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Assessment of the Air Pollution Risk in Kirkuk Government with the Analytic Hierarchy Process (AHP) Model

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Abstract

Air pollution susceptibility maps are important for planning and dealing with natural disasters in Kirkuk province such as Kirkuk study area. The present study uses Analytic hierarchy process (AHP) models to analyse the susceptibility of Kirkuk and its surrounding area to air pollution. Three data sources are used to create the air pollution inventory map, such as previous studies, field investigation and monitoring image. The satellite image used in this investigation is a monitoring image, which was downloaded from the USGS website and consists of 11 bands with temporal and spatial resolutions of 16 days and 10 meters respectively. Twelve factors of air pollution conditioning were studied in this case study to build Analytical Hierarchy Process (AHP) models to produce an air pollution assessment map. These factors include: aspect, slope, land use, elevation, gemi; NDVI; ndwi; ndmi, lai, savi, fvc. According to the AUC area under the curve, the result reveals that the model's disturbance level scale with AUC value of 0.6 has the maximum prediction accuracy of 65.416 percent and the accuracy area according to the method is 31.276. The pollution susceptibility maps generated by AHP produce an accurate prediction of the susceptibility of Kirkuk part to air pollution, which can be used as a tool for land use planning and disaster mitigation.

Keyword:

GIS, air pollution, review, hazard.

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Introduction

When making decisions on the management of the environment and its quality, environmental assessment has become increasingly important during the last half-century (Harbi & Abed, 2025). Accurately assessing environmental quality is crucial for developing a climate framework that effectively addresses environmental concerns. A region's capacity to sustain socioeconomic development over time and the degree to which human activity and the environment are coordinated can be revealed through an evaluation of the eco-environmental quality (Kurdi & Ahmed, 2025; Krishnamoorthy, 2026; Mousa & Rasheed, 2022). Improvements in environmental quality are associated with more robust economies. It is crucial to keep an eye on and comprehend the condition of the ecosystem because of the vital role it plays in supporting human progress and providing resources including land, water, biological resources, and climate.

The way nature is changing quickly is turning Environmental Assessments into yet another part of our national emergency (Rahman & Lalnunthari, 2024; Hassan et al., 2019). The ability of remote sensing technology to keep compliance dynamic and complete has boosted ecological monitoring (Patil, 2018). The Eco-Environmental Quality of a region is pivotal to its sustainable socio-economic development. The ecological index, therefore, becomes part of management activities to combat pollution and its adverse effects.

However, according to (Darko et al., 2019), the pressure-state-response (PSR) model emphasises how humans interact with ecosystems and how this affects environmental circumstances. Human activities put a burden on ecosystem health, as seen by social and resource demands. Indicators of an ecosystem's health include its structure, vitality, and resilience. Ecosystem response indicators reveal how a system reacts to environmental and human-caused changes in its general state of health (Qudsiah et al., 2024; Đurić & Topalić Marković, 2023).

These different variables can influence plant growth because of their effects on soil temperature, soil texture, vegetation, heat, aridity, and land use/cover. So, any change or distortion in one ecological factor will impact the ecosystem as a whole, whether that be directly or indirectly. Changes in land use and the difference in eco-environmental quality rating go hand in hand. For example, in areas where development is rapid, a greater proportion of land with poor environmental quality will be created (Ahmad et al., 2024). The alterations that happen within environmental quality and ecological elements result from a wide-ranging mixture of other different factors, both natural, like changes in temperature and precipitation and human, like economic growth and population growth (Dirie et al., 2024). Maps showing us land use and land cover enhance our understanding of environmental modeling and the management of water resources (Gehad et al., 2024).

When it came time to formulate policies, the OECD put out the Pressure State Response (PSR) paradigm. This system has the potential to integrate several data sets and remote sensing findings into a single index by employing techniques like the analytical hierarchy process (AHP) (Uslu et al., 2024; Jasim, 2024). These expressions are usually thought to mean the same thing, yet there are times when you might want to use each one separately. Feeling secure, healthy, and pleased with one's living conditions are all aspects of city life that terms like "liveability," "standard of life," "standard of place," "residential perception and satisfaction," "assessment of the residential and living environment," and "sustainable development" convey.

The study and analysis of urban policies inform this study which aims to assess the environmental system of the City of Kirkuk to devise ways to minimize pollution and design a blueprint to implement feasible means and effective measures (Ameen et al., 2024; Nsaif et al., 2024). This study also seeks to assess the impact of human activity and climate change on the ecological system by comparing five different ecological responses during a one-year period covering the seasons of spring and fall (Shekho & Shareef, 2025).

Materials and Data

Study Area

The northern Iraqi governorate of Kirkuk is bounded to the north by the Zagros Basin, the south by the Hamrin Mountains, the west by the Little Zab River, and the east by the city of Sulaymaniyah. The present research region covers approximately 9679 km2 and is situated between 39°34′ and 33°35′ north and 43°20′ and 40°44′ east, as illustrated in Figure 1 (Ajaj et al., 2023). In addition, the study region experiences harsh winters and hot, dry summers due to its location between the semi-arid and Mediterranean climates (Alqdori, 2025; Kasim et al., 2025). The majority of precipitation occurs between December and March, with summer characterized by little to no precipitation. Conversely, in this particular study, summer temperatures, which can peak to 48 °C, are of greater concern in determining the climate, while winter temperatures can drop to a minimum of -1 °C. Spring and autumn are described as transition periods between these (Shareef et al., 2021). The study area exhibits rolling hills with a topographic elevation ranging between 109 and 934 meters above sea level.

