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Urban Growth Influence on Green Spaces Using NDVI And NDBI Analysis: Erbil City District as a Case Study

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Abstract

Urban development is the result of population migration to the city. Therefore, sustainable development guidelines and strategic city planning are crucial for city expansion to avoid air pollution, PM value, and improve public health. Exploring the influence of rapid urbanization on Erbil city's green area. This study explores the effects of PM and air pollution reduction on public health. Physical changes in the city can be directed from 2000 to 2024 across the entire year, including all seasons, by using GIS (Geographic Information System) techniques. The city growth assessment using NDVI and NDBI index was provided with a statistical analysis. The result shows that both indices are not growing in harmony, resulting in multiple threads, including fragmented green spaces, street canyon impact on ventilation, urban island heat, and the vegetation condition as diseased plants, all of which increase air pollution and PM, causing public health. The results suggest that the government should include a green wedge in Erbil's master plan to create connectivity between green spaces and improve airflow. The evidence suggests that the amount, connectivity, and seasonal characteristics of green areas are crucial factors in shaping urban structure. These green space elements are likely to decrease air pollution, resulting in a significant improvement in public health. It concludes with the key techniques for developing tangible, practical solutions for the successful deployment of the green wedge.

Keywords: urbanization, air pollution, green wedge, sustainable city, public health.

1 Introduction

One of the recent issues is urbanization [1]. The procedure of urbanization is the moving of people from the countryside to urban areas, and the increasingly crowded relationships between the many population segments that support the city's growth [2,3]. The need for infrastructure grew, and internal organization and service quality have become critical components of a city's efficiency. Every resident wants a well-organized city structure since it makes necessary services easily accessible and aims to prevent detrimental effects on the environment [4]. Municipal planning and management become more challenging as a consequence of urbanization [5]. While this inclination promotes economic progress and creativity, it also presents a number of obstacles, such as the growth of concrete structures, diminished green cover, and higher pollution levels, impacting public health as well as the environment [2,6]. The community and local economy are at risk due to issues facing modern civilization, such as the absorption of forestry and agricultural land and the rise in transportation demands that impede the adequate service of current inhabitants [7].

Public health issues have also arisen as a result of the increase in pollution and sedentary lifestyles in metropolitan areas, underscoring the connection between environmental health and the health of individuals [2,8]. Recognizing the importance of urban green areas is crucial as the globe struggles with issues like climate change, biodiversity loss, and public health emergencies [2,9]. Policymakers find it difficult to understand the coherence and complexity of newly emerging social processes since developing a city management concept involves establishing a cohesive development vision and involving a variety of organizations [10,11]. The primary cause of urbanization is air pollution, which has recently led to an increase in fatalities [12]. It is estimated that up to 10 million unnecessary deaths occur worldwide as a result of particulate matter having a diameter of less than 2.5 µm, or PM2.5 [13,14]. Furthermore, almost 70% of people worldwide have health problems as a result of air pollution brought on by anthropogenic emissions, as a result of humanity's behaviour [14]. There are several ways to minimize air pollution, such as sustainable agricultural methods, less dependence on gasoline-powered cars, better energy production, and effective industrial exhaust stacks (United Nations Environment Programme,2021). An alternative set of strategies includes removing or cleaning up air pollution after it has been discharged, using both active and passive techniques [15]. Along with outdoor air pollution, a passive reduction method that uses vegetation is the method that is most commonly employed globally [16]. The contaminants (gaseous pollutants of various kinds) were over the national and international regulatory standards in numerous regions of Iraq [17]. The difficult political situation in Iraq, the history of Erbil due to multiple conflicts of wars, and the increasing volume of traffic and polluting businesses as a result of city expansion may all be factors in the buildup of different organic and inorganic pollutants in the urban environment of the city. The outcomes demonstrated that the high concentrations of Cu, Pb, Zn, Hg, and PAH contamination in street dust, particularly in the city's industrial and activity areas, posed serious ecological and health risks in the Erbil area [18].

The air pollution challenges spread globally. The capital of Iraq's Kurdistan region is Erbil. Numerous studies have explored how air pollution is causing health risks for its residents. According to the UN System of Environmental Economics, vegetation is the primary intervention that should be used to enhance human health and lessen air pollution. However, green spaces suffered as a result of Erbil's quick growth. According to the study's hypothesis, the arrangement of green areas and building spaces within urban structures could improve public health and reduce air pollution. This study aims to illustrate the development of urbanization and its long-term effect on green spaces over the period from 2000 to 2024. This will be achieved through the application of recent GIS tools combined with statistical analysis. The main objective of this research is to quantitatively evaluate the direct correlation and spatial relationship between vegetation cover loss, the extent of urbanization (land-use change), and the resultant vegetation state (health/condition).In conclusion, this research suggests pathways for streamlining urban planning protocols to ensure the consistent, complication-free integration of relevant technology into future development plans.

2 Literature Review

Growth in cities has become a permanent global phenomenon; most of the people on the planet now live in cities. As urban areas expand, the significance of incorporating green spaces into city planning is crucial for both human health and the ecosystem [2]. Their research offers a brief overview of an international assessment that examines the complex effects of urban green areas on ecological balance, sustainability, and well-being. Advantages of green areas in the city include improving air quality, as filtration systems, for example, trees serve as natural air purifiers by lowering airborne particles and pollutants via the process of photosynthesis, which lessens the negative impacts of urban pollution on our natural surroundings. Additionally, controlling the temperature by lowering surface temperatures and offering shade helps fight the urban heat island phenomenon. It also impacts urban dwellers' physical and emotional health. The spaces include many activities that contribute to stress reduction, strengthen social cohesion, and improve the mental and physical well-being of people. Furthermore, Jaung et al [19] claimed that urban green spaces help decrease air pollution and urban heat islands, which worsen climate change. Additional research indicates that green corridors improve human health by lowering air pollution, which is a major factor in lowering "urban heat islands," or urban regions that are noticeably hotter than the rural areas around them [20–23]. Therefore, urban green spaces are crucial for preserving biodiversity, improving air quality, controlling temperature, and fostering general well-being. Understanding the numerous advantages of these approaches is essential for directing global efforts toward sustainable urban design.

It is widespread in political and scientific discourse that vegetation enhances air quality. Nevertheless, modelling and experimental research indicate that the role of green space on urban air pollution varies greatly and depends on the situation (context). A study by Venter et al [24]in the context of Europe and the United States re-examined the connection between vegetation and air quality by utilizing satellite-derived changes in urban green space and air pollutants. They found that the overall impact of green space quantity on air pollution was negligible, especially at the street level (15 to 60 m radius), where vegetation may obstruct airflow. They added that even urban greening improves the quality of the air; conversely, at the city level, it has a moderately positive impact on air quality. However, it may have detrimental effects at street-level based on aerodynamic components such as urban design (shape) and kinds of vegetation. According to some research, fragmented green spaces significantly contribute to rising air pollution and detrimental effects on public health [20,25,26]. This is due to the fact that trees emit volatile organic compounds (VOCs), which have the ability to react with other substances in the atmosphere to produce secondary air pollutants [19,20,25,27–29] or by collecting air pollutants in canyons of streets [30], can hurt people by putting allergens into the air [31]. Especially evident in fragmented green spaces between buildings that can impede airflow, as well as in the street canyon effect, where tree canopies can obstruct air exchange and raise air pollution [16]. Additionally, the roadside vegetation has the potential to either improve or worsen the local air quality [16,25,32].

