Lowland Technology International 2017; 19 (2):111-116
International Association of Lowland Technology (IALT): ISSN 1344-9656

Research Paper

Methods for delineating the land leveling range in land consolidation and rehabilitation projects

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ARTICLE INFORMATION

Article history:

Received: 08 February, 2017
Received in revised form: 21 July, 2017
Accepted: 23 July, 2017
Publish on: 08 September, 2017

Keywords:

Land consolidation and Rehabilitation
Digital elevation model (DEM)
Neighborhood analysis
Singularity
Land leveling
Jianghan plain

ABSTRACT

Although elevation surveying has been widely used in land consolidation and Rehabilitation projects in China, the delineation of land leveling range still mainly depends on a person's subjective decision and therefore suffers from a lack of scientific criteria. Spatial analysis based on GIS is applied to provide a quantitative foundation for land leveling. Firstly, a grid map of DEM is obtained through spatial interpolation using elevation data; secondly, DEM data is disposed by two different methods based on sliding window arithmetic, i.e., neighborhood analysis method and local singularity analysis technique; at last, the range for land leveling is delineated by using these two methods respectively. This research shows that both methods can effectively identify the land leveling area with little differences and thus they could be used as quantitative tools for the planning and design of land levelling in land consolidation and Rehabilitation projects.

1. Introduction

As an important way to protect cultivated land, improve land productivity and carry out sustainable development strategies, Land consolidation and rehabilitation projects (LCRP) have been promoted by Chinese governments in the last 10 years. “Land consolidation and rehabilitation projects” is formally used to replace the former concept “land consolidation” in national land remediation planning (2011-2015). According to the new regulation, LCRP is to make a comprehensive improvement for inefficient use, unreasonable use and unused land, to perform a recovery of destroyed land caused by human buildings and natural disasters, and to improve the utilization of the land, including agricultural land consolidation, land reclamation and construction land remediation. Agricultural land consolidation is currently the focus of LCRP in China, and LCRP is taken as the most important way to adjust land-use structure in rural area (Long, 2014). The engineering measures of LCRP include land leveling, irrigation, farm roads and farmland shelterbelts. Since the first land consolidation regulation was made in China in 2003, the Chinese government has paid large sums of money to support the implementation of LCRP. Meanwhile, LCRP has attracted widespread attention in land management and related disciplines. Some scholars have paid attention to the application of new methods and technologies in their research, and published a series of papers and books. Since the development of Geographic Information System (GIS), Digital elevation models (DEM) has been used widely in land engineering and natural disaster evaluation. For example, Mustaffa et al. (2015) used DEM for flood risk assessment, Hoes et

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Note: Discussion on this paper is open until April 2018

al. (2014) used DEM to access the hydropower capacity potential, Hoes et al. (2012) established flood simulation models by using DEM. The terrain is also an important factor affecting land-use. DEM has become an important tool for land leveling and earthwork balanced deployment (Wang et al., 2010), since DEM can intimately describe the real terrain can offer powerful support for the design of land leveling and the layout of irrigation systems. At present, the main focuses on DEM in LCRP research include visualization and decision support (Li and Jing, 2010; Li et al., 2010; Zhang, 2010), earthwork calculations (Li and Jing, 2010), and irrigation system design (Yang et al., 2012; Zhu, 2011). Seldom is research focused on the delineation of the scope for land leveling and the evaluation of the flatness of the land. Zhu (2011) used DEM to obtain the maps of slope and aspect in the study area, determined the main direction of the irrigation, and then mapped the scope for land leveling according to the threshold of slope and the main irrigation direction. However, this is a kind of overall land leveling solution, requiring a lot of engineering and investment. Generally, partial leveling planning is more acceptable than an overall approach. When partial leveling planning is made, leveling works are implemented in those areas which are much higher or lower than the surrounding terrain. Land leveling is of great importance in LCRP. It usually takes up 20% to 30% of the total investment. Besides, it is the base for irrigation and other works. Contour and DEM are two popular ways for the delineation of the land leveling scope. Generally, contour can hardly reflect the local terrain changes because it is usually smoothed; the absolute value in DEM cannot accurately characterize the flatness of land either. In this research, two solutions, i.e., neighborhood analysis and local singularity analysis (LSA), based on GIS spatial analysis are used for the evaluation of the land flatness and determining land leveling range.

