Surface Disturbance Analysis in Rare Earth Mining

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Abstract. Mining ion-type rare-earth ore made the landscape and ecological environment degraded in mining area, and the tailing produced by rare-earth mining also led large areas land desertification, which resulted in surface temperature variations and significant differences in other types of mining disturbances. In order to analyse surface disturbance of rare-earth mining area, this paper applied the methods based on Normalized Difference Vegetation Index (NDVI) and Temperature different Coefficient (TDC) as the ecological disturbance indicator, compared and validated their applicability in Lingbei rare-earth mining area of Southern China. The results illustrated that, compared to NDVI, the TDC which reflected the characteristic of rare-earth mining technology has better discrimination of disturbance, especially for in-situ leach mining area. The places of tailing and the in-situ leach mining plants were the most dramatic mining disturbance. They had the biggest TDC value, followed by orchards and farmlands, reclamation plants, they had relatively small disturbance. And the last was the plant with the smallest TDC value. TDC in rare-earth mining could better correspond to the level of surface ecological disturbance. Therefore, TDC as the indicator of ecological disturbance factor had better performance than NDVI in rare-earth mining area.

1. Introduction

Surface mining activities led to enormous change of mine stripping topsoil, destruction of vegetation and soil physical and chemical properties in rare-earth mining area, and caused great disturbance of the ecosystems in mining areas, which directly brought about the degradation and destruction of mining landscape and ecological environment. For a long time, vegetation parameter was taken as a vital indicator of mining ecological disturbance, which was widely used (Peng and He et al., 2013). On the other hand, surface disturbance caused by surface mining activities could cause land surface temperature differentiation in rare-earth mining region. Hu’s study shown that heat island effect in coal mining area was significant, thermal field variance index and vegetation coverage were good negative correlation, it could be an important factor which could assess the regional ecological environment (Hu and Zhao et al., 2010); In Pingshuo surface mining area, Zhang’s study indicated that the perturbation intensity and range of disturbance affected the equilibrium of surface temperature spatial distribution, and existed the fierce game between low-temperature region and high-temperature region (Zhang, 2014). These studies indicate that the temperature variation of surface mining area could also be used as the indicator of mining ecological disturbance. Specific mining technology of ionic rare-earth directly caused the damage of the soil surface, vegetation and other environmental factors, which resulted in a large area vegetation of destruction and degradation and large-scale desertification in mining region. Due to the specific heat capacity of sand and vegetation are fairly
different, temperature difference maybe better reflects disturbance characteristics of rare-earth mining than vegetation parameter. Selecting Lingbei rare-earth mining area in Southern China as a research area in this paper, we firstly calculated the land surface inversion temperature in the mining area. Furthermore, we got the TDC and analyzed the same location in the high-resolution aerial images. Lastly, we explored the relationship between TDC of different land types and the levels of surface ecological disturbance in mining area.

2. Data acquisition and pre-processing
Lingbei rare-earth mining is located in Dingnan County Jiangxi Province with approximately 200 square kilometers. It is shown as Figure 1. This mining has been mined for more than twenty years. In this study, we firstly pre-processed the Landsat-8 OLI imagery of October 8, 2014 and took it as the test data. Meanwhile, we selected a resolution of 0.5 meters high resolution mining aerial remote sensing data as the validation data collected in the December 10, 2014. To ensure the accuracy of verification results, the aerial imagery and the corrected Landsat OLI imagery should be registered. Subsequently, in order to make sample point’s distribution uniformly, the error must be controlled within a cell.

3. Construction method of surface disturbance analysis
3.1. Surface temperature retrieval
Single-window Algorithm is a surface temperature inversion algorithm which was deduced by using the band 6 of Landsat TM based on the heat radiating surface conduction equations (Qin and Zhang et al., 2001). Due to this algorithm involved in the influence factors of the atmosphere and the surface in the calculation formula, it is easy to be calculated with high precision and widely used. The algorithm is calculated as the following equation (1), (2), (3).

\[
T_s = \frac{a(1-C-D) + [b(1-C-D) + C + D]T_b - DT_a}{C} \quad (1)
\]

\[
C = \varepsilon \tau \quad (2)
\]

\[
D = (1 - \tau) [1 + (1 - \varepsilon) \tau] \quad (3)
\]

Where \(T_s\) stands real surface temperature (K); \(a\) and \(b\) are constant; \(C\) and \(D\) are intermediate variable; \(\varepsilon\) is surface emissivity; \(\tau\) is atmospheric transmittance; \(T_b\) is pixel brightness temperature that the sensor detected on the satellite height (K); \(T_a\) is the average atmospheric temperature.

