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# Air Pollution Quality Assessment of Kirkuk Governorate using Remote Sensing and Geographic Information Systems Techniques

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**Abstract**

The ecological quality of Kirkuk city is an important indicator to assess the level of urbanization and sustainable development in the region. This study aims to assess the Environmental Index (EI) of Kirkuk using a pressure-state-response (PSR) framework, which integrates a set of statistical indicators, remote sensing techniques, and satellite data from Sentinel. These indicators were employed to accurately monitor and track environmental changes through Geographic Information Systems (GIS), providing a modern tool to guide sustainable development decisions and continuous monitoring of environmental quality. The results showed variation in environmental indicators associated with human activities and different weather conditions. Despite high concentrations of pollution in central urban areas, environmental conditions were seen to improve in some areas of the city, reflecting the impact of intense social and economic pressures. The study contributes to enhancing the scientific understanding of the dynamic relationships between human activity and climate change and its impact on ecosystems, emphasizing the importance of periodic monitoring and analysis of these indicators to support effective environmental policies and achieve sustainable development in the city of Kirkuk..

**Keywords:** Ecological index; Environment; GIS; PSR framework ; sentinel 1B

## 1. Introduction

Over the last fifty years, the importance of environmental assessment has increased significantly, particularly in decision-making regarding environmental management and quality. Developing an effective climate framework to address environmental challenges requires a thorough assessment of environmental quality (Streimikis 2020). Assessment of ecological quality can demonstrate the harmony between human activity and the environment, as well as the ability of a region to achieve long-term sustainable social and economic development. There is a positive relationship between environmental quality and economic growth.

Given its critical role in supporting human development and providing resources such as water, land, biological resources, and climate, it is essential to monitor and understand the state of ecosystems. Due to the significant changes in the natural environment over the past few decades, environmental assessment has become increasingly important in light of the current national emergency. Because



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remote sensing techniques can maintain dynamic and comprehensive monitoring, ecological monitoring has benefited greatly from them.

Kirkuk is a city in northeastern Iraq. It is flanked by the Zagros Mountains to the north, the Hamreen Mountains to the south, the lower Zab Mountains to the west, and Al-Sulaymaniyah city in the east. Kirkuk City is situated at longitudes (44° 00′ to 44° 50′ E) and latitudes (35° 13′ to 36° 29′ N) (Ajaj 2023). This city has an area of around 9,679 km2. It is around 250 kilometers from Baghdad, Iraq's capital. According to the Ministry of Planning's Central Bureau of Statistics, the population in 2021 is expected to be 1,726,409. Kirkuk is regarded as a prominent city due to its oil reserves and agricultural importance. It is also recognized as a connection point between the central and northern governorates, owing to its geographical location. Kirkuk's geography varies, including both mountains and plains. The climate varies by season, particularly in terms of temperature and rainfall. Kirkuk is rich in resources, particularly oil, as is the region's agricultural productivity. Fig1 depicts the study region that includes Kirkuk. Rapid population expansion in Kirkuk and changing lifestyles are the main sources of increased air pollution from human-caused waste. As a result, air quality in nearby areas is likely to deteriorate, indicating that the release of gas into the atmosphere will have a detrimental impact on people’s health. As a result, existing disposal sites will be inadequate.

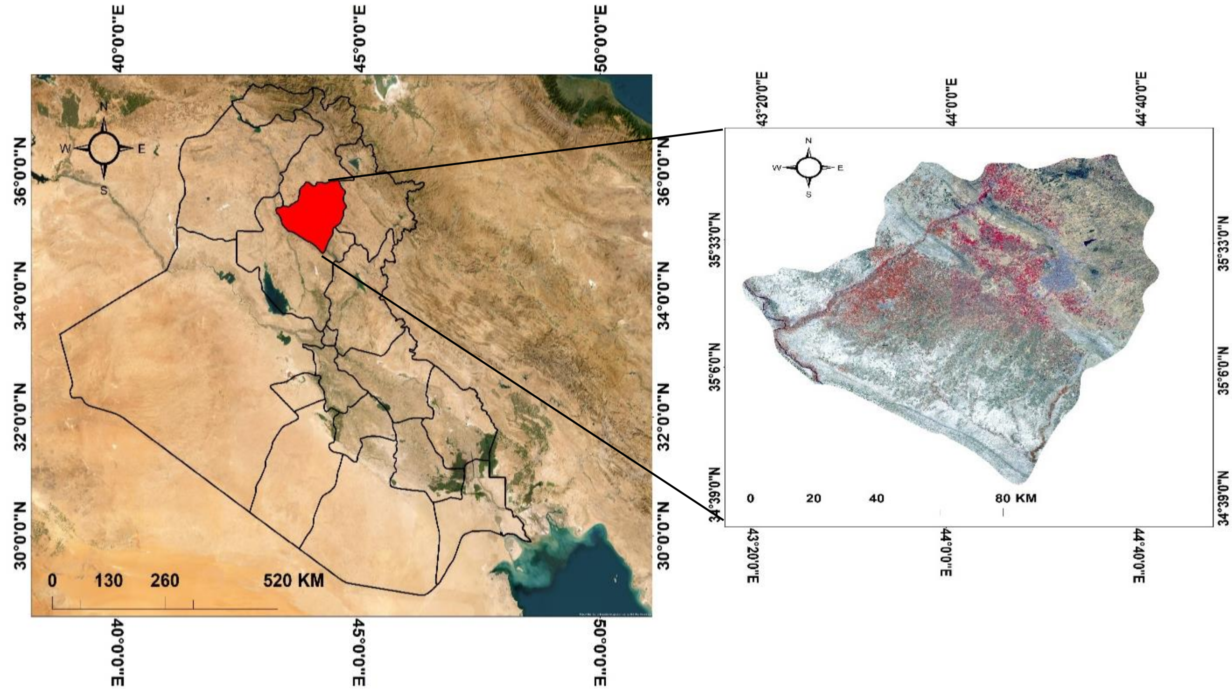


**Fig1**. The study area of Kirkuk governorate map

Since the quality of a region's ecological environment forms the basis for sustainable social and economic development, the ecological index is part of management activities and one of the best tools for reducing pollution in all its forms and harmful effects (Qian et al., 2023).

