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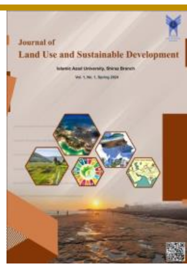

Original Research Paper

Evaluation of land use changes and their effects on soil erosion using multi-criteria decision-making algorithms and modern remote sensing methods (Case study: Gomish Tepe coastal city)

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abstract

One of the environmental consequences and conflicts of land use and land cover changes is the intensification of soil erosion, which seriously threatens the water and soil resources of cities. Therefore, there is a need to regularly identify the spatial dimensions of land use and land cover and its effects on cities so that policymakers and researchers can make the necessary decisions. Satellite data is one of the fastest and least expensive methods available to researchers to prepare land use maps. This study aimed to assess the changes in land use percentage and its impact on erosion between 1993 and 2023 in the city of Gomish-Tepe, located in Golestan province.For this purpose, initially, using the TM and OLI sensor images of the Landsat satellite, a vegetation cover percentage map was prepared, and after atmospheric and radiometric correction, a land use map was prepared using the pixel-based method (maximum likelihood algorithm), the object-oriented method (nearest neighbor algorithm), and the ARAS method. Then, the most important methods for assessing accuracy, including overall accuracy and classification kappa coefficient, were extracted. An erosion zoning map was prepared using the resulting land use maps and factors including slope, lithology, distance from the road, distance from the river, precipitation, and soil using the critical weighting method and the WLC method. The results showed that in the resulting land use map between 1993 and 2023, the increase in rainfed areas was accompanied by a decrease in pastures, and the largest change was related to pasture use, which had a decreasing trend. Also, according to the 1993 and 2023 erosion zoning maps, the city of Gomish Tepe is in two categories: very high risk and high risk.The reason for the increase in the area of very high-risk and high-risk erosion classes in the studied basin can be attributed to the conversion of pasture-covered lands to rainfed agricultural lands, the plowing of pastures on steep slopes, the increase in residential areas on the riverbanks, and the failure to respect the river's boundaries, which accelerates the erosion process

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Introduction

Ecosystems are constantly changing, and this change may be due to natural interactions of vegetation or to human interventions such as land use change, etc. Human and natural factors have various effects on the forms and phenomena of the earth's surface in different conditions. Depending on the intensity and power of the aforementioned factors, the map and process of changes will differ. Monitoring changes is the process of determining differences in the state of a phenomenon or object by observing it at different times. (Arkhi et al., 2010). Data resulting from land use change maps is one of the principles of natural resource management. Awareness of the proportion of uses in an environment and the conditions of its changes over time has been one of the most key issues in planning.By knowing the extent of change and transformation in land uses over time, future changes can be predicted and necessary actions can be taken. Monitoring and identifying change involves using a set of multi-temporal data to quantitatively analyze the temporal effects on phenomena. Given the high cost and timeliness of preparing these maps using ground operations, in recent years, the use of satellite images has been proposed as an efficient and optimal method for assessing environmental changes (Faizizadeh and Salmani, 2010). In addition, due to the advantage of repeated data acquisition, digital format, and synoptic view optimized for computer processing, remote sensing information has become the most effective data source for various applications of change monitoring in all the past years (Arkhi et al., 2010)

Literature review

Unprincipled and incorrect exploitation of soil resources has caused the destruction of many valuable agricultural and irrigated lands, which has ultimately led to soil erosion. To reduce the economic and environmental impacts resulting from irrational exploitation of land use, a type of regional planning is needed. In this way, sustainable development in natural and agricultural resource lands will be achieved by protecting resources, using them properly and sustainably, and reducing their loss and damage. Although it is not possible to completely stop erosion in terms of natural conditions, reducing the rate of erosion in watershed areas and water and soil exploitation programs is an effective and very important need. Among the appropriate measures to reduce erosion and protect soil is the optimization of the management of various types of soils and a set of biological operations.By optimizing land use and some biological operations, land use levels can be changed in a way that produces the most benefit and the least erosion (Moeini et al., 2019) Research question: - What impact have land use changes in the city of Gumish Tepe had on the soil erosion process? The aim of this research is to evaluate land use changes and their effects on soil erosion using a multi-criteria decision-making algorithm and modern remote sensing methods (case study: coastal city of Gumish Tepe).

