EVALUATION OF ECO-ENVIRONMENT QUALITY OF THE LOESS PLATEAU AREA BASED ON REMOTE SENSING AND GIS- A CASE STUDY OF LINFEN CITY

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ABSTRACT: The Chinese Loess Plateau is suffering from severe soil erosion. The eco-environmental changes of the plateau have attracted considerable attentions both from scientists and local governments. Aiming at the regional features of eco-environment and main environmental problems of Linfen City, the synthetic evaluation index system including Organism Abundance index, Vegetation Cover index, Water Density index and Land Degradation index were set up. Supported by GIS and taken the county as the evaluation unit, eco-environmental evaluation index method and spatial analysis were integrated into the eco-environmental quality evaluation during the 1987-2009 periods in Linfen city. The results showed that the integral eco-environment quality of Linfen city was of inferior level, the highly intense human activities speeded up the degradation of regional eco-environments in 2000, and nearly 10 years of restoration of the ecosystem had achieved some success, but also need further efforts.

Keywords: Eco-environmental quality Evaluation; Ecological index; Information extraction; GIS; Linfen City

1. INTRODUCTION

The Chinese Loess Plateau has a fragile ecosystem (Fu et al. 2000, 2006) and semi-arid climate (Xu 1994; Zhang and Liu 2005) with extensive monsoonal influence (Susan 2001). The fragile ecosystem has a very low resistance to natural disaster, such as soil erosion, vegetation degeneration and desertification. Once damaged, it is very difficult to restore. On the other hand, demanding on the region’s mineral resources and environment system are increasing. Therefore, the studies of the relationship between human activities and natural systems are needed for scientific and rational development programs to better manage and use natural resources.

At present, Remote Sensing (RS) is an important tool to monitor the ecological quality (Tao, et al. 2006; Liu, et al. 2000). RS can provide abundant image data for spatial analysis in GIS environment. For regional ecosystem assessment, the RS application has become the indispensable technique
This study applies RS techniques and ecological assessment method to evaluating Linfen City ecosystem quality in spatial dimension.

2. Materials and method

2.1 Study area

Linfen is located in southern part of Shanxi province in China, between 35° 23’ - 36° 37’ N and 110° 22’ - 112° 34’ E, covers 20,275 km². Linfen has a continental, monsoon-influenced semi-arid climate. Within its borders Linfen City has a variety of topographical features. It can generally be characterised as having a U shape, with mountains, covering 29.2% of the prefectural area, on all four cardinal directions, a basin, the Linfen Basin, covering 19.4%, in the middle, and intervening hills, covering 51.4%. The prefecture-level city of Linfen is divided into one district, two cities and fourteen counties.

The whole city has a great variety of terrain. The city itself sits in a basin-Lin fen basin, which exacerbates pollution problems. On the other hand, China's rapid industrialization and urbanization beginning in the 1990s led to increased energy demand causing a dramatic increase in the price of coal. This led to a rapid expansion of loosely regulated private mines. Mining and the heavy industry which developed around it led to severe environmental degradation.

2.2. Data
Landsat Thematic Mapper (TM) data (1987, 2000 and 2009) at a spatial resolution of 30 m were adopted for analysis. The satellite RS images were obtained from the Center for Observation and Digital Earth (CEODE), Chinese Academy of Sciences (CAS). The TM images taken in three intervals (1987, 2000 and 2009) cover 17 counties in Linfen City and their space and spectral information met the demand of this study. Other data used include ASTER GDEM with resolution of 30m download from NASA website. The condition of TM data is shown in Table 1.

Table 1 TM data condition of Linfen city

<table>
<thead>
<tr>
<th>Number</th>
<th>image</th>
<th>band</th>
<th>resolution</th>
<th>Data time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>TM19870830</td>
<td>7</td>
<td>30m</td>
<td>1987/08/30</td>
</tr>
<tr>
<td>2</td>
<td>TM 20000521</td>
<td>7</td>
<td>30m</td>
<td>2000/05/21</td>
</tr>
<tr>
<td>3</td>
<td>TM 20090506</td>
<td>7</td>
<td>30m</td>
<td>2009/05/06</td>
</tr>
</tbody>
</table>

3. Method

3.1. Data processing

Data processing is very important for obtaining accurate data. To keep the precision within 1 pixel between TM images, these entire data have been ortho-rectified with GDEM based on Transverse Mercator projection system. Before interpretation those images were processed by band combination and image enhancement on the platform of PCI Geomatica V10.0.