On the other hand, the Pressure-State-Response (PSR) model highlights the relationship between human intervention in an ecosystem and its impact on environmental conditions. Resource- and societal-related pressures emphasize the extent to which human activity impacts ecosystem health (WHO, 2005). State indicators indicate the resilience, vitality, and structure of an ecosystem,


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reflecting its current level of health. Response indicators, on the other hand, show how an ecosystem reacts to changes in its overall health, whether caused by environmental factors or human activity. These variables, through changes in soil temperature, vegetation, land use/cover, temperature, soil texture, and ultimately aridity, affect plant growth. Consequently, any change or disturbance in one of the ecological indicators directly or indirectly impacts the ecosystem as a whole.

Changes in land use and differences in ecological quality are related. For example, if development in a given area increases rapidly, the area of land with poor environmental conditions increases. Changes in environmental quality and ecological parameters are influenced by a complex interaction between factors arising from natural phenomena, such as precipitation and temperature fluctuations, and human actions, such as population expansion and economic progress. Maps that show land use and land cover improve our understanding of environmental modeling and water resources management.

The Organization for Economic Co-operation and Development (OECD) initially proposed the Pressure-State-Response (PSR) model for policy formulation. Using methods such as the Analytical Hierarchy Process (AHP), this system allows the integration of various remote sensing data and information into a single indicator (Youssef et al., 2011). Although these terms are often used interchangeably, there are cases in which they can be distinguished. Terms such as "livability", "quality of life", "site quality", "housing perception and satisfaction", "evaluation of the residential and living environment" and "sustainability" reflect aspects of urban life, such as safety, well-being, health and satisfaction with living conditions, and are derived from studies and analyzes related to city policies..

The quality of the ecological environment in Kirkuk is a vital indicator for assessing the level of urbanization and sustainable development in the region. This study aims to evaluate the Environmental Index (EI) for Kirkuk using the Pressure-State-Response (PSR) framework, integrating a set of statistical indicators, remote sensing techniques and Sentinel satellite data. These indicators were used to accurately monitor and track environmental changes through a Geographic Information System (GIS), providing a modern tool to guide sustainable development decisions and continuously monitor environmental quality. The results showed variations in environmental indicators associated with human activities and different climatic conditions. Improvements in environmental conditions were observed in some areas of the city, despite high concentrations of pollution in central urban areas, reflecting the impact of intense social and economic pressures. The study contributes to improving scientific understanding of the dynamic relationship between human activity and climate change and its impact on ecosystems. Emphasizes the importance of periodic monitoring and analysis of these indicators to support effective environmental policies and achieve sustainable development in Kirkuk.

The results show that interactions between pollution, population density and rising temperatures negatively impact the general state of the atmosphere in the region, while indicators related to humidity and vegetation play a positive role in improving environmental quality. The study also demonstrated that positive values resulting from natural responses are essential to improving environmental quality, especially taking into account the direct impact of human activity on increasing pollution levels. These results highlight the need for accurate and frequent ecosystem assessment and monitoring of ongoing changes, using effective tools such as GIS and remote sensing technologies, to ensure the formulation of scientifically evidence-based environmental policies that contribute to pollution control and sustainable development in Kirkuk..



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## 2. Materials and Methods

In this study, the combined environmental index in this study was derived using the pressure, state, and response (PSR) model. Nine variables were used to determine the pressure index, while three indices were used to determine the condition index. The indices were obtained in the SNAP 9.0.0 software and exported in the ArcGIS 10.8.1 software. The equations were implemented using ArcGIS 10.8.1 software. Sentinel satellite images were used, as well as data from the digital elevation model (DEM) and information from the road and railway network (Iraqi Ministry of Planning). Additionally, pressure indices included digital elevation model (DEM) with 12.5 resolution, Global Environmental Monitoring Index (GEMI), land use/vegetation (LULC), normalized difference moisture index (NDMI), normalized difference water index (NDWI), soil-adjusted vegetation index (SAVI), road network, railway network, and land surface temperature (LST). Condition indices were derived using partial vegetation cover (CVF), normalized leaf area index (LAI), and normalized difference vegetation index (NDVI), slope and aspect. To ensure that each indicator has the same weight and importance in the final score, all indicators were normalized and standardized on a scale of 0 to 1. Figure 2 illustrates the general approach. The main equation for extracting the indicators is given in Fig2.

Here is a brief explanation of some of these indicators:

### 2.1 Pressure Indicators

*2.1.1 Global Environmental Monitoring Index (GEMI):*

The Air Pollution Index is more resilient to atmospheric effects because it is based on satellite data and is used to track the worldwide environment. It is not advised to use the GEMI in regions with moderate to high levels of pollution because of its sensitivity. The values are on a numerical scale from 0 to 1, where 1 denotes total ground-level air pollution and 0 denotes no air pollution. The GEMI index can be used to extract and quantify the influence of reflected emissions in the atmosphere, particularly from regions. The GEMI index is depicted in Fig3.

