Remote Sensing Evaluation of Urban Ecological Changes in Arid Region Oasis: A Case Study in Liangzhou District of Wuwei, China

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Abstract. The ecological environment quality of the oasis city in Liangzhou District of Wuwei City in arid region from 2000 to 2016 is evaluated by using RSEI, which integrates four ecological evaluation indicators (greenness, humidity, dryness, and heat). The results show that the ecological index of remote sensing based on principal component analysis can objectively quantify regional ecological changes; the overall ecological environment quality in Liangzhou District of Wuwei is slightly improved, the average RSEI raised from 0.447 to 0.458, and the overall increased 2.46%. Liangzhou District Eco-environmental Quality Grades from Medium to Two Polarized Development. The large-scale cultivation of arable land in the northeastern desert area has improved the ecological environment. The expansion of urban areas and the construction of new areas in the central region have reduced the quality of the ecological environment. The NDSI (Normalized difference soil index) which represents the degree of dryness has the largest contribution to the RSEI, indicating that the decline in the quality of the ecological environment is closely related to the increasing impervious surface.

1. Introduction
Oasis is a unique ecological system with microclimate effects that is influenced by both natural and human factors in the arid region. It is one of the three major geographic systems in inland arid regions. The oasis-type cities are the major urban models in arid regions. In recent years, with the growth of population and the increase of social industrialization, urbanization has been accelerating and a large number of suburban arable and forestry lands have been transformed into urban construction land. The area of impervious water in cities has expanded rapidly. However, the land of ecologically valuable resources, such as vegetation and water, is shrinking and shattering. The escalating contradictions between the oasis population and the resources and environment, the drastic reduction of green land, the destruction of biodiversity, desertification, and soil erosion have become increasingly prominent. The urbanization process may have seriously threatened the fragile ecological environment of oasis cities. Correctly understanding and evaluating the ecological environment of urban oasis has become the basis for the prediction and early warning of the oasis urban ecological environment[1-2]. The Shiyang River Basin, an important ecological barrier in China, is located in the transitional belt of the three major plateaus[3-4]. It is a typical water shortage area in the interior of the northwestern region, and is also one of the ecologically and environmentally sensitive areas.

Satellite remote sensing Earth observation system has been widely used in urban ecological environment monitoring because of its advantages of large area synchronous observation, time-efficiency, periodic repeated observation and so on. Scholars have carried out a lot of research work on the evaluation of ecological environment using remote sensing technology, but most of the
monitoring is still based on a single index. In 2013, Xu Hanqiu [5] proposed a multi-index Remote Sensing Ecology Index, which is based on remote sensing information and can integrate multiple index factors, including green degree, humidity, dryness and heat. The calculation results are objectively stable without artificial selection of ecological index weights. At present, some scholars have analyzed the ecological changes using remote sensing ecological indices in some Chinese [6-10]. The results show that RSEI can fully reflect the characteristics of regional ecological environment quality changes. Therefore, this paper chooses a new remote sensing ecological index to evaluate the ecological changes of the oasis cities in the arid region, and analyzes the spatial-temporal characteristics of the ecological environment changes during the urban expansion period in Liangzhou District of Wuwei City. It is hoped that this paper will provide a scientific basis for urban eco-environmental protection and management in arid regions.

2. Study area and data sources

2.1. Study area
Liangzhou District, which lies in the upstream of Shiyang River Basin, is located in the eastern end of Hexi Corridor and the northern foot of Qilian Mountain, and ranges from 101°59′ to 103°23′E and from 37°23′ to 38°12′N (Fig.1). The altitude of Liangzhou District is ranges from 1440 to 3263 meters, topographically high in the west and low in the east, the southwest is the Qilian Mountain, the middle is the Hexi corridor plain oasis, the northeast is the Tengger Desert. The climate of the Liangzhou District is typically a temperate continental arid climate, featuring droughtless rain, sufficient sunshine, large temperature difference between day and night. The mean annual precipitation is 100 mm, and the annual mean temperature is 7.7 °C. Liangzhou District is the most important part of the Shiyang River Basin, where the population is overpopulated, the water sources is scarced and ecological environment is fragile of the whole valley. The study focused on the plain oasis in Liangzhou District, including the main urban area, the new district and its surrounding area, with a total area of about 1507km².