2. Experimental Data and Methods

2.1 *Neighborhood analysis*

Neighborhood analysis is a spatial analysis method based on neighborhood statistics. ArcGIS 10.2 offers a set of tools in Neighborhood under the directory of spatial analyst tools for the application of neighborhood analysis using both vector and raster data. Neighborhood analysis method is based on local window, which can be defined as certain shape, size and direction. In ArcGIS 10.2, one can define a local window as rectangular, circular, annulus, wedge, and even irregular shape with weights which can be user-defined. Generally, the rectangular window and circular window are used to keep things simple when raster data are used. The basic flow is as follows when the square window is chosen: (1) determine the window parameters and statistical parameter; (2) move the window from top to bottom and from left to right, calculate the statistical parameter in each local grid (pixel) within the determined window. It should be kept in mind that the length of side should be defined as an odd number if the pixel unit is used, to keep the local point at the center of the window. **Figure 1** shows how to perform a 3 × 3 local window in a 5 × 5 pixel raster.

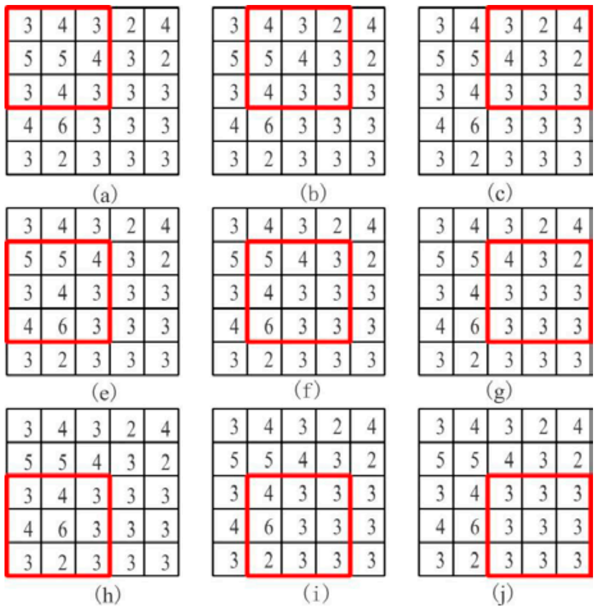


Fig. 1. Sliding window algorithm for Neighborhood Analysis.

Generally, the mean value in a local window reflects average local elevation, and the absolute value of the difference between the original elevation of the local point and the mean elevation of the local window can reflect the land flatness, see equation (1).

$$P_{ij}(\varepsilon) = Abs(X_{ij} - \overline{X}_{ij}(\varepsilon)) \quad [1]$$

where ε is the window size, i and j represent the row and column numbers of the current location center, X_{ij} and $\overline{X}_{ij}(\varepsilon)$ represent the elevation of current location and the mean value of current local window respectively, and Abs() indicates the absolute value. This arithmetic can be used to obtain a map which reflects the flatness of land in a certain scale that is controlled through the size of the window.

2.2 *Local singularity analysis*

Local singularity analysis (LSA) technique is developed from fractal / multi-fractal theories. Fractal was initially used to characterize the self-similar properties of the same geometric objects at different scales, i.e., the amplified parts are like the whole to some degree (Mandelbrot, 1975). Later fractal / multi-fractal were used to describe natural events with singularities in statistics, such as earthquake, cloud, mountain torrent, hurricane, landslide and wildfire, because there is a power-law relationship between the frequency and size of the studied objects (Sornette, 2004). Beyond this, Cheng (1994) brought spatial location information to bear on the power-law relationship and developed the concentration-area model, which can be used for the separation of anomalies from the ambient field. Later, Cheng (1999) successively proposed local singularity analysis (LSA) theory and the local singularity interpolation method.