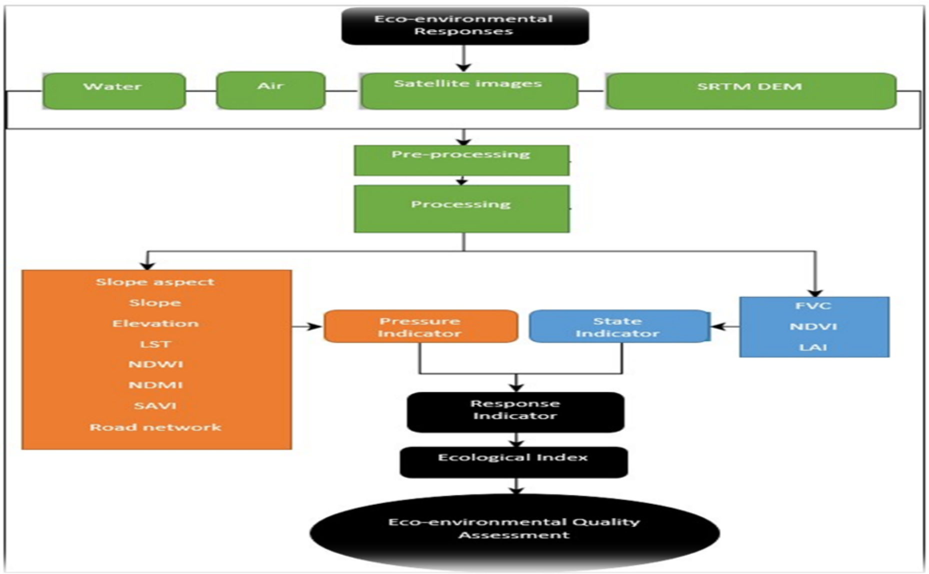


**Fig .2**. Flow chart represents the steps of methodology in current stud



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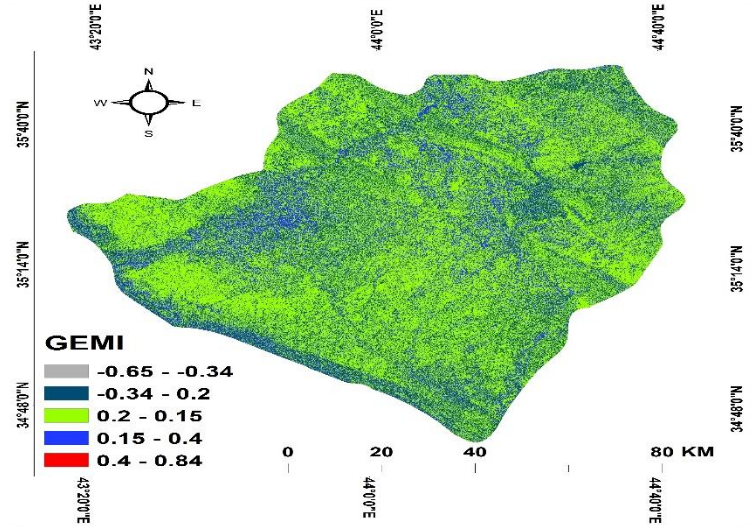


**Fig3**. Global Environmental Monitoring Index

*2.1.2. Fractional vegetation cover (FVC):*

Examine a crucial statistic in the study of ecosystem equilibrium, soil erosion, and climate change. It is frequently used to track and assess vegetation decline and desertification. The percentage of the study area covered by vegetation—, which includes leaves, stems, and roots—is an estimate. It is a measurement of the vegetation's spatial distribution throughout the ground. According to, FVC values vary from 0 to 1, where 0 denotes no vegetation cover and 1 denotes the whole amount of plant cover on the ground surface. The FVC, or the area of the vegetation canopy without any exposed soil between plants, is free of solar specks on the surface and slight disruptions in the vegetation cover, although such area Fig4.

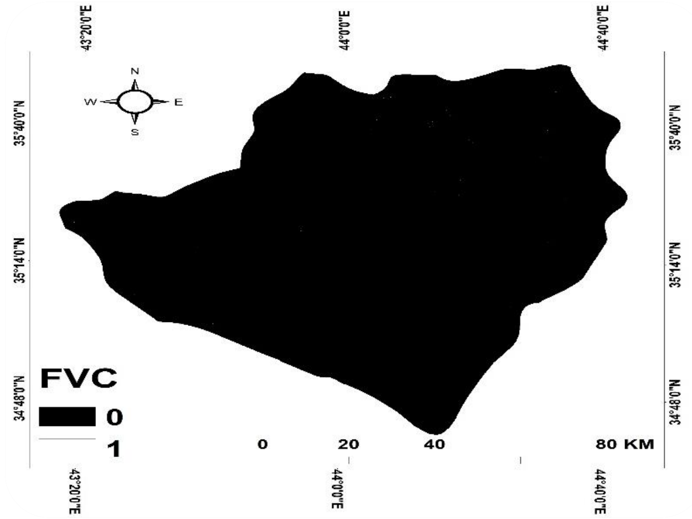


**Fig4.** Fractional vegetation cover

*2.1.3 Leaf Area Index (LAI):*

Plant canopies are described by the dimensionless leaf area index (LAI). The type of plant canopy present and the particular conditions determine the range of the leaf area index (Yow, D. M. 2006). Leaf area index values typically fall between zero (bare ground) and more than 10 (dense pine woods). A dimensionless metric called the leaf area index (LAI) shows the proportion of ground surface area to



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leaf area per unit area. The ratio might have something to do with gas exchange and photosynthesis in plants. In Figure5, the leaf area index is shown Fig5.

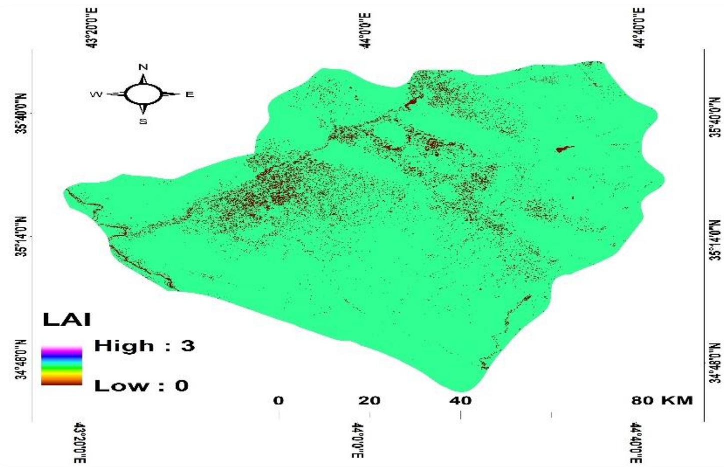


**Fig5.** Leaf Area Index

*2.1.4. Normalized Difference Moisture Index (NDMI):*

There is no standardization in this index. With values ranging from -1 to 1, the index is simple to understand. Increased density with lower air pollution and better health are indicated by higher values (Knack, S.2007). This index's primary uses include tracking plant moisture content and evaluating drought stress, both of which enhance the atmosphere and lower air pollution. Leaf solids and NDMI indices have a close relationship. The NDMI index is depicted in Fig6.

