Dynamic Monitoring and Spatiotemporal Analysis of Soil Erosion in Changting County, Fujian Province from 2005 to 2025

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Keywords: Soil erosion, Spatiotemporal variation, RUSLE, Ecological restoration, Changting County.

Abstract

Soil erosion is a major ecological problem in the red-soil hilly region of southern China. This study investigates Changting County, Fujian Province, utilizing multi-temporal remote sensing imagery from 2005 to 2025 and the RUSLE model to estimate soil erosion. A soil erosion intensity transition matrix was constructed, and global and local Moran's I indices were employed to reveal the spatiotemporal evolution patterns of erosion clustering. The results show that in 2005 the area of eroded decreased from 527.74 km² (17.00% of the county area) to 202.99 km² (6.54%) in 2025. The area affected by moderate or higher levels of erosion decreased from 230.08 km² to 107.17 km², while the area affected by severe or higher levels of erosion decreased from 79.86 km² to 26.65 km². The development of soil erosion showed a gradual downward trend. The spatial autocorrelation analysis also revealed a significant clustering of improved and deteriorated areas. The improved areas accounted for 88.47% of the entire county, while deterioration was mainly concentrated in construction sites, transportation corridors, and surrounding mining areas. These results provide scientific basis for the key protection planning and monitoring of the red soil hilly areas, combined with long-term remote sensing monitoring.

1. Introduction

Soil erosion is the primary form of land degradation and presents serious threats to natural habitats, agricultural yields, and sustainable development. Additionally, erosion adversely affects downstream water quality and plays a role in wider environmental degradation processes (Lal, 2001; Gupta et al., 2025). In southern China's red-soil hilly region, abundant rainfall, steep slopes, highly weathered soils, and intense human disturbance are all coupled factors contributing to extreme erosion risk. Changting County is a typical hotspot area in this region where ecological vulnerability and erosion sensitivity have been well-documented (Chen et al., 2019; Wu et al., 2022). Furthermore, the long-term land-use as well as land-cover change, in combination with human– environment interactions, has significantly influenced the regional mechanism of erosion (Ge et al., 2019). While large-scale ecological restoration has positively impacted local ecological conditions, a systematic quantitative study of the long-term evolution, transfer routes, and spatial clustering of soil erosion remains lacking. In recent years, remote sensing and GIS have emerged as relevant tools for large-scale and long-term monitoring of soil erosion, and the rapid development of cloud computing platforms has amplified accessibility and temporal comparability (King et al., 2005; Sepuru and Dube, 2018; Wang et al., 2024). The Revised Universal Soil Loss Equation (RUSLE) has been proposed within this framework for use on a regional scale as well as watershed in the study (Renard et al., 1997; Fu et al., 2005; Prasannakumar et al., 2012; Ganasri and Ramesh, 2016; Zerihun et al., 2018; Fahd et al., 2025; Nesru, 2025). These methods have been applied in previous studies: they were used to calculate erosion sensitivity, measure temporal changes, and study the ecological service responses in different landscape environments (Chen et al., 2019; Gao and Wang, 2019; Niu and Shao, 2020; Wang et al., 2022). Moreover, recent research efforts have also been promoting the development of this field towards multi-scale simulation, early warning or dynamic remote sensing analysis to show that soil erosion research is going from static mapping to integrated monitoring and prediction (Rao et al., 2025; Boali et al., 2025). In this context, this study takes Changting County as an example and combines multi-source remote sensing data for building soil erosion intensity maps of 2005, 2010, 2015, 2020, 2025 according to RUSLE model. By integrating transition-matrix analysis and Moran's I, the research aims to show both the spatial pattern of spreading patterns and the dynamics of soil erosion, and to investigate further causes of these phenomena. The outcomes will offer both theoretical support and practical guidelines for soil and water conservation, ecological restoration, and long-term monitoring in the red-soil hilly regions of southern China.

