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Research Article

Space-borne Air Quality Monitoring of Nitrogen dioxide (NO_2) over Karachi and Lahore using Remote Sensing Tools

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Abstract: In this study, we used Sentinel-5P TROPOMI satellite data to examine the NO_2 and gas concentrations in the cities of Lahore and Karachi, Pakistan, and to use environmental valuation methods that focus on air quality problems. Furthermore, the causes and main sources of NO_2 are discussed with its effect on the environment and the health of humans. This study examines the correlation between the tropospheric NO_2 collected from the recently launched Sentinel-5 Precursor, a low-earth-orbit atmospheric mission dedicated to observing air pollution and outfitted with the spectrometer TROPOMI (Tropospheric Monitoring Instrument). The average amount of NO_2 that was gathered between May 2018 and May 2022. The results showed higher levels of NO_2 concentrations were recorded in both, Karachi and Lahore. The concentrations exceed the WHO standard levels for NO_2 in ambient air. The NO_2 concentrations in Karachi ranged from 3.0e-6 mol/m² being the minimum average concentration to 4.0e-1 mol/m^2 being the maximum concentration. However, in Lahore, the minimum average value of NO_2 was ranging from 4.0e-5 mol/m^2 to 5.5e-1 mol/m^2 as the maximum average, which was higher than the minimum and maximum values of Karachi. The study also revealed that the NO_2 concentrations measured for both cities were higher than the WHO's yearly limit threshold, which is 53 ppb/year. Thus, it was crucial to take action to address this issue before it poses a severe risk to the local people. This study's identification of the key regions with the greatest NO_2 concentrations will aid in understanding the significance of satellite data for monitoring NO_2 concentration. Thus, the originality of the study lies in the fact that using the example of Karachi and Lahore, the dynamics of the deterioration of the environmental situation was revealed, and the main reasons for what was happening were also established. In this case, an available tool was used - remote sensing tools. The competent authorities can assist this study in managing and regulating the air quality in the most densely populated areas.

Keywords: Metropolis, Pollutants, Ecological air state, Public health, Sentinel 5p, GIS

1. INTRODUCTION

The problem of air pollution is getting worse as the world's population is growing so [1-3]. Urbanization, energy use, transportation, and motorization are some of the major contributors to air pollution. The environment's quality and people's health are also negatively impacted by population increase and exposure to air pollution [4]. Urbanization and transport have a negative impact on public health, air quality and, due to rapid population growth, contribute to global warming [5, 6]. Air pollutants

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are usually caused by industrial facilities and other activities. [7]. Nitrogen dioxide (NO_2), one of the worst air pollutants, is primarily produced when fossil fuels are burned, particularly in the exhaust emissions from moving vehicles. Satellite remote sensing data has been used to track air pollution over time [7]. In cities with large populations where CO, CH_4, NO_2, particulate matter $PM_{2.5}$ and PM10, as well as ozone and other gases, contribute to the deterioration of the population's health situation due to the occurrence of cardiovascular diseases, respiratory diseases, and even fertility diseases. These diseases affect people of all ages, including children, which has been confirmed by various studies on the relationship between road and industrial pollution and these diseases [8]. As a result, it is essential to continuously and accurately monitor the air quality in order to reduce the impact of air pollutants and ensure that modern discharges are given in accordance with administrative requirements [1].

Different ground-based and satellite-based observing techniques are used as a result. Due to a number of considerations, remote sensing or satellite-based monitoring has an advantage over conventional estimations and ground-based techniques [1]. In order to secure data about the Earth, such as land and sea surface temperature, vegetation cover, air quality, and even to predict and assess catastrophic events like wildfires, remote sensing techniques and GIS are suitable [1]. Sentinel-5P was used for this study of space-borne air quality monitoring of nitrogen dioxide (NO_2) [9]. The Sentinel-5P satellite mission, also known as the Sentinel-5 Precursor, was launched on October 13, 2017 [9-11]. The Sentinel-5P mission, a single-payload satellite in low Earth orbit, is the first in a line of atmospheric observation systems within Copernicus, the European Union's programme for Earth observation with the primary goal of examining the composition of the Earth's atmosphere [9].