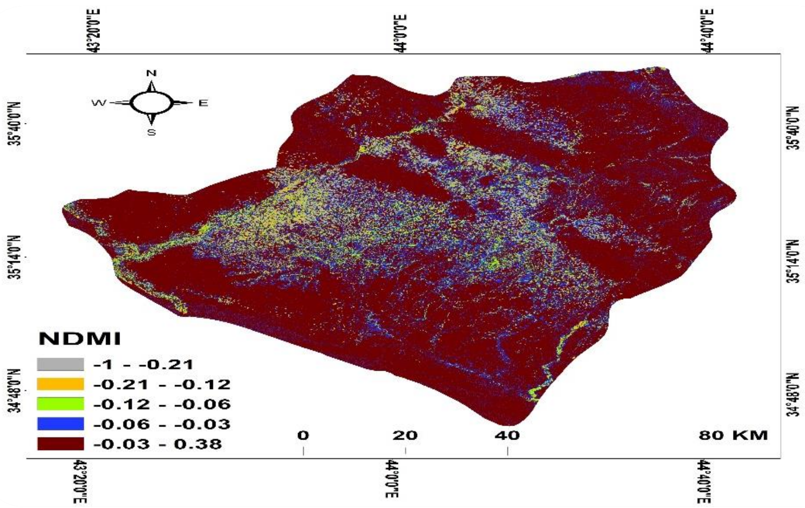


**Fig6.** Normalized Difference Moisture Index

*2.1.5. Normalized Difference Vegetation Index (NDVI):*

One often used metric is the measurement of plant vigor and density using sensor data. Near-infrared and red wavelength spectroscopic data are used for the computation. The index's values, which range from -1 to 1, are simple to grasp; lower values indicate air pollution, while higher values suggest very little. The values of the index, which range from -1 to 1, are simple to interpret. When



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features with low red reflectance and very low near-infrared (NIR) reflectance, such water, are diminished or removed entirely, the index takes advantage of this. Features with low red reflectance and high near-infrared reflectance, on the other hand, will be improved Fig7.

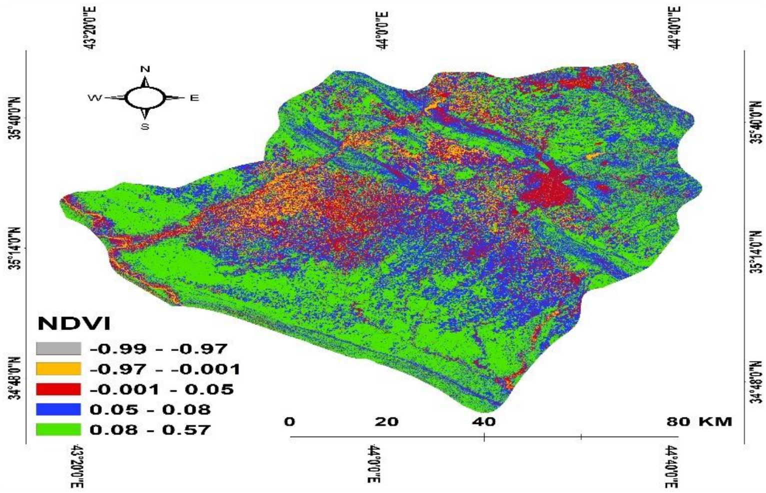


**Fig7**. Normalized Difference Vegetation Index

*2.1.6. Normalized Difference Water Index (NDWI):*

One commonly used statistic is the density of air pollution, which may be determined from sensor data. Spectroscopic information in the red and near-infrared wavelengths is used to do the calculation. The values of the index are between -1 and 1. Significant improvements in air quality are indicated by higher values, whereas excessive levels of air pollution are indicated by values of -1 (Bullock, J. M., 2018). Using these sensors, the NDWI can nevertheless reveal information about the health and pollution level of the air, even though spectrum matching techniques are not appropriate for figuring out the liquid water content of plants Fig8.

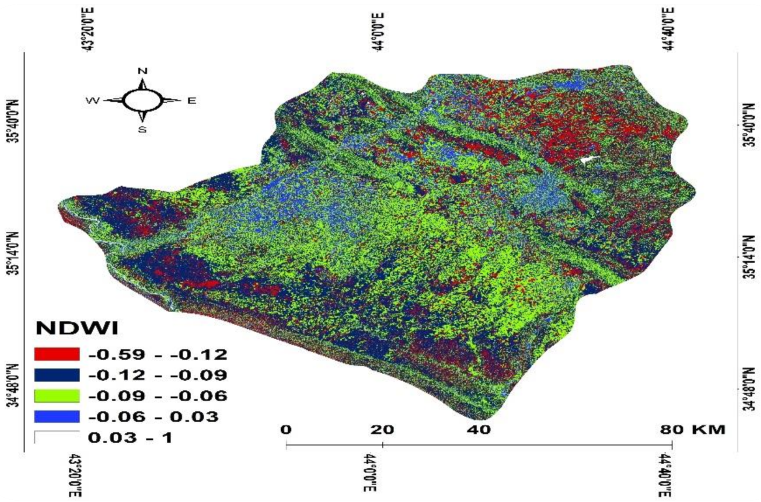


**Fig8.** Normalized Difference Water Index

*2.1.7. Soil-Adjusted Vegetation Index (SAVI):*



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In order to counteract the impact of soil brightness, the Soil Adjusted Vegetation Index, or SAVI for short, employs a soil brightness correction factor. Usually, more polluted places employ it. Greater densities, better health, and no air pollution are indicated by higher values (Kelly, F. J.2015).SAVI readings fall between -1.0 to 1.0.bodies, arid regions, farming regions, and vegetation Fig9.

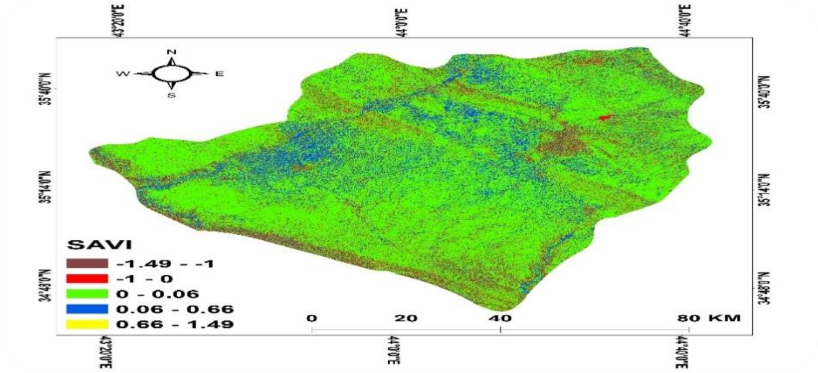


**Fig9**. Soil-Adjusted Vegetation Index

*2.1.8. Digital elevation model (DEM):*

One of the most crucial geographical resources in geographic information systems (GIS) is a digital elevation model (DEM). A structured or unstructured collection of digital data that shows the land's elevation (point elevation) is called topography (Hu, Y. 2003). A watershed's water balance is greatly influenced by topography, a notable aspect of the land surface. The pathways that water takes as it falls and traverses hillslopes, the speed of water movement, and the production of surface and groundwater runoff are some of these variables. The topography of the modeled area, as represented by a digital elevation model (DEM), is used to create bathymetry in all fully distributed and spatially explicit hydraulic and hydrological models. Critical data for appropriately distributed hydraulic and hydrological models is obtained using a DEM. The DEM used in this study is represented in Fig10.

