JOURNAL OF RESEARCH IN ARCHITECTURE AND PLANNING
Volume 34 Issue 2
ISSN (P) 1728-7715 - ISSN (E) 2519-5050
Journal DOI: www.doi.org/10.53700/jrap_neduet
Issue DOI: www.doi.org/10.53700/jrap3422024

IMPACT OF COVID-19 LOCKDOWN ON AIR QUALITY AND URBAN HEAT ISLANDS: A REMOTE SENSING ANALYSIS OF PM2.5, NO2, AND TEMPERATURE IN LAHORE, PAKISTAN

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Article DOI:
www.doi.org/10.53700/jrap3422024_5

Article Citation:

Qalb A., 2024, Impact of COVID-19 Lockdown on Air Quality and Urban Heat Islands: A Remote Sensing Analysis of PM2.5, NO2, and Temperature in Lahore, Pakistan, *Journal of Research in Architecture & Planning*, 34(2). 54-63.

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ABSTRACT

As the World was has faced with the COVID-19 restrictions, in actuality the pandemic has been a blessing for the urban local climate of many metropolitan cities. This study has presented the condition of Lahore through utilizing remote sensing technique. Due to less usage of vehicles and the ban on commercial activities, the UHI or Urban Heat Island effect has lessened for Lahore city. Similarly, Pearson correlation built between the air quality (NO2, PM2.5, SO2) and Land Surface Temperature (LST) are used to understand the spatial urban variability of SUHI. LST change determination with the help of satellite images Landsat 8 Operational Land Images(OLI) from the year 2018 till 2020 was observed. There is a demonstration of decrease in mean temperature 23.82 C in 2020 while this ratio is 27.92 and 31.79 in 2018 and 2019. Future urban local climate can be predicted with the help of remote sensing techniques and the decreaaed value of air quality may be addressed by the city management for sustainable urban development.

Keywords: Urban heat islands, urban climate, land surface temperature, COVID-19, lockdown.

INTRODUCTION

The COVID-19 significantly changed the human behavior worldwide. Different measures have been adopted to control the virus from spreading more, and efforts are made to reduce interaction among unidentified infected and non-infected persons. It is cleared from the past studies that travel restrictions have demonstrated a positive effect in controlling SARS, Ebola, and bubonic plague outbreaks (Yasin & Gouda, 2020). A lockdown imposes a bound on all commercial activities, construction industries, institutions, offices, labor supply while also limiting disease spread and

health costs (Sasidharan et al., 2020). Lahore city is under the influence of rapid urbanization since the last couple of decades (Basheer & Waseem, 2022). Currently, severe environmental challenges exist due to changes in land use pattern, difference forms pollution which causes events like urban flooding and smog especially in developing cities. Urbanization has aggravated climatic changes, which further impacted the metaphorical development in the city. Urban sprawl is quite visible in the surrounding areas, which mixed the rural lands into the built-up urban developments. There are abrupt changes in the rate of urban growth in Lahore city (Abbas et al., 2018; Rana & Bhatti, 2018). The ecological, climatic, biological, and regional elements are disrupted by it. The urban heat island (UHI) is becoming prominent due to the cutting of green land and increasing built-up areas. UHI is primarily the main result of encroachment, which has further increased temperature overall. This has been the main theme of study for many researchers since decades. Heat islands temperature is higher than the nearby areas because of the heavy traffic generation likewise Airport, shopping malls and industries (Imran & Mehmood, 2020; Mentaschi et al., 2022).

The Punjab government implemented lockdown in Lahore on March 20 for quick response to prevent the spread of Covid-19 in the city by limiting unrestricted movement throughout the Punjab province. The decision to enforce the strict lockdown was made by the government due to of the drastic increase in COVID-19 patients in the city. Strict measures were taken for people interest, and people commuting without any purpose were compeled stay at to home. Strict rules more imposed at the city boundary and the entry and exit points of Lahore city.

Compelled a large number of researchers have examined the empirical relationship between temperature and COVID-19 (Gollwitzer et al., 2021). Most of these studies have investigated the impact of temperature and humidity on COVID-19 cases. On contrary, this study is a pioneer to examine the impact of COVID-19 on city temperature. Lahore is selected as it is one of the second highest populated and dense city of Pakistan. One of the studies (Gautam, 2020; Khan et. al, 2023, p. 20; Saha et al., 2022) suggest that due to lock down activities during COVID-19, air quality has been enhanced.

