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RESEARCH ARTICLE

# Evaluating the COVID-19 Lockdown's Effects on Land Surface Temperature, $NO_2$, and $O_3$ in the Erbil City, Kurdistan Region of Iraq

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**ABSTRACT**

Humans' lifestyles were radically changed after the 2020 COVID-19 epidemic. To mitigate the effects of the disease, most countries have implemented lockout systems. This research aims to provide some recommendations for long-term, sustainable environmental management by analyzing how the COVID-19 lockdown affected nitrogen dioxide ($NO_2$), Ozone ($O_3$), the land surface temperature (LST), and the normalized difference vegetation index (NDVI). Sentinel Hub data and LANDSAT 8 satellite imagery from 2017 to 2022 were used to create land use land cover (LULC), NDVI, and LST maps. Digital thematic maps of $NO_2$ and $O_3$ with figures that demonstrate the correlation between NDVI-LST and LULC-LST were derived using Arc geographic information system 10.8. The spatial analysis showed that LST and LULC are noticeably correlated, in addition to an inverse proportion between NDVI and LST, as well as between $NO_2$ and $O_3$. The lockdown in Erbil drastically decreased $NO_2$ emissions by 54.5% and improved $O_3$ levels by 7.6%. While the NDVI and $O_3$ levels have increased significantly, the LST and $NO_2$ levels have declined considerably due to the shutdown of all industrial and transportation activities during the lockdown. Although COVID-19 caused a lot of damage, the lockdown contributed to healthier conditions of the environment.

**Keywords:** Geographic information system, land surface temperature, normalized difference vegetation index, COVID-19, remote sensing

## INTRODUCTION

In 2020, the world was threatened by the devastating COVID-19 global epidemic. Its global attack was so devastating that many lives were lost. Both the World Health Organization (WHO) and governments have regularly proposed multiple appropriate actions to slow the outbreaks of this disease.[1] Personal hygiene, keeping socially appropriate distance, preventing public crowds, and staying home unless it is unnecessary to go outside are a few of the precautions put in place to prevent the spread of the disease.[2,3] As a result of these restrictions, human activity has been severely limited, which has had a negative effect on economy and businesses on a global and national scale.[4-6] Apparently, the viable and impactful option for reducing COVID-19 from having a tragic effect on the globe was through a global lockdown. Wuhan City in China was the place of the first diagnosis of this deadly infectious disease on the 29th of December 2019.[7-9] As a substantial number of viral cases was reported across the country, Chinese authorities instituted lockdowns all over the country in an attempt to control the disease.[10] COVID-19 dramatically affected about 213 nations on earth, and as of February 21, 2023, the WHO recorded a total of 6,850,594 fatalities around the world, with 757,264,511 reported cases of COVID-19. Consequently, as of February 25, 2023, a total of 13,224,955,795 vaccine doses had been distributed globally.[11]

On February 24, 2020, Iraq reported the first case of COVID-19 in the south of Baghdad, in the city of Najaf. The WHO[11] and the Health Ministry of the Kurdistan Regional Government (KRG) reported the first cases of coronavirus in the region on March 1, 2020, and the first death on March 4, 2020. The shutdown of Iraqi governorates took place on Saturday, March 1, 2020, and lasted until August of the same year.[12] As soon as the first COVID-19 victims were identified throughout Iraq, the KRG made the decision to implement a complete lockdown of the region from March 5, 2020, to May 22, 2020.[13,14] To stop the infection from spreading, the government shut

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down meetings and religious ceremonies; shut down the education system and started giving classes online; shut down airports and borders; and limited or stopped transportation between cities.[15,16] 452 cases were diagnosed during the lockdown period, with a 1% rate of case deaths.[17] These immediate steps have been effective compared to neighboring countries.[16] To date (August 22, 2022), 464,976 infections, 456,080 recoveries, and 7464 deaths have been reported in the KRG. Only in the Erbil governorate were there 149,340 new cases, 146,707 recoveries, and 2186 fatalities.[18]

During shutdowns, however, pollution levels are much lower than they used to be because of strict rules and fewer pollutant emissions[12] and ecosystems in nearly every part of the globe were positively affected.[1] The lockdown process reduces pollution and helps produce a less polluted environment.[19-27] Transportation and industrial activity reduction minimize pollution and have a direct ecological benefit, although vegetation grows at a faster rate.[1] The air and land surface temperatures (LSTs) went down right away after the lockdown.[28,29]

The COVID-19 pandemic critically contributed in the environmental changes on a global scale. Multiple researches in recent years around the world emphasized the significant reduction in air pollutants, specifically nitrogen dioxide ($NO_2$) and particulate matter. Venter *et al*. for example, assessed the data from 34 different countries and showed that during the full lockdowns, the population-weighted $NO_2$ concentrations substantially reduced by 60%.[30] However, the impact of ozone ($O_3$) levels was varied in different places. In several urban regions, a reduction in nitrogen oxides (NOx) emissions was witnessed, however, $O_3$ concentrations increased. Shi *et al*. showed that while $NO_2$ pollutant reduced by 51.7%, $O_3$ concentrations increased by 36.4% in metropolitan areas.[28]

