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Ecological environment assessment based on Remote Sensing in Zhengzhou

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Abstract. In this paper, the ecological environmental quality of Zhengzhou city was evaluated and analysed by images of Landsat series of 1997, 2006 and 2014 based on the weights by using principal component analysis to determine the green degree, humidity, dryness and heat of the 4 indicators, using remote sensing ecological index (RSEI) evaluation model. The results showed that in 1997-2014, the ecological environment quality in Zhengzhou city was generally decreased, and the mean RSEI decreased from 0.553 to 0.401; the improving the ecological environment of the region was mainly distributed in the surrounding Zhengzhou City, accounted for only 23.86% of the total area; ecological and environmental deterioration in the region was mainly distributed around the built-up area in the city of Zhengzhou, accounting for 52.10% of the total area. The quality of the ecological environment in the study area was greatly affected by urban expansion, and its ecological environment quality was on the downward trend. The city's ecological environment needed to be further strengthened.

1. Introduction

With the rapid development of social modernization, the relationship between human activities and ecological environment is becoming closer, and the contradiction among population, resources and environment is becoming more and more prominent. Accurate evaluation of regional ecological and environmental conditions is beneficial for policy makers to recognize the current situation of regional ecological environment, and take positive measures to better realize regional sustainable development.

At present, remote sensing technology has been widely used in the field of ecological environment for its advantages of rapid, real-time and wide range monitoring. It has become an effective means to evaluate regional ecological environment. However, the current research on various ecosystem evaluation based on ecological environment of single index, such as the use of vegetation index of forest ecosystem[1,2], access to information extraction of water index river water environmental assessment[3,4], using the surface temperature measurement to evaluate urban heat island effect[5,6] etc. In fact, the formation and development of ecosystems are influenced by many factors[7]. A single ecological factor cannot reflect the change of ecological environment objectively and comprehensively. Therefore, it is very important to evaluate the regional ecological environment from the combined effects of multiple ecological factors[8,9]. In recent years, a new type of remote sensing ecological index entirely based on remote sensing information, has been put forward. This method integrates multiple indicators that reflect the ecological environment, and can realize rapid monitoring and evaluation of regional ecological environment. It has certain practical significance and high reference value.

2. Study areas and Methods

2.1 Study Areas

Zhengzhou (34°16'N-34°58'N, 112°42'E-114°14'E), is the capital of Henan province. Zhengzhou is located in the north central part of Henan Province, south of the North China Plain, north of the Yellow River, West to Songshan, southeast to the vast plains of Huanghuai. The research area for Zhengzhou urban area is shown in Figure 1 (excluding Shangjie District). Zhengzhou has a 2avourable geographical position and is the political, economic and cultural center of Henan province. It is one of the pilot cities of trade and Commerce in China. It is one of the largest railways cross hub passenger stations in China.