2.2 Data Sources and Preprocessing
The remote sensing data used in this study is provided by the Geospatial Data Cloud (http://www.gscloud.cn). In order to maintain the consistency of data sources, Landsat series satellite remote sensing images are used for both images. Among them, the Landsat5 TM image on August 11, 2000 and the Landsat8 OLI/TIRS image on August 7, 2016 are selected respectively. The images of the two scenes are very close to each other, and they are cloudless and of good quality. Atmospheric profile parameters are provided by NASA (http://atmcorr.gsfc.nasa.gov/), which could be obtained by entering the imaging time and center latitude/longitude on the website.

In order to reduce the differences in terrain, illumination, and atmosphere of different time images and to ensure the accuracy of spatial superposition analysis between images, this paper separately performs radiation correction and geometric correction on the two scene images. First, the image is subjected to radiation calibration, the DN value is converted to the reflectance at the sensor, and then the FLASHH atmospheric correction is performed on the image after the radiation calibration to eliminate the influence of atmospheric and light on the reflection of the ground object [11-12]. Finally, using the 2016 Landsat8 image as a benchmark, a quadratic polynomial and a neighboring pixel resampling method are used to perform relative geometric corrections on the two-view remote sensing image, and the registration error is within 0.5 pixels.
3. Methods
Aiming at the oasis urban ecosystem, this paper uses the remote sensing ecological index RSEI, which integrates various index factors. By extracting the normalized vegetation index, humidity index, bare soil index and surface temperature, it represents 4 indicators which are closely related to the survival of human being, such as green degree, humidity, dry degree and heat, and then using the principal component analysis method to generate RSEI.

\[ RSEI = f(G, W, D, T) \]  

In the formula: \( G \) is green degree index, \( W \) is humidity index, \( D \) is dry degree index, \( T \) is heat index.

3.1 Green degree Index
Normalized difference vegetation index (NDVI) is widely used in monitoring vegetation growth status and vegetation coverage. This article uses NDVI to represent the green degree index. The equation is as follows:

\[ NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \]  

\( \rho \) indicates the reflectivity of the corresponding band.

3.2 Humidity index
The humidity component of the transformation of the bonnet reflects the humidity status of vegetation and soil, and is widely used in ecological research. The value reflects the humidity status in the study area\(^{13}\). The Wet extraction formula based on TM and OLI reflectance data\(^{13,14}\) is showing below:

\[ Wet2000 = 0.0315\rho_{Blue} + 0.2021\rho_{Green} + 0.3102\rho_{Red} + 0.1594\rho_{NIR} - 0.6806\rho_{SWIR1} - 0.6109\rho_{SWIR2} \]  

\[ Wet2016 = 0.1511\rho_{Blue} + 0.1972\rho_{Green} + 0.3283\rho_{Red} + 0.3407\rho_{NIR} - 0.7117\rho_{SWIR1} - 0.4559\rho_{SWIR2} \]

3.3 Heat index
Land surface temperature (LST) is an important parameter that indicates the energy exchange between the surface and the atmosphere. Inversion of LST based on remote sensing data has been widely used in monitoring crops, urban heat islands and other fields. In this study, surface temperature is used to represent heat index. The LST inversion methods based on Landsat TM/ETM mainly include atmospheric correction, single-window and split-window algorithms\(^9\). In this study, atmospheric
correction is used to invert LST. The radiation intensity \( B \) (LST) of the black body is obtained by radiometric calibration of the thermal infrared band (Landsat 5 select TM 6 band, Landsat 8 select TIRS 10 band) of the two scenes, and the Planckian function is used to find the LST [15]. The formula shows below:

\[
LST = \frac{K2}{\ln(K1/B(LST)) + 1}
\]  
(5)

\[
B(LST) = \left[ L_\lambda - L_u - \tau(1 - \varepsilon)L_d \right] / \tau \varepsilon
\]  
(6)

\[
L_\lambda = \left[ \varepsilon B(LST) + (1 - \varepsilon)L_d \right] \tau + L_u
\]  
(7)

Where \( K1 \) and \( K2 \) are constants, obtained in the header file, \( L_\lambda \) is the thermal infrared radiance value, \( \tau \) is the atmospheric transmittance of the thermal infrared band, and \( L_u \) and \( L_d \) represent the radiance values of the atmosphere up and down, respectively. \( \tau \), \( L_u \) and \( L_d \) are obtained from NASA's atmospheric profile parameter website [16,17].

