Monitoring of Benggang erosion based on UAV photogrammetry technology

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Abstract. The benggang is seriously harmful for its tremendous amount of erosion. At present, the traditional methods in monitoring benggang gully are limited to some extent. The UAV photogrammetry technology combined with GIS spatial analysis was adopted to study the benggang in Bailu Village, Gan County, Jiangxi Province, South China. We measured some parameters and comparing the data of benggang at different times. ArcGIS was used to analyse the spatial and temporal distribution characteristics of benggang erosion. The results show that UAV photogrammetry technology has the advantages of high accuracy, high-speed and no damage to the surface ground, it can calculate the point cloud, reconstruct the benggang landform in three dimensions, and generate surface model DEM, which can provides an alternative for the study of benggang erosion monitoring.

1. Introduction
Soil erosion has become a global problem. There are about 10 km² of land lost due to soil erosion every year [1]. Benggang erosion is the main manifestation of gully erosion in red soil region of southern China [2]. The Benggang was first named by Zeng Zhaoxuan, a famous geomorphologist in China, in 1960 [3], then the English name benggang was published by Chinese geomorphologist Xu Jingxin in the international Journal Catena [4]. The benggang are mainly developed in the humid monsoon climate areas of the tropical and subtropical zones in southern and southeastern China. According to the general survey data of seven provinces (regions) in southern China in 2009, the number of benggang is about 239.1 million [5]. The erosion of benggang is large and explosive. The annual sediment yield of single benggang can reach more than 500-1000 cubic meters [6]. Benggang will destroy the integrity of ground surface, reduce soil fertility, and limit the sustainable development of local regional. Therefore it is particularly important to monitor and study the benggang.

The traditional monitoring methods of benggang are mainly by checkpoint station and erosion needle, which have the shortcomings of long observation period, high intensity of observation labor, and limited by financial and human resources. Liu et al. used three-dimensional laser scanner to study the collapse of Liantanggang hill in Wuhua County, Guangdong Province, and realized the analysis of the spatial and temporal variation of the erosion amount of the benggang during 2011-2013 [7]. However, the scanning area of the three-dimensional laser scanner is small, and it is easy to be occluded by terrain, resulting in information black holes, which have less effect on the acquisition effect of the top and side of the benggang [8]. Du et al. used the CORS-RTK dynamic measurement combined with GIS spatial analysis to study the collapsing gully in Chengfeng
Village in eastern Hubei Province [9]. But CORS-GTK technology will destroy the surface of benggang, which has a great impact on the accuracy of density, and a steep slope on safety [10]. Remote sensing can be used to monitor regional collapse, but the resolution for monitoring single benggang is not enough [11]. UAV low-altitude remote sensing has the characteristics of high accuracy, real-time and comprehensiveness. Relevant scholars have applied UAV remote sensing to the study of Micro geomorphological changes monitoring, and results showed photogrammetry can achieve centimeter-level accuracy and resolution [12, 13].

In this study, a benggang in Bailu Village, Gan County, Jiangxi Province, South China, was taken as the research object. The UAV was used to carry out field investigation, obtain multi-temporal aerial photographic data of Benggang, and GIS was used for two-dimensional and three-dimensional analysis, exploring a new method for monitoring benggang erosion.

2. Material and Methods

2.1 Study Area
Gan County lies in the south of Jiangxi Province China, it contains an extensive area of benggang [14]. Its located at subtropics monsoon area result in average annual precipitation of 1438 mm, annual average temperature of 19.3°C and annual average sunshine 1092 h. The terrain is hilly and lower mountainous, elevations from 82 to 1185 m. Red soils developed from granite are widely distributed.

A strip-shaped benggang which is widely distributed in the region and still in active period is selected as the research object (26°11′11.5″N, 115°10′40″E). Its drainage basin area is 1637 m², its length is approximately 60 m form south to north, its width is 20 m form west to east, its height is 6.5 m, and its altitude was 190 - 201 m. The slope angles of the colluviums range from 5° to 90°. It has six colluvium slopes were labeled A, B, C, D, E and F (Figure 1c).