The aim of this study is to investigate the urban local climate in Covid-19 period with the help of Landsat 8 Operational Land Imager (OLI) images. Specifically, we aim to quantify the Land Surface Temperature and build its Pearson correlation with air quality indicators. Furthermore, we assess the improvement in urban air quality by calculating the extent of Urban Heat Island reduction during this period through remote sensing. The primary research questions are:

- How did the COVID-19 restrictions impact LST in Lahore?
- What is the correlation between air quality indicators (NO2, PM2.5, SO2) and LST during this period?
- To what extend to the urban air quality of Lahore improved and UHI reduced; post covid-19?

LITERATURE REVIEW

The COVID-19 pandemic began to spread globally in the second fortnight of December 2019. This disease swiftly spread throughout China, Italy, France, Spain, Germany, the Russian Federation, the United Kingdom, the United States, and India, as well as the UAE, Australia, Brazil, Argentina, and many other nations. It took lives of 1,147,000 persons and infected over 42,500,000 people as of October 25th. Given this urgency and the threat posed by this virus, the majority of the world adopted lockdown (full or partial) after March 2020, freezing pollution-effective economic sectors such as industry, transportation, tourism, and so on. This imposed measure resulted in significant economic losses all over the world, yet nature had the opportunity to refresh its surroundings, as revealed by Tobias et. al,(2020).

A significant and sudden drop in global carbon emissions was detected as a result of reduced energy footprint (Wang and Su, 2020), industrial production halt (Muhammad et al., 2020), public transportation disruption (Chen et al., 2020), and so on. A temporary pause in economic operations not only lowered carbon emissions, but also limited the discharge of numerous other greenhouse gases (GHGs) and pollutants such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter 2.5 and 10 (PM 2.5, 10). In addition, a 25% reduction in CO_2, equivalent to 1 million tons of carbon, was discovered in China (Wang and Su, 2020). The megacity of Delhi, India, was the subject of research by Mahato et. al, (2020), who found that most areas of the city had significantly improved in quality. The air quality in the most polluted Indian cities during the COVID-19 lockdown was reported by Mahato and Ghosh (2020). According to Sharma et al. (2020), the AQI in 22 Indian cities showed improvements of 15–44%. According to Das et. al, (2021), during lockdown, the air quality in Indian megacities likewise improved by 50%, and during partial lockdown, the air quality hotspot was restored after dilution (Travaglio et al.,2021).

Human heat emissions and air pollution decreased as a result of the significant reduction in human activities during the COVID-19 lockdown, which had a significant impact on the urban heat island (UHI) phenomenon, a local climate change phenomenon in which temperatures in cities are higher than in rural areas due to urbanization. Changes in anthropogenic emissions and air pollutants have a considerable impact on land surface temperature (LST) (Qian et al., 2022). Despite a decrease in aerosol radiative forcing during the worldwide COVID-19 lockout, LST and air temperature did not rise as projected, and in some cases dropped in Europe and North America (Parida et al., 2021a). Similar conditions have been reported in Iran (Roshan et al., 2021) and India (Parida et al., 2021b).

MATERIALS AND METHODS

Study Area

Lahore city was selected as the case study area as it is the capital of Punjab and the second-largest city in Pakistan (figure 1). The city is currently experiencing bloating of transport sector development with new carpeted roads, flyovers, metro and orange line projects, rail tracks, road extensions, and other housing-related construction projects. Increased infrastructure development is accomponied with chopping down a massive number of trees. Furthermore, the city faces the challenges of smog, heatwaves and recent sandstorms which depicts the climate change impacts.

Data Collection Details

To analyze the spatial patterns of temperature variation in Lahore cloud-free Landsat-8 OLI was used for calculating the LST from 2018 to 2020 and all this data were collected on official US Geological Survey site (https://earthexplorer.usgs.gov/). Remote Sensing data was acquired for March and April month for the years 2018 till 2020 as corona lockdown started from March. Furthermore, a 5x5 filter of sharpening was used to remove blurring and increased image enhancement. Also, Data was obtained by the meteorological department to analyze air quality for the

