Simulation on the Evolution of Loess Gullies and Landforms Based on Archaeological Remains Information

Jiaming Na
Key Laboratory of Virtual Geographic Environment of Ministry of Education
Nanjing Normal University
Nanjing, China
najiaming92@gmail.com

Guoan Tang
Key Laboratory of Virtual Geographic Environment of Ministry of Education
Nanjing Normal University
Nanjing, China
tangguoan@njnu.edu.cn

Abstract—**This research fully used the evidences of Wucheng Remains. Extracted the valuable historical geomorphic information through field investigation, UAV photography and GPS sampling. Considering the dominant status of topographic factor on gully erosion of Loess Plateau and the capabilities of cellular automata, designed a time-inversed geomorphic evolution model based on LS factor and stochastic CA for restoration of ancient landforms in the different history of Wucheng watershed. The simulated result is a chronological sequence of DEMs and each DEM corresponds to a historical period. In order to date historical periods of every DEM, this research put forward a temporal calibration method based on foundation surface of ancient Wucheng city, integrating the topographic clues of Wucheng Remains. Analyses confirmed the reliability of the geomorphic evolution model that, to some degree, the simulation accords with the relative objective principles of Loess Plateau. Furthermore, through these analyses, this research explored the mechanisms of gully erosion and development and shown the DEM sequence is a capable new approach for the research on geomorphology.**

I. INTRODUCTION

China's Loess Plateau is regarded as one of the most unique and valuable geographic regions for geoscience research in the world. This area, as a complete geomorphic unit, has attracted much attention due to its severe soil erosion. Because of the erosive vulnerability of loess and even the anthropic destruction of past millennia, the CLP has been always suffering severe gully erosion and gradually takes the shape of current fragmented geomorphic landscapes intruded by varieties of gullies [1, 2]. Gully erosion is the main component of soil loss on the Loess Plateau and it plays an important role in shaping the terrain of the Loess Plateau. Researching on the geomorphic evolution and the gully erosion processes of Loess Plateau is of great significance for exploring the evolutionary mechanism of loess geomorphology and supporting the works of soil conversation on the Loess Plateau.

Massive documents and historical events record precious information about the gully development in history. Only if we retrospect the history of gully erosion and geomorphic evolution, can we understand how to control gully erosion and protect ecosystem of loess plateau in future. According to textual research from Delin Jiang, already in Han dynasty, Shu Zhang had pointed that large sediment concentration and deposition on riverbed is the main reason of dike breach of Yellow River[3]. In rule of Emperor Wudi of Han Dynasty, the executive ever encouraged reclamation on Loess Plateau and launched seven immigrations to Northwest of China. Large-scale reclamation and immigration certainly destructed the natural environment of CLP[4]. Because of frequent overflow of Yellow River, the Kaifeng city where located at lower reach of Yellow River was even repeatedly buried by sediment from Yellow River during many dynasties of China and formed the phenomenon of "city over city"[5]. Furthermore, there are many cases about extinction and relocation of towns due to gullies aggression. For instance, the townsite of Luochuan County relocated twice respectively at the 6th year of Kaihuang Period of Sui Dynasty (586 A.D.) and the 33rd year of Qianlong Period of Qing Dynasty (1768 A.D.)[6]. Another example is Wucheng Remains (Neolithic Age to Han Dynasty) which is also the study area of this research. Nowadays, the ancient townsite of Wucheng City located at the around of an outlet of a loess gully. Presumably, the reason of abandonment of Wucheng City in history is gully development had undermined the foundation of Wucheng townsite.

Consequently, all kinds of human remains (like ancient walls, graves, etc.) in Loess Plateau can provide us abundant geographical and historical clues and tell us how loess geomorphology evolves under continuous erosion. Utilizing historical information, not only can we simulate the future terrain of Loess Plateau, but restore the past. So the objective of this research is: integrating theories of historical geography, GIS and other disciplines, collecting multi-source data and materials of Wucheng area, based on the methods of digital terrain analysis, applying the models for simulation of geomorphic evolution, and restoring the topographies and gully patterns in history of Loess Plateau.

