Assessment of air quality and consequent in Erbil, Iraqi Kurdistan region based GEE, GIS, and remote sensing techniques

Zana Fattah Ali[1,2]*, *Dedar* Salam[3,4] , *Gábor* Pirisi[5], *Kinga* Kiss[6]

[1] Doctoral School of Earth Sciences, University of Pécs, Ifjúság Str 6, H-7624 Pécs,Hungary
[2] Department of Geography, Faculty of Education, Koya University, Kurdistan Region, Iraq
[3]Marcel Breuer Doctoral School, University of Pécs, Boszorkány u. 2, 7624 Pecs, Hungary
[4]Department of Architectural Engineering, Faculty of Engineering, Koya University, Erbil, Kurdistan Region, Iraq
[5]Department of Social Geography and Urban Planning, University of Pecs, Pecs, Hungary
[6]Department of Cartography and Geoinformatics, University of Pecs, Pecs, Hungary

Abstract: The global peril of air quality deterioration imperils the well-being of all living beings. Erbil, like many other regions, has suffered severe environmental degradation due to urban expansion, vehicular escalation, industrialisation, and substandard fuel usage. This research employs Google Earth Engine, GIS, and Remote Sensing to scrutinise alterations in pollutants (NO2, SO2, CH4, CO, O3, UV) spanning 2018 to 2022. It also incorporates PM2.5 data from Ankawa station (Jan 14, 2023 - May 4, 2023) and land use data (2005-2022) from Modis and Sentinel 2 satellites. The findings reveal a substantial increase in the levels of various pollutants during the specified period. However, in June 2020, most of these levels experienced a decrease due to the coronavirus quarantine measures. For instance, the concentration of NO2 decreased from 0.000256 mol/m2 in 2018 to 0.000166 mol/m2 in 2020. Conversely, by June 2022, the levels had significantly risen to 0.000277 mol/m2. Moreover, among the 107 days record, PM2.5 concentrations reached unhealthy levels on 44 days, while only five exhibited healthy PM2.5 levels. Furthermore, regions at lower sea levels, like Erbil and Khabat, exhibit the highest concentrations of these gases. In contrast, areas at higher sea levels, such as Mergasur and Choman, demonstrate these pollutants' lowest levels.

1 Introduction:

Air quality is paramount for the survival of life on earth, as it significantly impacts both the health of living beings and the progress of economic activities[1]. Air quality has changed considerably in modern times, characterised by excessive pollution. This phenomenon can be attributed to rapid industrialisation, amplified use of private transportation, and burning of fossil fuels[2]. The atmosphere contains many pollutants, including CO2, CO, SO2, O, NO2, CH4, O3 NOx, PM2.5, and PM10, that threaten living organisms and the atmosphere[3]. Air pollution can be classified into two main categories: (indoor and outdoor) Pollution[4]. Indoor air pollutants (SO2, CO, NOX, O3, VOCs, PM, radon, microorganisms) come from scented items, poor ventilation, pet dander, cooking, freshly painted rooms, high population density, smoking, and outdoor air. Outdoor air pollutants (SO2, CO, NOX, O3, HC, particulate matter) originate from power plants, industries, transportation, construction road dust, biomass burning, open waste burning, brick kilns, and emissions[5]. Air pollution represents the most prominent environmental peril to human health on a global scale, leading to an estimated annual death toll of approximately 7 million individuals. In 2019, around 4 million lives were lost, with Central Europe and East Asia experiencing the highest fatality rates attributed to this issue[6]. In contrast, various research indicates that air pollution substantially affects the rise of cancer occurrences. Several studies have shown that approximately 250,000 individuals globally lose their lives annually due to lung and stomach cancer caused by air pollution[7]. A survey by the EEA found that air pollution causes 10% of cancer cases in Europe, with approximately 3 million new cases and 1.3 million deaths annually, with an economic cost of 178 million euros[8]. In Iraq, air pollution levels surpass World Health Organization guidelines, leading to higher rates of premature mortality and cancer due to environmental pollutants.[9]. According to the Iraq Air Quality Index 2022, Iraq is second globally for poor air quality. Specifically, on May 19 2022, the air quality index in Erbil (PM2.5) was recorded at 162[10]. Using geographic

