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Climate crisis and spatial planning

Green infrastructure and supply of ecosystem services

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The cover image: The pedestrian route of Via Chiaia in the City of Naples by TeMA Editorial Staff

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Analysis of factors affecting urban land use changes (1993-2023): a case study of Urmia City, Iran

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Abstract
Urban land use changes are profoundly reshaping cities and often accelerating environmental degradation and unsustainable growth. In Urmia, a rapidly expanding mid-sized city in northwest Iran, these transformations have intensified over the past three decades without sufficient spatial or policy coordination. This study examines the dynamics and driving forces of land use change in Urmia from 1993 to 2023 using multi-temporal Landsat imagery and integrated analytical methods. Supervised classification in ENVI and ArcGIS was used to map land transformations, while the Fuzzy Delphi method and factor analysis identified the underlying social, economic, living standards, technological, political, and cultural drivers. The results reveal a 66 percent increase in urban areas, primarily at the expense of gardens, which declined by 56 percent, reflecting a pattern of unplanned sprawl and environmental decline. The findings indicate that rapid population growth, rising living standards, and technological advancement are the main forces driving urban expansion. This study provides an integrated spatial and analytical framework for understanding mid-sized city transformation and offers practical recommendations for managing urban sprawl and promoting sustainable land use in developing contexts.

Keywords
Land use planning; Change detection; ENVI; Urmia City; Iran

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1. Introduction

Urban growth and land-use change are just two of the many factors that will shape cities in the future (Alwedyan, 2022). The land is a unique and finite economic resource with diverse uses for various land uses that cannot be separated from the urbanization process (Borawski et al., 2019). As urban settlements expand, substantial changes occur in land use and ecosystems, notably the uncontrolled consumption of urban land and low-density urban sprawl. Urban sprawl, characterized by the irregular and unplanned expansion of urban areas into surrounding rural or undeveloped land, is often marked by low-density development, land-use segregation, and automobile dependence (Chettry, 2023; Dadashpoor & Shahhossein, 2024). This expansion leads to increased land consumption, environmental degradation (including loss of biodiversity and increased pollution), landscape fragmentation, and increased energy consumption and carbon emissions (Lu et al., 2019). These changes play a crucial role in addressing climate change, as urban growth and sprawl increase exposure to climate hazards and disasters.

The consequences of urban sprawl are multifaceted and often detrimental to both the environment and social fabric of communities. The consumption of agricultural land and natural habitats leads to significant environmental degradation. The dispersed nature of development in sprawling areas fosters automobile dependency, resulting in higher traffic congestion and air pollution. This dependency, coupled with a lack of efficient public transportation, can lead to a decline in public health and overall quality of life. In developing countries, particularly in rapidly urbanizing mid-sized cities, urban sprawl presents unique challenges. Haphazard growth patterns, driven by economic policies and inadequate land-use planning, can result in social inequalities and inadequate access to essential services (Chettry & Surawar, 2021; Dadashpoor & Shahhossein, 2024). Urban land-use planning examines how urban activities and functions are used, distributed, protected, organized, and spatially arranged based on the desires and needs of the urban community (Ziari, 2004). Analyzing the dynamics of urban growth and expansion, and the factors that influence it, provides a foundation for effective urban management and sustainable urban development (Ghorbani et al., 2014). The relationship between urban land-use changes and urban sprawl is characterized by the shifting of urban functions to urban fringe areas, leading to agricultural land conversion and subsequent urbanization (Giyarsih, 2017). This process is influenced by various factors, including groundwater availability, climate, terrain, employment patterns, transportation infrastructure, and uncertainties about metropolitan growth. The resulting socio-economic, cultural, and physical environment transformations vary across metropolitan areas (Burchfield et al., 2006). The world is witnessing a rapid urbanization process due to the remarkable growth of population, socio-economic development, and rapid urban expansion (Yuan et al., 2018). This rapid development strains infrastructure and services, leading to shortages, inequities, and the growth of slums and marginalized peri-urban areas. Land-use changes, including the conversion of forests and agricultural land into urban areas, are a significant factor in environmental degradation (Hersperger et al., 2018). Urbanization is a global phenomenon, with Asia being the fastest urbanizing region in the world (Bakker, 2022). Urbanization has led to changes in economic, social, and environmental aspects (Dolley at al., 2020). Urban land consumption is outpacing population growth, with substantial increases in urban area expected in the coming years (Biello, 2018; World Bank-Urban Development, 2023). Urmia, Iran, like many cities, has experienced significant expansion and land-use change due to population growth, rural-urban migration, and land speculation. This has resulted in uncontrolled physical growth, high-rise construction, and unplanned expansion, leading to challenges such as environmental pollution, traffic congestion, and infrastructure deficiencies. The lack of comprehensive data management hinders effective assessment and planning. Therefore, a comprehensive urban land-use plan is urgently needed to guide Urmia's expansion, identify the drivers of land-use change, and promote sustainable urban growth. This study aims to address the research gap by analyzing land-use changes in Urmia City over the past three decades. While the general phenomenon of urban sprawl and its drivers have been studied, there is a need for a detailed analysis focused on Urmia, a rapidly growing mid-sized city, using integrated spatial and analytical approaches. Despite extensive research on urban sprawl and land use dynamics in large metropolitan regions, mid-sized cities in developing countries remain underexplored, particularly in terms of long-term, integrated spatial analyses. Previous studies have often focused on short temporal periods or relied solely on either remote sensing or socio-economic data, without combining both to uncover underlying drivers. Partheepan et al. (2023) demonstrated the importance of integrating multi-temporal satellite imagery in analyzing land-use transformations in mid-sized cities, while Pultrone (2023) highlighted how external agents and governance structures shape urban expansion. In the case of Urmia, the absence of comprehensive studies that link multi-decadal satellite observations with expert-based analytical methods has limited understanding of the complex interactions between demographic, economic, and policy factors shaping urban growth. This research addresses this gap by integrating geospatial analysis with the Fuzzy Delphi method and factor analysis over a 30-year period to identify and quantify the key forces driving land use change. The study advances the existing literature by offering a holistic framework for analyzing urban transformation in mid-sized cities, where unplanned expansion often occurs without the governance structures seen in larger metropolitan areas. Specifically, this research seeks to:

- Analyze land use change patterns in Urmia City over past three decades using advanced geospatial techniques;
- Identify key socio-economic, political, and environmental factors driving these changes;
- Assess the ecological and urban planning implications of these transformations;
- Propose actionable recommendations for sustainable urban development and land management in Urmia City.

2. Study area

Urmia, the capital of West Azerbaijan province, is the tenth most populous city in Iran. Urmia is bordered by Lake Urmia to the east, and is surrounded by mountainous terrain (Fig.1).

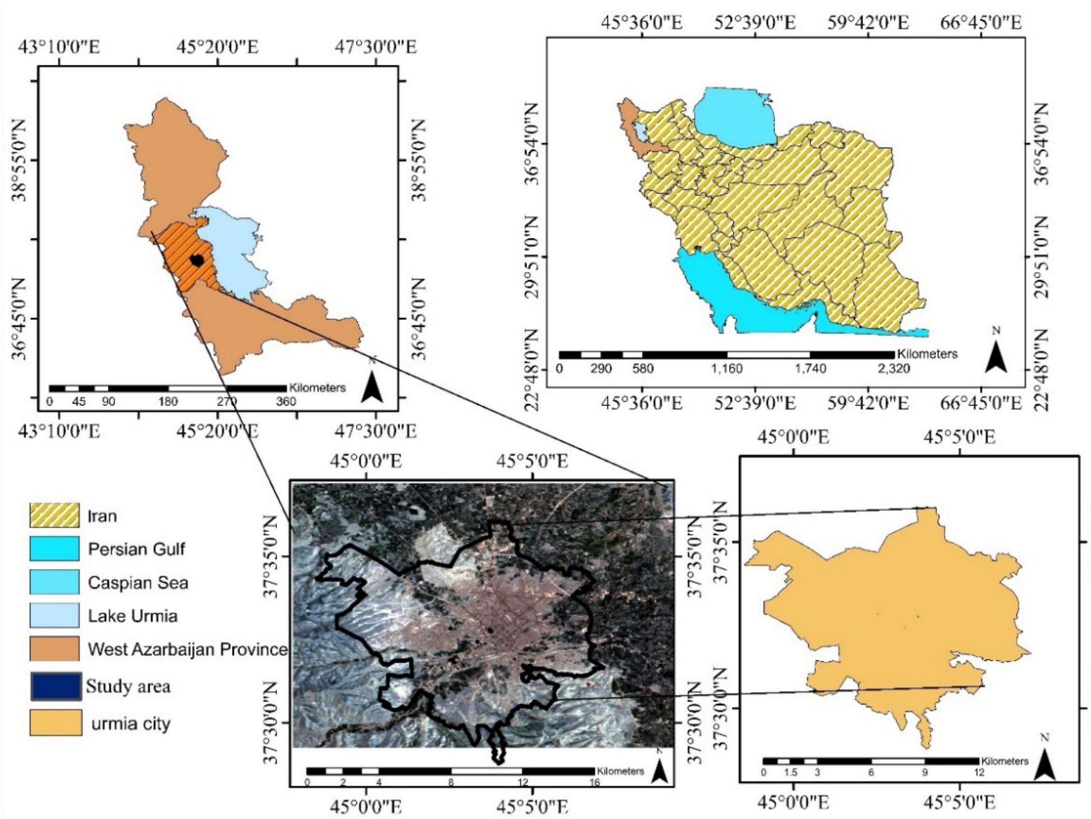

Fig.1 Study area of Urmia City, Iran

Urmia County[1] is one of the twelve counties in West Azerbaijan Province, situated in its central region. It is bordered by Salmas County to the north, Naghadeh and Maku counties to the south, Lake Urmia to the east, and the Iran-Turkey border to the west. With an area exceeding 5,251 square kilometers, the county encompasses approximately 14% of the province's total area.

From a national administrative perspective, Urmia County is divided into 5 districts, 20 rural districts, 5 cities, and 615 settlements. The city of Urmia itself is located approximately 18 kilometers away from Lake Urmia, positioned at 45 degrees and 4 minutes east longitude and 37 degrees and 33 minutes north latitude. It spans 70 kilometers in length and 30 kilometers in width within a plain.

3. Methodology

This study adopts a descriptive-analytical approach, employing an exploratory research design with both quantitative and qualitative methodologies. Data collection involves library research, document analysis, field studies, and the utilization of comprehensive urban plans, statistical centers, and municipal data from various sources such as the municipality of Urmia, the Environmental Protection Agency of West Azerbaijan, the Governorate of West Azerbaijan, the Department of Roads and Urban Planning, the Provincial Budget Planning Organization of West Azerbaijan, the Iranian Statistical Center, and satellite imagery. The research is structured into three main phases:

1) Examination and analysis of changes over the past three decades;
2) Analysis of spatial growth and urban development in both past and present contexts;
3) Analysis of factors influencing changes in land use.