The UN System of Environmental Economics considered international standards and other policy frameworks that recommend vegetation as the main intervention for decreasing air pollution and public health [30]. According to other research, public health professionals generally believe that urban vegetation, such as green spaces or green infrastructure, could improve air quality [25], urban planning [33], and ecosystem service [34]. Furthermore, green space, besides reducing air pollution, also improves human health through two mechanisms: first, the absence of main contaminants in green areas. The second mechanism has to do with air pollutants' direct deposition, dispersion, and absorption through green areas. The deposition first step in which the surfaces of vegetation absorb air contaminants. While dispersion is the process by which the aerodynamic effect of vegetation structures dilutes the amount of air pollutants. The plant structure (e.g., height, leaf density), site context (e.g., street canyon shape, distance to emission source), and current weather (e.g., wind speed and direction) all have an impact on dispersion effects that are an order of scale larger than deposition. On the other side, the levels of local air pollution are additionally increased by the processes of dispersion effects [24,25]. For exampleStreet canyons with a dense tree canopy may have less airflow, while open-road conditions with porous vegetation obstructions may have higher air pollution levels beside the road. However, there is currently conflicting information about this process in urban contexts, possibly as a result of the fact that its effects largely rely on how green areas are integrated into the city's structure (urban fabric). On the one hand, it has been demonstrated that vegetation may reduce particle matter by depositing it on plant surfaces and gaseous pollutants by absorbing them through leaf stomata (Figure 1). The majority of the data suggests a beneficial correlation between green space, air quality, and both physical and mental health, considering these possible negotiations. Cardinali et al. [20] explain that the relationship between green space, air pollution, and public health depends on two main parameters: first, the characteristics of green spaces, and second, their proximity to residents' homes. The outcome showed the indirect health risk of air pollution, and the findings lend evidence to the idea that the green space connection appears to be a crucial feature for reducing air pollution through the deposition, dispersion, and absorption of air pollutants.

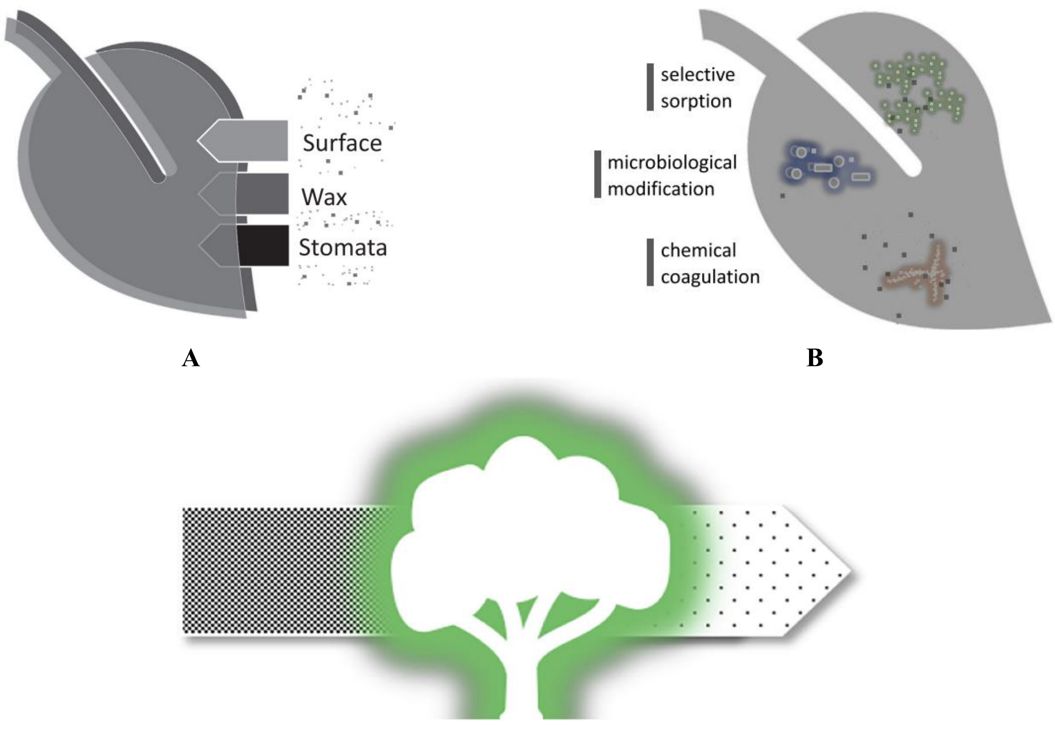


Figure 1: Diener and Mudu [25] present a symbolic illustration of

A. PM absorption mechanism at the scale of a leaf.

B. The three primary categories of processes for change.

C. of the filter effect and dispersion mechanism of a green space

Modification, dispersion, and deposition are the three approaches to PM mitigation in green areas studied by Diener and Mudu [25]. Deposition—more especially, PM quantity and settling velocity measurements on leaves of plants — is the most studied process. They combine the ways that various green space layouts differ in their ability to lower maximum emissions by scale and environment, Sources of pollution that are mobile (line) or stationary (point), and the elements of PM that have the greatest potential for harm. The reduction of airborne PM concentrations by green spaces is significant, multi-mechanistic, and dependent on scale, context, and vegetation types (Figure 2).

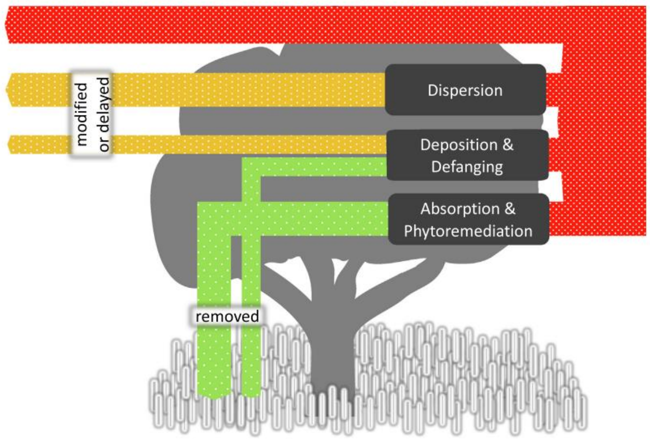


Figure 2: The rationale behind reducing PM exposure through green space interventions (green/light arrows = net removal, yellow/medium arrows = delayed or modified PM exposure, red/ dense arrows = no effect on PM) [25].