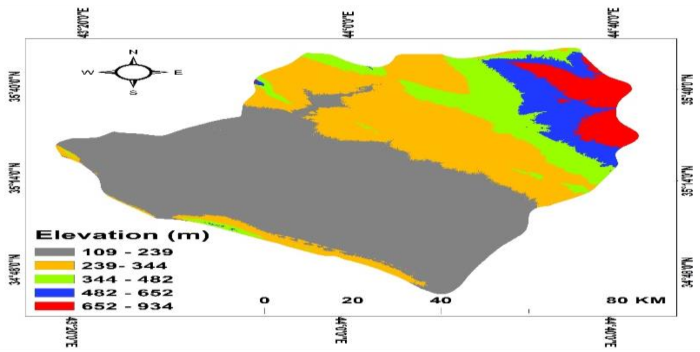


**Fig10.** Digital Elevation Model for Kirkuk City

*2.1.9. Land Surface Temperature (LST):*

Continuous monitoring of harsh settings is hampered by the sparse and irregular locations of weather observatories, the challenges of field surveys, and the intricate process of interpolating station data. Many people who study biology and the environment are interested in land surface temperature (LST) as measured by sensor technologies (Li, Z. L.2013). It influences the equilibrium of radiant energy at the surface of the Earth. Land surface models that track drought, estimate soil moisture content, and



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compute evapotranspiration rates depend on LST. This crucial factor affects how heat and long-wave radiation are transferred between the atmosphere and the land. LST also acts as an indication of surface environmental conditions, which affects trends in the reduction of air pollution Fig11.

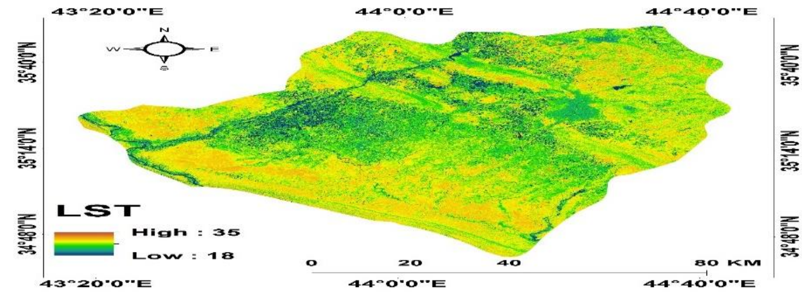


**Fig 11.** Land Surface Temperature

*2.1.10. Land Use/Land Cover:*

For a number of reasons, including urban planning, making educated decisions, comprehending population needs and distribution, and evaluating public health, precise statistics on land use and cover are essential. Land usage and land cover are often combined in inventories. Since land cover describes terrestrial ecosystems, natural resources, and habitats, it is an essential component of climate models. It can be ascertained by direct observation. The description of ecosystem function, together with its social, economic, and cultural utility, is part of land use. An examination of the socioeconomic activity occurring there is necessary (Pielke Sr, R. A 2011). The classes—urban areas, aquatic bodies, arid areas, agricultural areas, and vegetation—were obtained using the SVM classification algorithm Fig12.

*2.1.11 Slope degree:*

The slope gradient map in this study was generated at a resolution of 12.5 cm, the original slope angle values ranged from 0 to 55.8 degrees, and was divided into five groups based on the most common subdivisions as shown in Figure (14) (Zhu, Y. G. 2006).

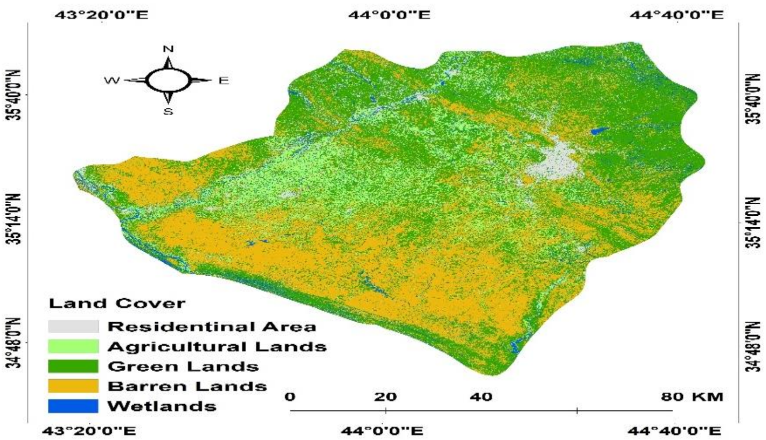


**Fig12.** Land Use/Land Cover



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*2.1.12 Slope degree:*

The slope gradient map in this study was generated at a resolution of 12.5 cm, the original slope angle values ranged from 0 to 55.8 degrees, and was divided into five groups based on the most common subdivisions as shown in Figure (13) (Zhu, Y. G. 2006).

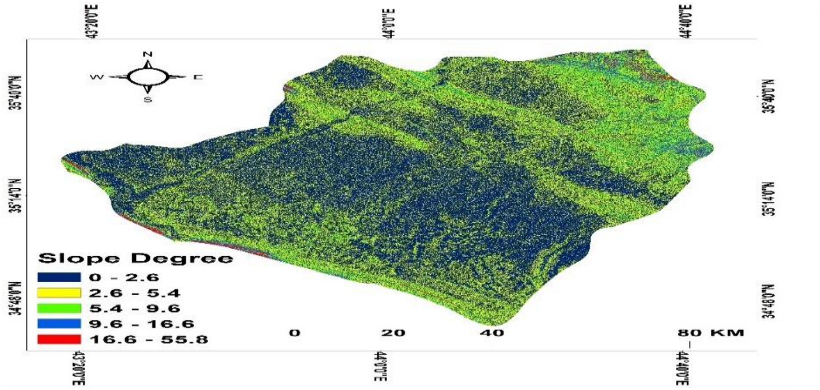


**Fig13.** Slope degree

*2.1.13 Slope aspect*

Since the slope aspect is physically related to factors like the direction of discontinuities that control environmental pollution, wind effects, exposure to sunlight, and rainfall, it is regarded as one of the most crucial factors when creating maps to identify areas of environmental pollution. Five groups were created from the study region, and each group displays the direction of the slope (Goodenough, D. G1982). As seen in Fig14, it was observed that the slope direction lies between the west and the south.