There is a linear relationship between \(T_a\) and air temperature near the ground (\(t\)) (usually at 2m), and the \(t\) could be collected data from local weather stations. In accordance with the study area is
located in the middle latitudes, the aver-age atmospheric temperature could be calculated by using the formula (4).

\[ T_a = 16.0110 + 0.92621(t + 273.15) \] (4)

From the above, the Single-window Algorithm’s key is the parameter of \( T_b, \varepsilon, \) and \( \tau. \) The atmospheric transmittance could be estimated by atmospheric moisture content \( \omega \) (\( g/cm^2 \)) (Zhang and Chen et al., 2013). Water vapor in the atmosphere is mainly distributed in the troposphere, and the total amount of moisture in the troposphere air column has the relation as the formula (5).

\[ \omega = 0.0981 \times (6.1078 \times 10^{7.5t/237.7}) \times RH + 0.1697 \] (5)

Where \( t \) stands the air temperature near the ground (usually at 2m) (°C); \( RH \) is relative humidity; the air temperature and relative humidity data were collected from local weather stations.

The calculation of surface emissivity is used by the NDVI threshold method as formula (6).

\[ \varepsilon = 0.004P_v + 0.986 \] (6)

Where \( P_v \) is vegetation coverage which is calculated by dimidiate pixel method as formula (7).

\[ P_v = \left( \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \right) \] (7)

Where \( NDVI \) stands normalized difference vegetation index. \( NDVI_{soil} \) is the NDVI values of completely bare soil or some region without vegetation; \( NDVI_{veg} \) is the NDVI values of the pixels completely covered by vegetation. We calculated the \( NDVI_{soil} \) and \( NDVI_{veg} \) by Li’s literature (Li and Liu et al., 2013). Firstly, we extracted the corresponding pure pixel of the bare soil and vegetation by using pure pixel extraction function. Secondly, the NDVI value of corresponding pure pixel could be extracted. Lastly, we could count average pure pixel NDVI value of bare soil and vegetation, and the vegetation coverage could be obtained by formula (7). Which it could overcome time and space uncertainty of \( NDVI_{soil} \) and \( NDVI_{veg} \) values, and enhance the \( P_v \) accuracy. Thanks to the geographical characteristics of the mining area that surface cover types such as water and towns in the study area are few, we calculated surface emissivity without consideration of water and towns, as a result, the natural surface emissivity could be calculated by formula (6). Brightness temperature could be calculated with the formula (8) and (9).

\[ T_b = k_2 / \ln(1 + k_1 / L_{a\lambda}) \] (8)

\[ L_{a\lambda} = L_{\min(a\lambda)} + \left( L_{\max(a\lambda)} - L_{\min(a\lambda)} \right) Q_{dn}/Q_{max} \] (9)

Where \( k_1 \) and \( k_2 \) are the preset value before satellite launch, \( k_1 \) is 774.89 \( W/(m^2 * \mu m \cdot sr) \) and \( k_2 \) is 1321.08 K; \( L_{a\lambda} \) stands pixel spectral radiance at the sensor; \( Q_{max} \) stands the maximum value of the DN with the value of 255; \( Q_{dn} \) is the band pixel gray value; \( L_{\max(a\lambda)} \) and \( L_{\min(a\lambda)} \) are the maximum and minimum radiation intensity received by the sensor.

3.2. Calculation and classification of temperature difference degree

In order to better reflect the temperature difference among different types of ground features, we applied the thermal field variance index method of urban heat island research (Yang and Li et al., 2014). In Accordance with the similarity criterion, the degree of surface temperature in the mining area is characterized by the temperature difference coefficient. It is defined as the formula (10).

\[ TVC\left( T \right) = \left( T - T_{\text{mean}} \right) / T_{\text{mean}} \] (10)

Where \( T \) (°C) stands surface temperature inversion of a certain point in the mining area; \( T_{\text{mean}} \) (°C) stands the average surface temperature inversion in study area.

