Evolution Analysis of Vegetation Cover under the Disturbance of Rare Earth Mining: a Case in Lingbei Mining Area

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Abstract

More and more attentions are paid to the problems which caused by ionic rare earth mining vegetation degradation and serious ecological environment. In Lingbei rare earth mining area, Dingnan County is regarded as the research object, the Landsat images of 23a as data source, monitoring and analyzing the spatiotemporal evolution of vegetation coverage under the disturbance of rare earth mining. In order to improve the reliability of monitoring and analyzing, using dimidiate pixel model (DPM) and linear spectral mixture model (LSMM) to extract vegetation coverage of mining area, vegetation coverage extraction accuracy is validated by Pleiades image with a 0.5 m spatial resolution. The results show that: LSMM takes the spectral characteristics of unique tailings into consideration, it is more suitable for the mining area vegetation coverage extraction; from 1990 to 2013, average vegetation coverage maintains a high level; concentrating trend of the low vegetation coverage areas is very obvious, mainly for bare surface due to the pool/heap leaching rare earth mining, ecological problem is still serious; vegetation degradation mainly caused by rare earth mining, in-situ leaching reduced the direct destruction of surface vegetation, but due to leakage of leaching liquid inevitably, may lead to a greater range of vegetation degradation; average vegetation coverage of each year increased with the mining area as the center, the effect area of coverage involves around 300 to 400 m, in-situ leaching on the surrounding vegetation effect is less than tank/heap leaching.

Key Words: Vegetation Coverage, Rare Earth Ions, Linear Spectral Mixture, Spatial-temporal Evolution

1. Introduction

Southern Jiangxi is known as “Rare Earth Kingdom”, total amount of ionic rare earth mining accounted for 70% of the China, rare earth mining started in the 1980s, has gone through the tank leaching, heap leaching and in-situ leaching three mining technology have caused vegetation degradation in mining area with varying degrees [1,2]. Vegetation is the connecting link between soil, atmosphere and water, with rainfall interception, reducing raindrop splash, reducing surface runoff, increasing soil, soil conservation and other functions, is the main monitoring factor of soil erosion, also is the important measure indicators of mining area ecological system [3]. Remote sensing because of its obvious advantages in the aspects of timeliness, measuring range, has become the main method of vegetation coverage monitoring [4]. The common methods involve forest canopy density mapping (FCD) model [5], DPM, LSMM, DPM does not depend on the measured data, using conveniently, being applied widely [6,7]. But this model has certain limitations on the soil background and topography, applicability of the model was challenged [8–10]. Ionic rare earth mining area is located in southern hilly region, complex

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terrain, lush vegetation, applicability of DPM in rare earth mining area is to be inspected. LSMM with the advantages of simple, efficient and clear physical meaning, is widely used to study specific regional vegetation extraction in recent years [11–14]. These studies show that LSMM has great potential applications for specific application. Rare earth mine land types are complex, especially rare earth tailing, has higher reflectivity being relative with soil, LSMM can through the end-member selection taking the characteristics into account, it maybe have better extraction accuracy than DPM in rare earth mining area. The paper uses high spatial resolution image, verifying the accuracy of two vegetation coverage extraction model, selecting a suitable vegetation coverage extraction method, on this basis, analysing spatio-temporal evolution of vegetation coverage disturbed by rare earth mining, and to provide the scientific basis for the ecological environment treatment of mining areas.

2. Study Area

The Lingbei mining area is located in about 20 km north of the town Dingnan County Jiangxi province. The study area is local approximately latitude 24°51’24"N to 25°02’56"N and longitudes 114°58’04"E to 115°10’56"E, an area of about 200 km². The mine has been 20 years of mining, according to the different mining processes, can be divided into two stages: before 2001, the main mining technology are tank and heap leaching, these two kinds of mining technology due to soil and ore body were stripped, not only it caused devastating damage on the vegetation, but also it will produce a lot of waste rock and tailings; after 2002, in-situ leaching has been promoted and popularized, comparing with tank and heap leaching, the direct damage of vegetation which caused by in-situ leaching mine was greatly reduced, but due to leaching ore solution has soaked mountain for a long time, the surface vegetation will be destroyed by the side seepage and capillary action.