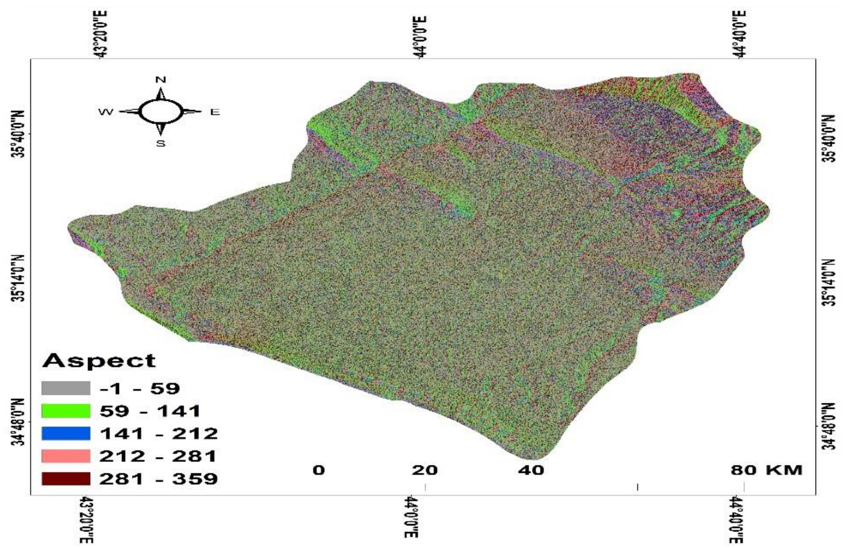


**Fig14.** Slope aspect


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The pressure (PI), state (SI), and response (RI) indices were calculated according to the equations adopted in previous studies (Kim, 2025; Solie, 2003)

The following is an explanation of these indicators:

## 2.2 State Indicators

### *2.2.1. Pressure indicator (PI)*

Resource restrictions have an impact on how human measures impact the reactions of small-scale individuals. The data determines the PI value, which is between 0 and 1. Each sign in the study region is given importance by this value, as indicated in the previous (1). In addition to the subsequent actions and measures that must be implemented in the future, it takes into account how human countermeasures respond to difficulties. For this reason, these neighborhood initiatives help manage minor pests so that they can support minor development. The CSR framework allows for the selection of indicators to identify the progress or contribution that requires analysis. No collection of indicators will be widely accepted, and options may differ by nation or area. Access to the bio data element allows (Long, Y. 2021).

$$PI = \frac{GEMI + SAVI + NDMI + LULC + slope + aspect + Lst + NDWI + DEM}{9}, \text{.......... (Long, Y. 2021)} \quad (1)$$

### *2.2.2. State indicator (SI)*

Condition indices evaluate the resilience, organization, and strength of an ecosystem to determine its current state of health. NDVI (Normalized Variable Vegetation Index), LAI (Leaf Area Index), FVC (Fraction of Vegetation), woods, mangroves, wetlands, and water bodies are examples of natural indices that are frequently found in healthy ecosystems. These ratings for air pollution show an ecosystem that has had little to no human interference. They receive a score of zero otherwise. Using Equation (2), the parameters were first standardized within a range of 0 to 1 and then given equal weight to create a condition index. Higher SI values signify better environmental circumstances and the absence of air pollution, whereas lower values signify worsening environmental conditions and air pollution (Kim, J. M. 2025)

$$SI = \frac{(NDVI + LAI + FVC)}{3}, \text{................Kim, J. M. (2025)} \quad (2)$$

### *2.2.3. Response indicator (RI)*

Response indices demonstrate how an ecosystem responds to shifts in its general health, including those brought on by both natural processes and human activity. Response indices are usually linked to high-stress situations, which point to numerous environmental changes and a detrimental environmental issue. High response rates therefore point to a significant ecological shift or environmental stress [22]. Low response indices, on the other hand, are indicative of low condition indices, which show relatively favorable or stable environmental circumstances as well as an established environment that has not changed much because of low human and natural demand. A controlled atmosphere and sustainable growth are indicated by low response indices. Equation (3) can be used to get the RI value.

$$RI = PI - SI, \text{............(Solie, J. B. 2003).} \quad (3)$$

"The pressure and state indices were calculated as averages of their respective normalized sub-indices, giving equal weight to each variable."



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### 2.3 Calculation of ecological index (EI)

Since the ecological index tends to closely match the average value within each period, it is a crucial tool for assessing ecological quality during the review process. On the other hand, an ecological indicator that is widely dispersed will have less of an effect on ecological quality within a certain range. Because each index's dimensions vary, it is crucial to normalize the index during the actual computation (Sensing and Index, 2020) [23]. Equation (4) can be used to calculate the ecological indicator (EI), which is based on the weight (w) and standardized data (c).

$EI = \sum_{i=1}^{n} W * C$ ………….. ( Plaza, A. 2023) (4)

The ecological indicator in this research was computed utilizing all the ecological response factors, as specified by equation (5).

$$EI = w(lst) + w(ndwi) + w(\text{Road network}) + w(LAI) + w(LULC) + w(ndvi) + w(dem) + w(slope), + w(aspect) + w(gemi) + w(Fvc) + w(savi) + w(Ndmi) \ldots\ldots\ldots\ldots [23] \quad (5)$$

The GEMI is a comprehensive index for tracking the global environment, and the word "environmental parameter" refers to it. Climate factor: The normalized differential moisture index (NDMI) and the soil adjusted vegetation index (SAVI) are used to measure soil moisture. A number of indicators, such as the fractional vegetation cover (FVC), leaf area index (LAI), and normalized difference vegetation index (NDVI), can be used to measure greenness. Land cover/use: LULC shift; Road and railway networks are examples of artificial features and energy. The normalized difference water index (NDWI) is used to measure the water content. Subject: Landscape Digital Elevation Model (DEM) .slope, slope aspect.