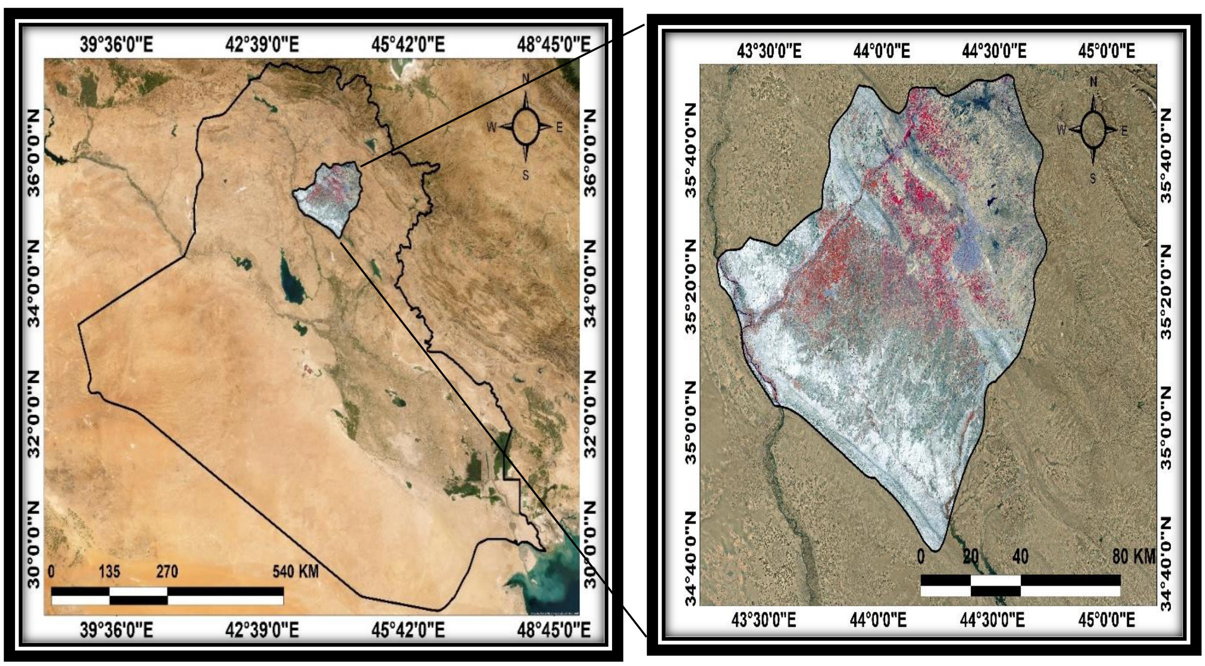

Figure 1. Map of the study area

Methods

We used the pressure, status, and response (PSR) model to calculate the atmospheric environmental index for this investigation. The condition index was calculated using three indices, but the pressure index was based on nine variables. We used SNAP 9.0.0 to get the indices, and then we exported them using ArcGIS 10.8.1. The ArcGIS 10.8.1 program was used to implement the equations. The condition indices were calculated by taking into account the following factors: slope, slope aspect, normalised difference vegetation index (NDVI), normalised leaf area index (LAI), and partial vegetation cover (FVC). All indicators were normalised and standardised on a scale from 0 to 1, ensuring that they all have equal weight in the final score. Figure 2 shows the overall method. In Figure. 2, we can see the primary formula for indication extraction.

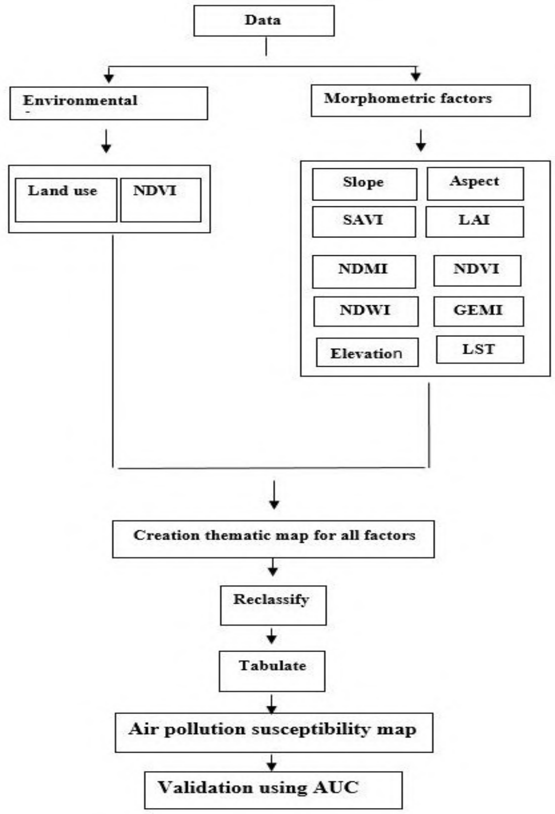

Figure 2. Flowchart of the proposed methodology overview

Extraction the Indicators

Global Environmental Monitoring Index (GEMI)

The Air Pollution Index demonstrates greater resistance to atmospheric impacts because it employs satellite data and monitors the global surroundings. Due to the sensitivity of the index, calculated with the values from 0 to 1, where 1 represents total dirt air pollution and 0 signifies no air pollution, GEMI is not suggested to be used in polluted areas of moderate to high pollution. The index GEMI permits the extraction and quantification of ground-the level atmospheric reflected emissions from the region (Kareem, 2023). The GEMI index is shown in Figure 3.