2. Materials and methods

2.1 Study Area

Changting County is situated on the southern aspect of the Wuyi Mountains, in western Fujian Province (25°18′ – 26°02′ N, 116°00′ – 116°39′ E), as shown in Figure 1, which covers a total area of 3099 km². The terrain consists of low mountain and hillland and the elevation in this region ranges from 200 meters to 1400 meters. It is a subtropical monsoon climatically influenced region, the average annual rainfall is approximately 1730 mm, characterized by intense rainy season and frequent severe weather. Common soil types are red, yellow, which are loose in texture, poor aggregate stability and highly susceptible to water erosion. Historically, excessive logging,

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slope cultivation and mining activities resulted in significant decrease in forest cover, and broad coverage of mountainous surfaces leading to increased soil erosion. However, since 2000 a series of ecological restoration projects, including conversion of farmland to forest and closure of hillsides for afforestation, has markedly increased forest coverage, and provided favorable conditions for enhancing regional soil and water conservation patterns.

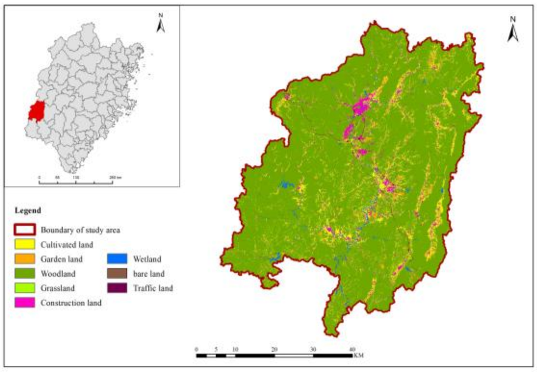


Figure 1. Location of the study area.

2.2 Data Sources

This study used Landsat TM/ETM+/OLI images from 2005, 2010, 2015, 2020, and 2025, all with a spatial resolution of 30 m. Atmospheric correction, cloud masking, mosaicking, and clipping were conducted on the Google Earth Engine platform. DEM data with a 30 m spatial resolution were obtained from the Geospatial Data Cloud (https://www.gscloud.cn/). Precipitation data were downloaded from the National Earth System Science Data Center, also at a 1 km resolution (https://www.geodata.cn/main/face_science_detail?guid=113786088533256&typeName=face_science) and used to represent average precipitation conditions from 2005 to 2025. Land-use data were derived from remote-sensing image interpretation, soil-type data were obtained from Harmonized World Soil Database v2.0 with a resolution of 1km (https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonizedworld-soil-database-v20/en/), and NDVI data were extracted from the MOD13Q1 dataset at a resolution of 250 m (http://lpdaac.usgs.gov/) for vegetation-cover estimation. To ensure analytical consistency, all datasets were thoroughly preprocessed, including resampling to a uniform 30m spatial grid and standardizing to the WGS_1984_UTM_Zone_50N coordinate system.

2.3 Soil Erosion Estimation Model

The RUSLE model was used to calculate soil erosion, as illustrated in Equation (1). The RUSLE framework has been extensively used in watershed- and regional-scale soil erosion assessment because it can effectively integrate rainfall erosivity, soil erodibility, topography, vegetation cover, and conservation practices within a spatially explicit GIS environment (Renard et al., 1997; Fu et al., 2005; Prasannakumar et al., 2012; Ganasri and Ramesh, 2016; Zerihun et al., 2018; Wang et al., 2024; Fahd et al., 2025).

$$A = R \times K \times L \times S \times C \quad (1)$$

where A is the annual average soil loss ($t \cdot ha^{-1} \cdot a^{-1}$), R is the rainfall erosivity factor, K is the soil erodibility factor, L and S are the slope-length and slope-steepness factors, C is the vegetation-cover and management factor, and P is the support-practice factor.

Based on the calculated soil loss, erosion intensity was classified into five levels ranging from mild to catastrophic.

