap, Manora, Orangi and Baldia.
Karachi South	Lyari, Saddar, Karachi Cantt, DHA, Malir Cantt, Bin Qasim Town and Korangi Cantt.

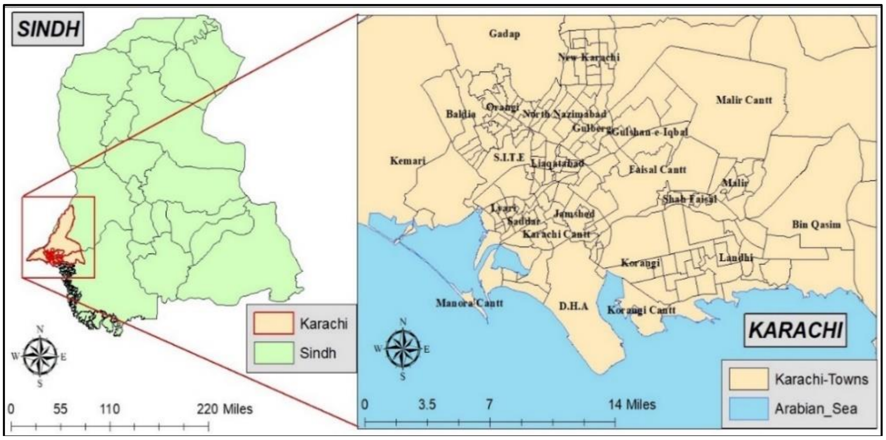


Fig.1: Study Area.

2. MATERIAL AND METHODS

2.1. Collection of Data

Historical data on air quality was obtained from the Plume Labs: Air Quality App. The major air quality parameter selected for analysis was Particulate Matter (2.5µm) PM2.5 and Nitrogen Dioxide (NO_2). Hourly data was recorded at four different times of the day (6 AM, 12 PM, 6 PM, and 12 AM), while daily data was also collected to capture the air pollution status throughout the day. The air quality data for Karachi was divided into four divisions: central, east, west, and south, as presented in Table 1. The data for the selected parameters were collected from October 2019 to October 2020, encompassing the period before, during, and after the initial pandemic lockdown in Karachi.

2.2. Analysis of Data

After tabulation, the data was imported into ArcMap for further analysis. Choropleth maps were generated for each month to visualize the changes in air quality, which could be attributed to variations in anthropogenic activities and the increase in COVID-19 cases. During the statistical analysis, the standard deviation was calculated for PM2.5 to assess the variation and future trends and their impact on the city's air quality. The standards presented in Tables 2 and 4 were considered to determine the extent of safe limits. Whereas the hazard classes shown in Table 3 were formulated according to USEPA standards to assess the degree of impact on the city.

Table 2: International Standards for PM 2.5 and NO_2.

STANDARDS	PM2.5	NO_2
USEPA	15 µg/m³ (annual average) 35 µg/m³ (24-hour mean)	53 ppb (annual average) 100 ppb (1-hour standard)
WHO	5 µg/m³ (annual average) 15 µg/m³ (24-hour mean)	5 ppb (annual average) 13 ppb (24-hour mean)

Table 3: PM2.5 Hazard Classification According to USEPA.

HAZARDS	PM2.5 (µg/m³)	NO_2 (ppb)
Good	0-15	0-40
Moderate	16-30	40-80
Healthy	31-40	
Unhealthy/High	41-50	80-100
Hazardous	>50	<100

Table 4: Classification of Months Included in the study According to the Imposed Lockdown due to pandemic.

LOCKDOWN CLASSIFICATION	MONTHS OF THE YEAR
Before	October, November, December 2019, January and February 2020.
During	March, April, May, June and July 2020.
After	August, September and October 2020.

3. RESULTS AND DISCUSSION

3.1. Air Quality Assessment Before Covid-19 Lockdown (2019-2020)

3.1.1. $PM_{2.5}$: During the pre-pandemic period, Karachi's Air Quality Index (AQI) was consistently at very hazardous levels due to unrestricted anthropogenic activities. The seasonal variation from autumn to winter led to a decrease in temperature and an increase in air pressure, which intensified the condensation of particulate matter caused by vehicular and industrial emissions and commercial activities. The concentration of PM2.5 in the air remained at very hazardous levels, with the highest value reaching 210µg/m³ in December and February. In other months, the concentrations varied, with 148µg/m³ values in October, 139µg/m³ in November, and 160µg/m³ in January. The spatial distribution of PM2.5 particles before the pandemic is illustrated in Fig.2 (a, b, c, d, and e), and the monthly variation in PM2.5 concentration is shown in Fig.3. The spatial analysis in Fig.2 and the monthly variation in Fig.3 demonstrate that PM2.5 levels at the southern towns of Karachi, located on the coastal belt, gradually deviate due to the influence of sea breeze. However, the congested and haphazard urbanization and vehicular and industrial emissions play a significant role in increasing the stay time and toxicity of PM2.5 in the air.

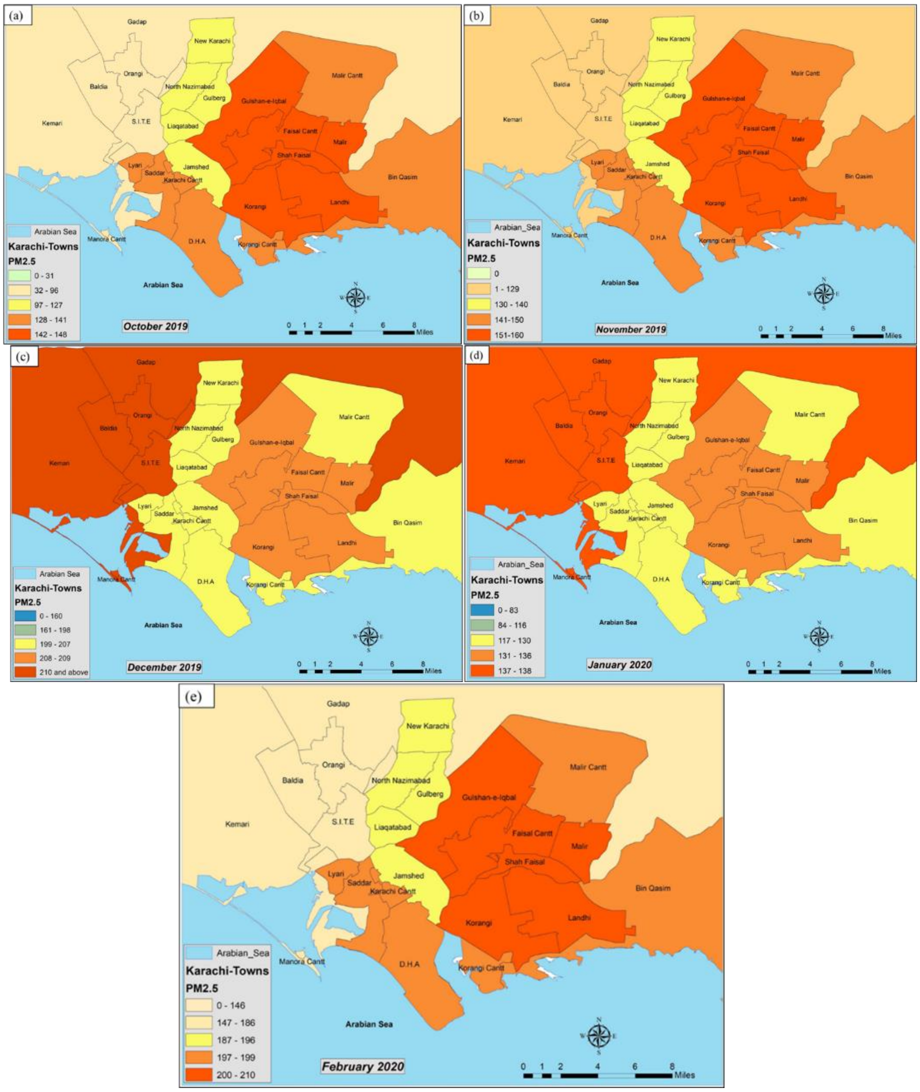


Fig. 2: Concentrations of PM2.5 Particles in Different Towns of Karachi before Covid-19 Lockdown.