All indicators were normalized using the min-max method to a range of 0–1

"Normalization of indices was performed using the min-max method as follows:

$$x' = \frac{\mathbf{X\,min - X}}{\mathbf{minXmaX - X}} \quad (6)$$

to scale data between 0 and 1, ensuring equal weighting in the combined index."

which facilitated equal integration of variables with different units and scales. Indices for pressure and state were calculated as the average of all sub-indices in each category, giving each indicator the same weight in the final combined index.

This research relied exclusively on open-access environmental and geospatial data; no studies involving human or animal subjects were performed and no ethical approval was required "All original datasets, processed layers, and scripts used for analysis are available from the corresponding author upon reasonable request and will be deposited in a publicly accessible data repository prior to publication, in accordance with the journal's open data policy." "This study used exclusively open-access environmental and geospatial data; thus, no ethical approval was required."

## 3. Results

An overall evaluation of the Pressure-State-Response (PSR) model was conducted, and the results are presented as follows:

### 3.1 Pressure-State-Response (PSR) Model Results

#### *3.1.1. Pressure indicator*

Nine indicators were given equal weights to create the pressure index. The pressure index map shows high pressure levels in developed areas. These areas typically experience high levels of social



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and economic activity. The pattern shows that the pressure index is increasing in the center of the study area as well as in neighboring communities. There is high pressure in the Kirkuk city center area, primarily due to increased human activity. The periphery of the area experiences lower pressure. Due to relatively low levels of social and economic activity, the villages surrounding Kirkuk city are subject to light pressure, as evidenced by the dry zone station. This disparity is more pronounced in rural areas. The study area is characterized by abundant dry and green areas and low air pressure due to the small population. It is important to understand that population size and the population index (PI) are positively correlated.

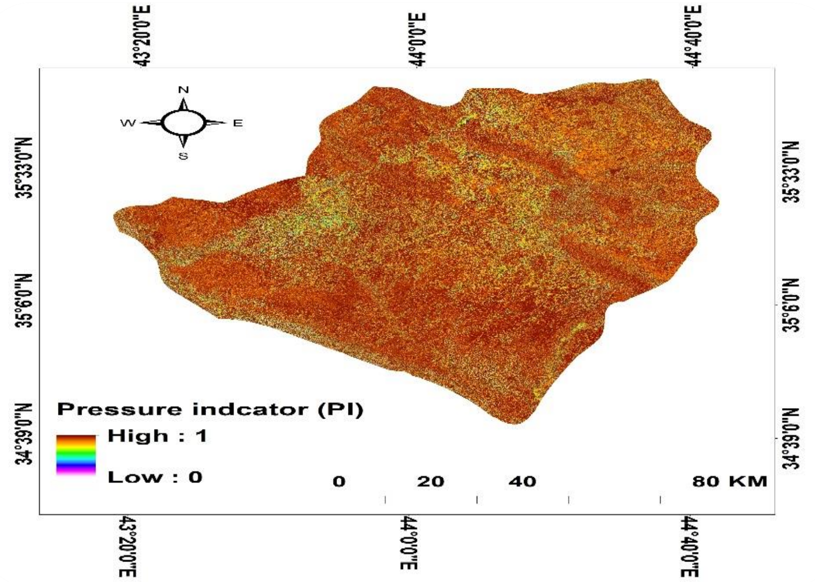


**Fig15.** Pressure indicator

*3.1.2. State indicator*

The Condition Index (SI) classification system is primarily based on measurements of partial vegetation cover (FVC), normalized difference vegetation index (NDVI), and leaf area index (LAI). The SI ranges from 1 to 0, where 1 indicates a healthy ecosystem, good weather conditions, and no pollution, while 0 indicates atmospheric pollution. The combined effect of all meteorological indicators is displayed on the Condition Index map. Due to market pressures to meet food demand, the Condition Index map shows a significant degree of human pressure in both urban and agricultural areas. In both seasons, the Condition Index typically shows a high value. Temperatures in the study area tend to be very high in summer and cold in winter.

*3.1.3. Response indicator*

High values of the Responsiveness Index indicate weaker, unhealthy, and unstable environmental conditions under intense human pressure, and vice versa. High SI values indicate increased natural and human pressures, as well as socioeconomic activities such as industrial expansion, agricultural practices, and urban development, which may negatively impact the environment. Low values for the response index indicate limited human interference in ecosystems, especially in areas rich in vegetation and water bodies, as well as areas far from urban centers.



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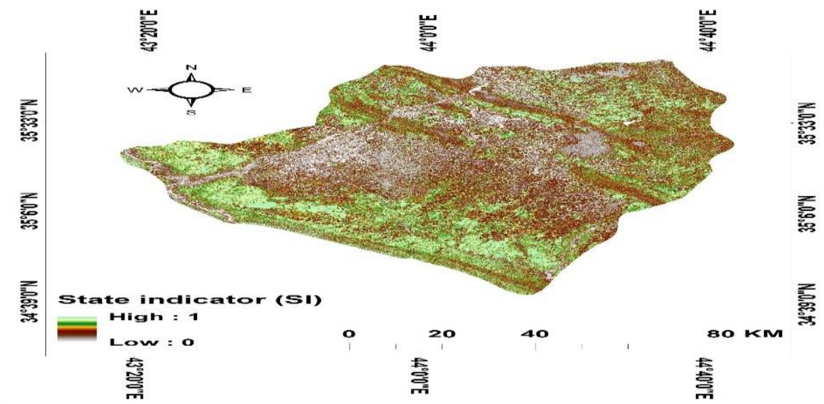


The study results indicate that the condition index ranges between 1 and 0, where 1 indicates a healthy ecosystem with good air and no pollution, and 0 indicates the presence of pollution. The response index maps indicate changes in the index value between summer and winter due to differences in human activity.

