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Research paper

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Assessment of the quality of the ecological environment of an area with tourist potential using the remote sensing ecological index: Case of El Kala National Park (Algeria)

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Summary

The assessment of the ecological quality of the environment in El Kala National Park plays an important role in the protection and management of its tourist potential in the face of ecological constraints that have arisen. The present study is based on the use of remote sensing data; its main objective is to analyze the ecological quality in a protected area using the remote sensing ecological index which is based on the calculation of vegetation indices based on Landsat images taken in 2013 and 2023. This observation period shows that the values of drought, temperature, and humidity in the study area increased while the greenness values decreased. The RSEI index was calculated using principal component analysis of the fourth indicators (NDVI, WET, NDBSI, and LST) which made it possible to quantitatively analyze, monitor, and dynamically evaluate changes in the ecological quality of the environment in this park over the past 10 years. The results obtained show that the spatio-temporal distribution of the ecological quality of the environment of the park experienced a downward trend from 2013 to 2023 with a regression rate of -10.16% for the classes of good and excellent quality ecological. This study is considered a reference for the formulation of measures aimed at protecting the quality of the environment in El Kala National Park, and also a database to determine monitoring indicators for sites characterized by significant tourism potential.

Keywords

tourism potential • ecological constraints • Remote Sensing Ecological Index • ecological quality • El Kala Park • Algeria

1. Introduction

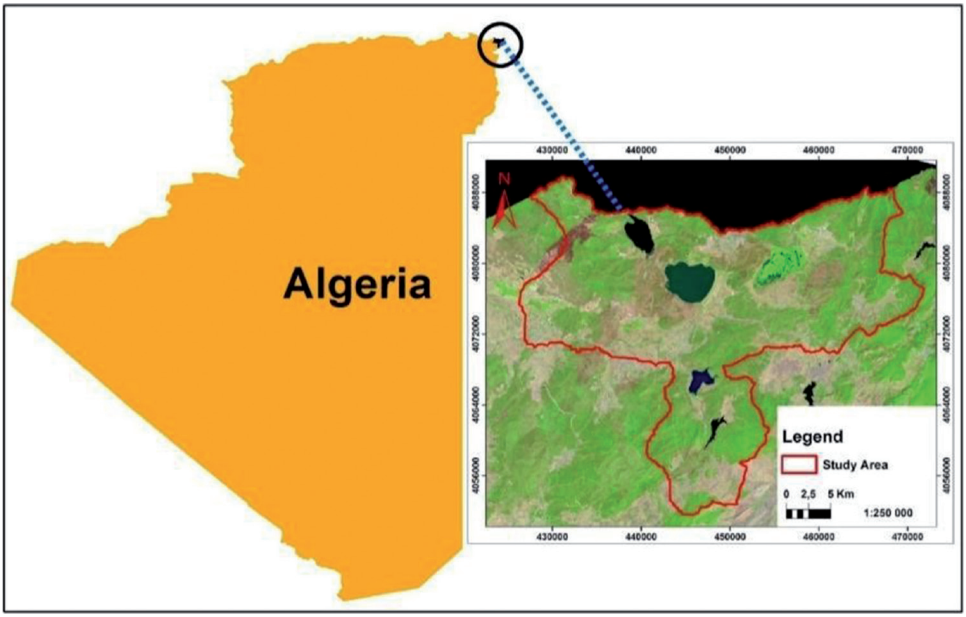
Global change and the intensification of human activity have a significant impact on ecosystems [Liu et al. 2019]. With the growing concern about the change in the ecological quality of the global environment, fragile ecological belts and their impact factors have become increasingly important to global research topics, particularly those focusing on wetlands [Zhang et al. 2018]. They constitute one of the three main types of natural ecosystems on the planet [Zedler and Kercher 2005] and play a dual role as aquatic and terrestrial ecosystems [Jogo and Hassan 2010]. These areas are also essential for human health and well-being, as well as maintaining the ecological balance of the planet and environmental security [Ma et al. 2014]. In Algeria, wetlands generally occupy transition zones between aquatic and terrestrial systems, whose landscapes typical of these zones include coastal lagoons, salt marshes, rivers and their floodplains, permanent marshes, and temporary lakes and salt pans [Khallef 2019]. It is well understood that these areas are characterized by a complex and fragile ecosystem that can be affected by natural and human factors. The ecosystem that characterizes these wetlands in Algeria has made them an excellent tourist destination; this is essentially due to the tourist potential of these areas. El Kala National Park is an illustrative example with these wetlands listed on the Ramsar list, and its endemic fauna constitutes a mosaic of particular and unique ecosystems in the Mediterranean basin [Khallef et al. 2021]. Its geographical location in the East as a transit zone towards the Tunisian Republic, its extent in the North along the Mediterranean coast and its landscape (forests, beaches, lakes, Animal Park, mountains, and amusement parks) make it a favored destination for Algerian tourists, particularly during the summer season. The tourist movement experienced by the park during the 2022 and 2023 summer seasons after the end of the COVID-19 health crisis was very significant. This tourist attendance has had a negative impact on the environmental and ecological quality of this area. During the 2022 summer season, massive fires broke out near El Mellah lake, destroying an area of 6,039 hectares of natural forest. Most reports and eyewitnesses claim that the outbreak of these fires was caused by tourists throwing cigarettes while passing on the national road No. 44 linking the town of Annaba and El Kala. These fires have had negative effects not only on the forest cover but also on the environmental and ecological levels. Field observation during the 2023 summer season made counting more than 38 seaside and recreational waste sites possible. Waste found in nature constitutes visual and olfactory pollution. When they decompose, their components are released and pollute the environment. These components last for a longer or shorter time in nature, which negatively influences this park's ecological and environmental quality. Faced with this paradoxical situation, the question arises as to the future of this park in view of the enormous tourist potential and the significant influx of tourists, especially in summer, on the one hand, and the ecological constraints on the other. To answer this question, an ecological quality assessment study using remote sensing data is most appropriate for the case of this site. Remote sensing technology provides a wide range of data for ecosystem monitoring. Several remote sensing indices have been developed to quantify ecological conditions [Pettorelli et al. 2005, Jiang et al. 2021, Prăvălie et al. 2022, Zhang et al. 2022]. The Remote Sensing Ecological Index (RSEI) method is widely used for rapid monitoring and assessment of regional ecological environments [Liu et al. 2020, Niu et al. 2020, Shi et al. 2021, Zhang et al. 2022, Yu et al. 2022, Jiang et al. 2023]. However, this index has been applied to wetlands [Wang et al. 2021], and these applications have not been used in El Kala National Park. Accordingly, the present research applies RSEI to assess the ecological quality of this park using images from the Landsat program for two shooting dates in 2013 and 2023. This research aims to study the ecological quality of this protected area and evaluate its state and spatio-temporal dynamics, using the remote sensing ecological index based on the calculation of plant indices from Landsat images. This study also provides scientific support and a database for the urgent implementation of protection and ecological and environmental assessment programs in this park in order to preserve these tourist potentials in the face of ecological and environmental risks.