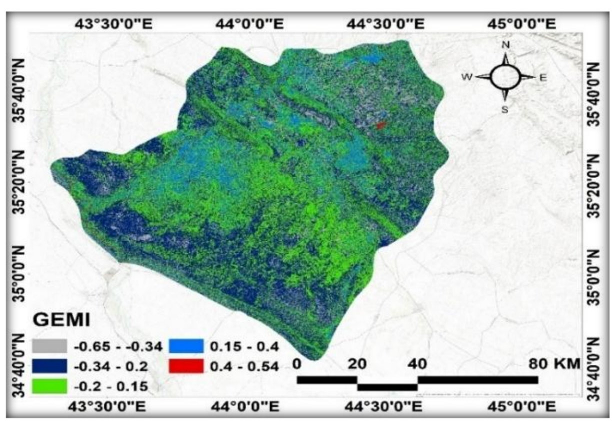

Figure 3. Global environmental monitoring index

Fractional Vegetation Cover (FVC)

Analyse a key metric used to evaluate ecosystem stability, soil degradation, and global warming. The rate of vegetation loss and desertification can be monitored and evaluated using this method. Vegetation (leaves, stems, and roots included) covers an approximate percentage of the research area. This metric quantifies the dispersion of plant life over the earth. There is a range of values for FVC, from 0 (no vegetation cover) to 1 (total plant cover), as stated by (Chu et al., 2020). Although such areas are illustrated in Figure 4, the FVC—the part of the vegetation canopy that is not exposed to soil between plants—is devoid of surface solar specks and minor interruptions to the vegetation cover (Chu et al., 2020).

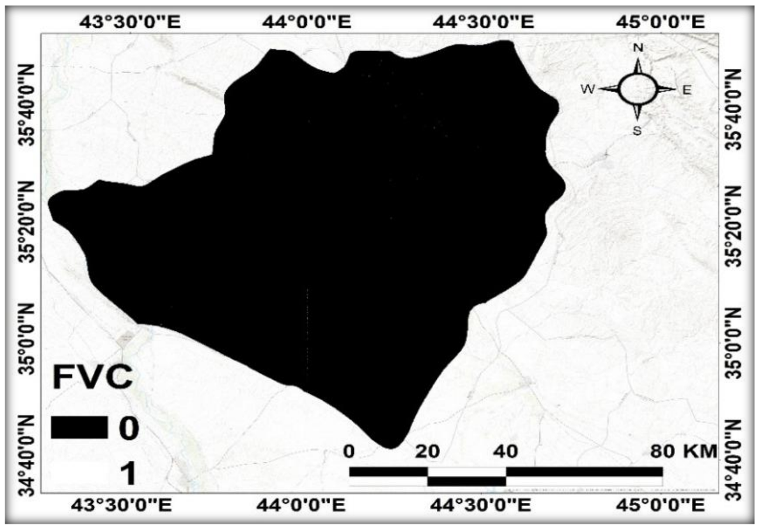

Figure 4. Fractional vegetation cover

Leaf Area Index (LAI)

A plant's canopy can be described using the leaf area index (LAI). A plant's leaf area index can vary greatly depending on its canopy type and the weather. In a typical setting, the leaf area index would be anywhere from zero (bare earth) to ten or more (heavy pine forest). One dimensionless way to estimate the amount of ground covered by leaves is via the leaf area index (LAI). Gas exchange and photosynthesis in plants may be linked to this ratio. Figure 5 shows the leaf area index.

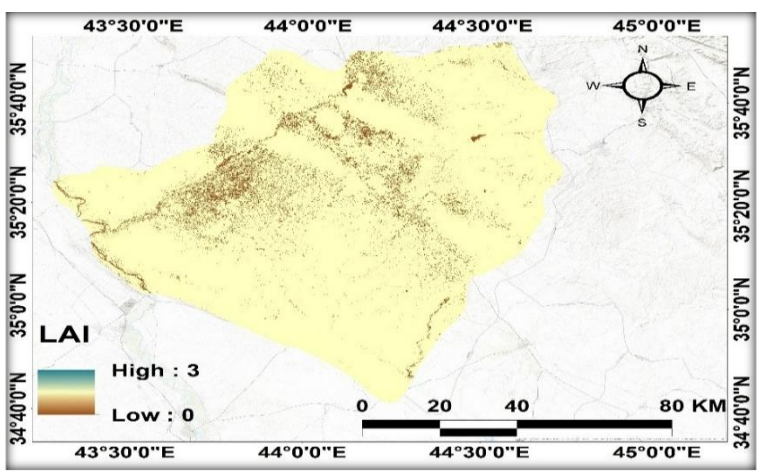

Figure 5. Leaf area index

Normalized Difference Moisture Index (NDMI)

This index is not standardised. You can easily grasp the index because its values go from -1 to 1. Values that are greater suggest a higher density, which in turn indicates less air pollution and better health. Two main applications of this indicator that improve air quality and reduce pollution levels are monitoring plant moisture content and assessing drought stress. There is a strong correlation between leaf solids and NDMI indicators (Hu et al., 2024). In Figure 6, we can see the NDMI index.

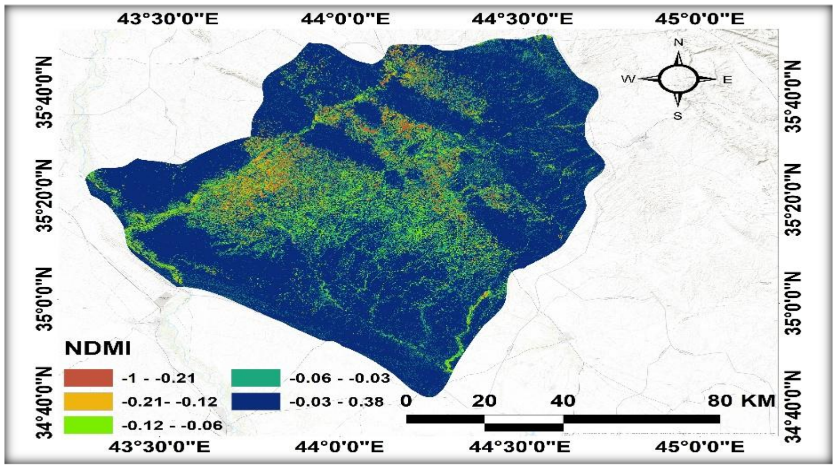

Figure 6. Normalized difference moisture index

Normalized Difference Vegetation Index (NDVI)