The nature of the land surface and the intensity of solar radiation have the main roles in determining LST.[1] The primary contributors to rising urban LSTs are rapid urbanization and fluctuations in the climate system.[31] Consequently, a core feature of LST is the development and planning of management approaches for land-use resources.[1]

The normalized difference vegetation index (NDVI) is the ultimate remote sensing index affecting LST variation. The NDVI and the LST typically produce negative proportions. The NDVI and LST correlation is substantially enhanced by a reduction in air pollution and an increase in air moisture.[1] The majority of studies show that a higher LST also causes a noticeable rise in atmospheric temperature.[32] Research was done in Kerbala during the outbreak to evaluate COVID-19's effect on the urban temperature. According to the study by Mohammed *et al*., relative to prior periods, LST in settlement regions lowered during the COVID-19 lockdown.[33]

However, a number of studies have examined how the lockdown has affected the air quality as well as the daily average levels of $O_3$ and $NO_2$ throughout the provinces of Iraq. Studies revealed that during the times of the shutdown, the quantity of environmentally harmful gases in Iraq drastically decreased, and $NO_2$ emissions reduced throughout Iraq, especially in Erbil, according to Hashim *et al*.[12] A few additional researchers discovered that the ozone and air quality in the Bagdad International Airport improved throughout the lockdown.[34] As stated by Kaplan *et al*., human activity is the primary source of environmental pollution.[35] $NO_2$ and $O_3$ are some of the most common atmospheric pollutants.[36] When fossil fuels are burned or during the transportation, $NO_2$ is released, which is a highly toxic gas.[37] The density of $O_3$ is impacted by the amount of greenhouse gases like NOx. In general, $O_3$ levels fall along with a decrease in NOx emissions. However, reduced NOx may cause an increase in ozone levels in densely populated urban areas.[38]

There is a critical gap in the literature in our understanding of the impact of urban conditions, specifically in the Kurdistan region of Iraq, and their correlation with the environmental impacts of COVID-19 lockdowns. Despite the contribution in the literature on changes of air quality during lockdowns, only a few researches focused on the comprehensive relationship between land use land cover (LULC) changes, LST, normalized difference vegetation index (NDVI), and air quality parameters such as $NO_2$ and $O_3$ in a single urban environment. The objective of this research is to address this issue by providing a comprehensive analysis of environmental changes in Erbil City using geographic information system (GIS) and remote sensing technology, offering valuable insights related to the impact of urban areas and vegetation on the overall environment conditions.

This study's main purpose was to evaluate the impact of Erbil City's COVID-19 lockdown on the environment using GIS tools and remote sensing air quality and LST data from 2017 to 2022. The study's method enables low-cost monitoring of the urban environment, allowing urban planners and policymakers to understand how COVID-19 influences the environment.

## MATERIALS AND METHODS

### Study Area

With an estimated population of 2,254,422 in 2020, Erbil is the capital and the biggest town of Iraq's Kurdistan region. The city, which has been continuously inhabited for around 6000 years and is one of the oldest settlements on earth, has been appointed a UNESCO World Heritage Site. Throughout the previous three decades, emigration from the countryside and rural areas has resulted in a tremendous rise in the city's population, resulting in noteworthy urban growth and fast geographic development.[39] It is located at 36°11' 28" N and 44° 0' 34" E latitude and longitude, respectively [Figure 1]. The area of Erbil city is about 1442.3 km$^2$, and it is 425 m above mean sea level. Erbil has a very hot summer and a cool winter. On average, it has 419.5 mm of rainfall per year with 51.2% humidity.[18]

Landsat-8 images were used for this study to compare LULC, NDVI, and LST variation before, during, and after the COVID-19 lockdown. Six spatially georeferenced Landsat imageries (GeoTIFF) were used for Erbil city using Path/Row 169/35 for the years 2017, 2018, 2019, 2020, 2021, and 2022 for the Landsat 8 satellite (Operational Land Image). The data were obtained using the USGS Earth Explorer service (USGS, 2023). The study required the use of red, NIR, and TIR bands. The spatial resolution of OLI/TIRS data bands