3. Results

3.1 Spatiotemporal Variation Characteristics of Soil Erosion Intensity

Figure 2 illustrates the spatial distribution of soil erosion intensity in Changting County from 2005 to 2025. On the whole, soil erosion severity within the study area decreased significantly during the last twenty years. The spatial distribution gradually shifted from widespread regional erosion with slight and moderate erosion during the initial period to a concentrated and dispersed trend during the latter stage, further limited by the contraction of severe erosion zones. In 2005, the total erosion area of the entire county was 527.74 square kilometers, accounting for 17.00% of the county's total area; among them, 230.08 square kilometers (accounting for 7.41%) were also classified as moderately severe or more erosion areas. By 2025, the total erosion area decreased to 202.99 square kilometers, accounting for 6.54% of the county's total area, while the area of moderately severe or more erosion regions was 107.17 square kilometers, accounting for 3.45%. High value erosion areas were predominantly represented in the southeastern and central hilly locations, which overlapped with sloping farmland, bare rock, and abandoned mining sites. In contrast, slight and moderate erosion areas were mostly sparse in the northern and western river-valley plains, where vegetation reclamation was relatively rapid and erosion severity was low. Notably after 2015, the number of severe erosion patches decreased considerably due to the double contribution of ecological rejuvenation and slope-to-terrace conversion projects. Consequently, the spatial profile progressively decreased with an erosion gradient with the intensity of erosion decreasing from core to periphery.

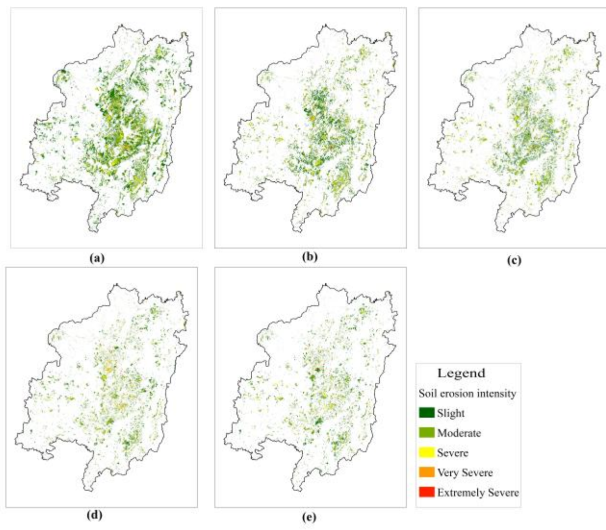


Figure 2. Spatial distribution of soil erosion intensity in Changting County in (a) 2005, (b) 2010, (c) 2015, (d) 2020, and (e) 2025.

3.2 Characteristics of Soil Erosion Intensity Transfer

Transition matrices for the four periods 2005-2010, 2010-2015, 2015-020, and 2020-025 showed a clear stage specific trends of evolution of soil erosion in Changting County along with a general trend of continuous improvement, as shown in Figure3 and Figure4. The county experienced a rapid period of improvement between 2005 and 2010. The transfer rate from moderate to slight erosion reached 33.04% during this period, and the intensity of soil erosion in high-intensity erosion areas generally decreased by 1 to 2 grades. while the areas where the intensity of soil erosion remained stable, decreased and increased accounted for 39.25%, 41.20% and 19.54% respectively, indicating that the erosion pattern was undergoing rapid restructuring. Although the transfer rate remained as high as 17.49% from slight erosion to moderate erosion, indicating that slope cultivation expansion and engineering disturbance were still playing an important role.

From 2010 to 2015, a consolidation and stabilization phase was introduced in the county. In slight- and moderate-intensity erosion, the proportion of stable areas increased to 68.65%, implying a gradual development of a moderately stable vegetation– soil structure. However, the proportion of areas with reduced erosion diminished to 20.34%, indicating that after high-risk zones were initially controlled, enhancement became progressively harder. The prevalence of areas changing from moderate to severe erosion to 8.20%, reflects the increasing local risks.

