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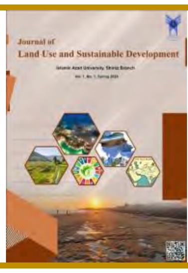

Original Research Paper

Evaluating Land Use and Land Cover Changes and Their Impacts on Soil (Case Study: The Coastal City of Gomish-Tepe)

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Abstract
One of the environmental consequences and conflicts arising from land use and land cover changes is the intensification of soil erosion, which seriously threatens urban water and soil resources. Therefore, it is necessary to regularly identify the spatial dimensions of land use and land cover and their effects on cities so that policymakers and researchers can make informed decisions. Satellite data is one of the fastest and most cost-effective methods available to researchers for preparing land use maps. this study aimed to evaluate the changes in land use percentage and its impact on erosion between 1993 and 2023 in the city of Gomish Tappeh, located in Golestan province. For this purpose, a vegetation cover percentage map was first prepared using TM and OLI sensor images from the Landsat satellite. After atmospheric and radiometric correction, a land use map was created using the pixel-based method (maximum likelihood algorithm), the object-oriented method (nearest neighbor algorithm), and the ARAS method. The most important accuracy assessment methods, including overall accuracy and the classification kappa coefficient, were then extracted. An erosion zoning map was prepared using the resulting land use maps and factors including slope, lithology, distance from roads, distance from rivers, precipitation, and soil, using the Kritik weighting method and the WLC method. the results showed that in the land use maps from 1993 to 2023, the increase in rainfed lands was accompanied by a decrease in pastures, with the most significant change being a downward trend in pasture use. Additionally, according to the 1993 and 2023 erosion zoning maps, Gomish Tappeh is categorized as having both a very high risk and a high risk of erosion.

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Introduction

Ecosystems are in a constant state of transformation. This transformation and change may result from natural interactions of vegetation or from human interventions such as land use change, among other factors (Akumu *et al.*, 2018). Human and natural factors have diverse effects on the forms and phenomena of the Earth's surface under various conditions (Asner and Houghton, 2005; Yadav and Prawasi, 2013). The pattern and trend of these changes will differ depending on the intensity and power of the influencing factors. Change monitoring is the process of determining differences in the state of a phenomenon or object by observing it at different times (Damor, 2024).

Data derived from land use change maps is one of the fundamentals of natural resource management. Awareness of the proportion of land uses in an environment and the conditions of its changes over time has been a key issue in planning (Vu and Bui, 2024). By knowing the extent of changes and transformations in land uses over time, future changes can be predicted and the necessary measures can be taken (Czajka *et al.*, 2023). Change detection and monitoring involve using a set of multi-temporal data to quantitatively analyze the temporal effects on phenomena.

Given the high cost and untimely nature of preparing these maps using ground operations, the use of satellite imagery has been proposed in recent years as an efficient and optimal method for evaluating surrounding changes (Feizizadeh and Salmani, 2020). Furthermore, due to the advantages of repeated data acquisition, a digital format, and an optimal synoptic view for computer processing, remote sensing information has become one of the most effective data sources for various change detection applications over the past years (Arkhi *et al.*, 2020).

In recent decades, extensive land use changes have become one of the most significant environmental challenges in various regions of the country, including coastal areas (Sreenivasulu and Rao, 2017). The coastal city of Gomish Tappeh, with its sensitive and fragile ecosystems such as agricultural lands, wetlands, pastures, and coastal areas, has undergone extensive land use changes over the past years that have directly and indirectly impacted soil erosion. The uncontrolled increase in agricultural lands, urban expansion, destruction of vegetation cover, and the conversion of natural lands to unsustainable uses have led to an intensification of the soil erosion phenomenon in this region.

Accurate measurement of these changes and their effects on the environment requires the use of modern technologies, including remote sensing (RS) and Geographic Information Systems (GIS), along with Multi-Criteria Decision-Making (MCDM) algorithms, which allow for the simultaneous analysis of diverse and complex factors. By integrating these methods, the trend of land use changes can be monitored with higher accuracy, and critical areas in terms of soil erosion can be identified. A precise analysis and evaluation of these trends help policymakers and planners take steps toward sustainable natural resource management and soil conservation.

- This raises the fundamental question: What effect have recent land use changes in the coastal city of Gomish Tappeh had on the intensity and spatial pattern of soil erosion, and how can these effects be accurately evaluated and managed using Multi-Criteria Decision-Making algorithms and remote sensing?

Literature Review

Land use change refers to the conversion or replacement of one type of land use with another, which typically occurs in response to human factors (such as population growth, urban development, and agriculture) or natural factors (such as climate change). These changes can have major impacts on the environment, natural resources, and ecological processes, including soil erosion, the water cycle, and biodiversity (Chang *et al.*, 2016). Furthermore, monitoring and analyzing these changes using remote sensing and GIS technologies are considered key tools in sustainable land planning and management (Verburg *et al.*, 2003). This process is one of the main indicators for evaluating environmental changes at regional and global scales (Putri, 2021).

Inefficient and improper use of soil resources has led to the degradation of many valuable agricultural and water lands, ultimately resulting in soil erosion. To mitigate the economic and environmental impacts of irrational land use, regional-level planning is necessary (Chen et al., 2002).

Through this approach, sustainable development of natural and agricultural lands will be achieved by protecting resources, ensuring proper and sustainable use, and reducing waste and damage (De Wrachien, 2003). Although it's not possible to completely stop erosion under natural conditions, reducing the rate of erosion in watersheds and in water and soil management programs is a crucial and highly important necessity (Kumawat *et al.*, 2020).

Appropriate measures to reduce erosion and conserve soil include optimizing the management of different types of lands and a set of biological operations (Hatfield, 2014). By optimizing land use and certain biological operations, the extent of land uses can be altered to generate the greatest benefit and the least amount of erosion (Moeini *et al.*, 2019).

The theoretical literature on "evaluating land use changes and their effects on soil erosion using multi-criteria decision-making algorithms and modern remote sensing methods" is divided into several main dimensions, each based on valid scientific perspectives and theories in the fields of environmental science, natural resource management, and geospatial technologies.

First, the theory of "human-environment interaction" emphasizes that land use changes are a reflection of human exploitation patterns, which can have destructive consequences such as soil erosion, the destruction of biological resources, and a decline in environmental quality. In this context, the conversion of vegetation cover to agricultural or urban land is considered one of the main factors accelerating soil erosion (Lambin *et al.*, 2001).

On the other hand, modern perspectives in the fields of remote sensing (RS) and Geographic Information Systems (GIS) highlight the importance of technology-driven tools for monitoring and spatially analyzing environmental changes. Satellite images with high temporal and spatial resolution enable the identification of land use changes over different time intervals (Jensen, 2015). Furthermore, GIS serves as a platform for integrating spatial and descriptive data, making spatial analysis and environmental modeling possible.

