TERRAIN MODELLING BASED ON ARCHAEOLOGICAL REMAINS IN THE LOESS PLATEAU OF CHINA

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ABSTRACT:

The geomorphology of loess plateaus continuously evolves with gully erosion. It is very hard to simulate geomorphic evolution in history, especially considering longer time spans, because of the lack of ancient geographic information. However, historical documents and archaeological sites are providing indispensable information about the past world. Using the remains of Wucheng in the Shanxi Province in China as the study area, we explored the possibility of combining UAV (unmanned aerial vehicle) photogrammetry and GNSS (global navigation satellite system) measurements for modelling current terrain as well as ancient terrain with the help of archaeological surveying. Finally, current and ancient topography were modelled and the soil erosion was assessed. We believe our work can provide a clear workflow for terrain modelling in archaeological sites and may offer new ideas for landform evolution studies.

1. INTRODUCTION

The Loess Plateau of China suffers from serious gully erosion (Liu, 1985; Wang et al., 2010). With the propulsion of gully erosion, the geomorphology of the Loess Plateau also continuously evolved. Studies on historical geomorphic evolution and gully erosion processes in Loess Plateau are of great significance for exploring the loess landform evolution and supporting the conservation of water and soil. However it is difficult to get terrain information in history as it disappeared. This leads the restoration of ancient landforms and further simulation on geomorphic evolution the difficult topics.

Traditional solutions to solve this problem are the use of ancient topographic maps or geochronology. Only for the last few decades, digital data in the form of satellite images (start of Landsat 1 in 1972 (Lauer et al., 1997)) or digital terrain models (term coined in 1958 (Miller and Laflamme, 1958)) is available. Geochronology use some evidence measured from rocks, fossils, and sediments to determine their age. This method depends on the sample quality, since the samples used for measurement are always influenced by the surrounding environment. For some landforms, for example the loess landform, it is very hard to find very good sediment samples since the soil can easily be eroded by water flow and there always happens a mixture of old and modern soil. Topographic maps are another powerful tool for terrain modelling. Contour maps from the history can be used. This is limited by the history of mapping and surveying, and thus the available data sources for ancient topographic map are usually very scarce. The possibility to model terrain by this method for the long time scale (e.g. 1000 years) is practically not given.

However, historical archives and archaeological sites provide indispensable information about the past world. This kind of information can come in many forms, such as the descriptions about the landscape, geography or topography of a certain area. They are always related to some important historical events such as wars or construction of outstanding buildings (see e.g. map in (Doneus and Kühtreiber, 2013)).

In many countries, there are usually lots of local history archives. By investigating them we can get a better understanding of the history of an area. In August 2016, we discovered ancient city remains during a field survey in the Loess Plateau. Named by its toponym this ancient city remain is called ‘Wucheng Remains’ and it is located in the Shanxi province of northern China. The Remain is an abandoned fortress from the early Han dynasty (202 B.C. – 220 A.D.). Through the field investigation, we found that for the whole fortress the entire city wall (Fig. 1) remained and has been cut into two halves by a gully now. This is because of the serious soil erosion. Given that the fortress cannot be built on the gully at that time, we can conclude that this gully through the Remain has developed after the abandonment. Therefore, this relationship between Wucheng Remains and the gully may help us to understand the historical geomorphic evolution of the Loess Plateau of China.

Inspired by this, we explored the possibility of terrain modelling from a combination of image matching photogrammetry and archaeological field survey. The objectives of this study were as follows: (1) to propose and evaluate a workflow for terrain modelling of the current site and the ancient city based on archaeological evidences; (2) to analysis the soil erosion in history.

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Figure 1. The ancient city wall of Wucheng Remains. Above is the remained city wall; below is an overview of the Remains from the bottom of the gully.