Between 2015 and 2020, the county entered stabilization and optimization phase. The proportion of stable, reduced, and aggravated erosion was 64.90%, 26.17%, and 8.91% respectively at this period, indicating ongoing optimization in a relatively stable background. Especially transfer rates from moderate to mild erosion and from severe to moderate erosion were 15.32% and 9.72% respectively, which illustrated that ecological restoration was still effecting greatly in medium and high erosion zones.

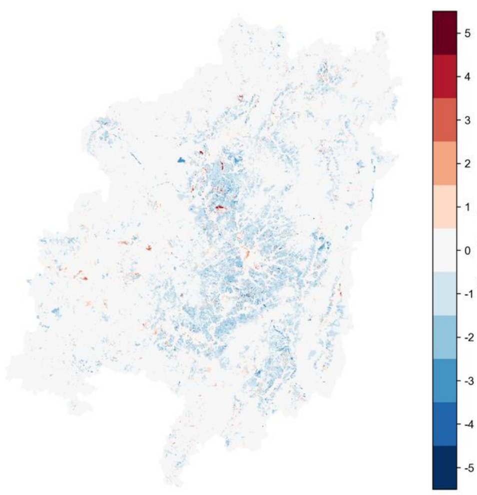
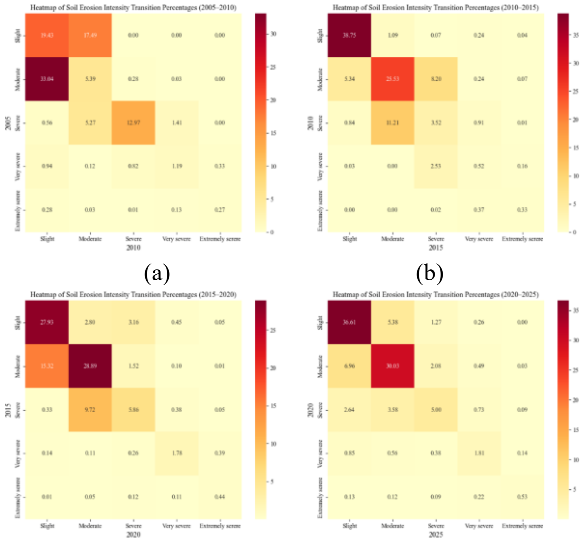


Figure 3. Spatial patterns of soil erosion change levels in Changting County, 2005–2025 (−: improvement; +: degradation; 0: stable).

From 2020 to 2025, the county underwent a period of sophisticated management. The percentage of stable areas increased to 73.98%, indicating that the erosion pattern was very stable and the management focus shifted from large-scale reduction to integration and small-scale maintenance. Still, the relative transfer rate between slight and moderate erosion remained at 5.38%, suggesting that local risk of degradation persisted under the combined influence of development activities and extreme rainfall.

Overall, the change in soil erosion intensity of Changting County followed a stepped-downgrading pathway from high-intensity erosion to less intense erosion close by to moderate and slight erosion. This is consistent with the iterative and cumulative nature of ecological restoration. The county underwent four sequential phases over the period of the study: rapid improvement, consolidation and stabilization, stable optimization, and refined management. Over the same time period, the proportion of stable areas increased from 39.25% to 73.98%. Meanwhile, high-intensity residual erosion continued to be found on steep slopes, in lithologically sensitive locations and places subject to strong human disturbance, indicating strong persistence and underscoring the need for future targeted management and risk prevention.



(a) (b) (c) (d)

Figure 4. Soil erosion intensity transition matrix heat map (a. 2005-2010, b. 2010-2015, c. 20115-2020, d. 2020-2025)

3.3 Spatial Autocorrelation and Aggregation Structure Changes

In order to reveal the spatial heterogeneity of the changes in soil erosion intensity across Changting County from 2005 to 2025, we developed a binary classification map of improvement and deterioration by pixel scale changes in erosion grades. Local indicators of spatial association (LISA) were then implemented and global Moran's I was calculated to describe the spatial clustering pattern. This method not only can comprehensively reflect the overall spatial dependence of erosion changes, but also can locally demonstrate this dependence, which is helpful for identifying the clustering phenomena in improved and deteriorated areas, and at the same time can reveal the differences in the types and patterns of spatial correlations.