In addition to these methods, multi-criteria decision-making algorithms such as AHP, TOPSIS, and ANP are also effectively used for the simultaneous evaluation of multiple indicators in complex and uncertain environments. These methods facilitate scientific decision-making and optimize analyses by considering the relative weight and importance of the criteria that influence soil erosion (Lambin, 2006).

The combination of these perspectives indicates that the scientific evaluation of the effects of land use changes on soil erosion requires an interdisciplinary and integrated approach, blending knowledge from environmental science, geospatial technologies, and decision-making sciences.

Lotfalizadeh Lahroudi (2023), conducted research on land use changes in the Urmia City-Chay watershed using Landsat satellite images from the TM and OLI-TIRS sensors for the years 1995, 2005, and 2021. To prepare the land use maps, a supervised classification method with the maximum likelihood algorithm was used in ENVI software. The results showed that throughout the study period, agricultural lands, gardens, residential areas, and water bodies had an increasing trend, with their area expanding in each period. In contrast, the area of barren lands and pastures showed a decreasing trend.

Arkhi *et al.* (2022), in their study titled "Evaluation of Land Use/Land Cover Change Techniques Using Satellite Imagery and GIS (Case Study: Gorganroud Watershed)," aimed to monitor land cover changes in the Gorganroud watershed in Golestan province. In this research, images from the TM sensor in 1987, the ETM+ sensor in 2000, and the OLI sensor in 2020 were processed and analyzed. After determining a change threshold, areas with decreasing changes, increasing changes, and no changes were identified.

Seyam *et al.* (2023), identified Land Use Land Cover (LULC) changes using a remote sensing and GIS approach in a case study in Bangladesh. These changes were identified over the past two decades in five classes using Landsat 7 and 8 images in Arc GIS 10.8. The overall accuracy was 87.2% for 2002 and 89.6% for 2022. The built-up area experienced the most significant changes, with a 217.1% increase (6.56 km²) due to urbanization and industrialization, which had a notable impact.

Bozkurt *et al.* (2023), examined land cover and land use change affecting forest and semi-natural ecosystems in the urban area of Istanbul (Turkey) between 1990 and 2018. For this purpose, using the Corine Land Cover datasets

(1990, 2000, 2006, 2012, and 2018), the land cover of the region was determined in 5 different classes (artificial surfaces, agricultural, forest, water, and others). LC/LU changes between 1990 and 2018 were determined using the Puyravaud land cover change rate and hot spot analysis methods.

Xia *et al.*, (2023), in an article, review the progress in research related to land use transformation. The results of this research show that land use transformation is a process in which land use patterns change from one state to another under the influence of socio-economic development. The concept was initially proposed in forestry studies, but over time, it has evolved into an analytical model for examining land use/land cover changes. In the early 21st century, this concept was introduced to China by Professor Hualuo Long and gradually gained attention in both academic research and government policymaking. Initially, land use transformation mainly referred to structural and temporal changes in land use, but with research advancements, the concept has expanded to include both overt (e.g., area, quantity, space) and covert (e.g., quality, ownership, function) dimensions of land. The findings of this research indicate that land use transformation is not only a reflection of physical land changes in response to socio-economic development but also a reflection of the interactions and conflicts among various stakeholders in the process of land planning and management.

The Area under Study

Gomishan County, with the city of Gomish Tappeh as its center, is one of the 14 counties of Golestan Province. The city is located in the northernmost part of the eastern coast of the Caspian Sea and is bordered by Turkmenistan to the north, Bandar Torkaman County to the south, Aq Qala County to the east, and the Caspian Sea to the west. The distance from this county to Bandar Torkaman is approximately 19.5 kilometers. Geographically, the county is situated between 36 degrees 50 minutes to 37 degrees 8 minutes east longitude and 53 degrees 54 minutes to 54 degrees 2 minutes north latitude, and it is located in the low-lying, coastal plain of the eastern Caspian Sea. The average elevation of this area is about 25 meters below sea level, which has led to the formation of wetlands, saline, and swampy lands in vast parts of the region. The county has a semi-arid, Caspian climate with hot and humid summers and relatively mild winters. Due to its unique coastal location and proximity to the border, this area holds special economic, environmental, and geographical importance (Fig. 1).

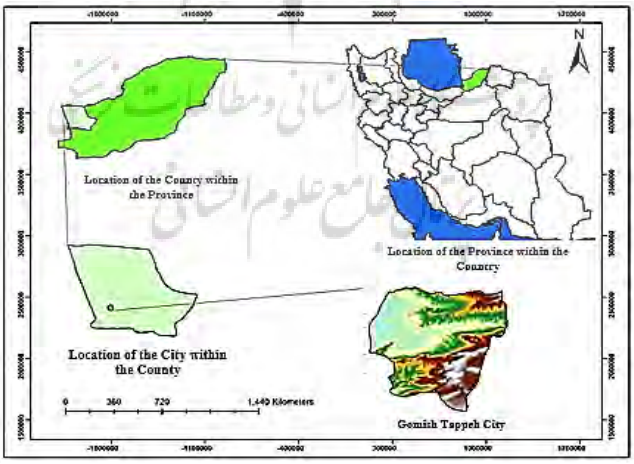

Fig 1. Geographical location of the city of Gomish Tappeh

Methodology

In the present study, the TM sensor image of the Landsat 5 satellite for August 1993, corresponding to July 1992, and the OLI sensor image of the Landsat 8 satellite for August 2023, corresponding to July 2022, were used to classify and analyze land use changes using the pixel-based and object-oriented methods. In order to prepare the images for classification and processing, the necessary preprocessing (including atmospheric, radiometric, and geometric correction) was first performed in the ENVI software using the FLAASH method. Then, object-oriented classification was performed in the eCognition Developer software and pixel-based classification was performed in the ENVI software, and then the kappa coefficient was used to evaluate the classification results to check the accuracy of the map classification. Finally, it was transferred to the Arc GIS software to obtain the final output, and the desired output was received from this software.After preparing the land use map, we took the DEM of the desired area from the USGS website and then in Arc GIS software, with the DEM of the area in hand, we obtained its slope and direction and the topography of the area. Then, by considering factors including slope, lithology, distance from the road, distance from the river, precipitation, soil and land use, using critical weighting and WLC (which is one of the multi-criteria decision-making methods) and fuzzy methods, a soil erosion zoning map was prepared under the influence of land use change in two time periods of 1993 and 2023.

- Satellite image preprocessing
- Atmospheric, radiometric and geometric correction

In this study, Radiometric Calibration and FLAASH tools were used to eliminate atmospheric and radiometric errors. After making the relevant corrections, Envi software was used to obtain the classification output using the pixel-based method, and eCognition software was used to obtain the classification output using the object-oriented method.