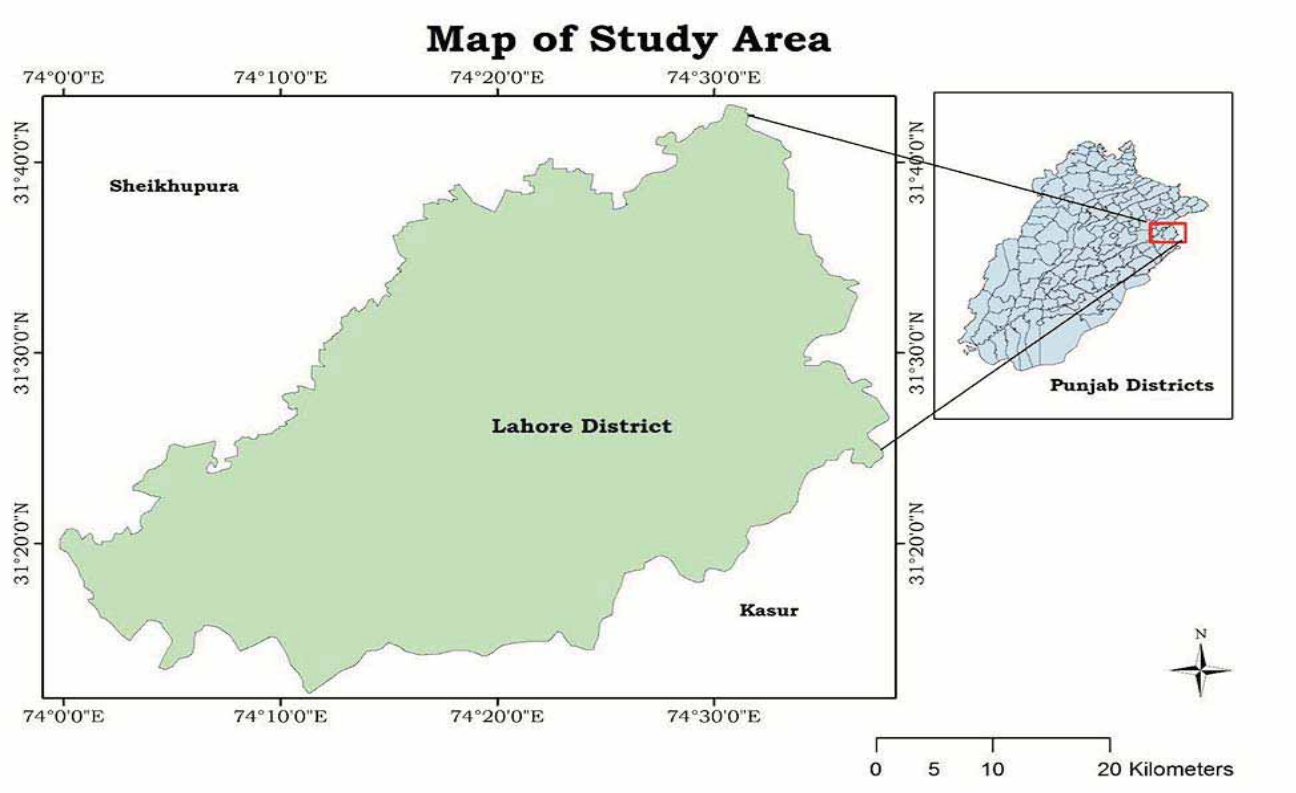

Figure-1: Sdudy Area Map of District Lahore.

overall two months' time period to check the difference of the environmental conditions in the time of lockdown.

LST Calculations and Abbreviations

LST is an important parameter to evaluate the environmental changes (Mustafa et al., 2020). Equation (1) to (6) explains the procedure to calculate the LST (Imran & Mehmood, 2020).

$$\frac{BT}{1 + (W) \text{ X } (BT / p) \text{ X In } (LSE)} \quad (1)$$

Where w represents the wavelength emitted radiance

p = he (1.438 X 10 - 2mK) (2)

Furthermore, BT travels upwards from the earth surface towards satellite and satellite captures it in the form of microwave radiation called Brightness Temperature. This was calculated as follows:

$$BT = \frac{K2}{\text{In } (K1/(L+1))} \quad (3)$$

As, BT is measured in temperature Kelvin, K1 and K2 are considered constant and its unit is watts / meter, L is spectral radiance in watts / (m sq * ster * um).

- If using Landsat 8 data then the value of K1 = 774.8853 and K2 = 1321.0789.

In the third step, Top of Atmospheric spectral radiance is calculated, whose details are in the metadata file:

$L\lambda = MLQcal + AL$ (4)

$L\lambda$ is the TOA. Its units are given as (Watts/(m² .sr.um), Pixel value is based on the Qcal, and ML = multiplicative rescaling factor and AL = additive rescaling factor of specific band.

- If using Landsat 8 data then the value of ML = 3.3420E-04 and AL = 0.10000. Furthermore, The Land Surface Emissivity (LSE) is calculated with the formula: LSE = 0.986 + 0.004 X PV(5)

Lastly, proportion of vegetation is calculated to estimate LST.

$$PV \frac{(NDVI - NDVImin)^2}{(NDVImax - NDVImin)^2} \quad (6)$$

The above equations are useful in predicting LST through ArcMap 10.8 and putting equations in raster calculator.