The field makes extensive use of data-driven metrics for assessing plant vigour and density. This kind of computation is carried out by means of spectroscopic data collected in the red and near-infrared regions. Simple logic dictates that lower index values indicate more polluted air and higher values suggest cleaner air; the index values range from -1 to 1. The index values are straightforward because they fall between -1 and 1. The index takes advantage of reduced or eliminated red and extremely low-NIR reflectance characteristics, like water, to its advantage (Huang et al., 2021). However, as shown in Figure 7, characteristics that have a low red reflectance and a high near-infrared reflectance will be improved.

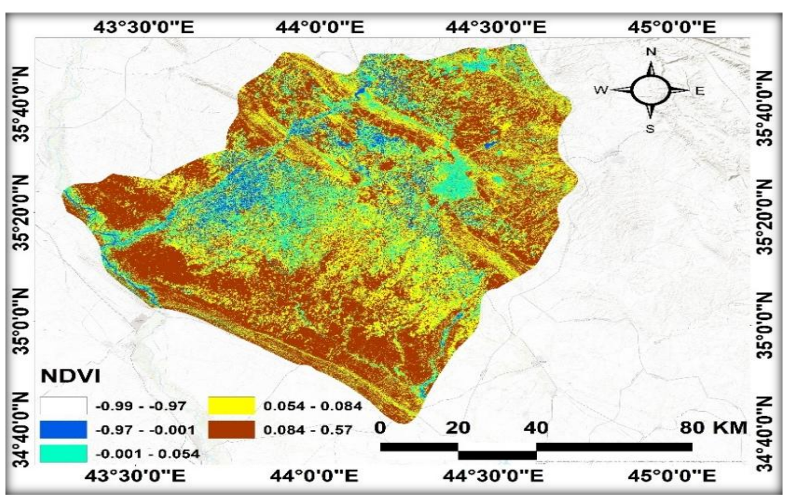

Figure 7. Normalized difference vegetation index

Normalized Difference Water Index (NDWI)

The air pollution density is a commonly used statistic that may be determined from sensor data. The computation is carried out utilising red and near-infrared spectroscopy data. Between -1 and 1 are the possible index values. According to (Ghalehteimouri et al., 2024), air pollution levels below 1 indicate very dirty air while values over 1 suggest significantly better air quality. In spite of the fact that NDWI spectrum matching methods aren't well suited for calculating plant water content shown in Figure 8, they can nonetheless reveal data regarding air pollution and health.

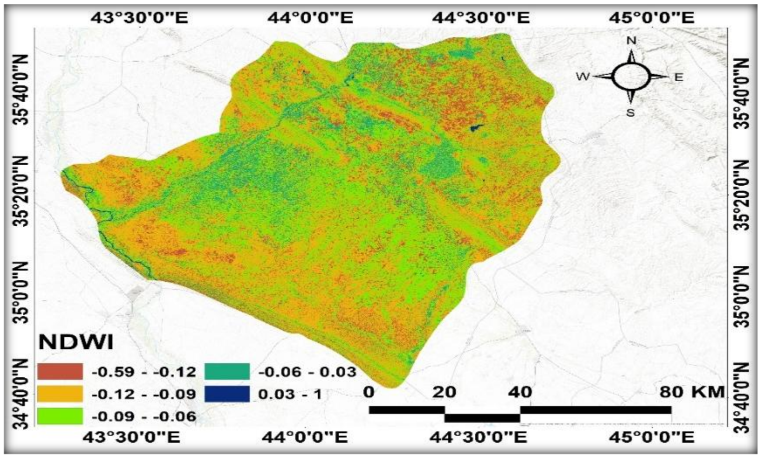

Figure 8. Normalized difference water index

Soil-Adjusted Vegetation Index (SAVI)

To mitigate the effects of soil brightness, SAVI utilizes a soil brightness correction factor (Msadek et al., 2025; Pahlevan et al., 2017). It is more often used in places with more pollution. Higher values indicate higher densities, good health, and no air pollution. SAVI values lie within the range of – 1.0 to 1.0. Figure 9 illustrates the SAVI in arid regions, farming regions and bodies of vegetation.

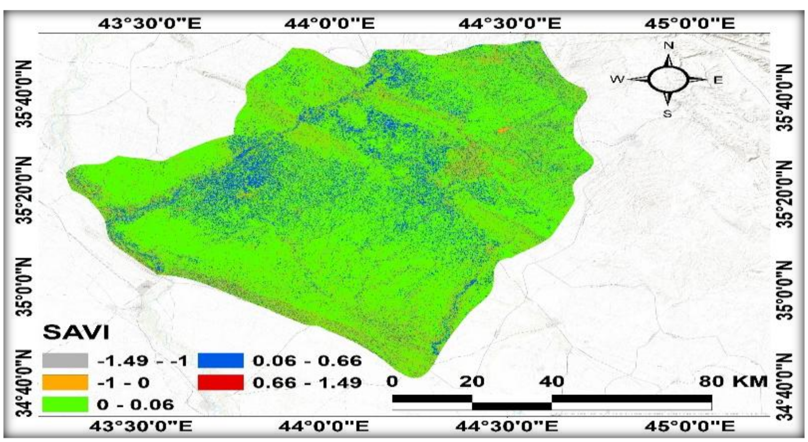

Figure 9. Soil-Adjusted vegetation index

Digital Elevation Model (DEM)

Digital elevation models (DEMs) are among the most important geographical resources used in GIS (Hamed, 2024). Topography refers to a set of digital data, either organised or not, that displays the height of the terrain, also known as point elevation. Topography, a prominent feature of the earth's surface, has a significant impact on the water balance of a watershed. Some of these factors include the routes that water takes as it flows downhill and around hills, the velocity of the water's movement, and the amount of surface and underground water that runs off. Every completely distributed and spatially explicit hydrological model uses the topography of the modelled area, as shown by a digital elevation model (DEM), to generate bathymetry. The use of a DEM allows for the acquisition of crucial data for the proper distribution of hydraulic and hydrological models (Balasubramanian, 2017). In Figure10, we can see the DEM that was employed for this research.