Identification indices

In this study, two indices (NDVI, normalized differential vegetation index) and (SAVI, soil-adjusted vegetation index), which are used in change detection applications and have high accuracy for preparing vegetation maps, are examined.

Satellite image processing

Pixel-based classification

In order to prepare training samples, Google Earth software was first used to better understand the area, then training samples were sampled using ENVI software.In two stages, separate collection and selection of test samples was done. The first stage is during classification and the other stage is the evaluation of classification accuracy. The basic pixel classification in this study was done based on the maximum likelihood algorithm. In basic pixel classification with the maximum likelihood algorithm, the pixels that are on the class dividing line must ultimately be assigned to one of the water, soil or plant classes (hard classification). This algorithm in the software calculates statistical parameters such as mean, variance and correlation between the data. In the next stage, assuming that the data distribution in each class is normal, the center of this distribution, which is the mean of the data, is calculated. Then, within a given search radius, it classifies the unclassified pixel in the class to which it belongs with maximum probability.• Class Determination

After determining the number of classes required for classification, the names and colors of the classes must be defined. This information, along with information about the visual characteristics of each class, provides the corresponding classes for pixel-based classification. In the land use maps of the study area in both the 1993 and 2023 time periods, lands were divided into 4 classes including irrigated agriculture, dryland, pasture, and man-made areas.

Object-oriented classification

The object-oriented classification method is a process that links different land cover classes to image objects. After the classification process, each image object is assigned to one of the classes. This type of classification is based on a fuzzy logic model and converts the value of the features into a fuzzy value (between zero and one) with a certain membership degree for each class.In this process, pixels with different membership degrees are classified into more than one class and based on the membership degree for each class, classification is done based on the nearest neighbor model. Then, the membership degrees for each class are measured to be the basis for fuzzy classification in the object-oriented method.

Weighted Linear Combination (WLC)

In this model, first the map layers that are considered evaluation criteria are determined, and then each criterion map layer is standardized. In this research, the fuzzy model has been used for standardization. In fuzzy sets, the highest value, i.e. the value of one, is assigned to the maximum membership and the lowest value, i.e. zero, is assigned to the minimum membership in the set.After standardization, the weights of the criteria are determined and a weighted criterion is assigned to each map relatively; in the current study, the erosion assessment criteria include seven criteria: land slope, soil, precipitation, lithology, land use, distance from the river, and distance from the road. In this study, the critical path method has been used. In this method, the data are examined based on the degree of interference and conflict between the criteria.

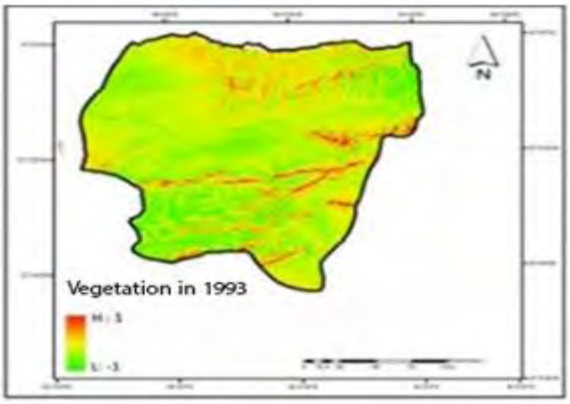

Fig 2. NDVI Index in 1993

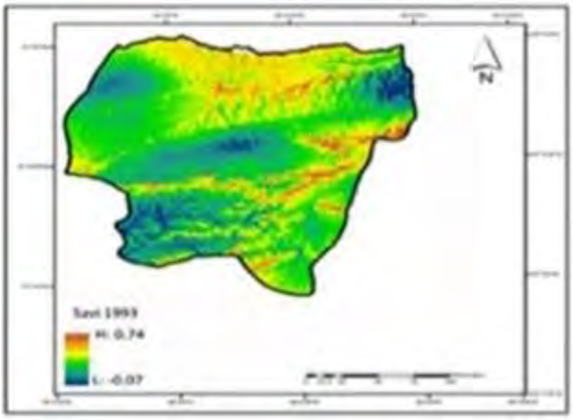

Fig 3. SAVI Index in 2023

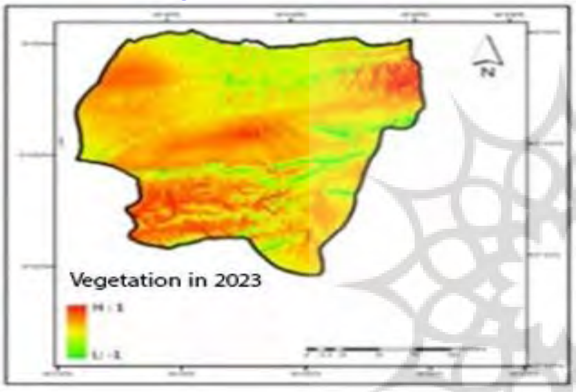

Fig 4. NDVI Index in 2023

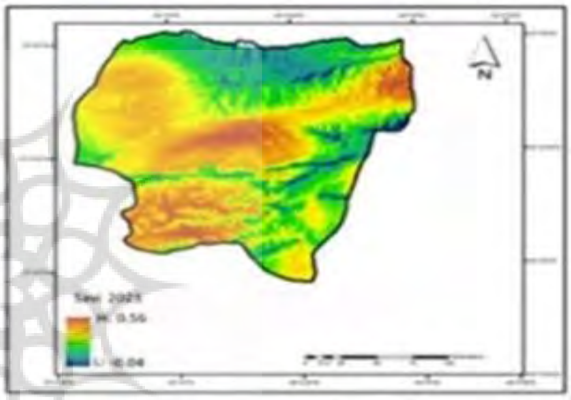

Fig 5. SAVI Index in 2023

Results and discussion

Results of the Analysis of NDVI and SAVI Indices in the Study Area

Given that vegetation cover is one of the most fundamental and important factors influencing the increase or decrease of erosion, vegetation cover indices were calculated for the study area. For this purpose, images from August of 1993 and 2023 were used to apply the vegetation indices. Since most pastures tend to turn yellow during this month, they are therefore included in the soil class when the index is classified into subclasses. The only features identified as vegetation cover in this season are irrigated fields, which are green. The generated NDVI and SAVI maps for the two selected images are shown in the respective figures.

According to the results, the minimum value of the NDVI index in 1993 was -0.32 and the maximum value was 0.65. In 2023, the region's vegetation cover increased compared to 1993. This increase in values during the study period amounted to 16,315 hectares. For the SAVI index, the minimum value in 1993 was -0.47 and the maximum was 0.98. This statistic for the SAVI index from 1993 to 2023 is 501,530 hectares. What is certain is the significant change in 2023 compared to 1993 for both indices. These values indicate the excessive use of river water and groundwater resources.