Surface Urban Heat Island (SUHI)

"Surface UHI" refers to warmer urban temperatures at the city level (Deilami et al., 2018). Surface temperature can be accessed by remotely sensed data. And it is measured with the help of satellites, so that the temperature of urban infrastructure can be measured. That's why Surface UHI is max during the day because earth warms quickly in the morning (Lehoczky et al., 2017; Zhang et al., 2023). All these steps are explained in the figure 2.

UHI = LST - LST (mean) (7)

RESULTS

Impact on Temperature

Extreme weather and climate events have wide ranging impacts on society as well as on biophysical processes. Many scientists from different parts of the world have linked increasing extreme weather events to global warming and it is assumed that intensities and occurrences of extreme weather will increase with the increase in global temperatures. Pakistan is the 5th most effected country (Nasim et al., 2018) by the climatic changes.

By delving deeper into the causes of spatial differences in UHI reduction, researchers discovered crucial elements that influenced the results. For example, variations in land use patterns, building density, and vegetation cover could all influence the efficiency of UHI mitigation. Understanding why particular locations face larger or smaller changes in UHI levels have allowed politicians and city planners to better customize their actions to meet the individual needs of diverse neighborhoods.

The temperature is considered to be a major factor in environmental evaluation of a city (Lau et al., 2020). The fluctuation in temperature creates a lot of changes in the city (Xie et al., 2020). Same is the case with Lahore city, climatic conditions are inter-changeable into different seasons with varying temperatures. The temperature trends are usually same each year but a significant change was observed in the temperature due to lock down of all commercial activities as well as automobiles and transport activities.

Comparing the pre-COVID-19 temperature and during COVID-19 temperature of Lahore during lockdown, a

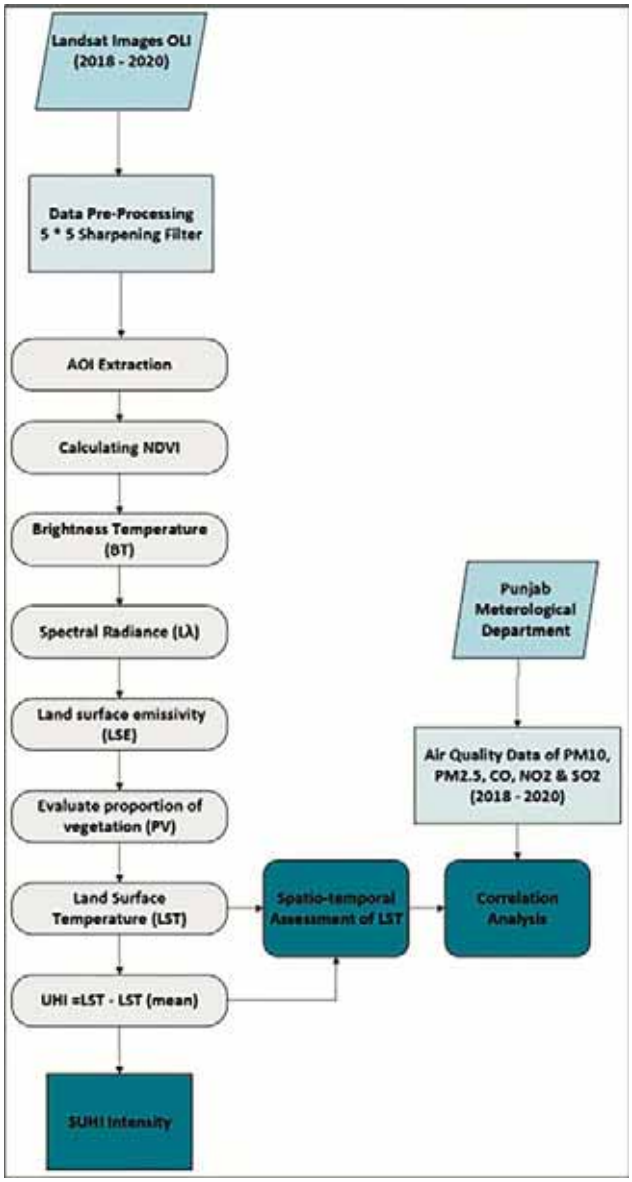

Figure-2: Methodological Flow of a Study.

significant change was observed as illustrated in figure 3 and 4. Resultantly, 33^0C temperature was observed in March 2020 during lockdown while this temperature was 42^0C in the last two years for the month of March. Also, in April month, decrease in temperature was observed during 2020, although 2018 and 2019 April showed higher temperature up to 42^0C. On the other side, if we compare LST mean, min and max temperature for the years 2018, 2019 and 2020 as shown in the figure 5 and 6. During lockdown in 2020, LST shows decrease in both March and April while rest of the years had shown increasing trends (Qalb et al., 2024). This evidently highlights that corona virus has had a great impact on living conditions and temperature as it has lessened