* Corresponding author: zana.ali@koyauniversity.org

information systems (GIS) combined with aerial imagery from the Sentinel-5P satellite plays a vital role in monitoring global air quality variations. This satellite effectively captures data on numerous air pollutants, including CH4, SO2, CO, NO2, and O3[11]. Advanced (GIS), combined with remote sensing through monitoring earth from space, data simplification in mapping, and specialised models, are valuable resources for monitoring environmental changes. These tools are instrumental in effectively managing and facilitating informed environmental decision-making processes [12]. This research examines the application of satellite Sentinel 5-P data and Air Quality Index (AQI) data obtained from monitoring stations in Erbil to observe and evaluate the air quality status in the Erbil province of Iraq between 2018 and 2022. The study investigates the effects of air pollution on human health and the environment while identifying the contributing factors responsible for the presence of pollutants in the air in Erbil.

2 Methodology and Data Processing

2.1 Study Area

Erbil is a significant province in the Iraqi Kurdistan Region, the fourth biggest city in Iraq, and serves as the Kurdistan Region's capital [13]. The area in question can be found situated in Iraq's northern region (Fig. 1). Its geographic coordinates lie between latitudes 35˚ 30' and 37˚ 15 N and longitudes 43˚ 22' and 45˚ 05' E [14]. It covers a total area of 14,818.1 km2 and comprises ten main districts (Koysinjaq, Soran, Mergasur, Rawanduz, Shaqlawa, Xabat, Dashte Hawler, Hawler, Choman, Maxmur [15]. According to Kurdistan Region Statistical Office, the Population of Erbil is approximately 2,250,000 as of 2020.

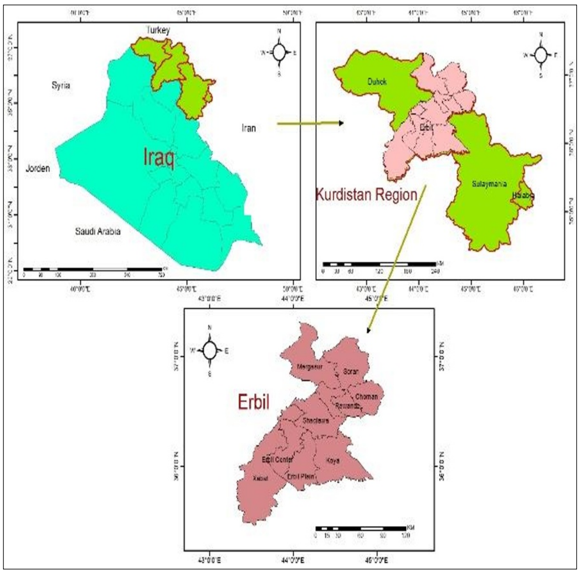

Fig. 1. Demonstrate Erbil study area in Iraq.

2.2 Data Collections

A comprehensive approach utilising primary and secondary data is necessary to assess the air quality accurately and systematically in Erbil and effectively evaluate the outcomes. The preliminary data employed in this study comprise: LULC classification data for August 2018 and 2022 were obtained from ESA Sentinel-2 imagery at a resolution of 10 meters. The classification process utilised the AL module for land processes. The land use components were categorised into nine classes. The Universal Transverse Mercator (UTM) WGS84 system was used as the source of these data. While The LULC classification process for August 2013 utilised MODIS MCD12Q1 V6 data, with a spatial resolution of 250m and a temporal resolution of 16 days. The data source for this classification was USGS Earth Explorer. The Earth Engine Data Catalog was utilised to gather Sentinel-5P Imagery with a resolution of 1113.2 meters from three distinct periods in July 2018, 2020, and 2022. These images were collected to assess air quality indicators, including NO2, SO2, CO, Aerosol, O3, and CH4. Digital elevation data (SRTM) The USGS website provides georeferenced data in UTM zone 38 and WGS 84 for October 2018, with a 30m resolution. Additionally, they utilised data from the Hankawa station, which records daily measurements of PM10.5 for the year 2023. Furthermore, multiple secondary data sources enriched the study, including government agencies and officially published sources.