Optimum window size is usually defined experimentally; small local window captures more detained information but may include random noise, whereas big local window results in relatively smooth maps with less information. The singularity index is obtained by the following power-law model.

$$\rho(\varepsilon) = c\varepsilon^{2-\alpha} \quad [2]$$

where c is a constant, ε represents window size, ρ represents an average local density within local window of size ε, and α is the local singularity index (LSI) that can be estimated by least squares as the slope of a straight line fitted to the relation between ln (ρ) and ln (ε), see **Fig. 2.**

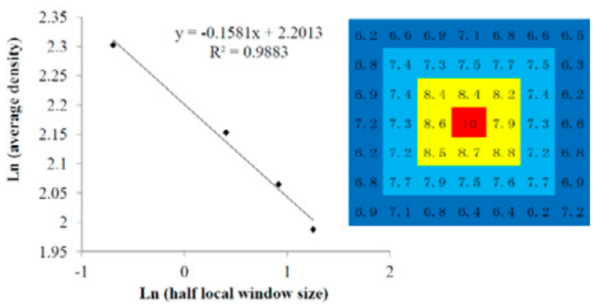
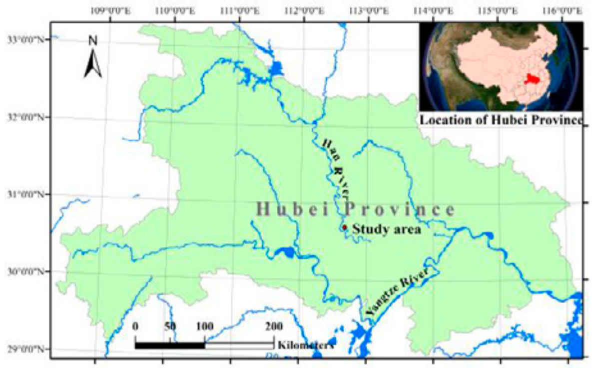


Fig. 2. Calculation of local singularity index.

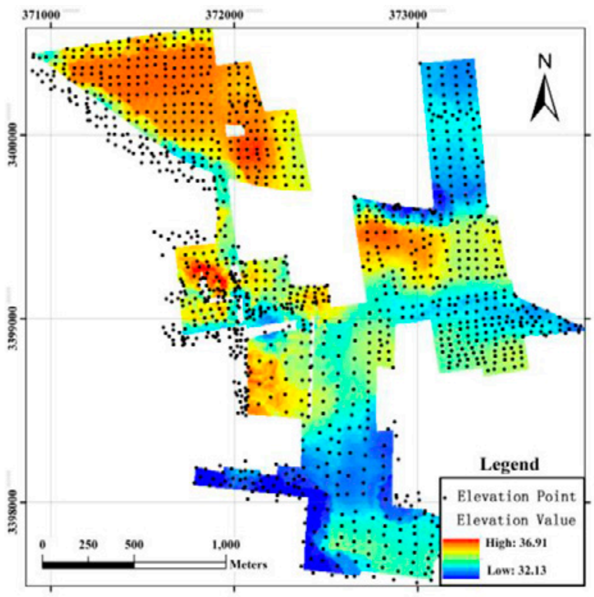
Broadly speaking, LSA is also a neighborhood method, and its implementation process is similar to **Fig. 1**. If ρ represents elevation, LSI (α) has the following properties: (1) when α is close to 2, it means that the terrain is flat or changes smoothly; (2) α > 2 means that elevation decreases with the narrowing of window size, indicating a positive local terrain and the current elevation is higher than the surround average elevation, and (3) α < 2 indicates a local negative terrain. Therefore, LSI can be used to evaluate the flatness of the land and map the range for land leveling.