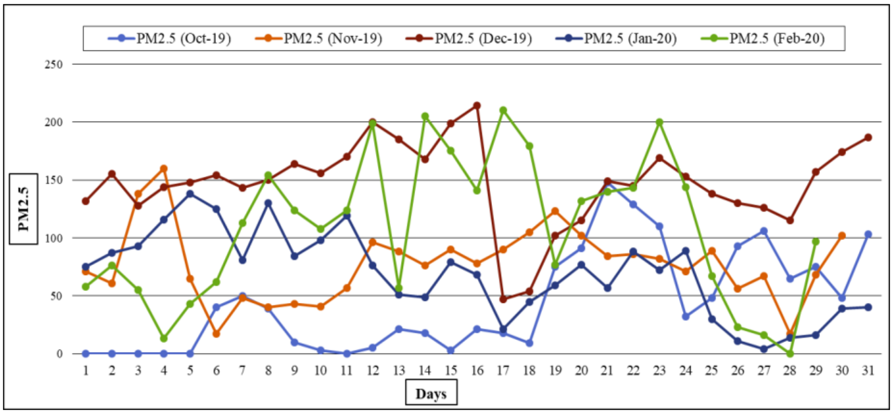


Fig.3: Monthly Variation of PM2.5 in Different Divisions of Karachi before Covid-19 Lockdown.

As evident by the spatial analysis in Fig. 2 and monthly variation in Fig. 3, PM2.5 on the coastal belt have shown gradual deviation because of the sea breeze. Whereas congested and haphazard urbanization, vehicular and industrial emissions, are also vital in increasing stay time and hence the toxicity in the air.

3.1.2. NO_2: The concentration of Nitrogen Dioxide (NO_2) in the atmosphere exhibited a varying trend with seasonal changes. In October 2019, NO_2 levels reached hazardous levels (158 ppb), exceeding the set standards (100 ppb). The highest concentration was observed in the southern part. In November 2019, as the seasonal shift from autumn to winter occurred, the hazard and NO_2 concentration decreased to 84 ppb in the east division. In December 2019, a further drop in NO_2 concentration was observed, with a value of 67 ppb in the central division. In January 2020, as the winter season fully approached the city, NO_2 concentration increased again, reaching 97 ppb in the same area. The concentration was just 3 units less than the recommended standard by USEPA. The most hazardous month before the lockdown was observed in February 2020, with NO_2 reaching 208 ppb in the south region. Other towns also exhibited recorded values that indicated toxic levels. The spatial distribution of NO_2 before the pandemic is depicted in Fig.4 (a, b, c, d, and e).

The monthly variation revealed higher fluctuations in October 2019, with all divisions exhibiting similar patterns of NO_2 concentration. In December 2019, NO_2 patterns remained the same throughout the city, with the highest concentration observed in the Karachi's central region. In January 2020, high hazard levels were observed in the central and east divisions, while the west and south divisions experienced safer conditions. The first two weeks of February 2020 exhibited high to hazardous concentrations in all divisions, with the highest levels recorded in the east and south.

However, by the end of the month, the hazard levels significantly reduced to moderate and good levels. (Fig.5).

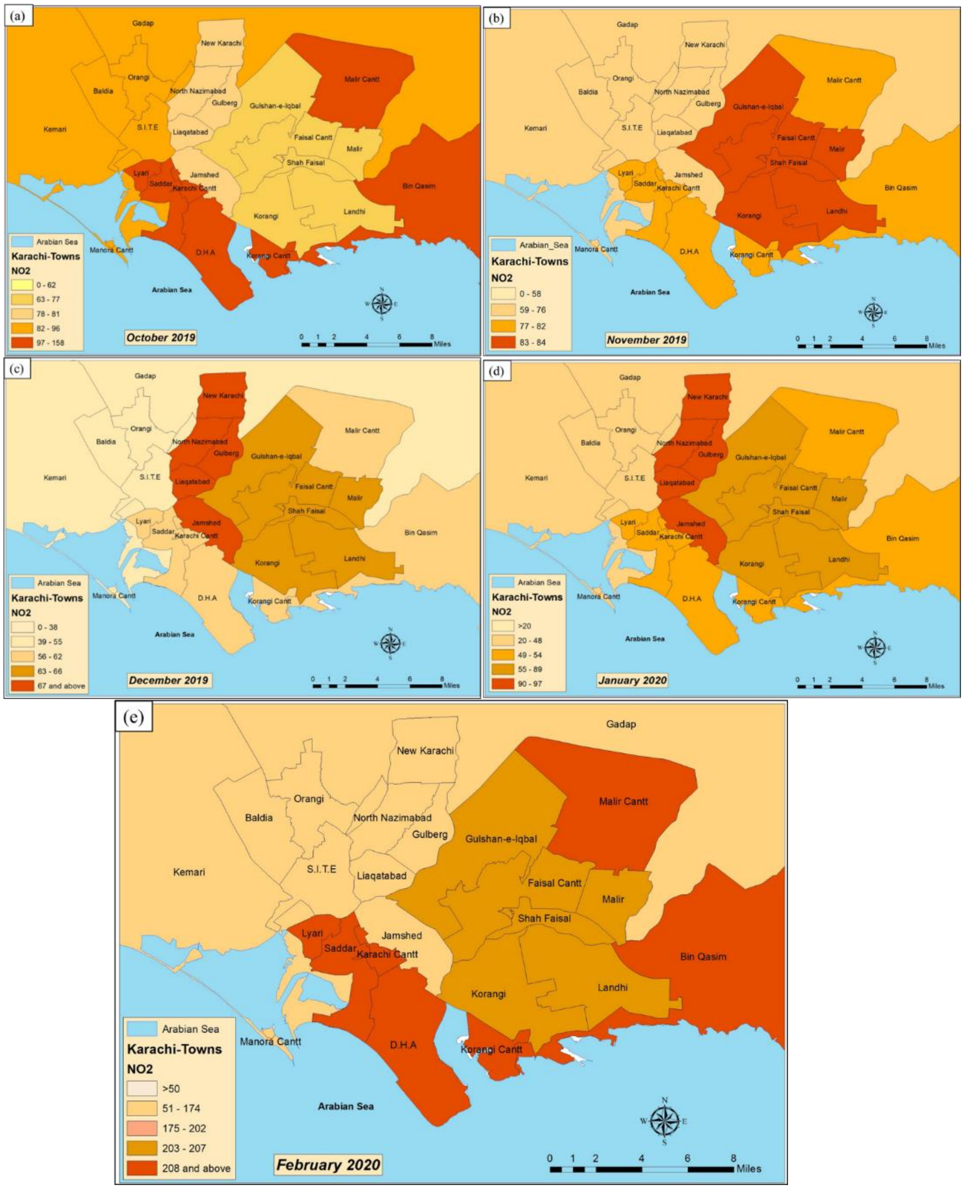


Fig. 4: Concentrations of NO_2 in Different Towns of Karachi before Covid-19 Lockdown.