The objective of this research is to simulate the historical processes of geomorphic erosive evolution within a small watershed of Loess Plateau, to restore the topographic surfaces of different historical periods and to acquire a series of DEMs (Digital Elevation Model) that depict the loess topographies of different historical times.

II. METHODS

A. Study area

Through the field investigation in Shanxi and Shaanxi Provinces, discovered Wucheng Remains (吴城遗址) and its small basin is a desirable research area. (Fig.1)

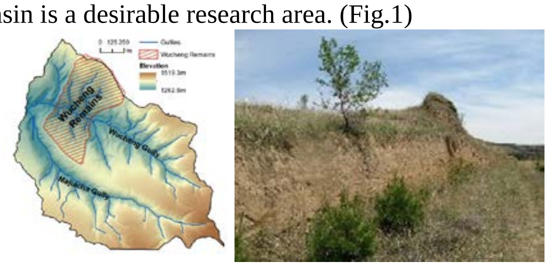

Figure 1. Study area

B. Data preparation

The core experiment of this research is time-inversed simulation of loess terrain based on 5m DEM. As basic data of the model, DEM provides elevation and terrain information for simulation. The 5m DEM data in this research were purchased from *Shanxi Administration of Surveying, mapping and Geoinformation*, produced by DLG(Digital Line Graphic). 5m DEM's projection is Gauss-Kruger projection (GK projection) with Xi'an-80 geodetic coordinates systems. SRTM DEM data are acquired from USGS. The usage of STRM DEM in this research is generation of stream network data in WGS-84 ellipsoid. The stream network data will be used for establish the transform relationships between Xi'an-80 GK projection and WGS-84 coordinate system so that convert data in WGS-84 to Xi'an-80 GK projection. Ariel imageries are from Google Earth software or capture by DJI P3 quadcopter. Ariel imageries are mainly used for visual interpretation of Wucheng Remains, observation of the landscapes of Wucheng Gully, confirmation of the extent of ancient Wucheng Town as well as sketch of relics' distribution. Topographic map is 1:10,000 national basic topographic map which server as the auxiliary data of 5m DEM. GPS measured sample points are used for interpolating the ancient town ground foundation surface for calibration of simulation.he boundary of Loess Plateau by 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, photos and so on. The 1: 100000 geomorphological map of China and 1: 10000 standard map subdivision grids are also used as important auxiliary data for this study.

The demanded data of this experiment are listed in Tab 1:

TABLE I. EXPERIMENTAL DATA

Data	Source	Coordinates
5m DEM	Shanxi Administration of Surveying, mapping and Geoinformation	Xi'an80 GK 3° 111E
SRTM DEM	USGS	WGS84
Ariel imagery	Google Earth	WGS84
Drone imagery	DJI Phantom 3	WGS84
Topographic map	Shanxi Administration of Surveying, mapping and Geoinformation	Beijing54 GK 3° 111E
GPS Samples	Field Surveying	WGS 84

C. Simulation method

CA(Cellular Automata) is used as the framework of this model. Based on theories of hydrology and loess erosion, LS factor is selected for establishing rules of CA. This model accepts a DEM raster as the input that represents the current topography of research area. Throughout model running, the time-inversed simulation of historical geomorphic evolution will be realized whereby a sequence of DEMs will be generated as the model output. Each DEM in sequence represents topography at a certain historical time.

Cellular Automata is a spatio-temporal dynamic simulation system that is discrete in spatial dimension, temporal dimension as well as states domain(WOLFRAM 1984). It is composed by cells regularly tessellated in Euclidean space. Every cell has its pertinent state at a certain time. As time goes on, every cell interacts each other and simultaneously evolve in a new state.

Standard CA consists of four elements: Cells, States, Neighbors and Rules. It is necessary to define these four elements in order to realize the geomorphic evolution model based on CA.

The rules and algorithm are as the flowchart of Fig 2.