The results show that soil erosion change was dominated by improvement during this period, with a global Moran's I value of 0.7641. This indicates that both the improved units and the deteriorated units have a high positive spatial autocorrelation, and this pattern also shows a strong clustering rather than random dispersion. In summary, the gradual change in the erosion pattern in Changting County is not a single or inconsistent one. In fact, it is caused by the combined effect of geographical features and human activities, and forms spatially interrelated improved areas and local deteriorated areas. At the local scale, through LISA analysis, the distribution of various changes was further clarified. The high-high improvement clusters represented 8.82% of the study area and were mainly characterized by strip-like and block-like patches of land on hilly slopes and a small-watershed treatment area where exhibited severe erosion phenomena. This indicates that in these areas, continuous ecological restoration, water resource and soil protection, as well as slope management activities have formed a relatively concentrated core area for improvement. Most significantly, this phenomenon of concentrated improvement suggests that the effects of management measures are not limited to isolated pixel areas, but have spread to a wider area through systematic watershed restoration and slope land governance. In contrast, high-value deterioration clusters in the study region accounted for 11.30%. These areas were mostly distributed in isolated patches, especially in areas with high levels of building interference, along transport corridors and around mining areas, respectively. This trend indicates that although the overall erosion situation has significantly improved, human activities remain the main source of local erosion risks. The regions most prone to local erosion deterioration are particularly affected by frequent ground disturbances, vegetation cover destruction, and terrain sensitivity. Furthermore, the HL and LH clusters are mainly distributed in the transitional areas surrounding the improved and stable regions. This indicates that due to the combined effects of management measures, topography and the surface, there is local heterogeneity in the erosion evolution.

Overall, from 2005 to 2025, the overall change in soil erosion in Changting County has a spatial characteristic. There are both overall improvements within the regional scope and the accumulation of local risks. On one hand, the improved areas are distributed in multiple bands throughout the county, indicating that the existence of ecological restoration projects can make their effects extend beyond the local communities and reach a wider range of spatial changes. However, although these deteriorated areas are relatively small in scale, they are still highly concentrated in areas prone to terrain damage and severely affected by human interference. This result indicates that the overall erosion intensity has decreased and the landscape stability has increased, although the fragile local soil and water quality are key issues that require strengthened monitoring and targeted control. Therefore, future work in soil and water conservation must particularly focus on dynamic monitoring or risk detection in densely developed, busy transportation, mining, and terrain-sensitive areas, while also combining remote sensing, spatial analysis, and zoning governance to better control these areas.

4. Discussion

4.1 The Dominant Role of Ecological Restoration Projects in Improving Soil and Water Loss

The transition-matrix data shows that from 2005 to 2025, the intensity of soil erosion in Changting County presented a gradual downward trend, with the transition from moderate erosion to mild erosion and from severe erosion to moderate erosion being the most common paths. These transitions from moderate to mild accounted for 33.04% during the period from 2005 to 2010, indicating that the areas with moderate and high-intensity erosion responded more strongly to intervention measures in the early stage. During the period from 2015 to 2020, transitions from moderate to slight and from severe to moderate accounted for a considerable proportion, and remained at relatively high levels: 15.32% and 9.72% respectively. This indicates that ecological restoration has a long-term impact effect, even though the overall erosion trend is relatively stable. These results prove that the soil erosion in Changting County is not a decrease in the intensity of erosion in the covered erosion areas, but a gradual transformation from a higher erosion level to a lower one. This process includes stages and compound effects.