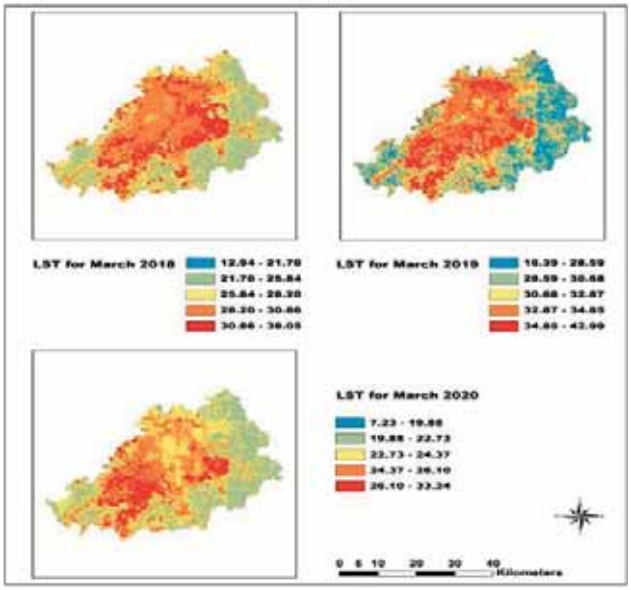

Figure-3: Lahore Surface Temperature (LST) for March 2018, 2019 and 2020.

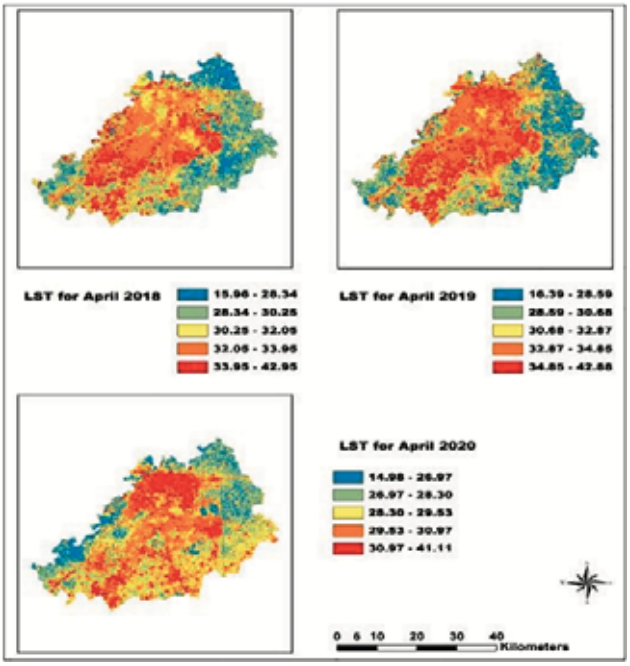

Figure-4: Lahoe Surface Temperature (LST) for April 2018, 2019 and 2020.

the city's temperature (Basit & Shakrullah, 2019; Khan, 2021).

The study period was selected for 2018 to 2020 because COVID-19 pandemic starts in 2019, and the restrictions imposed during this time period provides a unique opportunity to examine the impact on air quality of Lahore and UHI effects (Qalb et al., 2024). Before 2019, Lahore was

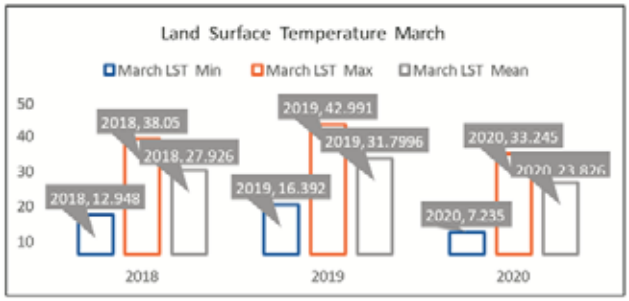

Figure-5: Lahore Surface Temperature (LST) for Marach 2018, 2019 and 2020, showing the minimam, maximam and mean values.