It costs more to keep green spaces in urban areas. People are increasingly drawn to greener locations. The majority of urban green areas are not constructed in accordance with sustainable principles that preserve open spaces, a range of building styles, and resident services.[10] A review of the literature shows how to enhance the welfare of people living in public green areas and areas where disputes between communities may arise by the application of the GIS (Geographic Information System) tool, thus changes in spaces can be directed. The development of green wedges was found to be correlated with a high green plot ratio. They discover how to apply GIS, create an urban greening plan, adjust the urban greenery to the estate structure, and create methods to get rid of inadequate city planning design management. Hence, carefully tending to a green wedge is necessary to guarantee that society maintains its unique landscapes and heritage through enduring vegetation.

GIS has emerged as a crucial instrument for assessing the connection between air quality, green spaces, and urban growth. As Venter et al. [24] in their study normalized difference vegetation index (NDVI) and visual interpretation of extremely high-resolution aerial pictures at a subset of air quality stations are employed as data measurement procedures. They use "linear mixed-effects models" to assess how green areas and the quality of air are related. In a study by Bhave et al. [35] examining the vegetation cover of the Wardha district by utilizing NDVI, they concluded that the potential of NDVI to differentiate between the different types of land covers present in a particular area was demonstrated. Also can be used to determine the type of classes within a range, such as Forest land, Barren land/Settlements, Shrubs/Agricultural land, and water bodies. When determining the kind of land cover in a given area, NDVI data can be utilized as predictors. Furthermore, Elnazir et al. [36]provide an example of a strategy for maintaining urban expansion. Using two distinct TM photos taken on various dates, the case study focuses on Shaoxing City, which is clearly observing an urbanization development. The NDVI equation was used to generate a vegetation index, and the photos were then texturized to provide a Normalized Difference Textural Index for 1984 and 2000. The ratio of modifications in the final image was indicated by this index. The technique is proven to be effective in highlighting the places where the two consecutive photos differ. The findings showed a significant shift in the amount of vegetation in and around, and the vegetation cover within and surrounding the City's grounds had changed significantly.

The study by Cardinali et al. [20] highlighted a few other gaps, such as the fact that, as of 2020, only 60% of studies found an intermediary impact of air pollution on indicators of physical and mental health. Additionally, the widespread application of land-use regression (LUR) models for calculating local air pollution could end up in biased results because these models actually include green space. We may conclude that the air pollution on human health is strongly correlated with urbanization and green space. Thus, GIS tools can be used for data measurement and accurate city planning, and for alternative concepts. Since the study explored that type of vegetation, green wedge, street canyon, connectivity of green spaces, and proximity of green spaces, all should be designed in a way that prevents fragmented green space, not just can not help decrease air pollution, besides causes an increase in air pollution and PM ratio.

Consequently, the rise in air pollution as a result of urban growth caused a decrease in green spaces. Fragmented green space is one of the factors for air pollution, and dense vegetation obstructs ventilation; hence, some may sometimes cause more air pollution instead of filtered air. Erbil city is one of the cities where, in recent years, increased air pollution and caused health risks. The layout planning of green spaces with urban development differences in urbanicity. In addition to offering insights into the possible health advantages and alternative ideas for future expansion, this study will provide a thorough examination of the requirements for green areas in Erbil City to be able to reduce air pollution. In order to guide changes in city layout to prevent air pollution, the study intends to evaluate the indicators of urban expansion based on urban development, such as green space, vegetation kind and condition, and the connectivity of green areas. We hypothesize that the fragmented green spaces could be solved by street canyon connection to the green wedge in Erbil city, and the GIS tool could be used as the main tool for analyzing and improving the idea of city expansion and public health. In order to address the global epidemic of diseases associated with air pollution, the research tries to add to the existing reservoir of knowledge and offer practical information for promoting health by design for cities that enhance the layout of green areas for better air quality.

3 Methodology

3. 1 Case Study:

Erbil city has been selected as a case study; it is the fourth largest city in Iraq, located in the Kurdistan region, as the capital of the region. Geographically located between (latitudes 35˚ 30' and 37˚ 15 N and longitudes 43˚ 22' and 45˚ 05' E) [37]. The Erbil district, with the urban and rural population, is 1,043,712' [38]. The population increased rapidly with the migration of foreign people to the district, as a result of the war led to a growth in residential blocks and infrastructure needs. Since 2003, the Erbil district has expanded rapidly in both fields of urban areas and economic growth, which has caused climate change and air pollution to increase gradually. The Erbil district developed radically, which affected the surrounding rural area's agricultural land and green space. The land use is composed of residential areas, industrial districts, commercial spaces, green and open spaces, and agricultural land. On the other side, industrial development caused air pollution and a decrease in green spaces. The average temperature ranges between 6.2°C in winter is rainy and freezing (December, January, February), and 42.70°C in summer is warm and dry (June, July, August).

3.2 Materials and Methods

The study extracted several dates of seasons (summer, spring, fall, and winter) using satellite photos of Landsat data 7 and 8, which were obtained from the United States Geological Survey (USGS) for periods such as 2000, 2013, and 2024 (Table 1).

Table 1: The Landsat dataset utilized for the case study's analysis

Landsat	Year	Month	Season	Spatial Resolution	True Color Composition
7 (ETM+)	2000	4	Spring	10m	Band 1,2,3,4,5,6,7
		7	Summer	10m	Band 1,2,3,4,5,6,7
		10	Fall	10m	Band 1,2,3,4,5,6,7
		12	Winter	10m	Band 1,2,3,4,5,6,7
8 (OLI/TIRS)	2013	4	Spring	10m	Band 1,2,3,4,5,6,7
		7	Summer	10m	Band 1,2,3,4,5,6,7
		10	Fall	10m	Band 1,2,3,4,5,6,7
		12	Winter	10m	Band 1,2,3,4,5,6,7
8 (OLI/TIRS)	2024	4	Spring	10m	Band 1,2,3,4,5,6,7
		7	Summer	10m	Band 1,2,3,4,5,6,7
		10	Fall	10m	Band 1,2,3,4,5,6,7
		12	Winter	10m	Band 1,2,3,4,5,6,7

The land use application cloud coverage percentage for urban growth estimation ought to be under five percent [39]. The natural color of a combination of bands 1.2.3 was used to detect changes in land utilization cover over the course of time [40]. Additionally, GIS tools and statistical analysis (mean, standard deviation, minimum, maximum, and correlation between NDVI vs. NDBI) were employed for analysis. The Landsat bands were utilized to assess the "normalized difference vegetation index" (NDVI), which measures the health of the vegetation, and vegetation cover, and the "normalized difference built-up index" (NDBI) used to detect built-up areas.