2. Materials and methods

2.1. Study area

With an area of 80,510 ha, El Kala National Park, one of the first parks created in Algeria (1983), was classified in 1990 in the category of national and international cultural heritage and biosphere reserve by UNESCO. The territory of this park with its tourist coast fits into the same pattern. Inside this park, two of the most beautiful areas of tourist expansion are located, namely: Messida and Cap Rosa, as well as Oubeira (fresh water), Mellah (salt water) and Tonga (brackish water) lakes. The park is located in the extreme northeast of Algeria (Fig. 1), in contact with the Tunisian border, and brings together on its territory the particularities of nature conservation issues and an attractive coastline for seaside tourism.

The park is a site of great interest not only because of its remarkable mosaic of biotopes where endemic, boreal and tropical species coexist but also because it brings together a significant part of the country's fauna and flora. The topography of the park is made up of a series of depressions, some of which are occupied by lacustrine or palustrine formations, and high ridges of various shapes: domes, escarpments and alignments of ridges generally covered by dense vegetation [Hamouda et al. 2012]. From north to south and west to east, the altitude varies from 0 to 1,073 meters. The climate is subhumid Mediterranean with a rainy period from October to April and a dry period from May to September, with precipitation amounts varying between 710 and 910 mm/year. The average annual temperature is around 18°C. The vegetation cover in this wetland is very diverse and takes different forms, globally distributed; in forests, maquis and reforestation [Khallef et al. 2018].



Source: Authors' own study

Fig. 1. Location of the study area

2.2. Data collection

Two medium-resolution (30 m) Landsat program images covering the study area, taken in 2013 (Landsat 8 OLI/TIRS) and 2023 (Landsat 9 OLI-2), available free online from the USGS (https: //earthexplorer.usgs.gov), were used to assess the ecological environment (Table 1). The date the Landsat program images were taken was in the dry season (summer) to avoid cloudy conditions.

Table 1. Satellite data

Satellite	Sensor	Spatial resolution [m]	Acquisition date
Landsat 8	OLI/TIRS	30	19.08.2013
Landsat 9	OLI-2	30	15.08.2023

The two images from the Landsat program underlying this work are all subject to preprocessing. In developing countries like Algeria, the radiometric correction operation is not effective because we do not have data on atmospheric properties (aerosol and gas content) at the time of acquisition of the satellite image [Khallef 2019]. The radiometric correction of Landsat images is therefore carried out by a single operation, the conversion of DN (Digital Number) values to physical values (reflectance above the atmosphere). For this study, the two images of the shooting are calibrated using ENVI 5.3 software. It is worth noting that the images in this program for collection 2 are geometrically correct. To evaluate and quantify the ecological and environmental quality of El Kala National Park, three types of software were used (ENVI 5.3, ArcGIS 10.8, Google Earth support) as well as a camera for the purpose of photographing certain seaside and recreational sites of waste during the inspection of the land at the end of August 2023.

2.3. Construction of an ecological remote sensing index [3]

The four spatial indices used to evaluate the RSEI model are normalized difference vegetation index (NDVI), humidity (WET), land surface temperature (LST), and normalized difference bare soil index (NDBSI). RSEI data were obtained by transforming the principal components of greenness, humidity, heat, and dryness [Xu 2013]. Four remote sensing indicators were calculated as follows.

2.3.1. Vegetation Index

NDVI is one of many most successful attempts to simply and quickly define vegetation zones and conditions and is also used to measure the photosynthetic capacity of vegetation cover [Rouse et al. 1973].

$$NDVI = (NIR - R)/(NIR + R) \tag{1}$$

In formula (1), NIR and red are the surface reflectance in the near-infrared bands and red of remote sensing images, respectively.

2.3.2. Wetness Index

The brightness, greenness, and humidity components of the bobble hat transformation are related to surface physical parameters [Niu et al. 2020, Jiang et al. 2023]. Here, the humidity index (WET) is expressed per humidity component. The expressions of the reflectance image data of Landsat 8 OLI/TIRS and Landsat 9 OLI-2 are as follows [Liu et al. 2022]:

$$WET_{OLI/TIRS} = 0.1511p1 + 0.1973p2 + 0.3283p3 + 0.3407p4 + 0.7117p5 + 0.4559p6 \tag{2}$$

$$WET_{OLI-2} = 0.1511p1 + 0.1973p2 + 0.3283p3 + 0.3407p4 + 0.7117p5 + 0.4559p6 \tag{3}$$

where:

WET (OLI/TIRS, OLI-2) are the moisture components of the Tassel Cap Transform algorithm of Landsat OLI/TIRS and OLI-2 images,

ρblue, ρgreen, ρred, ρNIR, ρSWIR1, and ρSWIR2 are the surface reflectance of Landsat OLI/TIRS and OLI-2 images in the blue, green, red, near-infrared, shortwave infrared 1 and shortwave infrared 2 bands, respectively.

2.3.3. Heat Index

The heat index is represented by the land surface temperature [Xu 2013] and the temperature value T at the sensor was calculated using the model in the user manual of Landsat. The actual temperature of the earth's surface can only be obtained by a specific emissivity correction. The land surface temperature is calculated using the following formula [Khallef et al. 2020]:

$$LST = BT/(1 + (10.8 \cdot BT/14388) \cdot Ln(E)) \tag{4}$$

where:

- LST - Land Surface Temperature,
- BT - Top of atmosphere brightness temperature (°C),
- E - Land Surface Emissivity.

2.3.4. Dryness Index

Drying of soil causes serious pollution of the ecological environment. The drier the soil, the more harmful it is to the environment. Bare soils such as rocks, sand dunes and urban areas also cause soil drying [Maity et al. 2022]. However, the NBDSI Drought Index was developed using the Bare Soil Index (SI) and an index-based built-up index (IBI), which can be calculated using the following formula [Gao et al. 2021]:

$$SI = [(P_{SWIR1} + P_{RED}) - (P_{NIR} + P_{BLEU})]/[(P_{SWIR1} + P_{RED}) + (P_{NIR} + P_{BLEU})] \tag{5}$$

$$IBI = \frac{\dfrac{2P_{SWIR1}}{P_{SWIR1} + P_{NIR}} - \dfrac{P_{NIR}}{P_{NIR} + P_{RED}} + \dfrac{P_{GREEN}}{P_{GREEN} + P_{SWIR1}}}{\dfrac{2P_{SWIR1}}{P_{SWIR1} + P_{NIR}} + \dfrac{P_{NIR}}{P_{NIR} + P_{RED}} + \dfrac{P_{GREEN}}{P_{GREEN} + P_{SWIR1}}} \tag{6}$$

$$NDBSI = (SI + IBI)/2 \tag{7}$$

2.3.5. Remote Sensing Ecological Index

The remote sensing ecological index was developed using GIS as a spatial tool and principal component analysis. The remote sensing ecological index was calculated using principal component analysis (PCA) as a statistical method, instead of standard weighted sum techniques. The values of the four indicators are normalized to a varied range from 0 to 1 before using PCA. The remote sensing ecological index is usually represented by the first component of the PCA (PC1) because this component generally explains most of the total variation in the dataset.

$$RSEI = PCA1[F(NDVI, WET, LST, NDBSI] \tag{8}$$

Remote sensing ecological index values should be normalized and rescaled between 0 and 1, such that 0 represents very poor environmental quality and 1 represents excellent environmental quality:

$$RSEI = (RSEI - RSEI_{min})/(RSEI_{max} - RSEI_{min}) \tag{9}$$

The normalized values of the remote sensing ecological index are classified into 5 classes: 0 to 0.2 (very low), 0.2 to 0.4 (poor), and 0.4 to 0.6 (moderate), from 0.6 to 0.8 (good), from 0.8 to 1 (excellent) [Liu et al. 2022].