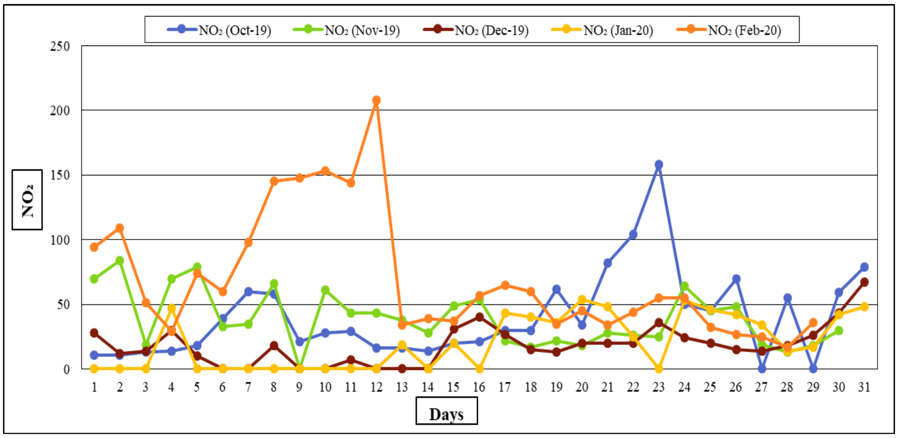


Fig.5: Monthly Variation in NO_2 in Different Divisions of Karachi before Covid-19 Lockdown.

3.2. Air Quality Assessment during Covid-19 Pandemic Lockdown (2020):

3.2.1. $PM_{2.5}$: During the Covid-19 pandemic lockdown in 2020, the air quality in Karachi experienced a significant shift towards moderate and good levels. With the restrictions imposed on human activities, the air quality had the opportunity to improve. In March 2020, PM2.5 concentrations were recorded at very hazardous levels, reaching 212 µg/m³ [Fig.6 (a)]. Although there was a slight drop in concentration in April, it remained above the limit at 87 µg/m³ [Fig.6 (b)]. However, as the lockdown continued and human activities were limited, PM2.5 levels steadily decreased. In May 2020, the concentration dropped to 32 µg/m³ [Fig.6 (c)], and in June, it reached the safest levels at 0 µg/m³. Nevertheless, as partial commercial activities resumed in July, PM2.5 concentrations returned to hazardous levels [Fig.6 (d)].

Spatial distribution analysis [Fig.6] showed the variation in PM2.5 levels across different towns of Karachi during the Covid-19 pandemic lockdown. The highest concentration was observed in March, predominantly in the eastern side of the city. In April, the lockdown positively impacted reducing PM2.5 levels, with the highest concentration observed in the east division, while other divisions recorded values below 80 µg/m³. By May, there was a significant drop in PM2.5 concentration, with the highest value of 40 µg/m³ observed in the east division. However, during the mid-month, PM2.5 exceeded the safe levels recommended by USEPA. These trends continued in June, with PM2.5 concentrations remaining low but exceeding safe levels on some days [Fig.7].

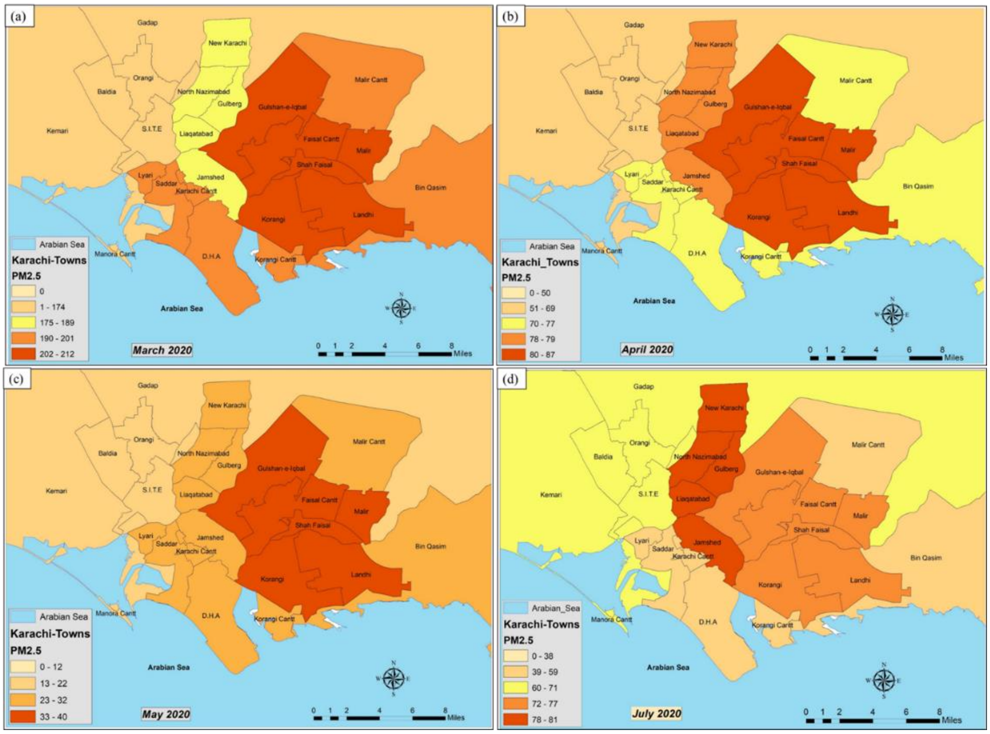


Fig. 6: Concentrations of PM2.5 in Different Towns of Karachi during Covid-19 Pandemic.

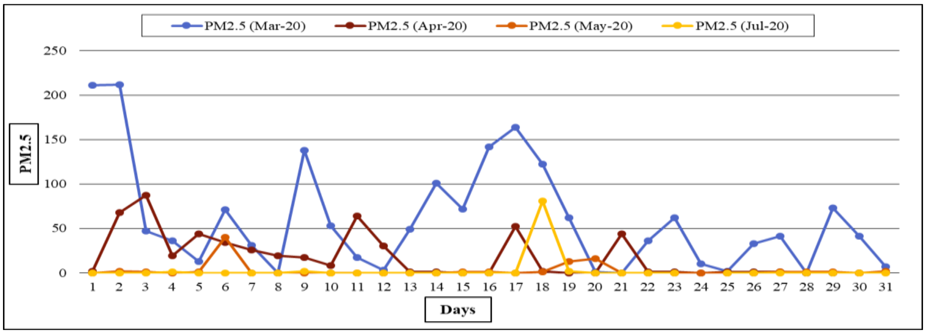


Fig. 7: Monthly Variation of PM2.5 in Different Divisions of Karachi during Covid-19 Lockdown.

3.2.2. NO_2: The concentration of Nitrogen Dioxide (NO_2) during the Covid-19 lockdown period showed varying trends with seasonal changes. In March, NO_2 concentrations were recorded at the highest levels throughout the lockdown. The east side had the highest concentration, reaching 89 ppb [Fig.8 (a)]. As the lockdown progressed, there was a significant drop in NO_2 levels. In April, the concentration decreased to a good level at 32 ppb [Fig.8 (b)]. Further reduction was observed in May, with NO_2 dropping to 22 ppb, and in June, it reached 19 ppb [Fig.8 (c) and (d)]. However, when the lockdown was partially lifted due to socioeconomic conditions, NO_2

concentrations slowly increased. The highest concentration in July was 50 ppb [Fig.8 (e)]. Spatial distribution analysis [Fig.8] depicted the variation in NO_2 levels across different towns of Karachi during the Covid-19 pandemic lockdown. Karachi's eastern side exhibited the highest NO_2 concentration in March, while other divisions showed relatively lower levels. As the lockdown progressed, there was a decrease in NO_2 levels, with values below 80 ppb observed in all divisions by April. The trends continued in May and June, with the east division still recording the highest concentration. However, the concentration dropped again in October to safe levels [Fig.9].