3. 2. 1 Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is an important tool for determining vegetation health in Geographic Information Systems (GIS). The NDVI techniques, which use the Landsat's red and near-infrared light to determine the vegetation index, were promoted by NASA scientists. The NDVI value is a number between (-1) and (1); a greater number denotes a dense or deep state of vegetation, while a lower number denotes no vegetation, which is represented by the color green. The following Equation 1 is used to calculate it [41]. Based on the band designations for Landsat 8 and Landsat 7, the NDVI equation is specifically rewritten by substituting the corresponding band numbers for the NIR and Red reflectance values (ρ) [42,43]. Using the proper band combination is critical for accurately calculating the NDVI for your investigation.

$NDVI = (NIR-RED)/(NIR+RED)$ (1)

The average of all wavelengths in the red visible (λ~0.6µm) and near-infrared (IR) ranges (λ~0.8 µm). The NDVI is a well-known method for calculating the quantity of vegetation. Whenever the NDVI value is greater, the amount of vegetation in a selected area is overwhelming [40,44]. It can also be used to display vegetation conditions (Figure 3).

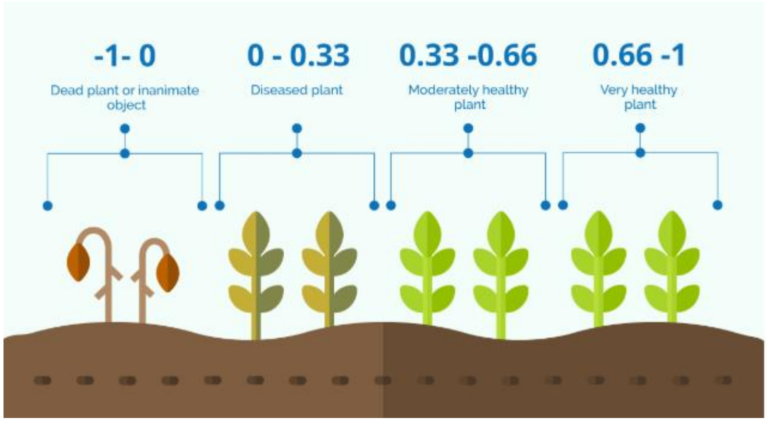


Figure 3: illustrates the value of the vegetation condition ranging from (-1) to (1)

3. 2. 2 Normalized difference built-up index (NDBI)

Zha, Y., et al advocate calculating (NDBI) by using Landsat's short-wave infrared (SWIR) and near-infrared (NIR) imagery to measure the built-up area [45]. As shown in Equation 2 [40]. A value higher than zero indicates a significant amount of built-up area, while a value that is negative indicates the pixel zone is in a non-built-up covering region. The NDBI value ranges from (-1) to (1). The NDBI is displayed in red colour.

$NDBI = (SWIR-NIR)/(SWIR+NIR)$ (2)

3. 2. 3 The Statistical Analysis

The statistical analysis means, standard deviations, minimum, and maximum rates for both NDVI and NDBI throughout the whole year for four seasons were calculated [16,36]. Then it is used to compare the three-year means of the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI) is a standard technique in remote sensing for urban change detection. This comparison is necessary since NDVI and NDBI are basically inverse indicators: NDVI measures vegetation greenness and health, whereas NDBI measures the presence of built-up, impermeable surfaces. The comparison focuses on how the mean values and standard deviation of these indices evolve over a three-year period, which usually reflects the direction and rate of urban sprawl or green space change and condition. The last, maximum, and minimum indicate the highest and lowest pixel values in the zone. The maximum shows the best condition, for instance, dentest and best condition of vegetation for NDVI, and the most urbanized pixel for NDBI. The minimum illustrates the worst condition, for example worst condition of vegetation, bare soil, or the least built-up area.

4. Results

Erbil City is a radial concentric city structure plan with a circular land use pattern, where the street extends outward from the centre of the city. The combined Landsat over time presents the real colour of city expansion over time. (Figure 4) shows the variations in urbanization over time through a GIS study of satellite pictures. The change had happened to the city structure is circular with radical extension of the street, as a result of city development, which causes fragmented green spaces with a low ratio and an increase in land use. The image in 2000, illustrates a large agricultural land area outside of the city that has healthy vegetation, but with the urbanization phenomena if compared to the image of 2013, and 2024, it is clear that urban development caused a decrease in green spaces, increase in land use and "urban heat island" on the other side increase in both air pollution and PM. The comparison of all images over time illustrated that Erbil city undergoes obvious transformations towards urbanization growth. By the expansion of the city due to population growth, the farming area around the city has become a land-use area. While urban green spaces are often regarded as fragmented green spaces in the city, they are actually the main cause of air pollution rather than a contributing component to its reduction.

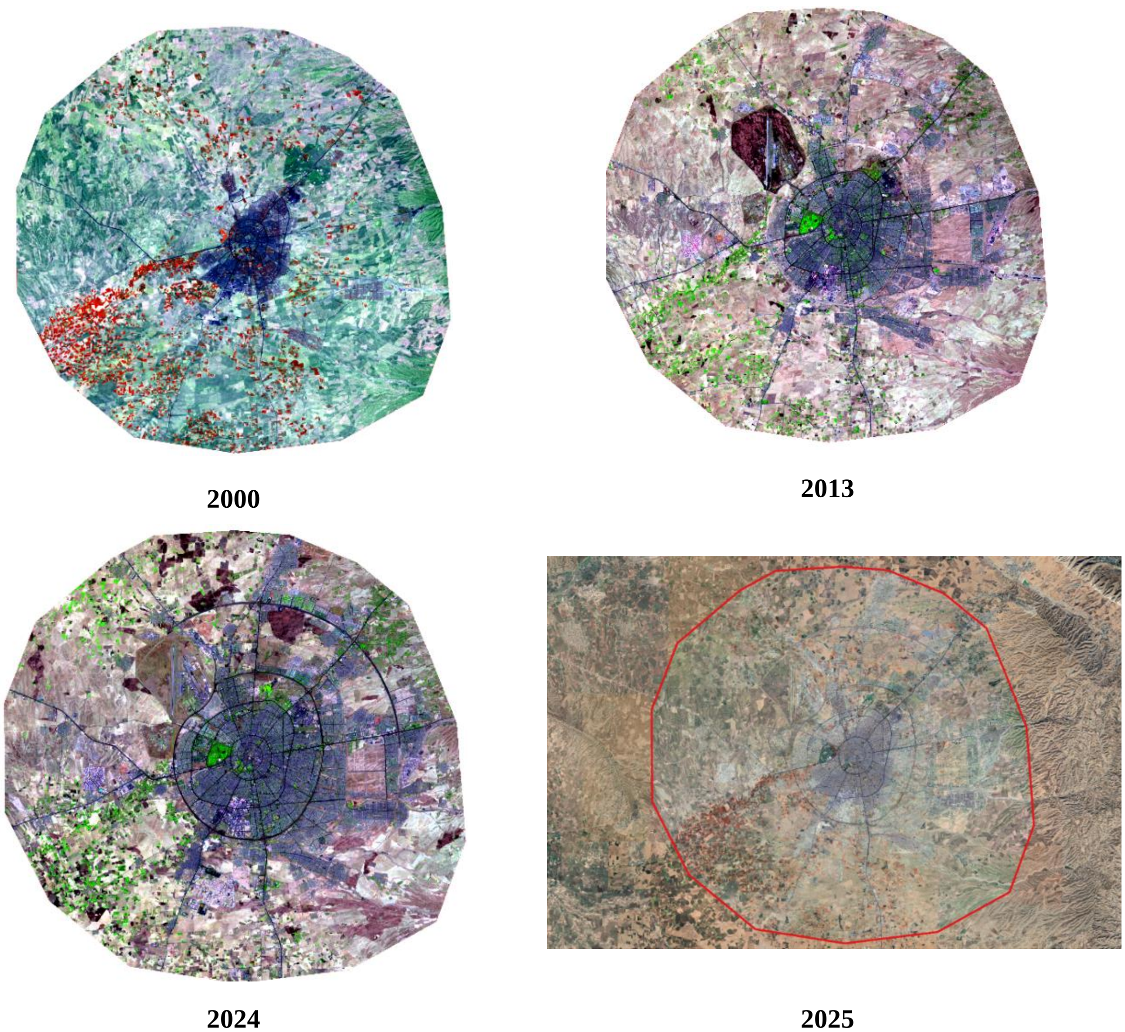
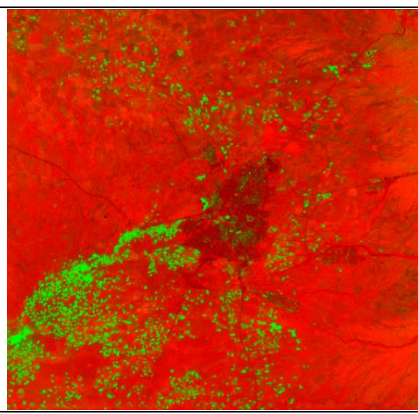