2.4. Spatial autocorrelation analysis of RSEI

Spatial correlation is an important indicator for determining whether the attribute value of an element is significantly correlated with the attribute value of the adjacent space. This reveals the correlation of attribute values between spatial reference units and their neighboring spatial units. The Moran index and the local spatial correlation index (LISA) were used to analyze the spatial correlation of the eco-environmental quality of El Kala National Park. The two indices were calculated using ArcGIS 10.6 software according to the following formulas [Liu et al. 2022].

$$\text{Global Moran's} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} Wij\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{m} Wij} \tag{10}$$

where:

x_i – the attribute value of position i,
n – the total number of grids in the study area,
Wij – the weight of the matrix, which represents the relationship of space objects = 1, 2, 3..., N, j = 1, 2, 3..., M, Wij = 0 when i and j are adjacent.

If the Moran index is +1 the spatial autocorrelation is positive at −1 the autocorrelation is negative, equal to zero indicating the absence of spatial autocorrelation.

$$LISA = \frac{\left(x_i - \bar{x}\right)}{m}\sum_{j=1}^{m} Wij\left(x_i - \bar{x}\right) \tag{11}$$

$$m = \frac{\sum_{j-1}^{m}, j \neq 1x_i^2}{\left(n-1\right)} - x^2 \tag{12}$$

LISA represents the spatial grouping of similar values whether high or low around the spatial unit. If LISA is negative, then it represents spatial clustering between different values. Calculation of this index can generate five spatial distribution classes as follows: high-high cluster (H-H), low-low cluster (L-L), high-low outliers (H-L), low-high (L-H) outliers and insignificant. H-H presents the presence of a high value surrounded by a high value, and L-L presents the presence of a low value surrounded by a low value. H-L indicates a high value anomaly and L-H indicates a low value anomaly. Non-significant values indicate that the attribute values are almost randomly distributed [Liu et al. 2022].

2.5. Change detection of RSEI

Change detection made it possible to identify and evaluate any change in difference between two images of the same study area on different dates [Khallef et al. 2022]. For the present study, image differentiation is used by subtracting the recent image from the old one to know the extent of change. This change detection is calculated by the following formula:

$$\Delta RSEI_{2013/2023} = RSEI_{PC1-2023} - RSEI_{PC1-2013} \tag{13}$$

3. Results

3.1. Principal component analysis of RSEI

Table 2 indicates that the contribution rate of the eigenvalue of the first principal component of the RSEI in both observation periods is greater than 61%, thus the contribution rate of each index has the same positive and negative distribution in the first principal component. However, the contribution rate of NDVI and WET in the first principal component is positive, while the contribution rate of LST and NDBSI is negative. This result shows that NDVI and WET play an increased role in improving the ecological environment. Unlike the LST and the NDBSI which have a restrictive role in improving the ecological environment. This result is also consistent with the reality of the effects of the four indicators on the ecological environment. For the two shooting dates, the contribution rate of the first principal component (PC1) is 62.38% in 2013 and 61.82% in 2023. For this purpose, both rates are above 61%, which indicates that the first principal component is essentially based on the information from the four indices. In addition, the contribution of the four indicators making up PC1 is relatively stable. Therefore, PC1 replaced the four component indices when creating the RSEI index.

Table 2. Results of the first PC1 of the RSEI in 2013 and 2023

Indices	PC1-2013	PC1-2023
NDVI	0.39	0.21
WET	0.70	0.81
NDBSI	–0.37	–0.19
LST	–0.47	–0.52
Eigenvalues	0.098	0.075
Percent of eigenvalues	62.38	61.82

In 2013 and 2023, the contribution of the drought index in PC1 is −0.37 and −0.19 respectively and −0.47 in 2013 and −0.52 in 2023 for the heat index in the same PC1. This indicates that urbanization in El Kala National Park accelerated after 2013, leading to an increase in the area of built-up land, including tourism infrastructure such as roads, hotels, camps, public spaces, and the extension of beaches. The drought index reflects the evolution of building land in this study area. Among the consequences of continued urban land use is an increase in ground surface temperature. Apart from the huge amount of waste in various places, especially during the summer season, this is due to the influx of a large number of tourists. Waste, particularly plastic, decomposes into compost, generating heat in the soil. However, urbanization and the expansion of tourist infrastructure have obvious influences on the eco-environmental quality of the park.

3.2. Indicators of RSEI

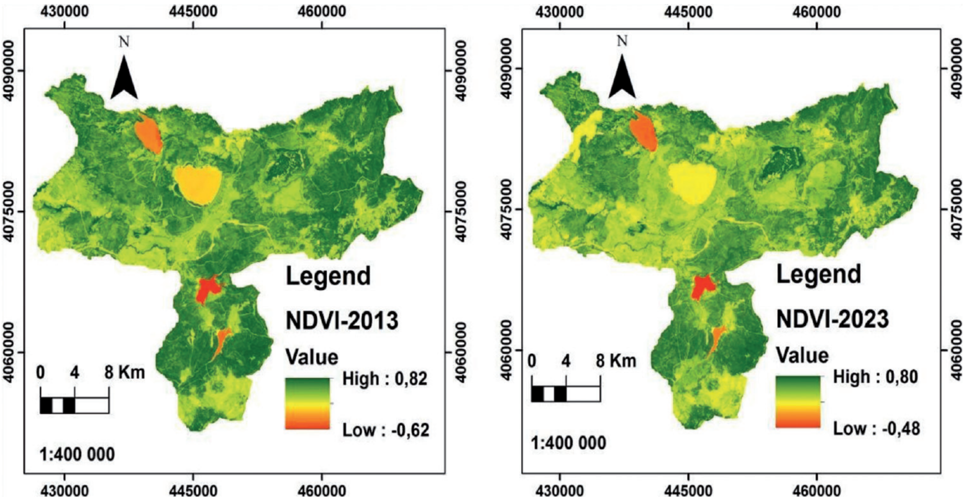
Taking the two observation dates, the statistics of the four indicators relative to minimum, maximum, average and standard deviation values are inserted in Table 3 to better understand the evolution of these indicators over time (Table 3).