3. Data and Methods

3.1 Data Sources and Pre-processing

Using remote sensing image as data source in the study, including Landsat series data with a long history archive and Pleiades data with high spatial resolution, which Landsat series data comes from the geospatial data cloud platform, all data is cloud free coverage in Lingbei mining area, specific data parameters as shown in Table 1.

Pre-processing for Landsat series data, including radiometric calibration, atmospheric correction, geometric correction and image clipping. Taking 2008 TM images as reference images, relative registration of Landsat image in other years were performed, finally clipping images, obtaining remote sensing images of mining area. The panchromatic and multispectral bands of Pleiades data uses principal component transformation method for image fusion, obtaining 0.5 m high spatial resolution remote sensing image.

Due to the influence of Landsat satellite return cycle, weather and other factors, all images with similar Pleiades data acquisition time both have cloud coverage, so we choose the December image and Pleiades image to compare vegetation coverage. The region vegetation cover change is relatively small, it has less impact on the results, can be used for precision inspection. In order to ensure the accuracy of verification, registration between Pleiades image and corrected OLI image is performed.

3.2 Research Methods

Using DPM and LSMM to extract vegetation cover-

Table 1. The data parameter of satellite in the study area

<table>
<thead>
<tr>
<th>Date</th>
<th>Spacec-raft</th>
<th>Sensor</th>
<th>Path/Row</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-12-09</td>
<td>Landsat-5</td>
<td>TM</td>
<td>121/43</td>
<td>30 m (MS)</td>
</tr>
<tr>
<td>1999-12-26</td>
<td>Landsat-7</td>
<td>ETM+</td>
<td>121/43</td>
<td>30 m (MS)</td>
</tr>
<tr>
<td>2008-12-10</td>
<td>Landsat-5</td>
<td>TM</td>
<td>121/43</td>
<td>30 m (MS)</td>
</tr>
<tr>
<td>2013-12-24</td>
<td>Landsat-8</td>
<td>OLI</td>
<td>121/43</td>
<td>30 m (MS)</td>
</tr>
<tr>
<td>2013-10-31</td>
<td>Pleiades</td>
<td></td>
<td></td>
<td>2 m (MS) 0.5 m (P)</td>
</tr>
</tbody>
</table>

Note: MS = multispectral, P = panchromatic.
Evolution Analysis of Vegetation Cover under the Disturbance of Rare Earth Mining: a Case in Lingbei Mining Area

3.2.1 Dimidiate Pixel Model

Spectral information of mixed pixels is regarded as a linear combination of vegetation and soil spectral information (such as NDVI), and the proportion is related to their respective area, therefore, vegetation coverage calculation as formula (1).

\[ V_f = \frac{(\text{NDVI} - \text{NDVI}_{\text{soil}})}{(\text{NDVI}_{\text{veg}} - \text{NDVI}_{\text{soil}})} \]  

where \( V_f \) is vegetation coverage, \( \text{NDVI} \), \( \text{NDVI}_{\text{soil}} \) and \( \text{NDVI}_{\text{veg}} \) respectively represents the NDVI values of arbitrary pixels, pure soil and pure vegetation pixels. Theoretically, \( \text{NDVI}_{\text{soil}} \) does not change with time, the value should be close to zero. However, due to atmosphere, surface humidity and other factors, \( \text{NDVI}_{\text{soil}} \) will change with time and space [4]. In order to overcome the uncertainty of time and space, \( \text{NDVI}_{\text{soil}} \) and \( \text{NDVI}_{\text{veg}} \)’s value learning from literature 4.

