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Monitoring Bioenvironmental Impacts of Dam Construction on Land Use/Cover Changes in Sattarkhan Basin Using Multi-temporal Satellite Imagery

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A B S T R A C T

Dam construction has caused pressure upon land use/land cover change (LUCC) which is a major cause of bio-environmental changes. In this paper, the environmental impacts of Sattarkhan dam construction from 1987 to 2010 were monitored and recent changes are analyzed, using the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) images of 1987 and 2010; the time before and after the dam construction. The methodology consists of two main stages. In the first stage, image process techniques were employed to classify satellite images using the post-classification comparison change detection method. Results indicate that irrigated agriculture, bare lands, and dry agriculture were reduced in the study period, while water bodies and built-up areas increased. Based on this finding, significant changes in land use/land cover have occurred in Sattarkhan dam basin. In the second stage the bioenvironmental indices were applied to evaluate the bioenvironmental impacts of LUCC and it revealed that the maximum detrimental indices were concerned with conversion of agricultural land use and orchards to built-up lands and water bodies. As an overall evaluation, dam construction has a positive impacts rather than negative environmental impacts.

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INTRODUCTION

Land use/land cover change (LUCC) detection is considered as one of the significant and fundamental techniques for evaluation of the bioenvironmental effects. Evaluating LUCC is necessary for natural resource management decision making for land use planning and bioenvironmental studies. Based on this assumption, investigation on LUCC has been assigned as an important concept in environmental studies. This important is remarkable when it comes into account of assessing the impacts of dam construction on LUCC. One of the serious challenges associated with dam's construction is about its environmental degradation such as rapid expansion, growth and developmental activities (for instance: LUCC changes in agriculture lands, deforestation, irrigation, fishing, and construction of bridges and roads). In the course of carrying out these activities, the environment is degraded and thereby damaging the ecosystem and the landscape, and offsetting the already fragile ecological balance [1]. Obviously, LUCC studies provide a great and significance information to strengthen the protection of land resources, determent unreasonable exploitation, improve ecological environment and promote integration development [2].

In order to monitor the LUCC during time, Earth Observation satellite images provide a powerful methodology for assigning the trends of LUCC by means of comparing time series of satellite images to recognize the LUCC. Remote sensing technology has greatly facilitated investigation and monitoring of LUCC [3]. One of the major advantages of remote sensing system is its capability for repetitive coverage, which is necessary for change detection studies at global and regional scales. Jenson has suggested that detection

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of changes in the land use/land cover involves use of at least two period data sets [4]. A practical approach to study changes in land use/land cover, which may be caused due to natural/human activities, can be accomplished using current and archived remotely sensed data [5]. With the availability of multi-sensor satellite data at very high spatial, spectral and temporal resolutions, it is now possible to prepare up-to-date and accurate land use/land cover maps in less time, at lower cost and with high accuracy [6].

In order to model LUCC, the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) data have been widely applied in for land use and change detection studies[7, 8]. The accuracy of the resulting change maps is subjected to error propagation and is dependent on the accuracy of the input classification maps, the individual classified images constitute a historical series that can be used in applications other than change detection[9]. Reviewing related literature indicates that remote sensing together with Geographic Information System (GIS) have been applied to LUCC detection all over the world. In this regard, Adeniyi and Omojola [10] have used aerial photographs, Landsat MSS, Spot XS/Panchromatic Image Transparency and Topographical maps to study LUCC in Sokoto and Guronyo dams in Nigeria for a period of time 1962 to 1986. Results of their work revealed that settlement covered most part of the area before and after the construction of the dam. Zhao et al. [11] have investigated the effect of construction of Manwan dam in Yunnan, China on land use change during 1974-2004. Ahadnejad [12] has recognized the LUCC in the basin of Alavian dam using GIS and remote sensing. In order to evaluate the land use changes from the bioenvironmental point of view, he used the detrimental index. Similarly, Rostamzadeh [13] has investigated the bioenvironmental effects of Sattakhan dam by using satellite images of ETM and TM for time period of 1987 to 2002. This study has been carried out in order to detect the land use changes due to Sattarkhan dam construction and its water channel and evaluation of its bioenvironmental effects during the period of 1987 to 2002.