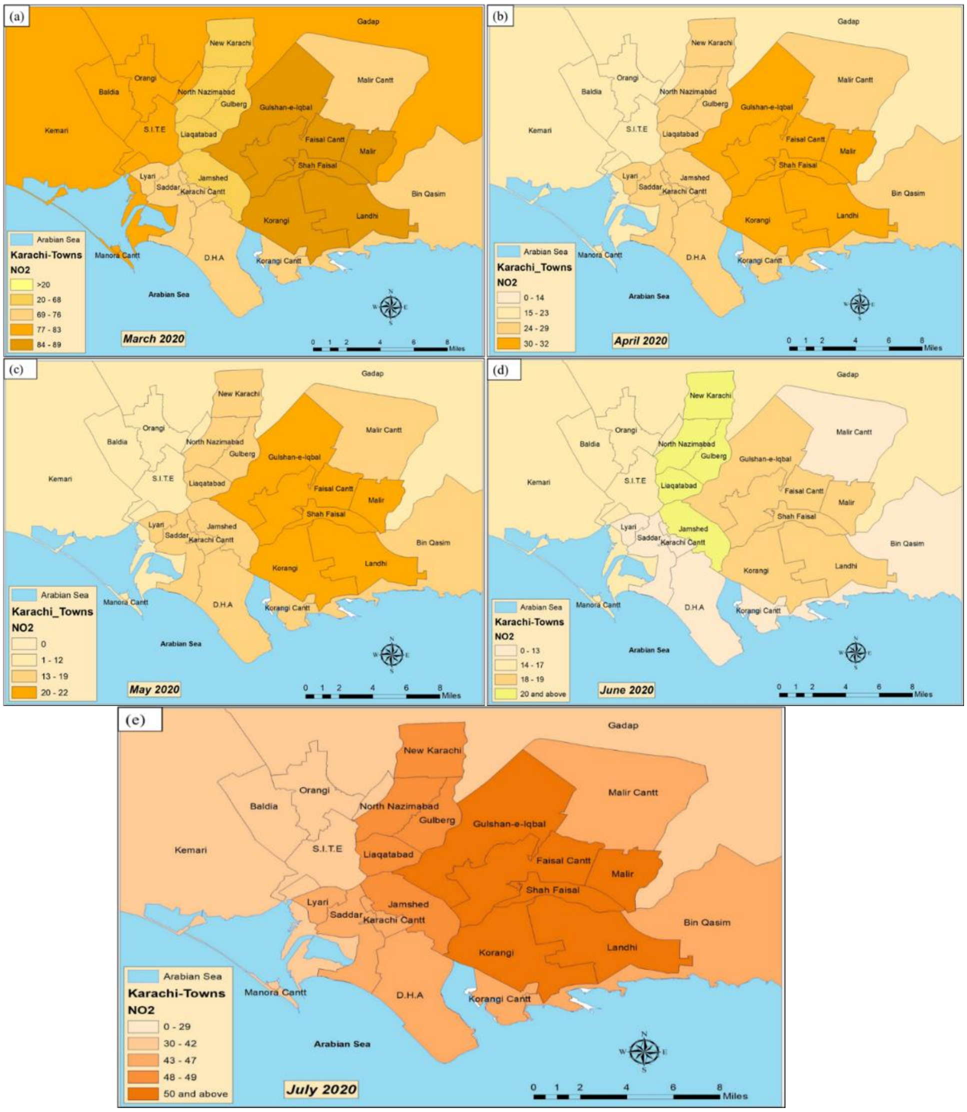


Fig.8: Concentrations of NO_2 in Different Towns of Karachi during Covid-19 Pandemic.

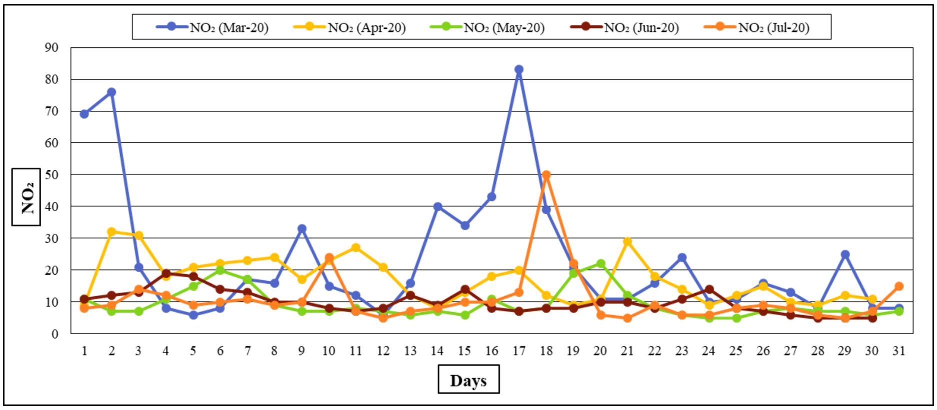


Fig.9: Monthly Variation of NO_2 in Different Divisions of Karachi during Covid-19 Lockdown.

3.3. Air Quality Assessment after Covid-19 Lockdown (2020):

3.3.1. $PM_{2.5}$: After the lifting of the Covid-19 lockdown, there was a gradual restoration of commercial, trading, and industrial activities, which resulted in an increase in PM2.5 concentration. Fig.10 (a) presents the recorded PM2.5 levels within safe limits. In August, the PM2.5 concentration reached 36 µg/m³. In September [fig.10 (b)], as anthropogenic activities resumed completely, the PM2.5 levels exceeded the standard limit, reaching 62 µg/m³. In October [fig.10 (c)], the PM2.5 levels became even more hazardous, reaching 175 µg/m³. After implementing the smart lockdown in July 2020, the PM2.5 levels dropped to safe levels in August, as shown in Fig.11 (a). The air quality in August was classified as very good in terms of PM2.5 levels. With the gradual increase in human activities, the PM2.5 concentration in September [Fig.11 (b)] rose towards hazardous levels again, exceeding 60 µg/m³, but only on one day. In October [Fig.11(c)], when the lockdown had completely ended, the PM2.5 levels exhibited hazardous to very hazardous levels (>40µg/m³) on most days. The central division of Karachi recorded high hazardous levels, while the south division experienced relatively less hazardous days.

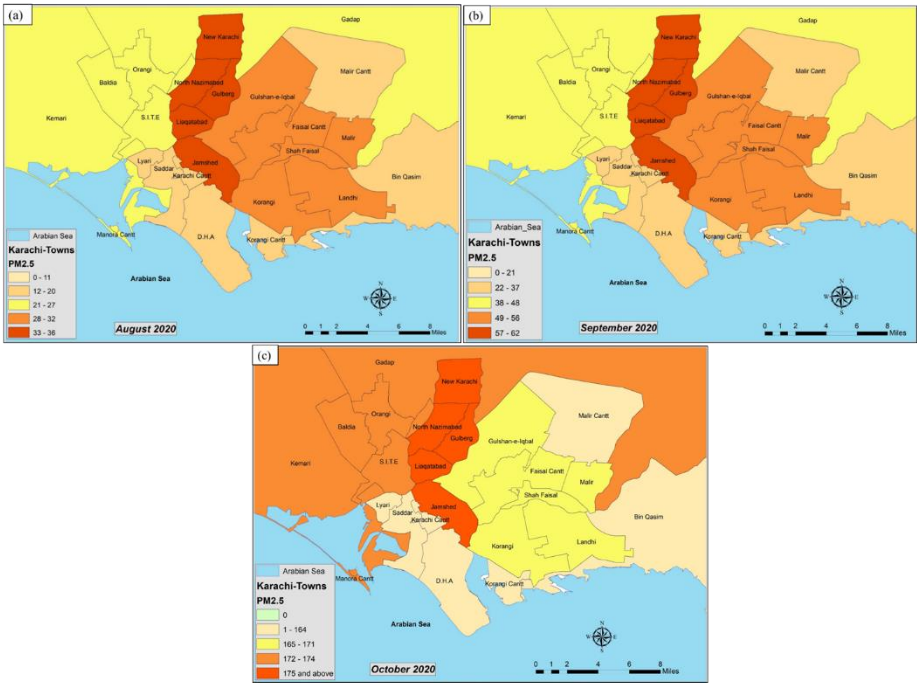


Fig.10: Concentrations of PM2.5 in Different Towns of Karachi after Covid-19 Pandemic.

