Delimitation of the transition zone between active and inactive gully erosion in the Chinese Loess Plateau

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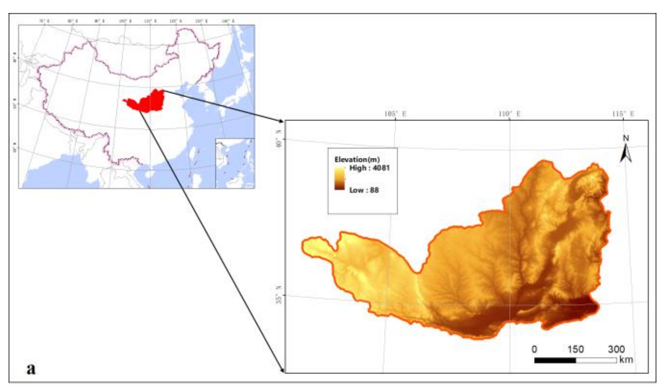
Abstract—**The interaction of various erosivities is the main factor that causes significant spatial differences in the gully development of the Loess Plateau. In some areas of the western Loess Plateau, the accumulation process is greater than erosion process, most of the gullies are in an inactive state while the loess gullies in the east is eroded with a high degree of active development. From the view of the geographical system boundary, there must be a transition zone with in the process of activity of loess gully erosion. In view of this geographical phenomenon, the definition of the erosion-active and erosion-inactive loess gully is given firstly, and then the objective existence of the transition zone is demonstrated. Based on the field investigation data and corresponding remote sensing images, the characteristic system of active and inactive loess gully is constructed. Combining the data of 1: 1000000 geomorphological map and 1: 10000 standard mapsheet of China, the loess erosion-active and erosion-inactive loess gully are identified by visual interpretation method, and the spatial location and trend of the transition zone are determined. The results show that the boundary is essentially a complex transition zone, and the core part is located in the middle of the Longxi Loess Plateau. The development characteristics of loess gullies in the transition zone and on both sides are also analyzed from the aspects of geology, natural environment and climate.**

I. INTRODUCTION

The Loess Plateau is located in the semi-arid part of China and is regarded as one of the most eroded areas in the world (Figure 1a). Different erosivities (internal and external agencies, human activities, etc.) play an important role in shaping the topography of complex gullies, leading to the diversification of soil erosion patterns and types in the Loess Plateau [1], [2]. It is precisely because of the existence of different erosivities, showing a geographical phenomenon from east to west in the Loess Plateau: the accumulation process is greater than erosion process in some areas of the western Loess Plateau, most of the gullies are in an inactive state. The gullies in the east are eroded with a high degree of active development. For example, in Lanzhou and Baiyin of the Loess Plateau, due to less annual rainfall, the climate is arid, the following seepage is dominated by precipitation, the vegetation coverage is low, the slope is relative rounded, and no significant loess shoulder lines are developed. Thus, the gully erosion is not active yet. However, the topography of the Loess Plateau is mostly characterized by loess tablelands, loess hills and loess ridges (Figure 1b).



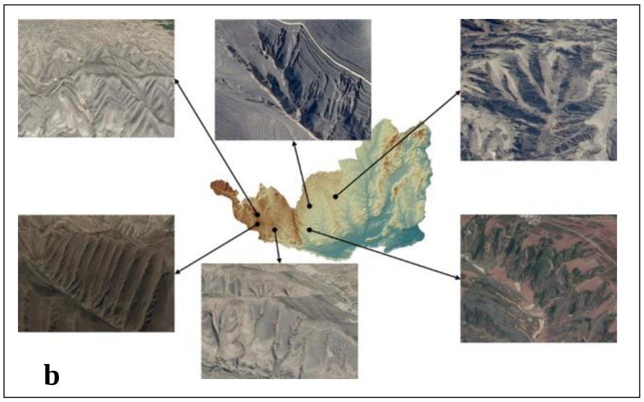


Figure 1. a: Location of the Loess Plateau in China; b: Schematic diagram of different characteristics of gullies in the Loess Plateau.

From the perspective of geographical system boundary, the Loess Plateau, as a spatial organized whole, must have a dividing line or transition zone in which the dynamic activity of loess gully erosion changes. In this work, we call it the transition zone between the active and the inactive of loess gully erosion. As an extremely important zone (or boundary) of geography, geomorphology, soil and water conservation regionalization, it is of great significance for us to construct a basic scientific understanding of the spatial pattern of the loess landform.