: Seyam et al. (2023) have identified changes in land use cover (LULC) using remote sensing and a GIS approach in a case study in Bangladesh. This change has been identified in five classes over the past two decades using Landsat 7 and 8 images in Arc GIS 10.8. The overall accuracy was 87.2 percent for 2002 and 89.6 percent for 2022. The built-up area experienced the most significant changes, increasing by 217.1 percent (6.56 km2) by the urbanization and industrialization process which has a significant impact. Bozkurt et al. (2023) investigated the land cover and land use change affecting forest and semi-natural ecosystems in the Istanbul metropolitan area (Turkey) between 1990 and 2018. For this purpose, using the Corin land cover dataset (1990, 2000, 2006, 2012 and 2018), the land cover of the region was determined in 5 different classes (artificial surface, agriculture, forest, water, water). It was generated and tabular data was created. LC / LU changes between 1990 and 2018 were determined according to the Puyravaud land cover change rate and hot spot analysis methods. Lotfalizadeh Lahrudi (1402) studied land use changes in the Shahrchay watershed of Urmia through Landsat satellite images of TM and OLI-TIRS sensors for the years 1995, 2005, and 2021. In order to prepare land use maps of the region, the supervised classification method and the maximum likelihood algorithm were used in ENVI software.The results of the study of land use changes showed that during the statistical period under study, agricultural land uses and orchards, residential areas and water areas have had an increasing trend and their area has increased in each period. In contrast, the area of barren lands and pastures shows a decreasing trend. Arkhi et al. (1401) in their study titled Evaluation of Vegetation / Land Use Change Techniques Using Satellite Images and GIS (Case Study: Gorganrood Basin) aimed to monitor land cover changes using satellite images in the Gorganrood watershed in Golestan province. In this study, TM sensor images from 1987, ETM sensor from 1990 and OLI sensor from 2010 were processed and analyzed. After determining the change threshold, areas with decreasing, increasing and no change were identifiedUnprincipled and incorrect exploitation of soil resources has caused the destruction of many valuable agricultural and irrigated lands, which has ultimately led to soil erosion. To reduce the economic and environmental impacts resulting from irrational exploitation of land use, a type of regional planning is needed. In this way, sustainable development in natural and agricultural resource lands will be achieved by protecting resources, using them properly and sustainably, and reducing their loss and damage. Although it is not possible to completely stop erosion in terms of natural conditions, reducing the rate of erosion in watershed areas and water and soil exploitation programs is an effective and very important need. Among the appropriate measures to reduce erosion and protect soil is the optimization of the management of various types of soils and a set of biological operations.By optimizing land use and some biological operations, land use levels can be changed in a way that produces the most benefit and the least erosion (Moeini et al., 2019) Research question: - What impact have land use changes in the city of Gumish Tepe had on the soil erosion process? The aim of this research is to evaluate land use changes and their effects on soil erosion using a multi-criteria decision-making algorithm and modern remote sensing methods (case study: coastal city of Gumish Tepe).

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Study area

Gumishan County, centered on the city of Gumiş Tepe, is one of the 14 counties of Golestan Province. This city is located in the northernmost part of the eastern shore of the Caspian Sea and borders Turkmenistan to the north, Bandar Turkmen to the south, Aq Qala to the east, and the Caspian Sea to the west. This city is about 19.5 km away from Bandar Turkmen. This county is geographically located between 53 degrees and 54 minutes to 54 degrees and 2 minutes north latitude on the eastern coast of the Caspian Sea. Figure 1 shows the geographical location of the study area.

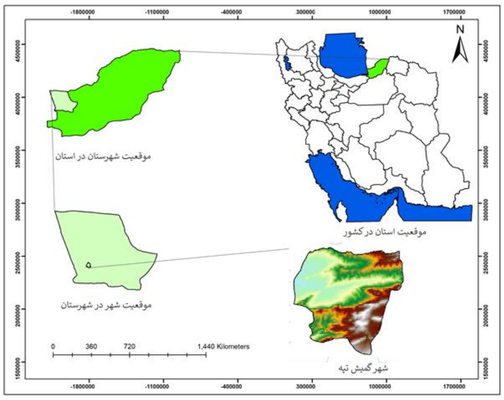

Figure 1. Geographical location of the city of Gomish Tepe

Methodology

▪ In the present study, the TM sensor image of the Landsat 5 satellite for August 1993, corresponding to Mordad 1371, and the OLI sensor image of the Landsat 8 satellite for August 2023, corresponding to Mordad 1401, 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.

• 4.1.3 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.