Step 1: Initialize input parameters that include initial DEM raster, initial iteration, maximum iteration, resolution, cutoff threshold, high point value and soil particle height;

Step 2: Then calculate LS raster according to algorithms mentioned before;

Step 3: Normalize the LS raster for unifying the numeric magnitude; then calculate backfill matrix by roulette method integrating stochastic factor and probabilistic normalized LS factor;

Step 4: According to backfill matrix, backfill soil particles on current DEM whereby refresh and obtain the next DEM;

Step 5: Step into next iteration. If the current iteration do not yet reach the maximum iteration, use the current DEM to repeat Step 1-5 again. Otherwise, stop procedure.

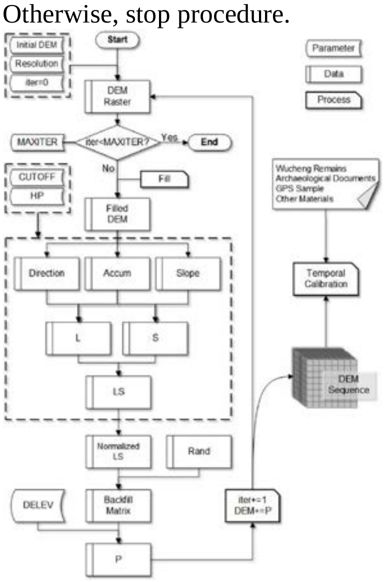

Figure 2. Flowchart of model

Finally, the CA model and its DEM results should be calibrated so that the numbers of iteration can correspond to real historical times. Only in this way, the DEM sequence results can possess real historical meanings. The content about temporal calibration will be introduced in next chapter.

III. RESULTS & DISCUSSION

All kinds of documents about Wucheng Remains must be fully used for seeking the relationships between DEM sequence and ancient topography of Wucheng area. After the field investigation of Wucheng, the calibration method based on foundation surface of Wucheng Remains was raised. Fig 4 is flowchart of this method.

The foundation surface of Wucheng Remains is the ancient topographic surface on which ancient Wucheng city was ever built. Throughout erosion of more than 2000 years, the ancient topographic surface was definitely destructed by younger gullies and gradually missed its original landscapes. In order to reconstruct the foundation surface of ancient Wucheng city, it is necessary to locate points where survive from gully erosion and retain its original elevation. These points are named foundation surface samples. The walls of Wucheng city still persist up to now that can proves there must exist locations that foundation surface survives inside extent of Wucheng walls. So the walls provide significant reference for seeking relict of foundation surface. In order to seek foundation surface samples, some sample rules and conditions must be made. According to the geographic features of Wucheng area, the conditions of foundation surface are as follows: Beside the foot of walls; Locates at the places of relics; Places inside Wucheng city where are not destructed by gullies.

According to above conditions, we can locate the survived foundation surface samples, the sampling ways include: Sampling by GPS device during field trip; Detection by the archaeological distribution map; Holistic judgement where satisfy sample conditions by drone imageries.

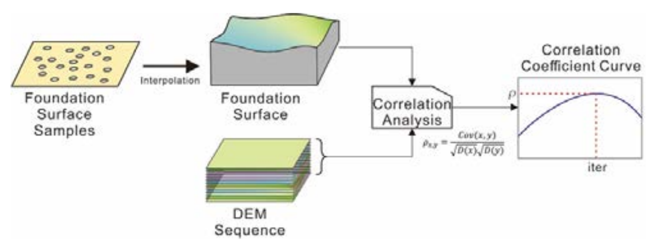

Figure 3. Flowchart of temporal calibration method

Fig 4 is the result of 1ka simulation. It is need to note that every DEM in Fig 4 was labeled by a concrete historical time that is determined by temporal calibration.