2.3 Study Area

The study area is located in south-central of Hubei province, which belongs to the hinterland of the Yangzi-Han River Plain (see **Fig. 2(a)**), with an average elevation of 34.55 meters. The highest point in the study area is 36.91 meters above sea level, and the lowest point is 32.13 meters, with the maximum height difference of 4.78 meters. The overall terrain shows a northwest to southeast trend, as can be seen from **Fig. 2 (b)**.



(a)



(b)

Fig. 3. Location (a) and DEM (b) of the study area.

2.4 Data preprocessing

The 1: 2000 elevation data is obtained through real-time kinematic (RTK) GPS measurement. The data have been corrected by the reference points in and around the study area before transformed into Xi'an 80 rectangular coordinate system from WGS 84 geographic coordinate system. The DEM is made according to following steps.

(1) Elimination of altimetric points with outlier values. The points which have elevation values much higher or lower than surround points should be eliminated, because they may be obtained either by mistake or from special linear objects such as ditches, dams and roads. These altimetric points often show special distribution in space, thus it is easy to distinguish them through an integrating matching method offered in ArcGIS 10.2.

(2) Determine the scope of the study area. The predetermined area for LCRP should be the main part of the study area, but some non-constructed areas and reclamation areas should be excluded. The non-constructed area contains inhabited area, industry area and some other area; and the reclamation area includes abandoned inhabited area and unused land. The final study area is shown in **Fig. 3 (a)**.

(3) Determine the resolution of the DEM and build the mask for the study area. It is of great importance to select a suitable resolution for the raster data, and it should be related to the scale of the elevation survey and the required accuracy. Here the pixel is determined as 5 meters × 5 meters, and then the mask of the study area shown in **Fig. 3 (a)** is obtained.

(4) Build up the DEM for the study area. Based on the mask of the study area and the optimal resolution for the DEM obtained in step (3), the DEM of the study area is set up through ordinary kriging interpolation method. **Figure 3 (b)** is the original DEM of the study area.

3 Results and Discussion

3.1 Case study based on neighborhood statistical analysis method

Statistical parameters should be determined firstly when the neighborhood statistical analysis method is used to extract information for spatial variables. As to elevation variable, the absolute value of the difference between the elevation value of the current point and the average elevation value of the local window, which centers on the current point, reflects the extent that the current point elevation deviates from the local terrain trend. Thus Equation (1) can be used to evaluate the degree of field flatness. As is mentioned above, it is important to determine the size of local window. According to the regulation of field design in LCRP, the width of a regular cropland is about 150 meters to 300 meters. To reflect the ground rolling on that scale, the size of local window is designed as 195 meters × 195 meters. Considering the DEM resolution is 5 meters × 5 meters, the local window determined above can also be expressed as 31 pixels × 31 pixels. Steps are as following:

Firstly, the map of average elevation based on the determined local window is calculated by using the neighborhood tool in ArcGIS 10.2.

Secondly, the map of land flatness is obtained through Raster Calculator tool based on Equation (1), and the results can be seen in **Fig.4 (a)**.

Then the scope for land leveling can be delineated based on an appropriate threshold, which can be obtained by the limitation of investment, the flatness requirement of certain land use approaches, or some other methods. In this study, the top 15% of uneven land in the study area is delineated as the target area for land leveling according to the land flatness obtained in **Fig.4 (a)**, and **Fig.4 (b)** shows the 3D rendering map of the result.