4.1.4 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

Results and discussion

Results of the NDVI and SAVI indices in the study area Considering that vegetation is one of the most important and effective factors in the increase or decrease in erosion, vegetation indices were calculated in the study area. In this way, images of August 1993 and 2023 were used to apply vegetation indices. Considering that in this month most of the pastures turn yellow, therefore, in the index classification into subclasses, they are included in the soil class and the phenomena that are considered vegetation are irrigated fields that are green in this season of the year. The NDVI and SAVI maps produced on the two selected images are shown in the figures, respectively

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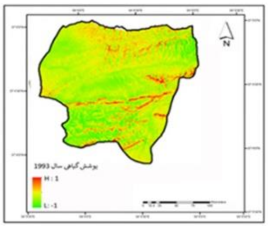

Figure 2 NDVI index in 1993

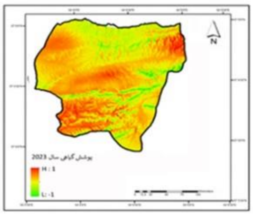

Figure 3 NDVI index in 2023

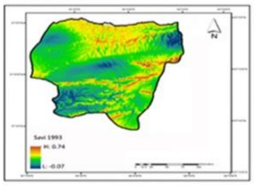

Figure 4 SAVI Index in 1993

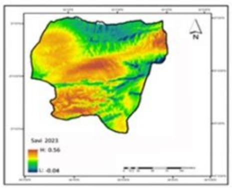

Figure 5 SAVI Index in 2023

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

Satellite image classification

Based on the objectives of the study, a supervised classification method was used to prepare a land use / cover map of the coastal city of Gomish Tepe. Through field visits and evaluation of the conditions of the study area, four types of land use were finally identified in the area: man-made lands, irrigated agriculture, pasture, and dry land

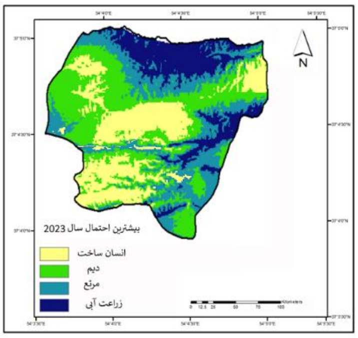

Figure 6: Land use map extracted with the maximum likelihood algorithm in the 1993 base pixel classification method

According to the resulting shape and the results obtained from the area, it is observed that the largest area in the study area in 1993 belongs to pasture land use with the pixel-based method. After pasture land use in 1993, the largest area was extracted for irrigated agriculture land use. Most of this area is mapped as irrigated agricultural land, which is observed in most areas. After pasture land use and irrigated agriculture, the dryland land use has also allocated an area of 6168 hectares of the study area. The smallest area in this classification method belongs to man-made areas (3260) hectares, which is natural

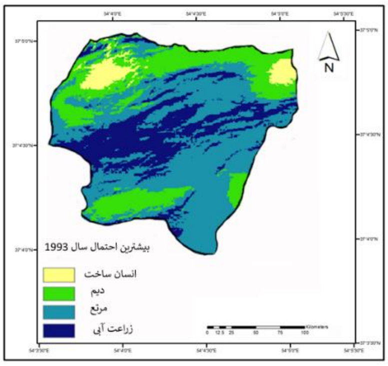

Figure 7: Land use map extracted with the maximum likelihood algorithm in the base pixel classification method for the year 2023

According to the map obtained in 2023, the largest area related to man-made areas is 56,315 hectares. The smallest areas of land use are: irrigated agriculture (512 hectares), pasture (4,973 hectares) and dryland (10,980 hectares).

The area and rate of change of land use classes of the studied city of Gomish Tepe in 1993 and 2023 using the pixel-based method are shown in the table. The results show a decrease in the amount of irrigated agricultural land and an increase in the remaining land uses. So that this increase in dryland land use has had a significant trend. It seems that the decrease in rainfall in recent years could be one of the reasons for this

Table 1: Area and rate of change of land uses classified using the pixel-based method

	2023	1993

The process of change	Amount of change (hectares)	Area (hectares)	Area (hectares)	User type
Decreasing	6878	512	7390	Irrigation
Incremental	4812	10980	6168	Dry land
Decreasing	9225	4973	14198	Pasture
Incremental	53055	56315	3260	Man-made areas

- Object-oriented classification

First, image segmentation was performed using a multi-scale segmentation model. For this purpose, by analyzing the results of image segmentation with different scale parameters, spatial resolution of the image, and considering the study area, which is vast, appropriate values were selected through trial and error for the desired image segmentation, which can be seen in the figure and table

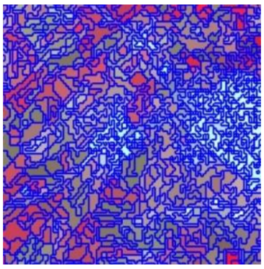

Figure 8: Segmentation of the image of the year 2023 with a scale of 20 (map factor 0.5 and compression factor 0.5)