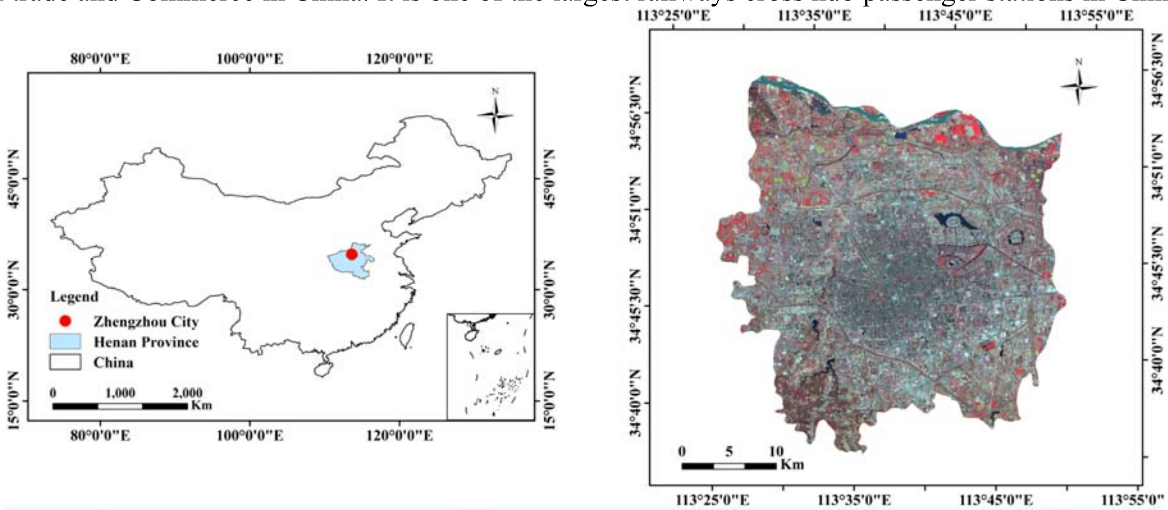

Figure 1. The location of the study area

2.2. Data and preprocessing

Remote sensing data, which is the Landsat 5 TM images of May 23, 1997 and May 16, 2006, and the Landsat 8 OLI and TIRS images of May 6, 2014, was downloaded from the US Geological Survey (USGS) web site. The images of different periods were consistent, which could guarantee the comparability of the results. Radiometric calibration of images was carried out respectively in ENVI 5.1[10,11], the gray value of the image was converted to the reflectivity of the sensor, and atmospheric correction was performed for visible and near infrared bands of each phase by the FLAASH atmospheric correction tool[12,13]. Finally, all data was cropped by the Zhengzhou border.

2.3 Construction of remote sensing ecological index

4 important indexes related to human survival, namely greenness, humidity, heat and dryness, are important factors of ecological conditions of human intuition. Therefore, they were often used to evaluate ecosystems[14,15]. The information of these 4 important indexes from the scattered remote sensing image information was extracted by thematic information enhancement technology, such as the use of humidity component of vegetation index, surface temperature and tasseled cap transformation respectively representing the green degree, heat and humidity. Because the building is an important part of ecological system, the emergence of a large number of building impervious surface to replace the natural ecological system of the original surface, leading to the surface of the "dry", so it was used to represent "dry building index". In this way, the proposed remote sensing ecological index (RSEI) was expressed as a function of these 4 indicators, this is:

$$\text{RSEI} = f(G, W, T, D) \quad (1)$$

where G is green, W is humidity, T is heat, and D is dryness.

2.3.1. Index calculation. (1) Humidity. Brightness, greenness and humidity component obtained by tasseled cap transformation were directly related to the physical parameters of the earth's surface. The humidity component reflects the humidity of soil and vegetation, and is closely related to ecology. Therefore, the humidity index of this study was represented by this humidity component. Take the Landsat TM image as an example, the expression[16] is:

$$\mathrm{Wet} = 0.03151\rho_{\mathrm{Blue}} + 0.2021\rho_{\mathrm{Green}} + 0.3102\rho_{\mathrm{Red}} + 0.1594\rho_{\mathrm{NIR}} - 0.6806\rho_{\mathrm{SWIR1}} - 0.6109\rho_{\mathrm{SWIR2}} \quad (2)$$

where Wet is the humidity index; ρBlue, ρGreen, ρRed, ρNIR, ρSWIR1, ρSWIR2 respectively, corresponding to reflectance of each image of blue band, green band, red band, near-infrared and shortwave infrared band 1 and band 2 (the same below).

(2) Greenness. The normalized difference vegetation index (NDVI) is closely related to plant biomass, leaf area index and vegetation coverage[17]. Therefore, it could be used to represent the greenness index:

$$\mathrm{NDVI} = (\rho_{NIR} - \rho_{\mathrm{Red}})/(\rho_{NIR} + \rho_{\mathrm{Red}}) \quad (3)$$

(3)Temperature. Heat indicators use surface temperatures instead[18]. Many studies used Landsat 8 images to retrieve surface temperatures[19-23].

$$LST = K_2 / \ln(K_1 / B_{10}(T_s) + 1) \quad (4)$$

where K1 and K2 are scaling coefficients gotten in the metadata of the image, B10 (TS) is the thermal radiation brightness of a blackbody at the same temperature as TS ,and LST is the real surface temperature.

(4) Dryness. The dry index is the building index[24]. The formula is:

$$\mathrm{IBI} = \frac{(2\rho_{\mathrm{SWIR1}}(\rho_{SWIR1} + \rho_{NIR})^{-1} - \rho_{\mathrm{NIR}}(\rho_{SWIR1} + \rho_{NIR})^{-1} - \rho_{\mathrm{Green}}(\rho_{SWIR1} + \rho_{Green})^{-1})}{(2\rho_{\mathrm{SWIR1}}(\rho_{SWIR1} + \rho_{NIR})^{-1} + \rho_{\mathrm{NIR}}(\rho_{SWIR1} + \rho_{NIR})^{-1} - \rho_{\mathrm{Green}}(\rho_{SWIR1} + \rho_{Green})^{-1})} \quad (5)$$

2.3.2. The construction of comprehensive index. (1) Standardize. Because the dimension of the 4 indexes is different, in order to reduce the influence of the numerical value of different indexes on the result, standardization is needed:

$$\mathrm{NI} = (I - I_{\min})/(I - I_{\max}) \quad (6)$$

where NI is the index value after standardization; I is the numerical value of this index; I_{max} and I_{min} are the maximum and the minimum values of this index respectively.