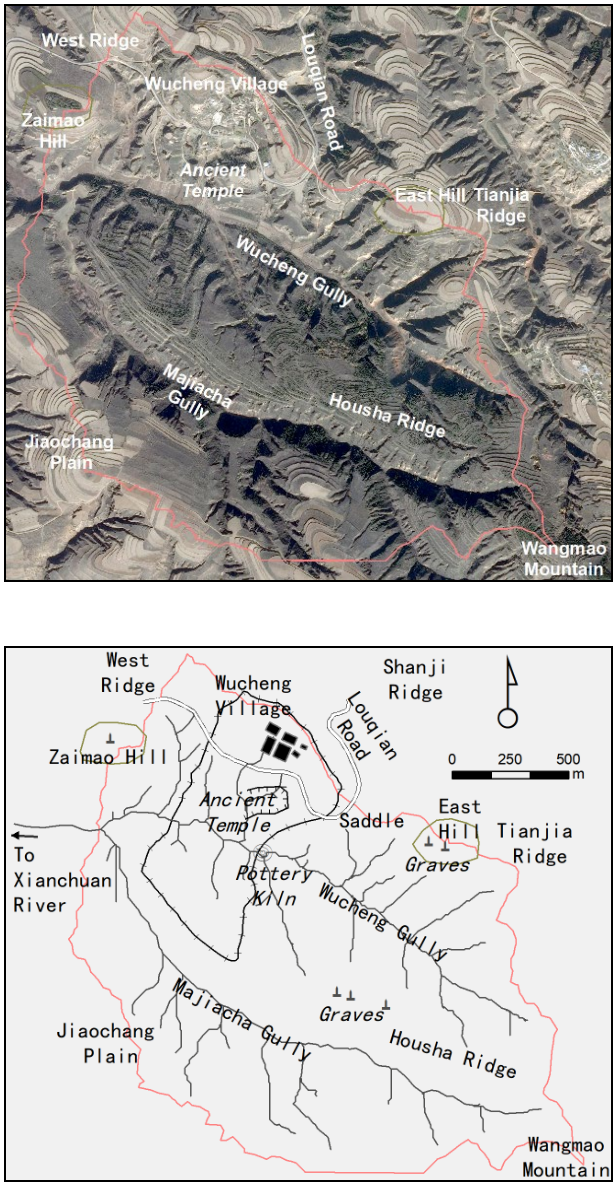

Figure 2. Archaeological Distribution (Wang, 2016). The scale is same. Above is the image and area (red line is the catchment boundary); below is the distribution of the Remains and gullies (black line in the upper-middle is the boundary of the Remains)

2. DATA AND METHODOLOGY

2.1 Study Area

Wucheng Remains administratively is located in Lougou Town, Pianguan County, Shanxi Province, China (39°16'49.2"N, 111°33' 49.3"E). The remains are believed to be the "tribe ruins" or fortress according to the archaeological survey. Ranging from 1262.6m to 1519.3m in elevation, the surrounding area shows the typical loess landform system of loess hills. A branch-like gully system is well developed in the area. The main gully about 2km in length goes through in the middle of the Remain. The extent of site is 1000m in north-south direction and 500m in east-west direction. Both, south and north part of this remain, are on two ridges now. An amount of yellow sandy pottery sherds and ashcans were discovered in both sides of Wucheng Gully (Wang, 2016).

2.2 Method

The basic idea of this study is to model the terrain with the help the archaeological evidences and other information from historic archives. Considering that the whole fortress should be built at a plain terrain, we can assume that the gully has developed after erection of the building. The foundation of the city wall can provide historical terrain information of that time. The current terrain can be modelled by UAV photogrammetry. By a comparison between current and ancient terrain, we obtain knowledge about the soil erosion and gully formation at the site of the Remain.

2.2.1 Current Terrain Modelling: The current terrain could be modelled by UAV image matching photogrammetry. The drone DJI M200+ was used to capture serial imageries by means of vertical photography. Then Pix4Dmapper software (Pix4D SA, 2020) was used for aerial triangulation and point densification. Finally, the vegetation points were removed semi-automatically from the image matching point cloud by using CloudCompare (CloudCompare Development Team, 2020) and OPALS (Pfeifer et al., 2014). Finally a grid digital elevation model (DEM) was generated.