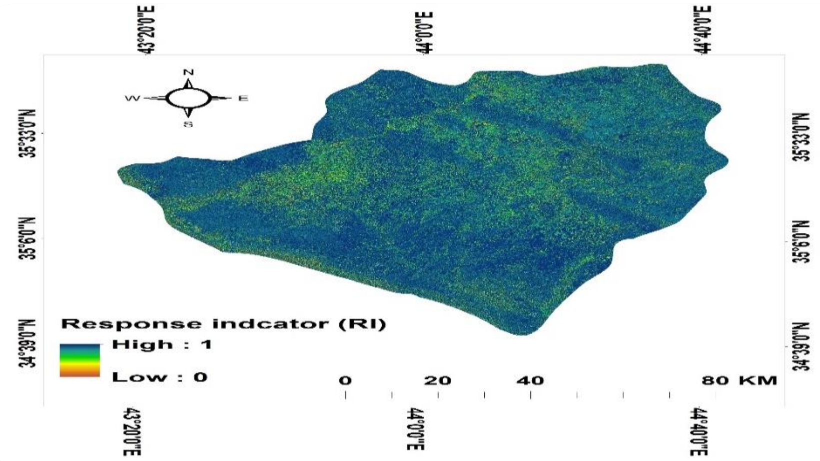


**Fig17**. Response indicator

### *3.1.4. Ecological Index*

High values for the environmental index indicate a stable and healthy atmosphere, while low values are the opposite. The study area exhibits medium to high values for the environmental index, as shown in Figure 18. Due to the high population density that contributes to increased air pollution, we find that the ecological index value is higher in residential areas in terms of air pollution. The highest values are concentrated in the cities of Sulaymaniyah and the eastern part of the study, with the northeastern and eastern regions performing better than others. In the center of the study area, there is a significant increase in human activity, making the most polluted areas in Kirkuk city located in the center. The spatial distribution of the atmospheric environmental impact maps shows good to average environmental conditions in the surrounding areas, while exceptional conditions were found near water bodies. In some residential and industrial areas, environmental conditions ranged from poor to acceptable. Environmental conditions in the northern part of the study area are characterized as good to exceptional, while they are favorable to moderate in the southern part.



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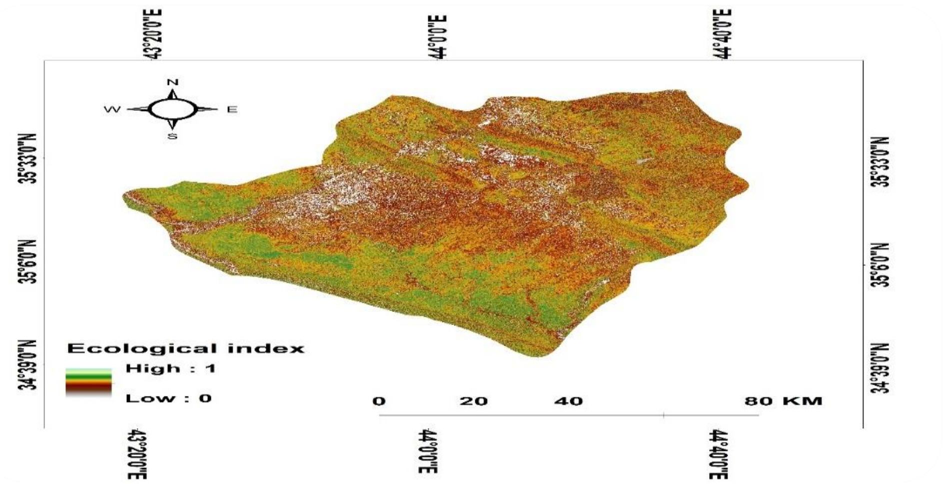


**Fig18.** Ecological Index

### 3.2 General assessment of Ecological Environment Quality (EEQ)

This study uses a wide range of input indicators to assess environmental quality in Kirkuk Governorate. The study relies on time-lapse satellite data, particularly Sentinel imagery, within a framework that allows for rapid and analytical assessment of EEQ, resulting in the creation of 18 atmospheric environmental indicators. A condition index was created to monitor pressure levels and response indicators, and a pressure index was created to assess socioeconomic pressures. Criteria include land cover changes, natural and human impacts, overall environmental condition, and ecosystem health.

## 4. Discussion

The Pressure-State-Response (PSR) model was used in this research to assess the ecological quality of the Kirkuk region. The results showed increased stress indicators in urban areas, particularly in Kirkuk city center, consistent with the study by Ajaj et al. (2023), which emphasized the impact of industrial and social activity on increasing environmental stress. The lower stress indicators in rural areas reflect different population distributions and lower levels of economic activity. This is consistent with the observations of Pielke Sr et al. (2011) on the relationship between land use and land cover and social and environmental factors.

The Condition Index (SI), which is based on indicators such as FVC, NDVI, and LAI, provided a clear picture of the health of the ecosystem in the region. The results showed that vegetation indicators were poorer in areas with high human activity. This relationship was confirmed by studies by Kelly and Fussell (2015) and Parker (2020), which indicated that vegetation cover and quality are affected by human pressure and climate change.

Regarding the Response Index (RI), high values were recorded in areas with intensive industrial, agricultural, and urban activities, indicating that these ecosystems are under increasing pressure. This trend is consistent with the findings of Mullen et al. (2003), who emphasized the importance of response indices in assessing the impact of economic and human pressures on ecosystems, as well as with the study by Bullock et al. (2018), which discussed the response of ecosystems to changes in human activity.



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The Ecological Index (EI) combined these indices to reflect the ecological balance in the region. Highly populated areas showed deteriorating levels, while the spatial distribution favored areas close to water bodies and green areas. This is consistent with the findings of Wang et al. (2023), who demonstrated the role of these areas in supporting environmental stability and preserving biodiversity.
The results indicate an urgent need to strengthen monitoring of human activities and their environmental impacts, especially in dense urban areas. It also emphasizes the importance of using remote sensing and geographic information systems (GIS) techniques, as used in this study (Hu 2003; Teillet et al. 1982), to support environmental decision-making and sustainable planning.
For future research, it is recommended to expand the scope of the study to include monitoring the impact of seasonal climate changes on environmental indicators, in addition to examining new dimensions such as the relationship between environmental quality and public health. Integrating qualitative and quantitative data, as proposed in Rosenzweig et al. (2007), may also help provide a deeper understanding of human-environment relationships in such areas.

## 5. Conclusions

This study highlights the assessment of the state of the atmosphere in Kirkuk using key environmental indicators and utilizing GIS and remote sensing techniques within the framework of environmental impact assessment. The results demonstrate the impact of pollution, population density, and rising temperatures on deteriorating air quality, while humidity and vegetation cover have contributed to its improvement. The study confirms the clear relationship between human activities and pollution levels, calling for the adoption of sustainable strategies to mitigate these effects and enhance continuous environmental monitoring using modern technologies. This study provides a valuable contribution to understanding and assessing air quality at the local and regional levels and encourages the expansion of future research to review the impact of climate change and incorporate deeper health and environmental indicators.

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