The European Space Agency operates various Earth observation satellites that are available under the Copernicus program. These satellites are used to map and monitor the Earth's chemical and physical changes [7]. Sentinel, one of the largest Earth monitoring programmes, uses a variety of satellites. The TROPOMI (Tropospheric Monitoring Instrument) spectrometer on the Sentinel-5p measures CO, CH_4, NO_2, O_3, HCHO, as well as SO_2 in various wavelength ranges (short-wavelength infrared, near, visible, and ultraviolet [12, 13]. Through the Copernicus Open Access Data Hub, all data, including offline and reprocessed data, is publicly available [7]. The former study [14] analyzed, using the ozone-monitoring instrument (OMI) dataset 2004-2008, the spatiotemporal variability of monthly averaged vertical tropospheric columns (VTCs) of NO_2 over Pakistan. A study compared the air pollutants of smog near the border and other sites in Lahore [15]. This research work was performed based on space-borne air quality monitoring of nitrogen dioxide (NO_2) over Karachi and Lahore using remote sensing tools. Karachi and Lahore of Pakistan are two metropolitan areas with their own unique culture. Karachi is often referred to as a mini-Pakistan as it is Pakistan's largest populous city due to the significant influx of migrants. Lahore is the capital of the Punjab province with a rich history. Both cities are rapidly developing and are the center of technological progress, which certainly affects the environmental performance of the environment.

Up-to-date, very limited research work has been done on NO_2 concentration in the mega cities of Pakistan. Such work on NO_2 has not been done in the mega cities including Karachi and Lahore, Pakistan by using remote sensing yet. The Sentinel 5p mission has been used for the collection of data. Furthermore, the results are analyzed and displayed using Arc Map in the research paper. Therefore, the current study's purpose was to investigate the NO_2 pollution spatiotemporal patterns and the data availability for the operational TROPOMI NO_2 product over Karachi and Lahore. Based on the findings, concentrations of NO_2 were determined. Seasonal variations were analyzed to assess the status of nitrogen dioxide (NO_2) using Sentinel 5p data.

2. MATERIALS AND METHODS

2.1. Study Area

The two research areas that were chosen for this study are both in Pakistan. Karachi and Lahore as shown in Figure 1, two cities in Pakistan, are among the sites. These cities were chosen because they

represent the majority of Pakistan's large, highly populated cities. Pakistan, one of the most populous nations on earth, is home to several megacities. Karachi is situated on a shoreline between the Arabian Sea (AS) and the continent of South Asia (SAC), which is known for its sea-land breezes and dominant northeast and southwest winds [16]. Due to this, Karachi, a typical coastal metropolis, is vulnerable to a variety of air pollution sources that are both terrestrial and oceanic in origin [16]. Lahore, Pakistan's Punjab Province's most populous city, has a total area of 1772 km^2 [17]. From May to September there is a hot, rainy summer and from November to February there is a cold, dry winter in Lahore [18]. Since it is a semi-arid region, pollution from industry, work, and transportation is a major cause of a number of environmental issues [19].

2.2. Materials and Mapping

Data from the TROPOMI device of the SENTINEL-5P satellite mission, which monitored nitrogen dioxide levels for the Pakistani area, were used. Through a number of websites, data gathered during the SENTINEL-5P mission is freely available and can be downloaded without charge. Table 1 shows the different properties of Sentinel 5p. Data collected from May 2018 to May 2022, on a daily basis, was downloaded and processed. The methodological network was indicated in Figure 2.

2.3. Data Acquisition

The desired study area, for which data was needed to be downloaded, can be drawn or designated with a point, rectangle, or polygon on the interface for showing and downloading data. The time window during which the data must be downloaded is an optional choice. Additional filters can be chosen, including those for product type and processing technique. First, a rectangle designates the region of Pakistan's territory. In the event that a specific portion of the boundary data is lost during processing, a little broader region than the default