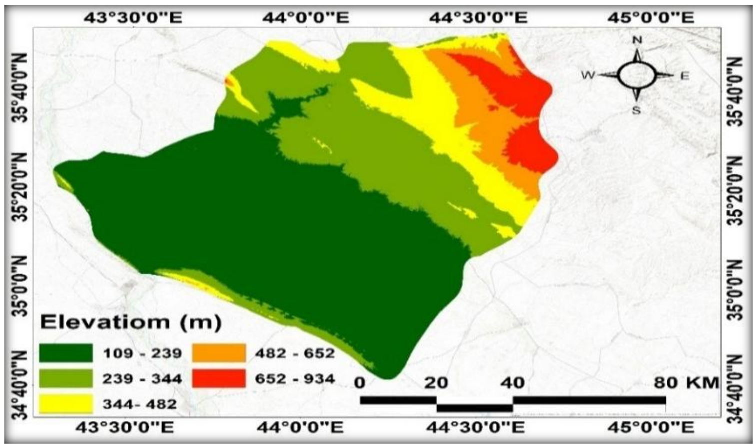

Figure 10. Digital elevation model for kirkuk city

Land Surface Temperature (LST)

The irregular placement of meteorological stations, difficulties in conducting field research, and the lack of effective interpolation methods for station data greatly limit the ability of researchers to monitor the most severe environments on a continuous basis. For those working in the biological and environmental sciences, the measurement of land surface temperature (LST) using remote sensing technologies is of great interest. LST influences the balance of radiant energy at the Earth's surface. For LST, land surface models monitor and forecast drought, estimate soil moisture content, and calculate evapotranspiration rates (Umbarkar et al., 2024). LST crucially determines the rate of transfer of sensible heat and long-wave radiation between the land and atmosphere. Furthermore, LST indicates the surface state of the environment and influences the changes in airborne pollutants, particularly the reduction of pollutants (see Figure 11).

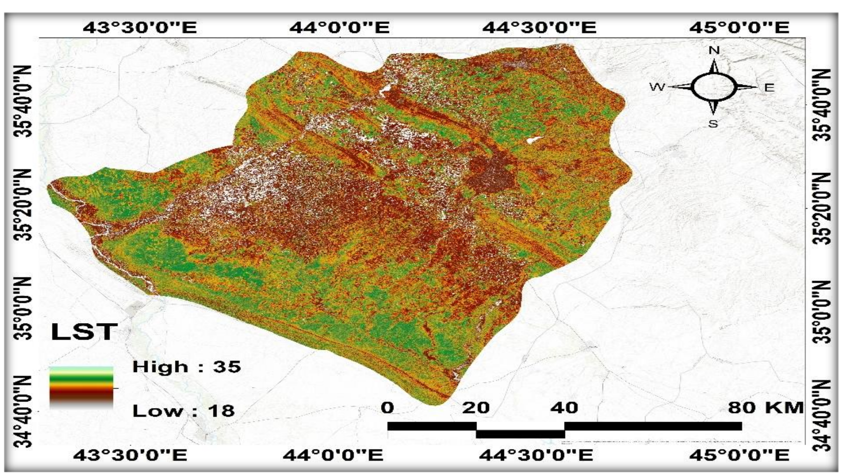

Figure 11. Land surface temperature

Land Use/Land Cover

Urban planning, informed decision-making, understanding population demands and distribution, and public health evaluation all rely on accurate statistics on land use and cover. Inventories frequently include both land use and land cover. An integral part of climate models, land cover describes habitats, natural resources, and terrestrial ecosystems. Just by looking at it, you can tell. One aspect of land use is the description of ecosystem function, which includes its social, economic, and cultural utility. It is essential to investigate the local economy and society. Figure 12 shows the results of applying the SVM classification algorithm to divide the world into five categories: urban, aquatic, arid, agricultural, and vegetation (Maheng et al., 2024).

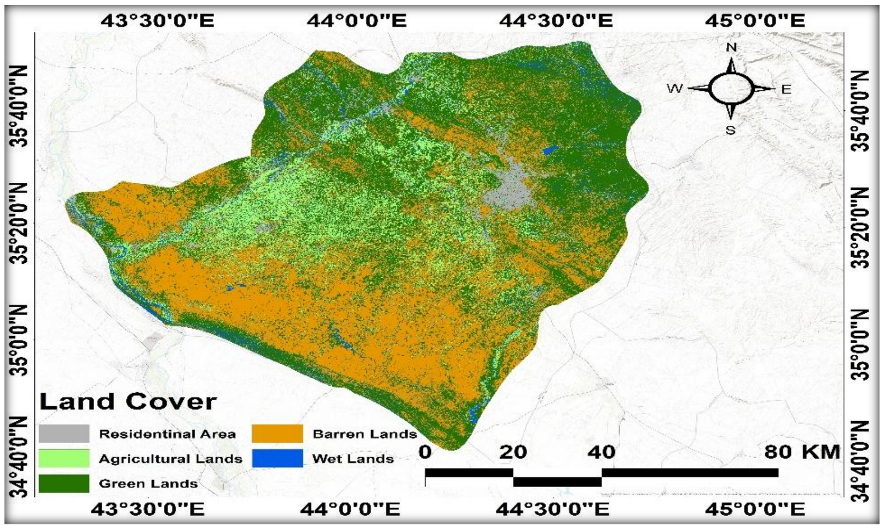

Figure 12. Land use/land cover

Slope Degree

A 12.5 cm resolution slope gradient map was created for this study. There were five categories established from the initial set of slope angle values, which varied from zero to fifty-five and eight degrees, according to the most prevalent subdivisions depicted in Figure thirteen are shown in Figure 13 (Wang et al., 2024).