In this research, Landsat and OLI satellite images from 1992 to 2023 are initially processed in ENVI software, incorporating various indices after geometric and atmospheric corrections. Land use patterns are then analyzed using Google Earth and ArcGIS software, enabling the identification and assessment of land use changes. Final land use maps are generated and the observed changes in the years 1992, 2003, 2013, and 2023 are compared and evaluated.

For the analysis of factors influencing land use, statistical data from the National Statistical Portal are utilized, along with the Fuzzy Delphi method and factor analysis techniques implemented in SPSS software. SPSS was used to compute eigenvalues, variance explained, factor loadings, and scree plots, facilitating the interpretation of how multiple observed indicators grouped into six meaningful dimensions. To identify the underlying drivers of land use change, expert input was collected using the Fuzzy Delphi Method (FDM). Sixty urban planning and geography experts participated by rating the importance of 60 pre-identified indicators related to social, economic, living standards, technological, political, and cultural factors. Their responses were processed using triangular fuzzy numbers to generate consensus scores. Indicators with low fuzzy consensus values were excluded from further analysis, allowing a refined set of 25 effective variables to be retained for statistical modeling. The reduced set of variables was analyzed using exploratory factor analysis (EFA) in SPSS to uncover the latent dimensions driving land use change.

To assess land use changes in the city of Urmia, satellite imagery (Landsat) from the past three decades (2023, 2013, 2003, and 1993) was obtained from the United States Geological Survey (USGS) website. Images were downloaded for all four periods within a consistent and specified area, ensuring minimal cloud cover, using data from three satellites: Landsat 8/9, Landsat 7, and Landsat 5, and relying on the Landsat Collection 2 – Level 1 dataset. The images underwent radiometric corrections, addressing atmospheric and sensor-related errors, to process the data effectively and determine the extent of changes (Tab.1).

For image classification across the four time periods, a supervised classification method was employed, with sample data selected for each class. In this study, four land use classes were defined for the years 2023 and

[1] Urmia County's strategic location along historical trade and invasion routes has made it vulnerable to repeated invasions and damage, but it has also fostered rich ethnic-cultural diversity and a valuable historical heritage.

2013: (1) Urban (man-made structures), (2) Gardens (forested areas), (3) Agricultural land (plowed), and (4) Barren land (mountains and other uncultivated areas). For the years 2003 and 1993, a fifth class, Water bodies, was included in addition to the aforementioned four classes (Fig.2).

Year	Date Acquired	Scene Center Time
1993	1993-06-24	07:01:04.1860940Z
2003	2003-05-11	07:27:20.7352759Z
2013	2013-06-15	07:40:34.9676120Z
2023	2023-06-27	07:38:09.6369179Z

Tab.1 The dates of images acquired for each year

After classifying the images and determining the number of classes, the selected samples were validated through a supervised classification process. The accuracy of the classifications was assessed by comparing satellite imagery with Google Earth data. Multiple classification algorithms were applied, including Maximum Likelihood, Minimum Distance, Neural Network, and Support Vector Machine (SVM) methods, to ensure robust and reliable results.

An initial list of 60 indicators related to demographic, economic, technological, political, and cultural drivers of land-use change was developed through an extensive review of international and Iranian literature on urban growth, land-use dynamics, and spatial development. These indicators were also cross-referenced with sustainability frameworks and previous studies focusing on land transformation in developing urban contexts. The intention behind starting with a broad set of indicators was to ensure that all potentially relevant dimensions were included before applying expert-driven refinement.

Using the Fuzzy Delphi Method, these indicators were evaluated by experts to determine their relevance and importance for explaining land-use changes in Urmia. In this process, each expert provided linguistic assessments that were converted into triangular fuzzy numbers. The fuzzy consensus threshold was set at 0.7, meaning that indicators with a fuzzy consensus value below 0.7 were excluded from further analysis. Application of this threshold reduced the initial list of 60 indicators to 25 variables that met the minimum agreement level among experts.

Experts were selected through purposive sampling to ensure that participants possessed strong and directly relevant knowledge of land-use dynamics in Iranian cities. The panel consisted of 60 experts with academic or professional backgrounds in urban planning, urban geography, environmental planning, GIS, remote sensing, or land-use management. To ensure high-quality judgments, only individuals with a minimum of ten years of experience were invited, and preference was given to those with direct familiarity with Urmia or comparable mid-sized cities in Iran. The panel deliberately included experts from a diverse range of institutions, including universities, municipal planning departments, environmental organizations, and provincial development agencies, in order to capture multiple perspectives on land-use change. The final number of 60 experts was chosen to enhance the reliability of the Fuzzy Delphi process, exceeding the standard minimum requirements for Delphi studies and ensuring a robust and balanced consensus.

Following the refinement of indicators through FDM, Exploratory Factor Analysis (EFA) was applied to the 25 retained variables to identify the latent dimensions influencing land use change. Before extraction, sampling adequacy was assessed using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett’s Test of Sphericity. Factors were extracted based on eigenvalues greater than 1, and variables with factor loadings below 0.5 were removed to ensure meaningful correlations within each factor. An oblique rotation (Promax) was used because the underlying dimensions (e.g., population growth, economic conditions, political structure) were expected to be correlated rather than independent. This procedure resulted in six interpretable factors, which together explained more than 71 percent of the total variance.

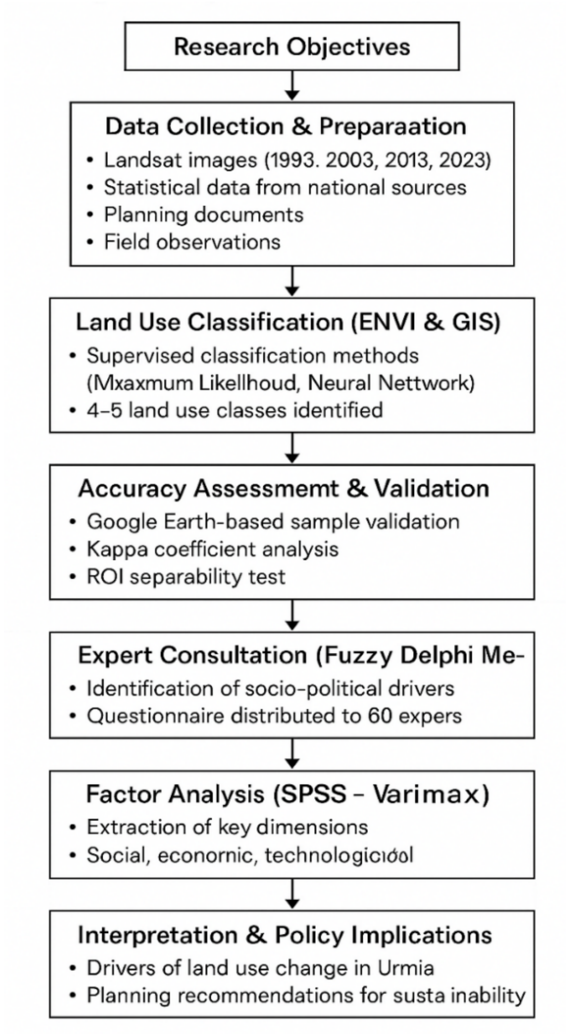

Fig.2 Research methodology Sequence

4. Results

4.1 Classification

To determine land uses in the years 2023 and 2013, four land use classes were used: Urban (man-made), Gardens (forest), Agricultural lands (plowed) and Barren lands (mountains, etc.) Additionally, for the years 2003 and 1993, five classes were utilized, including the aforementioned four classes plus a class for water bodies. For the classification of images in the four time periods, a supervised classification method was employed. For each class, 70 samples were used, totaling 280 samples for the 2023 and 2013 maps and 350 samples for the 2003 and 1993 images.

4.2 Class separability

The accuracy of separating the selected classes depends on the accuracy, number, and size of the samples. To compare classes and selected samples, the Compute ROI separability command is used, which yields results in a table or matrix around the number 2. If the values are closer to 2, it indicates a higher possibility of separating classes from each other with greater ease. However, as the distance from the number 2 increases, the homogeneity of the area decreases, making it harder to discern phenomena or classes, and the likelihood of errors increases.

The fundamental point in producing land use maps lies in the precision of determining the training samples (first sample) and, importantly, the validation sample (essentially based on a thorough understanding of the region through either physical survey or software such as Google Earth). Furthermore, increasing the number of selected pixels for each category in each sample will enhance the accuracy of the generated raster map. This is reflected in the ROI Separability report, where in this study, the minimum separability value is 1.94150149 for the barren lands with agriculture in 1993, 1.995442302 for gardens with agriculture in 2003, 1.98556922 for agricultural lands with barren lands in 2013, and 1.99945853 for gardens with urban lands in 2023.

4.3 Validation using Kappa Coefficient

The Kappa coefficient measures accuracy inversely to the overall accuracy based on all pixels that are correctly and incorrectly classified. In the current paper, Kappa coefficients above 79% along with appropriate accuracy of classified images will yield acceptable results. Following the classification, classes are supervised and necessary sampling is done using Google Earth software, which requires precise knowledge of the study area. Sampling for each image is done separately; for each class in ENVI, 70 samples are taken, and for images of 2023 and 2013 in Google Earth Pro, 50 samples per class are taken, totaling 200 samples for each image. For images of 2003 and 1993, considering they have five classes, 250 samples are selected, totaling 900 samples for all four images and all classes. Specifically, 400 samples are for images of 2013 and 2023, and 500 samples are for images of 1993 and 2003 in Google Earth. In total, approximately 1260 selected samples are drawn. The results, including the concordance of these samples in terms of error percentage and Kappa coefficient for each year using the introduced methods, are presented in the Tab.2.

	Classification method	overall accuracy	Number of errors	kappa
1993	**Maximum likelihood**	85.42%	164.192	0.8114
2003	Maximum likelihood	75.3676	205.272	0.6782
2013	Neural network	90.243	259.287	0.869
2023	Neural network	92.029	254.276	0.8932

Tab.2 Results of error matrix, Kappa coefficient and the classification method for each year

Based on the Kappa coefficients obtained, the best classification method for the year 1993 (Tab.2) is the Maximum Likelihood method, with a Kappa value of 0.81 and an accuracy of 85%. Out of 192 selected samples, 164 samples were accurately classified while 28 samples were misclassified. Among these, 56 samples were urban areas, 47 samples were agricultural land use, 31 samples were barren land, 45 samples were gardens, and 13 samples were water bodies. The highest error occurs between the barren land and agricultural land use classes, while the lowest error is observed in the urban land use class, with an accuracy of 93%.

For the land use classification of the year 2003, 272 samples were selected. The Maximum Likelihood method exhibits the least error, with a Kappa coefficient of 0.67 and an accuracy of 75% (Tab.2). Out of these samples, 205 samples were consistent with the Google Earth imagery. Specifically, 64 samples were urban areas, 86 samples were agricultural land, 40 samples were barren land, 73 samples were gardens, and 9 samples were water bodies. Gardens achieved the highest accuracy at 99%, followed by agricultural land at 79%, urban areas at 78%, barren land and water bodies at 48% and 42% accuracy respectively. However, in terms of error, it's notable that barren land and water bodies exhibit relatively higher inaccuracies, which could potentially result in significant inaccuracies in area estimation.