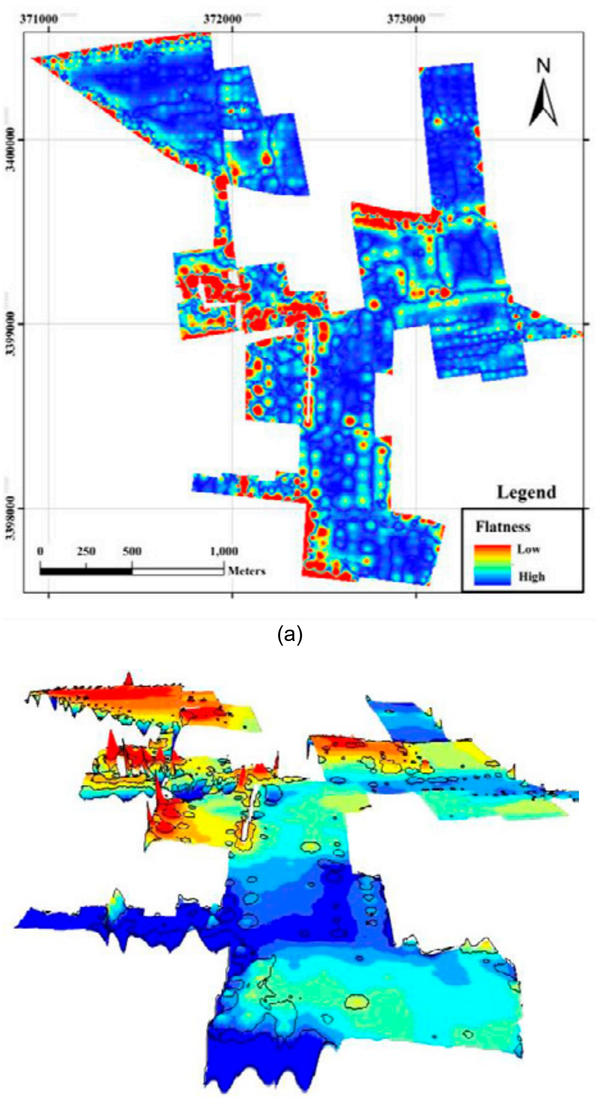


Fig. 4. Results of the farmland leveling range obtained through neighborhood statistical analysis method, which are displayed in 2D (a) and 3D (b) perspectives respectively.

3.2 Case study based on local singularity analysis technique

The formation of the land surface morphology satisfies the assumptions of classic multi-fractal cascade model processes, and multi-fractal methods have been applied for the characterization and information extraction of terrain using DEM (Sun et al., 2011). The LSA technique is derived from fractal / multi-fractal theories, so it can be used to characterize the flatness of the farmland. Similar to other neighborhood statistical analysis methods, the determination of the shape and the size for the local window is also needed when LSA is applied. In order to make a comparison between LSA method and neighborhood statistical analysis method, the same window shape and size as determined in the last section are chosen. According to Equation (2), the LSI close to 0 indicates flat terrain; when LSI deviates from 2, the bigger the absolute value shows, the rougher is the land. Therefore the absolute value of the results from Equation (2) can be used to indicate the flatness of the farmland. The results can be seen in **Fig. 5**, and the top 15% area is delineated as the target area for land leveling.

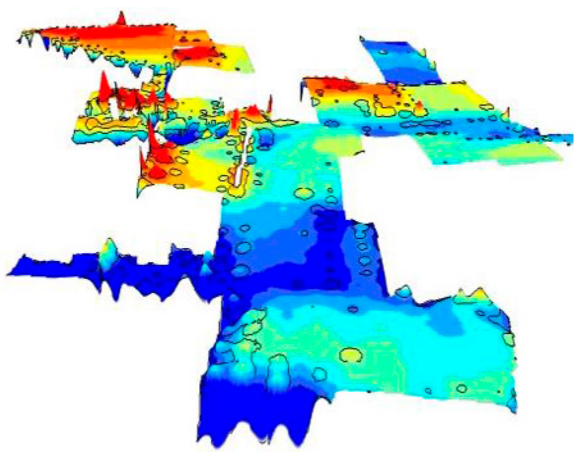


Fig. 5. Results of the farmland leveling range obtained through local singularity analysis method, which are displayed in 3D perspective.