Due to the ionic rare-earth mining area are in southern hilly region, natural vegetation is lush and ecological situation is generally good, rare-earth mining is the most strong natural ecological disturbance in the region, and the ecological environment in the region brought very bad influence. The temperature difference coefficient of the mining area could assess the human disturbance level and ecological function of the natural surface in a certain extent. To clear strength of mine region
temperature difference coefficients, we classified the similarity criterion based on the Sun's study on the intensity of Urban Heat Island (Sun and Lu, 2002). Different temperature divided into different grades and ecological disturbance level, as show in Table 1.

| Temperature difference coefficient | Temperature difference degree | Disturbance level | Ecological Assessment |
|-----------------------------------|-------------------------------|-------------------|-----------------------|
| <0.005                            | weaker                        | no                | excellent             |
| 0.005-0.05                        | weak                          | weak              | good                  |
| 0.05-0.1                          | Mild                          | medium            | general               |
| 0.1-0.15                          | Moderate                      | Stronger          | Poor                  |
| 0.15-0.2                          | Heavier                       | Strong            | difference            |
| >0.2                              | Severe                        | Very strong       | Very poor             |

3.3. Method validation
Taking the Landsat OLI Imagery as the test data, we could calculate the surface temperature and the TVC in the study area with above method. We could classify the TVC in mining area as the Table 1. In order to study the relations between TDC and NDVI, we localized with the geographical links pixel-level ways in the study area of temperature differences degree images and NDVI images. A total of 111 samples were randomly collected based on various temperature different degrees, the NDVI and TVC of corresponding samples were recorded.

In order to reflect the relationship between NDVI and Temperature Difference Coefficient (TDC), we drew a line chart based on 111 samples of NDVI and TDC data in rare-earth mining area as shown in Figure 2. As we could see from Figure 2, on the whole NDVI and TDC are not related, especially in the middle part of the samples have no relationship. Which is different with the research of coal mining areas (Qiu and Hou, 2013.), therefore, the effect of temperature difference in rare-earth mining area has its own characteristics, not only related to vegetation degradation caused by rare-earth mining, and it is not only related to the vegetation degradation caused by rare-earth mining.

![Figure 2](image)

Figure 2. NDVI and TVC line chart of sampling points

From Figure 2, we could know that there is no obvious linear relationship between NDVI and TVC, and some samples appear that NDVI is high, but TDC also is high, there may be some kind of special relationship because of the rare-earth mining technology. To find the general rule of temperature
difference in rare-earth mine region, we cropped aerial imagery in 10 December 2014, furthermore, found the 111 corresponding samples of different types of ground features and recorded the temperature difference degree through geographical links ways.

Then we could draw the figure of temperature difference degree in study area as shown in Figure 3. Analysed from the 111 corresponding samples of different types of ground features in Landsat-8 imagery and Figure 2, we could know that the region of the highest temperature different degrees is the tailing ground with less vegetation coverage. This region with a large area in rare-earth mining region is also very strong mining disturbance and poor ecological environment; the region of the higher temperature different degrees is the tailing ground and in-situ leaching area with more vegetation coverage. Due to the in-situ leaching technology that workers excavated the injection hole and poured ammonium sulfate liquid on the ground, which had made the vegetation degradation and the mountain water and soil pollution, and finally, it resulted in a larger ecological disturbance. If only just taking NDVI as the indicator, it is more difficult to distinguish the disturbance of different types of ground features, but TDC could better distinguish them; Orchards, farmlands, plant reclamation have a strong human disturbance with the result of human action on the natural terrain. And their NDVI is almost close to natural vegetation, but their TDC is at different levels, and they have a good ability to distinguish; tailing and in-situ leaching could be distinguished by TDC, and the TDC also has ability to distinguish the orchard, farmlands, plant reclamation in mining area and natural vegetation. Therefore, the TDC could be chose as an indicator to assess the level of ecological disturbance in the rare-earth mining area; TDC could better assess in-situ leaching disturbance such as the sample of 31, 37, 38 in Figure 2, but NDVI could not identify it, because the NDVI values of in-situ leaching vegetation and natural vegetation are in the same range.