Understanding and delineating geographical boundaries is an important way to reveal the temporal and spatial orderliness of geographical environment [3]. It is also a difficult point in the work of geographical regionalization. With the development of GIS, remote sensing and digital terrain analysis technology, many scholars have studied the erosion activity of loess gully and the division method of specific geographical boundaries from qualitative and quantitative perspectives [4], [5], [6], [7]. However, no researches have been addressed on the certain types of geographical boundaries, especially the transition zone of erosion-active loess gully in this study. Therefore, based on the existing knowledge, this paper systematically defines the erosion-active and erosion-inactive loess gully of the Loess Plateau, demonstrates the objective existence of the transition zone between the two types of gullies at the same time. The aim of this study is to extract the most notable features of the two types valleys based on the Google Earth images, the field survey data, and 1: 1000000 geomorphological map of China [8]. Then, combined with the standard mapsheet of 1: 10000, the transition zone of active gully erosion in Loess Plateau is obtained. Finally, this work also analyzes the natural environment and the geomorphological features on both sides of the transition zone.

II. RESEARCH FOUNDATION

A. Definition of the erosion-active and erosion-inactive loess gully

In the Loess Plateau, the gully, with the characteristics of the development of loess vertical joints, slope linear erosion, frequent occurrence of gravity erosion, severe headward erosion is known as the erosion-active gully. On the contrary, due to coarser grain loess size, low vegetation coverage, long-term non-directional uniform erosion of the slope surface, caused by the combination of factors in the relatively stable state of the gullies known as the erosion-inactive gully.

B. Objective existence of the transition zone

The region is divided based on objective understanding of geographical differences and according to certain indicators and methods. The existence of geographical boundary depends on the existence of geographical area and it is a reflection of the change of natural geography phenomenon. Whether it is the overall division of spatial point aggregation by themselves or indicators, we can get a consistent space with same meanings, but different from the adjacent space, which determines the objective existence of geographical boundaries.

In the study, these two kinds of gullies are mostly developed in the typical loess landform area, and they are products of the interaction between the gully system and the environment. It can be seen from the above statements that there must be a western geographical boundary between the active developing region and the inactive region of loess gully erosion. Of course, this may not be an "either-or" line, but cannot deny its objectivity of the transition zone.

III. METHODS

A. Data preparation

The boundary of Loess Plateau by [9] scheme is obtained by interpreting and classifying MODIS images and DEMs by using GIS and remote sensing image processing technology in this paper. In addition, Google Earth images as the basic data and the field survey data of summer 2016, including the spatial location of typical gullies, basic morphological features, and photos. The 1: 1000000 geomorphological map of China and standard mapsheet of 1: 10000 are also used as important auxiliary data for this study.

B. Delimitation principles

In order to scientifically and rationally divide the transition zone, this study should follow the following principles:

1) Scientific principle: the delimitation method should conform to the basic theory of geography and meet the rules of object identification and classification.

2) Systematic principle: consider the influence of various factors (climate, geology, etc.) during the development of the loess gullies comprehensively and systematically.

3) Timely principle: this study should use the latest data sources to ensure the current situation of interpretation results.

C. Delimitation method

In the Loess Plateau, we first use the field survey data and 1: 100000 geomorphological map of China to establish the corresponding relationship of typical loess gullies - remote sensing images geomorphological types in this work (Figure 2). Furthermore, the basic discriminant criteria of erosion active gullies and inactive gullies are summarized from the individual and group scales (Table I). For a single gully, we conclude the interpretation signs from the three characteristic elements of point, line and surface, respectively. On a larger scale, the main consideration is the spatial distribution of the gully group, the fragmented degree of surface, and the level of gullies.

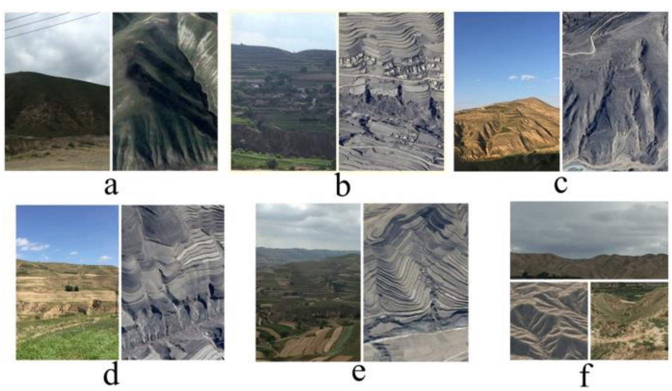


Figure 2. Photos of typical loess gullies and corresponding remote sensing images (**a:** Erosional-denudational steep middle mountain; **b:** Erosional-depositional shallow valley high loess hill and loess ridge; **c:** Loess-covered mild/steep middle mountain; **d:** Erosional-depositional shallow valley low loess hill and loess ridge; **e:** Erosional-depositional deep valley high loess hill and loess ridge; **f:** Tectonic-depositional flat intermountain loess flatland).