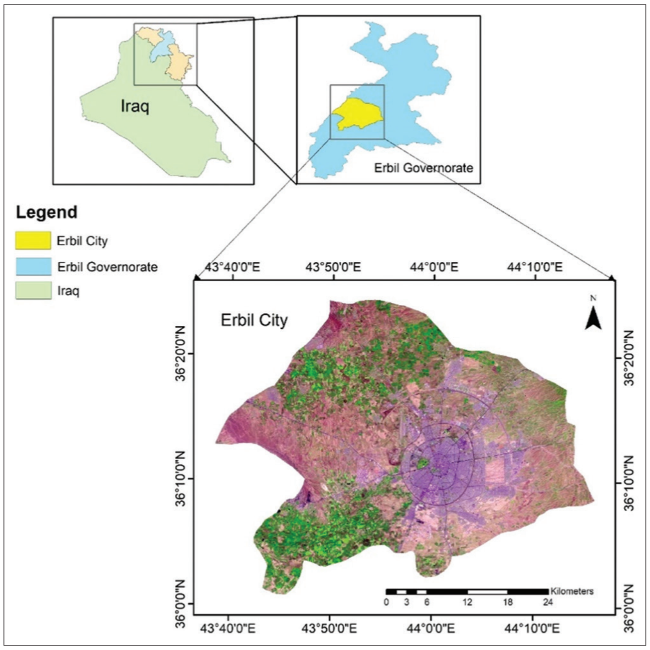


**Figure 1:** Study area (Erbil city)

4, 5, and 10 is 30, 30, and 100 m, respectively. $NO_2$ and $O_3$ data were downloaded from Sentinel Hub website (https://www.sentinel-hub.com/) (Hub, 2023). ArcGIS 10.8 was used throughout the research process. For the LST and NDVI calculations, LULC classification, and correlation analysis, the spatial analyst tools in ArcGIS were used [Figure 2].

## LULC Classification

LULC was divided into three categories using the ISO Cluster Unsupervised Classification algorithm: green area, settlement, and bare land. LULC classification has been carried out for 2017, 2018, 2019, 2020, 2021, and 2022 [Figure 3]. To evaluate the LULC classification, the exact locations of 600 randomly chosen points on the LULC maps were compared with ground data from Google Earth Pro satellite images. For the years 2017, 2018, 2019, 2020, 2021, and 2022, the overall accuracy for classified images was 0.9, 0.9, 0.94, 0.92, 0.90, and 0.96, respectively. Moreover, the Kappa coefficient was used to assess the reliability of the results[40]. The calculated values of the Kappa coefficient were as follows: 0.84, 0.83, 0.91, 0.82, 0.84, and 0.94. Through the creation of LULC maps for the years 2017–2022, differences in LULC were evaluated. [Figure 3] shows the distribution of LULC across Erbil city.

## Retrieval of LST

The LST in Erbil City was calculated using a single-channel algorithm [Figure 4]. This method is more accurate than others and is often used to get LST from a single thermal band.[41] LST was estimated using the following equations: [41]

$$L_\lambda = M_L * Q_{cal} + A_L \quad (1)$$

Where the top-of-atmosphere (TOA) is defined by $L_\lambda$

Calibrated digital number is defined by $Q_{cal}$

Band-specific additive rescaling factor $A_L$

$$T_B = \frac{K_2}{L_\lambda * \left(\frac{K_1}{L_\lambda} + 1\right)} \quad (2)$$

Brightness temperature is represented by $T_B$

The top-of-atmosphere (TOA) is represented by $L_\lambda$

Thermal conversion constant is $K_1$ and $K_2$

$$NDVI = \frac{Band_{RED} - Band_{NIR}}{Band_{RED} + Band_{NIR}} \quad (3)$$

Normalized Difference Vegetation Index is defined as NDVI

$$P_V = \left(\frac{NDVI - NDVI_{min}}{NDVI_{max} + NDVI_{min}}\right)^2 \quad (4)$$

Proportion of vegetation denoted by $P_V$

Normalized Difference Vegetation Index is represented as NDVI

The highest amount of NDVI is represented as NDVI max

The lowest amount of NDVI is represented as NDVI min

$$\varepsilon = 0.004 * P_V + 0.986 \quad (5)$$

Emissivity of land surfaces is represented by $\varepsilon$

Proportion of vegetation represented by $P_V$

$$LST = \frac{T_B}{\left[1 + \left(\lambda * \frac{T_B}{\rho} * \ln(\varepsilon)\right)\right]} \quad (6)$$

*LST* is the temperature of the Earth's land surface (Kelvin scale)

Brightness temperature is represented by $T_B$

*Wavelength of emitted radiance is represented by* $\lambda$

$$\rho = h * \frac{c}{\sigma} \left(0.01438 \quad mK\right) \quad (7)$$

$\sigma$ = Boltzmann constant = $1.38*10^{-23}$ J/K

$h$ = Constant of Planck = $6.626*10^{-23}$ Js

$c$ = Light speed = $2.998*10^{8}$ m/s

$\varepsilon$ = Land surface emissivity

After LST extraction, we converted LST in Kelvin to LST in Celsius by subtracting 273.15 from the result.