3.3.2. NO_2: After the Covid-19 lockdown, the concentration of NO_2 exhibited a decline to 20 ppb, as depicted in Fig.12 (a), and then gradually increased to 49 ppb in September [Fig.12 (b)]. It is worth noting that Karachi experienced heavy rainfall during this period, and previous research has indicated that NO_2 levels in the air can significantly increase with rainfall. However, in October, the concentration dropped again to safe levels of 23 ppb [Fig.12 (c)]. The monthly variation in the concentration of NO_2 is shown in Fig.13.

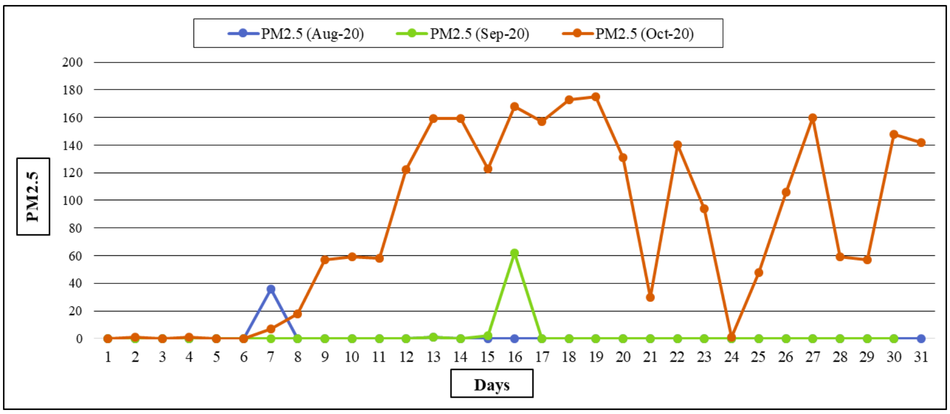


Fig. 11: Monthly Variation of PM2.5 in Different Divisions of Karachi after Covid-19 Lockdown.

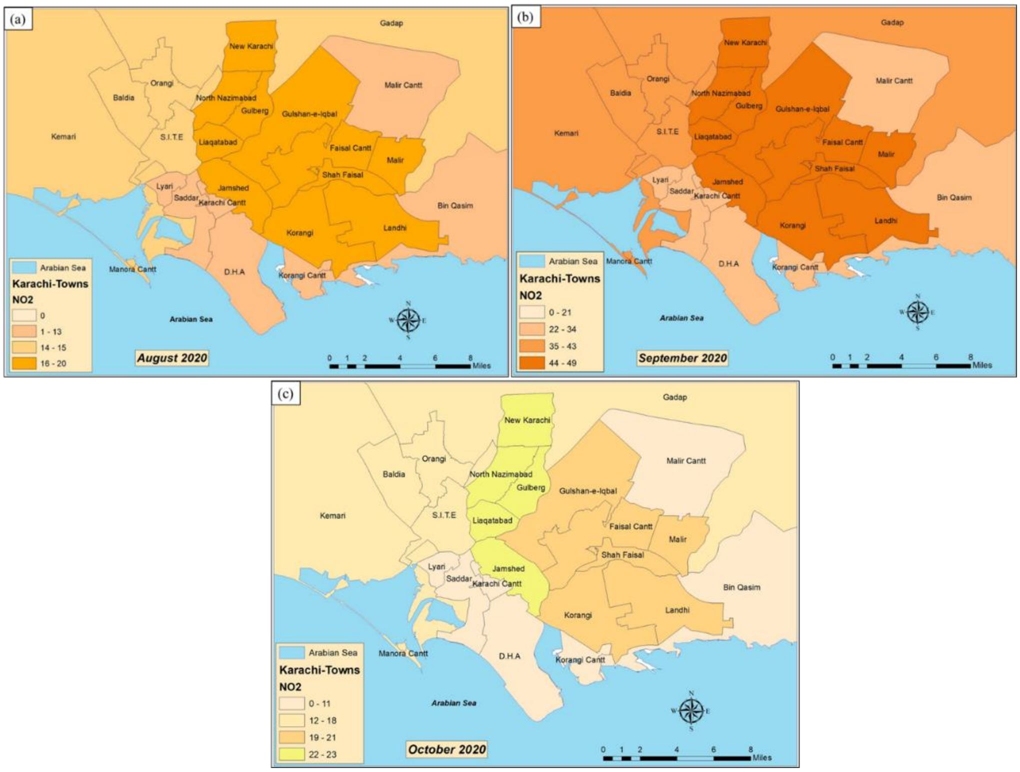


Fig.12: Concentrations of NO_2 in Different Towns of Karachi after Covid-19 Pandemic.

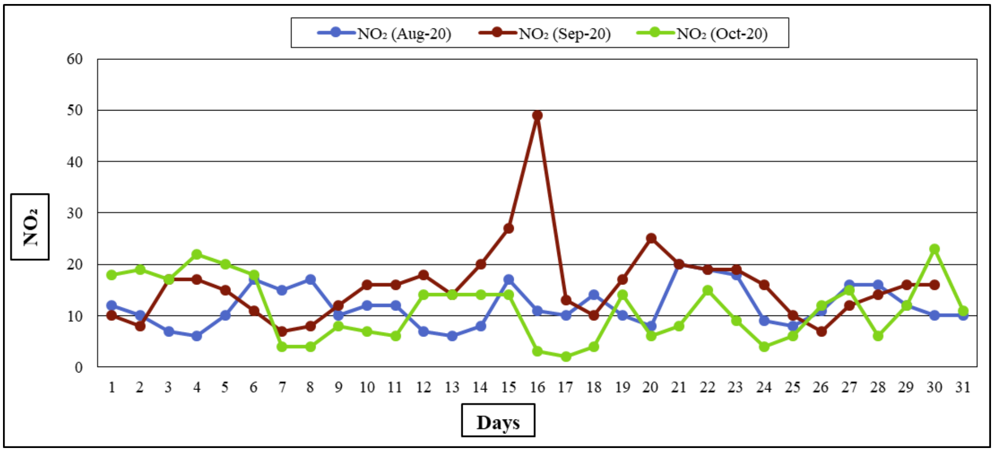
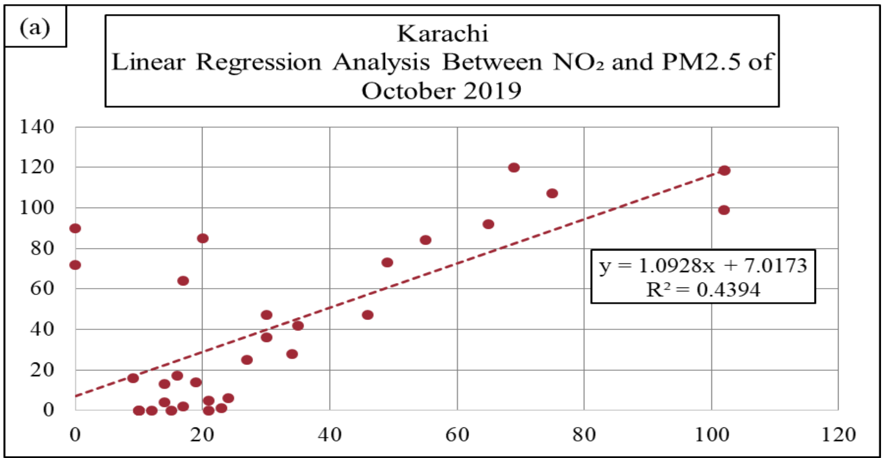
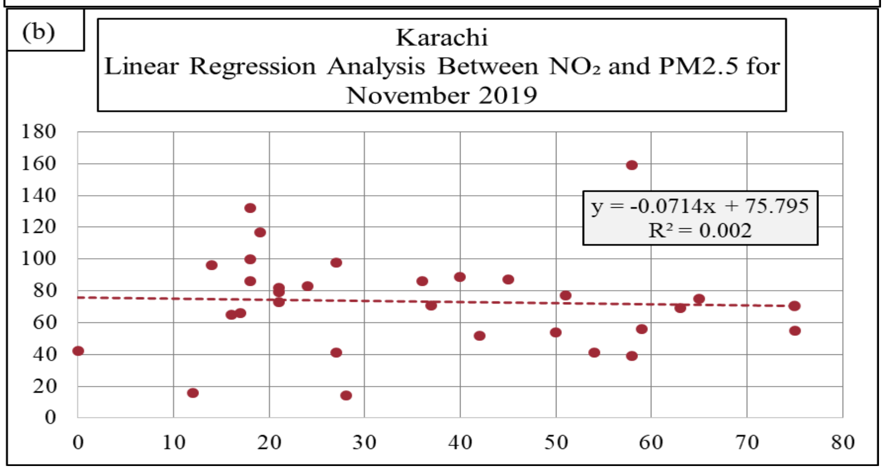