Within this research we aim to determine the trends, rates, nature, location and magnitudes of LUCC under impacts of dam construction in Sattarkhan basin using remote sensing and GIS techniques. We also aim to evaluate the environmental and socioeconomic implications of the LUCC. For this to happen, the multi-temporal satellite dataset in Sattarkhan dam basin has been analyzed to understand LUCC as a consequence of driving factors.

The study area and aim of this study

The study area was Satarakhan dam basin which is sub basin of Aharachei. This area is located in the North-western Iran in East Azerbaijan province (see Figure 1). Sattarkhan dam was constructed in 1998 to provide water for drinking, irrigation, mining and industrial use in the region. This dam covers a watershed area of 950km^2. This dam is one of the major dams which are important in terms of agricultural activities and in particular orchards activities. Our study focused on the following two aspects: (1) to estimate LUCC from 1987 to 2010 in the study area, being the time before and after the dam construction using post-classification comparison change detection, and (2) to analyze the bio-environmental effects of these changes in the study area using detrimental index. Based on TM and ETM+ images in period 1987 to 2010 and by the support of GIS, we analyzed the spatial-temporal changes of land use pattern in the study area which can provide the basis for further research driving factors and change mechanism of LUCC.

MATERIAL AND METHODS

Data set and preprocessing

In this study, we used TM and ETM+ satellite images (see Figures 2 and 3). The TM image was acquired on July 19, 1987 and the Landsat ETM+ data was acquired on August 14, 2010. In order to start data processing at first step we performed geo-referencing process on our satellite images. For this to happen, the 50,000 topographic maps were used to select 22 ground control points and correct satellite images geometrically. Satellite images got geo-referenced and projected to the Universal Transverse Mercator (UTM) zone 38, WGS84. The estimated resulting *root-mean-square error* (RMSE) was 0.47 pixels which was an acceptable error [14].

Supervised classification

The principle of image classification is that a pixel is assigned to a class based on its feature vector, by comparing it to predefined clusters in the feature space. In doing so for all image pixels results in a classified image[15]. The classic image classification method that classifies remote sensing images according to the spectral information in the image and the classification manner is "pixel by pixel" and one pixel can only belong to one class. In pixel-based classification, there are two kinds of traditional classification methods-unsupervised classification and supervised classification[16].

Unsupervised classification is used when there is little or no external information about the distribution of land cover types. The results of unsupervised classification are spectral classes. It is by the analyst associate the spectral classes with the land cover types using reference data [17].