Satellite Image Classification

Based on the study objectives, the supervised classification method was used to prepare the land use/land cover map of the coastal city of Gomish Tappeh. Through field visits and an assessment of the conditions in the study area, four types of land use were ultimately identified: built-up areas, irrigated farmlands, pasture, and rainfed farmlands (Fig. 6).

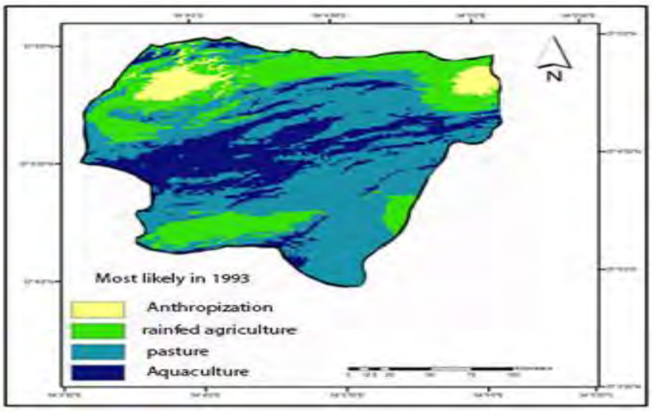

Fig 6. Land use map extracted with the maximum likelihood algorithm using the pixel-based classification method, 1993

According to the resulting figure and the area data, the largest area in the study region in 1993, using the pixel-based method, belonged to pasture. After pasture, the largest area in 1993 was extracted for irrigated farmlands. Most parts of this mapped region are irrigated agricultural lands, which are observed in most areas. Rainfed farmlands, after pasture and irrigated farmlands, accounted for an area of 6,168 hectares. The smallest area in this classification method belonged to built-up areas (3,260 ha), which is a natural outcome (Fig. 7).

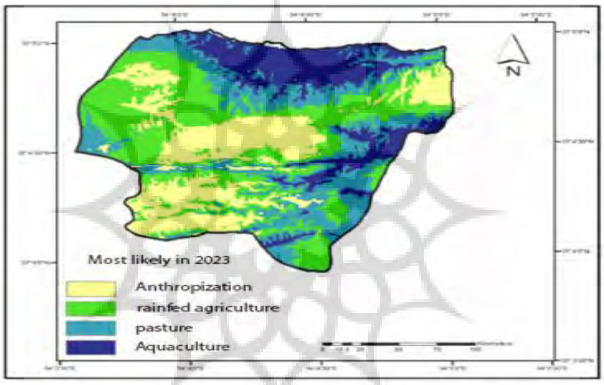

Fig 7. Land use map extracted with the maximum likelihood algorithm using the pixel-based classification method, 2023

According to the map obtained in 2023, the largest area belonged to built-up areas, with a value of 56,315 hectares. The smallest land use areas were, in order: irrigated farmlands (512 ha), pasture (4,973 ha), and rainfed farmlands (10,980 ha).

The extent and rate of change for the land use classes in the study area of Gomish Tappeh between 1993 and 2023, using the pixel-based method, are shown in the table. The results indicate a decrease in the amount of irrigated farmlands and an increase in the rest of the land uses. This increase in rainfed farmlands was particularly significant. It seems that a decrease in rainfall in recent years could be one of the reasons for this trend (Table 1).

Table 1. Area and amount of change for land uses classified by the pixel-based method

Land Use Type	Area (ha) 1993	Area (ha) 2023	Change Amount (ha)	Change Trend
Irrigated Farmlands	7,390	512	-6,878	Decreasing
Rainfed Farmlands	6,168	10,980	4,812	Increasing
Pasture	14,198	4,973	-9,225	Decreasing
Built-up Areas	3,260	56,315	53,055	Increasing

Object-Oriented Classification

First, image segmentation was performed using a multi-scale segmentation model. For this purpose, suitable values for the segmentation of the image were selected through trial and error by analyzing the results of image segmentation with different scale parameters, considering the spatial resolution of the image and the large size of the study area. These values are shown in the figure and table (Table 2).

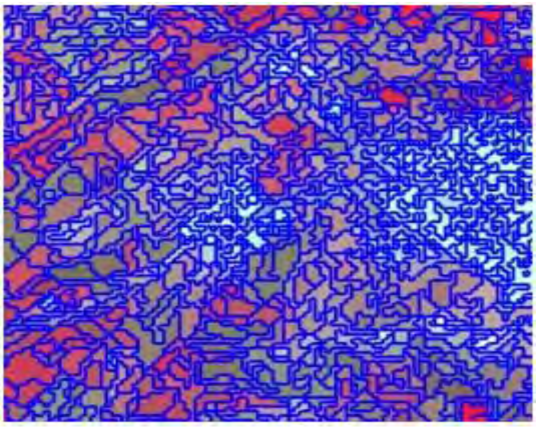

Fig 8. Image segmentation for 2023 with a scale of 20 (shape factor 0.5 and compactness factor 0.5)

Table 2. Effective parameters for segmentation

Segmentation Parameters	**Values (Applied Weight)**
	1993
Scale	12
Shape factor	0.4
Compactness factor	0.5

Next, classification was performed several times in the eCognition software to achieve the highest degree of membership (based on the nearest neighbor algorithm) for the classes. The land use maps for Gomish Tappeh for the years 1993 and 2023, using the object-oriented method, were obtained as shown in the respective figures (Fig. 9).

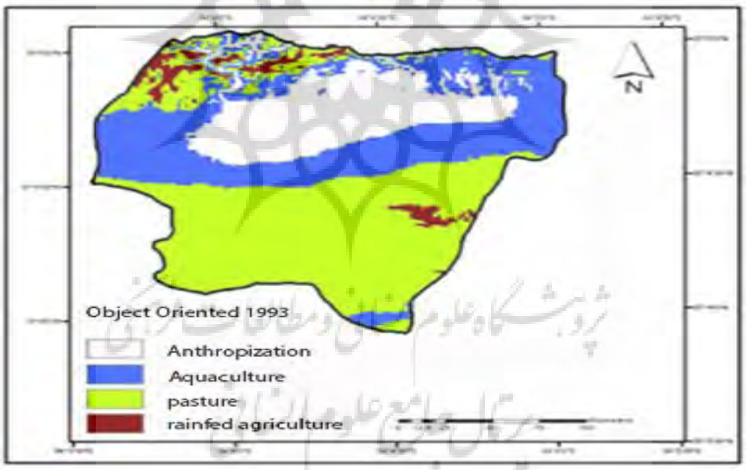

Fig 9. Land use extracted with the nearest neighbor algorithm in the object-oriented method, 1993

According to the resulting map, the largest area in 1993 belonged to pasture with 26,594 hectares, followed by irrigated farmlands with 6,551 hectares. The smallest areas were for rainfed farmlands with 946 hectares and built-up areas with 482 hectares, respectively (Fig. 10).