(2)RSEI. RSEI was used by principal component transformation to integrate the above 4 indexes. The advantage of this approach was that the weights of the indicators are independent of human factors, and determined by the contribution of the indicators to the first principal component(PC1). After the index was standardized, the initial ecological index ($RSEI_0$) can be obtained by principal component analysis.

$$RSEI = PCA(f(NDVI, WET, LST, IBI)) \quad (7)$$

In order to facilitate the measurement and comparison of indexes, the standard $RSEI_0$ was standardized by using (6), and the final RSEI value was between 0 and 1. The closer the RSEI is to 1, the better the ecological environment.

Table 1. Principal component analysis of four factors

	1997			
	PC1	PC2	PC3	PC4
Wet	0.537	0.063	0.827	0.153
NDVI	0.5275	0.2945	-0.4825	0.635
LST	-0.5395	-0.287	0.231	0.757
IBI	-0.378	0.909	0.172	0.023
Eigenvalue	0.174	0.025	0.005	0
Percent eigenvalue	85.29%	12.26%	2.45%	0
	2006			
	PC1	PC2	PC3	PC4
Wet	0.515	0.014	0.845	0.139
NDVI	0.533	0.360	-0.434	0.631
LST	-0.413	0.880	0.236	0.008
IBI	-0.529	-0.309	0.202	0.763
Eigenvalue	0.212	0.024	0.004	0
Percent eigenvalue	88.33%	10 %	1.67%	0
	2014			
	PC1	PC2	PC3	PC4
Wet	0.510	-0.105	0.854	-0.018
NDVI	0.541	0.347	-0.265	0.719
LST	-0.384	0.860	0.336	0.002
IBI	-0.548	0.359	0.297	0.695
Eigenvalue	0.193	0.025	0.008	0
Percent eigenvalue	85.40%	11.06%	3.54%	0

Table 1 is the principal component matrix of 4 indicators of the study area, from which we can see: 1) the first principal component (PC1) of the contribution rate is greater than 85%, indicating that it has concentrated most of the features of 4 indicators; 2) 4 indicators of PC1 have certain contribution, and relatively stable that does not appear like the flickering phenomenon in other characteristic components, thereby losing some of the indicators; 3) in PC1, Wet and NDVI are positive, indicating that they have a positive contribution to ecological environment; LST and IBI are negative in PC1, indicating that they have a negative impact on ecological environment; this is consistent with the actual situation. In other components, these indicators are negative, and difficult to explain ecological phenomena. Obviously, compared with several other components, PC1 has obvious advantages. It reflects the variability of the original data of each index to the maximum extent, and explains the ecological phenomenon reasonably. Therefore, it can be used to create a comprehensive ecological index.