Considering the classifications conducted using the four methods, the neural network emerges as the best approach with an accuracy of 90.24% for the image of the year 2013 (Tab.2). The error rate for the four classes is 10%, which is acceptable, resulting in a Kappa coefficient of 0.8625. This coefficient is deemed acceptable for validation and matching the selected classes with reality. According to the Kappa coefficient table, out of the 28 errors observed, 7 errors occurred between urban areas and agricultural land, barren land, and gardens; 8 errors occurred from agricultural land to urban areas, barren land, and gardens; 9 errors occurred from barren land to agricultural land and gardens, and 4 errors occurred from gardens to both barren land and agricultural land classes. Urban areas had a 91% accuracy rate, agricultural land had an 89% accuracy rate, barren land had an 88% accuracy rate, and gardens had a 95% accuracy rate. Among the employed methods, the neural network appears to be the most suitable approach for the image of the year 2023, achieving the highest possible accuracy (Tab.2) Out of the 276 selected samples, 254 were correctly classified, while 22 samples contributed to errors across all classes. The overall measurement accuracy for this image was 92%, with a corresponding Kappa coefficient of 0.89.

In this image, urban areas had a 90% correct selection rate, agricultural land had a 64% correct selection rate, barren land had an 88% correct selection rate, and gardens had a 97% completely correct selection rate. The distribution of errors in terms of percentages is as follows: the highest error rate, at 2.63%, occurred between agricultural land and urban areas and gardens. Barren land had a 12% error rate with agricultural land, gardens had a 3% error rate with agricultural land, and urban areas had the highest error rate of 8% with barren land.

Based on the satellite image of the year 1993, the areas of the five land use classes - urban, agricultural, water, barren, and gardens - with pixels measuring 30*30 meters, are respectively 4,630.63, 6,448.03, 227.26, 5,210.61, and 10,252.15 hectares out of a total area of 26,768.7 hectares. These areas cover the specified region, with gardens covering the largest area at 38.3% and water covering the smallest area at 0.85%, which is linear and only represents the Silvana River. Agricultural land, barren land, and urban areas represent 17.30%, 19.47%, and 24.1% of the total land, respectively (Fig.3).

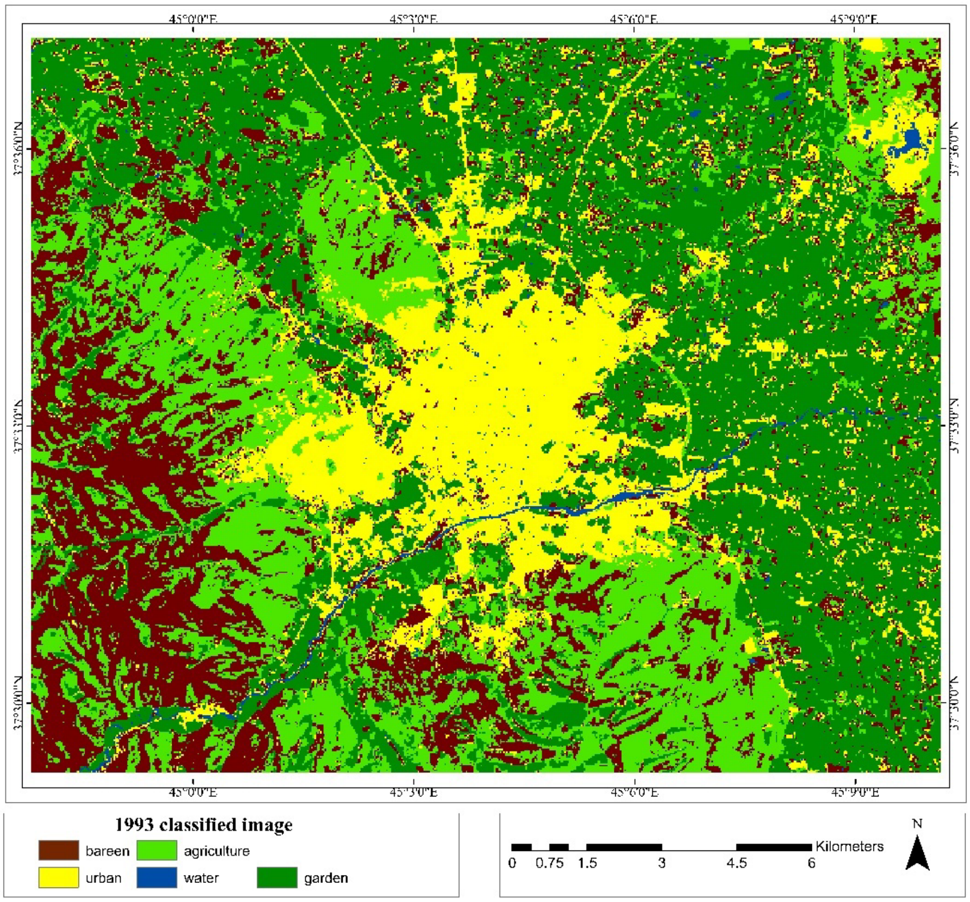

Fig.3 Classified image in 1993

The satellite image of the year 2003 comprises 5 land use classes with a total area of 26,768.7 hectares, with pixels measuring 15*15. Urban areas cover 5,569.77 hectares, water areas cover 89.1 hectares, agricultural land covers 7,854.64 hectares, barren land covers 4,254.98 hectares, and gardens cover 9,000.08 hectares. Barren land constitutes the largest area at 33.62%, while water areas constitute the smallest area at 0.33%. Gardens, agricultural land, and urban areas account for 20.81%, 29.34%, and 15.90% respectively.

Compared to 1993, the changes in each class are as follows: a decrease of 18.3% in barren land, an increase of 21.8% in agricultural land, a decrease of 12.2% in gardens, a decrease of 60.8% in water areas, and an increase of 20.3% in urban or human-made areas (Fig.4).

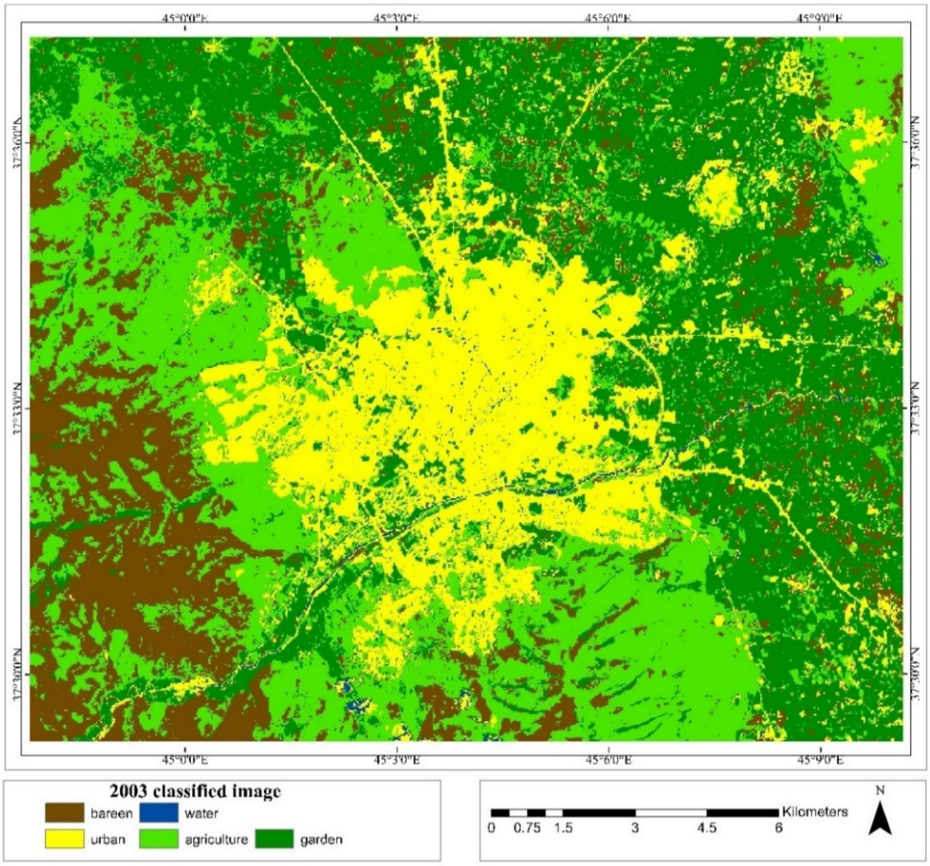

Fig.4 Classified image in 2003

The changes in the year 2013 are as follows: Initially, the reduction in the number of classes from five to four is due to the fact that after the completion of the Silvana Dam project, the Silvana River, which flows from Urmia City to Lake Urmia, partially opens its reservoirs solely for agricultural purposes. Consequently, the riverbed remains dry for most seasons and days of the year.

Therefore, starting in 2013, the water class was removed. Urban areas slightly decreased by about 1.22%, from 5,569.7 hectares to 5,501.57 hectares. Agricultural land, in terms of cultivation, experienced a 2.73% change, increasing from 7,854 hectares to 8,585 hectares. Barren land also increased by 6.9%, from 4,254 hectares to 6,104 hectares, and gardens decreased by 9.05%, from 9,000 hectares in 2003 to 6,576 hectares in 2013.

The satellite image of 2013, with pixels measuring 15*15 meters, covers a total area of 26,768.7 hectares. Agricultural land constitutes 32.07% of this area, gardens cover 24.57%, urban areas cover 20.55%, and barren land covers 22.81% (Fig.5).