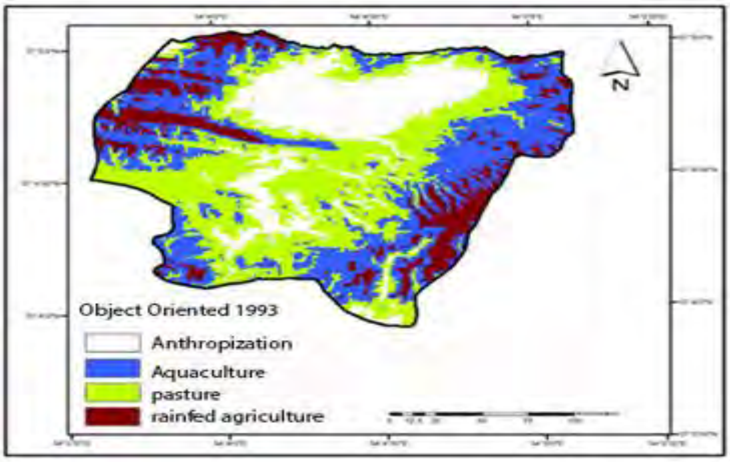

Fig 10. Land use extracted with the nearest neighbor algorithm in the object-oriented method, 2023

The results show that in 2023, the largest area belonged to pasture, at 22,816 hectares. Irrigated farmlands accounted for 4,853 hectares, built-up areas for 3,673 hectares, and rainfed farmlands for 3,911 hectares (Table 3).

Table 3. Area and change amount of land uses classified by the object-oriented method

Land Use Type	Area (ha) 1993	Area (ha) 2023	Change Amount (ha)	Change Trend
Irrigated Farmlands	6,551	4,853	-1,698	Decreasing
Rainfed Farmlands	946	3,911	2,965	Increasing
Pasture	26,594	22,816	-3,778	Decreasing
Built-up Areas	482	3,673	3,191	Increasing

Classification Accuracy Assessment

Classification accuracy for all images was calculated using a confusion matrix. Producer's accuracy, overall accuracy, user's accuracy, and the kappa coefficient were extracted in ENVI software, and the results of the accuracy assessment are presented in the tables below (Table 4 , 5).

Table 4. Accuracy assessment results for land use classified images (pixel-based method) in percent

Year	Land Use	User's Accuracy	Producer's Accuracy	Kappa Coefficient	Overall Accuracy
1993	Irrigated Farmlands	85.30	94.43		95.46
	Rainfed Farmlands	90.50	99.30	0.93	
	Pasture	99.90	99.50		
	Built-up Areas	96.10	88.30		
2023	Irrigated Farmlands	85.36	94.48		96.23
	Rainfed Farmlands	95.51	99.31	0.94	
	Pasture	99.91	99.55		
	Built-up Areas	96.19	88.34		

Table 5. Accuracy assessment results for land use classified images (object-oriented method) in percent

Year	Land Use	User's Accuracy	Producer's Accuracy	Kappa Coefficient	Overall Accuracy
1993	Irrigated Farmlands	88.71	90.76	0.95	96.67
	Rainfed Farmlands	91.59	95.47		
	Pasture	93.49	93.56		
	Built-up Areas	98.90	98.23		
2023	Irrigated Farmlands	89.59	93.48	0.96	95.54
	Rainfed Farmlands	96.41	98.74		
	Pasture	97.51	97.34		
	Built-up Areas	97.16	98.42		

Change Detection

In this research, the post-classification comparison method was used for change detection. As noted, images were first classified separately using both the pixel-based and object-oriented methods. The final changes in land use classes were then analyzed based on the maps obtained from the object-oriented method due to its higher accuracy. In the pixel-based post-classification comparison, the area of these changes is obtained on a one-to-one basis. a general summary of the changes that occurred between 1993 and 2023 is presented. It is clear that the increase in rainfed farmlands was accompanied by a decrease in pastures. Additionally, the decrease in irrigated farmlands was accompanied by an increase in built-up areas. Based on the 1993 to 2023 change matrix, 3,877.36 hectares of pasture were converted to rainfed farmlands. A detailed, class-by-class breakdown of the changes is provided, where the estimated percentage of change is relative to the changes within the same land use (Table 6).

Table 6. Change matrix between 1993 and 2023 in hectares

1993 Land Use	2023 Land Use			
	Irrigated Farmlands	**Rainfed Farmlands**	**Pasture**	**Built-up Areas**
Irrigated Farmlands	1,908.38	803.38	970.84	769.32
Rainfed Farmlands	337.90	1,956.92	3,664.07	220.14
Pasture	1,168.27	3,877.36	19,787.77	432.27
Built-up Areas	4.05	0	432.27	392.22

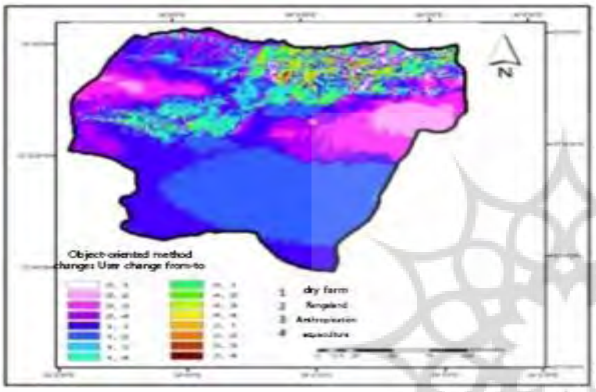

Fig 11. Changes between the year 1993 in hectares

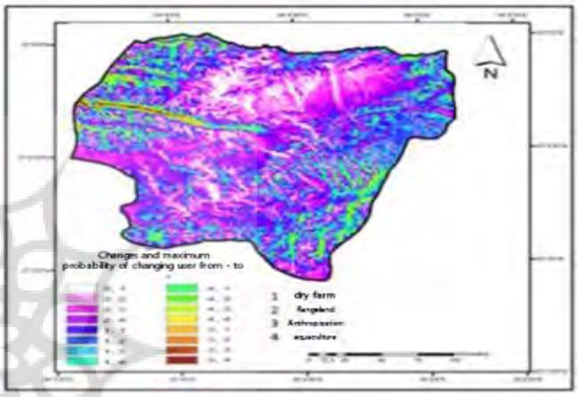

Fig 12. Changes between the year 2023 in hectares

Soil Erosion Zoning - Determining the Importance or Weight of Each Criterion

In the assessment of soil erosion for the land use in question, not all criteria are of equal importance; some act as key and critical factors. Accordingly, to rank the importance of the decision-making criteria for the intended purpose, the factors are weighted. To integrate the criteria for the soil erosion assessment, the Weighted Linear Combination (WLC) method was used. Using this method, the rate of erosion for the studied land uses is calculated based on a linear combination of criteria, taking into account their relative degree of importance.