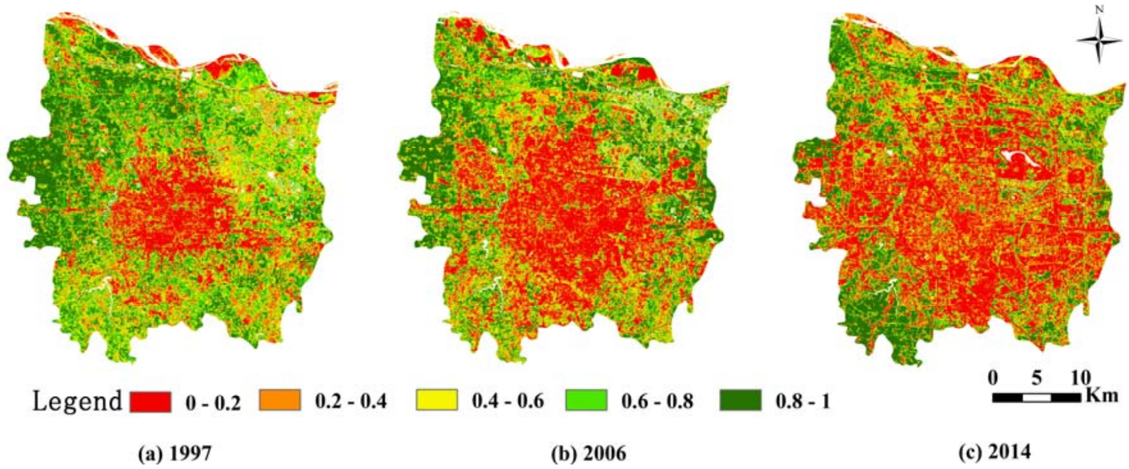

Figure 2. The map of Zhengzhou's results of the RSEI

3. Results and analysis

3.1. Ecological comparison of Zhengzhou City

From the change of 4 indexes and RSEI of each year (Table 2), the statistical results showed that 1997 - 2014 years, the trend of RSEI of the study area was downward. The average of RSEI dropped from 0.553 in 1997 to 0.464 in 2006, and then to 0.401 in 2014, a decrease of about 27%. The changes of indicators showed that the average value of ecological beneficial greenness and humidity had decreased during the past 18 years, while the average value of heat and dryness on behalf of poor ecological conditions had increased significantly. The performance of the above 4 indexes showed the ecological quality of the study area was a downward trend. Therefore, the results of RSEI are consistent with the results of the 4 indexes, which can represent 4 indicators comprehensively. If you relied on the individual evaluation of indicators, you couldn't take into account the interaction between indicators. It can be seen that the new comprehensive index can not only integrate all the original indexes to comprehensively assess the ecological quality of the region, but also quantitatively describe the change degree of ecological quality. So it had more advantages than analysis of single index.

Table 2. The average change of 4 indexes and RSEI in each year of the study area

Year	Wet	NDVI	IBI	LST	RSEI
1997	0.518	0.551	0.488	0.368	0.553
2006	0.464	0.469	0.571	0.524	0.464
2014	0.442	0.386	0.593	0.552	0.401

In order to analyze the rationality of the new index better, the RSEI index of each year was divided into 1~5 grades at 0.2 intervals, representing 5 grades (poor, inferior, medium, good and excellent) of ecological difference.

From the change of ecological level, the proportion of ecological grade to good and excellent decreased from 47.84% to 27.79%, while the proportion from poor to medium increased correspondingly. The ecological quality of Zhengzhou city has shown a downward trend.

In order to analyze the spatial and temporal variation of the ecological status in different years, the ecological difference between red and green could be detected on the basis of the 5 RSEI ecological grades of Table 3 in Zhengzhou city. This method uses tricolor principle, the increasing the quality of the green ecological area, the greater the difference in color, the more green; falling in red on behalf of ecological area, the greater difference in color, the more red; and the yellow represents the constant region of the ecological quality (Figure 3). From the time point of view, from 1997 to 2006, the ecological level was poor to inferior level (1 - 2) for the upward trend in the area, and the good and excellent grades (4 - 5) of the area showed a downward trend (Figure 3), indicating that the ecological quality of the study area decreased. From the change detection results (Table 3), from 1997 to 2014, the area of ecological decline in this area is 516.62 km2, accounting for about 52.10% of the total area, while the ecological improvement area is 236.59km2, accounting for 23.86%. Spatially, sites with better ecological conditions were distributed mainly around the urban area (Figure 3). The main ecological changes were some new construction sites (Figure 3), while the surrounding areas of the city vary greatly. The center of the city had changed little, and the yellow pattern was the main one.