Table 2. Parameters effective in segmentation

Values (weight applied)		Segmentation parameters
2023	1993	
22	12	Scale
0\5	0\4	Map coefficient
0\5	0\5	Compression ratio

Then, classification was performed in eCognition software several times until the highest degree of membership (based on the nearest neighbor algorithm) was achieved for the classes, and the land use map for the years 1993 and 2023 for the city of Gumish Tepe was obtained using an object-oriented method in the order of shapes

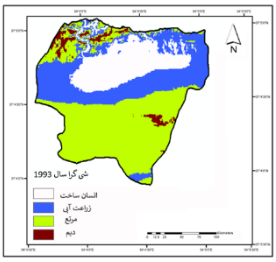

Figure 9. Land use extracted with the standard nearest neighbor algorithm in the 1993 object-oriented method

According to the resulting map, the largest area in 1993 was occupied by pasture land with 26,594 hectares, followed by irrigated agricultural land with 6,551 hectares. The smallest area was occupied by dryland land with 946 hectares and man-made areas with 482 hectares, respectively

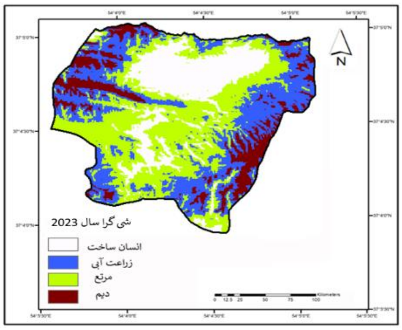

Figure 10. Land use extracted with the standard nearest neighbor algorithm in the object-oriented method in 2023

The results show that in 2023, the largest area of rangeland is 22,816 hectares. Also, irrigated agriculture accounts for 4,853 hectares, man-made areas for 3,673 hectares, and dryland for 3,911 hectares

Table 3: Area and rate of change of land uses classified using the object-oriented method

		2023	**1993**	
The process of change	Amount of change (hectares)	Area (hectares)	Area (hectares)	**User type**
Decreasing	1698	4853	6551	**Irrigation**
Incremental	2965	3911	946	**Dry land**
Decreasing	3778	22816	26594	**Pasture**
Incremental	3191	3673	482	**Man-made areas**

Classification accuracy

The classification accuracy assessment for all images was calculated using the error matrix. Using the producer accuracy matrix, total accuracy, user accuracy, and kappa coefficient were extracted in ENVI software. The results of the classification accuracy assessment are presented in Tables 5 and 6

Table 4: Results of the accuracy assessment of classified land use images (pixel-based method) in percentage

Total accuracy	Kappa coefficient	Manufacturer's accuracy	User accuracy	User	Year
95\46	0\93	94\43 99\30 99\50 88\30	85\30 90\50 99\90 96\10	Irrigation Dry land Pasture Man-made	1993
96\23	0\94	94\48 99\31 99\55 88\34	85\36 95\51 99\91 96\19	Irrigation Dry land Pasture Man-made	2023

Table 5: Results of evaluating the accuracy of classified land use images (object-oriented method) in percentage

Total accuracy	Kappa coefficient	Manufacturer's accuracy	User accuracy	User	Year
96\67	0\95	90\76 95\47 93\56 98\23	88/71 91/59 93/49 98/90	Irrigated agriculture Rainforest Range Man-made	1993
95\54	0\96	93\48 98\74 97\34 98\42	89/59 96/41 97/51 97/16	Irrigated agriculture Rainforest Range Man-made	2023

Revealing changes

In this study, the post-classification comparison method was used to detect changes. For this purpose, as seen, first the images were classified separately using two methods: pixel-based and object-oriented. Then, the final changes in land use classes in the maps obtained using the object-oriented method were examined due to their higher accuracy. In the post-classification pixel-based comparison method, the area of these changes is obtained one by one.

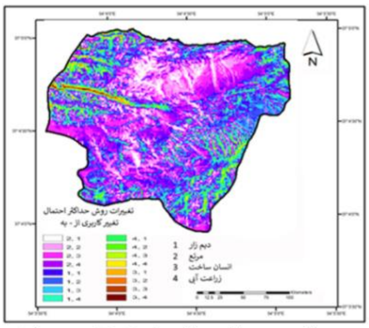

Figure 12. Detecting changes from 1993 to 2023 using

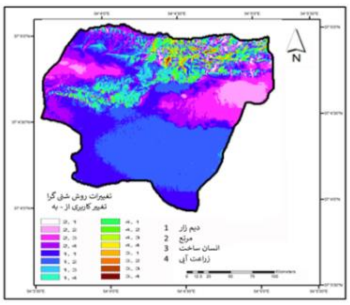

Figure 11 Disclosure from 1993 to 2023 object-oriented method

It provides general statistics on the changes made between 1993 and 2023. What is certain is that the increase in dryland has been accompanied by a decrease in rangelands. In addition, the decrease in irrigated agriculture has been accompanied by an increase in man-made areas. Based on the matrix of changes from 1993 to 2023, 36.3877 hectares (3877 hectares) have been converted from rangelands to dryland lands. The changes are presented in detail below, with the percentage of estimated changes relative to the changes in the same land use.