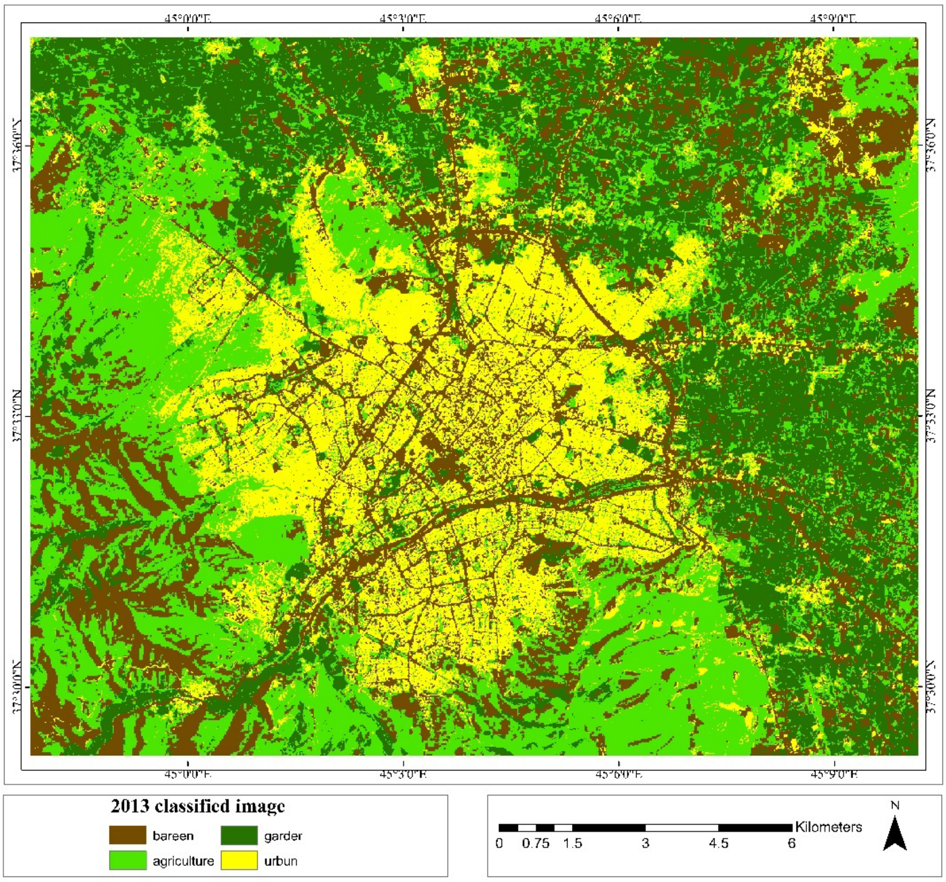

Fig.5 Classified image in 2013

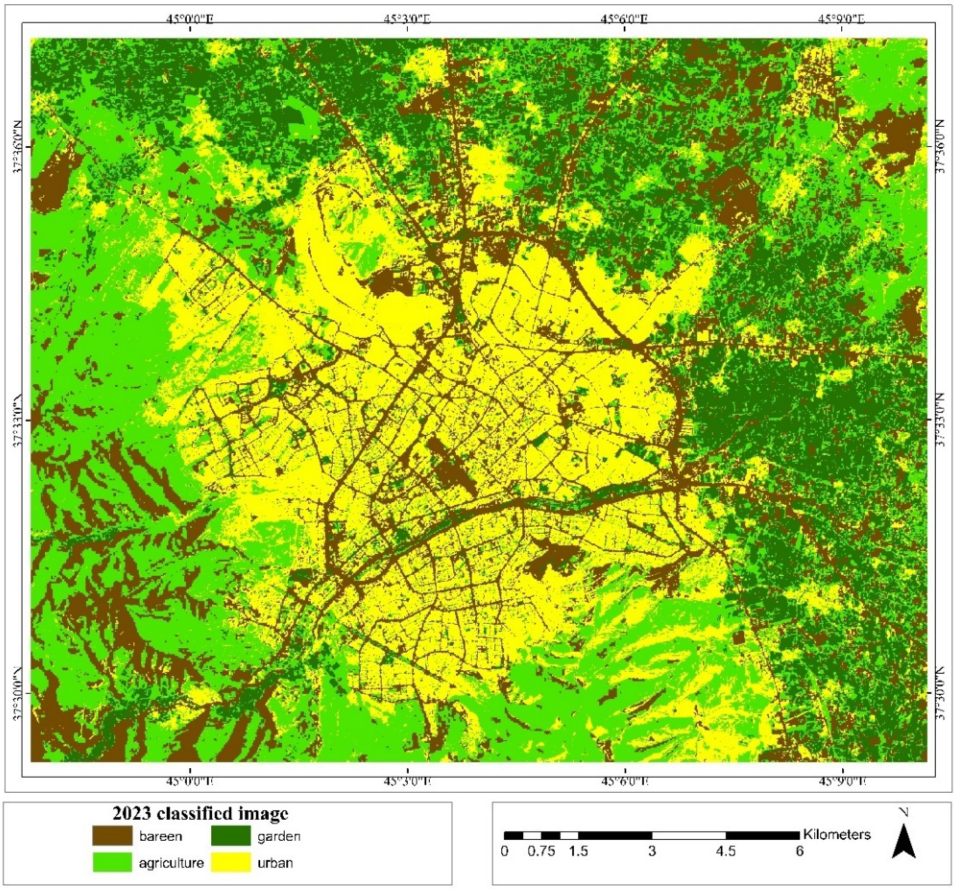

Fig.6 Classified image in 2023

In 2023, relative to the year 2013, there have been notable changes in the four existing land classes over a span of 10 years. Urban lands have experienced a 39.8% increase in area, expanding from 5,501 hectares to 7697 hectares. Agricultural lands have seen a negligible increase of 10.2%, maintaining a relatively stable figure over the decade. Barren lands have decreased by 2.85%, shrinking from 6,104 hectares to 5,930 hectares. Additionally, gardens have witnessed a significant decline of 31.7%, decreasing from 6,567 hectares in 2013 to 4,487 hectares in 2023. In 2023, out of the total area of 26,768.7 hectares, agricultural lands cover 8,652.81 hectares, gardens cover 4,487.68 hectares, urban and human-made lands encompass 7,697.96 hectares, and barren lands contribute 5,930.24 hectares to this total. This distribution is observed within a grid of dimensions 15*15 meters (Fig.6 and Tab.2).

The results obtained from the four periods of 1993, 2003, 2013, and 2023 are as follows:

		urban	**agriculture**	**barren**	**garden**	**water**	**Total**
1993	Area(ha)	4,630.63	6,448.03	5,210.61	1,0252.15	227.26	26,768.7
	percent	17.3	24.1	19.45	38.3	0.85	100
2003	Area(ha)	5,569.77	7,854.64	4,254.98	9,000.08	89.21	26,768.7
	percent	20.81	29.34	15.9	33.62	0.33	100
2013	Area(ha)	5,501.27	8,585.91	6,104.7	6,576.7	-	26,768.7
	percent	20.55	32.07	22.81	24.57	-	100
2023	Area(ha)	7,697.96	8,652.81	5,930.24	4,487.68	-	26,768.7
	percent	28.76	32.33	22.16	16.75	-	100

Tab.3 Land use area in 4 time periods (1993-2003-2013-2023)

According to the Fig.7, over three decades from 1993 to 2023, the changes in land use within the studied area of 26,768.7 hectares are as follows: riparian lands for the Silvana River, which were only flowing in 1993 and 2003 due to the completion of the Silvana dam construction, are now only used for agricultural purposes. Therefore, since 2003, water reservoirs have only opened in the spring and summer months, and the riverbed also passes linearly through the city center; its width has decreased and urban constructions and vegetation cover have been established around it. This classification was omitted in the 2013 and 2023 images.

Urban or human-made lands, which are among the most significant objectives of this study, have consistently shown an upward trend from 1993 to 2023, as indicated in the chart. There has been significant growth in such a way that during these three decades, an area of 3,067 hectares has been added to it, approximately doubling its area compared to 1993, representing a 66% increase in area over these three decades. This expansion consistently leads to environmental degradation and the destruction of natural lands, steppes, and gardens.

Agricultural lands, typically cultivated with wheat, barley, and chickpeas within the study area, have also undergone incremental changes. Due to the proximity to Urmia City and expansion beyond its boundaries, coupled with advancements in agricultural tools, more steps are being cultivated, and more natural lands are being destroyed. Specifically, these lands increased from 6,448 hectares in 1993 to 8,652 hectares in 2023, representing a 34% increase over the past three decades. Steppes increased from 5,210 hectares in 1993 to 5930 hectares in 2023, partly due to methodological errors.

The most significant degradation and transformation occurred in the classification of gardens, which consistently showed a declining trend. Its area decreased from 10,252 hectares in 1993 to 4,487 hectares in 2023, marking a 56% reduction compared to the total area. It can be said that this area halved in 2023 compared to 1993. Most of the changes observed are related to the conversion of gardens to urban or human-made lands and agricultural lands (Tab.3).

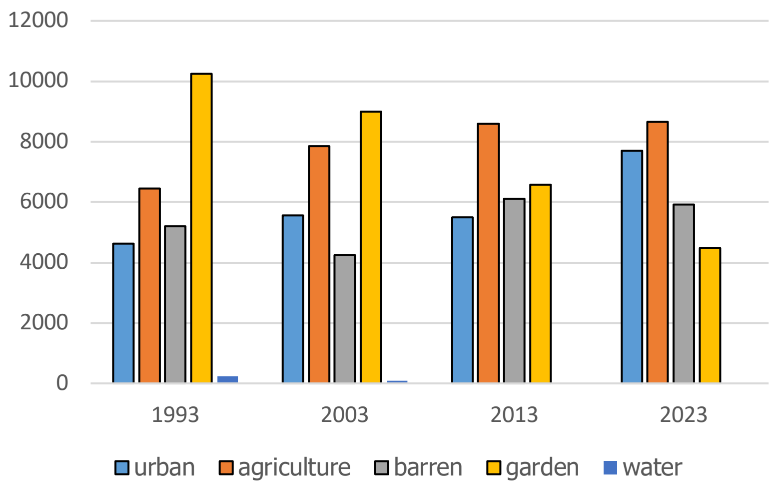

Fig.7 Land use area in 4 time periods (1993-2003-2013-2023)

4.4 Investigating changes

Using the Thematic Change Workflow, we derive land use changes from 1993 to 2023 by comparing images from different periods. Initially, we compare the images of 1993 with 2003, then the changes obtained from the 2003 images are compared with those from 2013, and finally, we compare the images of 2013 with 2023. Ultimately, to ascertain the land use changes over the past three decades within the study area, we utilize a comparison between the images of 1993 and 2023.

Changes from 1993 to 2003

In the examination of land use changes within the study area, according to the land use change map of 2003 compared to 1993, alterations have occurred in 35 different scenarios among the defined 5 land use change classes. However, in 7 instances of these classifications, where no changes have occurred, the least change is attributed to barren lands remaining as barren lands, amounting to 18 pixels with an area of 3.05 hectares. The most substantial land use transformation over the span of 10 years for barren lands amounts to 621.91 hectares, converted into agricultural lands. This transformation is primarily due to human activity, as barren lands surrounding and extending beyond the urban limits have been cultivated, leading to environmental degradation.

Agricultural lands have experienced minimal changes, with 9.17 hectares transitioning from agriculture to water bodies, and the most significant change being 775.8 hectares of agricultural lands remaining uncultivated and barren. It should be noted that due to seasonal fluctuations when crops are not cultivated, most agricultural lands are identified as barren during certain months of the year.

The least changes observed pertain to water bodies, particularly the Silvana River basin, where the least alteration along its course amounts to 11.19 hectares, converted into barren lands. This segment could be attributed to the depletion of water resources in this area, leading to the emergence of barren lands. The most significant transformation involves the conversion of these lands into urban areas, amounting to 92.64 hectares.

Subsequently, changes in gardens exhibit the least alteration, with 17.67 hectares transitioning into water bodies, while the most substantial change involves their conversion into gardens in the vicinity of Urmia City, totaling 832.36 hectares.

The most crucial changes pertinent to this study are those associated with urban and human-made lands. It is imperative to understand the predominant types of transformations occurring within urban areas and identify the predominant land use changes. The least urban land use change amounts to 9.2 hectares transitioning into water bodies, converted into riverbeds. Conversely, the most significant change amounts to 490 hectares transitioning into gardens. It can be inferred that urban areas have experienced more extensive development than expansion into surrounding areas over the ten-year period from 1993 to 2003 (Tab.4 and Fig.8).