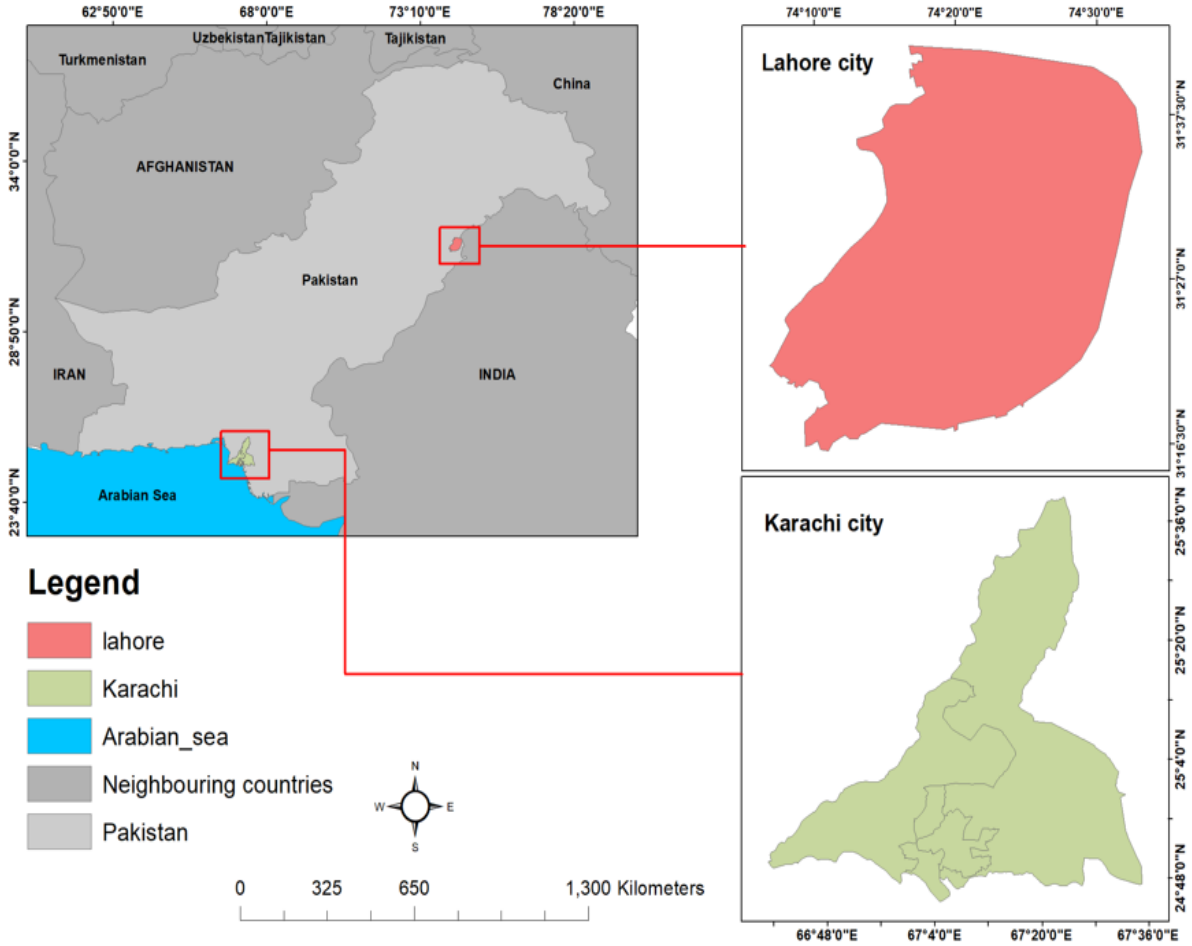

Fig. 1. Study areas, Karachi and Lahore

Table 1. Properties of Sentinel 5p

Spectral band		Spectral coverage, nm	Aperture width, km	Spectral res, nm	Time resolution	Spatial res, km2
Ultraviolet	1	270 - 320	2600	0.49	daily	7 x 28
	2					
Visible	3	320 - 495		0.54		7 x 3.5
	4					
Near-infrared	5	675 - 775		0.38		
	6					
Shortwave infrared	7	2305 - 2385		0.25		7 x 7
	8					