Table 6: Matrix of changes between the years 1993 and 2023 in hectares

Land use in 2023				Land use in 1993
Man-made areas	Pasture	Dry land	Irrigation	
769/32	970/74	803/38	1908/38	Irrigation
220/14	3664/7	1956/92	337/90	Dry land
432/27	19787/77	3877/36	1168/27	Pasture
392/22	432/27	0	4/05	Man-made areas

Zoning of soil erosion and determining the importance or weight of each criterion

In assessing soil erosion for a given land use, not all criteria are equally weighted and some of them act as important and key factors. Accordingly, factors are weighted to rank the importance of decision-making criteria for the desired goal. To combine criteria for assessing erosion for a given land use, the weighted linear combination (WLC) method was used. Using this method, the erosion rate for the studied land uses is calculated based on the linear combination of criteria, taking into account their relative importance. Thus, in order to zone erosion, according to the land use map for two time periods (1993 and 2023) and the map of other relevant criteria, the criteria were first weighted.The basic assumptions and final weights obtained from critical weighting among the criteria considered in the erosion zoning of the city of Gomish Tepe, using pixel-based, object-oriented, and ARAS methods, are given in the tables,

Table 7: Total contrast, standard deviation, amount of information and final weight in erosion zoning using the pixel-based method

Final weight	Amount of information	Standard deviation	Total contradiction	Criteria	
0/16	1/7	0/39	3/66	Slope	Using the 1993 land use map
0/14	1/6	0/32	2/10	Lithology	
0/16	1/5	0/41	2/48	Soil use	
0/14	1/9	0/18	2/00	Rainfall	
0/12	0/96	0/27	2/14	Distance from river	
0/12	0/91	0/41	2/27	Road	
0/12	0/91	0/40	2/28		
0/16	1/1	0/31	3/39	Slope	Using the 2023 land use map
0/14	1/7	0/32	2/47	Lithology	
0/14	1/7	0/35	3/29	Soil use	
0/14	1/8	0/38	2/70	Rainfall	
0/12	1/9	0/37	2/30	Distance from river	
0/12	1/9	0/42	2/35	Road	
0/11	1/8	0/40	2/19		

Table 8: Total contrast, standard deviation, amount of information, and final weight in erosion zoning using the object-oriented method

Final weight	Amount of information	Standard deviation	Total contradiction	Criteria	
0/15	1/12	0/31	3/30	Slope	Using the 1993 land use map
0/14	0/99	0/32	2/29	Lithology	
0/17	1/27	0/54	2/28	Soil use	
0/15	1/04	0/39	2/69	Rainfall	
0/19	0/98	0/37	2/30	Distance from	
0/12	0/82	0/42	2/40	river	
0/16	0/94	0/40	2/29	Road	
0/16	1/16	0/39	3/52	Slope	Using the 2023 land use map
0/14	1/03	0/32	2/49	Lithology	
0/15	1/08	0/44	2/38	Soil use	
0/14	1/04	0/38	2/60	Rainfall	
0/12	0/82	0/32	2/61	Distance from	
0/12	0/94	0/41	2/30	river	
0/10	0/92	/40	2/25	Road	

Table 9: Total contrast, standard deviation, amount of information and final weight in erosion zoning using the ARAS method

Final weight	Amount of information	Standard deviation	Total contradiction	Criteria	Using the 1993 land use map
0/16	1/16	0/39	3/52	Slope	
0/14	1/03	0/32	2/49	Lithology	
0/15	1/08	0/44	2/38	Soil use	
0/14	1/04	0/38	2/60	Rainfall	
0/12	0/82	0/32	2/61	Distance from	
0/12	0/94	0/41	2/30	river	
0/10	0/92	/40	2/25	Road	
0/16	1/7	0/39	3/66	Slope	Using the 2023 land use map
0/14	1/6	0/32	2/10	Lithology	
0/16	1/5	0/41	2/48	Soil use	
0/14	1/9	0/18	2/00	Rainfall	
0/12	0/96	0/27	2/14	Distance from	
0/12	0/91	0/41	2/27	river	
0/12	0/91	0/40	2/28	Road	