## RESULTS AND DISCUSSIONS

Pairing GIS and remote sensing made continuous environmental monitoring more efficient. The result of our research indicates that between 2017 and 2022, there is a substantial growth in settlement area in Erbil from 190 $km^2$ to 271.2 $km^2$ (13.2–18.8%) and bare land from 646.5 $km^2$ to 711.5 $km^2$ (44.8–49.3%). However, the green area declined significantly from 2017 to 2022, falling from 605.8 $km^2$ to 459.6 $km^2$ (42–31.9%)

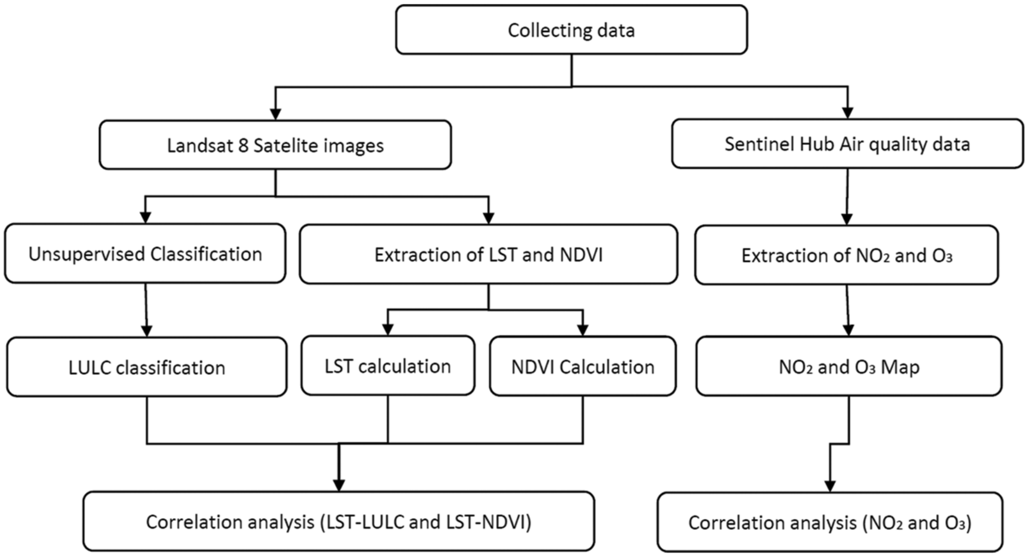


**Figure 2:** The flowchart of the research

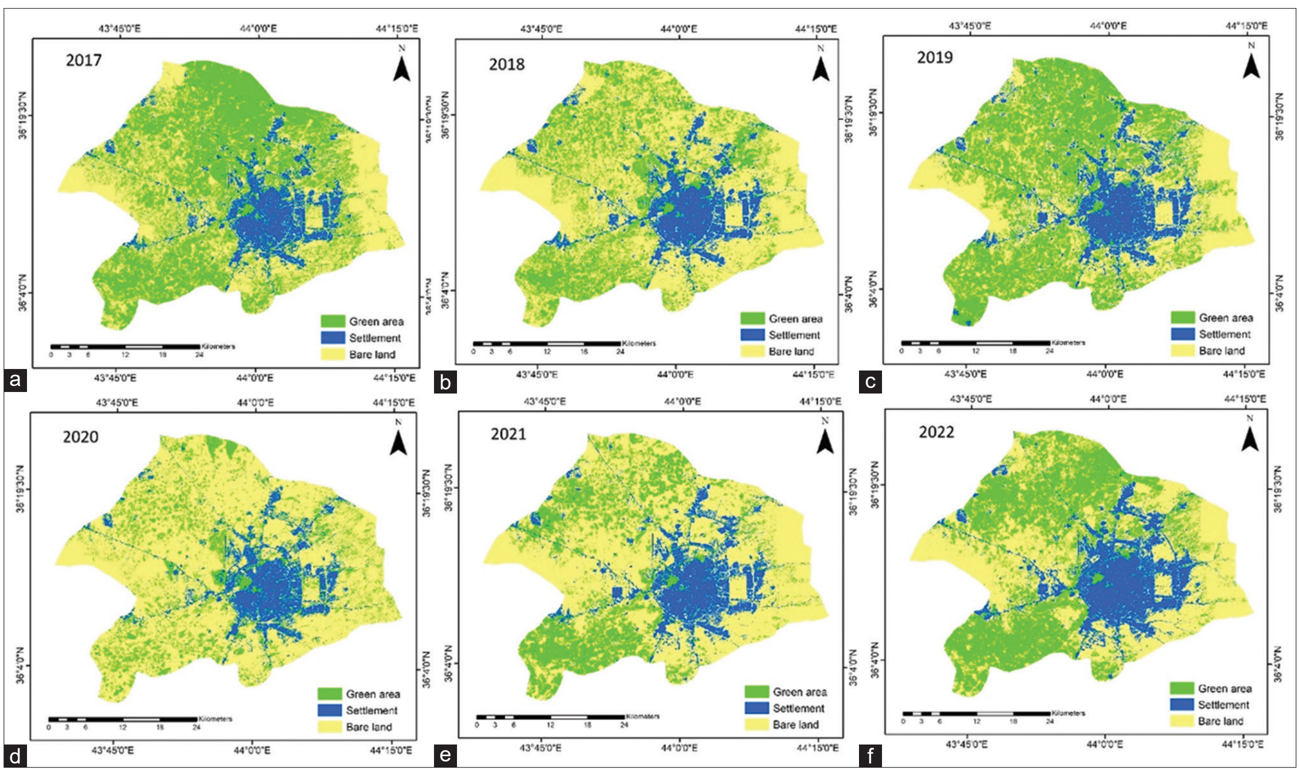


**Figure 3:** Land use land cover of Erbil for May; (a) 2017, (b) 2018, (c) 2019, (d) 2020, (e) 2021, and (f) 2022

**Table 1:** Results of the LULC classification for 2017, 2018, 2019, 2020, 2021, and 2022 images showing the area of each category and category percentages (Erbil city)

| LULC | 2017 Area | | 2018 Area | | 2019 Area | | 2020 Area | | 2021 Area | | 2022 Area | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | km² | % | km² | % | km² | % | km² | % | km² | % | km² | % |
| Green area | 605.8 | 42 | 344.2 | 23.9 | 534.2 | 37 | 230.8 | 16 | 303.8 | 21.1 | 459.6 | 31.9 |