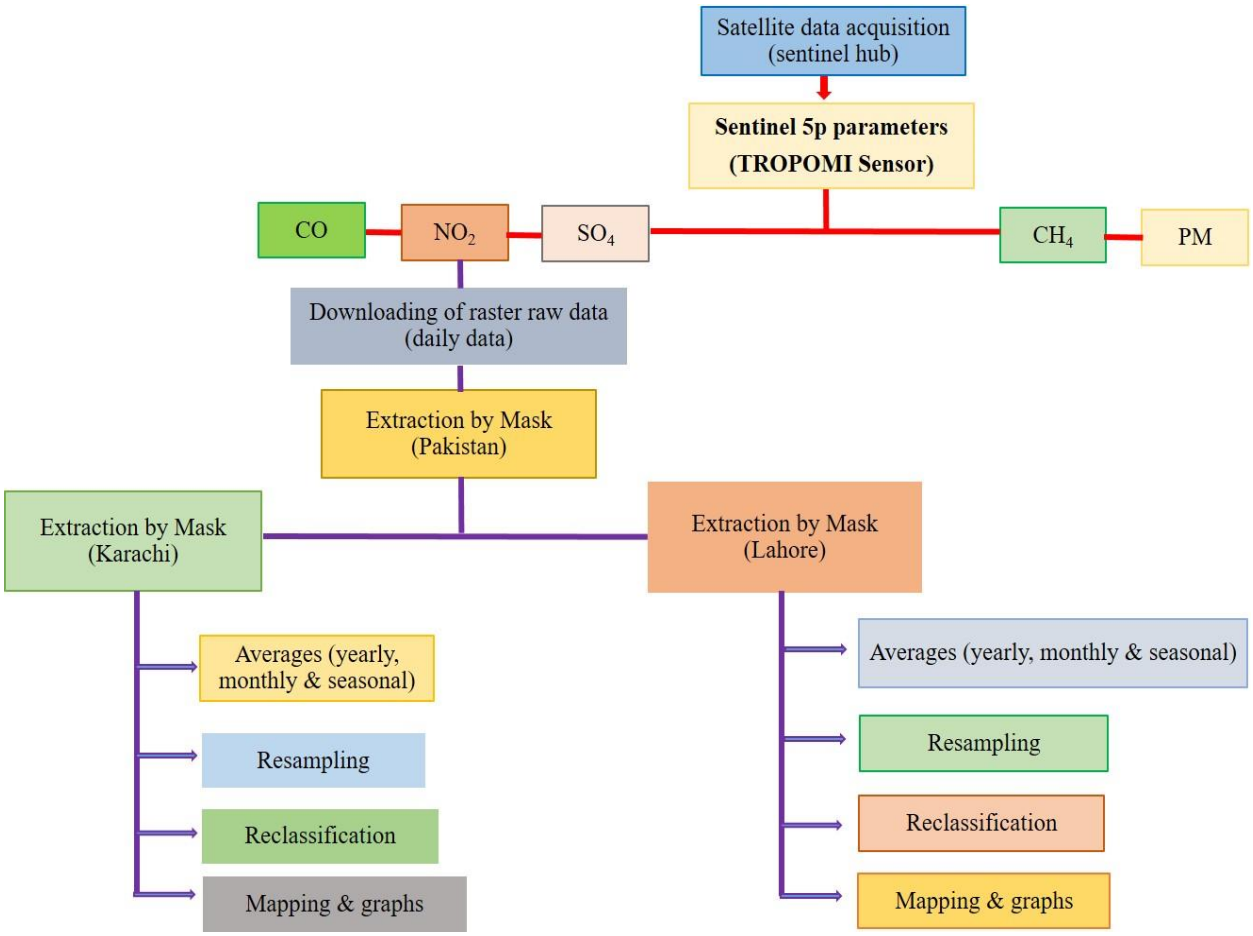

Fig. 2. Methodological network

one is drawn. Data on a daily basis was downloaded from May 2018 to May 2022, and the time span for each individual file was chosen in accordance with this. Every piece of information is correctly geo-referenced, shown using the correct coordinates for the WGS84 (World Geodetic System 1984) coordinate system, and converted into raster TIF format.

2.4. Data Processing

Pakistan's border is first removed from the layer of all administrative borders during data processing. In order to accomplish this, the Pakistan boundary was chosen and stored in certain individual layers, keeping in mind that alone certain objects should be kept. After that, just the data that was located on

the territory of Karachi and Lahore was obtained by cutting all other vector layers to each individual boundary layer of Karachi and Lahore, using the spatial operation crossing. The Clip raster by mask layer operation was used to remove the raster layer. Averages were calculated to cover the missing locations and smooth the data.