These criteria and indices have been selected in a reliable and accurate way that can provide the best estimate of the severity of erosion. In 2023, the highest final weight was obtained for the slope factor (0.16). The effect of the slope index has been examined and confirmed in various studies and sources, including. After that, the land use index was ranked next with a weight of 0.15 and the soil dimension was ranked next with a weight of 0.14. This criterion is determined according to the type of soil type, texture, amount of organic matter and permeability of the soil structure. A weight of 0.14 was obtained for the lithology index. In the category of the least important formations in sediment production and erosion, grains of various origins (dacite-rhoid-dacetic outcrops and lava flows, light gray rhyodacite, rhyolite and lava outcrops) are seen. The greatest weight and importance has been given to old terraces and alluvial fans The distance from the river index was ranked next. Waters that flow on the slope surface and water that penetrate between the earth materials are among the components that stimulate slope materials. An indisputable principle is that wherever the slope slope has an upward trend and the type of formations is also optimal, the waterways cause erosion by destroying the support of the slope materials and washing the slopes. After that, the precipitation index is located. This criterion was also examined by determining the index stations in the Gomish Tepe area, estimating the monthly and annual rainfall at the stations and in the period of time studied

Distance from the road is another criterion that can be used to assess its role in erosion. Generally, road construction operations cause upstream runoff to concentrate in the waterways under the roads and create ditches downstream of the road. It is also important to consider the distance from the road due to undercutting and removal of the slope heel and changes in slope slope

Erosion zoning using land use map derived from the pixel-based method

Erosion zoning was carried out according to the relevant land use map and the proposed criteria using the pixel-based method. The resulting map for this zoning in 1993 and 2023 is shown in the map, respectively. The area and number of pixels related to each of the risk classes in the pixel-based method are also listed in the table

Table 10: Erosion risk class information for the years 1993 and 2023 for the city of Gomish Tepe using the pixel-based method

Very low risk	Low risk	Moderate risk	High risk	Very dangerous	Danger class	
0/19 0 –	0/39 0/2 –	0/4 – 0/59	0/79 0/6 –	0/80 – 1	Value range	
2767	4300	5305	6808	4232	Area (hectares)	Year 1993
11/56	22/02	22/12	27/93	16/37	Area (percentage)	
4681	8148	8760	8176	1747	Area (hectares)	Year 2023
15/29	26/47	25/40	27/26	5/58	Area (percentage)	

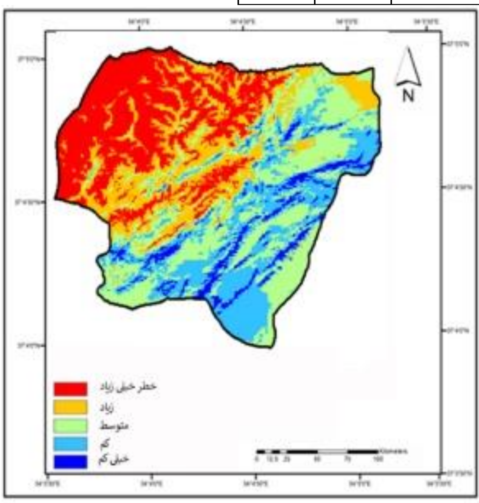

Figure 14 Erosion zoning in 1993 using the method WLC

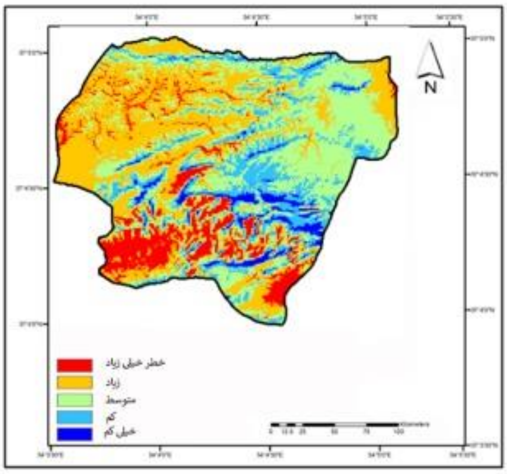

Figure 15 Erosion zoning in 2023 using the method WLC

Erosion zoning maps using the pixel-based method in the study area in 1993 and 2023 show that the areas of the very high and high risk categories are mostly located in rainfed land uses, irrigated agriculture, and some rangelands, and the areas with low and very low risk are located in man-made areas. In the study area in 1993, the area of the high-risk category (equivalent to 8808 hectares) is larger than the other categories, followed by the medium-risk category. In 2023, the area of the high-risk category is also in first place, with a decrease of 209 hectares compared to 1993. In 2023, the area of the very high-risk category also decreased by 3431 hectares, which can be attributed to the decrease in the area of rangeland, part of which has been placed in high-risk areas with this zoning method.According to the results of zoning using the pixel-based method, the area of very low-risk and low-risk classes has increased in 2023, which also includes man-made areas