3.2.2 Linear Spectral Mixture Model

LSMM assumes that the solar radiation works only a ground surface, objects without interaction, spectral reflectance of pixels obtained by sensors, can be described by the material endmember reflectivity of pixel and their proportional weighted sum in the pixel, expressions and constraints such as (2), (3) and (4) are shown.

\[ R_{ia} = \sum_{k=1}^{n} f_{ik} C_{ka} + e_{ia} \]  
\[ \sum_{k=1}^{n} f_{ik} = 1 \]  
\[ 0 \leq f_{ik} \leq 1 \]  

\( R_{ia} \) of formula (2) presents the spectral reflectance of the \( i \)th pixel on the \( a \) band; \( C_{ka} \) stands for the spectral reflectance of \( k \)th end-member on the \( a \) band; \( f_{ik} \) is the end-member abundance of \( k \)th in the \( i \)th pixel; \( n \) is the number of pixel basic components; \( e_{ia} \) stands for the residuals of \( i \)th pixel on the \( a \) band, reflecting the differences of LSMM calculation results and actual vegetation coverage. Formula (2) as the basic form of the LSMM, formula (3) and (4) as the constraint equation. Only satisfies formula (2) for unconstrained LSMM, meets (2), (3) the two conditions for semi constrained LSMM; three conditions are satisfied for fully constraints LSMM. Some scholars in the practical application shows that compared with unconstrained and semi constraint model, the fully constrained LSMM has higher retrieval precision [14,15], so this study choose the fully constrained model to extract vegetation coverage in the mining area.

Accurate end-member selection is the key to ensure the accuracy of the model, through MNF transform, PPI computing and N visualization of the original image to achieve endmember extraction, vegetation and tailing end-members is easier to extract due to concentrated distribution, soil end-members is difficult to extract due to dispersed distribution, but soil is constituted the main end-members for the mining area pixel, accurately extracted is particularly important. Combining with bare soil index for soil end-member extraction, as shown in formula (5) [16].

\[ \text{NDSI} = \frac{\rho_{\text{SWIR}} - \rho_{\text{NIR}}}{\rho_{\text{SWIR}} + \rho_{\text{NIR}}} \]  

\( \rho_{\text{NIR}} \) and \( \rho_{\text{SWIR}} \) of formula, respectively represents reflectivity of near infrared and infrared band. Due to limitation of the method, no soil information could be extracted, it can be removed by a high spatial resolution image closing to time. Through the above steps, it can be successfully extracted the vegetation, soil and tailings endmember, obtaining vegetation end-member proportions of pixel by full constraints LSMM is the vegetation coverage of the pixel.

3.2.3 The Grading of Vegetation Coverage

Because the study area is located in the hilly region of southern China, belongs to the serious soil erosion area. Vegetation coverage is an important influencing
factor of soil erosion, according to technical standard for comprehensive control of soil erosion in hilly area of South China (SL757-2014) formulated by the water resources ministry, the different intensity of soil erosion levels correspond with different levels of vegetation coverage, and combined with local vegetation structure types, vegetation coverage is divided into 5 levels, the grading standards such as Table 2 shows.

4. Results and Analysis

4.1 Testing of the Accuracy

Sample randomly in vegetation coverage map, in order to reduce the error of image registration, Sampling window sets for 3 * 3, average pixel value of the window is regarded as vegetation coverage of sample. At the same time, with the corresponding location in Pleiades image (namely 180 * 180 pixels), calculating the proportion of vegetation through visual interpretation, it is the vegetation coverage of sample in Pleiades image, this is regarded as test data. Randomly selected 30 samples in vegetation coverage map of DPM, LSMM and Pleiades image. Taking abscissa as sample point, ordinate as vegetation coverage, as shown in Figure 1.