Fig.13: Monthly Variation of NO_2 in Different Divisions of Karachi after Covid-19 Lockdown.

3.4. Linear Regression Analysis:

3.4.1. Pre-COVID Lockdown: Linear regression analysis was performed to examine the relationship between NO_2 and PM2.5 concentrations before the COVID-19 lockdown. The analysis aimed to determine the extent of correlation between the two pollutants. In October 2019, the highest correlation was observed, with an R^2 value of 0.4394 (40% relationship), indicating a positive increasing trend between NO_2 and PM2.5 concentrations (Fig.14a). However, during the transition from autumn to winter in November and December, there was either no correlation or very little correlation between the two pollutants, as indicated by steady trends (Fig.14b and 14c). The regression analysis observed a decreasing trend in the winter months of January and February (Figs.14d and 14e). In January, the correlation between NO_2 and PM2.5 increased to 20% (R^2 = 0.2485), whereas in February, the trend showed a slight increase but with a low correlation (R^2 = 0.09). These results suggest that the concentrations of PM2.5 and NO2 had less of a relationship with each other during these months, and other atmospheric components may have contributed to their high concentrations (Fig.14).





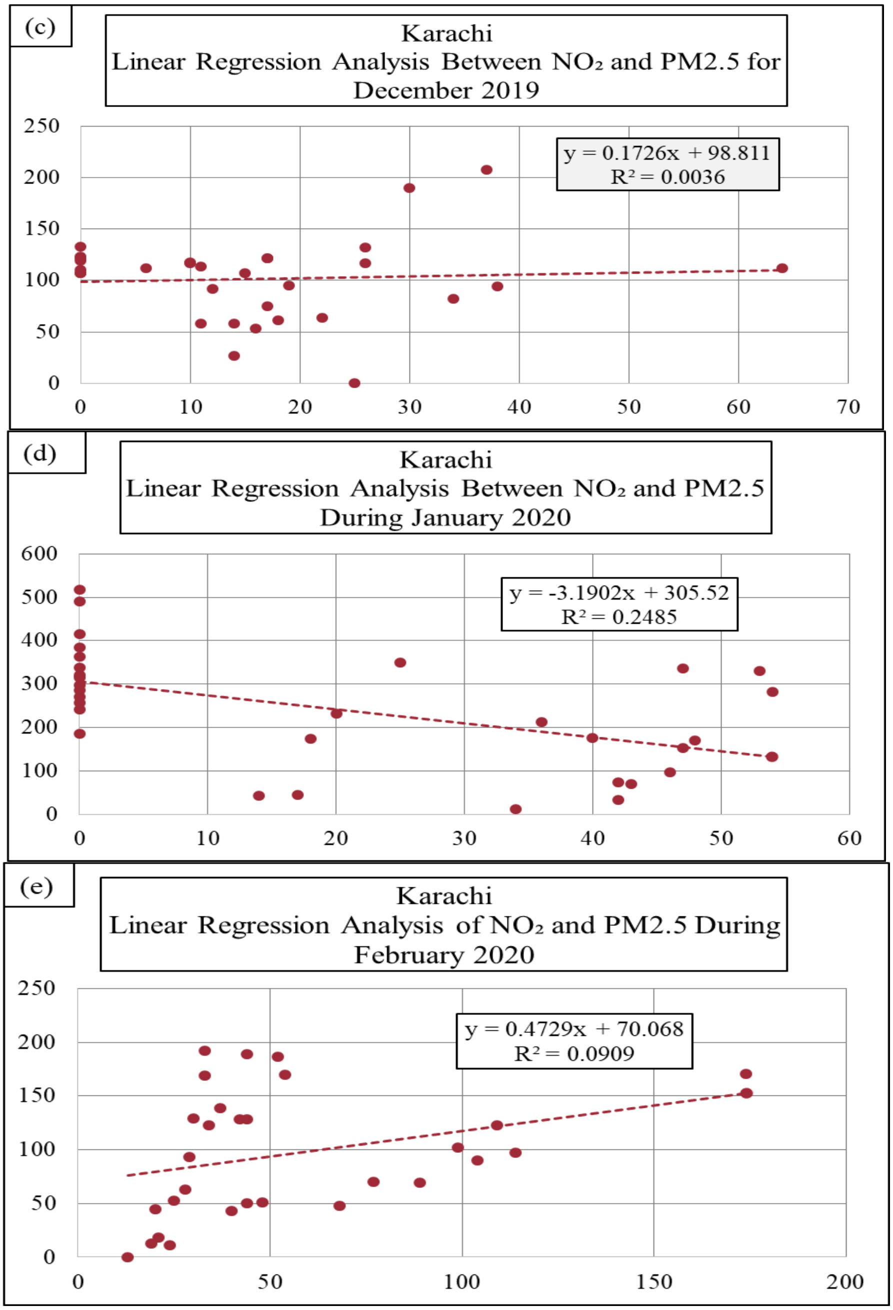
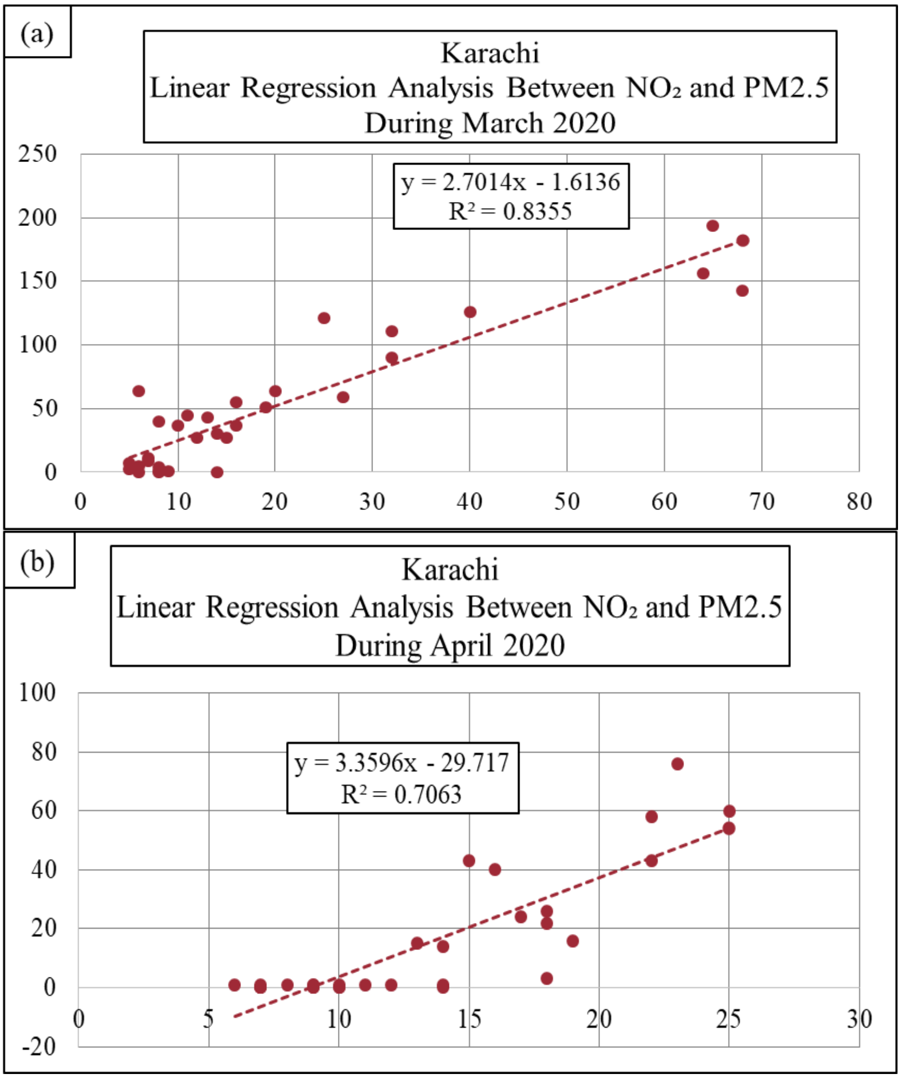