Furthermore, the most substantial urban degradation has occurred on the outskirts of the city, with changes from suburban to agricultural and gardens, indicating a population influx towards the city center, resulting in high population density. The largest area of land transformed into urban areas is attributed to the conversion of gardens in the northern and northeastern parts of Urmia, totaling 781.13 hectares. Conversely, the least transformation into urban areas amounts to 92.64 hectares, transitioning from water bodies to urban and human-made lands.

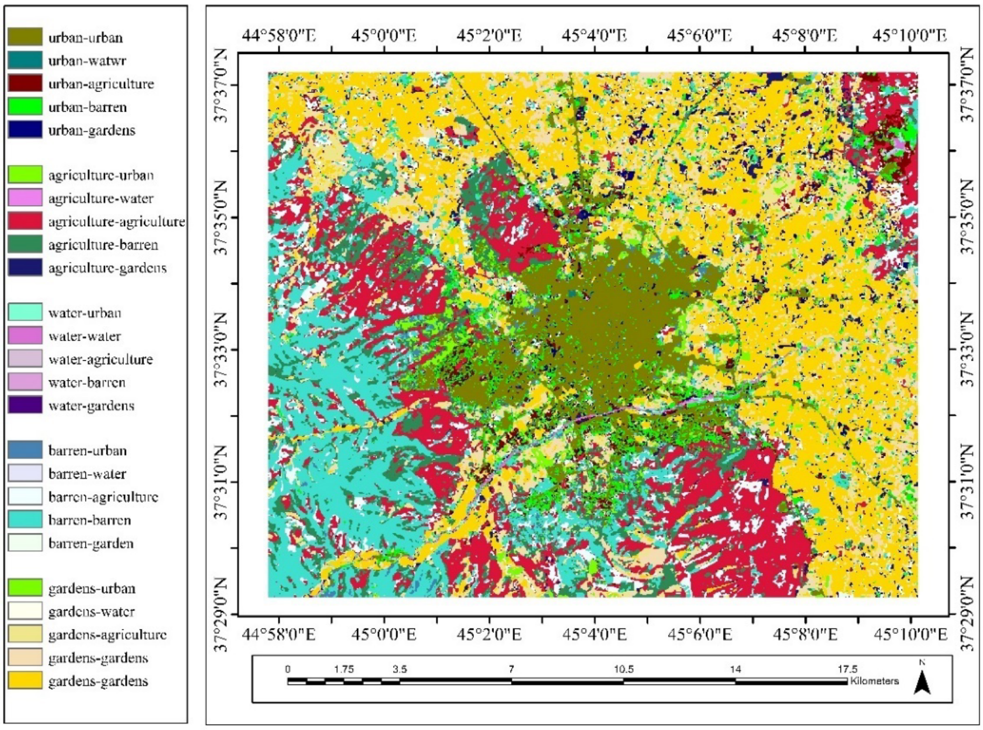

Fig.8 Changes from 1993 to 2003

1993 \ 2003	Urban [ha]	Agriculture [ha]	Barren [ha]	Garden [ha]	Water [ha]
Urban	3635	353.87	140.93	490.91	9.2
Agriculture	666.85	4401	775.8	557.2	9.17
Barren	454.33	1,671.07	2,384.19	621.91	3.05
Garden	781.13	1,268.47	832.36	7,380.77	17.67
Water	92.64	23.4	11.19	46.7	40.06

Tab.4 Land use change from 1993 to 2003

Changes from 2003 to 2013

The changes that occurred from 2003 to 2013, according to the table and land use change map, indicate that the least alterations in the water bodies class amount to 1.93 hectares, which have been converted into agricultural lands, while the most significant changes in this class amount to 46.09 hectares, transformed into barren lands in 2013.

In the agricultural land's class of 2003, the least changes amount to 1,125 hectares, converted into barren lands, while the most substantial alterations in this class amount to 522 hectares, transformed into gardens. This implies that more than 522 hectares of agricultural lands were destroyed and converted into gardens from 2003 to 2013 (Tab.5). The least changes in the barren lands class amount to 202.75 hectares, converted into urban areas, while the most significant alterations in this class over the ten-year period amount to 1621.58 hectares, transformed into agricultural lands. These changes predominantly occur in the northern and southwestern outskirts of Urmia City. The most minor changes in the gardens class amount to 523 hectares, converted into urban and human-made lands, while the most significant alterations in this class over the ten-year period occur in barren lands. However, this change is not in the form of gardens disappearing entirely; rather, it is due to the preservation of garden land use itself, but changes arise due to alterations in irrigation methods and the age of gardens. The most significant changes occur in urban lands, with the least area of change being 8.946 hectares, converted from human-made lands into agricultural lands, while the most substantial alterations amount to 110.997 hectares, transformed into barren lands. Most of these changes manifest as access roads between urban areas and their surroundings. Furthermore, during this period from 2003 to 2013, the most significant changes in transitioning to urban lands amount to 1,901.745 hectares, converted into urban areas (Fig.9).

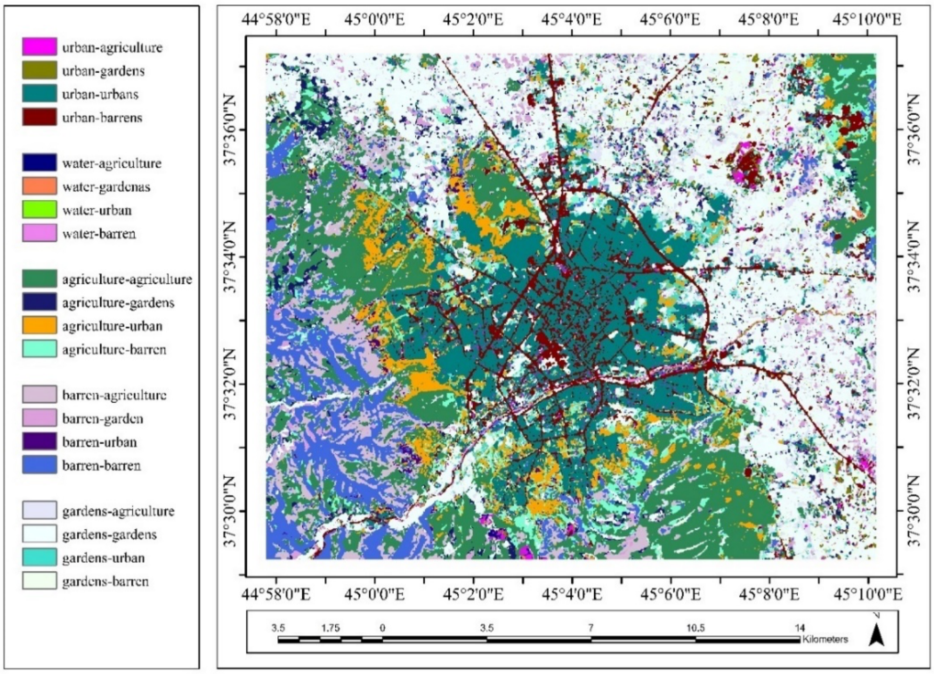

Fig.9 Changes from 2003 to 2013

2003 \ 2013	Urban [ha]	Agriculture [ha]	Barren [ha]	Garden [ha]	Water [ha]
Urban	3,550.87	234.3	1,695.28	185.43	-
Agriculture	1,376.82	4752	1,125.53	522.56	-
Barren	202.75	1,621.58	1,842.84	490.15	-
Garden	523.14	1,693.95	1,851.55	5,017.21	-
Water	1.93	14.46	46.09	19.52	-

Tab.5 Land use change from 2003 to 2013

Changes from 2013 to 2023

During the years 2013 to 2023 (Tab.6), in the agricultural lands class, the least changes occurred, amounting to 313.16 hectares, which were converted into barren lands, while the most significant changes amounted to

1020.55 hectares, transformed into urban and human-made lands. In the gardens class, the least area of change was 80.49 hectares, converted into urban and human-made lands, while the most substantial change was 598 hectares, converted into agricultural lands. In the urban lands class during this period, the least transformation occurred, with an area of 19.51 hectares converted into gardens, while the most significant change, with an area of 346 hectares, was converted into barren lands. Most of these alterations occurred in large areas outside the city, such as access roads and abandoned workshops, which were transformed into barren lands. Barren lands experienced the least conversion to urban areas, with an area of 905 hectares, while the most significant changes, amounting to 2,959 hectares, were converted into agricultural lands (Fig.10). Over the course of these ten years, the least area converted to urban lands was 80 hectares, transformed from gardens into urban areas. The most significant changes to urban lands occurred in the outskirts and urban expansion areas, with an area of over 1020 hectares converted from agricultural lands into urban areas. In total, more than 2000 hectares of garden, barren, and agricultural lands were transformed into urban areas over the ten-year period, indicating urban expansion within Urmia City.

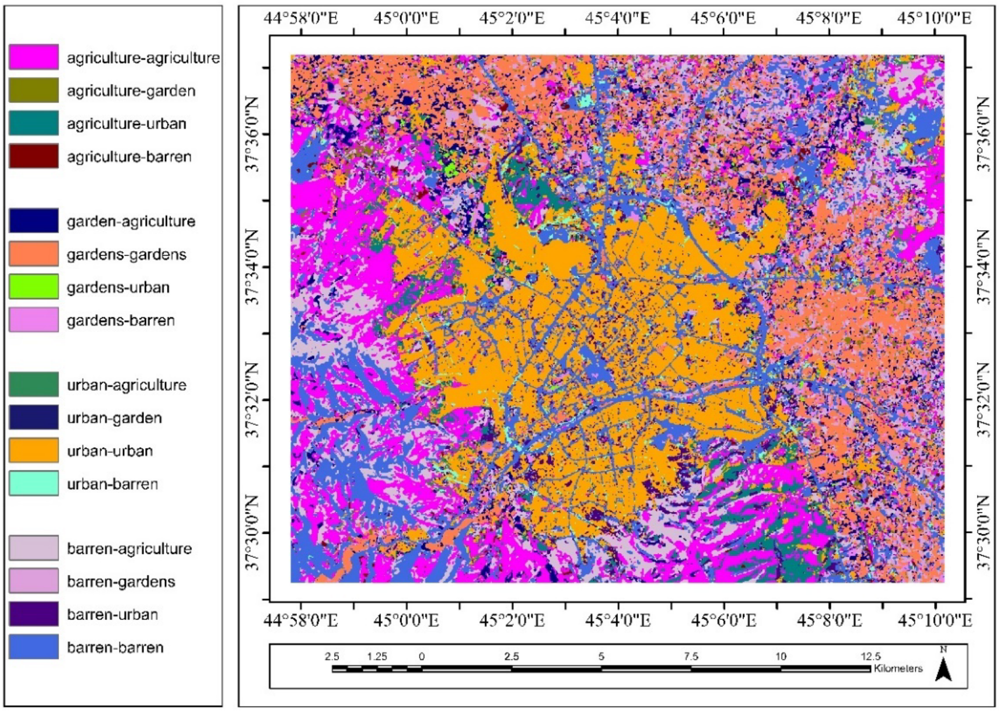

Fig.10 Changes from 2013 to 2023

2013 \ 2023	Urban [ha]	Agriculture [ha]	Barren [ha]	Garden [ha]	Water [ha]
Urban	5,851.44	199.78	346.02	19.51	-
Agriculture	1,020.55	4,067.72	313.16	377.76	-
Barren	905.1	2,959.96	4,671.63	924.11	-
Garden	80.49	1,127.11	598.32	3,305.96	-
Water	-	-	-	-	-

Tab.6 Land use change from 2013 to 2023

Changes from 1993 to 2023

Over the three decades from 1993 to 2023 (Tab.7), the summary of changes for five land use classes between 1993 and 2003, and four land use classes between 2013 and 2023 is as follows.