Erosion zoning using land use maps derived from object-oriented methods

By performing other steps of the WLC model, the soil erosion zoning map of Gomish Tepe city was obtained in five classes from very high risk to very low risk, in the years 1993 and 2023, using an object-oriented method. The value range of these classes is 1.3 to 3.4

11. Data on erosion risk classes for the years 1993 and 2023 in the city of Gumish Tepe using an object-oriented method

Very low risk	Low risk	Moderate risk	High risk	Very dangerous	Danger class	
0 – 0/19	0/2 – 0/39	0/4 – 0/59	0/6 – 0/79	0/80 – 1	Value range	
5161	10104	7056	5216	3975	Area (hectares)	Year 1993
16/23	32/68	22/19	16/40	12/50	Area (percentage)	
4905	8811	5915	6070	5811	Area (hectares)	Year 2023
15/42	28/61	18/60	19/09	18/28	Area (percentage)	

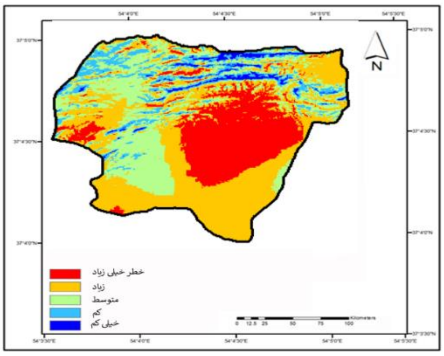

Figure 16 of the 1993 Error Zoning Map of the city of Gomish Tapeh using the WLC (object -oriented method)

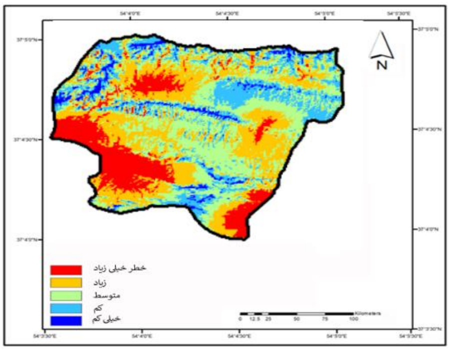

Figure 17: Erosion zoning map for the year 2023 of the city of Gomish Tepe using the WLC method (object-oriented method)

Soil zoning using the ARAS method

In order to investigate the risk of erosion using the ARAS method, first, considering the natural and human conditions of the region, the factors of slope, soil, lithology, distance from the communication road, distance from the waterway, and precipitation were identified as effective factors in soil erosion in the basin

According to the erosion zoning maps in the study area, it can be said that in the 1993 and 2023 erosion maps, mainly areas with very high and high risk categories are located in dryland and irrigated agriculture. Rangeland uses are mostly at medium risk, and areas with very low risk are mainly located in man-made areas. It seems that one of the reasons for the increase in the area of high-risk categories is related to land use conversion. Given that the study area does not have much limitation in terms of water supply for agriculture, most of the rangeland lands have been converted to agricultural lands (irrigated and dryland cultivation) by the villagers of the region. On the other hand, since most of the agricultural lands in the region are located on steep slopes and have been converted to agriculture due to the change of use from forest and rangeland lands, over time, the soil and fertile materials of these lands become inaccessible due to erosion.Also, considering the lithology of the region, most of the dryland and irrigated agriculture lands are located in areas with erosion-sensitive formations (alluvial cones and young alluvial dunes) and slopes above ten percent. Comparing the results of erosion zoning maps using the object-oriented and pixel-based methods during the period 1993 to 2023, indicates that in both methods, dryland land uses, irrigated agriculture, and part of the rangelands are in the high-risk erosion category, and man-made areas face a low erosion risk. However, the change in the area of the risk categories in these methods was different. For example, in the pixel-based method, the area of the very high-risk category has decreased in 2023, which can be attributed to the decrease in the area of irrigated agriculture land use according to the pixel-based land use classification.This is while in the object-oriented method the area of this risk class has increased from 1993 to 2023, which is due to the increase in the area of rainfed agriculture in the use classification in the object-oriented method. It should be noted that changing pasture land uses to agricultural land, especially in areas with high slopes, will not only cause soil erosion, but will also cause flooding and affect soil qualit

Table 12: Erosion risk class information for the years 1993 and 2023 for the city of Gumish Tepe using the ARAS method