2.3 Data Processing

2.3.1 LULC Classification

Over the past two decades, rapid changes in land use have altered the environment and air quality in cities, particularly in urban areas, leading to increased levels of gases such as ozone, nitrogen, and PM2.5[16]. This study utilised Modes and Sentinel 2 satellite data from August 2005, 2018, and 2022 to demonstrate how changes in land use structure affect air pollutant emissions. The variety divided changes into six categories: Built-Up, Open Land, Bare Land, Crops, Water, and Trees. Table 1 shows a significant transformation in the earth's composition between 2005 and 2022. For instance, the Built-Up area expanded from 120 km2 to 753 km2, representing a 525.93% increase. This suggests that alterations in soil composition influence changes in air quality. Using GIS techniques, the raster data was reclassified, and Extraction by Mask was employed to showcase the types of classification in the study areas.

Table 1. LULC class from 2005 to 2022 in Erbil.

Land Use Class	**Area KM²**			**Area %**		
	2005	2018	2022	2005	2018	2022
Built-Up	120	608	753	8.1	41.1	50.8
Open Land	5212	9515	9548	21.5	39.2	39.3

Bare Land	3446	657	977	67.8	12.9	19.2
Crops	5580	3759	3264	44.3	29.8	25.9
Water	25	26	28	31.6	32.9	35.4
Trees	278	96	91	59.8	20.6	19.6

Source: Landsat data from Sentinel-2 and Modis in 2005-2022

2.3.2 Elevation Map

Elevation maps in the study area are utmost importance, as they provide valuable insights into the distribution of pollutants across different geographical features such as valleys, plains, and mountains. These maps are instrumental in demonstrating that pollutant concentrations tend to be higher in lowland areas than in higher elevations, with air pollutants like carbon dioxide and nitrogen dioxide particularly prevalent in such regions[17]. The research utilises SRTM data from DEM (earth explorer) with a 30m resolution. GIS software reclassifies the raster bands and extraction using a study area mask. The resulting map classifies the study area into five elevation classes: 162-518, 518-923, 923-1439, 1439-2120, and 2120-3601(Figure 2).

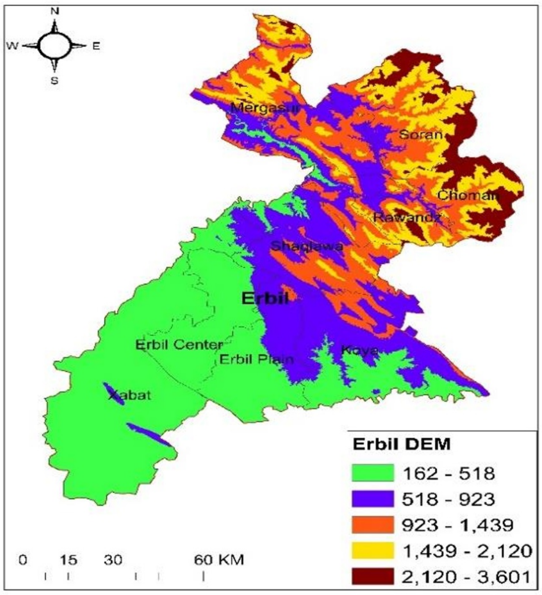

Fig. 2. Elevation of the study area.
Source: Earth Explorer USGS

2.3.3 GEE and satellite sensors (Sentinel-5 Precursor) in geospatial analysis Maps

Google Earth Engine (GEE) is a popular geospatial processing service that supports scientific analysis and visualisation of geospatial data. It hosts a vast collection of satellite images dating back over forty years and offers global-scale data capabilities. Sentinel-5P (S5p) is an atmospheric surveillance project focused on the troposphere. It is hailed as the inaugural Copernicus mission to incorporate multiple tools for detecting (NO2, SO2, CH4, CO, O3 and aerosols. The mission has been collecting data since 2018 and continues to do so[18]. The GEE platform was utilised in this research to handle the data obtained from Sentinel-5P. The received data was processed by organising the bands and filtering the images. Specific regions were identified, and the raster data was transferred to the ArcGIS program for reclassification and generating maps Using Sentinel-5 satellite images alongside the cloud computing tool (GEE). It examines pollutant levels such as (NO2, SO2, CH2O, CO, and CH4) in the air over the Zapadnyy Bulganak, Alma, Kacha, Belbek, and Chernaya river basins in the Crimean Mountains' northwestern slope. GEE is employed to extract average annual and monthly pollutant substance maps[19]. The flowchart (Figure 3) represents the sequential processes involved.