Figure 3. The temperature difference degree in study area

In summary, NDVI has obvious defects in the analysis of surface disturbance in rare-earth mine region, and TVC has obvious advantages. Especially most of rare-earth mining was using in-situ leaching process in Ganzhou City, the TVC can reflect the in-situ leaching characteristics. Thus, it can be used to distinguish the surface disturbance in mining area by the temperature difference degree method, which can provide a rapid quantitative method for the ecological evaluation in rare-earth mining area.
4. Conclusion
Taking Lingbei rare-earth mining area in Southern China as a study region in this paper, we calculated the surface inversion temperature and explored the relationship between TDC of different land types and the levels of surface ecological disturbance in mining area. We could conclude that compared to NDVI, TDC proposed in this paper could analyse rare-earth mining region disturbance recognition and better reflect the characteristics of the rare-earth mining area. Vegetation destruction of in-situ leaching area is relatively small, hence, in-situ leaching vegetation and general plants are difficult to distinguish with NDVI, but they could be distinguished by TDC because of in-situ leaching vegetation’s the heavier lever of temperature difference degree. In-situ leaching vegetation area and tailing are the most severe disturbance area in rare-earth mining region, they also have the highest value of TDC. Followed by orchards, farmlands, plant reclamation, their ecological disturbance is relatively small with TDC value of successive reduction. Finally, the general vegetation has a minimum TDC value. TDC could preferably correspond with surface disturbance level in rare-earth mine region, so as an indicator of ecological disturbance in the mining area, TDC has better performance than NDVI.

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References
Hu W L, Zhao P and Dong Z Y. Thermal environmental effect of coal mining area and its ecological significance based on TM data[J]. JOURNAL OF HEFEI UNIVERSITY OF TECHNOLOGY, 2010, 33(5): 741-744. (In Chinese)
Li H K, Liu X S, Li B and Li F S. Vegetation Coverage Variations and Correlation with Geomorphologic Factors in Red Soil Region: A Case in South Jiangxi Province[J]. SCIENTIA GEOGRAPHICA SINICA, 2013, 34(1): 103-109. (In Chinese)
Peng Y, He G J and Jiang W. Eco-environment Quality Evaluation of Rare Earth Ore Mining Area Based on Remote Sensing Techniques[J].Geo-Informatics in Resource Management and Sustainable Ecosystem. Springer Berlin Heidelberg, 2013:246-257.
Qiu W W and Hou H P. Study on Surface Temperature Variation Caused by Ecological Disturbance in the Mining Area Based on RS[J]. MINING R & D, 2013,33(2): 02:68-71+83.(In Chinese)
Qin Z H, Zhang M H, Karnieli A and Berliner P. Mono-window algorithm for retrieving land surface temperature from Landsat TM6 data[J]. ACTA GEOGRAPHICA SINICA-CHINESE EDITION, 2001, 56(4): 466-474. (In Chinese)
Sun S M, Lu C Y. Study on Monitoring Intensity of Urban Heat Island and Taking it as an Indicator for Urban Ecosystem by Remote Sensing[J]. Journal of Xiamen University (Natural Science), 2002, 41(1): 66-70.(In Chinese)
Yang W R, Li F and He Y. Characteristic change and analysis of urban heat island in Beijing, China, Summer, 2003 — 2011[J]. ACTA ECOLOGICA SINICA, 2014, 34(15): 4390-4399.(In Chinese)
Zhang C C, Chen D H and Dong H T. Land Surface Temperature Retrieval based on Landsat-5 TM Data in Baisha Irrigation of Henan province[J]. REMOTE SENSING TECHNOLOGY AND APPLICATION,2013,06:964-968.(In Chinese)
Zhang Y L. Open Cast Mine Monitoring and Ecological Effect Assessment through Remote Sensing — A Case Study from Pingshuo[D]. China University of Geosciences (Beijing), 2014. (In Chinese)