For urban lands, the least changes occurred, amounting to 233.33 hectares converted into gardens, while the most significant area transformed, totaling 1,384 hectares, was converted into barren lands. In agricultural lands, the least changes observed were 165 hectares converted into gardens, whereas the most significant alteration amounted to 2518 hectares transformed into urban areas. In the water class, measured only over two decades, the smallest conversion area was 20.65 hectares, transformed into urban lands, while the most substantial changes were 121.39 hectares converted, respectively, into urban and barren lands. Throughout these 30 years, barren lands experienced the least changes, with 295.31 hectares converted into gardens, and the most significant alterations, with 2183 hectares converted into agricultural lands. Gardens had the least changes, with 1546 hectares converted into urban lands, and the most substantial changes, with 2887 hectares converted into gardens (Fig.11). The most considerable changes occurred in the urban and human-made land use class, with the least transition observed in water class, converting 20.65 hectares into urban lands, and the most significant change, with 2518 hectares converted from agricultural to urban lands. Moreover, over these three decades, the least change occurred from water to urban lands, with 20.65 hectares, and the most significant transformation was from gardens to agricultural lands, with 2,887.41 hectares.

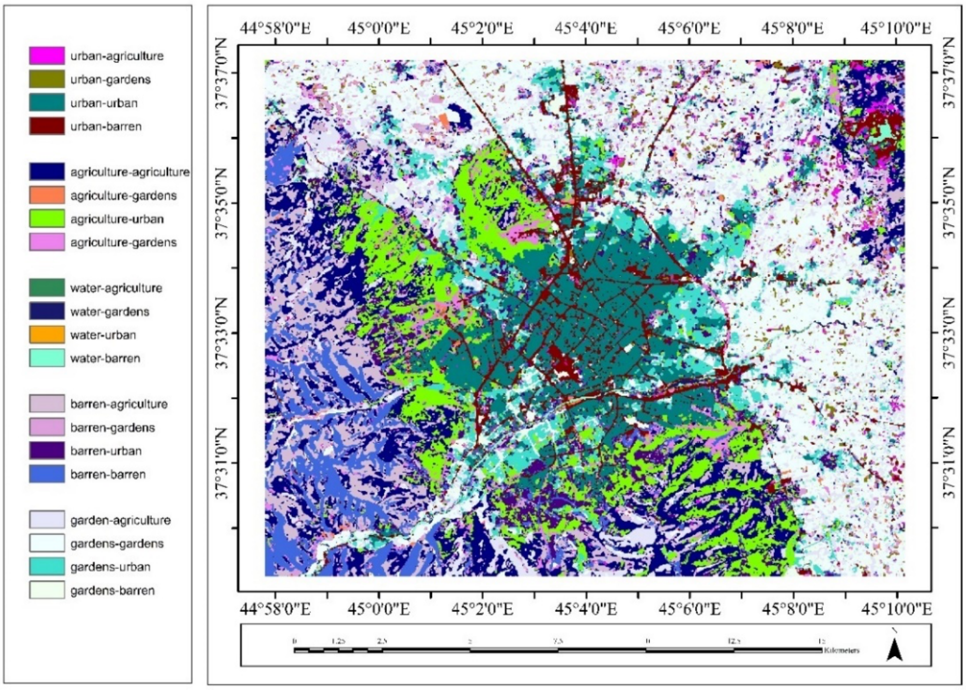

Fig.11 Changes from 1993 to 2023

2023 / 1993	Urban [ha]	Agriculture [ha]	Barren [ha]	Garden [ha]	Water [ha]
Urban	2,691.8	316.34	1,384.08	233.33	-
Agriculture	2,518.85	2,973.33	763.82	165.79	-
Barren	1,059.81	2183	1,622.62	295.31	-
Garden	1,546.21	2,887.41	1,972.77	3834.4	-
Water	20.65	34.93	121.39	43.67	-

Tab.7 Land use change from 1993 to 2023

The land-use analysis across the four study periods reveals several clear and consistent trends that characterize Urmia's spatial transformation. Urban areas expanded steadily from 1993 to 2023, reflecting the city's outward growth and the conversion of surrounding agricultural and garden lands. The most pronounced decline occurred in garden areas, which experienced a continuous reduction over the three decades. This pattern indicates a shift from traditional orchard-based landscapes toward built-up structural development. Agricultural lands displayed moderate fluctuations, largely influenced by seasonal cultivation cycles and periodic expansion into barren lands, while barren lands experienced gradual reduction as they were repurposed for either cultivation or urban development. These trends demonstrate a long-term transition from a mixed agricultural-garden landscape to a more urban-dominated pattern, consistent with broader regional shifts in mid-sized Iranian cities.

4.5 Urban areas

According to the results obtained from land use changes, urban areas do not deteriorate over time and are converted to other uses. Therefore, urban areas should increase compared to previous periods. To rectify this error, we utilized the ERASE tool in GIS software to minimize these errors on urban land parcels according to the maps (Fig.12).

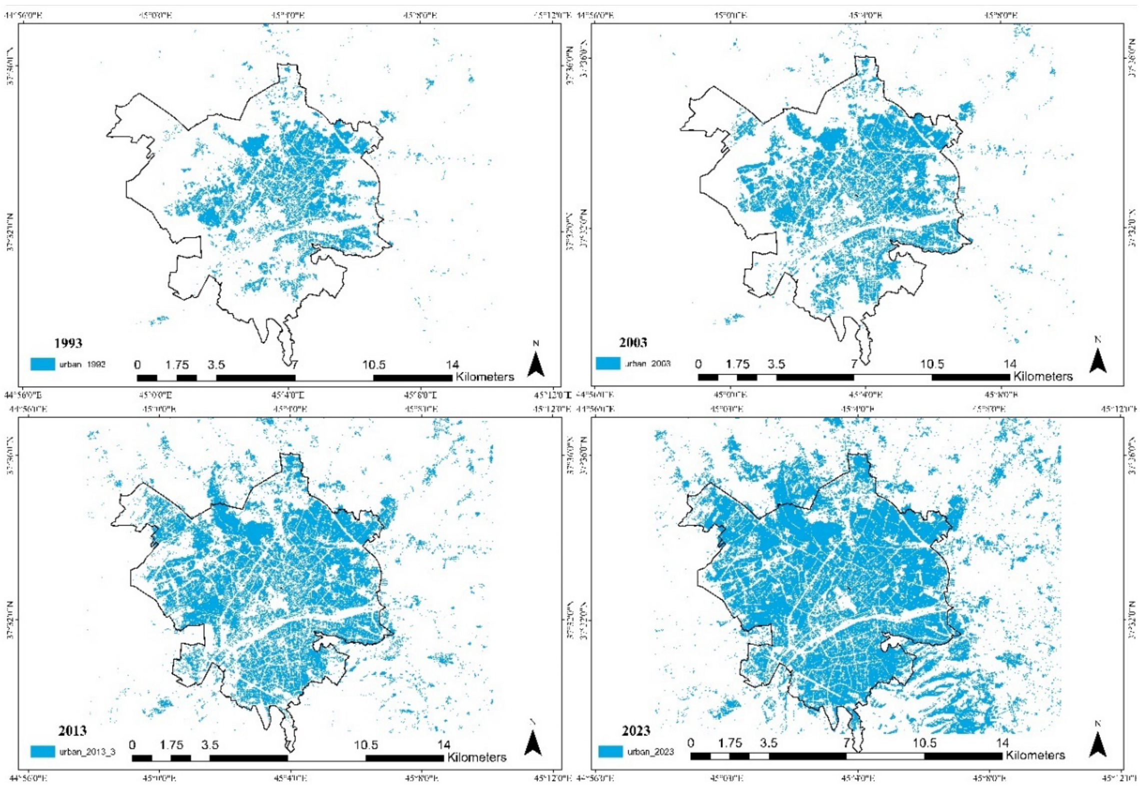

Fig.12 Urban Lands 1993-2003-2013-2023

In 1993, the urban land area was 3,953.95 hectares, which increased to 5,179.74 hectares in 2003. By 2013, the urban or human-made land area had reached 5,411.37 hectares, and finally, in 2023, it reached 7,697.96 hectares. In the comprehensive plan of Urmia City in 2016, the urban area boundary was declared as 10,000 hectares. However, the results obtained indicate discrepancies due to processing errors, unclear delineation of the urban boundary, and the absence of a road network matching the declared boundary in the Urmia comprehensive plan.

4.6 Factors

To identify the factors influencing land use changes, various dimensions and reasons for urban growth and expansion at a global level were identified after research in various sources. In this regard, the Fuzzy Delphi method was used to achieve this goal. By collecting opinions from urban experts in Urmia, several steps were taken to identify the factors affecting land use changes in Urmia through defining the research problem, dimensions, and various components using factor analysis. The criteria introduced by the experts categorized these factors into 6 dimensions as follows (Tab.8). In these 6 categories, the first three dimensions are particularly important and are the main drivers of changes, while the other three dimensions are supportive and complementary to the first three dimensions, hence not significantly impactful on land use changes.

Criteria	Explanation
Social Dimension (Population)	Rate, growth, and density of the population
Living Standards	Economy, income levels, and livelihood of individuals
Technological Advancement	Transportation, construction of power plants, industries, etc.
Political Economy	Production and distribution of income and public wealth in various regions of Urmia
Political Structure	Political system, role of the government, plans and policies, management
Attitudes and Values	Culture, customs, and traditions of the city's ethnic groups and religions (Urmia)

Tab.8 Defined dimensions

By selecting these 6 dimensions according to the experts' opinions, the main criteria for each dimension were determined. Then, through reviewing the literature of various research studies and investigations and considering the opinions and suggestions collected from 60 experts, 60 indices were introduced for each of these dimensions. To identify the effective factors, 25 components out of the mentioned 60 sub-criteria entered the analysis. The oblique rotation method was used for Factor analysis, determining the factors based on the assumptions of the test, with eigenvalues of 0.5 or 1. The aim was to identify the best model and eliminate inefficient variables with lower factor loads that had insignificant correlations with other variables. Meaningful factor loads with higher significance coefficients in each factor analysis round, exceeding 0.5, were selected for a more precise and better analysis. As a result, 6 factors were extracted, encompassing 19 variables.