Therefore, for erosion zoning, based on the land use map for the two time periods (1993 and 2023) and the maps of other relevant criteria, the weighting of the criteria was first performed. The underlying assumptions and final weights obtained from the Kritik weighting method among the criteria considered for the erosion zoning of Gomish Tappeh, using the pixel-based, object-oriented, and ARAS methods, are presented in the following tables (Table 7).

Table 7. Total Conflict, Standard Deviation, Information Amount, and Final Weight in Pixel-Based Erosion Zoning

With the 1993 Land Use Map				
Criterion	**Total Conflict**	**Standard Deviation**	**Information Amount**	**Final Weight**
Slope	3.66	0.39	1.7	0.16
Lithology	2.10	0.32	1.6	0.14
Land Use	2.48	0.41	1.5	0.16
Soil	2.00	0.18	1.9	0.14
Precipitation	2.14	0.27	0.96	0.12
Distance from River	2.27	0.41	0.91	0.12
Road	2.28	0.40	0.91	0.12

With the 2023 Land Use Map				
Slope	3.39	0.31	1.1	0.16
Lithology	2.47	0.32	1.7	0.14
Land Use	3.29	0.35	1.7	0.14
Soil	2.70	0.38	1.8	0.14
Precipitation	2.30	0.37	1.9	0.12
Distance from River	2.35	0.42	1.9	0.12
Road	2.19	0.40	1.8	0.11

Table 8. Total Conflict, Standard Deviation, Information Amount, and Final Weight in Object-Oriented Erosion Zoning

With the 1993 Land Use Map				
Criterion	**Total Conflict**	**Standard Deviation**	**Information Amount**	**Final Weight**
Slope	3.30	0.31	1.12	0.15
Lithology	2.29	0.32	0.99	0.14
Land Use	2.28	0.54	1.27	0.17
Soil	2.69	0.39	1.04	0.15
Precipitation	2.30	0.37	0.98	0.19
Distance from River	2.40	0.42	0.82	0.12
Road	2.29	0.40	0.94	0.16
With the 2023 Land Use Map				
Slope	3.52	0.39	1.16	0.16
Lithology	2.49	0.32	1.03	0.14
Land Use	2.38	0.44	1.08	0.15
Soil	2.60	0.38	1.04	0.14
Precipitation	2.61	0.32	0.82	0.12
Distance from River	2.30	0.41	0.94	0.12
Road	2.25	0.40	0.92	0.10

Table 9. Total Conflict, Standard Deviation, Information Amount, and Final Weight in ARAS Erosion Zoning

With the 1993 Land Use Map				
Criterion	**Total Conflict**	**Standard Deviation**	**Information Amount**	**Final Weight**
Slope	3.52	0.39	1.16	0.16
Lithology	2.49	0.32	1.03	0.14
Land Use	2.38	0.44	1.08	0.15
Soil	2.60	0.38	1.04	0.14
Precipitation	2.61	0.32	0.82	0.12
Distance from River	2.30	0.41	0.94	0.12
Road	2.25	0.40	0.92	0.10
With the 2023 Land Use Map				
Slope	3.66	0.39	1.7	0.16
Lithology	2.10	0.32	1.6	0.14
Land Use	2.48	0.41	1.5	0.16
Soil	2.00	0.18	1.9	0.14
Precipitation	2.14	0.27	0.96	0.12
Distance from River	2.27	0.41	0.91	0.12
Road	2.28	0.40	0.91	0.12

These criteria and indices have been selected in a valid and precise manner to provide the best estimate of erosion intensity. In 2023, the highest final weight was obtained for the Slope factor (0.16). The influence of the slope index has been examined and confirmed in various studies and sources. Following that, the Land Use index ranked next with a weight of 0.15, and then Soil with a weight of 0.14. This criterion is determined based on soil type, texture, organic matter content, and the permeability of the soil structure. A weight of 0.14 was obtained for the Lithology index. The least important formations in terms of sediment production and erosion were found to be grains of various origins (dacitic-rhyodacitic protrusions and lava flows, light gray rhyodacite, rhyolite protrusions and lava). The highest weight and importance were given to old terraces and alluvial fans.The Distance from River index was ranked next. Both surface runoff on slopes and water that infiltrates the ground are components that stimulate slope materials. A clear principle is that wherever the slope is steep and the geological formations are optimal, waterways intensify erosion by removing the support of slope materials and undercutting the slopes. Following this is the Precipitation index, which was examined by identifying key meteorological stations in the Gomish Tappeh area and estimating monthly and annual rainfall at these stations during the studied time period.Distance from Road is another criterion whose role in causing erosion can be examined. Generally, road construction operations lead to the concentration of upstream runoff in the waterways beneath roads and the creation of gullies in the downstream section of the road. Additionally, examining the distance from roads is very important due to its role in undercutting and removing the toe of the slope and altering slope gradients.

Erosion Zoning Using the Land Use Map from the Pixel-Based Method

Erosion zoning was performed using the relevant land use map and criteria with the pixel-based method. The resulting maps for this zoning in 1993 and 2023 are shown in the respective figures. The area and pixel count for each risk class in the pixel-based method are also listed in the table (Table 10).

Table 10. Erosion Risk Class Data for Gomish Tappeh in 1993 and 2023 using the Pixel-Based Method

Risk Class		Very High Risk	High Risk	Medium Risk	Low Risk	Very Low Risk
Value Range		0.80 - 1	0.60 - 0.79	0.40 - 0.59	0.20 - 0.39	0 - 0.19
1993	Area (ha)	4,232	6,808	5,305	4,300	2,767
	Area (%)	16.37	27.93	22.12	22.02	11.56
2023	Area (ha)	1,747	8,176	8,760	8,148	4,681
	Area (%)	5.58	27.26	25.40	26.47	15.29

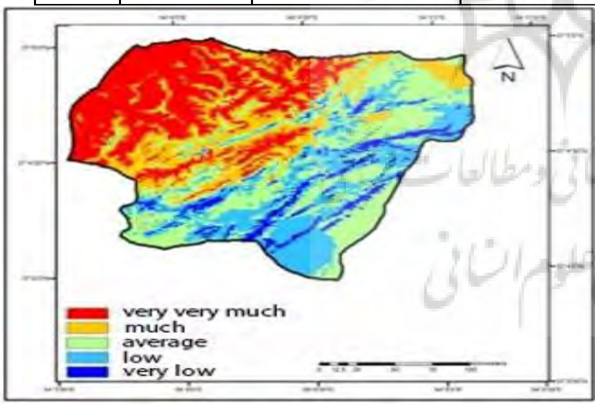

Fig 13. Erosion Risk Class Data for Gomish Tappeh in 1993 using the Pixel-Based Method