This evolution is consistent with the wider adoption of ecological restoration measures in Changting County for long-term governance, such as converting farmland into forest land, enclosing slopes for afforestation, building terraced fields on slopes, and comprehensive small watershed management. The results show that engineering measures combined with specific environmental measures play a core role in controlling erosion. Mechanically speaking, vegetation restoration increases surface coverage, interception capacity of litter, and root reinforcement strength, and reduces the direct impact of rainfall on the soil surface. This direct impact can be reduced through mechanical means and increase the porosity and permeability of the lower soil layer. Measures such as terraces, contour ditches, and runoff interception projects significantly shorten the slope length, reduce the concentration of slope runoff and the kinetic energy required for erosion. These measures act together at the slope and watershed levels, gradually transforming high-intensity erosion areas into low-intensity erosion areas, thereby reducing the erosion risk of the region.

From a temporal perspective, we can consider 2005 to 2010 as the most critical period in Changting County, during which the benefits brought by soil and water conservation achieved the fastest growth rate. The rapid decline trend during this period indicates that a large number of moderate and high-intensity erosion areas were rapidly reduced through concentrated governance measures, and significantly changed the erosion distribution pattern. This is consistent with the fact that in the governance aspect, early governance often coincides with the peak of policy support, engineering investment, and ecological restoration efforts. However, after 2010, the overall progress slowed down because the remaining erodible areas are located in more complex terrain, more unstable land surface conditions, and areas with higher management costs. Nevertheless, the moderate and high-intensity erosion areas are still decreasing to a lower level, indicating that the ecological restoration work has not weakened but has shifted from rapid reduction to gradual optimization. This also indicates that the restoration projects have a clear impact on soil erosion, because over time, through the growth of vegetation, soil regeneration, and the reorganization of slope hydrological processes, there are obvious lag and cumulative effects.

More broadly, the decline in soil erosion intensity in Changting County also reflects a transition from single-measure treatment to using a combination of single and comprehensive watershed management. Vegetation restoration can to some extent reduce surface erosion, but using only biological measures usually cannot achieve long-term control of erosion in large-scale sloping farmland, significant terrain undulations, and complex soil erosion processes in the red soil hilly area, which require a more extensive spatial scale for achieving long-term control of erosion. Coordination intervention measures for slope management, gully control, fence protection, and watershed management are effective in changing the local surface conditions, runoff-sediment processes, and landscape structure within the watershed. The stepwise degradation path determined in the transfer matrix most fully reveals the interactions among the interrelated governance mechanisms, rather than any single intervention measure.

More importantly, the reduction in erosion intensity also indicates the restoration of slope hydrological functions and soil ecological processes. With the increase in vegetation coverage and improvement in soil structure, the consistency of rainfall influence, surface runoff, and sediment carrying gradually weakens. Previously highly sensitive slopes have gradually transformed into more stable features. From this perspective, the importance of ecological restoration in Longting County cannot be underestimated, as it reflects the process of enhancing landscape stability and ecological resilience.

4.2 Persistence of Residual High-Intensity Erosion under Natural Topographic Constraints

During 2005-2025, the overall area affected by intense erosion decreased significantly. However, from 2015 to 2020 and from 2020 to 2025, some severe, very severe and extremely sever erosion phenomena persisted. This indicates that in certain specific areas, the intense erosion areas have persisted even when the overall environment has improved. From the actual situation, this suggests that although the relatively easier-to-manage and control erosion areas have gradually been replaced, the remaining intense areas mainly concentrate in areas with more complex natural conditions and where erosion processes are more likely to occur. Therefore, these areas are more sensitive to rainfall and external disturbances and are often much more difficult to recover than standard erosion areas. Spatially, the remaining intense erosion areas are mainly distributed on steep slopes, fractured rock layers, and slope deposits with thin soil layers. Such terrain usually has low slope stability, poor surface cover recovery, and weak erosion resistance. Under heavy rainfall conditions, they are therefore more prone to concentrated runoff, gully formation, and frequent surface soil erosion problems. This problem is particularly severe in red soil hills. When weathered soil and severely degraded structures interact with heavy rainfall, and when vegetation is insufficient or ground disturbance occurs, it will trigger further erosion. Therefore, the overall erosion intensity of the entire area has decreased, but these naturally scarce and restricted areas still remain more susceptible to long-term intense pressure.