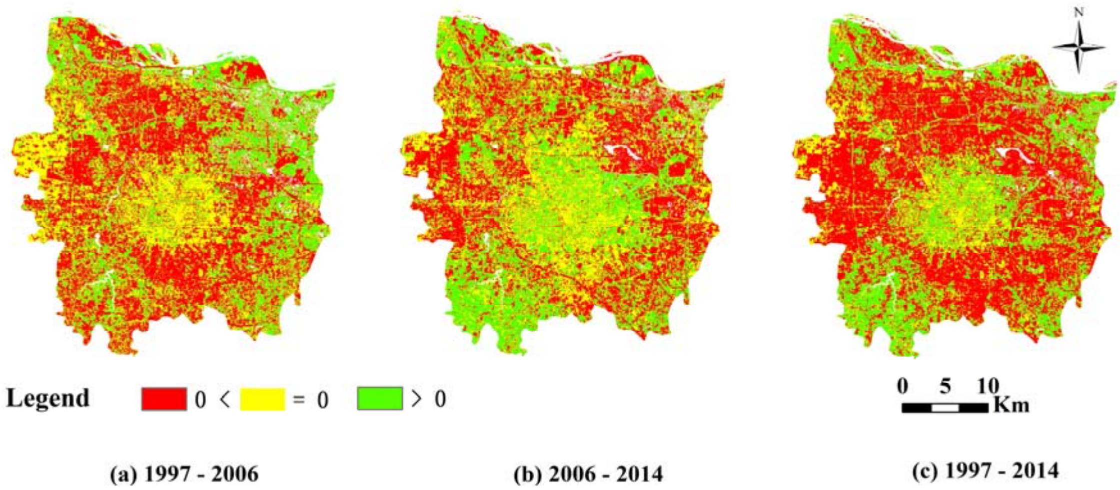

Figure 3. Detection of ecological red green difference in Zhengzhou urban area

Table 3. Area and proportion of ecological grade of Zhengzhou City

RESI Level	1997		2006		2014	
	Area(km2)	percentage	area(km2)	percentage	area(km2)	percentage
1：poor	151.6266	15.16	270.4338	27.14	360.1575	35.45
2:Inferior	154.4328	15.44	193.059	19.38	216.7821	21.33
3：Medium	215.514	21.55	178.4061	17.91	156.8295	15.43
4：Good	240.1389	24.01	157.1004	15.77	113.1732	11.14
5：Excellent	238.3362	23.83	197.3115	19.8	169.1487	16.65
Sum	1000.0485	100	996.3108	100	1016.091	100

3.2 Comprehensive representativeness analysis of RSEI index

The comprehensive representation of RSEI could be further quantified by the correlation between it and the other indexes. The stronger the correlation between RSEI and the other indexes, the more comprehensively it could represent the others. Table 4 was the correlation coefficient of 4 indexes and RSEI, and the correlation coefficient between the indexes themselves. In terms of single index, the highest average correlation is Wet, with an average of 0.843 in 3 years, and the lowest was temperature component, with an average of 0.731 in 3 years. The new ecological index of the average value was 0.916, 9.85% higher than that of Wet which is the highest, 25.3% higher than that of LST which is the lowest, 15.2% higher than that of the 4 indicators (0.795). Obviously, the higher correlation between the new index and each index showed that it could better integrate the information of each index. It is more representative than any single index, and can more comprehensively represent the ecological status of Zhengzhou city.

Table 4. Correlation coefficient matrix of each index and RSEI

Year	1997				
Index	Wet	NDVI	LST	IBI	RSEI
Wet	1	0.902	-0.931	-0.666	0.965
NDVI		1	-0.990	-0.579	0.965
LST			1	0.588	-0.976
IBI				1	-0.735
Mc	0.833	0.824	0.836	0.611	0.910
Year	2006				
Wet	1	0.923	-0.769	-0.944	0.976
NDVI		1	-0.659	-0.992	0.968
LST			1	0.680	-0.808
IBI				1	-0.952
Mc	0.879	0.858	0.703	0.872	0.926
Year	2014				
Wet	1	0.865	-0.723	-0.859	0.942
NDVI		1	-0.621	-0.998	0.969
LST			1	0.618	-0.770
IBI				1	-0.967
Mc	0.816	0.828	0.654	0.825	0.912
MC3	Wet=0.843，	NDVI=0.837，	LST=0.731，	IBI=0.769，	RSEI=0.916

(Note: *Mc is the average correlation degree, calculated by the absolute value of the correlation coefficient of some index with other indexes, taking Wet in 1997 as an example: Meanwet_1997 = [|0.902| + |-0.931|+|-0.666|]/3=0.833. Mc3: averages three years of average correlation.)

4. Conclusion

The RSEI is an index based on remote sensing information and natural factors. Therefore, it could be used to assess regional ecological quality quickly and simply. The integration of the indexes of RSEI was not artificial weighted sum, but integrated according to the contribution of each index to the first principal component. Therefore, RSEI can objectively coupling each index and rationally represent the regional ecological quality.

Green degree, humidity, heat and dryness are important evaluation indexes of the natural ecological system. RSEI can well integrate their information, reflect and describe the ecological quality and changes. In Zhengzhou,

The greenness index (NDVI), contributes most to the ecological index (RSEI) in the 4 indicators, indicating that vegetation is very important factor of ecological environment. So tree planting and greening can effectively improve the ecological quality of the region. While developing urban economy at high speed, we should pay attention to the change of urban ecological quality at all times. During the 18 years in the study area, the RSEI value decreased by 27.49%, and the ecological quality decreased significantly.

RSEI having higher correlation degree with each index can better couple each index, more objectively represent the regional ecological quality. The RSEI index is completely based on the index of remote sensing information and natural factors, and obtained easily. Without artificial weight setting calculation process, it provides an objective, rapid and simple technique for monitoring and quantitative evaluation of regional ecological quality.

RSEI is unfit for use in large areas of water. In the study area, if there is a large area of water, it is better to masking the areas before applying it. Since the construction of RSEI requires the use of thermal infrared images, RSEI is mainly suitable for mesoscale mapping. For small-scale scales, it is better to refine the thermal infrared images first.

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