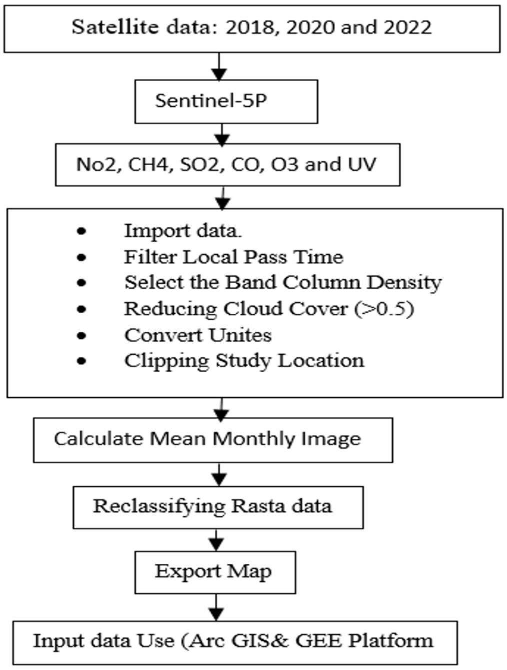

Fig. 3: Demonstrate the Flowchart Methodology.

3 Results and Discussions

3.1 Spatial and temporal fluctuations of air Quality in Erbil

The study utilised data from the Sentinel 5P satellite, which was processed using (GIS) and (GEE) programs. The data covered the period from 2018 to 2022, specifically focusing on June. June was chosen because it represents the middle of the year and typically offers clear and cloudless skies. By examining Figures (4-9), which illustrate the changes in air quality during this period, noticeable variations in the concentration of various pollutants per cubic meter in Erbil were observed.

For instance, the concentration of CH4 in 2019 was recorded as 1916 mol/m2, and this value exhibited a significant increase to 1936 mol/m2 by 2022. Similarly, the concentration of NO2 was 0.000256 mol/m2 in 2018, which rose to 0.000277 mol/m2 by 2022. The concentration of UV radiation showed an increase from 0.9956 mol/m2 in 2018 to 1.7431 mol/m2 in 2022.

Furthermore, the concentration of O3 was 0.1288 mol/m2 in 2018 and increased slightly to 0.13039 mol/m2 in 2022.

In contrast, June 2020 was chosen as a reference point due to the quarantine period during the COVID-19 pandemic. The restrictions on traffic and temporary shutdowns of factories resulted in a decrease in most air pollutants. For example, the concentration of NO2 decreased from 0.000256 mol/m2 in 2018 to 0.000166 mol/m2 in 2020. Similarly, the concentration of CH4 decreased from 1916 mol/m2 in 2019 to 1903 mol/m2 in 2020. In March 2020, strict quarantine and reduced human activity in Quito, Ecuador, led to significant reductions in NO2 (–68%), SO2 (–48%), CO (–38%), and PM2.5 (–29%) during the first month[20].

Analysing the figures (4-9) reveals that the highest density of these pollutants is primarily concentrated in the central areas of Erbil and some surrounding regions. Conversely, the northern part of Erbil exhibits the lowest levels of these pollutants. This disparity can be attributed to the distance from pollution sources, as illustrated by the maps depicting NO2 and CH4 concentrations.

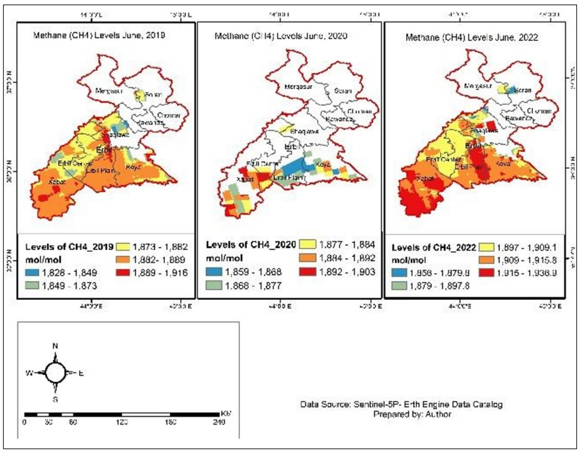

Fig. 4. Spatial distribution of CH4 from 2019-2022.