Figure 4: The urban expansion of Erbil city over time from 2000 to 2025

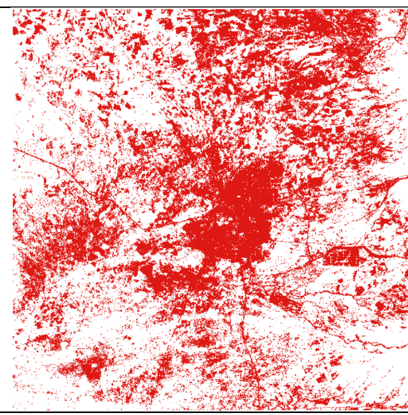
Figure 5, illustrates the calculation of both NDVI and NDBI over time. On the left are both layers of NDVI and NDBI combined to illustrate the change of urbanization and vegetation cover, besides vegetation condition, and compare them. On the right is the NDBI, which displays the building index only, and thus can help urban designers and planners develop the master plan of Erbil city. There are two main colours in this calculation: dark red indicates built-up area (NDBI) and light green indicates healthy dense vegetation (NDVI). Light green is considered healthy vegetation; the colour other than near green to brown is considered a dead plant or diseased plant. The colour brownorange to light green is considered a fertile soil and plant condition, as color-based vegetation classifications in relation to the value in (Figure 3).

Three different approaches to computing a combined Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) were compared in the investigation. The seasonal index values were averaged over the four observation periods to create the annual statistics for each approach. A summarized annual statistic that is intended to clearly show the annual change in the land cover categorization is produced by this approach. The comparison between the vegetation index and the building index through the whole year of 2000 outcomes displays that there is healthier vegetation and less land use; when the building index is extracted from NDVI, it shows the colour of the urban area and soil appears mixed, this is because of the spectral similarities in the band which is used for the calculation of NDBI. Conversely, when compared to the year 2013, the vegetation decreased and the urban area increased. It can be seen that the green area inside the city is still a less fragmented space; besides, it's clear that the dead plants and diseased plants start to grow. On the right, the NDBI image illustrates rapid expansion over ten years; the city expanded radically with a circular pattern of streets. In 2024, the expansion of the city continued, but green spaces inside the city did not grow in harmony with urbanization growth. Another important thing is that the expansion without considering the continuity of green spaces is one reason that causes air pollution. One significant finding is that, in addition to urbanization, the number of dead and diseased plants and fertile soil has significantly decreased between the years 2000, 2013, and 2024 (Figure 5).

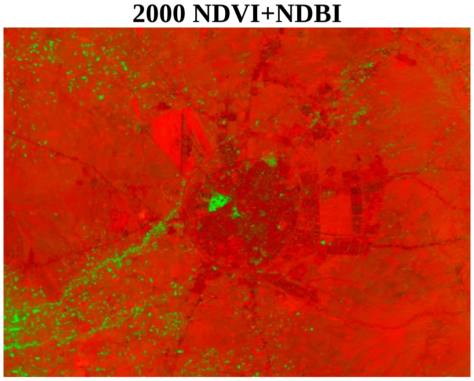
Overall, the expansion between NDVI and NDBI is not harmonious, and the NDBI is more than NDVI, besides the dead and diseased plants increased in recent years. To reduce air pollution and improve urban ventilation, the problem of fragmented green spaces must be addressed through careful planning. This finding supports the research premise that incorporating and creating green spaces within built-up urban areas efficiently reduces air pollution and enhances public health. Moving forward, urban designers and planners should not only focus on the spatial design of green areas but also carefully consider the type and characteristics of vegetation in accordance with UN sustainability standards to maximize benefits in air quality and public well-being.



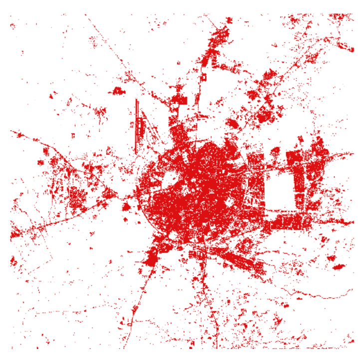
2000 NDVI+NDBI



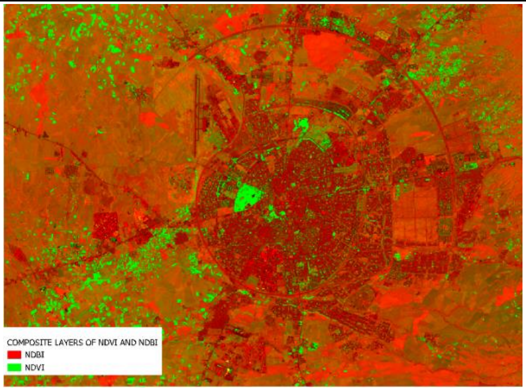
2000 NDBI



2013 NDVI+NDBI

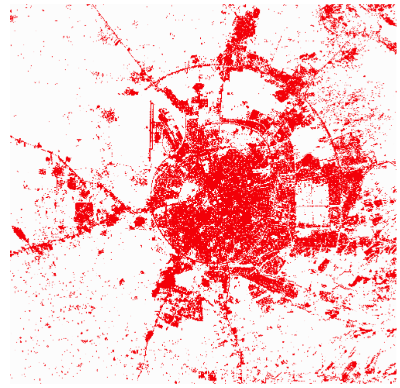


2013 NDBI



2024 NDVI+NDBI

COMPOSITE LAYERS OF NDVI AND NDBI
NDBI
NDVI



2024 NDBI

Figure 5: Calculation of NDVI and NDBI over a series of time for four seasons of Erbil city