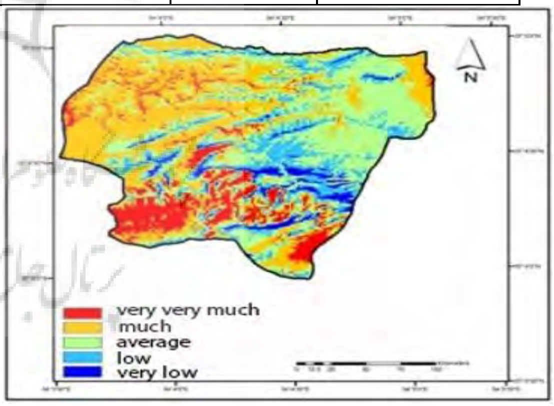

Fig 14. Erosion Risk Class Data for Gomish Tappeh in 2023 using the Pixel-Based Method

The erosion zoning maps of the study area for 1993 and 2023 using the pixel-based method show that the very high-risk and high-risk classes are mostly located in rainfed farmlands, irrigated farmlands, and parts of the pastures, while the low-risk and very low-risk areas are in built-up areas. In the study area in 1993, the area of the high-risk class (equivalent to 8,808 ha) was larger than the other classes, followed by the medium-risk class. In 2023, the high-risk class, with a decrease of 209 hectares compared to 1993, ranked first. In 2023, the very high-risk class also saw a decrease of 3,431 hectares, which can be attributed to the reduction in pastureland area, a portion of which was located in high-risk zones according to this zoning method. According to the results from the pixel-based zoning method, the areas of the very low-risk and low-risk classes increased in 2023, which also includes the built-up areas.

Erosion Zoning Using the Land Use Map from the Object-Oriented Method

By performing the other steps of the WLC model, the soil erosion zoning map of Gomish Tappeh was obtained in five classes from very high risk to very low risk for the years 1993 and 2023 using the object-oriented method. The value range for these classes is 1.3 to 4.3 (Table 11).

Table 11. Erosion Risk Class Data for Gomish Tappeh in 1993 and 2023 using the Object-Oriented Method

Risk Class		Very High Risk	High Risk	Medium Risk	Low Risk	Very Low Risk
Value Range		0.80 - 1	0.60 - 0.79	0.40 - 0.59	0.20 - 0.39	0 - 0.19
1993	Area (ha)	3,975	5,216	7,056	10,104	5,161
	Area (%)	12.50	16.40	22.19	32.68	16.23
2023	Area (ha)	5,811	6,070	5,915	8,811	4,905
	Area (%)	18.28	19.09	18.60	28.61	15.42

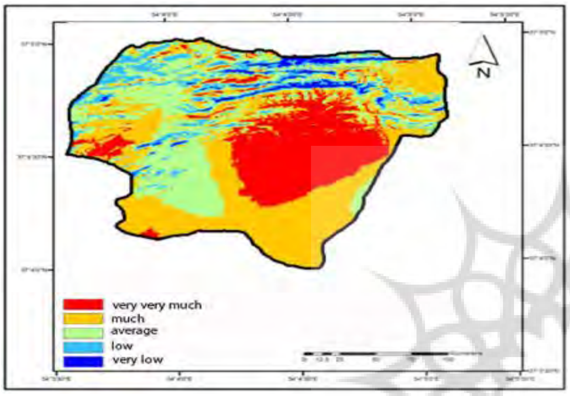

Fig 15. Erosion zoning map of Gomish Tappeh city in 1993 using the WLC method (object-oriented method)

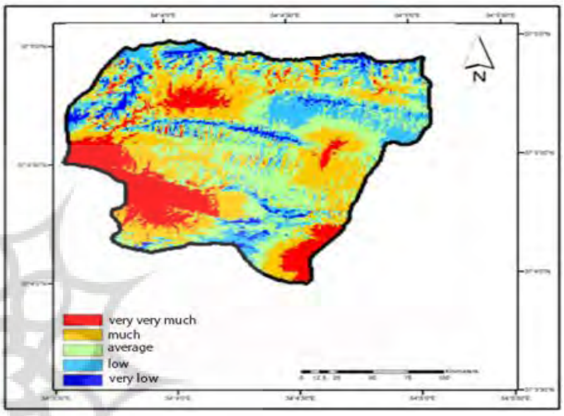

Fig 16. Erosion zoning map of Gomish Tappeh city in 2023 using the WLC method (object-oriented method)

Soil Zoning Using the ARAS Method

To assess erosion risk using the ARAS method, factors such as slope, soil, lithology, distance from roads, distance from waterways, and precipitation were first identified as influential factors in the watershed's soil erosion, based on the natural and human conditions of the area.

Based on the erosion zoning maps of the study area, it can be said that in the erosion maps for 1993 and 2023, the very high-risk and high-risk classes are mainly located in rainfed and irrigated farmlands. The pasture land use is mostly at medium risk, and the very low-risk areas are predominantly located in built-up areas. It seems that one of the reasons for the increase in the area of high-risk classes is the conversion of land use. Given that the study area does not have significant limitations in terms of water supply for agriculture, most pastures have been converted by local villagers to agricultural lands (irrigated and rainfed crops). Furthermore, since most agricultural lands in the area are located on steep slopes and have been converted from forest and pasture lands, the fertile soil and material are gradually lost due to erosion over time. Additionally, based on the lithology of the region, most rainfed and irrigated farmlands are situated in areas with formations sensitive to erosion (alluvial fans and young alluvial terraces) and slopes greater than ten percent.

A comparison of the results from the object-oriented and pixel-based erosion zoning maps for the period 1993 to 2023 indicates that in both methods, rainfed farmlands, irrigated farmlands, and parts of the pastures are in the high-risk erosion class, and built-up areas face a low risk of erosion. However, the change in the area of the risk classes was different between these methods. For example, in the pixel-based method, the area of the very high-risk class decreased in 2023, which can be attributed to the decrease in the area of irrigated farmlands according to the pixel-based land use classification. This is in contrast to the object-oriented method, where the area of this risk class increased in 2023 compared to 1993, which can be attributed to the increase in the area of rainfed farmlands in the land use classification by the object-oriented method. It should be noted that the conversion of pasturelands to agricultural fields, especially in areas with high slopes, will not only cause soil erosion but also lead to flooding and affect soil quality (Table 12).