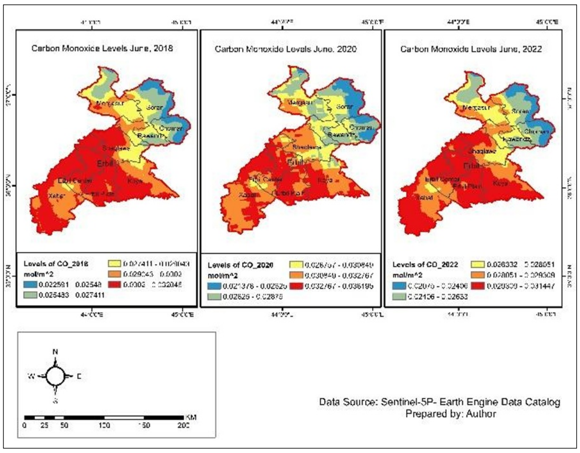

Fig. 5. Spatial distribution of CO from 2018-2022.

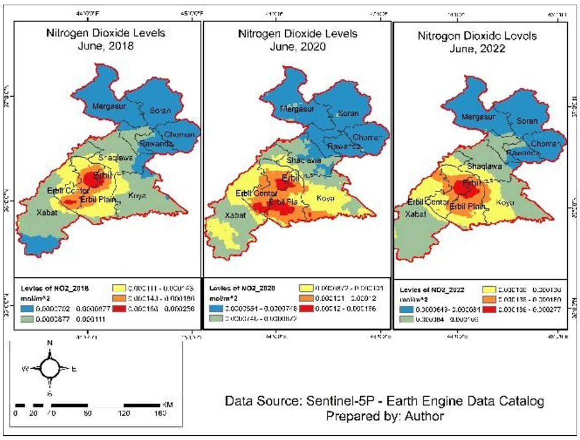

Fig. 6. Spatial distribution of NO2 from 2018-2022.

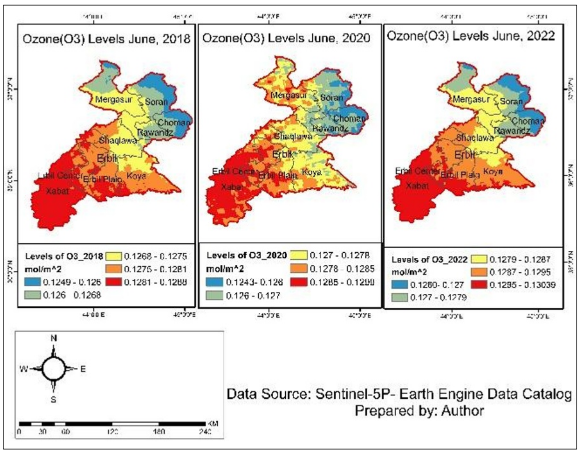

Fig. 7. Spatial distribution of O3 from 2018-2022.

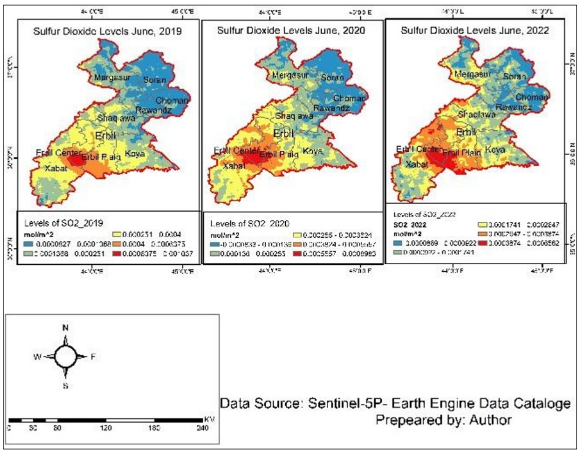

Fig. 8. Spatial distribution of SO2 from 2019-2022.