Table 3. Indicator statistics in 2013 and 2023

Year	Indicators	Min	Max	Mean	StdDev
2013	NDVI	−0.62	0.82	0.49	0.21
	WET	0	0.0871	0.031	0.01
	NDBSI	−0.27	0.35	0.03	0.14
	LST	26.65	36.36	28.92	1.79
2023	NDVI	−0.48	0.8	0.44	0.19
	WET	0.0054	0.0878	0.034	0.01
	NDBSI	−0.23	0.36	0.07	0.13
	LST	24.36	48.28	33.86	3.64

3.2.1. NDVI

The more greenery, the higher the plant cover rate and this leads to an improvement in the ecological quality of the environment [Li 2022]. On the contrary, if the value of greenery decreases, the value of vegetation cover decreases, which leads to a deterioration in the ecological quality of the environment [Ren et al. 2022]. The greenness indices in 2013 and 2023 are between 0 and 1 after the normalization treatment. Figure 2 shows the spatial distribution of NDVI in the two different years whose values varied from −0.62 to 0.82 in 2013 and −0.48 to 0.80 in 2023. These values are higher in the East, North East, South, and North West, unlike the center of this park, the NDVI values decrease significantly in the Western part. According to Table 3, the values of NDVI for the year 2013 are higher than those of the year 2023, and the maximum value of NDVI decreases by 0.02, which provides information about the decrease in vegetation cover during this observation period. The average NDVI value for 2013 is estimated to be 0.49 while the average NDVI value for 2023 is 0.44.



Source: Authors' own study

Fig. 2. Spatial distribution of NDVI in El Kala National Park in 2013 and 2023

3.2.2. WET

The higher the humidity values, the higher the surface water content, which leads to better environmental quality and vice versa [Sun et al. 2020]. The humidity indices in 2013 and 2023 are between 0 and 1 after the standardization treatment.

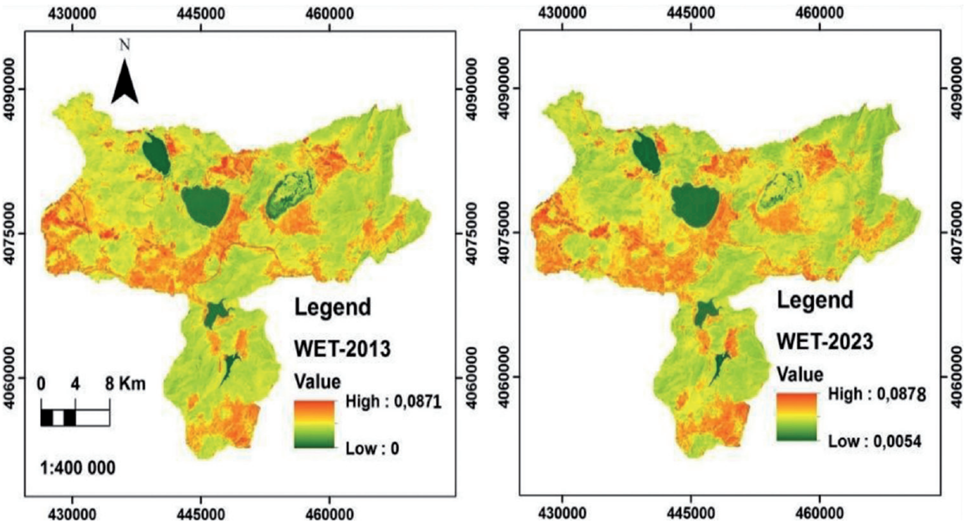


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Fig. 3. Spatial distribution of WET in El Kala National Park in 2013 and 2023

Table 3 shows that from 2013 to 2023, the maximum humidity values in El Kala National Park increased from 0.0871 to 0.0878, an increase of 0.0007. Generally, increasing plant cover increases water demand, leading to a decrease in soil moisture. Figure 3 shows that the humidity values in 2013 and 2023 are higher around bodies of water (lakes, dams, beaches), as well as the central, southern, and northeastern parts, while the Humidity values are very low to low in areas of vegetation cover.

3.2.3. NDBSI

According to Zheng et al. [2020] high NDBSI values increase the soil degradation of the areas, which inevitably leads to deterioration of environmental quality. In contrast, low NDBSI values increase environmental quality. The values of the drought index in 2013 and 2023 after the standardization operation are between 0 and 1. Table 3 reveals that the average values of the NDBSI index of the two observation dates 2013 and 2023 respectively are 0.03 and 0.07. With the increase in buildings in El Kala National Park, the soil deteriorated significantly between 2013 and 2023, this is generally linked to the acceleration of economic and tourist development and urbanization (Fig. 4).

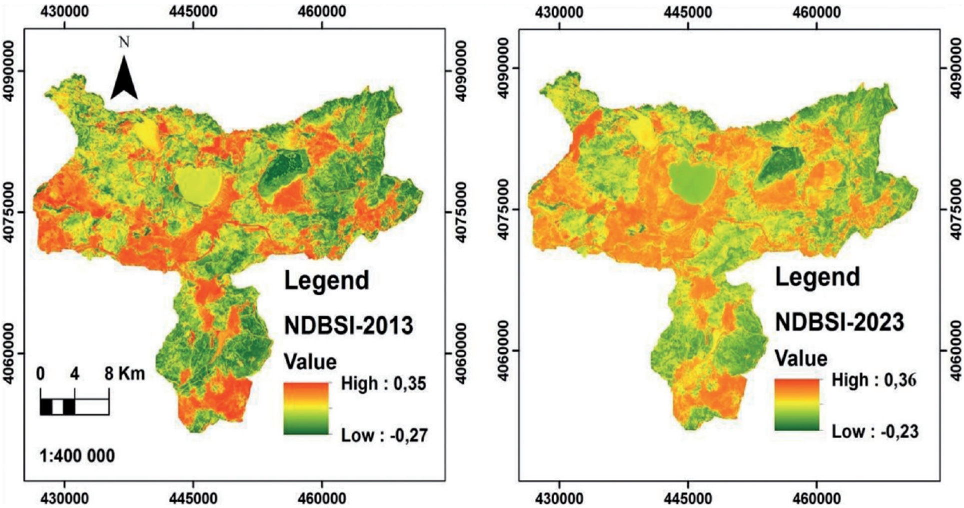

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Fig. 4. Spatial distribution of NDBSI in El Kala National Park in 2013 and 2023

3.2.4. LST

Land surface temperature plays a very important role in determining the ecological quality of the environment [Khallef 2023]. The higher the land surface temperature values, the worse the ecological quality of a given area. Figure 5 shows the distribution of LST in the study area where areas with high LST values show an increasing trend from 2013 to 2023. For both shooting dates, the average LST values increased from 28.92°C in 2013 to 33.86°C in 2023 (Table 3). LST values are higher in urban areas and bare soils and significantly lower in areas covered with vegetation and around water sources.

