Monitoring of soil erosion caused by construction projects using remote sensing images

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Abstract The application of Remote Sensing (RS) images to soil erosion monitoring caused by construction projects can meet the needs of dynamic supervision and early warning, and can also significantly improve the efficiency of supervision. In this paper, a technical process for monitoring soil erosion caused by construction projects was proposed. As an example, the high-definition RS survey of the whole city of Zhoushan was carried out. Firstly, the contour lines of the protection range determined during the approval of the construction project were vectorized. Secondly, RS interpretation of perturbation patches of construction projects was carried out with the aid of interpretation marks. Thirdly, preliminary judgment of perturbation compliance was made through the spatial overlay of the interpretation results and approved prevention scope. Finally, field investigation was done to correct the results of RS image analysis. The results show that this technical process can interpret the activity status of construction projects, effectively determine the compliance of perturbation conditions, and improve the efficiency of soil-water conservation supervision.

1. Introduction
In recent years, the impact of human activities such as production and construction projects on soil erosion has become increasingly severe [1-2] (Rejani et al., 2010; Andriyanto et al., 2015). It is necessary to adopt new technologies to strengthen monitoring and regulation of soil erosion caused by construction projects. The remote sensing technology that has been applied to soil erosion monitoring, achieved very good results [3-5] (Peng et al., 2012; APAAdélia et al., 2011; Ning et al., 2006). The efficiency of soil-water conservation supervision has been distinctly improved with the aid of RS image [6-8] (Pradhan et al., 2012; Kheir et al., 2008; Dabral et al., 2008). In this paper, a technical process for monitoring soil erosion caused by construction projects was established. As an example, the process of the high-definition RS survey of the whole city of Zhoushan was discussed. Zhoushan City is a southern hilly area of red soil, and the main type of soil erosion is hydraulic erosion [9] (Chen et al., 2020). There is wind erosion sometimes on the coastal side of some islands, and gravity erosion such as landside and collapse in some area with large slope or construction projects with slope excavation. According to the dynamic monitoring results of soil erosion in 2018, Zhoushan City had a total soil erosion area of 105.98 km\textsuperscript{2}, accounting for 7.4\% of the city's total land area. In view of the current situation of soil erosion in Zhoushan, this paper studied the application of RS images in soil erosion monitoring caused by...
construction projects. The 18-view Gaofen-2 (GF2), 8-view Gaofen-1 (GF1) and 3-view Ziyuan 3 (ZY3) RS images were selected, which can cover the entire supervision area, with a spatial resolution of 0.8 m², as shown in Figure 1. Then, by analyzing overlay of the interpretation results and approved prevention scope, the compliance of soil-water perturbation in construction projects is preliminarily judged.

![RS image coverage of Zhoushan City.](image)

2. Materials and methods

2.1. RS image pre-processing

In order to meet the requirements of RS interpretation of perturbation patches, the RS images needed to be preprocessed. The preprocessing included six steps.

1. Feature point matching. Automatic digital photogrammetric processing software was used to extract feature points from the images to be processed and reference images, and automatically match the control points and connection points between the reference map and the images to be processed.

2. Adjustment calculation. The external parameters of the image were calculated by the method of area network adjustment. And open the adjustment project after the software automatic solution was completed to check the error in the control point and connection point. It was required that the error in the control point was less than 5 and the error in the connection point was less than 1. If the middle error was too large, the characteristic points with large residual value should be deleted manually and recalculated until the middle error meets the requirements.

3. Orthographic correction. The images were corrected by the whole scene, and resampling adopted bilinear difference. The grayscale and contrast of the image should not be stretched, the pixel number not be changed, and the band combination not be changed. There was no vulnerability area within the corrected orthophoto data range. The registration correction of multispectral images and panchromatic images was based on the control of corrected panchromatic images. In order to ensure the fusion effect, the error of the control point residuals corrected by registration was not more than 1 pixel. The resolution after image correction was consistent with the ground resolution of the original image.

4. Image fusion. After fusion, the image had natural colors, rich layers and moderate contrast. The image texture was clear, without ghostly shadows or virtual phenomena, and the information of ground object interpretation can be significantly improved after fusion, as shown in Figure 2.

5. Image enhancement. In order to make the color of vegetation incline to reality and enrich the layers among vegetation, in the combination of true-color images, about 15% near-infrared bands were superimposed on the green bands to obtain three-band true-color images enhanced by the green bands. The superimposed image not only enriched the image hierarchy, but also reduced the influence of haze on the image to some extent and increased the clarity of the image surface, as shown in Figure 3.
Figure 2. Image fusion results.
(multispectral and panchromatic images before fusion on the left, images after fusion on the right).

Figure 3. Band enhancement contrast (standard true-color image on the left, enhanced image on the right).

(6) Image mosaic. Before image mosaic, all images to be mosaic should be uniformly sampled to the same resolution according to the final resolution requirement. During image mosaic, the color transition between the indirect edges of the scene and the scene should be natural, the ground objects should be properly connected, and there should be no ghosting or virtual phenomena. For example, when there is a construction site in the mosaic area, the mosaic line should be adjusted to bypass the artificial surface so that the mosaic result can maintain the integrity and rationality of the artificial surface, as shown in Figure 4.