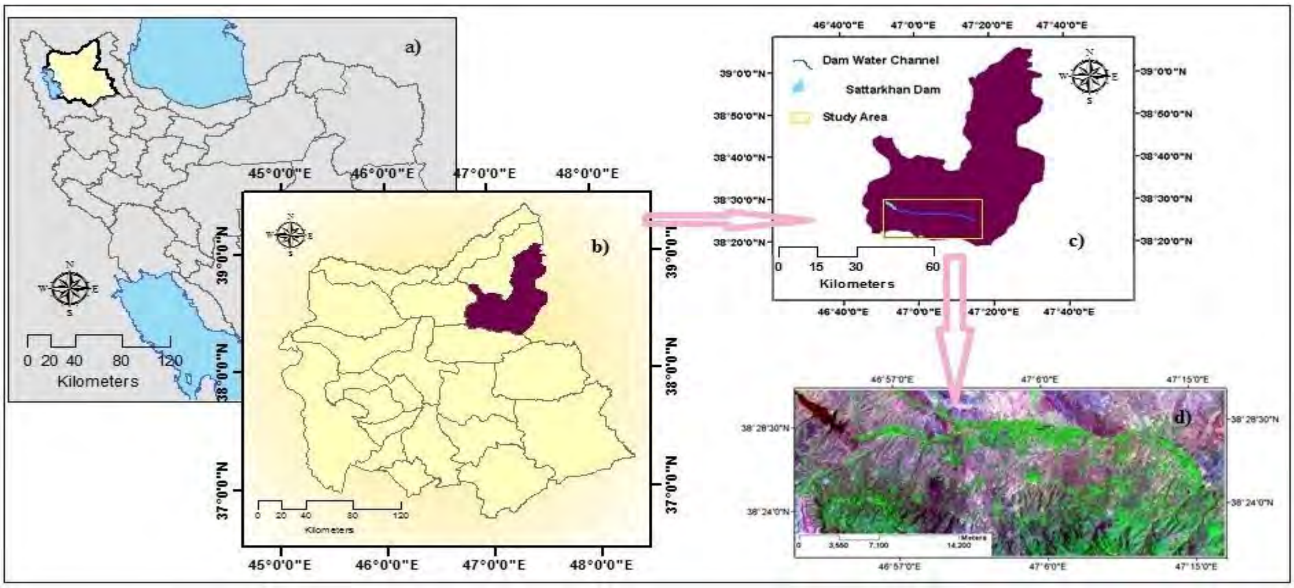

Figure 1. Location of study area: a) Iran, b) EastAzerbayjan province , c) Ahar County and d) Sattarkhan Dam

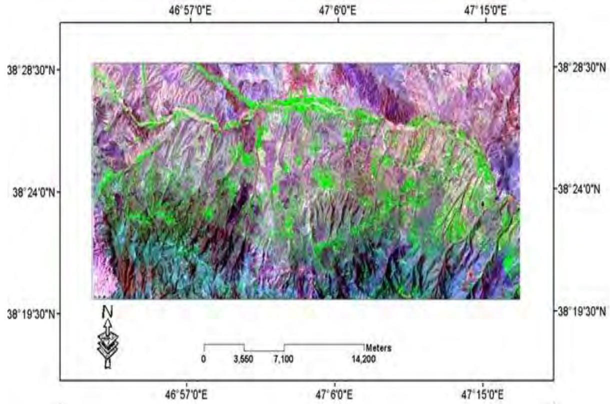

Figure 2. False color representation for TM satellite image of 1987

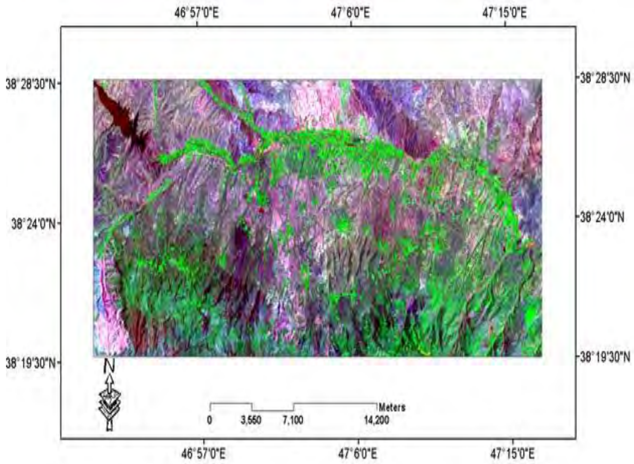

Figure 3. False color representation for ETM+ satellite image of 2010

In our research we used supervised classification by specifying to the computer algorithm and numerical descriptors of various land cover types present in an image. Training samples that describe the typical spectral pattern of the land cover classes are defined. Pixels in the image are compared numerically to the training samples and are labeled to the land cover class that has similar characteristics. We used fifteen field-collected spectral training sites of each land type within the image area, representing seven different land use types. The field data was collected in 2010. The land use types were bare lands, orchards, water bodies, built-up lands, dry/rainfed agriculture, irrigated agriculture and grasslands. Accordingly, maximum likelihood classifier is performed after specifying a set of training samples and a certain classification algorithm. The maximum likelihood decision rule is based on a normalized (Gaussian) estimate of the probability density function of each class[18]. This method quantitatively evaluates both the variance and covariance of the category spectral response patterns when classifying an unknown pixel. An assumption needed in maximum likelihood classifier is the distribution of the cloud of points forming the category training data in Gaussian (normally distributed). Under this assumption, the distribution of a category response pattern can be completely described by the mean vector and the covariance matrix. Given these parameters, the statistical probability of a given pixel value being a member of a particular land cover category may be computed. After evaluating the probability in each category, the pixel would be assigned to the one with highest probability value or be labeled “unknown” if the probability values are all below a threshold set by the analyst [17]. The statistical probability of a given pixel value being a member of a particular land cover category may be expressed by the following equation [19]:

$$p(x|i) = (2\pi)^{-n/2}|\Sigma i| \exp\left[\frac{-1}{2}(x - m_i)^t \textstyle\sum_i^{-1}(x - m_i)\right]$$

where $p(x|i)$ is used to denote the probability of X if the i class occurred; $|\Sigma i|$ is the determinant of variance-covariance matrix in i class; $(x - m_i)^t$ is the transposition of the difference between x vector and mean vector of m_i; $\sum_i^{-1}(x - m_i)$ is the variance and covariance matrix inversion in class i and $(x - m_i)$ is the pixel value vector in the used spectral bands.

Accuracy of assessment

No classification is completed until its accuracy has been assessed [18]. In this context, the “accuracy” means the level of agreement between labels assigned by the classifier and the class allocations on the ground collected by the user as test data. To reach valid conclusions about map’s accuracy from some samples of that map, the sample must be selected without bias. When performing accuracy assessment for the whole classified image, the known reference data should be another set of data, different from the set that is used for training the classifier[17]. The two methods that commonly are used to do the accuracy assessment are error matrix and kappa statistics[16].

In this study, an accuracy assessment on the two classified images using 16 field data points tested the degree of accuracy between classified and actual mapped land use types and Kappa statistic were run on the 30×30m 1987 and 2010 images. The Kappa analysis is a discrete multivariate technique used in accuracy assessment for statistically determining if one error matrix is significantly different than another [20]. The result of performing a Kappa analysis is a KHAT statistic (actually ∧K, an estimate of Kappa), which is another measure of agreement or accuracy. This measure of agreement is based on the difference between the actual agreement in the error matrix and the chance agreement, which is indicated by the row and column totals [16]. The overall accuracy and overall kappa statistics are 84.30 and 0.841%, respectively which was sufficient and appropriate by taking in to consideration of standard overall accuracy number.

Bioenvironmental analysis

Dam construction as a supply to much of the society’s water demands is a process which may cause significant changes to the environment. Unless nature is treated with respect and water resources development projects consider environmental factors very specifically during their planning and construction phases, unexpected adverse impacts can be expected on the environment. All dams whether they are small or large, will cause environmental changes, some of which are likely to be positive, but others are likely to be negative[21]. In this study, detrimental index is used in order to evaluate LUCC qualitatively and bio-environmentally. One of the common methods in investigating the detrimental index due to the land use changes in one area is weighing the changes related to each of converted land uses [22]. The standardization of detrimental indices is based on researches conducted by Neshat and Ahadnejad [12, 23]. The final result is offered with categorized maps and one coefficient is specified for each land use. In this research, we used numbers 1 to 10 for indicating minimum and maximum detrimental index, respectively (see Table 1).

Matrix 7×7 will be produced based on years 1987 and 2010 by assigning weights to the LUCC. The matrix’s columns represent LUCC in 1987 and its rows show LUCC in 2010 (see Table 2) in which, the changing values will be calculated according to the detrimental indices of the related columns and rows by the following equation:

$$\Delta E_{ij} = E_i - E_j$$

where:

ΔE_{ij} denotes the matrix coefficient for each i and j LUCC;

E_i represents the detrimental coefficient for new LUCC in 2010;

E_j represents the detrimental coefficient for new LUCC in1989.

The obtained coefficients can be both negative and positive. The positive coefficients represent the increase in detrimental index due to the LUCC and the negative ones indicate decrease in detrimental index. Having calculated the matrix coefficients by using the number of changed pixels of LUCC, the detrimental index of each change in the area was calculated by following equation:

$$D_{ij} = \Delta E_{ij} - P_{ij}$$

where:

D_{ij} shows the general detrimental index related to the i and j land use conversion;

ΔE_{ij} denotes the detrimental index of each i and j land use conversion;

P_{ij} represents the ratio or amount of converted pixels from i and j land use/cover.