| Settlement | 190 | 13.2 | 212.9 | 14.8 | 243.3 | 16.9 | 186.7 | 12.9 | 226.5 | 15.7 | 271.2 | 18.8 |
| Bare land | 646.5 | 44.8 | 885.2 | 61.4 | 664.8 | 46.1 | 1024.8 | 71.1 | 911.9 | 63 | 711.5 | 49.3 |

**Table 2:** The mean of LST, NDVI of Erbil for 2017, 2018, 2019, 2020, 2021, and 2022

| Acquisition Date | NDVI | | | | LST (°C) | | | |
|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Mean | SD | Max. | Min. | Mean | SD |
| 9-5-2017 (before lockdown) | 0.608 | −0.117 | 0.197 | 0.09 | 43.64 | 17.98 | 33.61 | 2.83 |
| 28-5-2018 (before lockdown) | 0.568 | −0.12 | 0.128 | 0.512 | 50.1 | 20.99 | 41.32 | 3.18 |
| 31-5-2019 (before lockdown) | 0.632 | −0.229 | 0.153 | 0.055 | 51.34 | 29.69 | 41.34 | 2.38 |
| 17-5-2020 (during lockdown) | 0.615 | −0.163 | 0.168 | 0.062 | 51.07 | 26.86 | 39.8 | 2.83 |
| 4-5-2021 (after lockdown) | 0.391 | −0.297 | 0.129 | 0.06 | 49.09 | 8.87 | 39.7 | 3.99 |
| 15-5-2022 (after lockdown) | 0.542 | −0.083 | 0.153 | 0.069 | 35.04 | 16.20 | 25.99 | 2.88 |

LST: Land surface temperature, NDVI: Normalized difference vegetation index, SD: Standard deviation