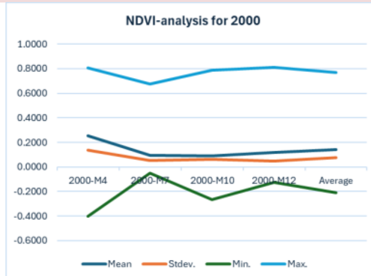
Table 2, illustrates the statistical analysis for conditions of both vegetation and urbanized areas. The urban area with a high mean NDBI and low standard deviation, suggesting a strongly built-up and consistent area. On the other hand, the lower NDBI and higher standard deviation show a mix of vegetation and sparse buildings. The results indicate that in 2000, shows a mix of vegetation and sparse buildings, than other years, 2013 and 2024. The mean values suggest a transitional or mixed urban fringe area rather than a dense, uniform urban core or a dense forest. The standard deviation indicates the spatial uniformity or heterogeneity of land covers.

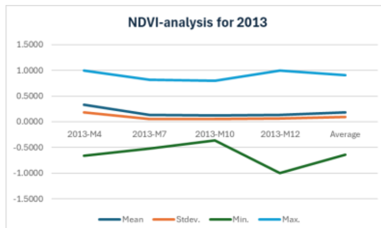
The finding for 2024, NDVI has a low positive value for NDVI. It indicates the presence of sparse to moderate vegetation, such as grasses, shrubs, scattered trees, or a mix of crops. The observed vegetation health levels do not correspond to those of a dense, healthy forest, which normally has a mean NDVI value of more than 0.6. Furthermore, (Figure 3) shows that NDVI levels ranging from 0 to 0.33 are associated with diseased or highly stressed plant life. As compared to the average mean (NDVI 2000 Av.mean '0.1395') and (NDVI 2013 Av.mean '0.1787'). This finding needs increased focus and strategic planning during the city's current master planning and implementation phases. The average NDBI Mean (-0.0090) for 2024, the value is very close to zero and slightly negative. NDBI values near zero typically indicate bare soil or mixed/transitional surfaces. The slight negative value suggests that, on average, the area reflects slightly more Near-Infrared (NIR) light (like vegetation) than Short-Wave Infrared (SWIR) light (like built-up areas), but the value is too close to zero to be considered truly vegetated. The standard deviation indicates the spatial uniformity or heterogeneity (mix of land covers) within the area. As compared to (NDBI 2000 Av. mean '0.0595'), (NDBI 2013 Av. mean '0.0233'). In 2024, NDVI Stv. is (0.1198). The value is moderately high compared to the mean. It suggests a moderate variation in vegetation health or density. It is relatively dense vegetation mixed with areas of sparse vegetation or bare ground. As compared to (NDVI 2000 Stv. '0.0749') and (NDVI 2013 Stv. '0.0905'). In addition to NDBI, Stv. is (0.0908). The value is also moderately high relative to the mean. It suggests that while the average NDBI is near zero, there are pixels with high NDBI (built-up) and pixels with negative NDBI (vegetation) mixed together. The relatively high standard deviations for both indices confirm that the area is spatially heterogeneous (mixed). It is a patchwork of different surfaces, which is highly characteristic of a low-to-medium density urban area, such as residential neighborhoods with gardens, roads, and parks interspersed with buildings. As compared to (NDBI 2000 Stv. '0.0583') and (NDBI 2013 Stv. '0.0665')

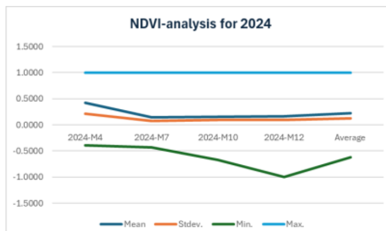
The seasonal comparison of NDVI over three years indicated that there is a loss of vegetation and greenness beside diseased plants in Erbil city over the years an average range between (0.1395-0.2220). The slight change in standard deviation indicates the urban pressure on the vegetation condition. The seasonal comparison shows that the NDVI-measured general health of the vegetation significantly improves in the spring. The mean NDVI for the spring month (M4) has steadily increased over time (2000: 0.2548, 2013: 0.3323, 2024: 0.4216). The statistical significance of this data reveals that the NDVI improved during the spring compared to the average mean and standard deviation values for the entire year. This phenomenon is brought on by the start of the growth season as well as major shifts in the climate and physiology of plants. Furthermore, spring, the fourth month, will be greener than other seasons because of the bushes, grasslands, and farmland. This indicates that the dense green area is less in Erbil city.

Table 2: Comparison between statistical analysis of NDVI vs. NDBI.

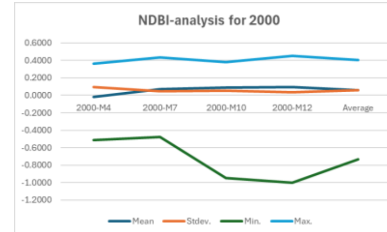
NDVI Statistical Analysis	Mean	Stdev.	Min.	Max.
2000-M4	0.2548	0.1350	-0.4023	0.8051
2000-M7	0.0950	0.0537	-0.0521	0.6762
2000-M10	0.0909	0.0619	-0.2658	0.7861
2000-M12	0.1175	0.0490	-0.1267	0.8113
Average	**0.1395**	**0.0749**	**-0.2117**	**0.7697**
2013-M4	0.3323	0.1864	-0.6620	1.0
2013-M7	0.1301	0.0523	-0.5180	0.8152
2013-M10	0.1182	0.0561	-0.3668	0.8007
2013-M12	0.1341	0.0673	-1.0	1.0
Average	**0.1787**	**0.0905**	**-0.6367**	**0.9040**
2024-M4	0.4216	0.2126	-0.3928	1.0
2024-M7	0.1474	0.0740	-0.4321	1.0
2024-M10	0.1536	0.0975	-0.6655	1.0
2024-M12	0.1653	0.0952	-1.0000	1.0
Average	**0.2220**	**0.1198**	**-0.6226**	**1.0**