2.2.2 Ancient Terrain Modelling: As for ancient terrain modelling, GNSS sampling and spatial interpolation were performed. The foundation surface of Wucheng Remain is the ancient topographic surface on which ancient Wucheng city was built. Throughout erosion of more than 2000 years, the ancient topographic surface was definitely destructed by young gullies and gradually developed from its original landscape. Therefore, the key to reconstruct the foundation surface of ancient Wucheng Remains is to locate those points which "survived" the gully erosions and retained its original elevation. The sampling measurement was performed by RTK-GPS devices. Since that the city walls of Wucheng Remains still persist up to now some terrain information must remain. So the walls provide significant reference for seeking the relicts of the foundation surface. The criteria used are as follows:

1) the sample should be underneath the foot of walls;
2) the locations of relics can be used as samples (Fig. 3);
3) locations which is inside the remains but in rid of soil erosion can also be used.

Figure 3. Relics used for elevation sampling. Archaeological dating shows these relics are from early Han dynasty (~4 A.D.)

After the sampling process, the ancient terrain can be generated by interpolation. As convenient and efficient method, spline interpolation (Franke, 1982), can be applied. It adapts to the situations that the sample data distribution is very inhomogeneous.

2.2.3 Soil Erosion Assessment: After the terrain modelling for both the current and ancient topography, the erosion can be assessed by comparison between two generated DEMs. From the comparison we can get an idea of the soil volume that was eroded during time.

Factor	Indicator
Climate	Rainfall Capacity, Rainfall Intensity etc.
Soil	Porosity, Erodibility, etc.
Vegetation	Vegetation Type，Vegetation Coverage, etc.
Human	Construction, Farmland, Conservation, Road, etc.
Terrain	Slope, Catchment Area, Landform, etc.

Table 1. Main influence factors on soil water erosion in the loess plateau of China conducted by Wang et al. (1996).

The erosion on Loess Plateau includes water erosion, wind erosion, freeze-thaw erosion and other types (Zhao et al., 2013). The water erosion caused by heavy precipitation and slope runoff is the most important type of loess erosion. Therefore in this study we only consider the effect of water erosion, which is influenced by following factors listed in Tab. 1.

For a better understanding on the soil erosion process, we preformed the Cellular Automata (CA) model to simulate it. The water erosion caused by precipitation and runoff is the most important type of loess erosion. So the CA model in this study will only consider the effect of water erosion. CA is a spatio-temporal dynamic simulation system that is discrete in the spatial dimensions, the temporal dimension as well as in the states domain (Wolfram, 1984).

The water erosion of loess is controlled by multiple factors such as the soil factor, the vegetation factor, the climate factor, the human factor and the terrain factor (Poesen et al., 2003). This is described in the empirical model for soil loss, the Universal Soil Loss Equation (USLE, (Wischmeier and Smith, 1978)) which predicts the soil loss in mass per area and year ($t/a\cdot km^2$). In this study, since the whole remain was abandoned and there is rarely human activity, and also because the soil layer and vegetation are almost the same everywhere because of the small extent of the study area, we excluded the soil, human activity, and vegetation factors in our model.

Based on loess erosion theories, the commonly used terrain attribute, the slope length-steepness (L·S) factor is used for establishing rules of the CA. The formulas of L·S in USLE (Willgoose et al. 1991) model is defined as follows:

$$S=65.4\sin^2\beta+4.56\sin\beta+0.0654$$

$$L=(\lambda/22.13)^m$$

$$m=\begin{cases}0.5 & \tan\beta>0.05\\ 0.4 & 0.03<\tan\beta\leqslant 0.05\\ 0.3 & 0.01<\tan\beta\leqslant 0.03\\ 0.2 & \tan\beta\leqslant 0.01\end{cases}$$

where S is the S factor, β is the slope in degree, λ is cumulative slope length (i.e. the length of the slope from peak/ridge to its foot), and m is a coefficient.

A standard CA consists of four elements: Cells, States, Neighbors and Rules. It is necessary to define these four elements in order to realize the model.

Cells. Considering the gird structure of DEM data, this model adopts square as cell shape; and the cell size was set equal to DEM resolution.