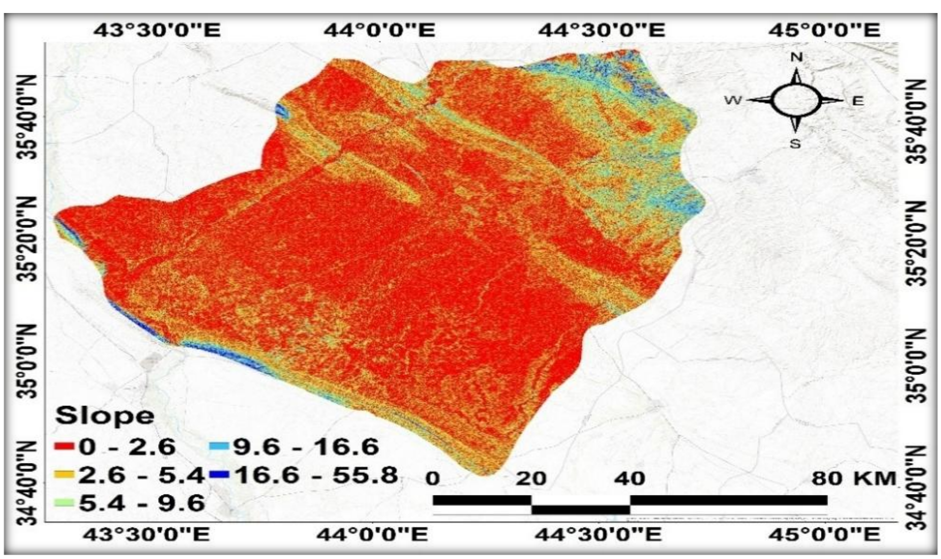

Figure 13. Slope degree

Slope Aspect

When making maps to find polluted places, the slope aspect is considered very important because it is physically related to things like the direction of discontinuities that influence pollution, wind effects, sunshine, and rainfall. The study region was divided into five groups, with each group representing a different slope direction. The slope direction was found to be between the west and the south, as shown in Figure 14 (El Mazi et al., 2025).

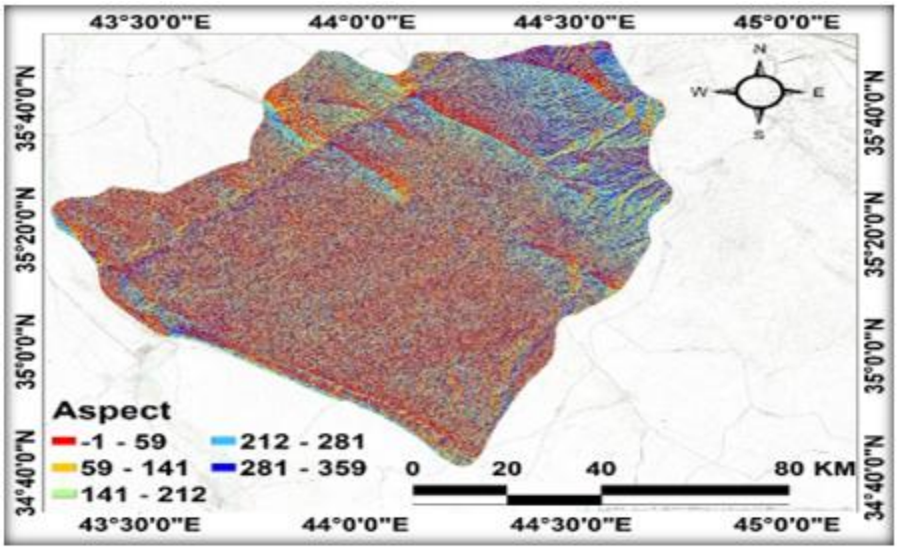

Figure 14. Slope aspect

Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is a structured framework for the decomposition and subsequent evaluation of complex choices grounded on the cross-disciplinary fields of psychology and mathematics. Since the process's conception in the 1970's by Thomas L. Saaty, the AHP methodology has been the subject of extensive research and enhancements. Expert Choice, estimably the first AHP software, was developed in 1983 by Saaty in collaboration with Ernest Forman. It is a precise approach for deriving the importance weights of the decision criteria. The subjective estimations of various experts are captured and structured for assessment through pairwise comparisons. Each expert is supplied a purpose-built form for assessing the importance of each pair of factors and how they compare. The AHP enables experts and decision-makers to establish the importance of a set of criteria by completing a series of pairwise comparisons of the criteria, and, if applicable, the sub-criteria, determining the best decision alternative in the process (Moslem, 2024).

Air Pollution Susceptibility Index Map

An air pollution map was created by transferring the computed hierarchical analyses of the discovered causal variables to the GIS and then combining all of the factors (Noori & Abdulmajeed, 2025). Following the arrangement of the index criteria in decreasing order for all cells in the study region, the categorised cell's value was then separated into 100 groups with a total interval of 1%. Hence, eleven distinct air pollution conditions were used to ascertain the spatial connection between landslip and conditioning variables (Table 1). By superimposing and computing the air pollution frequency, the frequency ratio (FR) model generated the final air pollution evaluation map for Kirkuk city. Figure 15 displays the resultant LSI map, which classifies the research region into five levels: safe, low, medium, high, and extremely high.