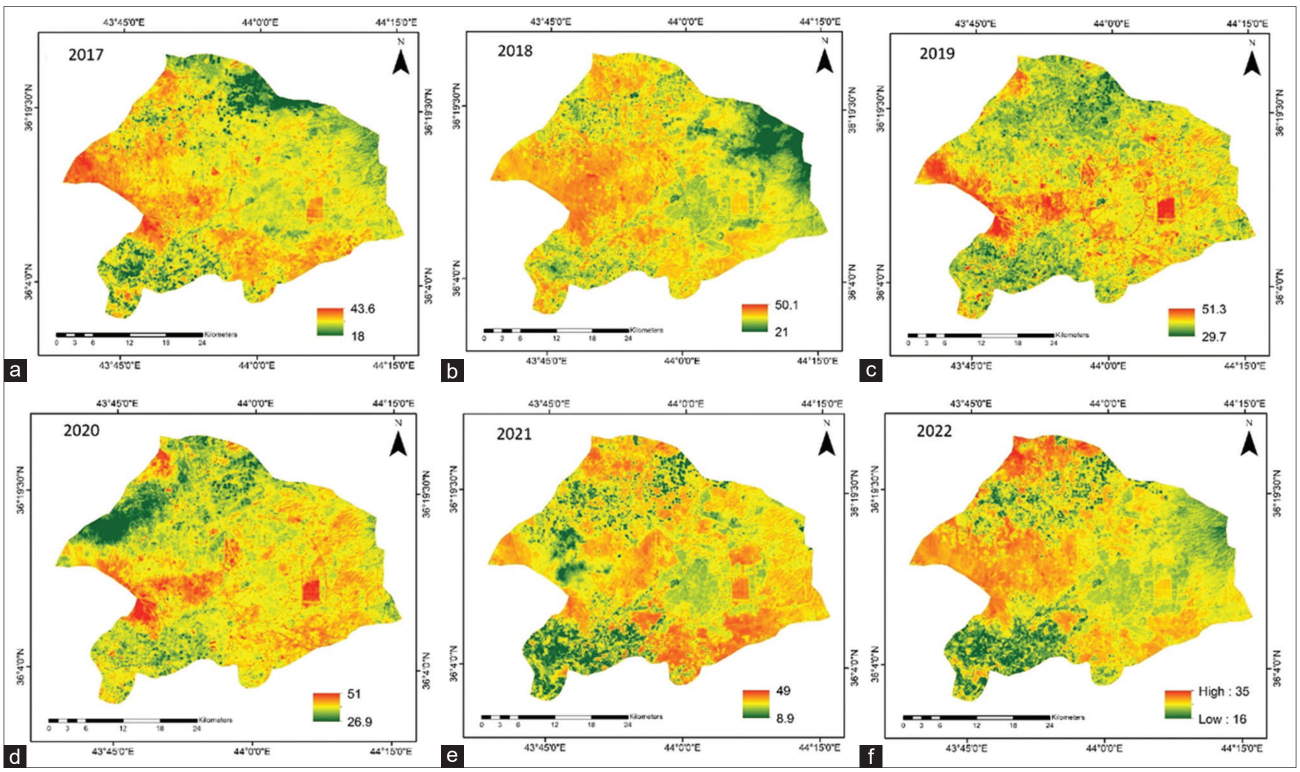


**Figure 4:** Land surface temperature of Erbil (°C); (a) 2017, (b) 2018, (c) 2019, (d) 2020, (e) 2021, and (f) 2022

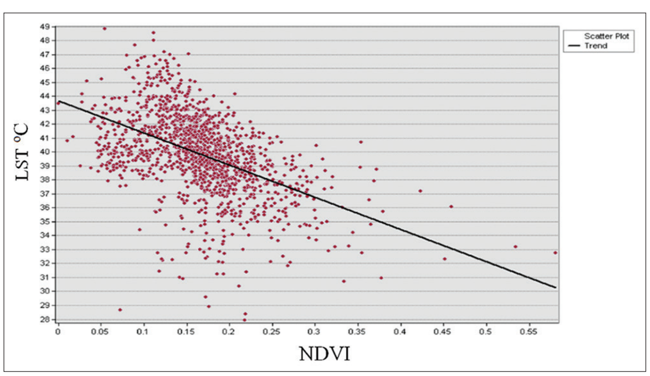


**Figure 5:** Erbil's mean land surface temperature and normalized difference vegetation index values in 2020 and their correlation

[Table 1]. Before, during, and after the lockdown, there was a noticeable change in LST. The maximum temperature increased from 43.6°C in 2017 before the lockdown to 51.07°C in 2020 during the lockdown. However, 2 years following the lockdown, the highest temperature dropped dramatically from 51.07°C in 2020 to 35.04°C in 2022 [Table 2]. This meant that the temperature of the ground surface was significantly lower following the shutdown compared to previous years.

Furthermore, the analysis revealed that rapid changes in LULC affected LST. During the time period mentioned, the highest temperature reached 51.3°C on a wide region of barren ground. However, green area had the lowest temperatures. The mean LST reduced dramatically from 39.8°C to 25.99°C [Table 2] as the green area doubled from 16% to 31% between 2020 (during lockdown) and 2022 (after lockdown) [Table 1]. This demonstrates that vegetation areas and NDVI have a negative relationship with LST [Figure 5]. That is, increased vegetation cover leads to reduced LST.[42]

The average NDVI went up during and after the lockdown [Table 2], and the health of vegetation covers in all areas