Table 12. Erosion Risk Class Data for Gomish Tappeh in 1993 and 2023 using the ARAS Method

Risk Class		Very High Risk	High Risk	Medium Risk	Low Risk	Very Low Risk
Value Range		0.80 - 1	0.60 - 0.79	0.40 - 0.59	0.20 - 0.39	0 - 0.19
1993	Area (ha)	4,060	21,610	19,623	5,535	3,457
	Area (%)	11.56	34.28	25.99	21.91	6.26
2023	Area (ha)	9,355	9,249	1,910	2,940	8,058
	Area (%)	31.52	24.57	9.10	11.37	23.44

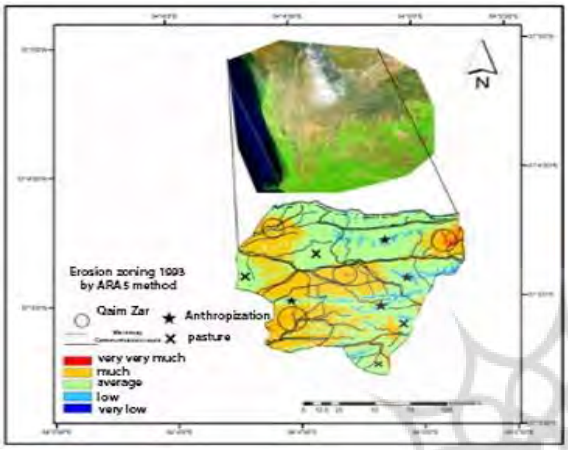

Fig 17. Erosion Risk in Gomish Tappeh in 1993

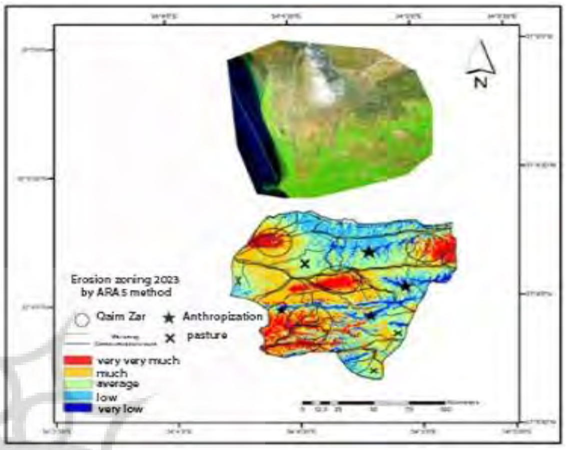

Fig 18. Erosion Risk in Gomish Tappeh in 2023

Conclusion

The results of this study align with the findings of researchers such as Chen et al. (2019) and Poussant et al. (2021), whose studies identified object-oriented classification as the most accurate method for preparing land use maps. The findings confirm that object-oriented methods, by leveraging knowledge-based algorithms, can overcome the weakness of the pixel-based approach, which fails to use the geometric and textural information of objects. Similarly, in this research, the ARAS method successfully differentiated regular geometric shapes like agricultural and built-up areas. However, the pixel-based and object-oriented methods did not provide a good distinction, especially for irrigated farmlands and residential areas.

After performing the classification with the ARAS method (due to its higher accuracy), the results were prepared as a map to better extract and understand the land uses. The results from the maps and existing statistical data indicate that, for the period between 1993 and 2023, the very high and high-risk erosion zones have faced a relative increase. Consequently, it can be stated that factors such as the unprincipled exploitation of pastures, the destruction of vegetation due to the conversion of pasturelands to agricultural land, dry farming on steep slopes, the plowing of pastures on steep slopes, a lack of crop rotation, the improper use of riverbeds and riparian zones, and the increase of residential and built-up areas, along with other factors like erosion-sensitive and loose Quaternary formations, adequate rainfall, and an abundant waterway network, are the most important factors involved in soil erosion in the city of Gomish Tappeh.

The increase in rainfed farmlands has been accompanied by a decrease in pastures. Furthermore, the decrease in irrigated farmlands has been accompanied by an increase in built-up areas. During the mentioned time interval, the most significant change was a decrease in pastureland, while the most important change was the increase in rainfed farmlands. According to the results of the erosion risk zoning for Gomish Tappeh, the area of the very high-risk and high-risk classes increased in 2023, which can be attributed to the increase in the area of rainfed farmlands and the decrease in pastures. Given the topography of the study area, the conversion of pastures around villages into rainfed farmlands and the plowing of pastures on steep slopes increase the probability of erosion. Therefore, according to the erosion zoning maps for the study area in 1993 and 2023, the very high-risk and high-risk areas are mainly found in rainfed and irrigated farmlands, a significant portion of pastures faces a medium risk, and built-up areas are in the low-risk class.

These results are consistent with the findings of Tiwari et al. (2022) in India, Touriman et al. (2020) in Malaysia, and Ghahremannejad et al. (2017) in the Kali Burchay region, who all stated that agricultural land use has the highest rates of erosion and runoff. In conclusion, the results of this research indicate that optimizing land use in Gomish Tappeh is a necessary and unavoidable measure to reduce erosion and resource loss, which is of great importance for the sustainable management of the study watershed, and appropriate management actions must be considered. In response to the user's request, I will provide a summary of the practical recommendations for Gomish Tappeh based on the research findings.

Based on the research findings, including the analysis from the ARAS and object-oriented methods and land use change trends from 1993 to 2023, the following practical recommendations are proposed for Gomish Tappeh to reduce erosion, optimize land use, and achieve sustainable resource management:

1. Implement Rangeland Vegetation Restoration Plans: Given the trend of decreasing pastures, it is essential to develop and restore native plant cover to prevent soil erosion and stabilize sloped lands.

2. Prohibit Plowing on Steep Slopes: Strict regulations must be adopted to prevent the conversion of pasturelands on steep slopes to rainfed farmlands.

3. Use Conservation Tillage Patterns: Implementing **conservation agriculture** (such as strip cropping, no-tillage, and mulching) on erosion-prone lands can help reduce runoff and preserve soil.

4. Organize the Development of Built-up Areas: The development of residential and infrastructural areas should be controlled and guided by **land use planning principles** to prevent damage to fertile lands and natural resources.

5. Implement Crop Rotation Plans: Adopting **crop rotation systems** is necessary to maintain soil fertility, reduce pests, and stabilize the productivity of agricultural lands.

6. Prevent Improper Use of Riverbeds: The buffer zones of rivers must be protected, and any encroachment, cultivation, or construction in these areas should be prohibited.

7. Educate and Empower Farmers: Providing training courses on **sustainable agriculture**, soil and water resource management, and erosion control can effectively change the behavior of land users.

8. Develop and Implement a Comprehensive Land Use Management Plan: A comprehensive roadmap based on erosion risk zoning data and remote sensing information is recommended to guide the optimal management of land uses.

9. Continuous Monitoring Using Satellite and Remote Sensing Data: Using modern technologies for the continuous monitoring of land use changes and identifying critical areas is essential.

10. Develop Multi-Purpose Land Use Patterns: Employing a combination of land uses (such as afforestation alongside agriculture or rangeland management in low-yield areas) can integrate resource exploitation with conservation.

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