Figure 4. Schematic diagram of mosaic (before mosaic on the left, after mosaic on the right).

2.2. Vectorization of the approved prevention scope
The prevention or responsibility scope map of soil erosion control in the construction project needed to be spatially and graphically processed to obtain vector map with spatial geographic coordinates and attribute information. The prevention scope map collected by this regional supervision mainly included
control point coordinate representation scope, paper scanning map, dwg format and other types. The technical process of vectorization of construction projects is shown in Figure 5.

![Diagram](image-url)

**Figure 5.** Vectorization process of responsibility scope of the construction project.

### 2.3. Establishment of interpretation marks

Interpretation signs included the main construction project types in the supervision area, with no less than 2 sets of interpretation signs for each type of construction project. Each set of interpretation signs included 1 field photo and corresponding RS image, and the RS image should indicate the shooting area, as shown in Figure 6.

![Field Photo](image-url)

![RS Image](image-url)

**Figure 6.** Interpretation signs of the construction project (field photo on the left, RS image on the right).
2.4. Plot of perturbation patches in RS images
RS image processing software or GIS software was used to plot the perturbation patches of the construction projects with the aid of the characteristics of RS images, prior knowledge and RS interpretation marks. Perturbation patches with minimum mapped area $\geq 4.0 \text{ mm}^2$ can be interpreted by RS, while perturbation patches with mapped area $\geq 1.0 \text{ cm}^2$ must be interpreted. Monitoring of specific targets can be adjusted appropriately according to the resolution of RS images and practical application requirements. The displacement of the disturbed spot boundary was not more than 1 pixel relative to the same spot on the processed remote sensing image.

2.5. Compliance analysis
The preliminary analysis of compliance of the construction projects that meet the vectorization requirements, was done. By using GIS software as spatial overlay analysis tool, the spatial overlay of the vector diagram (expressed in Y, dotted line) of the perturbation patches in supervision area and the approved prevention scope vectors (expressed in R, solid line) was analyzed. The compliance of the construction projects was initially determined, see the section of case study.

2.6. On-site review
Through on-site review, the spatial characteristics and attribute information of the vector data of the perturbation patches after RS interpretation were revised and improved. The revision mainly included the following three types: (1) Delete other patches misjudged as perturbation patches of the construction projects, as shown in Figure 7. (2) Combine multiple perturbation patches adjacent to each other belonging to the same construction project, as shown in Figure 8. (3) Divide a single perturbation patch belonging to two or more different construction projects, into multiple perturbation patches according to the boundaries of each project, as shown in Figure 9.

Figure 7. Spots misjudged as disturbance (green block on the left, demolition block on the right).

Figure 8. Perturbation patches of the same construction project (before merger on the left, after merger on the right).
Figure 9. Cut apart perturbation patches including different construction projects.

3. Results and discussions

Three typical cases were analyzed. The red line in Figures 10, 11 and 12 represents the prevention or responsibility scope of the approval, and the blue line represents the perturbation scope that was interpreted from the RS image.

Figure 10. Compliance project cases (under construction on the left, completion on the right).

Case analysis of compliance projects. The left side of Figure 10 is a project under construction. From the image, the perturbation patches are within the approved scope of prevention, indicating that the construction was carried out in accordance with the approved plan. Thus, the preliminary analysis of compliance was judged as "compliance". The existing project on the right of Figure 10 shows that the approved prevention scope was overlapped with the perturbation scope, indicating that the construction was carried out in accordance with the approved plan, and the preliminary analysis of compliance was judged as "compliance".

Figure 11. Projects suspected to be beyond the scope of approved prevention scope.

Figure 12. Projects suspected to be built without approval.
Case analysis of the construction projects suspected of exceeding the approved prevention scope. According to Figure 11, not only the scope of the project approval has been carried on the main project construction, but also the construction area has been set up in the west and east directions of the construction unit, the scope of which is beyond the scope of the approved.

Suspected construction projects without approval. According to the RS image in Figure 12, ground perturbation and construction were carried out, but there was not the approved prevention scope for soil-water conservation control. Only the perturbation scope was found, and the project was suspected to be built before approval.

4. Conclusion
In this paper, a technical process for monitoring soil erosion caused by construction projects was proposed based on remote sensing images. The results of this paper showed that this method can effectively interpret the activity status of the construction projects by using remote sensing images, timely insight into actual disturbance of soil erosion. Moreover, the method can effectively analyze and judge the compliance of perturbation status, improve the supervision efficiency of soil erosion. But, there were also the following deficiencies. For a project with a short construction period, due to the timeliness of RS image and cloud cover, the actual perturbation situation of the project may not be recognized during the interpretation of perturbation patches. It is difficult to identify whether the project has been approved before the construction. It was difficult to judge the perturbation position and condition of the drainage pipeline under the ground, and not easily to be vectorized. For the longer linear projects, the important monitoring sites such as waste dump site and soil dump site in the scheme were only indicated by dots, which made it difficult to figure out the approved scope and judge the compliance.

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