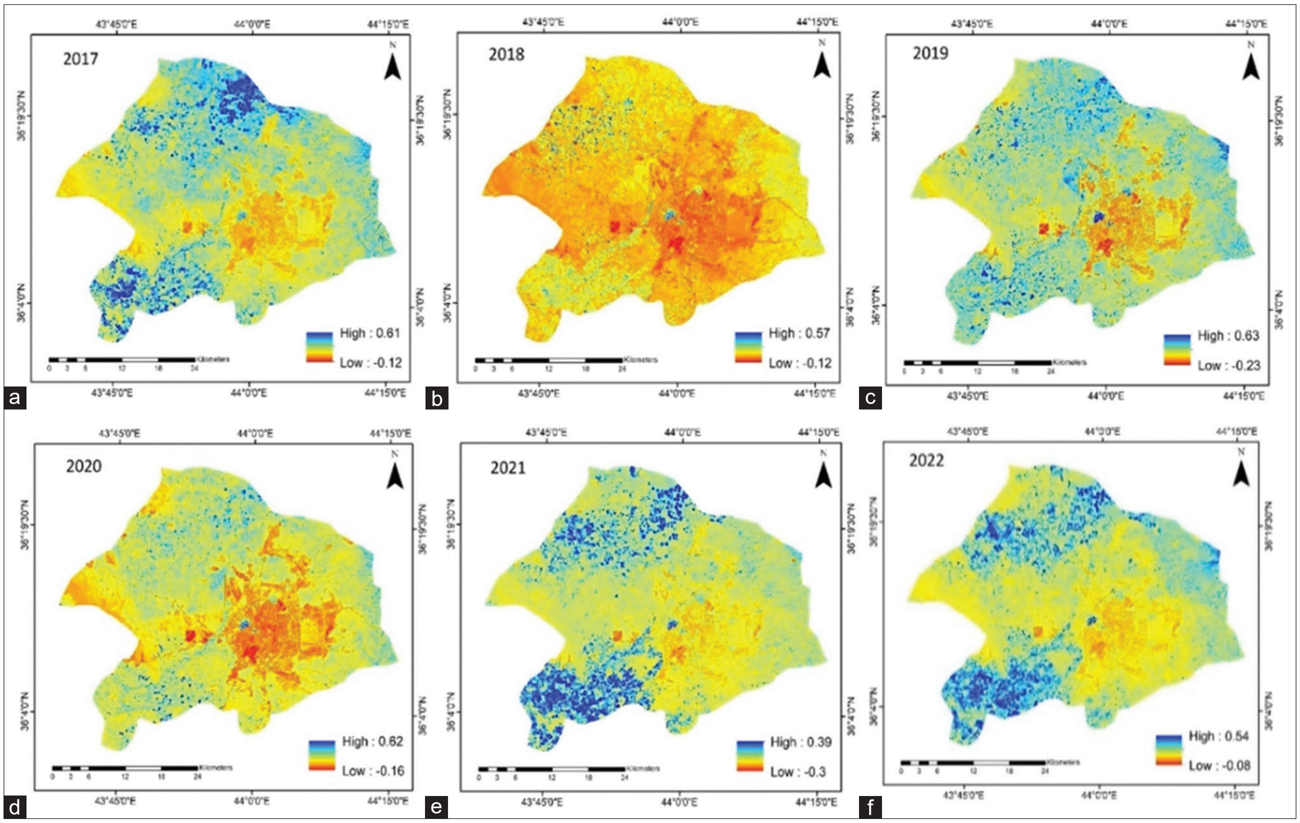


**Figure 6:** Normalized difference vegetation index of Erbil city; (a) 2017, (b) 2018, (c) 2019, (d) 2020, (e) 2021, and (f) 2022

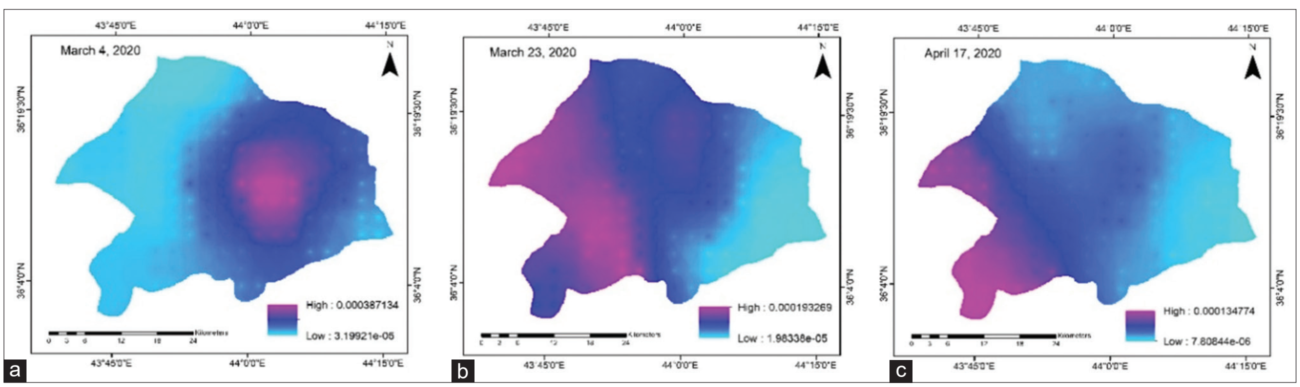


**Figure 7:** Nitrogen dioxide emissions in Erbil (mol/m²); (a) March 4, 2020, (b) March 23, 2020, and (c) April 17, 2020