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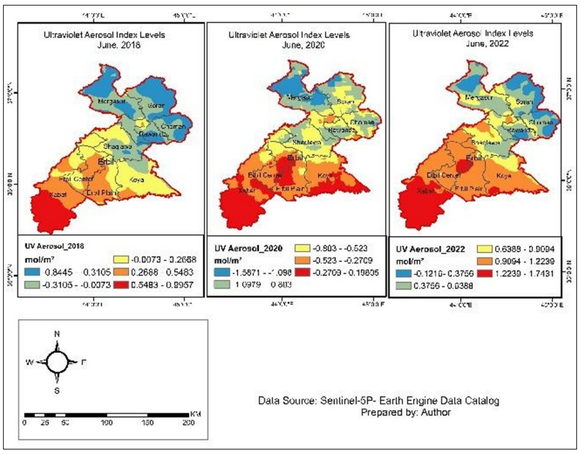
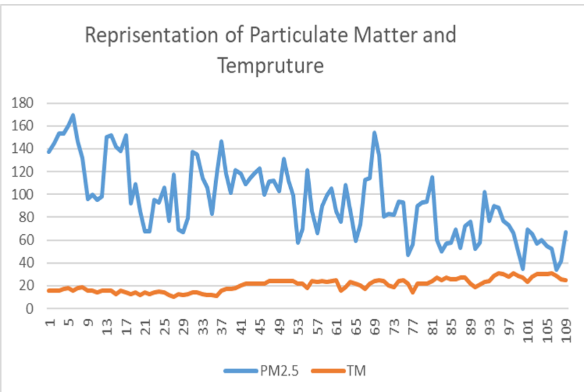


Fig. 9. Spatial distribution of UV from 2018-2022.

3.2 Particulate Matter (PM2.5) and Temperature Representation

Particulate matter 2.5 denotes minuscule particles or liquid droplets suspended in the atmosphere, measuring two and a half microns or smaller in diameter. These particles include pollen, soot, dust, smoke, and other contaminants[21]. According to the World Air Quality Standards, if the measurement rate of PM2.5 exceeds 100 micrograms per cubic meter (µg/m³), the area is considered unhealthy regarding air quality and poses a danger to human health from the environment. The study area experienced 44 out of 107 days with PM2.5 levels exceeding 100 (µg/m³), while only five days were below 50 (µg/m³) Figure 10, 11. This indicates that the air quality in the study area is hazardous and poses a risk to the environment and human health. Based on the analysis of Figures 10 and 12, it can be observed that there exists a weak association between the average PM2.5 and increasing temperature; the average PM2.5 decreases with increasing temperature, as indicated by a correlation coefficient of 0.203. According to a study, to measure the effect of temperature change on the rate of PM2.5 in Hamilton, Canada, during the years 2002-2007 found that The PM2.5 level rose by 54% during nighttime, going from 6.8 to 10.5 µg/m3, while it decreased by 14% during daytime, dropping from 8.4 to 7.2 µg/m3[22].



Fi. 10. Recorded daily data on the rate of PM2.5 and temperature From Jan 14 to May 04, 2023, at the Ankawa station in Erbil. Source[23].

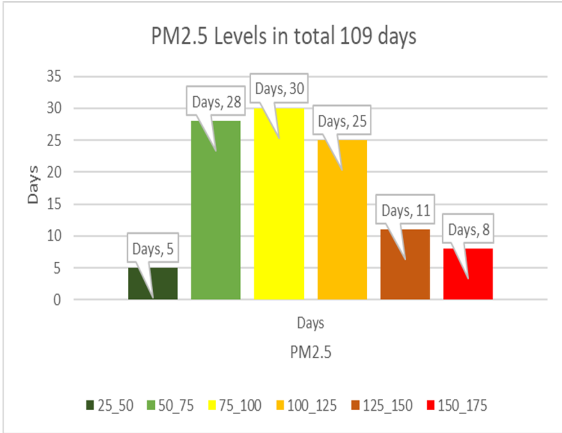


Fig. 11. Demonstrate the levels of PM2.5 in 109 days in Erbil (Jan 14 to May 04, 2023). Source Fig 10.