3.4 Normalized difference soil index

The normalized difference soil index (NDSI) is generated by combining an index-based built-up index (IBI) and a bare soil index (SI) [18].

\[
NDSI = (SI + IBI) / 2
\]  
(8)

\[
SI = \left( \frac{\rho_{\text{SWIR1}} + \rho_{\text{Red}} - \rho_{\text{NIR}}}{\rho_{\text{SWIR1}} + \rho_{\text{NIR}} + \rho_{\text{Red}}} \right) / \left( \frac{\rho_{\text{SWIR1}} + \rho_{\text{Red}} + \rho_{\text{NIR}}}{\rho_{\text{SWIR1}} + \rho_{\text{NIR}} + \rho_{\text{Red}}} \right)
\]  
(9)

\[
IBI = \left( \frac{\rho_{\text{SWIR1}} + \rho_{\text{Red}} - \rho_{\text{NIR}}}{\rho_{\text{SWIR1}} + \rho_{\text{NIR}} + \rho_{\text{Red}}} \right) / \left( \frac{\rho_{\text{SWIR1}} + \rho_{\text{Red}} + \rho_{\text{NIR}}}{\rho_{\text{SWIR1}} + \rho_{\text{NIR}} + \rho_{\text{Red}}} \right)
\]  
(10)

3.5 Construction of ecological index of remote sensing

The principal component analysis (PCA) can select a few important variables by orthogonal linear transformation [19]. This method can not only eliminate the correlation among the variables, reduce the information redundancy, but also avoid the interference caused by human weight setting. In order to avoid the influence of the unification of the indexes on the calculation results, the indexes should be normalized before the principal component transformation, and their values are mapped to the 0 to 1 interval and converted to the dimensionless PCA. The regularization formula of each index is showing below:

\[
NI = \frac{(I - I_{\text{min}})}{(I_{\text{max}} - I_{\text{min}})}
\]  
(11)

In the formula: \( NI \) is the index value after standardization; \( I \) is the numerical value of the index; \( I_{\text{max}} \) and \( I_{\text{min}} \) are the maximum and minimum values of the index in the two period.

RSEI uses principal component analysis to integrate the above 4 indicators. First of all, the 4 indexes of two scene images are calculated respectively. After normalization of the 4 indexes, a new image is synthesized. Then the principal component analysis is carried out for the new image, and the principal component matrix (Table 1) is generated.

| Table 1 The Results of principal component analysis of each index |
|---------------------------------------------------------------|
| Index | 2000 | PC1 | PC2 | PC3 | PC4 | 2016 | PC1 | PC2 | PC3 | PC4 |
|-------|------|-----|-----|-----|-----|------|-----|-----|-----|-----|
| NDVI  | 0.476| 0.361| -0.429| 0.678| 0.564| 0.360| 0.674| 0.312|
| WET   | 0.393| 0.043| 0.852| 0.171| 0.234| 0.082| -0.595| 0.765|
| NDSI  | -0.503| -0.463| 0.172| 0.709| -0.585| -0.389| 0.438| 0.562|
| LST   | -0.527| 0.808| 0.245| 0.094| -0.533| 0.844| -0.028| 0.051|
| Eigenvale | 0.082| 0.009| 0.003| 0.001| 0.084| 0.008| 0.002| 0.000|
| Contribution | 86.990| 9.240| 3.010| 0.760| 89.780| 8.210| 1.740| 0.270|

From table 1, it can be seen that the contribution rate of the first principal component (PC1) over two years is greater than 85%, indicating that PC1 concentrates most of the characteristics of the 4 indicators. In PC1, NDVI and WET are positive values, indicating that green degree and humidity index play an active role in ecological environment quality, while NDSI and LST are negative, indicating that dry degree and heat index play a negative role in ecological environment quality.
In the principal component analysis, the first principal component (PC1) integrates the information of each index to the maximum extent. Therefore, the above four indexes can be coupled with PC1, and the RSEI index is constructed and the RESI is normalized. The equation shows below:

\[
RSEI = \frac{PC1 - PC1_{\text{min}}}{PC1_{\text{max}} - PC1_{\text{min}}}
\]  

In the formula, \(PC1_{\text{min}}\) is the minimum value of the first principal component, and \(PC1_{\text{max}}\) is the maximum value of the first principal component, and its value is between 0 and 1. The closer the RSEI value is to 1, the better the ecological environment, and vice versa.