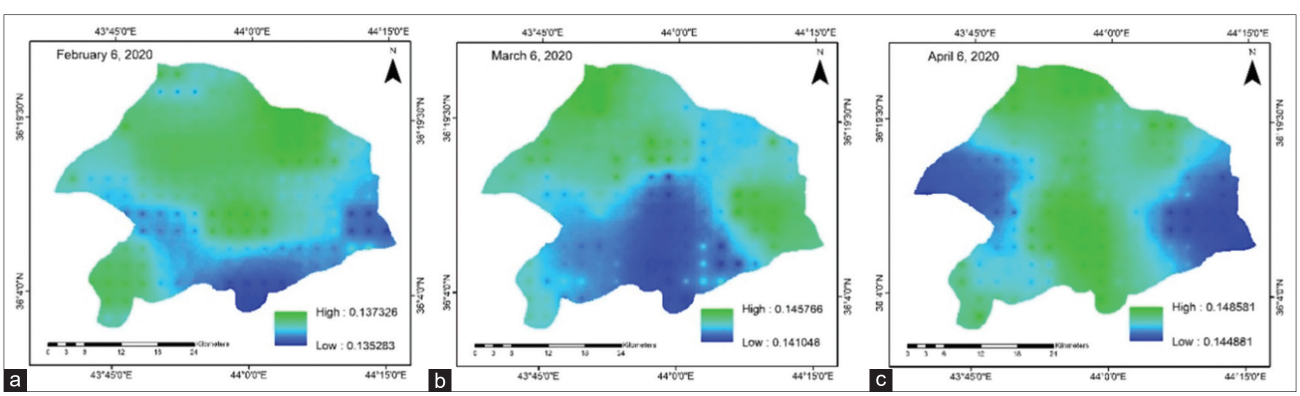


**Figure 8:** Ozone Emissions in Erbil (mol/m²); (a) February 6, 2020, (b) March 6, 2020, and (c) April 6, 2020

got much better [Figure 6]. This had an immediate impact on decreasing the LST. The outcome implies a positive shift during the quarantine. That is mostly due to a decrease in human activities such as transportation and industrial pollution, which played a major role in lowering the mean LST in Erbil City after the lockdown period. Furthermore, the period of lockdown had a valuable effect on the environment, and we found a negative correlation between $NO_2$ and $O_3$ the quarantine.[1,43,44] We noticed a noticeable decline [Figure 7] in the mean amount of NO2 pollution (54.5%) and a noticeable improvement [Figure 8] in the mean levels of $O_3$ (7.6%).

## CONCLUSION

Although COVID-19 was responsible for a significant amount of damage, the lockdown helped to improve the overall environmental situation. GIS and remote sensing are two low-cost and valuable tools for continuously monitoring LST, NDVI, air quality, and LULC changes. The study showed that the COVID-19 shutdown in Erbil city had an influence on air quality, LST, and NDVI, and it also shows that there is a significant correlation between LST and transitions in LULC in Erbil. As urban zones and bare lands replaced green spaces, the mean LST increased noticeably between 2017 and 2020. This research aims to examine, for the years 2017, 2018, 2019, 2020, 2021, and 2022, how the LST varies based on NDVI and LULC changes. Additionally, the study observed a significant improvement in $NO_2$ and $O_3$ levels during the COVID-19 lockdown, with noticeable changes both before and after the lockdown period.

The correlation analysis of LST, LULC, and NDVI revealed a significant relationship, providing compelling evidence of how lockdown and land use change impact the environment over time [Figure 6]. According to the findings, there is an inverse proportion between NDVI and LST. The main cause of changes in LULC and a rise in LST is urbanization. A valuable effect on the environment was noticed, as $NO_2$ pollution was decreased by 54.5% [Figure 7] and the levels of $O_3$ in Erbil were enhanced by 7.6% [Figure 8]. We can apply numerous management measures to prevent rising LST, such as planting trees in front of every house and converting open spaces to green areas. The growing tendency of industrial and residential areas is the reason for Erbil's substantial rise in LST. Because the LST is rising at an alarming rate, it has the possibility of harming the ecosystem and habitat of Erbil city. Sustainable urban land use plans are needed to deal with the rise in LST and keep the environment clean and healthy. As a result, new land conversion strategies, such as expanding green space, are urgently needed. The proposed inner greenbelt for Erbil by the Kurdistan region of Iraq would include a wooded area, a sustainable fruit garden, and gateway parks, which will stop the city from growing in an unsustainable way while also improving the climate and having a beneficial effect on LST and air quality.

The main findings of the study were as follows:

- Despite the significant damage by COVID-19 lockdowns, it led to improved overall environmental conditions in Erbil city.
- GIS and remote sensing offered valuable, low-cost tools for comprehensive assessment of LST, NDVI, air quality, and LULC changes.
- Notable correlation in Erbil city between LST and LULC transitions was identified.
- The value of mean LST increased significantly between 2017 and 2020 as a result of converting green spaces to urban zones and bare lands.
- During the lockdown in Erbil city, $NO_2$ pollution decreased by 54.5%, however, $O_3$ levels improved by 7.6% in the period.
- Urbanization was found to be the primary contributor of LULC changes and rising LST in Erbil.

## FUNDING

No funding was received for conducting this study.

## CONFLICTS OF INTEREST

The author declared that they have no conflicts of interest.

## AUTHOR CONTRIBUTION

The author is contributed to the study conception and design. Material preparation, data collection, and analysis were performed by the author. The first draft of the manuscript was written and revised by the author. The author read and approved the final manuscript.

## DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are available from the corresponding author on request.

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