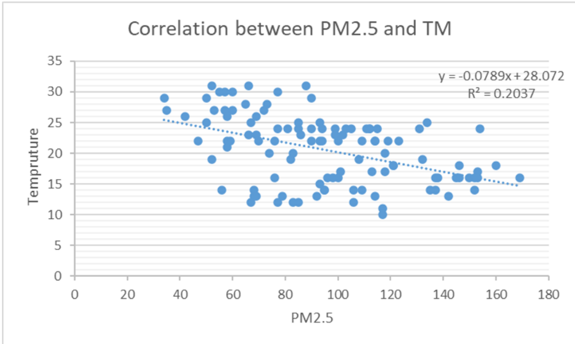


Fig. 12. showing the Correlation between PM2.5 and TM in Erbil (14th January to 4th May 2023

3.3 The correlation between Elevation and Air quality levels in Erbil

The impact of elevation on the varying dispersion patterns of pollutants in Erbil is noticeable. By comparing the maps depicting air quality and altitude, it becomes evident that regions below sea level (ranging from 162 to 923 meters) exhibit higher concentrations of air pollutants like (Erbil, Erbil Centre, Erbil Plain and Xabat). On the other hand, regions situated between 1000 and 3600 meters above sea level demonstrate notably reduced concentrations of air pollutants, as depicted in figures 2, 4, 5, 6, 7, 8, and 9.

3.4 Key Factors Influencing Air Quality Variations in Erbil

3.4.1 LULC Changing

Changes in land use patterns have emerged as a primary driver of escalating environmental pollution, particularly in the central area of Erbil. Over the past two decades, the city's landscape has undergone significant transformations (Figure 13); this transformation has resulted in a decline in the presence of green spaces while witnessing a surge in land allocation for construction, commercial activities, industrial purposes, and road networks. Consequently, these developments have become significant sources of atmospheric pollutants in Erbil. By examining the figures (13,14), it is evident that the proportion of built-up areas is projected to increase by a staggering 50.8 per cent or 6.7 times between 2005 and 2022. Over the period 2012 to 2018 in Dhaka city, an increase in vegetation and waterbodies has corresponded with a reduction in PM2.5 levels. This is highlighted by negative correlations of -0.212 and -0.028 between PM2.5 concentration and vegetation and waterbodies, respectively[24].

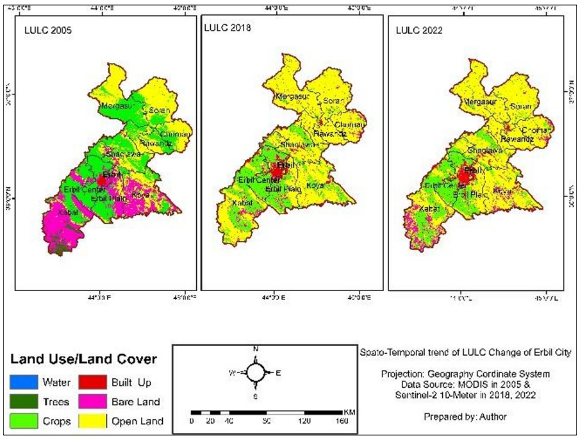


Fig. 13. Displaying LULC changes in Erbil from (2005-2022

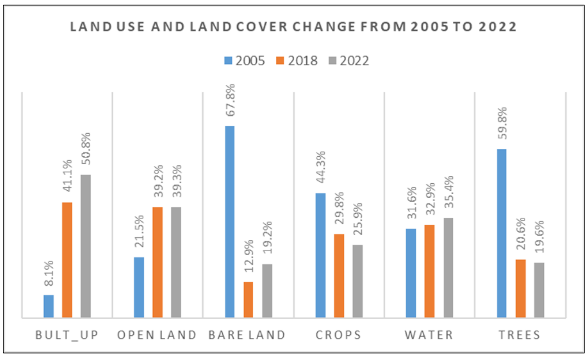


Fig. 14. Shows the percentage of LULC classes in Erbil from (2005-2022)—source Fig 13.