States. State is the attribute value of a cell at a certain time (Packard and Wolfram, 1985). States can be discrete scalars or continuous variables. Actually, the microscope process of land surface erosion is actually the detachment and movement of soil particles under flow water, so we introduced an implicit state named soil particle as the basic granularity of this model. In this model, the soil particle is defined as a cube whose basal plane is identical to DEM pixel and possesses a certain customized height. The height of soil particle decides the granularity and precision of simulation.

Neighbours. Standard CA has two main types of neighbour: Von Neumann neighbourhood and Moore neighbourhood (White and Engelen, 1997). Since in LS factor calculation we need the flow direction and accumulation result. These DEM based algorithm is under a 3×3 cell window, which is matched to Moore neighbourhood.

Rules. The key of CA modelling is to establish the transition rules of each cell. In this work, the changing of elevation is expressed by backfilling of soil particles. This soil particle backfilling process was driven by the LS factor result. The designed rules of our model are as follows: 1) initialize input parameters (initial DEM, iteration, cutoff threshold); 2) current LS calculation and probabilistic normalization; 3) DEM will be updated by the LS normalization result; 4) keep the iteration of step 2 and 3 until current DEM match the ancient terrain.

The CA model accepts a DEM raster as the input that represents the current topography of the research area. Throughout model running, the time-inversed simulation of historical geomorphic evolution will be realized whereby a sequence of DEMs is generated as the model output. Each DEM in sequence represents the topography at a certain historical time. The model will be ended when the simulated result matches the ancient terrain modelling result. By this approach we obtain the entire process of soil erosion in the study area.

3. RESULTS AND DISCUSSIONS

3.1 Terrain Modelling Results

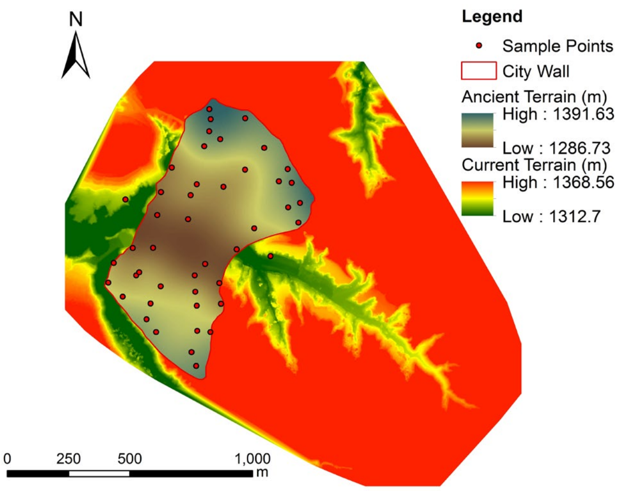

Figure 4. Terrain Model Results. The background is current terrain; above is ancient terrains and sample points used.

For current terrain modelling, 196 photos were captured by UAV flights in May 2017. The current topography of 1.4492 km^2 was finally modelled by UAV photogrammetry. To assert a high accuracy, 43 ground control points are used. By using Pix4D Mapping Software, 541273 points was used for bundle block adjustment and a 0.2m DEM was generated. To make the current and ancient terrain model comparable, the 0.2m DEM was then resampled into 1m resolution. The man reprojection error is 0.24 pixel. The GCP accuracy was 6.53cm in mean and 2.62cm in stand variation.

For ancient terrain modelling, 52 sample points were measured by GPS-RTK and then interpolated into a 1m DEM. The parameters used for interpolation are as follows: weight of spline function 0.1; the window dynamic and the number of points 12. This result can be presumed as the trend surface of ancient Wucheng Remain before abandonment.

3.2 Topographic Analysis

The city walls of Wucheng Remains were made of rammed earth and relatively strong because of the ridge-shape structure. Therefore, the walls survived from long-term severe soil erosion. We can even distinguish their distribution from UAV imageries clearly. It should be noted that the ancient Wucheng city was not build on an absolute plain area in history. The walls of Han Dynasty was built on the pale grey layer of Neolithic period that we can find as pale layer in the northwest corner of the wall even now (Fig. 5).