Based on the above criteria, the specific methods are as follows: First, 1: 10000 standard mapsheet is spread on Google Earth platform, and each grid is taken as the interpreter unit, which is interpreted one by one grid. Second, with the features listed in the Table I as the main interpretation keys, the image visual interpretation of the erosion-active and erosion-inactive loess gully is based on the geometric center points of grids. Specifically, the characteristics of the gullies within the range of a grid are in accordance with the established criterion, and the grid is considered to be the erosion-active loess gully area, and the attribute is marked as 1, otherwise marked as 0. Finally, the 0, 1 value is taken as the boundary to connect the central points of the grids to obtain the boundary lines on both sides of the transition zone between active and inactive gully erosion (Figure 3).

TABLE I. BASIC DISCRIMINANT CRITERION FOR VISUAL INTERPRETATION

Basis	**Geomorphic types**	**Characteristics**
Loess distribution	Wind-born sandy region	Thin sand accumulation (especially in watershed outlets)
	Sand loess, sticky loess	Beaded pits, kettle depressions, tunnels…
	Typical loess region	Severe gully erosion (gully heads, shoulder lines…)
	Mountains, Basins…	Natural barriers
Gully erosion patterns	Surface morphology	Fragmented surface, high gully density…
	Gully levels	Gully multi - grade, tributaries development
	Gully profiles	General 'v-type'
Other conditions	Erosion baselines	Complex gully longitudinal sections
	Bedrock	Paleotopography, tectonics…
	Environment	Rainfall, temperature, vegetation…

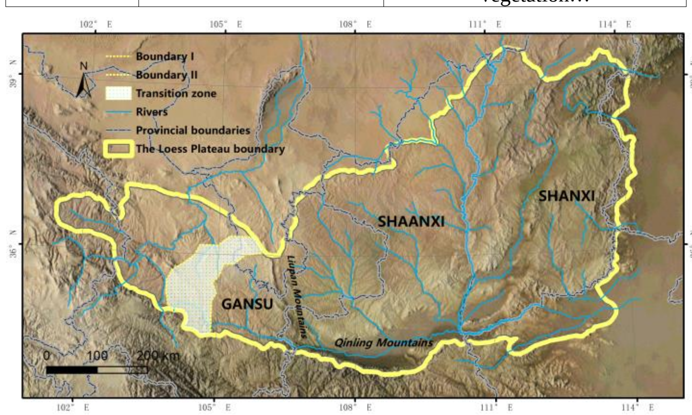


Figure 3. Delimitation results of the active gully erosion zone, transition zone, and inactive gulley erosion zone.

IV. RESULTS & DISCUSSION

Due to the complex diversity of the natural environment, the transition zone should be characterized by abrupt changes, gradual changes and fuzzy alternations. The results of this work also confirms the fact that the line is not a narrow boundary line, but a broad transition zone.

The transition zone is located in the western foot of Liu-p'an Mountains, the central part of Longxi Loess Plateau. The annual average temperature in this area is approximately 5.5-7.5 ℃, the average precipitation is approximately 500 mm, and it is arid and dry with much more evaporation than precipitation. The terrain of this area is inclined from southwest to northeast, and the whole area is located at the western margin of the Loess Plateau and the end of the West Qinling. Meanwhile, the Liu-p'an Mountains, as a natural barrier, has led to the hydrothermal conditions unbalanced distributed in this area. On the west side of the boundary, it is the transition zone of the Tengger Desert and Qilian Mountains to the Loess Plateau. The vegetation cover on the slope is sparsely covered, the surface of the slope is rounded and the climate is arid. On the contrary, the eastern side of the boundary, it is subject to linear erosion and is cut into thousands of loess ridges and terraces [10]. At the same time, it should be noticed that although Liu-p'an Mountains exists as a natural barrier, it could not be completely regarded as the basis for dividing the boundary of abrupt changes. The results also show that the activity of loess gully shows a trend of gradual changes, and eventually reaches the most complicated level of the gully erosion in Dingxi, the main core zone.

In summary, the main characteristics and discriminant criteria of erosion-active and erosion-inactive loess gullies are proposed through field investigation and detailed remote sensing image visual interpretation. Thus, the delimitation of the transition zone between active and inactive gully erosion is using the method of interoperability between Google Earth and ArcGIS has been done to qualitatively determine the spatial location and direction of the boundary. The results of this study are also in line with the spatial understandings of geology and physiognomy, natural environment and climate change. Some deficiencies and limitations still exist in this research, e.g., low interpretation accuracy of results, over-reliance expert knowledge in the interpretation process, etc. These problems still need to be explored in future works, but this study can provide an important reference for the further study of the quantitative geographic boundary model.

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