2.5. Presentation of Data

Mapping was done of the averaged data maps for monthly, seasonal, and yearly data. For mapping, maps were classified into twelve classes according to their highest and lowest values overall. This way, a legend can be prepared to designate different colours for different values of NO_2 concentrations in both cities as shown in Figure 3.

For making graphs, python coding was used to collect the minimum and maximum concentrations of the map automatically and produce an Excel sheet. These graphs helped in demonstrating the rising or falling trend of the CO concentrations over the year or month. The amount of atoms per surface is expressed in the data's unit of measurement, which is mol/m^2. Finally, the graphs were plotted by using the mean values of the four seasons from the year 2018 to 2022.

3. RESULTS

The results are described for seasonal nitrogen dioxide concentrations over the city of Karachi and Lahore, for the years, 2018 to 2022. Besides, the results of this research study are divided into three major parts such as results of Karachi, the results of Lahore, and the causes and impacts posed by nitrogen dioxide pollutants, and the discussion for each of them is done in accord with it and completely fulfills all the objectives narrated above.

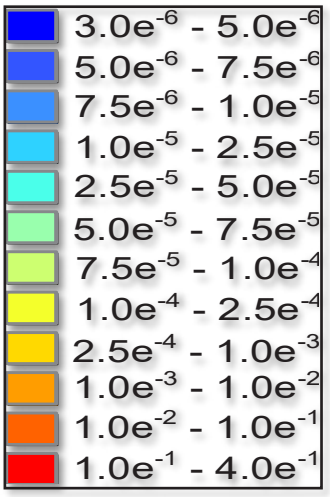

Fig. 3. Legend used in maps

3.1. Karachi Seasonal Average

The NO_2 concentrations for Karachi were assessed through the data collected from Sentinel 5p. The results displayed much higher concentrations than the standards set by WHO or NAAQS, which was 53 ppb. Using NO_2 satellite data products, the NO_2 air pollutant around Karachi city has been examined on a seasonal basis winter (DJF), spring (MAM), summer (JJA), and autumn (SON)) from 2019 to 2022. Seasonal changes have a great impact on the concentrations of the pollutants. Therefore, they must be examined seasonally to assess their scale of risks and impacts.

The map in Figure 4 shows the seasonal mean average NO_2 surface concentration varies from $6.42e^{-6}$ to 0.037 mol/m^2 overall. Concentrations are seen high in winter and summer due to the accumulation of pollutants in atmosphere. However, lower concentrations are seen in spring and autumn, which are the seasons of wind and rain. The graph in Figure 5 shows a uniform shift in values from winter and summer to spring and autumn respectively. This sudden concentration shift between the seasons is due to the different atmospheric conditions in all four seasons. The study reported that Karachi has shown the maximum and minimum mean monthly average values of NO_2 by 11.33×10^{15} molecules/cm^2 and 0.98×10^{15} molecules/cm^2, accordingly, furthermore, the annual increasing concentration of NO_2 was noted at 3.29 % [14].

3.2. Lahore Seasonal Average

The second study area, Lahore, was assessed for its NO_2 concentrations from May 2018 to May 2022. The data acquisition was done through Sentinel 5p and later assessed in yearly, seasonal, and Monthly manner. Lahore is a well-known city for its smog during winter. The major contributor to this smog is NO_2 which reacts with sunlight and produces smog. The results below show that the concentrations of NO_2 in Lahore are higher than the WHO International standards for NO_2. Our results are in line [20].