From the findings, it can be noted that 10% of the area is classified as very safe, with a prediction range of 1-10. This is followed by 25% of the area classified as having low susceptibility, with a prediction range of 11-36. The area of the study region classified as having a medium susceptibility prediction range of 36-60 constitutes 24%, and the range of 61-80 constitutes 20%. For the very high category, which is dangerous and a threat to human life, especially in the city of Kirkuk, is 19%. This corresponds to a prediction range of 81-100 and signifies the region is heavily polluted. Thus, the sample areas with score evaluations of 1-10 signifies the sample areas with the most pronounced air pollution. The air pollutant assessment for Kishuk Governorate was validated by LSI, which used a success rate curve, for which the index value for each pixel is displayed in Figure 16.

Verification showed that 65.416% of the pixels were correctly identified as landslip pixels. When the influencing factors are substantial, it is possible to identify, analyse, and forecast air pollution by evaluating the evaluation rate of the components that describe it the best. Additionally, as seen in Figure 16, the results show that the model's disturbance level scale has an area under the curve (AUC) of 0.6, a maximum prediction accuracy of 65.416%, and an accuracy area under the method of 31.276.

Table 1. Spatial relationship between each factor of air pollution conditioning through AHP and the certainty factor

SAVI	1	15600	19.64	597732	31.61353687	0.621485512	0.05476142
	2	26200	32.9974811	584801	30.92962728	1.066856733	0.09400475
	3	14000	17.6322418	449516	23.77451875	0.741644531	0.06534908
	4	5000	6.29722922	205589	10.87342728	0.579139315	0.05103014
	5	18600	23.4256927	53109	2.80888982	8.339840363	0.73485461
		79400	100	1890747	100	11.34896645	1
LAI	1	16400	17.7489177	341700	19.24260607	0.922375986	0.18649306
	2	13400	14.5021645	366516	20.64010245	0.702620762	0.14206126
	3	30800	33.3333333	390577	21.99508151	1.51549033	0.30641347
	4	15400	16.6666667	337656	19.01487092	0.876506958	0.17721891
	5	16400	17.7489177	339298	19.10733905	0.928905783	0.1878133
		92400	100	1775747	100	4.945899819	1
NDMI	1	5200	5.62770563	86069	6.589352334	0.854060512	0.09131986
	2	30200	32.6839827	579152	44.33926946	0.737133992	0.07881757
	3	26400	28.5714286	440709	33.74021864	0.846806266	0.0905442
	4	17400	18.8311688	165900	12.70112993	1.482637287	0.15853002
	5	13200	14.2857143	34353	2.630029636	5.431769319	0.58078836
		92400	100	1306183	100	9.352407377	1
NDVI	1	9000	9.95575221	92486	6.904568157	1.441908022	0.28262252
	2	10600	11.7256637	220529	16.46365408	0.712215141	0.13959839
	3	16400	18.1415929	345598	25.8007152	0.703143025	0.1378202
	4	40000	44.2477876	396948	29.63426379	1.493129302	0.2926622
	5	14400	15.9292035	283929	21.19679878	0.751491001	0.14729669
		90400	100	1339490	100	5.101886491	1
NDWI	1	9000	9.14634146	358521	18.22818212	0.501769261	0.00916024
	2	86800	88.2113821	1603449	81.52370542	1.082033522	0.01975348
	3		0	3005	0.152782368	0	0
	4	2600	2.64227642	977	0.049673336	53.19305406	0.97108628

	5		0	898	0.045656761	0	0
		98400	100	1966850	100	54.77685685	1
GEMI	1	26000	27.2536688	374428	19.6473089	1.387145125	0.27587705
	2	9000	9.43396226	365075	19.15653022	0.492467172	0.09794245
	3	16400	17.1907757	405064	21.25486751	0.808792418	0.16085359
	4	14200	14.884696	393417	20.64371609	0.721027937	0.14339888
	5	29800	31.2368973	367763	19.29757728	1.618695281	0.32192802
		95400	100	1905747	100	5.028127933	1
LST	1	26400	27.9069767	345901	17.6380573	1.582202409	0.31321138
	2	16400	17.3361522	353521	18.02661355	0.961697668	0.19037682
	3	25000	26.4270613	493466	25.16263782	1.050250037	0.20790657
	4	17000	17.9704017	374202	19.08117154	0.941787125	0.18643534
	5	9800	10.359408	394016	20.09151979	0.515610971	0.10206989
		94600	100	1961106	100	5.051548211	1
FVC	1	20800	24.0740741	7505	13.49941542	1.78334197	0.3941649
	2	59200	68.5185185	15974	28.73279971	2.384679502	0.52707611
	3	6400	7.40740741	11557	20.78784063	0.356333663	0.07875899
	4		0	10308	18.54123572	0	0
	5		0	10251	18.43870852	0	0
		86400	100	55595	100	4.524355135	1
Elevation	1	38400	44.4444444	371419	20.06470726	2.215055713	0.44399442
	2	19200	22.2222222	372888	20.14406522	1.103164727	0.22112265
	3	28800	33.3333333	369326	19.95163972	1.670706458	0.33488293
	4		0	369096	19.93921472	0	0
	5		0	368377	19.90037307	0	0
		86400	100	1851106	100	4.988926898	1
SLOPE	1	11200	12.962963	189785	10.2525193	1.26436855	0.25770305
	2	12800	14.8148148	353254	19.08340203	0.776319379	0.15822908
	3	4800	5.55555556	147080	7.945520138	0.699206025	0.14251187
	4	36800	42.5925926	771682	41.68761811	1.021708472	0.20824418
	5	20800	24.0740741	389305	21.03094042	1.144697935	0.23331183
		86400	100	1851106	100	4.906300361	1
ASPECT	1	8000	9.25925926	368015	19.8808172	0.465738363	0.09892753
	2	4800	5.55555556	135276	7.307847309	0.760217793	0.16147793
	3	4800	5.55555556	100729	5.441557642	1.0209495	0.21685998
	4	32000	37.037037	728201	39.33869805	0.941491175	0.19998223
	5	36800	42.5925926	518885	28.0310798	1.519477412	0.32275234
		86400	100	1851106	100	4.707874244	1
land use	1	3200	3.703703704	81069	6.327667476	0.585318953	0.070109617
	2	35200	40.74074074	589152	45.9849998	0.88595718	0.106120122
	3	22400	25.92592593	400709	31.27648431	0.828927116	0.09928905
	4	14400	16.66666667	175900	13.72949844	1.213931211	0.145404915
	5	11200	12.96296296	34353	2.681349971	4.834491246	0.579076295
		86400	100	1281183	100	8.348625706	1