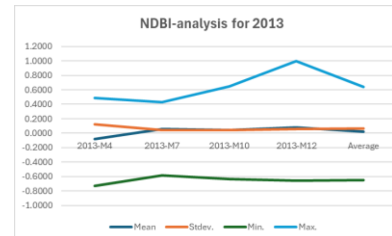






NDBI Statistical Analysis	**Mean**	**Stdev.**	**Min.**	**Max.**
2000-M4	-0.0183	0.0968	-0.5114	0.3605
2000-M7	0.0729	0.0455	-0.4769	0.4343
2000-M10	0.0903	0.0528	-0.9499	0.3786
2000-M12	0.0933	0.0380	-1.0000	0.4502
Average	**0.0595**	**0.0583**	**-0.7345**	**0.4059**
2013-M4	-0.0822	0.1255	-0.7286	0.4858
2013-M7	0.0557	0.0409	-0.5796	0.4305
2013-M10	0.0406	0.0451	-0.6315	0.6506
2013-M12	0.0791	0.0543	-0.6561	1.0
Average	**0.0233**	**0.0665**	**-0.6490**	**0.6417**
2024-M4	-0.1708	0.1529	-0.6803	0.4488
2024-M7	0.0463	0.0554	-0.6876	0.4770
2024-M10	0.0493	0.0813	-0.7199	0.6460
2024-M12	0.0394	0.0738	-0.7068	1.0
Average	**-0.0090**	**0.0908**	**-0.6986**	**0.6429**





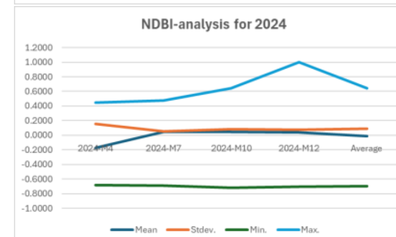


Table 3, shows the correlation between NDVI and NDBI. The result is an increase with a negative correlation, which indicates that by increasing the built-up area, the vegetation decreased. The correlation between NDVI and NDBI, in 2000, is (-0.9613); in 2013 is (-0.9601), and in 2024 is (-0.9994), respectively. The main reasons are that with growth in population and urban development, the population lifestyle and people's demand has changed over time from houses with a large garden, to small houses or apartment, for example, 100m2 houses without a garden or an apartment, because they are employed, they can not take care of the garden, and the cost of living has increased. Another reason the city changed to an industrial city was increased consumption with population growth; all of these create negative conditions for the city and public health. The data validate the hypothesis that the spatial pattern of urban development and green infrastructure directly influences environmental stressors and public health. This includes the layout's effect on air quality and its influence on overall community health.

Table 3 Correlation between NDVI and NDBI

	Mean-NDVI	Mean-NDBI	Correlation (NDVI vs. NDBI)
2000-M4	0.2548	-0.0183	
2000-M7	0.0950	0.0729	-0.9613
2000-M10	0.0909	0.0903	
2000-M12	0.1175	0.0933	
Average	0.1395	0.0595	
2013-M4	0.3323	-0.0822	
2013-M7	0.1301	0.0557	-0.9601
2013-M10	0.1182	0.0406	
2013-M12	0.1341	0.0791	
Average	0.1787	0.0233	
2024-M4	0.4216	-0.1708	
2024-M7	0.1474	0.0463	-0.9994
2024-M10	0.1536	0.0493	
2024-M12	0.1653	0.0394	
Average	0.2220	-0.0090	

5. Discussion

The visual interpretation was carried out on the outcomes combination layer of NDVI and NDBI, with the NDBI to illustrate the structural growth of Erbil city. Also, [24] in their studies show the importance of visual interpretation in solving the issue of NDVI. Furthermore, the real colour of the image outcomes as results from a combination of bands of the whole year. Several studies have proposed ways to use the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Building Index (NDBI) to identify shifts in urban expansion. It helps to understand the rapid growth of the city and the condition of vegetation [10]. Besides, it is one best ways to control urban expansion and manage this complexity [5]. The analysis by GIS helps to be aware of the difficulties between urbanization and green spaces of the rural environment that arise from city expansion into formerly non-urbanized areas [10,46].

The correlation between NDVI and NDBI is a negative correlation, illustrating urban area development and a decrease in overall vegetation greenness and condition. One of the important points is that the distribution of green spaces and their continuity during city planning has not been taken into account; thus, the condition of Erbil city's green spaces could be considered as fragmented green spaces. Since there is no connectivity between spaces could cause more air pollution instead of decreasing it, which is parallel with outcomes of studies by [20,25,26]. Nowadays, the most crucial green belt model for green spaces has recently been questioned. Several alternative models have been developed, such as “the perennial urban meadow” [10,47] or “the wildflower” meadow [10,48].

The best way to address the issue of fragmented green spaces is a green wedge, which increases the connectivity between green spaces and provides good ventilation by selecting the most suitable vegetation. Most studies mentioned the importance of this model. This model could be easily applied to Erbil city since the structure of the city is a radial and circular pattern. Another issue that Erbil City will face in the future street canyon problem and become an industrial one, which will prevent ventilation and causing increased air pollution on the other side, causing public health, as supported by Amjadian, K. et al. [18]. According to the World Health Organization (WHO), air pollution can lead to major health issues such as neurological disorders, cardiovascular diseases, respiratory diseases, and metabolic disorders. Air pollution is the world's second leading cause of death, after high blood pressure [49,50]. Residents of Erbil are at risk for health problems due to the city's high levels of air pollution. The main pollutants are sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and fine particulate matter (PM2.5). These contaminants come from a variety of sources, including dust storms, industrial processes, and car emissions. Research has linked Erbil's rising asthma cases, especially among youngsters, as a result of air pollution [51]. Cardiovascular and respiratory problems as emphysema, heart disease, and bronchitis, can all be made worse by exposure to pollutants like PM2.5 and NO_2. [52]. In addition, environmental pollution has been connected to an increase in cancer cases in Erbil city. Based on academic research and the WHO, vegetation improves public health and lowers air pollution; therefore, creating green areas within city planning is essential.

A green wedge needs to be properly maintained in order to guarantee that society sustains its unique environmental and cultural values with resilient vegetation. "Green wedge" guides urban growth toward flexible, more integrated development, provides opportunity for development, ecological development, and increases connectivity and accessibility in the end, sustainable urban growth [10]. The study organizes its findings around three core problem areas. These include: green infrastructure concerns (such as urban heat islands, biodiversity, and water management); urban sprawl and density issues (like preventing uncontrolled expansion, zoning for mixed-use, and infrastructure efficiency); and finally, managing heterogeneity problems (including inconsistent aesthetic quality and targeting specific interventions). GIS has emerged as a crucial instrument for assessing the connection between air quality, green spaces, and urban development.