The general detrimental index was standardized by the following equation:

$$\Delta I_s = \frac{(\Delta I_{ij} - \text{Min}\Delta I_{ij})}{(\text{Max}\Delta I_{ij} - \text{Min}\Delta I_{ij})}$$

where ΔI_s denotes the standardized value for each class of matrix which will be in the range of 0 to 1 where in index of 1 denotes the maximum of detrimental index and 0 represents the minimum of detrimental index;

ΔI_{ij} denotes the value obtained by multiplying the number of pixels in detrimental indices in each row of the matrix;

$Max\Delta I_{ij}$ and $Min\Delta I_{ij}$ denote the highest and the lowest obtained values, respectively.

Having standardized the matrix, the detrimental indexes were classified in to 4 classes: the most detrimental index, detrimental index, the moderate detrimental index, the least detrimental index (Table 3).

TABLE 1. Detrimental indices weights assigned to the change in land use/land cover.

Land use	Bare lands	Orchards	Water bodies	Built-up lands	Dry/Rainfed agriculture	Irrigated agriculture	Grassland
weight	2	1	10	10	2	1	1

TABLE 2. Matrix coefficients for determining detrimental index due to the land use changes.

1987 / 2010	Bare lands	Orchards	Water bodies	Built-up lands	Rainfed agriculture	Irrigated agriculture	Grassland
Bare lands	0	2	-7	-7	1	2	2
Orchards	-2	0	-9	-9	-1	0	0
Water bodies	7	9	0	0	8	9	9
Built-up lands	7	9	0	0	8	9	9
Rainfed agriculture	-1	1	-8	-8	0	1	1
Irrigated agriculture	-2	0	-9	-9	-1	0	0
Grassland	-2	0	-9	-9	-1	0	0

TABLE 3. Detrimental index after matrix standardization.

detrimental index classes	values
the least detrimental index	0-0.25
the average detrimental index	0.26-0.5
detrimental index	0.51-0.75
the most detrimental index	0.76-1

RESULTS

A classification and change information extraction about the land use/land cover in Sattarkhan dam basin was conducted, using Landsat TM and ETM + images. Then the land use/land cover and its accompanied change information from 1987 to 2010 were obtained (see Figures 4 and 5, Table 4). This can be summarized as a decrease of the area of irrigated agriculture, bare lands and dry agriculture and a significant increase in the area of built-up lands and water bodies (see Figure 6).

In order to detect LUCC, post-classification comparison change detection method was used [24]. Table 5 shows the results based on the number of pixels. From this table, it can be observed that the maximum changes are concerned respect to the water levels by 88.81%, Orchards by 86.57%, built-up lands by 85.07%, and the minimum changes are concerned with bare lands by 36.74% and dry agriculture by 39.52%.

The next stage is to use detrimental index method in order to investigate the bioenvironmental effects of Sattarkhan dam construction.

Table 6 shows the standardized detrimental indices. It is determined that the highest detrimental index is related to built-up lands (see Figure 7). These areas increased at the cost of decreased agricultural land uses, Orchards and bare lands. Also development of water bodies after dam construction has led to a decrease in agricultural land areas and also caused pollution of air and water