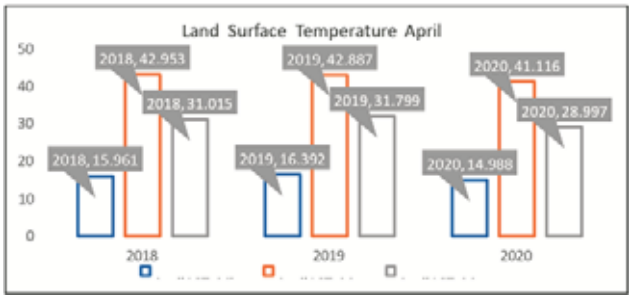

Figure-6: Lahore Surface Temperature (LST) for April 2018, 2019 and 2020, showing the minimam, maximam and mean values.

experiencing increasing trends of UHI due to rise in temperature and escalating traffic congestion (Imran & Mehmood, 2020). By comparing data from 2018, influence of COVID-19 restrictions on urban climate and air quality of Lahore was assessed. However, when the lockdown was implemented in the 2019 and 2020, we observed drastic decline in UHI. Specifically, the temperature data from 2019 still shows an upward trend because lockdown is not fully implemented. In contrast, April 2020 temperature shows a declining trend due to decreased vehicular movement and industrial activity. This dramatic shift supports the rationale for choosing the dataset from 2018 to 2020 as it highlights the direct impact of lockdown on UHI and urban air quality of Lahore. This study provides a unique insight into how human activities influence the urban climate.

Impact on the Heat Islands

During the COVID-19 period lockdown, significant decrease in LST is observed, and at the same time heat islands are lessened and shifted from inner city to the outskirts of a city as shown in the figures 7 and 8. During 2018 and 2019, UHI is at its peak but during lockdown, UHI zones diminish. Figure 7 and 8 highlight the UHI through remote sensing in ArcMap 10.8 (El Kenawy et al., 2021; Parida et al., 2021, p. 19).

Impact on the Air Quality

Many countries are imposing lockdowns to make safe residents from virus (Atalan, 2020; Chintalapudi et al., 2020). This has had a substantial impact on Lahore's environment. NO2 essentially gets noticeable all around, as the consuming of fuel and outflows from vehicles, trucks and transports are limited, power plants, and rough terrain hardware are not operational in many parts of the city. Less vehicles on the streets implies less pollution and ban of industrial and commercial activities benefits the overall quality of air in the city. Figure 9 and 10 shows the comparison between the air quality of year 2019 with 2020. A significant change in air quality can be observed.

The values obtained, which are shown in figure 10 and 11 are in accordance with Punjab Environmental Quality Standard. By comparing these we can conclude that air pollutants are showing decreasing trend. While the PM10 in March 2019 is reported at 119.95, in March 2020, the PM10 comes down to 32.72. For PM2.5, the value in March 2019 is 62.23 which turn to 21.72 in March 2020. The value for nitrogen oxide (NO) is 46 and 10.22, in March 2019 and March 2020, respectively. Figure 11 shows the fluctuations in air quality right after the lockdown ended. The observed changes in primary pollutants are linked to decrease in emissions during the lockdown period (Wu et al., 2020). Emissions estimates based on current activity levels suggest an overall decrease of Sulphur and carbon oxides, which was generated from road traffic, from industry and power plants. Therefore, it can also be said that poor quality of air and commercial and business activities relate with each other (Wang et al., 2020).

The COVID-19 lockdown has provided us with the positive opportunity to observe the impact of reduced human and industrial activities on air quality and the environment. During lockdown, a sharp decline was observed in vehicular emissions which led to noticeable improvements in the AQI as shown in the figure 9 and 10. These changes highlight the potential for integrating environmental considerations into future urban planning. Environmentalists and urban planners can use these insights to develop hybrid approaches to manage city. To create a balance between economic activities and environmental sustainability. Policies that promote cleaner transportation, greener spaces, roof top gardens and reduced industrial emissions to tackle smog and other environmental challenges, always positive growth of urban area (Graceetal, 2023, Thompson et. al, 2024). Such policies would not only help in the improvement of public health but also develop cities based on sustainable