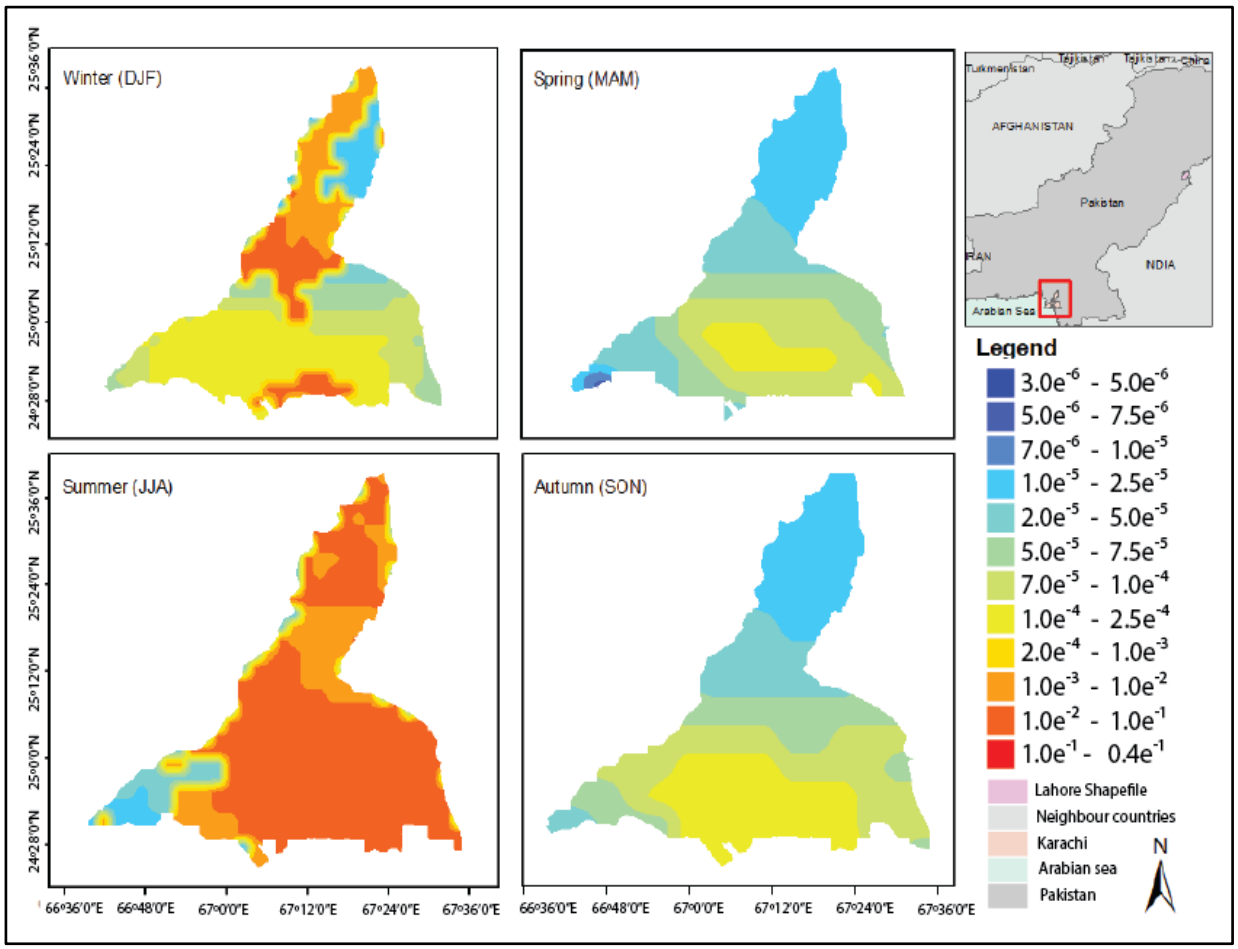

Fig. 4. The seasonal average concentrations of NO_2 in Karachi for last five years (2018 – 2022) in mol/m^2