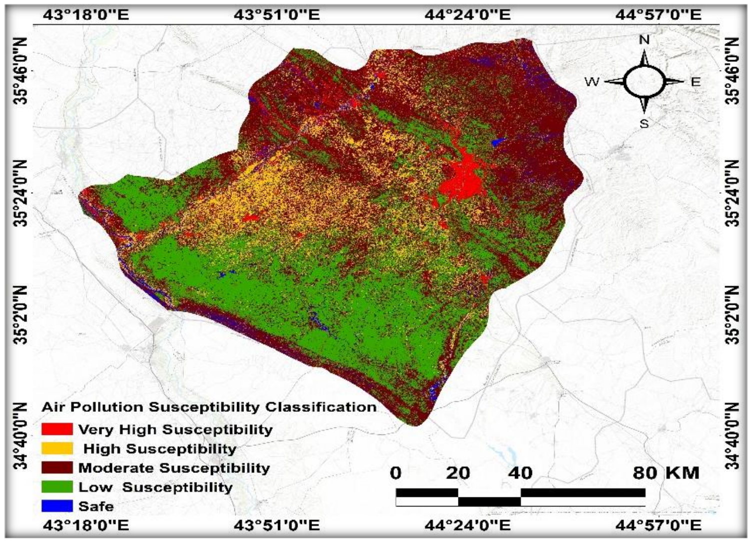

Figure 15. Air pollution susceptibility map using analytic hierarchy process (AHP)

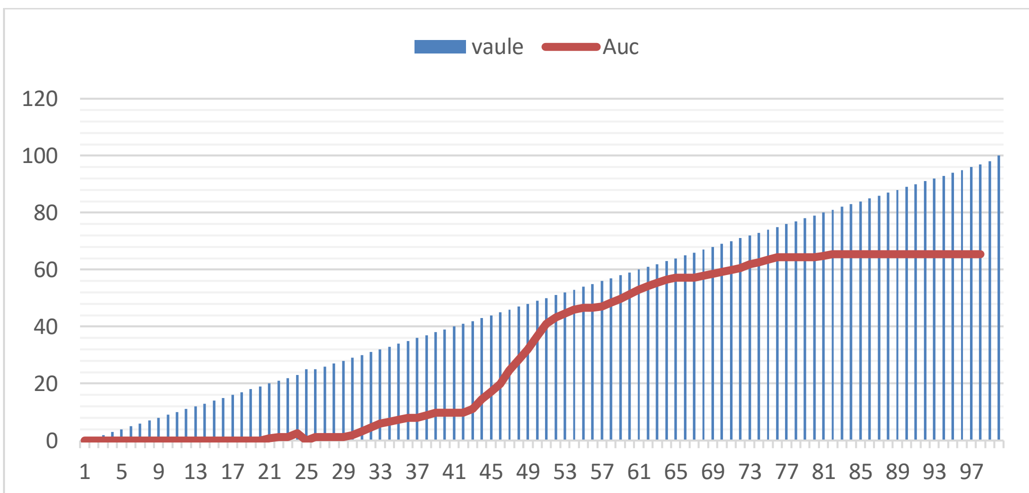

Figure 16. Prediction rate curve plot evaluation of the analytic hierarchy process model

Conclusions

The Analytic Hierarchy Process (AHP) was used in conjunction with geographic information systems (GIS) and remote sensing in this study to evaluate a number of environmental and anthropogenic indicators in order to determine the risk of air pollution in Kirkuk Governorate. According to the results, the most important factors that determine a region's vulnerability to pollution are its population density, the amount of industrial activity, the emissions from vehicles, and the patterns of land use. An invaluable foundation for environmental monitoring and decision-making, the resultant spatial map accurately delineates high-, moderate-, and low-risk zones. This study adds to the environmental pollution literature by describing the patterns of pollution and showing the use of GIS and remote sensing technologies for assessing the environment at huge scales. The use of these technologies together with multi-criteria analysis improves pollution mapping and enables targeted pollution management. Sustainable land management and disaster mitigation can be achieved with the use of the AHP-GIS framework that was established here. Planners can use it to design pollution buffers, regulate industrial zones, and prioritise greenbelt development. Potential future uses include optimizing land use and reducing emissions through its incorporation into urban planning and policymaking. The model also provides a scalable, evidence-based strategy for tracking and reducing pollution hazards, which is in line with worldwide objectives for managing air quality and contributes to the United Nations' Sustainable Development Agenda (SDG 11 and SDG 13).

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Author Contributions

Mohammed Moayad Abdul Karim: Writing – original draft, Visualization, Validation, Methodology, Investigation.

Muntadher Aidi Shareef: Formal analysis, Data curation, Conceptualization. Supervision.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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