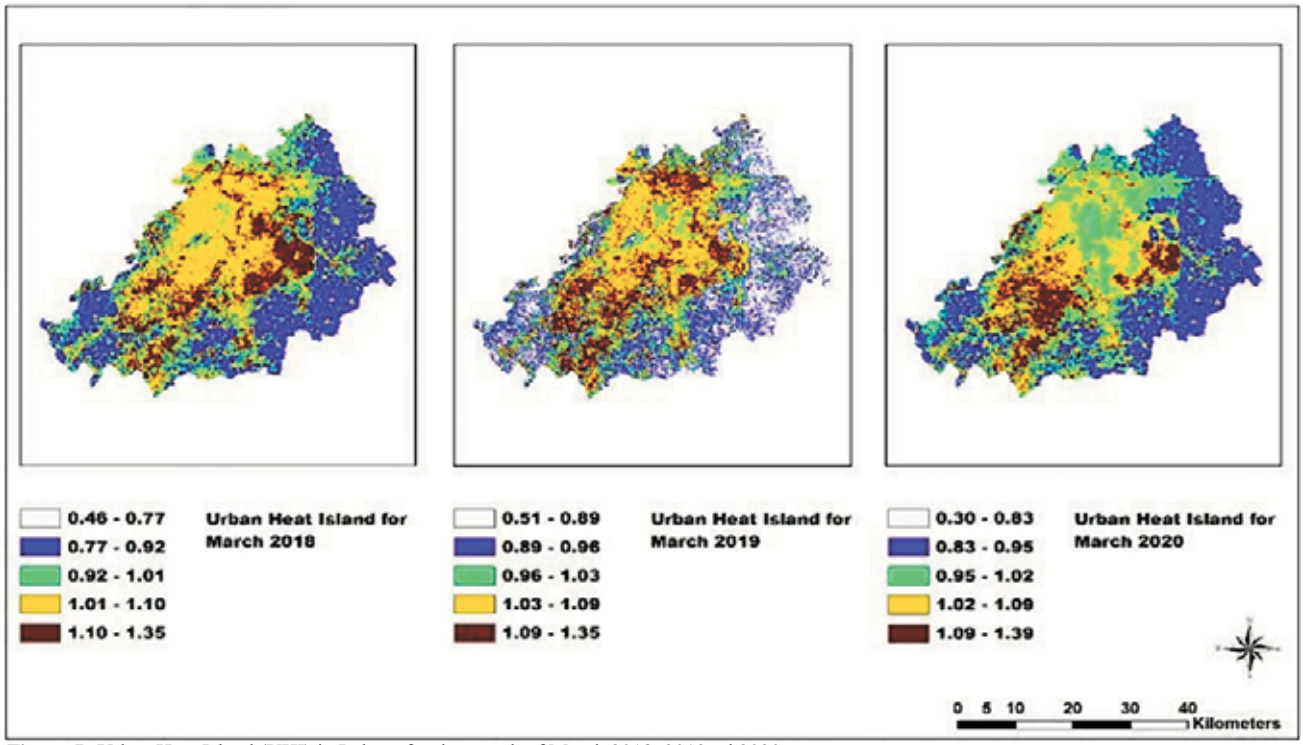

Figure-7: Urban Heat Island (UHI) in Lahore for the month of March 2018, 2019 nd 2020.