Based on the analyses conducted using the Fuzzy Delphi method and the results derived from factor analysis, the driving forces behind land use and land cover changes in Urmia can be broadly categorized into six main groups: socio-demographic factors, economic conditions or living standards across social classes (wealth), technological advancement, political economy, political-administrative structure, and cultural attitudes and values. Among these, the first three categories (population, wealth, and technology) are primarily associated with environmental changes, accounting for 18.499%, 14.509%, and 11.765% of the variance, respectively. These findings suggest that environmental transformations are largely driven by population growth, economic conditions, and technological progress, with population being the most influential factor in altering land surfaces. In addition to these three primary forces, three other categories also contribute to land use changes, though to a lesser extent: political economy (including exchange systems, private property, state control, and planning mechanisms), political structure (referring to governmental institutions and administrative organizations), and cultural attitudes and values of individuals and groups. These latter factors account for 9.610%, 9.175%, and 7.716% of the variance, respectively. While these additional drivers are indeed relevant, their impact on land use change in Urmia is significantly less than that of the primary demographic and economic forces, especially population growth, which remains the most influential variable in shaping urban land transformations.

Tab.9 represents the number of factors extracted from the data (initial variables). Factors in this section are considered influential if their characteristic value (sum column) is greater than one. The last column of this table indicates the percentage of variance explained by all factors (from the first factor to the current factor) together. According to the table, 6 factors have been extracted, which collectively account for 71.274% of the variability of the main variables. The total variance for each test is equal to 100%. The closer this value is to 100, the better the interpretation of the number of factors. The eigenvalue for the first factor is 4.625. Other eigenvalues for subsequent factors are also listed in the Total column.

	Initial Eigenvalues			**Sum of Squared Loadings**			**Sum of squared loadings after rotation**
	Total	Percentage of variance	Cumulative percentage	Total	Percentage of variance	Cumulative percentage	Total
Social Dimension (Population)	4.625	18.499	18.499	4.625	18.499	18.499	3.908
Living Standards	3.627	14.509	33.008	3.627	14.509	33.008	3.521
Technological Advancement	2.941	11.765	44.773	2.941	11.765	44.773	3.185
Political Economy	2.402	9.61	54.383	2.402	9.61	54.383	2.582
Political Structure	2.294	9.175	63.558	2.294	9.175	63.558	2.572
Attitudes and Values	1.929	7.716	71.274	1.929	7.716	71.274	2.728

Tab.9 Eigenvalues, Percentage of Variance, and Cumulative Percentage

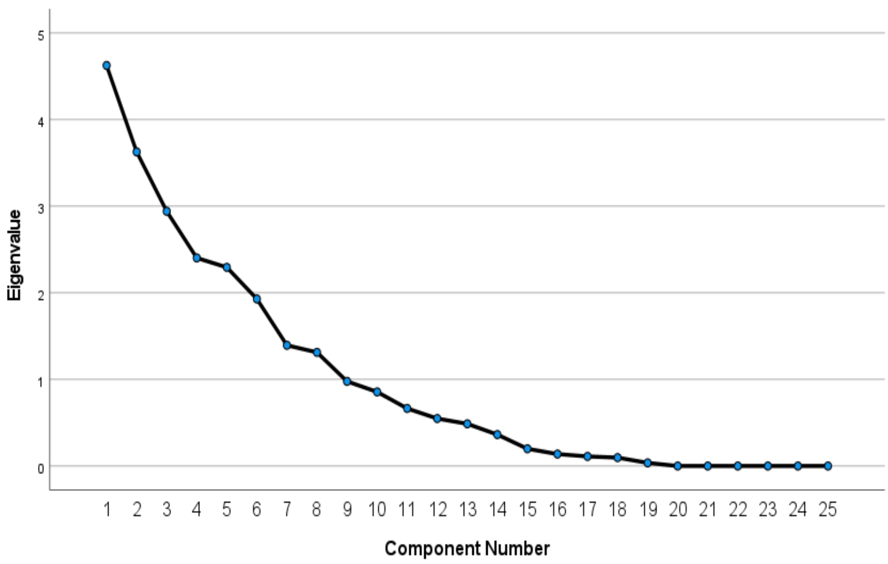

Fig.13 Scree plot

The scree plot (Fig.13) graphically displays the eigenvalues of each of the extracted components, starting from the largest eigenvalue. It consistently exhibits a descending slope. The scree plot indicates which factor had a noticeable change. It's quite evident that the initial 3 factors have a steeper slope compared to the second set of 3 factors. In fact, the results from the Total Variance Explained table are observed graphically in the scree plot, revealing which factor contributes to a higher percentage of variability in the variables. It's apparent in the plot that the initial 3 factors encompass more variability, covering 44% of the total, while the subsequent 3 factors also cover nearly 27% of the variability, as visible in the plot. Considering the scree plot, factors 7 and 8 could also be taken into account.

The higher contribution of social and economic factors to land-use change in Urmia can be explained by several key trends:

Social Factors: Rapid Population Growth and Urban Expansion: Urmia has experienced rapid population growth; driven by factors such as rural-urban migration and natural population increase. This population growth has created a substantial demand for housing, infrastructure, and services, leading to the expansion

of urban areas into previously agricultural and garden lands. In many cases, urban planning efforts have not been able to keep pace with this rapid population growth, resulting in unplanned urban sprawl and encroachment on valuable agricultural land. For example, the city's population has increased from 500,000 in 1993 to over 800,000 in 2023, placing significant pressure on existing urban infrastructure and land resources.
Economic Factors: Investment in Construction and Real Estate: Economic development in Urmia, particularly in the construction and real estate sectors, has also played a significant role in driving land-use change. Increased investment in housing and commercial development has led to the conversion of land from agricultural to urban uses. For instance, government policies aimed at stimulating economic growth have sometimes inadvertently encouraged land speculation and the conversion of agricultural land for development.
Technological improvements, including new highways, ring roads, and mechanized agriculture, opened up undeveloped areas and accelerated land transformation around Urmia. Economic and policy forces also played a major role: government-backed housing programs such as the Mehr Housing scheme, the creation of industrial townships, and weak taxation on vacant land encouraged speculation and drove rapid conversion of land, especially in western and southwestern areas. Cultural shifts also contributed, with many families moving away from traditional orchard-based lifestyles toward suburban villas and leisure properties, especially in Silvaneh, Nazloo, and the northeastern outskirts, leading to widespread conversion of gardens into residential and recreational land uses.

5. Discussion

Based on the changes from 1993 to 2003, the smallest change was from barren land to water land, covering an area of 11.19 hectares. The largest change during this period was from barren land to agricultural land, encompassing 1671 hectares. From 2003 to 2013, the smallest change was from water land to urban land, with an area of 1.93 hectares, while the largest changes involved barren land transforming into both barren and agricultural lands, totaling 1,851 hectares, and agricultural land converting to urban land, covering 1376 hectares. In the period from 2013 to 2023, the smallest changes were from urban land to garden land, and the largest change was from barren land to agricultural land, spanning 19.51 hectares. Additionally, 2,959.96 hectares of agricultural land were converted to urban land.
According to the land use changes from 1993 to 2023, the smallest change was from water land to urban land, with an area of 20.65 hectares. The largest changes over the 30 years were from agricultural land to urban land, covering 2,518 hectares, barren land to agricultural land, spanning 2,183 hectares, and garden land transforming, totaling 2,887 hectares, primarily converted into agricultural lands. This indicates that the most significant land use changes over the three decades pertain to urban and man-made lands, with their area approximately tripling.
Water Bodies: The water bodies in the specified area encompass the Silvana River, also known as the Berdeh Soo River, which flows through the city of Urmia and empties into Lake Urmia. In 1993, this stretch of land had an approximate area of 227.26 hectares, which decreased to 89.21 hectares by 2003. According to analytical tables, this reduction in area can be attributed to various reasons. Firstly, the widening of the riverbed due to urban development and beautification projects by the Urmia Municipality. Additionally, the construction of the Silvana Dam both upstream and downstream has led to a significant portion of the riverbed being utilized for agriculture and gardens due to reduced river volume. Furthermore, in the past decade, due to drought and limited rainfall across the country, water from the dam has only been released for agricultural purposes on specific days and months of the year, resulting in periods of water scarcity in the riverbed. Therefore, in 2013 and 2023, the classification of water classes in the images was omitted due to these reasons.
Urban Areas (Human-made): In 1993, the total identified urban area in Urmia was 4,630.63 hectares, which significantly increased over three decades to 7,697.96 hectares in 2023. Over 3,000 hectares have been added

during this period, representing a 65% increase compared to 1993. All land conversions to urban areas were calculated in season 4. The major reasons for the tripling of Urmia's urban area over these three decades include population growth and subsequent construction activities, particularly unauthorized constructions, mass housing developments in the northern, northwestern, southern, and southwestern parts of the city, along with infrastructural developments, highways, factories, industrial workshops outside the city limits. Residential and commercial township constructions outside the city limits and obtaining top positions in industrial township constructions nationwide, along with achieving the third position nationally in the executive performance of the construction movement, have contributed to numerous economic activities and constructions across the city. Gardens constructed outside the city limits have, inevitably, led to changes in culture and the construction of small orchards or garden villas, subsequently necessitating the construction of access roads for transportation due to the high cost of land and the consequent influx of people to the outskirts and suburban areas for housing construction. Additionally, the construction of large administrative centers in the city's periphery has been another major factor driving urban expansion and growth in the specified area.

Agricultural Lands: Agricultural lands covering 6,448.03 hectares in 1993 increased to 8,652.81 hectares in 2023, representing an addition of 2204 hectares, approximately a 35% increase compared to 1993. While the percentage change in agricultural lands may not seem significant at first glance, a closer examination reveals substantial changes in land use over the three decades. It's notable that for every unit of agricultural land converted to urban areas or gardens due to various reasons, such as construction activities, an equivalent area of agricultural land has been added annually. Barren lands have been increasingly cultivated, leading to the degradation of natural and pristine lands.

Barren Lands: Barren lands are among the most critical lands from an environmental perspective, upon which human life depends. In 1993, these lands covered an area of 5,210.61 hectares within the specified area, but by 2023, this area decreased to 5930.24 hectares, nearly halving compared to 1993. More than 44% of the land area in 1993 has been lost, which is approximately 462 hectares converted from barren lands to other uses by 2023. Barren lands have undergone significant changes, being converted to agricultural lands, gardens, and most significantly, urban areas.

Land Use Changes: Urmia had 10,252 hectares of gardens in 1993, primarily consisting of vineyards and apple gardens. However, by 2023, due to significant urban development and human interventions, the area of these lands has decreased to 4,487.68 hectares. More than 22% of these gardens, totaling 129 hectares, underwent transformation into other land uses. This transformation mainly occurred through the construction of various urban roads, resulting in a change of land use along these roads. Additionally, all gardens in recent years have been equipped with recreational facilities such as garden pavilions or at least one residential structure within the gardens for leisure activities and other purposes.

Through fuzzy Delphi analyses and factor analysis results, the driving forces behind land use changes and land cover in Urmia can be broadly categorized into six socio-demographic, economic or lifestyle strata (wealth), progress and technology, political economy, political-administrative structure, attitudes, and values (culture). The first three categories are associated with environmental changes, where environmental impact is a function of population, wealth, and technology.