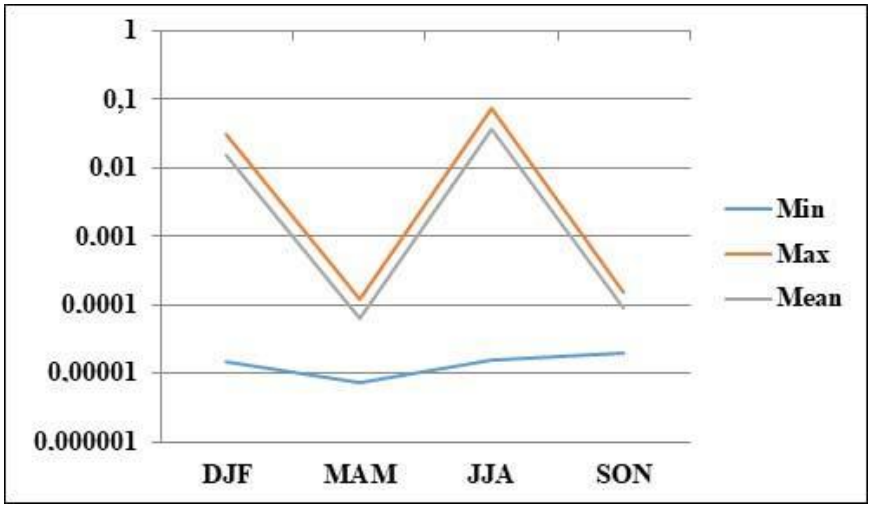

Fig. 5. The logarithmic graph of seasonal average concentrations of NO_2 in Karachi for the last five years (2018–2022)

The NO_2 air pollution in the area of Lahore city has been studied from 2019 to 2022 on a seasonal basis winter (DJF), spring (MAM), summer (JJA), and autumn (SON). Pollutant concentrations are greatly impacted by seasonal fluctuations. As a result, they must be evaluated every season to gauge the severity of the dangers and effects. As it was obvious, the concentration of NO_2 was higher

in winter, which cause the formation of smog in the Punjab province. The map in Figure 6, shows the seasonal mean average NO_2 surface concentration varies from 5.5 e^{-5} to 0.6 mol/m^2 overall. Due to the accumulation of pollutants in the atmosphere, concentrations are higher in the winter and summer. However, the windy and rainy seasons of spring and fall show lesser quantities. The burning of fossils, waste from crops and agriculture, and burning in industries and vehicles contribute to these high-level NO_2 concentrations which result in environmental and human health degradation. Some researchers [15] observed a higher concentration of NOx, whereas SO_2 concentration was found to be lower in the air as compared to national environmental quality standards (NEQS).

The data in Figure 7 demonstrates a consistent change in values from winters and summers to, respectively, springs and autumns. Due to the various atmospheric conditions in each of the four seasons, there is a dramatic concentration change between the seasons. Previously, the researchers [21] performed a case study, and, as a consequence, significant NO_2 concentrations could be observed for high-density housing estates (like high-rise buildings) and food businesses.

4. CONCLUSION

Pollution associated with road traffic and transport is a problem in both developed and developing countries, showing increased levels of NO_2 pollution in the air. At the same time, such areas are more extensive compared to industrial and urban areas, which requires additional modelling of the development of the situation. Since the COVID-19 epidemic began, NASA has published findings showing that the COVID-19 lockdown measures have resulted in a drop in NO_2 concentrations. According to numerous additional researches, the limited human activity during the lockdown led to a considerable decrease in surface NO_2 emissions in cities and megacities. Thus, the originality of the study lies in the fact that, using the example of Karachi and Lahore, the dynamics