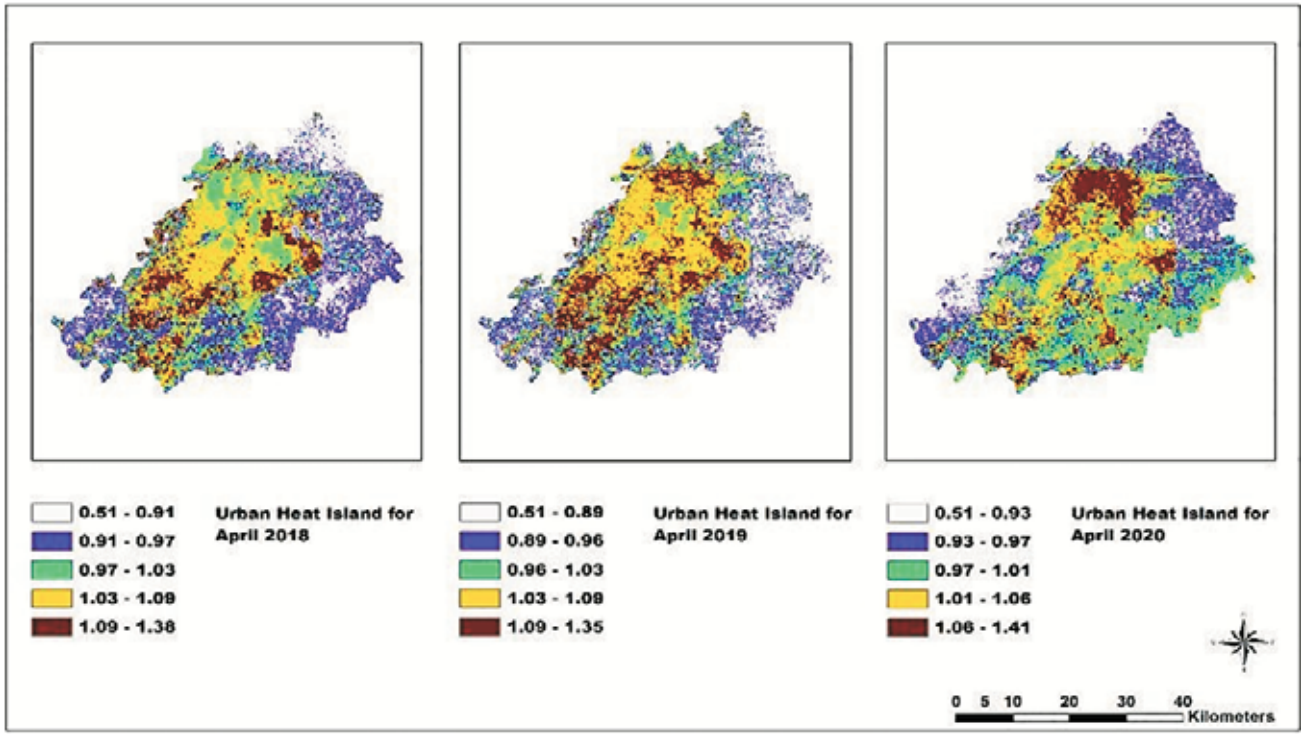

Figure-8: Urban Heat Island (UHI) in Lahore for the month of April 2018, 2019 and 2020.

Figure-9: Air Quality Comparison of Marach 2019 amd 2020 in Lahore, Showing Concentrations of PM10, PM2.5. CO, NO2, and SO2 and a Comparison with Punjab Environmental Quality Standards (PEQS).

Figure-10: Air Quality Comparison of April 2019 amd 2020 in Lahore, Showing Concentrations of PM10, PM2.5. CO, NO2, and SO2 and a Comparison with Punjab Environmental Quality Standards (PEQS).

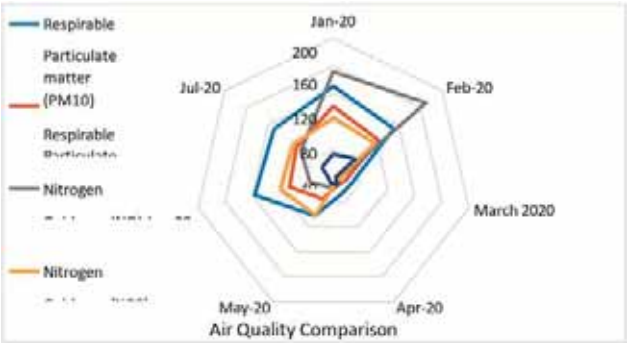

Figure-11: Air Quality Comparison in Lahore from January to July 2020, Showing monthly concentrations of PM10, PM2.5, CO, NO2 and SO2.

and resilient policies.

Potential limitations, such as seasonal influences, significantly affects the validity and reliability of study results. Seasonal impacts, for example, can cause biases in data collection and interpretation, resulting in incorrect findings. Changes in climatic circumstances, such as temperature or precipitation, had an impact on the precision of remote sensing observations, jeopardizing the research's integrity. Furthermore, potential measurement errors, such as air interference or sensor breakdowns, corrupted the obtained data, skewing the results.

CONCLUSION

Lahore being the epicenter of the pandemic during corona, was being closed down with partial opening of commercial activities, travel restrictions, and require its citizens to stay home beginning in late March 2020. The decrease in tropospheric NO2, in PM2.5 pollutants in the Lahore city.

Sstrict policies reduced human induced air pollution emissions in the City (Jin et al., 2016). Yet, significant reductions in primary pollutant emissions were observed in the city. This lockdown was economically disastrons and could not continue indefinitely, thus, so the government needs to find ways to reduce temperature and pollutants from the atmosphere of Lahore and ten there similar cities.

The present study conducted the correlation of different air pollutants in Lahore and their impacts on the heat islands through utilization of remote sensing techniques. Results shows negative LST as compared to mean temperature of 2018 and 2019 as described due to lockdown effect (García and Díaz, 2022). This reduced LST was directly linked with the air temperature calculated by the meteorological department and compared with Pakistan National Environmental Quality Standards. Additionally, high spatial-temporal variation of temperature in a city like Lahore, concludes that cities are highly vulnerable to climate changes and high pollution rates makes them attractive to analyze and do further studies in urban heat islands.

These findings highlight the importance of incorporating sustainable environmental strategies into urban planning. Moving ahead, it is important for city planners to implement measures such as increasing green spaces, promoting the use of public transportation, promote car-sharing options and enforce stricter air quality regulations by Environmental Protection Agency. Moreover, future research could explore the varying impacts of lockdowns duration on urban air quality and temperature across different regions. Reseavding the role of urban density, UHI due to industrial activities, and traffic pattern in defining air quality can help us to mitigate smog and improve overall urban quality of life for the citizens of a city.

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