Fig. 14: Linear Regression Analysis between PM2.5 and NO_2 before Covid Lockdown.

3.4.2. During Covid Lockdown: During the COVID-19 lockdown period, as human activities significantly reduced, the concentrations of PM2.5 and NO_2 steadily declined. Regression analysis during this period showed a high correlation between the two pollutants. The most significant dependency relationship was observed in March, with an 80% correlation and an R^2 value of 0.8355 (Fig.15a). This indicates a strong positive relationship between NO_2 and PM2.5 concentrations. As the lockdown began in March, the toxic concentrations of both pollutants started to decline. In April, a further decrease was observed, with a correlation of 70% (R^2 = 0.7265) (Fig.15b). The declining trend continued in May, June, and July, indicating a high correlation between NO_2 and PM2.5 concentrations during the lockdown period (Fig.15c, 15d, and 15e).



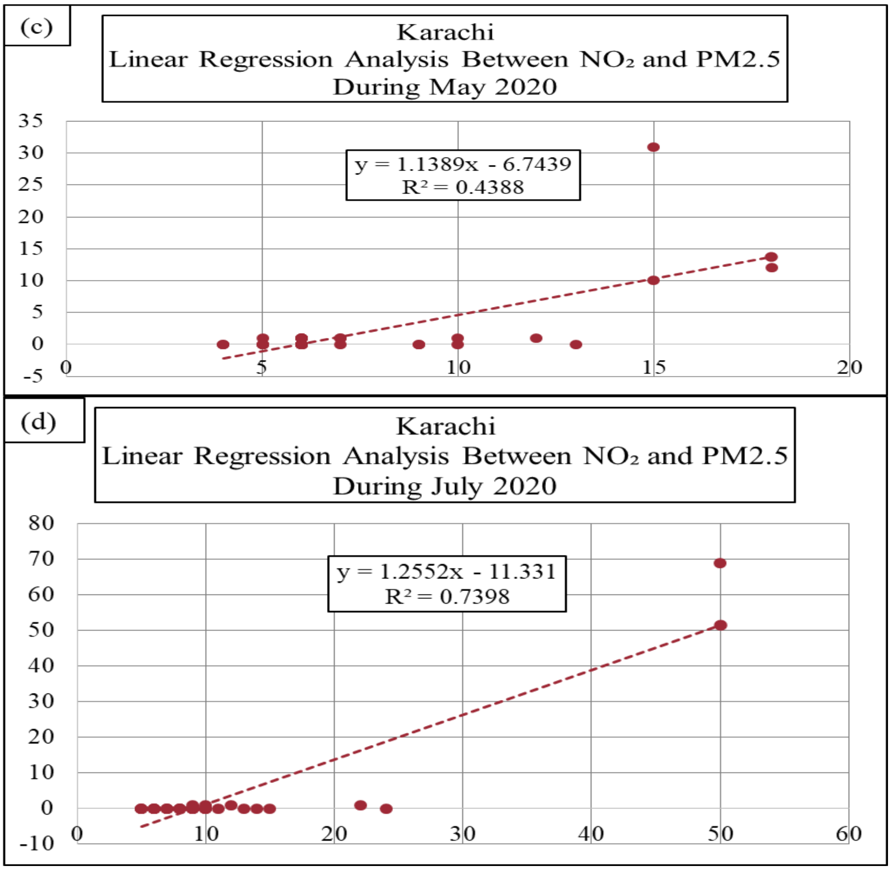


Fig.15: Linear Regression Analysis between PM2.5 and NO_2 during Covid Lockdown.

3.4.3. After Covid Lockdown: After the lifting of the COVID-19 lockdown and the resumption of commercial, trading, and industrial activities, the concentrations of PM2.5 gradually increased. In August, PM2.5 concentrations were recorded below the safe limits, with a concentration of 36 μg/m³ (Fig.16a). However, in September, as anthropogenic activities resumed completely, the PM2.5 concentrations exceeded the standard limit and reached 62 μg/m³ (Fig.16b). In October, the PM2.5 levels became more hazardous, with concentrations reaching 175 μg/m³ (Fig.16c). The linear regression analysis for this period indicated an increasing trend in the relationship between NO_2 and PM2.5 concentrations, although the correlation values were not provided.

The linear regression analysis revealed varying relationships between NO_2 and PM2.5 concentrations in different periods. Before the COVID-19 lockdown, the relationship was inconsistent and weak, indicating the influence of other atmospheric components. During the lockdown, a strong positive relationship was observed, suggesting that reduced human activities contributed to the decline in pollutant concentrations. After the lockdown, as human activities resumed, the relationship between NO_2 and PM2.5 concentrations increased again.