3.2. Data extraction

To obtain accurate information of the eco-environmental types and their spatial distribution, an understanding of spectrum and radiation information and geometric features is needed. To establish a unified classification system, vegetation characters, ground slope, micro topographic conditions and other environmental factors must be investigated. Based on land use/cover types, the interpretation key was developed for this study. All images were classified into six primary environmental types (forest, water, grassland, farmland, construction land and unused land) and 12 sub-types. The sub-types were developed based on the differences of land use/cover types, vegetation coverage, and underlying layers. Forestlands based on forest coverage, grasslands based on grass coverage, and construction areas were classified into urban areas, rural residential areas and traffic construction areas.

Based on supervised classification for six primary environmental types, the Normalized Difference Vegetation Index (NDVI) was adopted to indicate the degree of vegetation cover.

The model of vegetation cover is as:

$$F_c = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}}$$  (1)
Where NDVIso is NDVI value of bare soil or region without vegetation, NDVIveg stands for pixel with vegetation cover completely.

After extracting the result of classification, the visual image interactive interpretation method was used to obtain the vector and attribute data. This processing was fulfilled in the ArcTools module of ArcGIS.

3.3. Establishment of the evaluation index system

The establishment of a proper evaluation index system was based on the scientific analysis of eco-environment. Referencing to the evaluation method of “Technical Criterion for Eco-environmental Status Evaluation(trial)” issued by the State Environmental Protection Administration of China, taking into account the main eco-environmental problems of Linfen and access to the required data, the eco-environmental quality evaluation index system of Linfen City was established, which including Organism Abundance index, Vegetation Cover index, River Density index, Land Degradation index, and environmental quality index.

Organism Abundance Index

The Organism Abundance Index is defined as the difference in organism number of different ecosystem types in unit area, which reflects indirectly the organism abundance degree of the assessed region. The calculation equation is:

\[
\text{Organism Abundance index} = (0.35 \times \text{woodland area} + 0.21 \times \text{grassland area} + 0.28 \times \text{wetland area} + 0.11 \times \text{plowland area} + 0.04 \times \text{construction area} + 0.01 \times \text{unutilized area}) / \text{regional area}
\]

(2)

Vegetation Coverage Index

The Vegetation Coverage index is defined as the proportion of woodland, grassland, plow land, construction land and unutilized land area to the regional area of assessed zone, which reflects the vegetation coverage degree of it. The calculation equation is:

\[
\text{Vegetation Coverage index} = (0.38 \times \text{Woodland area} + 0.34 \times \text{grassland area} + 0.19 \times \text{plowland area} + 0.07 \times \text{construction land area} + 0.02 \times \text{unutilized area}) / \text{regional area}
\]

(3)

Water density index

The Water Net density index is defined as reflection of water abundance of the assessed region, which is calculated as the proportion of river length, water area and water resources to assessment region area. The calculation equation is:

\[
\text{Water Net density index} = (\text{Normalized coefficient of river length} \times \text{river length} + \text{Normalized coefficient of water area} \times \text{water area} + \text{Normalized coefficient of water resources} \times \text{water resources}) / \text{regional area}
\]

(4)
Land Degradation Index

The Land Degradation index is defined as the reflection of land degradation degree of the assessed region, which is closely linked to the degree of soil erosion. The calculation equation is:

\[
\text{Land Degradation index} = 0.05 \times \text{light erosion area} + 0.25 \times \text{middle erosion area} + 0.7 \times \text{intense erosion area} / \text{regional area}
\]

According to the method of “Standards for classification and gradation of soil erosion” (SL 190-2007) issued by the national ministry of water resources, taking into account the actual situation of Linfen, the adjusted soil erosion intensity classification table are shown as table 2.