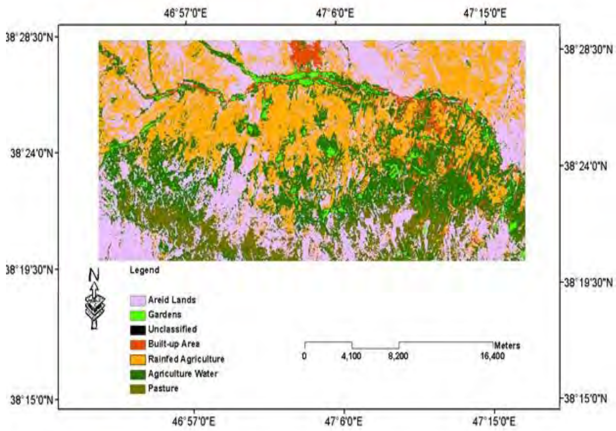

Figure 4. The developed land use land cover map for1987

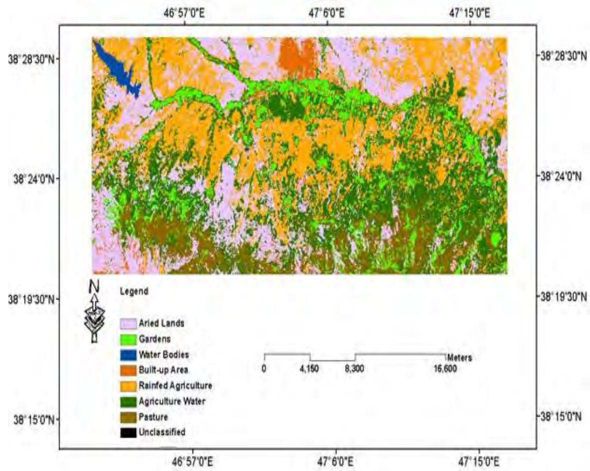

Figure 5. The developed land use land cover map for 2010

TABLE 4. Changes of LUCC in Sattarkhan basin.

Land use	1987		2010		The relative changes(1987-2010)
Area	Hectare	percent	Hectare	percent	percent
Bare lands	19348	32.87	11313.2	19.18	-41.53
Orchards	1238.8	2.1	7302	12.38	589
Water bodies	0.72	0.001	402.1	0.68	584
Built-up lands	2147.8	3.64	3955.3	6.7	181
Dry/Rainfed agriculture	17161.3	29.1	15989	27.11	-16.83
Irrigated agriculture	14261.9	24.18	5479.6	9.3	-62.63
Grassland	4786.6	8.12	14531	24.64	303

TABLE 5. Matrix of land use changes in 2010 and 1987(number of pixels).

2010 \ 1987	Bare lands	Orchards	Water bodies	Built-up lands	Dry/ Rainfed agriculture	Irrigated agriculture	Grassland	Changes percent
Bare lands	7156.26	10.62	0.00	225	3208.59	586.80	126	36.74
Orchards	931.500	980.91	0.00	244.44	942.12	3597.48	605.52	86.57
Water bodies	74.43	10.62	45	42.93	138.06	135	0.63	88.81
Built-up lands	2577.78	16.20	0.27	590.49	256.05	488.97	25.56	85.07
Dry/ Rainfed agriculture	3699.45	12.15	0.00	534.15	9669.69	2036.70	36.90	39.52
Irrigated agriculture	3746.79	133.47	0.00	507.51	2691.09	6075.63	1376.55	58.19
Grassland	1161.81	74.88	0.00	30.33	255.69	1341.36	2615.49	52.27
Sum	19348.02	1238.85	0.72	2147.85	17161.29	14161.94	4786.65	……

TABLE 6. Standardization of detrimental index results.

2010 \ 1987	Bare lands	Orchards	Water bodies	Built-up lands	Dry/Rainfed agriculture	Irrigated agriculture	Grassland
Bare lands	0.29	0.12	0.29	0.23	0.24	0.14	0.15
Orchards	0.55	0.10	0.29	0.93	0.46	0.29	0.39
Water bodies	0.11	0.20	0.29	0.80	0.34	0.34	0.49
Built-up lands	0.45	0.15	0.29	0.29	0.27	0.26	0.30
Dry/Rainfed agriculture	0.35	0.19	0.29	0.65	0.12	0.17	0.29
Irrigated agriculture	0.4	0.14	0.20	0.79	0.28	0.09	0.29
Grassland	0.43	0.15	0.16	0.47	0.19	0.09	0.11