As can be seen from Figure 1, the LSMM with respect to DPM, a higher consistency with the validation data, but their values is both lower compared with validation data, taking the Pleiades image acquisition time is earlier than Landsat 8 image into account, growth of herbaceous plants is denser, it will make higher for the overall value of test data sample, from this point of view, LSMM is closer to the real ground vegetation coverage.

Quantitative analysis uses correlation coefficient (R) and root mean square error (RMSE) to reflect accuracy of the two models. The R is shown in the formula (6), which reflects correlation between the test and estimation value, the greater the absolute value, the higher the related level; RMSE reflects the overall accuracy of sample, as shown in formula (7), the smaller the value, the higher the precision.

\[
R = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n} (Y_i - \bar{Y})^2}} \tag{6}
\]

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{n}} \tag{7}
\]

Here, \(X_i\) of the formula is the estimation value, \(\bar{X}\) is average value of the estimation, \(Y_i\) is test value, \(\bar{Y}\) is mean value of test sample, \(n\) is the sample number, the accuracy of two methods were tested through formula (6) and (7), the results are shown in Table 3.

From Table 3 we can see that the R between LSMM and test value is 0.93 and it improves 0.02 than 0.91 of DPM; also LSMM’s RMSE is 0.10, is obviously superior to 0.25 of the DPM. Anyway, no matter from the perspective of qualitative or quantitative, these results indicated that the LSMM can reflect the actual condition of vegetation coverage, has higher precision, can be used to extract vegetation coverage in rare earth mining area.

### Table 2. The classification standard of vegetation coverage

<table>
<thead>
<tr>
<th>Class ID</th>
<th>Class names</th>
<th>Vegetation coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Low vegetation coverage</td>
<td>0.00-0.30</td>
</tr>
<tr>
<td>II</td>
<td>Lower vegetation coverage</td>
<td>0.30-0.45</td>
</tr>
<tr>
<td>III</td>
<td>Medium vegetation coverage</td>
<td>0.45-0.60</td>
</tr>
<tr>
<td>IV</td>
<td>Higher vegetation coverage</td>
<td>0.60-0.75</td>
</tr>
<tr>
<td>V</td>
<td>High vegetation coverage</td>
<td>0.75-1.00</td>
</tr>
</tbody>
</table>

### Table 3. R and RMSE of two estimating models

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DPM</td>
<td>0.91</td>
<td>0.25</td>
</tr>
<tr>
<td>LSMM</td>
<td>0.93</td>
<td>0.10</td>
</tr>
</tbody>
</table>
4.2 Vegetation Coverage Grading and Area Change Analysis

Using LSMM to extract vegetation coverage of Landsat images, classification according to Table 2, getting vegetation coverage classification map in Lingbei mine, as shown in Figure 2. The statistical analysis of vegetation coverage in different grades shown in Table 4.

According to Figure 2 and Table 4 shows that: in the past 23 years, the change trend of low vegetation coverage area increases first, then decreases and increases last, which is fluctuant and unstable; from 1990 to 2008, the high vegetation coverage area has been steadily increasing, increases 60.26%, but from 2008 to 2013 dropped by 16.77 km²; lower, medium and higher vegetation coverage area has fallen to minimum in 2008, the decline reached 37.47%, 47.77%, 80.06%, it indicated that mining area vegetation coverage transformed frequently, human activities had a massive effect on it, existing certain ecological risks.

On the whole, higher and high vegetation coverage accounted for the largest proportion. These four years reach 82.72%, 83.81%, 88.44% and 84.98%, low vegetation coverage in four years whose proportion is respectively: 5.03%, 7.32%, 4.72% and 6.42%, although the proportion is not high, but from Figure 2, we can see contiguous focus trend is very clear. From 1990 to 1999, low vegetation coverage is mainly due to forestry policy and forestry management system, factors of stealing and illegal logging and so on, the trees have been cut down [17], it is further to expand in 1999 on the basis of in 1990; after 1999, the policy of returning farmland to forest was really implemented, but due to increase of rare earth price, mining area is expanding rapidly, low vegetation coverage area was mainly for the bare land of rare earth mining; in 2013, the reclamation of mining area causes increase of vegetation coverage, however, due to the expansion of mining scale, low vegetation coverage area rapid expansion, and there are a lot of lower vegetation coverage area around it, vegetation degradation has further expanding trend, the relevant departments need to be paid attention to it.