Among these three categories of driving forces, the population generates the most significant changes in land use. Additionally, three other groups are added to these driving forces: political economy, which includes exchange systems, private ownership, government controls, and planning; political-administrative structure, which encompasses governmental institutions and organizations; and attitudes and values of individuals and groups. The categorized driving forces in this classification are much fewer than the previous three groups, and particularly, population growth is confirmed to have caused the land use changes in Urmia.

The findings of this study show that socio-economic factors had a stronger influence on land-use change in Urmia compared to political or cultural drivers. This reflects the city's development pattern over the past thirty years, during which rapid population growth, rising living standards, and expanding technological capacity directly shaped land transformation. Political and cultural factors had a weaker role because they often influenced land use indirectly. In Urmia, political institutions have generally responded to demographic and economic pressures rather than guiding or regulating long-term spatial development. Planning regulations were not consistently enforced, and administrative structures lacked the continuity required to manage growth effectively. Cultural influences were also less prominent because traditional practices related to orchard cultivation and the preservation of community landscapes have gradually diminished. These practices have been overtaken by the economic appeal of property development and by modern residential preferences. As a result, socio-economic forces tended to overshadow political and cultural mechanisms that might otherwise have moderated the pace or direction of land-use change.

The land-use changes observed in this study have several broader implications for Urmia's social, economic, and environmental future. Socially, the rapid expansion of built-up areas and the decline of garden and agricultural zones have intensified spatial inequalities. Former rural areas that were absorbed into the urban boundary did not always receive corresponding improvements in infrastructure or public services, creating uneven access to transportation, utilities, and social facilities. Economically, the loss of productive agricultural and garden lands reduces long-term food security and weakens the livelihoods of households that historically depended on orchard-based income. Although construction activity has attracted investment and created employment, it has also stimulated speculative land markets. This can raise property prices and limit access to affordable housing for many residents.

Environmental consequences are equally significant. The reduction of garden areas has removed an important source of green cover that once helped regulate temperature, support biodiversity, and improve air quality. Their disappearance contributes to higher heat stress and increased dust emissions, particularly in an area already affected by the ecological challenges surrounding Lake Urmia. The expansion of impermeable urban surfaces increases surface runoff, heightens flood risks, and places additional pressure on already strained water resources. These environmental effects match patterns seen in many mid-sized cities in arid and semi-arid climates, where rapid urbanization exceeds the capacity of natural systems to absorb and adapt to change.

Overall, the dominance of socio-economic drivers over political and cultural influences suggests that Urmia's land-use trajectory is shaped by short-term development pressures rather than long-term strategic planning. Without stronger governance structures and coordinated land management policies, continued expansion may intensify environmental degradation, social disparities, and economic vulnerabilities. This highlights the need for integrated planning approaches that protect remaining green areas, regulate urban expansion more effectively, and balance development needs with ecological and social sustainability.

The findings of this study align with and expand upon established hypotheses in the urban geography and land change literature. Specifically, the 66% increase in urban areas and the simultaneous 56% decline in gardens over the three-decade study period reflect well-documented global patterns of urban sprawl driven by rapid population growth, socio-economic development, and inadequate planning (Lu et al., 2019; Burchfield et al., 2006; Yuan et al., 2018). These outcomes reinforce the hypothesis that unregulated urban expansion often occurs at the expense of agricultural and vegetated lands, a phenomenon also observed in studies across Asia and the Global South (Dolley et al., 2020; Dutta et al., 2020). Moreover, the identification of six key dimensions social, economic, technological, political, and cultural supports frameworks that consider land-use change as a multi-dimensional process influenced by demographic pressures and institutional weaknesses (Hersperger et al., 2010; Wang et al., 2020).

The role of governance and urban planning policies has been pivotal in shaping the trajectory of Urmia's land use changes. Mass housing developments, industrial zones, and extensive road network construction were largely facilitated by government policies that prioritized rapid economic development over controlled urban growth. During the 1990s and early 2000s, zoning regulations in Urmia were either weakly enforced or selectively applied, allowing construction projects to expand into peri-urban agricultural and garden lands without sufficient environmental assessments. Economic incentives, such as low-interest loans for housing and subsidies for industrial establishment, further accelerated construction beyond the formal urban boundary. Although government plans such as the Comprehensive Urban Plan of Urmia (2016) nominally aimed to curb sprawl by promoting satellite cities and designated growth corridors, implementation was inconsistent. Informal settlements and speculative developments often bypassed regulatory oversight, resulting in fragmented and unplanned urban expansion. Thus, policy failures played a central role in enabling unregulated growth.

Regarding hydrological changes, the reduction of water bodies, notably the Silvana River and adjacent wetland areas, was influenced by a combination of factors: urban development along riverbanks, dam construction, and climate change-induced drought. Among these, the construction of the Silvana Dam and related water diversion for agricultural irrigation had the greatest direct impact on the observed reduction in surface water. By altering the river's natural flow regime, the dam significantly decreased water availability downstream, leading to seasonal desiccation of river channels and the disappearance of wetlands. Reduced rainfall and higher temperatures exacerbated this trend but were secondary compared to anthropogenic water management practices. This pattern mirrors trends observed in other arid and semi-arid regions globally, for instance in parts of Central Asia (e.g., the Aral Sea basin), where river flow regulation for agriculture has led to large-scale hydrological degradation, even before climate change impacts became predominant. Urmia's case thus highlights how localized water management decisions can accelerate hydrological vulnerability in urbanizing landscapes, requiring integrated watershed and land-use planning to mitigate long-term risks.

6. Conclusion

This study not only confirms established urban geography theories regarding the drivers of urban expansion, such as rapid population growth and technological development, but also extends them by highlighting the crucial role of political economy and socio-cultural attitudes in shaping land use changes in a mid-sized city context. While Urmia's urban expansion mirrors global trends of outward growth and garden loss, it exhibits distinct local patterns. In particular, the city has experienced a dramatic decline of private gardens and peri-urban agricultural lands tied to informal governance practices, speculative land markets, and fragmented administrative control. These localized dynamics underscore the interplay between global forces and local contexts in shaping Urmia's urban form.

This research offers a fresh perspective by linking long-term satellite observations with expert-driven insights to uncover how diverse factors interact in shaping urban land use. Beyond documenting spatial change, it introduces a multi-dimensional analytical framework that captures the influence of social, economic, technological, and institutional forces. The study's integration of geospatial and qualitative methods provides a valuable tool for diagnosing land transformation processes in rapidly evolving cities like Urmia and can inform more adaptive, locally grounded urban planning strategies.

To promote sustainable urban development in Urmia, planners should implement several key strategies: enforce zoning laws to control sprawl, incentivize green infrastructure, support higher-density mixed-use development, protect remaining agricultural and garden lands, and improve public transportation systems. These measures collectively aim to reduce informal expansion, enhance resilience, and guide the city toward more sustainable and compact growth. This study provides valuable insights into urban land use change in Urmia through the integration of geospatial analysis and expert-based methods. However, several limitations should be noted. The temporal starting point of 1993 restricts long-term historical analysis, and classification challenges arose in peri-urban areas due to overlapping land use types. The omission of water bodies in later years may have led to an underestimation of hydrological impacts, while the ecological consequences of garden loss remain underexplored. Additionally, the use of the Fuzzy Delphi method introduces subjectivity, as expert selection and indicator weighting may reflect institutional biases. Although focused on a single case, the study's methodological framework is adaptable to other rapidly urbanizing mid-sized cities, particularly in developing regions.

Future research should consider comparative analyses involving multiple cities and extend the temporal scope to include earlier historical periods. Employing econometric models and scenario-based forecasting could also provide insight into the long-term impacts of various urban planning strategies. Furthermore, integrating ecological and social metrics, such as biodiversity, carbon emissions, and community perceptions, would contribute to a more comprehensive and policy-relevant understanding of urban land dynamics. Ultimately, this study highlights the importance of interdisciplinary approaches in addressing the complex challenges of urbanization. By integrating spatial, socio-economic, ecological, and political dimensions, it advances theoretical understanding and supports the development of more resilient, sustainable, and inclusive urban planning strategies.

To enhance the practical value of this research, the study offers several specific and context-driven policy recommendations for urban planners and decision-makers in Urmia. A central priority is the establishment and strict enforcement of a clear urban growth boundary, since the city has expanded well beyond the limits defined in its 2016 Comprehensive Plan. Preventing new construction outside the designated boundary would help curb informal sprawl and protect the remaining agricultural and garden lands. Within the existing urban area, redevelopment and densification should be encouraged, particularly in underutilized or low-density neighborhoods. Incentives such as reduced permitting times, tax benefits, or density bonuses could motivate developers to focus on infill rather than outward expansion. Protection of garden and agricultural lands also requires targeted zoning regulations supported by economic incentives, including subsidies for orchard maintenance and compensation programs for landowners who choose to maintain green land uses rather than selling to developers.

A systematic land monitoring program, based on periodic satellite imagery, would help local authorities detect and respond to illegal construction and rapid land transformations. Integrating water resource management with land-use planning is also essential, since the decline of gardens in Urmia is closely linked to water scarcity. Coordination with water authorities to modernize irrigation systems and preserve riparian areas would support both agricultural sustainability and environmental resilience. The municipality could also designate ecological corridors that link remaining gardens and natural areas in order to reduce heat stress, preserve biodiversity, and guide development away from environmentally sensitive zones. Additionally, reforms in the land market, such as taxing vacant land or regulating land subdivision in peri-urban villages, would discourage speculative practices that have accelerated unplanned expansion. Improving coordination among the various agencies involved in land and development decisions would further strengthen the city's capacity to manage growth effectively.

The study also contributes to both theory and practice in several important ways. Theoretically, it advances understanding of urban land-use change in mid-sized cities by combining long-term satellite observations with expert-based evaluation methods. This integrated approach addresses a gap in the literature where most studies either rely solely on remote sensing or focus primarily on socio-economic indicators without linking the two. The findings also refine existing theories of urban sprawl by showing that in semi-arid, rapidly developing contexts like Urmia, socio-economic drivers can overshadow political and cultural influences, particularly when institutional capacity is limited. Furthermore, the multi-decadal assessment presented here adds empirical depth to theoretical discussions about the relationship between demographic pressure, economic restructuring, and land-market dynamics.

Practically, the study provides urban planners in Urmia with clear insights into the dominant forces shaping land-use change. By identifying population growth, rising living standards, and technological expansion as the most influential drivers, the research supports more targeted planning interventions. This is consistent with

Partheepan et al. (2023), who observed similar socio-economic pressures in Batticaloa, and with Pultrone (2023), who emphasized the role of external agents in accelerating urban sprawl. The work also demonstrates how geospatial tools can be operationalized by local agencies to track urban expansion and environmental degradation. The policy-oriented recommendations derived from the results offer concrete steps that can be implemented in the short and medium term, contributing directly to urban management and sustainability efforts. Finally, the methodological framework developed in this study can be applied to similar mid-sized cities in Iran and other developing countries, making the research relevant beyond the specific case of Urmia.

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