Through the correlation analysis between the RSEI and the other four sub indexes (Table 2), it is found that the average correlation between the NDSI and other four indexes is the highest, which is 0.9 in 2016, and the average value for two years is 0.88. The average correlation is the lowest for LST, with a mean of 0.778 for two years, while the two-year mean value of RSEI and other four indexes is 0.939, 6.7% higher than the NDSI with the highest single index, 20.69% higher than the lowest LST, and 10.93% higher than the average of the four indicators. Thus, the correlation between RSEI and the single index is the strongest, which can well represent the ecological quality of Liangzhou district.

| Index | 2000 | 2016 |
|-------|------|------|
| NDVI | 1.000 | 1.000 |
| WET | 0.865 | 0.867 |
| NDSI | -0.962 | -0.962 |
| LST | -0.753 | -0.945 |
| RESI | 0.950 | -0.794 |

| Correlation | 0.860 | 0.855 | 0.859 | 0.764 | 0.935 | 0.874 | 0.867 | 0.792 | 0.942 |
| Average of two years | NDVI=0.867 | WET=0.861 | NDSI=0.880 | LST=0.778 | RSEI=0.939 |

4. Research results and analysis

4.1 Analysis of ecological variation in Liangzhou District

The RSEI index model is used to form the RSEI map of Liangzhou District in 2000 and 2016, and then the RSEI is divided into 5 ecological grades (such as worse, poor, medium, good and better), according to the value of 0.2. At last, the values of 1, 2, 3, 4 and 5 are quantified respectively, and the RSEI classification map of Liangzhou District in 2000 (Fig. 2a) and 2016 (Fig. 2b) is obtained.
Fig. 2 The RSEI classification map in 2000 and 2016

Table 3 Area and percentage of RSEI in Liangzhou District from 2000 to 2016

| RSEI level | 2000          | 2016          |          |
|------------|---------------|---------------|----------|
|            | Area/km²      | Percentage/%  | Area/km² | Percentage/% |
| Worse      | 167.435       | 11.100        | 105.060  | 6.965        |
| Poor       | 504.452       | 33.442        | 635.833  | 42.152       |
| Medium     | 438.793       | 29.090        | 357.815  | 23.721       |
| Good       | 357.845       | 23.723        | 292.964  | 19.422       |
| Better     | 39.897        | 2.645         | 116.749  | 7.740        |

On the whole, the proportion of poor and worse grade in the 2000 and 2016 research areas increased from 44.542% to 49.117%. The proportion of the good and the better in the ecological class increased from 26.368% to 27.162%, while the proportion of the medium decreased from 29.09% to 23.721%. From the RSEI mean value, the RSEI in the two years changed from 0.447 to 0.458, slightly improving but not changing overall. Based on the difference principle, the ecological change of Liangzhou area is tested in 9 grades. Among them, the "0 level" is basically unchanged, and "better" and "worse" are all divided into 4 grades. Table 4 is shown in the statistical table of change levels.

From the table 4, it can be found that from the range of change, the area of the ecological condition is 324.483 km², which accounts for about 21.51% of the total area, and the ecological area is 355.353 km², accounting for 23.56%.

From the spatial analysis, the worse grade of ecology is distributed in the desert regions of the northeast and the southwest of the mountainous areas, while the good and better grade of ecology is distributed in the middle of the oasis. At the same time, with the expansion of central plain oasis cities, large blocks of cultivated land are fragmented. The ecological level in the middle of the region becomes worse. The development and utilization of unused land at the edge of the oasis has transformed large areas of desert into arable land and green land, thereby enhancing the ecological level of the area. From the variation detection results of Fig. 3, the red variation region is mainly...
distributed in the urban areas and newly developed area. The green ecological improvement area is most prominent in the desert area of the northeast, mainly in the original oasis edge, and the ecological level is unchangeable in the mountainous area of the southwest.