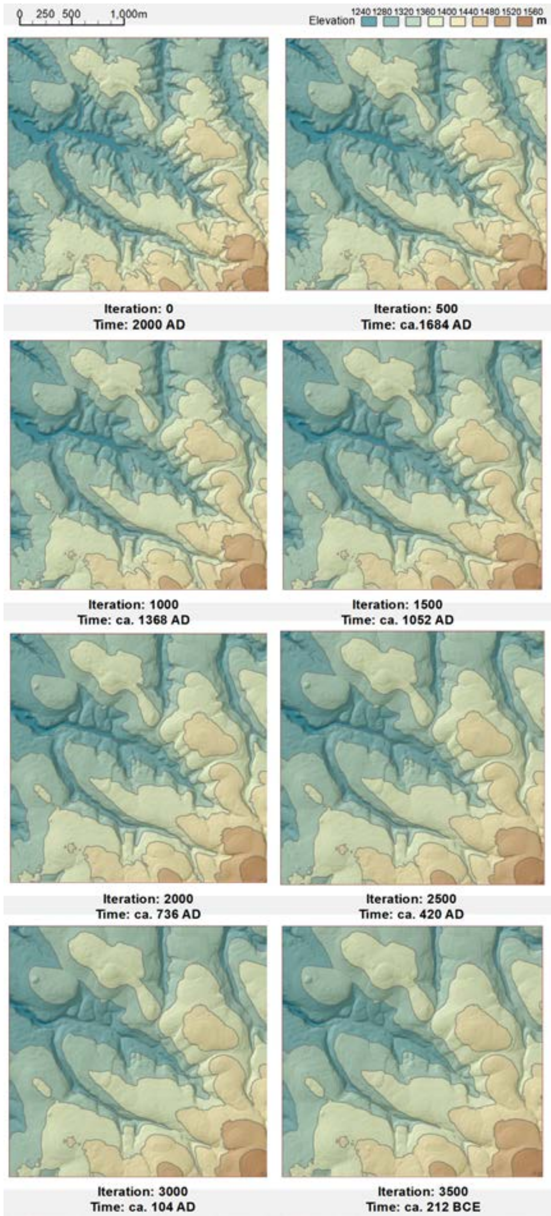

Figure 4. Simulation of 1ka timescale

In addition. This model did not consider other erosive factors (like vegetation, soil properties) expect terrain factor. Firstly, this is because the long-term historical geographic data of Loess Plateau are unavailable. Secondly, complexed erosion mechanism will magnify errors in long-term simulation. Thirdly, the topography play a dominant role in erosion processes of Loess Plateau. But anyway, the simplification of erosive mechanism will possibly lead to uncomprehensive simulation.

In conclusion, the future research should systematically explore the erosive mechanisms of Loess Plateau and make the model can be competent to more complicated situations. The several problems need be solved are: (1) how to set empirical parameters of LS factor for different research areas; (2) how to quantify the erosive factors of human activities, vegetation and soil properties. (3) how to improve the mechanism of soil particle and stochastic factor. (4) how to explore and excavate valuable information out of the DEM sequence.

REFERENCES

[1] LIU D. Loess and environment in China [M]. Beijing: Science Press.(in Chinese). 1985.

[2] FENLI Z, PEIQING X. Eorsive Sediment Yield and Gull Erosion Evolution of Loess Plateau [M]. Beijing: Science Press, 2010.

[3] DELIN J, LI X. Great Achievements Can Be Made by Mankind in Controlling the Soil Loss [J]. Soil and Waster Conservation in China, 1990, 01(04): 4-8+19+64.

[4] FEI W, RUI L, YONGSHENG X. Analysis on Eco-environment Construction in Human Period on Loess Plateau [J]. Research of Soil and Waster Conservation, 2001, 08(02): 138-42.

[5] YONGHONG L, ZHAOLIANG G. The Loess Plateau Area the Characteristics of Soil and Water Loss, Damages and Management [J]. Ecological Environment, 2011, 01(08): 148-53.

[6] Li, L.P., and Lu, H.Y., 2010. A Preliminarily Quantitative Estimation of the Sedimentation and Erosion Rates of Loess Deposits in Chinese Loess Plateau over the Past 250 ka. Acta Geographica Sinica, 65(1): 37-52.