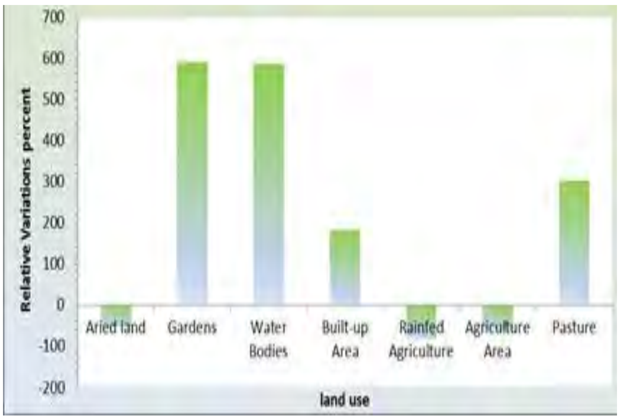

Figure 6. Percent of occurred land use and land cover changes from 1987 to 2010

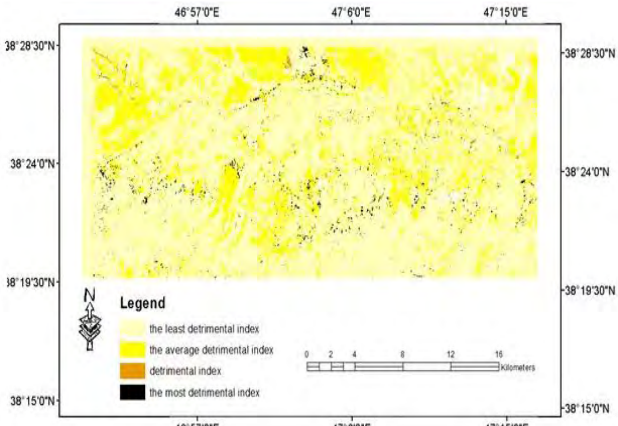

Figure 7. The detrimental index map from 1987 to 2010

DISCUSSION AND CONCLUSION

This paper has demonstrated the bioenvironmental approach in the study of LUCC within specific periods of time using remotely sensed data. Remarkable changes were observed for a period of time duration 1987 to 2010; which were mainly due to dam construction and agricultural practices. The results of this research in GIS environment as thematic maps presented, indicate that dams construction have caused pressure upon changes of land use. Further, our results indicate that bare lands, dry agriculture and irrigated agriculture in this area decreased and orchards, grasslands, built-up lands and water levels increased. Evaluation of matrix of changes shows that the highest alterations are related to the water bodies and the least ones are concerned with dry agriculture.

It is figured out that area of orchards have increased dramatically. Finally, having calculated the detrimental index, it was determined that the highest detrimental index is related to the converting of the agricultural land uses, orchards, grasslands, bare lands to water bodies and built-up lands and the minimum detrimental index is related to converting of these land uses to orchards and irrigated agriculture. Thus, the occurring changes in this area and after the construction of dam and its water channel indicated that even though the natural tranquility of this area disrupted in dam construction area. The results of this research will be important for decision makers and, in particular, for government departments such as the Ministry of Agriculture, the Ministry of Water Resource Management, and the Ministry of Natural Resources of the East Azerbaijan Province of Iran. Initial discussions have already been triggered about how to enhance further the level of detail portrayed in the LUCC maps. This enhancement will be carried out for Sattarkhan basin in collaboration with the decision-making authorities. It will include actions to designate specific areas in agricultural land use planning. However, in cultural landscapes the ecological and socio-economic realms are intricately linked [25, 26].

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چکیده

ساخت وسازسدسبب ایجاد فشاربرLand use/Land cover(LUCC) شده است که عامل اصلی تغییرات زیست محیطی است. دراین مقاله، اثرات زیست محیطی ساخت وسازسدستارخان ازسال۱۹۸۷تا۲۰۱۰بررسی شده وتغییرات اخیرباستفاده ازعکس های TMو(ETM+) درزمان های ۱۹۸۷و۲۰۱۰،یعنی دوره زمانی قبل وبعد از ساخت سدبررسی شدند. روش بررسی شامل دومرحله اساسی است. درمرحله ی اول، تکنیک های پردازش تصویر برای دسته بندی عکس های ماهواره ای بااستفاده از روش تشخیص تغییرات مقایسهpost-classification انجام شد. داده هامشخص می کندکه کشاورزی باآب وزمین های بایروکشاورزی بدون آب دراین دوره ی مطالعاتی کاهش یافته است درحالی که ساخت وسازآبی افزایش یافته است. براساس این مفهوم، تغییرات قابل توجهی درLUCC به کارگرفته شده ونشان داده که بیشترین نشانه های خسارت آور، مربوط به تبدیل زمین های کشاورزی وباغ هابه ساخت وسازهای آبی بوده است. به عنوان یک ارزیابی کلی، ساخت وساز سدتاثیرات مثبت بیشتری نسبت به اثرات منفی زیست محیطی داشته است.