The persistence of erosion in such zones is due not only to the direct influence of slope and lithology, but also to the uneven response of geomorphic units to restoration. Gentle slopes, low hills, and valley margins show thicker soil layers and better water and nutrient retention conditions, allowing vegetation to be restored and slopes maintained while significant improvements can be achieved within a relatively short time. Instead, the response tends to be much more concealed in regions with steep slopes, shallow soils, and abundant rocks on the surfaces, especially even in the presence of these other measures, even within the same treatment method. This imbalance in feedback indicates that the distribution of ecological restoration is uneven. The improvements at the county-wide level do not mean all the patches are in stable recovery. By contrast, the presence of ongoing high-intensity residual erosion reflects that topography still determines the upper limit of the restoration effect and the spatial constraints.

From an engineering perspective, patch-based improvement is still challenging as it is generally the case that several unfavorable factors coexist. Thin soil layers, high gravel content, and poor organic material levels hinder natural regeneration as well as artificial development. Therefore, short-term effective surface protection measures are not feasible. Meanwhile, a series of steep slopes supports the production of high-energy runoff on the part of the newly-formed vegetation during rainy season but can damage it easily and disturb the stability of structure in the soil. Additionally, there are occasional, random human interventions from road construction and slope development, mining activity, which can easily reactivate erosion in these very sensitive environments. As the overall stability of Changting County continues to improve, this residual erosion is also likely to be the object of future soil and water conservation activity. These areas have a relatively small size and high governance costs, but they have a disproportionately significant impact on ecological integrity and the sustainability of restoration effects. Once disturbed by extreme rainfall or construction activity, these areas may quickly become new local erosion sources. Thus, over a period of development it is very important in the long-term monitoring and adaptive management, which in turn can be supported by remote sensing, field investigation and risk assessments, and through which targeted intervention can be ensured.

4.3 Evolution of Spatial Aggregation Patterns and Improvement of Landscape Stability

In the spatial autocorrelation analysis, global Moran's I remained significant throughout the study period, which indicates a strong spatial dependence and clustering between soil erosion intensity in Changting County. Thus, the changes in erosion were not uniform across the landscape, but depended on the combined effect of topography, land use, vegetation restoration, and human disturbance. At the same time, the decline in Moran's I over the study period was consistent with the increase of stable units and the decline of transition between grades reflected in the transition matrix. Overall, these results indicate that the spatial stage of erosion evolved from a more dynamic adjustment stage to a relatively stable structure. In other words, the strength of erosion fell, and the spatial structure of the erosion processes became less unstable.

The LISA analysis explains how this structural change occurred. In the initial stage, high-value clusters were widely distributed in large adjacent areas; high-intensity erosion units also had strong spatial adjacency and continuity. This pattern indicates that the similar nature of surface conditions, slope processes, and disturbance regimes were spatially connected, increasing the likelihood of regional-scale erosion expansion under heavy rainfall. However, as ecological restoration and comprehensive management efforts continue, the number of these high-value areas has significantly decreased, and they have largely changed from large contiguous regions to strips, patches or fragmented distributions. This transformation indicates that erosion cores from initially high-risk areas are now becoming increasingly fragmented and compressed, with a more dispersed distribution, weakening their spatial continuity and influence in the county-wide erosion pattern. Simultaneously low-value clusters expanded steadily, then gradually but progressively formed a more coherent erosion-reducing background and stable patches in the northern valleys and western piedmont areas. This trend indicates that management impacts were not only manifests in the elevation level of individual erosion patches, but also with the systemic extension of low-risk and stable units throughout the map. These units are increasingly interconnected, becoming more coherent as a whole, and forming a continuous landscape matrix. From the perspective of landscape ecology, such a stable matrix reduces the connectivity of high-risk patches, reduces the spatial spread of erosion activities, and alleviates the increase in local degradation events. This transition from a dense and highly aggregated state to a dispersed and patch-like state indicates a greater transformation in the erosion ecological pressure of the region: the system shifts from a widespread and connected risk state to a local restricted state.