3.4.2 Industrial and Vehicle Emission

Transportation and industry are fundamental aspects of daily life for humans, and in the study area, these sectors have experienced significant growth. Due to the absence of public transportation options like trams and subways in Erbil, forcing most citizens depend on their vehicles. Unfortunately, the fuel used in these vehicles is of poor quality, leading to detrimental effects on the environment and increased emissions of greenhouse gases. The number of registered cars in Erbil has nearly doubled from 458,235 in 2011 to around 900,000 in 2020, resulting in daily fuel consumption of approximately 4 million litres. About one out of every 3.5 individuals in the population gets a car, which is significantly higher than in the surrounding countries[25], [26].

3.4.3 Emissions originating from generators and refineries

In Erbil, the availability of electricity relies heavily on privately-owned generators scattered across residential areas and public spaces. Approximately 2,000 generators are in Erbil, each consuming 40 litres of diesel per hour. Unfortunately, these generators, primarily located in neighbourhoods, contribute significantly to air pollution due to the emission of harmful gases[25]. Additionally, around the central area of Erbil, there are approximately 200 illicit refineries that produce fuels notorious for releasing excessive smoke and pollutants, further deteriorating the environmental conditions[27].

3.4.4 Proposed Mitigation Measures for these pollution gases

The results indicate an annual increase in the concentration of these gases. Therefore, emphasizing crucial measures to reduce the sources of air pollutants (such as Ch4, So2, O3, Co, and No2) and lowering PM2.5 levels is vital. To achieve this goal, various scenarios need implementation to address these risks:
Scenario I: to amplify the utilisation of eco-friendly sources such as natural gas and hydropower for electricity generation. Concurrently, the reliance on urban electricity generators should be curtailed, aiming to decrease their usage to 70%. Also, the relocation of these generators away from urban centres is advised, given their substantial contribution to air pollution.

Scenario II: there should be stringent regulations governing traffic networks. This includes the expansion of public transportation options like buses, trams, and trains aimed at replacing private transport within the city. The importation of cars should also be reduced. The enhancement of public transit services by 60% is recommended. Moreover, optimising fuel consumption quality to minimise environmental waste is imperative. Exploring alternative fuel sources such as electricity and gas for transportation, instead of gasoline, is advocated.

Scenario III: addresses the considerable emissions of greenhouse gases from numerous factories, including some unauthorized ones, surrounding Erbil. Endeavors to decrease these emissions by 50% are underway. Shifting to cleaner fuels like natural gas and electricity for factory operations, or incorporating specialized filters to mitigate environmental harm, is suggested.

Scenario IIII: Expanding green spaces within and outside the city by 5-10% constitutes . This strategic increase in greenery profoundly contributes to the reduction and absorption of these gases, subsequently enhancing the urban environment's health.

Lastly, focuses on winter air quality. The promotion of cleaner sources, such as natural gas, instate of biomass and kerosene, is pivotal in minimizing PM2.5 levels during this season.

4 Conclusions

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Erbil, like many other regions, has faced significant environmental pollution over the past two decades due to urbanisation, increased vehicular activity, industrial facilities, generators, and the use of low-quality fuel. By utilising advanced techniques such as Google Earth Engine, GIS, Remote Sensing, and satellite imagery, the study analysed pollutant variations from 2018 to 2022, including NO2, SO2, CH4, CO, O3, UV, as well as PM2.5 data from the Ankawa station and land use data from Modis and Sentinel 2 satellites spanning from 2005 to 2022. The research also assessed the influence of elevation on pollutant distribution using DEM data.

The findings indicate a significant increase in pollutant levels over the specified period. However, implementing coronavirus quarantine measures in June 2020 briefly reduced most pollutant levels. Nevertheless, by June 2022, the groups had risen significantly, as observed for other gases. The highest concentrations of these gases were found in central areas of Erbil and surrounding regions like Khabat and the Erbil Plain; out of the 107 days recorded, 44 days had hazardous levels of PM2.5, while only five days had safe or healthy levels. Lower elevation regions like Erbil and Khabat exhibited the highest concentrations of these gases, while higher elevation areas like Mergasur and Choman had the lowest levels of pollutants.

These findings emphasise the urgent need for comprehensive measures to mitigate air pollution in Erbil and other affected regions. Efforts should focus on reducing emissions from urban sources, improving fuel quality, promoting sustainable transportation, and implementing stricter regulations for industrial activities.

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