**Table2: Soil erosion intensity classification of Linfen**

<table>
<thead>
<tr>
<th>Vegetation Cover</th>
<th>Slope (unit: degree)</th>
<th>0-3</th>
<th>3-5</th>
<th>5-8</th>
<th>8-15</th>
<th>15-25</th>
<th>25-35</th>
<th>&gt;35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-cropland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45%-60%</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>middle</td>
<td>middle</td>
<td>intense</td>
<td></td>
</tr>
<tr>
<td>30%-45%</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>middle</td>
<td>middle</td>
<td>intense</td>
<td>intense</td>
<td></td>
</tr>
<tr>
<td>&lt;30%</td>
<td>light</td>
<td>light</td>
<td>middle</td>
<td>middle</td>
<td>intense</td>
<td>intense</td>
<td>intense</td>
<td></td>
</tr>
<tr>
<td>Cropland and other land types</td>
<td>Slope cropland</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>middle</td>
<td>intense</td>
<td>intense</td>
<td>intense</td>
</tr>
<tr>
<td>Water area</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td>Construction land</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td></td>
</tr>
<tr>
<td>Unused land</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td>light</td>
<td></td>
</tr>
</tbody>
</table>

3.4. Selection of evaluation unit

The evaluation units were composed of many factors that affected the eco-environment quality. Taking account to the county administrative division was also the grass root for the protection and remediation of the eco-environment. Data of this study were based on the county administrative division, the basic statistic unit, total 17 county administrative divisions were chosen as the basic units for eco-environment quality evaluation.

3.5. Establishment of the model of EI

The ecological index (EI) is defined as reflection of regional eco-environmental status which valued from 0 to 100. Because of lacking of Linfen environment statistical yearbook data of each township removing environmental quality index in the evaluation model, and distributing the weight of the Index's average 0.15 to biological abundance Index, the Index of water network density and vegetation Index, the adjusted Ecological environment condition Index (Ecological Index, EI) model calculation formula is:
\[
EI = 0.3 \times \text{Organism Abundance index} + 0.25 \times \text{Vegetation Coverage index} \\
+ 0.25 \times \text{Water Net density index} + 0.2 \times (1 - \text{Land Degradation index})
\]  

(6)

4. Results and analysis

According to the equation of EI, the value is calculated and divided into five degrees as follow: excellent (\(EI \geq 75\)), good (\(55 \leq EI < 75\)), general (\(35 \leq EI < 55\)), inferior (\(20 \leq EI < 35\)) and bad (\(EI < 20\)).

The results showed that Linfen eco-environmental status was of inferior level. There were only 6 among 17 counties of the eco environment quality were in general level in 1987, while others were all in low level. In 2000, the condition continues to deteriorate and only 1 in 17 counties were in general level of eco environment quality. Until 2009, the condition turned to better, and 3 more counties were in this level than in 2000.

According to the value of EI, the trend of change is shown in Figure 2.

![Figure 2. Ecological index (EI) of Linfen](image)

The amplitude of variation of eco-environmental status can be divided into four degrees as follow: no change (\(|\Delta EI| \leq 2\)), slight variation (\(2 < |\Delta EI| \leq 5\)), marked variation (\(5 < |\Delta EI| \leq 10\)), significant change (\(|\Delta EI| > 10\)).

From 1987 to 2000, the overall eco-environmental of Linfen was slightly deteriorates, the change of YongHe county and Da Ning county were obvious, the change of Fen xi, Pu xian, Xi xian, Ji xian, and Xiangning were slight, and other conties were of no change; From 2000 to 2009, the integral eco-environment quality of Linfen intend to be better, Gu xian, Fushan, Yicheng and Anze were of slightly change, and other counties had no change.

5. Discussion and summary
The use of satellite RS and GIS techniques to detect and analysis the eco-environmental change in Linfen was generally successful. The man-machine interactive interpretation method coupled with GIS technique has demonstrated its ability to provide comprehensive information on eco-environmental changes. The evaluation index system proved useful in monitoring and analyzing the dynamic eco-environmental changes in the semiarid area of Linfen.

Linfen city is located in the Loess Plateau Area and has fragile ecosystem, the rapid expansion of loosely regulated private mines and the heavy industry which developed around it led to severe environmental degradation, speeded up the degradation of regional eco-environments from 1987 to 2000. With the degradation of regional eco-environments efforts of local government were made to clean up the private mines, then years of restoration of the ecosystem had achieved some success, and the environmental situation had improved from 2000 to 2009.

It is important to weigh the contradictions between resource use and the harmonious development of society and environment to protect the function of the regional ecosystem. Restoration of the ecosystem and elimination of poverty in the region with such a fragile ecosystem are a long-term process. To encourage prevention and amelioration, public awareness of eco-environment conservation must be increased, proper management plans developed, wise use of natural resources increased, and eco-engineering analysis used to decrease land use disasters. Scientific monitoring and forecasting systems for eco-environmental planning, dynamic analysis, and environmental protection should be encouraged to find methods for restoration of ecosystems in the semiarid region.

REFERENCES