![Image of variation detection results from 2000 to 2016]

To sum up, from 2000 to 2016, the overall ecological quality of Liangzhou district has improved slightly. The variation trend is the decline of ecological quality and the improvement of marginal ecological quality in the middle part of the oasis.

### 4.2 Modeling and analysis of RSEI

In order to further simulate and predict the variation trend of urban ecological environment, a model for RSEI can be established. In this study, 100 x 100 grid is used in the total image sampling method. 28671 samples are collected in each image, and the values of NDVI, WET, NDSI, LST and RSEI in

| Category   | Gradation | Level area/km² | Class area/km² |
|------------|-----------|----------------|----------------|
| Worse      | -4        | 0.177          |                |
|            | -3        | 23.837         |                |
|            | -2        | 133.907        | 324.483        |
|            | -1        | 166.562        |                |
| Unchanged  | 0         | 828.585        | 828.585        |
| Better     | 1         | 165.917        |                |
|            | 2         | 141.026        |                |
|            | 3         | 44.710         | 355.353        |
|            | 4         | 3.701          |                |

To sum up, from 2000 to 2016, the overall ecological quality of Liangzhou district has improved slightly. The variation trend is the decline of ecological quality and the improvement of marginal ecological quality in the middle part of the oasis.
each year are extracted. SPSS, NDVI, WET, NDSI and LST are independent variables in SPSS, and RSEI is the dependent variable. The urban quality evaluation model of ecological environment is established by regression analysis. The number of samples and the penetration of all images can ensure the objectivity and representativeness of the regression analysis results.

\[ RSEI = 0.329NDVI + 0.321Wet - 0.348NDSI - 0.345LST + 0.527 \quad (R^2=0.957) \]

\[ 2016: RSEI = 0.398NDVI + 0.165Wet - 0.413NDSI - 0.376LST + 0.56 \quad (R^2=0.993) \]

From the simulation results of each year, the fitting effect is good. In the stepwise regression analysis, the 4 indicators are not removed, indicating that they are the key indicators of ecological measurement. From the regression coefficient, the coefficients of NDVI and WET are positive values, which have positive effects on ecology, NDSI and LST coefficients are negative values, and have negative effects on ecology. Among the 4 indicators, the absolute value of the regression coefficient of NDSI is the largest, indicating that the negative impact of the urban water surface on the ecology is quite large, and also is an important factor restricting the ecological improvement. Therefore, in urban planning and construction, it should be properly controlled the proportion of impervious surface area, expand the area of urban green space and increase the amount of urban green space.

5. Conclusion
RSEI remote sensing ecological index is based on remote sensing information, which combines the green degree, humidity, heat and dryness index, and can quickly and easily evaluate the regional ecological quality. The RSEI index, based on the contribution rate of each index to the first principal component, avoids the artificial setting of weights. It can objectively couple each index, reasonably represent the ecological quality of the oasis city, and quantitatively evaluate the ecological environment of the oasis city, which can better reflect the ecological environment variation in the Liangzhou District for many years. The study results showing that:

(1) From 2000 to 2016, the ecological quality of Liangzhou District improved slightly, but the mean RSEI value increased from 0.447 to 0.458, and the overall quality increased by 2.46%. In the study area, the proportion of the region with poor, worse, good and better levels has increased, and the proportion of the total area with moderate ecological level has decreased. Therefore, the ecological environment quality grade of Liangzhou district is developing from middle to polarization.

(2) In terms of spatial distribution, the ecological environment quality of the Northeast desert area is rising, which is closely related to the development and utilization of unused land and the reclamation of cultivated land. The ecological environment quality of the central part of the oasis is decreasing, mainly due to the construction of the new urban area, which makes the impervious surface of the city increase and makes the surface "dry".

(3) Among the four indicators, NDVI (representing green degree) and Wet (representing humidity) play a positive role in ecology. NDSI and LST, which represent dry degree and heat, play a negative role in ecology. NDSI, representing dry degree, has the greatest contribution to RSEI, which indicates that the decline of eco-environmental quality is closely related to the increasing of impervious surface. Through the modeling and prediction of RSEI, it is found that the rational allocation of land resources, the scientific layout of the urban development space, the expansion of urban green area and the increasing of urban green capacity can improve the ecological environment of the city.

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