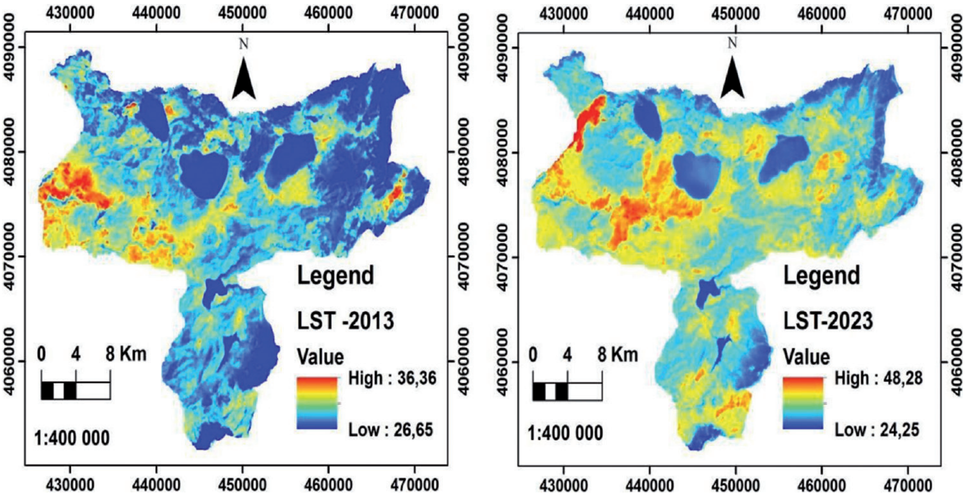

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Fig. 5. Spatial distribution of LST in El Kala National Park in 2013 and 2023

3.3. Spatio-temporal distribution of RSEI

The spatio-temporal distribution of the ecological quality of the environment in El Kala National Park for the two reference dates, 2013 and 2023, is illustrated in Figure 6. The varied classes from 0 to 0.4 represent very poor to poor ecological qualities, while the middle class from 0.4 to 0.6 represents moderate ecological quality. However, the classes of good ecological quality (good and excellent) vary from 0.6 to 1. The classes of poor ecological quality (Very poor and poor) are mainly located in the South, South-West, and West, in the center near lakes and dams, and at the beaches and urban areas (City of El Kala, El Taref).

The moderate classes are scattered throughout the territory of the study area, while the classes with very good to good ecological quality are the areas of vegetation cover distributed from east to west and from south towards the North. Table 4, which shows the different levels of RSEI resulting from the classification of the first principal component for the years 2013 and 2023, reveals that the Very poor to Poor classes occupy 24.62% and 34.11%, i.e. (19,826 ha, 27468 ha) hectares of the total area of the study area respectively for the two observation dates 2013 and 2023. With an area of 43,417 ha in 2013 and 35,234 ha in 2023) of total area of the study area (53.93% in 2013 and 43.77% in 2023), the Good and Excellent classes are the type of level of the Most dominant RSEI. However, the Moderate classes represent an area of 21.45% and 22.12% or (17,267 ha and 17,808 ha) of the study area in 2013 and 2023 respectively.

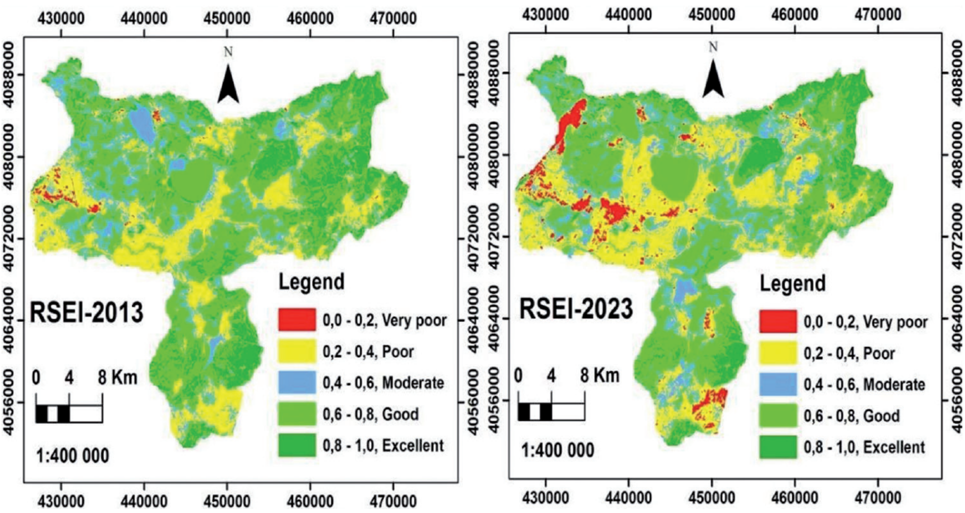

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Fig. 6. Spatial distribution of RSEI in El Kala National Park in 2013 and 2023

Table 4. Area of each level of the RSEI in 2013 and 2023

Classes of RSEI	Year			
	2013		2023	
	Area [ha]	Area [%]	Area [ha]	Area [%]
Very poor	593	0.74	3 424	4.25
Poor	19 233	23.88	24 044	29.86
Moderate	17 267	21.45	17 808	22.12
Good	30 391	37.75	26 694	33.16
Excellent	13 026	16.18	8 540	10.61
Total	80 510	100	80 510	100

3.4. Spatial autocorrelation analysis of RSEI

Figure 7 presents the overall Moran index and its corresponding Z values which are respectively 0.486, 22.67 in 2013 and 0.528, 24.61 in 2023 with Z values above the critical level of 1.96. At the 1% significance level, there is a probability that this clustered pattern is the result of random chance. RSEI increases in areas with wide spatial distributions of environmental ecological quality. In contrast, the RSEI decreases if the spatial distribution of the ecological quality of the environment is small. Over the 10 years from 2013 to 2023, the Moran index trended downward, as the degree of spatial autocorrelation weakened and the spatial distribution became more dispersed. This result indicates that there is consistency with the spatio-temporal variation characteristics of the results of the level of ecological quality of the environment.