Figure 6, demonstrates a conceptualized model of how the green wedge concept applies to Erbil city. The goal is to create a city with flexible, sustainable urban expansion. Since Erbil city was at an early stage of growth, it was easy to adapt the conceptualized model; several strategies were illustrated to address the highlighted issue in the model and the shape of the master plan. One of the major points is the shape of green spaces in urban design at the city level. Effective urban planning must integrate strategies that boost NDVI and manage stormwater. This includes connecting existing green areas into a seamless infrastructure network to combat the urban heat island. It also requires establishing minimum tree canopy coverage for all new developments (e.g., 20–30%). Finally, mandating permeable surfaces in parking and driveways is critical to facilitating rainwater infiltration and controlling runoff. Effective management of urban sprawl relies on concentrating development within existing boundaries. This requires mandating infill development on already-serviced land to prevent expansion onto peripheral areas. Furthermore, adopting Form-Based Codes is key to promoting mixed-use, moderate-density construction, thereby optimizing the utility and efficiency of the existing low-density landscape. Due to the low-density nature of the area, major infrastructure upgrades (sewer, roads) should be staged to align with expected density increases, thus preventing costly overinvestment. To manage heterogeneity, establish design guidelines for suburban architecture and landscape to ensure new construction respects the existing green character. Use NDBI and NDVI index data to map built-up clusters and vegetation hotspots. Apply green roof/wall regulations in built-up clusters and enforce development protection in high-vegetation areas.

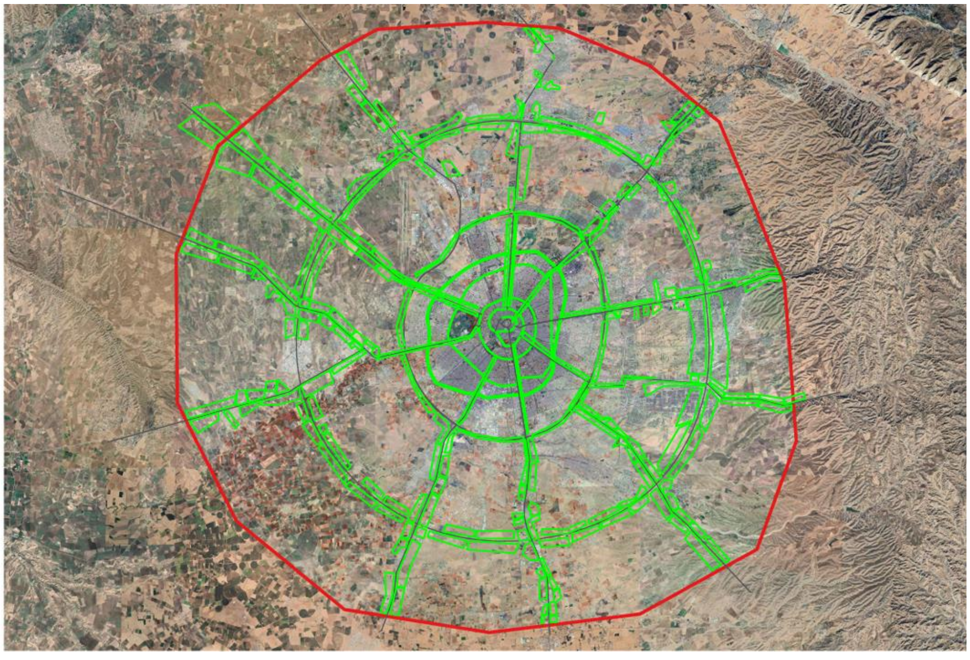


Figure 6: Conceptual green wedge notion application in Erbil city

Since the Erbil master plan is circular, its multiple strategies can be integrated to enhance their effect. For example, Green Wedge's primary goal is to bring greenery, fresh air, and sunlight into the heart of a city; to create accessible green areas for urban residents; and to connect with rural green spaces. The Form consists of linear strips of open ground extending from the countryside toward the city center. Its function is to divide built-up regions, ensuring that nature remains accessible even as cities grow, and to serve as key green infrastructure corridors. For accessibility purposes, designed to blend into the urban fabric and reach more inner-city populations. The model can be integrated into the green belt. The primary goals of green belts are to preserve agricultural land, wildlife habitats, ecosystems, and rural character, to stop unrestrained urban growth, and to act as a buffer zone. The Form is a huge, uninterrupted, undeveloped region that wraps around a city. Its purpose is to establish a permanent boundary between rural and urban areas. Accessibility is frequently found on the outskirts of cities, which may keep those living in inner cities more distant from expansive natural regions.

6 Conclusion

The rapid urbanisation in Erbil City resulted in an increase in air pollution, and the PM ratio caused a negative impact on public health locally and globally. This study explored the thread developed in Erbil city urban planning as a result of urbanisation. Erbil city dramatically expanded between 2000 and 2024, a change measured through GIS analysis. The study investigates how these changes transpired and their specific impact on green spaces over time. The outcomes are intended to support urban planners in managing the complexity of urbanization and mitigating associated threats to public health. The study categorizes urban challenges into three areas: green infrastructure (urban heat islands, biodiversity, etc.); sprawl and density (controlling expansion, mixed-use zoning); and heterogeneity management (inconsistent aesthetic quality and targeted design).

It is concluded that there is no harmonious growth between the vegetation index (NDVI) and building index (NDBI) in city structure and planning. The city expanded radically with a circular pattern. The ratio of land cover is much higher than vegetation cover, resulting in fragmented green spaces. The condition of the vegetation is not dense, and includes diseased plants. In contrast, in the spring season, vegetation increased since most is grassland, shrubs, and agriculture, which are green during spring. This indicates the city requires dense vegetation like trees for four seasons, and connectivity between them improves airflow and ventilation, which decreases the air pollution, improves public health, and. Another point, modern lifestyles have changed human behaviour to favor smaller, garden-less homes, such as 100m2 are becoming common. To prevent a resulting lack of green space, municipal planning must prioritize and integrate green space design specifically within the residential sector, beside public green spaces. Furthermore, the street canyon grows in the city, which will obstruct ventilation and increase the urban heat island. In addition to the rise in air pollution's impact on public health, it also affects the condition of vegetation, which the government should take into consideration. As explained, vegetation is the primary source for decreasing air pollution, urban heat island, and PM values. To overcome urbanization threats, the study proposes integrating a green wedge—a linear, densely vegetated green space that penetrates the city—into the Erbil city master plan. This provides natural and essential ventilation year-round. It can be easily integrated with other strategies as the green belt, to maximize impact.

The current study was limited to a macro-level urban design analysis of Erbil City, focusing on overall urban structure shape and general vegetation condition, rather than detailed micro-level design. Future research should address several gaps: vegetation control, investigate the type and characteristics of vegetation needed for seasonal control, particularly concerning the street canyon effect on the urban heat island phenomenon. Also, sector-specific green spaces conduct a more detailed analysis of green space types within both the residential and public sectors to inform targeted planning solutions.

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Author contribution

The sole author [Sweyda A.Azeez] contributed to all aspects of the manuscript. This includes Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Data Curation, Writing – Original Draft, and Writing – Review & Editing.

Conflicts of interest

The author declares no conflicts of interest.

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