This change is of great significance for understanding the improvement of landscape stability. If high-risk erosion areas are extensive and connected, and have a high severity, then extreme rainfall or nearby disturbances may trigger a chain reaction, spreading rapidly along the slope and entering the watershed. Once these areas are divided into small patches and in some cases become isolated, their ability to dominate the regional erosion pattern will be greatly reduced. At the same time, the continuity of low-risk and stable units is continuously increasing, enhancing the landscape's ability to absorb local disturbances. In this regard, the improvement of landscape stability in Changting County is not only due to decreased area eroded, but also to the increased resilience of the ecosystem and its capability to absorb external forces. The greater stability of the landscape at large, however, does not mean less risk for erosion. Conversely, these individual areas of degradation might become easier to overlook precisely because the overall regional environment has improved greatly. These patches can be focused in construction disruptions, transport corridors, and topographically sensitive zones, and retain local roles as potential sources of fresh soil erosion, unless properly managed. Therefore, for soil and water resource protection management, merely conducting static mapping of erosion areas and intensities is not sufficient; more careful consideration should be given to the dynamic risk signals brought about by the evolution of spatial patterns. Identification and monitoring of local areas of high-risk patches will remain important to avoid further aggregation and expansion of erosion.

The dominant role of ecological restoration shown in this study is consistent with the previous research results in Changting and other Chinese river basins, which show that vegetation restoration, watershed range management, and land use correction can reduce erosion risk and long-term enhance the ecosystem's function (Chen et al., 2019; Niu and Shao, 2020; Wang et al., 2022; Wu et al., 2022). At the same time, the continued occurrence of local degradation and residual high-risk patches also prove that in current environmental research, it is necessary to strengthen dynamic monitoring and simulation to provide early warnings of erosion risks (Rao et al., 2025; Bo Ali et al., 2025). It is also proposed that future soil erosion studies would benefit from more than static intensity mapping and from the more integrated view of process interpretation, spatial heterogeneity and adaptable risk management under continuous human disturbance and climate change.

5. Conclusions

From 2005 to 2025, the intensity of soil erosion in Changting County significantly decreased, with the erosion area reducing from 17.00% of the total area of the county to 6.54%. During the same period, the proportion of moderate and above erosion decreased from 7.41% to 3.45%, while the proportion of severe and above erosion decreased even more significantly, indicating that the control of soil erosion in this area has achieved remarkable progress. From 2005 to 2010, the intensity of soil erosion gradually decreased, and then entered a stable consolidation period from 2010 to 2015, remained stable and optimized from 2015 to 2020, and then dropped to the stable optimal level from 2020 to 2025, and further management was carried out. Spatial autocorrelation analysis also indicated that in the entire study area, the intensity of soil erosion showed a highly positive correlation feature at all time points, although the Moran index decreased. High-value clusters continued to decrease, while low-value groups expanded, indicating that the landscape pattern was the form of continuous high-intensity erosion extension and was transforming to a more dispersed and fragmented form, which was more in line with the characteristics of a more stable ecosystem. In summary, the ecological restoration project significantly reduced the phenomenon of soil erosion, especially in the early stage, when the effect of reducing moderate and high erosion levels was most obvious in this area. At the same time, slope, rock type, and rainfall affected the underlying patterns of these types of erosion risks, and human activity disturbances, including construction and mining, remained important causes of local degradation. The soil and water conservation work in Changting County should focus on consolidating the current achievements, carrying out governance measures for residual high-intensity erosion areas in specific regions, strengthening supervision and disaster warning of damaged areas, and establishing a regular method that combines remote sensing monitoring, spatial analysis, and adaptive management system feedback to achieve ecological restoration and high-quality protection of the red soil hilly area.

Acknowledgements (optional)

This work was funded by the National Natural Science Foundation of China (Grant No. 4191310), Geological Survey Project (DD202607102602, DD20230103), Ministry-Province Collaborative Projects (2023ZRBSHZ008).

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