4.3 Temporal and Spatial Distribution of Vegetation Coverage Change

To study mining area vegetation coverage changes in the spatial distribution, especially the spatial distribution of vegetation degradation. In order to highlight the impact of rare earth mining on vegetation, the difference of vegetation coverage in three time periods was classified by the classification standard of Table 5, as shown in

![Vegetation classification figure of mining area.](image)

**Figure 2.** Vegetation classification figure of mining area.

<table>
<thead>
<tr>
<th>Class ID</th>
<th>1990</th>
<th>1999</th>
<th>2008</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
<td>Percentage</td>
<td>Area</td>
<td>Percentage</td>
</tr>
<tr>
<td>I</td>
<td>10.75</td>
<td>5.03</td>
<td>15.64</td>
<td>7.32</td>
</tr>
<tr>
<td>II</td>
<td>9.23</td>
<td>4.32</td>
<td>7.93</td>
<td>3.71</td>
</tr>
<tr>
<td>III</td>
<td>16.94</td>
<td>7.93</td>
<td>11.03</td>
<td>5.16</td>
</tr>
<tr>
<td>IV</td>
<td>67.23</td>
<td>31.45</td>
<td>18.78</td>
<td>8.78</td>
</tr>
<tr>
<td>V</td>
<td>109.60</td>
<td>51.27</td>
<td>160.37</td>
<td>75.03</td>
</tr>
</tbody>
</table>

**Table 4.** The vegetation coverage area of different year (km²)
According to Table 5 and Figure 3, it can be seen, the vegetation coverage whose percentage of stabilization area continues to rise, increased from 99.64 km² in 1990-1999 to 164.22 km², accounting for 77.1% of the total area in 2008-2013, the vegetation coverage change of mining area keeps a relatively stable state; bad degradation percentage is biggest in 1999-2008, accounted for 4.08% of the total area, was 8.69 km², and the Figure 3b shows that it is mainly concentrated in nearby mines, reflecting serious damage to vegetation coverage in the rare earth mining; from 2008 to 2013. It accounted for 2.97% of the total area, combined with distribution map of mine, on one hand, which part of reason is new rare earth mines, on the other hand, is man-made interference effect, in the past 5 years, the area of degradation increased sharply, accounting for 15.11% of the total area, and its distribution is consistent with mine distribution, mainly for during this period, mining scale has a large area of expansion, but it is mainly mining in situ leaching, in-situ leaching compared with pool and heap leaching, vegetation destruction is relatively weaker, it turns out that vegetation is mainly reflected as degeneration and not bad degeneration.

Overall, average vegetation coverage of the whole mining area is higher, vegetation degradation mainly for local degradation caused by rare earth mining, in-situ leaching technology reduces the damage to vegetation, but due to the inevitable leakage of leaching liquid, it may lead to larger area of weak vegetation degradation.

### 4.4 Rare Earth Mining Effect on Vegetation Coverage

For further quantitative analysis influence of vegetation coverage in rare earth mining, mine distribution map of each year was obtained by backtracking method [18] and high spatial resolution image. Taking mine as the centre, we analyses the average vegetation coverage within different ranges, as shown in Table 6.