3.3 Comparison and Discussion

As is shown in **Figs. 4 (b)** and **5**, there are few differences in delineating the range for land leveling between the above two methods, and both of them effectively map the range for land leveling, which fitted the original DEM well because all the targets were located in the dramatically raised or depressed area. In principle, LSA technique is derived from fractal / multi-fractal theories, and the result is the index for the local singularity, which is the fractal dimension of the topography and has clear statistical and physical meaning. From the perspective of assessment of uncertainty, LSA shows an advantage that the goodness of fit (R^2) and the t statistics which reflect the statistical uncertainty can be obtained at the same time when the slope of ln (ρ) and ln (ε) is calculated in rectangular coordinates. As to the neighborhood statistical analysis method, there is no uncertainty parameter offered in ArcGIS 10.2, although it obtained almost the same result as LSA.

In order to further analyze the composition of the delineated area for land leveling obtained by using LSA technique, the target area is superimposed on the layer of the land-use map of the study area (**Fig. 6**). The statistical results between these two layers are shown in **Table 1**. It can be seen that 56.38% of the total vegetable area is chosen for leveling, which is far higher than that of any other land-use types. It reflects that the flatness of vegetable land is the lowest among all land-use types in the study area. It does make sense because vegetable land is often sporadically located around the inhabited area, which makes it easy to become the place for putting soil or borrowing soil when building houses; besides, the factor of flatness is not so important to vegetable land, which may also lead to a low flatness of vegetable land. According to Table 1, the proportions for leveling in woodlands and dry land area are very close; in fact, these woodlands were changed from dry land several years ago. The flatness of paddy is the highest among all land-use types in the study area, which also matches with the actual situation, because paddy land has a high requirement of flatness.

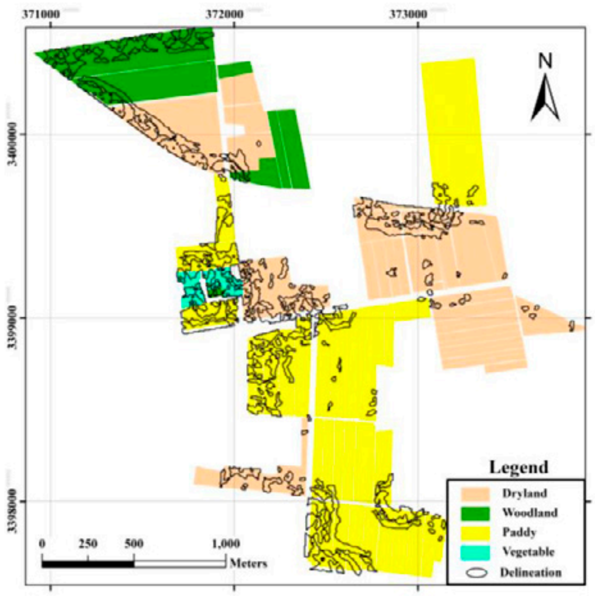


Fig. 6. The spatial relationship between land leveling range and land type distribution in the study area

Table 1. the areas of all land types in the study area.

Land-use type		The Proportion of Leveling Area
Vegetable	%	56.38
Dry land	%	17.13
Woodland	%	17.41
Paddy	%	16.54

4 Conclusion

Land leveling is an important part in LCRP. In the past, the delineation of the range for land leveling was usually made through a qualitative or semi-quantitative way based on DEM or contour map, and people's subjective judgments and experiences play a crucial role. In this study, two quantitative methods, i.e., neighborhood statistical analysis method and LSA technique are applied after establishing the DEM of the study areas. The case study shows that these two methods delineate similar ranges for land leveling, while the LSA technique has its advantage in physical meanings and statistical uncertainties; the case study also shows the effectiveness of LSA technique in mapping land levelling range, and the results match with the actual situation well. The authors hope that this research would promote more quantitative methods and ideas that can benefit the delineation of range for land leveling in LCRP.

Acknowledgements

This research has benefited from joint financial support of the Programs of China Postdoctoral Science Foundation (Nos. 2016M592840 & 2017T100773), National Natural Science Foundation of China (Nos. 41602336 and 71503200), Shaanxi provincial natural science Foundation (No. 2017JQ7010), and the Fundamental Research from Northwest A&F University in 2017 (No. 2017RWYB08).

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