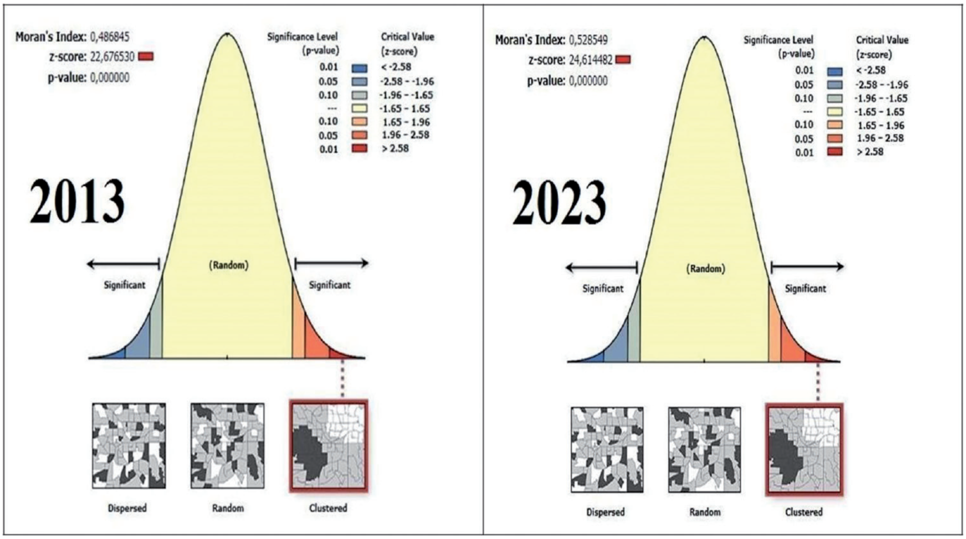

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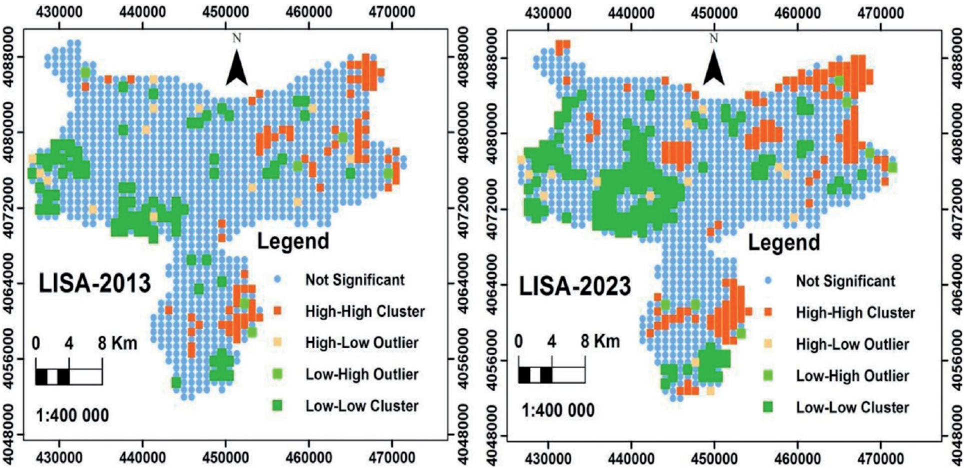
Fig. 7. Moran Index in 2013 and 2023

3.4.1. Local spatial autocorrelation of RSEI

In order to better understand the spatio-temporal distribution of the ecological quality of the environment, the RSEI local spatial correlation model using LISA clustering was used (Fig. 8).

The LISA clustering diagram (Fig. 8) reveals that the H-H clustering areas in 2013 and 2023 are mainly distributed in the East, Northeast, South, Northwest and Center only for the year 2023. The L-L grouping is located in the south, center, east and west of the park. The two clusters H-H and L-L are considerably increased from 2013 to 2023, due to rapid urban growth, the increase in bare soil (clearing, subdivision, fires, and extension of agricultural land). This spatial mutation leads to the degradation of the original soil structure and the regression of plant cover, which potentially increases the loss of ecological quality of the environment. This result supports previous studies. The urban area in El Kala National Park increased from 606 ha in 1987 to 2427 in 2016, of which the bare soil areas have the highest growth rate (5.2%) among all the occupation units of the soil [Khallef et al. 2021]. This indicates that human activities cause land construction and fires cause soil erosion, thereby deteriorating the environmental quality of the park.



Source: Authors' own study

Fig. 8. Map of LISA in 2013 and 2023

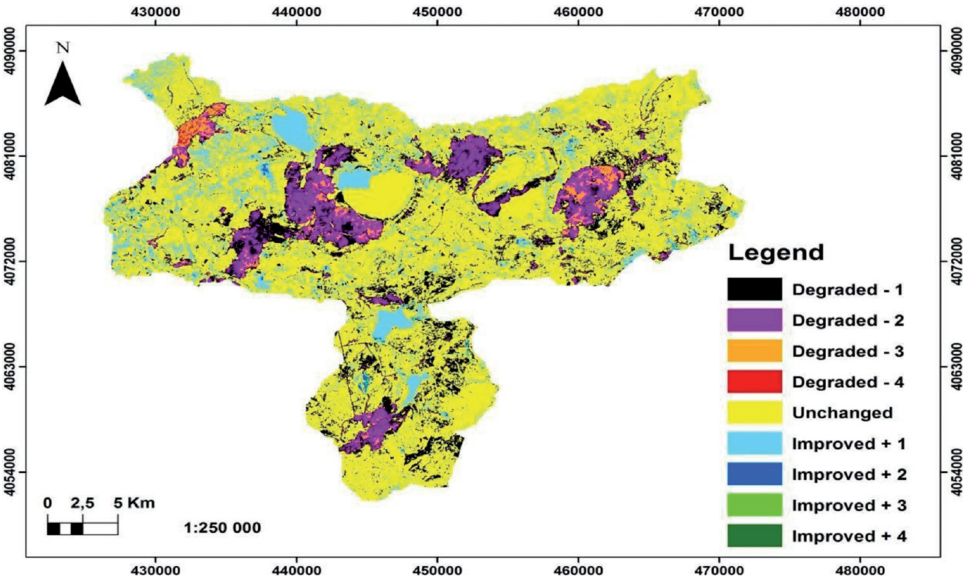
3.5. Change detection of RSEI

Calculation of ΔRSEI by applying equation (2) reveals changes in the ecological quality of the environment within El Kala National Park during the observation period (Table 5).

Table 5. Area changes of RSEI classes during the observation period (2013–2023)

Classes of RSEI	Change detection of RSEI between 2013 and 2023		
	Area [ha]	Area [%]	Average rate [ha/year]
Very poor	2831	3.51	283.1
Poor	4811	5.98	481.1
Moderate	541	0.67	54.1
Good	-3697	-4.59	-369.7
Excellent	-4486	-5.57	-448.6
Total	0	0	0

Table 5 shows different evolutions (progression or regression) of the RSEI over the 10 years of recording. The Very poor classes increased from 593 ha in 2013 to 3424 ha in 2023, an increase of 3.51%, this is mainly due to the increase in land uses. The area of Poor classes ranges from 19,233 hectares in 2013 to 24,044 hectares in 2023, showing an upward trend of 5.98%, indicating increasing complexity of environmental quality. However, Moderate classes estimated at 17,267 ha in 2013 reached 17,808 ha in 2023, which represents a slight increase of 0.67%. The classes which really represent the ecological quality of the environment (Good and Excellent), go from 43,417 ha in 2013 to 35,234 ha in 2023, which generates a negative change of −10.16%. According to Table 4, El Kala National Park loses 818.30 ha of its ecological quality annually for the observation period 2013–2023, which explains the increase in the area of the classes from Very poor to Poor and Moderate. This regression is mainly due to the influences of natural factors and human activities, particularly tourist activities during the summer season. The change map illustrates significant ecological changes in El Kala National Park over 10 years (2013–2023) in spatial and quantitative terms. These changes in the RSEI are represented by nine classes which are: the class of positive change for areas where the RSEI has progressed (+1,+2,+3,+4), the class of negative changes for areas where the RSEI underwent regression (-1, -2, -3, -4) and the class of zero changes for the stability zones (Fig. 9). Figure 9 shows that the regression areas (negative changes) are mainly located in the central part, East, South and North-West, with a rate of 23.935% ha of the total area of the study perimeter. However, areas of positive change increased at a rate of 12.923% of the total area of the study area.