It can be seen from Table 6, average vegetation coverage in each year as centre of mining area, the farther the points, the bigger the average vegetation coverage, it indicated that rare earth mining has significant influence on the surrounding vegetation; mine average vegetation coverage is smaller, less than 0.3, mining area average vegetation coverage decreased first and then increased, it was minimum in 2008, was 0.14, the main reason for a smaller scale mining in 1990s, mainly for pool/heap leaching, it not only caused vegetation damage, but also a serious change in the pH value of soil, vegetation is hard to a natural restoration after 10 years, and soil pH value is the dominant environmental factors that limits

<table>
<thead>
<tr>
<th>Table 5. Change area statistics of vegetation coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time period</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>1990-1999</td>
</tr>
<tr>
<td>1999-2008</td>
</tr>
<tr>
<td>2008-2013</td>
</tr>
</tbody>
</table>

![Figure 3. Vegetation coverage change grading.](image)
local biodiversity directly development [19]. With con-
tinuous expansion mining of scale, the bigger bare area,
after 2002, in-situ leaching was popularized, part ex-
posed mines began to a natural recovery, to 2013, re-
gional vegetation coverage increased gradually. Around
300 to 400 m of mining area, rare earth mining still has
an impact on vegetation growth, the vegetation coverage
is gradually increased with a mineral occurrence area
distance. Compared with the other years, ore area and
surrounding vegetation coverage is lower in 1990 and
1999, explain the effect of rare earth mining on vegeta-
tion is more intense; in 2008 and 2013, out of the ore
area, vegetation coverage increased sharply, it indicate
compared with pool and heap leaching, in-situ leaching
has a smaller impact on surrounding vegetation.

5. Conclusions

LSMM with respect to the DPM, the R between
LSMM and test value is 0.93, better than 0.91 of DPM.
RMSE is 0.10, which is better than 0.25 of DPM. It
shows that the LSMM can reflect the actual condition of
the vegetation coverage, which has higher precision, and
can be used as a method to extract the vegetation cover-
age of the rare earth mining area.
From 1990 to 2013, as a result of the implementation
of closing hillsides to facilitate afforestation, returning
farmland to forest and development of mine reclamation,
the ecological environment is significantly improved in
mining areas. Higher and high vegetation coverage ac-
counted for the largest proportion, although the percent-
age of low vegetation coverage is not high, but the con-
tiguous trend is very clear, mainly for bare surface of leg-
cacy in pool/heap leaching rare earth mining. Ecological
problem is still serious.

Vegetation degradation mainly for local degradation
caused by rare earth mining, in-situ leaching reduces
damage to vegetation, but due to the inevitable leakage
of leaching liquid may lead to a greater range of vegeta-
tion degradation. Average vegetation coverage of each
year as the centre of the mining area, the farther the ore
location, the bigger average vegetation coverage. It indi-
cates that rare earth mining has significant influence on
the growth of surrounding vegetation rare earth mining
area around 300 to 400 m, it still has an influence on
vegetation growth.

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Area,” Transactions of the Chinese Society of Agri-
cultural Engineering, Vol. 29, No. 21, pp. 223–232
Coverage Variations and Correlation with Geomor-

Table 6. Average vegetation coverage in the buffer of Mines

<table>
<thead>
<tr>
<th>Time</th>
<th>Mine area</th>
<th>0-60</th>
<th>60-120</th>
<th>120-180</th>
<th>180-240</th>
<th>240-300</th>
<th>300-400</th>
<th>400-700</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>0.30</td>
<td>0.47</td>
<td>0.57</td>
<td>0.60</td>
<td>0.62</td>
<td>0.64</td>
<td>0.68</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>0.20</td>
<td>0.57</td>
<td>0.68</td>
<td>0.74</td>
<td>0.75</td>
<td>0.76</td>
<td>0.77</td>
<td>0.78</td>
</tr>
<tr>
<td>2008</td>
<td>0.14</td>
<td>0.75</td>
<td>0.86</td>
<td>0.88</td>
<td>0.89</td>
<td>0.89</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>2013</td>
<td>0.24</td>
<td>0.67</td>
<td>0.76</td>
<td>0.78</td>
<td>0.80</td>
<td>0.82</td>
<td>0.83</td>
<td>0.85</td>
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