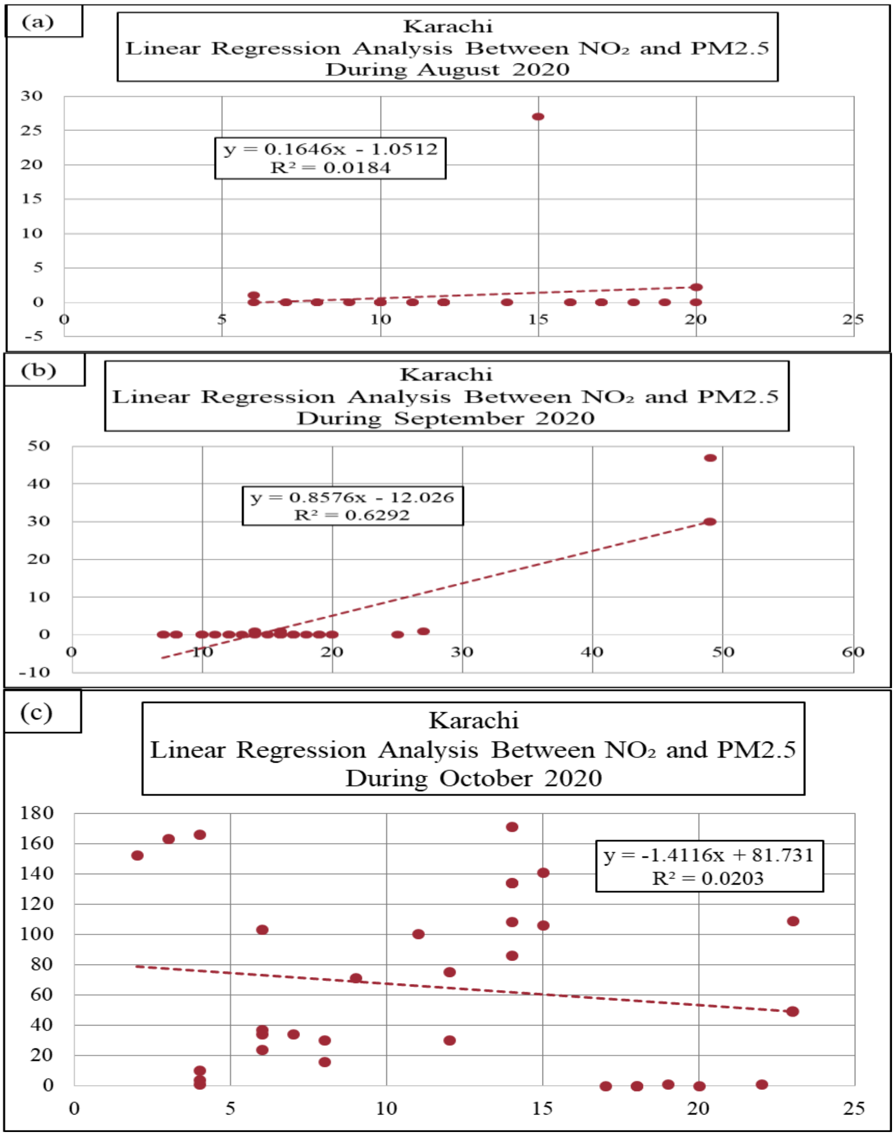


Fig. 16: Linear Regression Analysis between PM2.5 and NO_2 after Covid Lockdown.

3.5. Relationship Analysis between Covid-19 Cases, PM2.5 and NO_2:

The initial case of Covid-19 was reported in Karachi, Pakistan, on February 26, 2020, followed by the imposition of a lockdown in March. From March until the end of 2020, Punjab and Sindh Province consistently reported the highest number of cases (Waris et al., 2020). The Health Department of Sindh and UNICEF commenced case registration in major cities in March 2020 and extended it to the district level in July 2020. According to a report by the National Institute of Health (NIH) on March 29, 2020, Karachi had 769 confirmed cases. Subsequently, a gradual increase in cases was observed in April and May 2020, with the tally reaching 8,051 and 29,066, respectively. However, a significant surge occurred in June 2020, with 68,443 confirmed cases registered. By October 31, 2020, the total number of confirmed cases had reached 98,860.

Figure 17 presents a graphical analysis illustrating the relationship between registered cases of Covid-19 patients and the highest recorded levels of PM2.5 and NO_2 from the onset of the pandemic until October 2020. The figure also displays the ratio of Covid-19 patients, which appears to increase as the concentration of PM2.5 and NO_2 decreases. This finding suggests that open spaces were relatively safer than enclosed environments. Nevertheless, when PM2.5 levels began to rise again in September 2020, the graph demonstrates a stabilization in the recorded number of patients. Thus, a plausible relationship between PM2.5-NO_2 and Covid-19 cases has been observed.

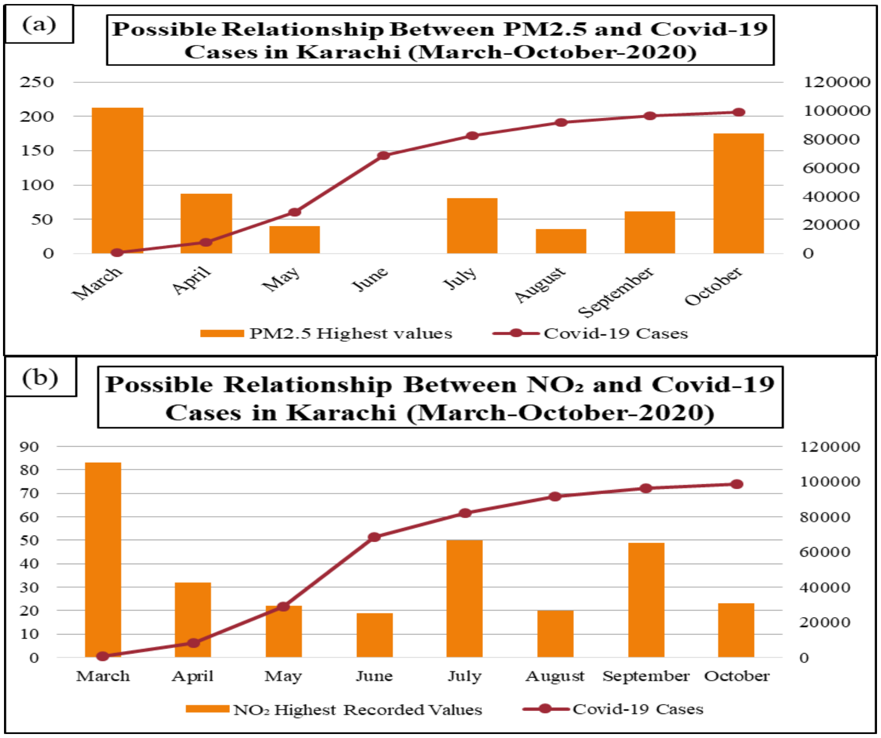


Fig.17: Graphical Analysis of Covid-19 Cases of Karachi (a) With PM2.5 (b) With NO_2

4. CONCLUSION

The air quality in Karachi was among the worst in the world, and the concentration of PM 2.5 and NO_2 was dangerously elevated before the COVID-19 pandemic. Less than 2.5 micrometres in diameter, fine particulate matter (PM2.5) is extremely dangerous to human health as it could penetrate deep into the lungs and the blood stream. PM 2.5 concentration was well above the safety levels of WHO before the pandemic, particularly in the winter season when there was a calm weather trapping polluted air close to the surface. The analysis of the space revealed a marginal lesser level along the coastline, owing to the sea breezes, urban, and industrial cores registered the highest pollution. On the same note, the highest levels of NO_2 were recorded in October 2019, especially in southern and eastern Karachi, which is an indication of heavy traffic and industrial emissions.

The natural experiment to see the impact of reduced human activity was the beginning of the COVID-19 lockdown in 2020. The concentration of PM2.5 and NO_2 reduced significantly and became not dangerous but moderate during the lockdown. In June 2020, PM2. 5 was at its lowest levels in years. Nevertheless, later in July, when the restrictions were lifted, the pollution levels increased once again, and this proves the direct correlation between air pollution and human activity. The spatial analysis during the lockdown has shown that hotspots persisted in the eastern industrial regions yet there was an overall improvement of air quality in the city during pandemic.

Overall, the outcomes of study show that Karachi has poor air quality that is a result of anthropogenic factors such as vehicular traffic, industrial emission, and fuel combustion. This study underscores the dire need of policy intervention and the possibilities of sustainable actions like adoption of clean energy, tightening of emission laws, enhancement of the transport system and efficient monitoring. The fact that clean air can be obtained by means of collective policy and behavioral change, which is demonstrated by the temporary improvement during lockdown. The experience of Karachi is one of the wake-up calls to pay more attention to air quality management and to consider environmental sustainability as part of future urban planning.

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