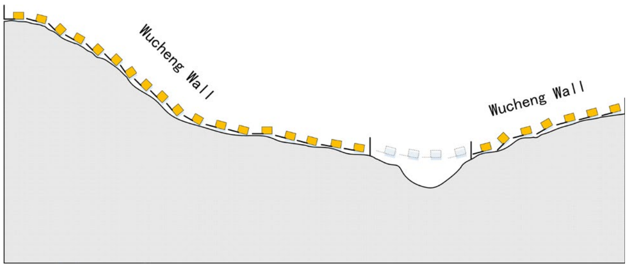

Figure 5. Profile of City Walls

Even though city walls are persisted, the middle part of city walls disappeared because this part locates at bottom of gully where suffers severe gully erosion. The current status of city walls indicates that the ancient topography before the built of Wucheng not entirely plain but a gully was developed after that.

3.3 Soil Erosion Assessment

Statistical analysis was conducted based on the generated DEMs to assess the soil erosion. The maximum elevation has decreased from 1541.1m to 1524.3m (i.e. approximately -17m over a period of 2200 years), the minimum elevation has decreased from 1278.8m to 1247.8m (approximately -14m). The change in the elevation difference between maximum and minimum increased from 262.3m during ~23 AC to 276.5m by now. The increase of elevation difference shows the effect of gully erosion.

Figure 6 shows the CA simulation result. After 3000 model iterations, the erosion process was simulated. All the DEM results showing are rendered by uniform color ramp. Through visual inspection, with time roll back, we can find out low-level shallow gullies gradually fade, the main gully and secondary gullies gradually become short, narrow and shallow, which is in accordance with the theoretical laws of loess geomorphic evolution.

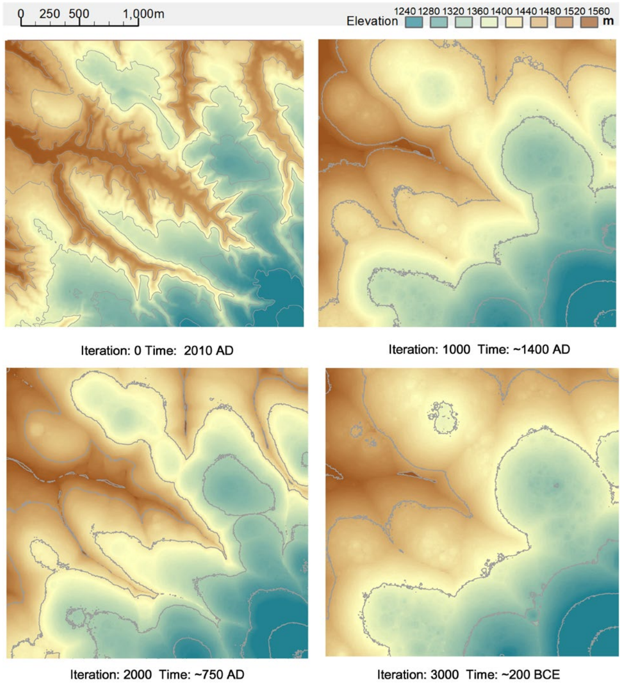

Figure 6. CA simulation result

4. CONCLUSIONS AND FUTURE WORKS

Terrain modelling for historical time is always a hard task due to the data limitation. Topographic map always help but are not available if we look for a very large time scale. Also the geochronology method is limited by the quality of samples. Archaeology or historic archives can be useful since they may also contain some terrain information.

In this study, based on the theories of loess geomorphology and loess erosion, we realized the terrain modelling of a historic site. An easy-achieved workflow was proposed and the soil erosion was assessed. UAV photogrammetry was applied to model the current terrain and the ancient terrain was modelled by GPS measurement and interpolation.

Located in the Loess plateau of China, the modelling work can help us to understand the soil erosion process. By using the CA model, a simulation on the geomorphic evolution in history of study area was achieved. The common used L·S factor in soil erosion was used for the CA model. While this model is relative preliminary since more erosive factors should be considered in the future work. In CA modelling, only terrain factor was considered, the consideration of our model in other important factors such as climate and vegetation need be further explored.

We believe our work may provide a new workflow for the archaeological and soil erosion study in the loess plateau of China.

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