Source: Authors' own study

Fig. 9. Map of RSEI changes between 2013 and 2023

This progression is concentrated mainly in the southern, central, eastern, western, and northern parts, while the stability zones cover almost the entire territory of the park, covering 63.142% (Table 6).

Table 6. Change detection of RSEI class from 2013 to 2023

Class change	Level	2013–2023	
		Percent change [%]	Total percent change [%]
Degraded	−4	0.112	23.935
	−3	1.522	
	−2	7.136	
	−1	15.165	
Unchanged	0	63.142	–
Improved	1	12.42	12.923
	2	0.456	
	3	0.045	
	4	0.002	

4. Discussion

Environmental quality is a set of generalized or objective environmental characteristics that affect living organisms. It is one of the metrics used to measure the state of the environment in relation to the requirements of surrounding elements and human needs and goals [Roche 1997]. The most important causes of damage to environmental quality are natural and anthropogenic factors. Precipitation changes are directly related to NDVI and WET in this area, they can improve the quality of the local ecological environment. In this sense, water and thermal conditions play an important role in the ecological environment of this park. However, in the study area, temperature and precipitation showed no significant increasing trend, while NDVI showed a decreasing trend, indicating that other factors affect NDVI. Among these factors are the recurring forest fires (Fig. 10) each summer season, particularly during the period of high tourist influx between July and the end of August, which constitute major obstacles to the quality of the environment and, on the other hand, contribute to the emergence of water erosion, which increases the complexity of environmental quality.

The NDBSI, which is negatively related to the ecological environment, contributes more to the RSEI, which corresponds to the characteristics of global warming in El Kala National Park with the progression of global climate change. The negative correlation between LST and RSEI explains the urban heat island effect evident in large urban centers with a significant population density in this park such as the cities of El Kala, El Taref, Bouteldja, and others. Human activities are considered as a reference to the different activities of life. The population density of El Kala National Park increases significantly, the number of population increased from 144,880 inhabitants in 2013 to 205,360 inhabitants in 2023. Therefore, the study area is limited, as is the

Source: Authors' own study

Fig. 10. Forest fires in El Kala National Park (November 2022)

Source: Authors' own study

Fig. 11. Waste inside El Kala National Park (November 2023)

environmental carrying capacity, so that population and economic growth gradually approaches the environmental limit. In an area with tourist potential such as the case of El Kala National Park, population growth not only leads to higher consumption of resources but also aggravates ecological disturbances. The large population especially during the summer season leads to frequent human activities. To meet the needs of the population, especially tourism, it is necessary to accelerate the process of exploitation of environmental resources, forcing cities, roads, beaches, public spaces, and others to expand to the detriment of vegetation, ultimately changing the structure ratio of the land type, thereby affecting the ecological quality of the environment. Generally speaking, the territory of El Kala National Park contains an ecosystem exposed to natural and human factors. It is necessary to find appropriate solutions to reduce the rapid deterioration of the ecological quality of the environment. Moreover, in tourist areas, including beaches, recreational forests, summer camps, mountains, and other areas heavily dependent on natural resources, the protection of ecological quality of the environment depends solely on the elimination of certain aspects that harm environmental quality, such as the discharge of various types of waste (Fig. 11).

The study area is located in the far northeast of Algeria and constitutes an exceptionally humid area. The complexity of the ecosystem in this area is widespread, and the problem of ecological constraints in the face of significant tourist potential has become the main obstacle to creating a sustainable local ecological environment. Considering the influence of certain natural and human factors, this study used the RSEI to monitor and analyze the ecological situation in El Kala National Park from 2013 to 2023. The field survey and careful inspection demonstrated the effectiveness of RSEI in assessing the ecological quality of the environment in El Kala National Park. The method adopted in this research can provide a reference for the assessment of environmental quality in wetlands and can also be a good attempt to apply it to other areas of the Algerian territory.

5. Conclusion

This study shows that Landsat program data can be directly used to characterize the ecological quality of the environment using the Remote Sensing Ecological Index. The purpose of this study is to evaluate the current situation of El Kala National Park between significant tourist potential and ecological constraints. This assessment is essentially based on the RSEI model which was adopted by combining four indicators related to greenness, humidity, heat and drought using Landsat images taken in 2013 and 2023. The obtained result shows that from 2013 to 2023, the values of greenness, humidity, dryness and heat have changed spatially. The values of Wet, NDISI and LST increased while the value of NDVI decreased. According to the results, the values of good to excellent ecological quality of the RSEI environment in El Kala National Park from 2013 to 2023 regressed with a rate reaching 10.16% of the total surface of the study area. This is mainly linked to natural and human factors. To this end, and in order to preserve the good environmental quality of the study area, which is a wetland with the most suitable tourism potential in the country, environmental sustainability plans must focus on green planning practices. It is important to coordinate development with the ecological environment and land use if we are to achieve sustainable development in this protected area.

References

GAO W.L., Zhang S.W., Rao X.Y., Lin X., Li R.S. 2021. Landsat TM/OLI-based ecological and environmental quality survey of Yellow River Basin, Inner Mongolia Section. Remote Sens. 2021, 13, 4477. https://doi.org/10.3390/rs13214477

Hamouda S., Tahar A. 2012. Apport de l'analyse spatiale dans le suivi du couvert végétal du parc national d'El-Kala, (Algérie). Synthèse: Revues des sciences de la terre et de la technologie, 25. https://www.ajol.info/index.php/srst/article/view/117257

Jiang L., Liu Y., Wu S., Yang C. 2021. Analyzing ecological environment change and associated driving factors in China based on NDVI time series data. Ecol. Indic. 129, 107933. https://doi.org/10.1016/j.ecolind.2021.107933

Jiang X., Guo X., Wu Y., Xu D., Liu Y., Yang Y., Lan G. 2023. Ecological vulnerability assessment based on remote sensing ecological index (RSEI): A case of Zhongxian County, Chongqing. Front. Environ. Sci. 10:1074376. https://doi.org/10.3389/fenvs.2022.1074376

Jogo W., Hassan R. 2010. Balancing the use of wetlands for economic well-being and ecological security: The case of the Limpopo wetland in southern Africa. Ecol. Econ., 69, 7, 1569‑1579. https://doi.org/10.1016/j.ecolecon.2010.02.021

Khallef B., Brahmia K., Ouerbi A. 2018. Study of the vulnerability of soil to water by remote sensing and GIS: Case of the El Kala National Park (Algeria). Journal of Biodiversity and Environmental Sciences (JBES), 13(6), 52 65. www.innspub.net/wp-content/uploads/2019/01/JBES-Vol-13-No-6-p-52- 65.pdf