Very low risk	Low risk	Moderate risk	High risk	Very dangerous	Danger class	
0/19 0 –	0/39 0/2 –	0/4 – 0/59	– 0/79 0/6	0/80 – 1	Value range	
3457	5535	19623	21610	4060	Area (hectares)	Year 1993
6/26	21/91	25/99	34/28	11/56	Area (percentage)	
8058	2940	1910	9249	9355	Area (hectares)	Year 2023
23/44	11/37	9/10	24/57	31/52	Area (percentage)	

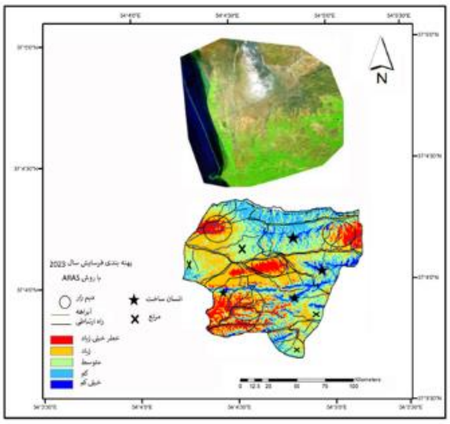

Figure 19 Zoning for 2023 by method ARAS

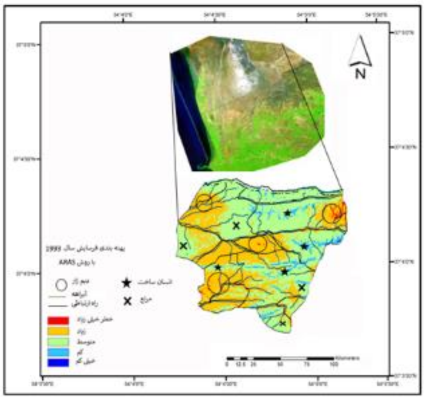

Figure 18 Zoning in 1993 by method ARAS

Conclusion

The results of this study are consistent with the findings of researchers such as Chen et al. (2019), Poissant et al. (2021), who in these studies introduced the results of object-oriented classification as the most accurate method for preparing land use maps. The results indicate that object-oriented methods, by utilizing knowledge-based algorithms, can overcome the weakness of the pixel-based method in not using geometric and textural information of objects (Dragut and Isank (2022). As in this study, the ARAS method distinguished regular geometric shapes such as agricultural lands and man-made areas well. However, the pixel-based and object-oriented methods did not distinguish well, especially for irrigated agriculture and residential areas. After performing the classification with the ARAS method (due to higher accuracy), the results obtained were prepared in the form of a map in order to extract information and better understand the land uses.The results obtained from the available maps and statistical information indicate that for the period 1993 to 2023, the amount of very high and high erosion risk zones has increased relatively during the period under study. As a result, it can be stated that the existence of factors such as; unprincipled exploitation of rangelands, destruction of vegetation cover due to conversion of rangelands to croplands, rainfed cultivation on sloping lands and plowing of rangelands on steep slopes, failure to observe crop rotation, inappropriate use of river beds and boundaries, increase in residential and man-made areas, along with other factors such as; sensitive and erodible formations which are mainly loose Quaternary formations, adequate rainfall and abundance of watercourse network, are the most important factors involved in soil erosion in the city of Gumish Tepe. The increase in rainfed lands has been accompanied by a decrease in rangelands.In addition, the decrease in irrigated agriculture has been accompanied by an increase in anthropogenic areas. During the aforementioned period, the largest change was related to pasture land use, which was accompanied by a decreasing trend. Also, the most important change was the increase in dryland land use. According to the results of erosion risk zoning in the city of Gumish Tepe, the area of the very high-risk and high-risk categories has increased in 2023, which can be attributed to the increase in the area of dryland agriculture and the decrease in the area of pastures. Considering the topography of the study area, the possibility of erosion increases with the conversion of pastures around villages to dryland and the plowing of pastures on steep slopes. Therefore, according to the erosion zoning maps in the study area, in 1993 and 2023, mainly areas with very high-risk and high-risk categories are located in dryland and irrigated land uses, and a large part of the pastures face moderate risk.Also, man-made areas were classified as low risk. These results are consistent with the findings of Tiwari et al. (2022) in India, Toriman et al. (2020) in Malaysia, and Ghahramannejad et al. (2017) in the general Barchai region, who stated that agricultural land use has the highest rate of erosion and runoff. Overall, the results of this study show that optimizing land use in the city of Gumish Tepe to reduce erosion and resource waste seems to be necessary and inevitable, which is very important in terms of sustainable management of the studied basin and management measures should be considered.

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