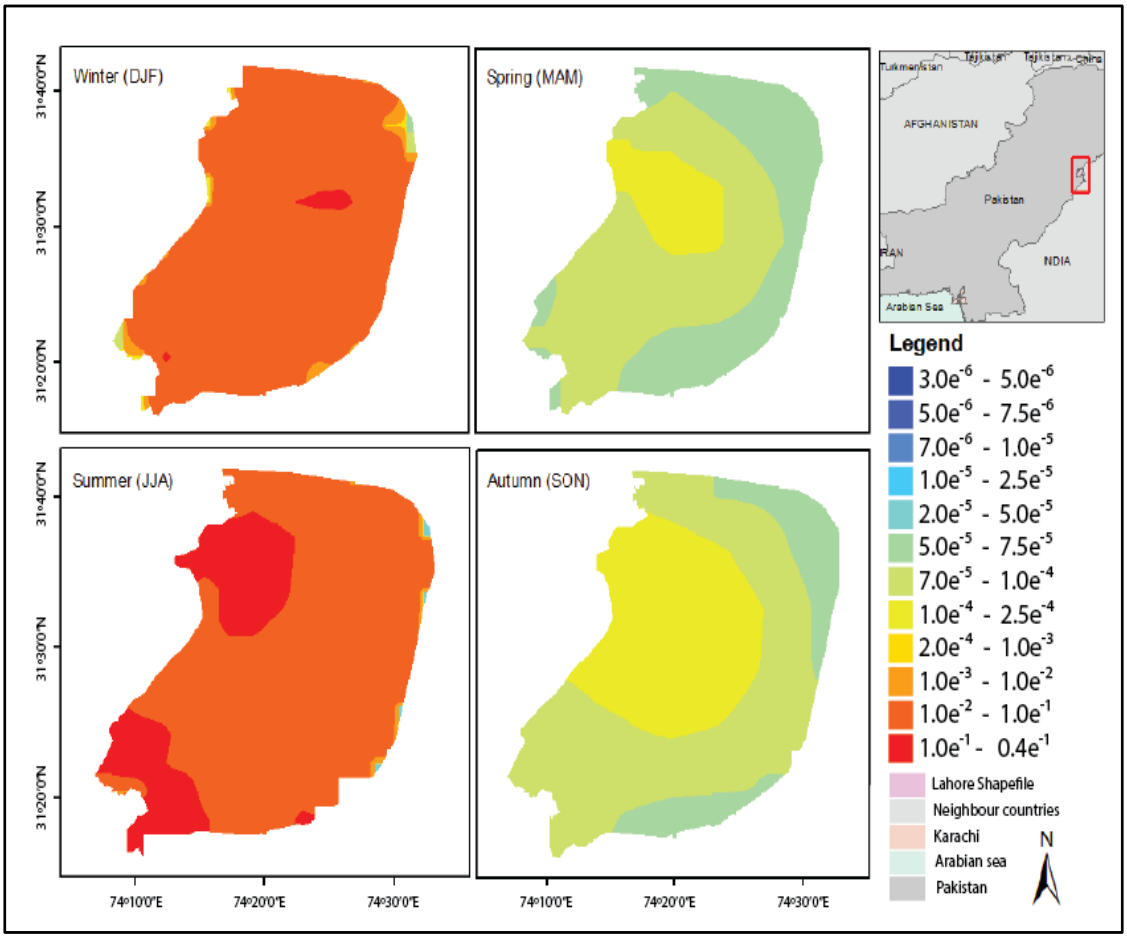

Fig. 6. The seasonal average concentrations of NO_2 in Lahore for last five years (2018 – 2022) in mol/m^2

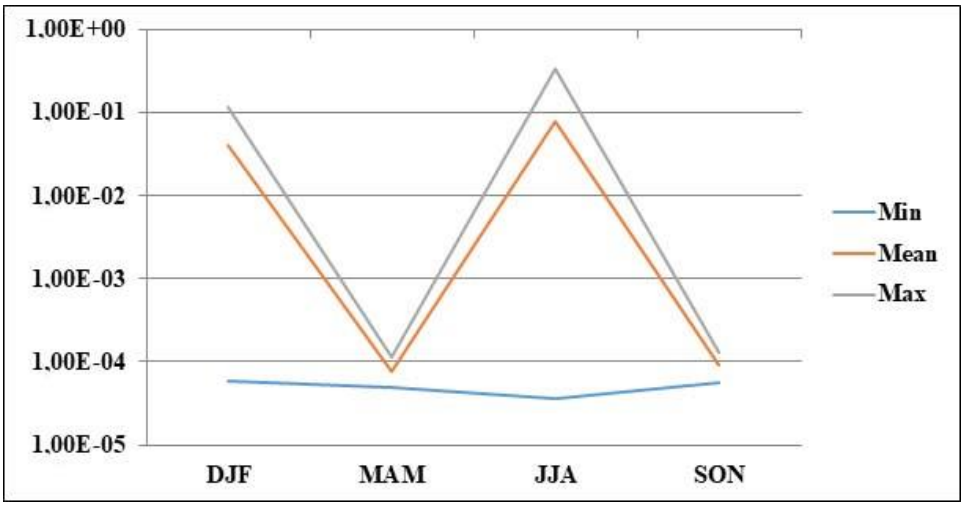

Fig. 7. The logarithmic graph of seasonal average concentrations of NO_2 in Lahore for the last five years (2018 – 2022)

of the deterioration of the environmental situation was revealed, and the main reasons for what was happening were also established. In this case, an available tool was used - remote sensing tools. Government and policy makers are encouraged to take into account the results of the current study when developing NO_2 emission reduction and air pollution management plans.

5. CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

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