Khallef B. 2019. Contribution à l'étude des facteurs de vulnérabilité par des images satellitaires: Cas du Parc national d'El Kala Wilaya d'El Taref-Algérie. Thèse de doctorat, Faculté des Sciences de la Terre. Département d'Aménagement, Université Badji Mokhtar – Annaba, Algérie, 163 p. https://biblio.univ-annaba.dz/wpcontent/uploads/2021/01/These-Khallef-Boubaker.pdf

Khallef B. 2023. Use of remote sensing as an indicator of the urban heat island effect: The case of the municipality of Guelma (north-east of Algeria). Geomatics, Landmanagement and Landscape, 3, 61–72. http://dx.doi.org/10.15576/GLL/2023.3.61

Khallef B., Biskri Y., Mouchara N., Brahamia K. 2020. Analysis of Urban Heat Islands Using Landsat 8 OLI/ TIRS Data: Case of the City of Guelma (Algeria). Asian Journal of Environment & Ecology, 12(4), 42‑51. https://doi.org/10.9734/AJEE/2020/v12i430167

Khallef B., Brahamia K., Oularbi A. 2021. Study of the dynamics of vegetation cover by satellite images: Case of El Kala National Park (Algeria). September 2021. Ekológia (Bratislava), 40(3), 212‑221. https://doi.org/10.2478/eko-2021-0023

Khallef B., Zennir R. 2022. Forest cover change detection using Normalized Difference Vegetation Index in the Oued Bouhamdane watershed, Algeria. A case study. Journal of Forest Science, 69, 2023 (6), 254–265. https://doi.org/10.17221/192/2022-JFS

Li P.H. 2022. Research on Eco environmental quality evaluation system based on big data analysis. Comput. Intell. Neurosci., 5191223. https://doi.org/10.1155/2022/5191223

Liu Q., Yu F., Mu X. 2022. Evaluation of the Ecological Environment Quality of the Kuye River Source Basin Using the Remote Sensing Ecological Index. Int. J. Environ. Res. Public Health, 19, 12500. https://doi.org/10.3390/ijerph191912500

Liu Y., Zhang Z., Tong L., Khalifa M., Wang Q., Gang C., Wang Z., Li J., Sun Z. 2019. Assessing the effects of climate variation and human activities on grassland degradation and restoration across the globe. Ecological Indicators, 106. https://doi.org/10.1016/j.ecolind.2019.105504

Liu Y., Zhang X.X., He Y.R., Luan H.J. 2020. Monitoring and Assessment of Ecological Change in Coastal Cities Based on Rsei. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-3/W10, 461-470. https://doi.org/10.5194/isprs-archives-XLII-3-W10-461-2020

Ma Z.J., Melville D.S., Liu J.G., Chen Y., Yang H.Y., Ren W.W., Zhang Z., Piersma T., Li B. 2014. Rethinking China's new great wall. Science, 346, 212, 912–914. https://doi.org/10.1126/science.1257258

Maity S., Das S., Pattanayak J.M., Bera B., Shit P.K. 2022. Assessment of ecological environment quality in Kolkata urban agglomeration, India. Urban Ecosyst., 25, 1137–1154. https://doi.org/10.1007/s11252-022-01220-z

Niu X., Li Y. 2020. Remote sensing evaluation of ecological environment of Anqing city based on remote sensing ecological index. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B3-2020. https://doi.org/10.5194/isprs-archives-XLIII-B3-2020-733-2020

Pettorelli N., Vik J.O., Mysterud A., Gaillard J.-M., Tucker C.J., Stenseth N.C. 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. Trends. Ecol. Evol., 20 (9), 503–510. https://doi.org/10.1016/j.tree.2005.05.011

Prăvălie R., Sîrodoev I., Nita I.A., Patriche C., Dumitraşcu M., Roşca B., Tişcovschi A., Bandoc G., Săvulescu I., Mănoiu V., Victor Birsan M. 2022. NDVI-based ecological dynamics of forest vegetation and its relationship to climate change in Romania during 1987–2018. Ecol. Indic., 136, 108629. https://doi.org/10.1016/j.ecoinf.2016.05.004

Ren W., Zhang, X.S., Peng, H.J. 2022. Evaluation of temporal and spatial changes in ecological environmental quality on Jianghan Plain from 1990 to 2021. Front. Environ Sci., 10, 406. https://doi.org/10.3389/fenvs.2022.884440

Roche P. 1997. Espace et modèles en écologie du paysage. Ecologia Mediterranea, Année, 23, 1-2, 7-12. https://www.persee.fr/doc/ecmed_01538756_1997_num_23_1_1817

Rouse J.W., Haas R.H., Schell J.A., Deering D.W. 1973. Monitoring vegetation systems in the Great Plains with ERTS. https://ntrs.nasa.gov/api/citations/19740022614/downloads/19740022614.pdf.

Shi H., Shi T., Liu Q., Wang Z. 2021. Ecological Vulnerability of Tourism Scenic Spots: Based on Remote Sensing Ecological Index. Pol. J. Environ. Stud., 30, 4, 3231-3248. https://doi.org/10.15244/pjoes/129916

Sun C.J., Li X.M., Zhang W.Q., Li X.G. 2020. Evolution of ecological security in the Tableland Region of the Chinese Loess Plateau using a remote-sensing-based index. Sustainability, 12, 3489. https://doi.org/10.3390/su12083489

Wang P., Zhao W., Ke X. 2021. Evaluation and Spatiotemporal Evolution of Ecological Vulnerability of Qianjiang Based on SRP Model [J]. Res. Soil Water Conservation, 28 (5), 347–354. https://doi.org/10.13869/j.cnki.rswc.2021.05.040

Xu H. 2013. A remote sensing urban ecological index and its application. Acta Ecol. Sin., 33 (24), 7853–7862. https://doi.org/10.5846/stxb201208301223

Yu J.B., Li X.H., Guan X.B., Shen H.F. 2022. A remote sensing assessment index for urban ecological livability and its application. Geo-Spat. Inf. Sci., 25, 1–22. https://doi.org/10.1080/10095020.2022.2072775

Zedler J.B., Kercher S. 2005. Wetland resources: status, trends, ecosystem services and restorability. Annual Review of Environmental Resources, 30, 39-74. https://doi.org/10.1146/annurev.energy.30.050504.144248

Zhang X., Yu W., Cai H., Guo X. 2018. Review of the evaluation methods of regional eco- environmental vulnerability. Acta Ecologica Sinica, 38 (16), 5970, 2018. https://doi.org/10.5846/stxb201708211502

Zhang Z., Cai Z., Yang J., Guo X. 2022. Ecological environmental quality assessment of Chinese estuarine wetlands during 2000–2020 based on a remote sensing ecological index. Front. Mar. Sci., 9, 981139. https://doi.org/10.3389/fmars.2022.981139

Zheng Z.H., Wu Z.F., Chen Y.B., Yang Z.W., Marinello F. 2020. Exploration of eco-environment and urbanization changes in coastal zones: A case study in China over the past 20 years. Ecol. Indic. 2020, 119, 106847. https://doi.org/10.1016/j.ecolind.2020.106847