![Figure 1. (a) Location of study area. (b) One colluvium slope. (c) Landforms of Bailu benggang](image-url)
2.2 UAV image and photogrammetric processing

The construction of DEM based on UAV imagery consisted of a set of operation, ranging from physical imagery acquisition, positioning of ground control points (GCPs) and photogrammetric processing, where a point cloud is generated from which the DEM is derived.

In our study, the UAV imagery was acquired by a multirotor DJI Phantom 4 Pro Imaging platform with a digital camera equipped with a 20 mm prime lens. The digital camera was equipped with a 35 x 20 mm CMOS sensor of micro 4/3 standard with a resolution of 4096 x 2160 pixels (16 Mpix). The flights were entirely automated with an image heading overlap of 70% and side overlap of 80%. Two aerial surveys were taken on April 3, 2018 and March 14, 2019.

Trimble R4 GNSS Differential GPS was used for georeferencing of the imagery. Seven well-distributed ground control points were collected. Photogrammetric processing of the UAV imagery was performed in the Agisoft PhotoScan professional software suite employing the structure from motion bundle adjustment algorithm [15].

2.3 DEM differentiation analysis

Residual errors were calculated to assess the DEM quality. The total error corresponds to the global error of the measurements, obtained as the square root of the sum of the square of contributions measured on the x, y and z axes.

Using ArcMap raster calculator, the two DEM data were compared and subtracted to form a new DEM layer. Cell attributes reflect the elevation difference before and after surface erosion or accumulation. Positive value indicates that the latter elevation value was smaller than the former one, means erosion decreases, negative value indicates that the latter elevation value is larger than the former one, and means surface accumulation increases. The absolute value indicated the depth of erosion cutting or the thickness of accumulation rising. The surface runoff overflow model was used to extract the channel water system of the river basin, which can better reflect the relationship between erosion and the distribution of main and branch ditches by superimposing DEM layers.

2.4 Filed survey data

Ground survey was conducted at the same time of each UAV flight. A camera on the ground was used to taken close range photographs of areas where collapse may occur after rain for verification.

3. Results

3.1 Evaluation of the high resolution DEM

Table 1 shows the results of image processing acquired after two missions. It can be found in the chart that more than 72 images were captured each time, and the success rate of image calibration was 100%. The optimal ground resolution was 1.78 mm and 1.66 mm. The average resolution of the two DSMs was 1.72 mm. The number of characteristic point clouds and dense point clouds obtained from the two groups of data processing was not much different, and the results were relatively uniform. The results of the difference between different DODs proved that the number of control points was enough. The average number of control points of the two sets of data in the image can reach 47. The average re-projection error of the two data processing was about 0.185 pixels. The optimized camera pixel size in this experiment was 2.35 um, and the average re-projection error was about 0.00043 mm.

| parameter                 | 20180403 | 20190314 |
|---------------------------|----------|----------|
| Number of images          | 72       | 75       |
| Aligned images            | 72       | 75       |
| Flying altitude (m)       | 23.5     | 22.8     |
| Ground resolution (mm/pix)| 1.78     | 1.66     |
| Tie-points for the point cloud | 61872   | 67064    |
Markers 6 6
Markers projections 47 49
Re-projection error (pixel) 0.19 0.18

Table 2 shows seven ground control point errors after flight data processing for analysis of DEM accuracy. The mean value of the total root mean square error of seven ground control points was 12.7 mm. It can also be found that the root mean square error of Z coordinates is larger than that of X and Y coordinates, and its root mean square error was about twice that of Y coordinates. The average re-projection error of the two groups of ground control points was about 0.3 pixel, which showed that the adjustment effect was very good.

Table 2. Evaluation of the accuracy of each image block

| Flight | RMSE (mm) | Mean re-projection error (in pixel) |
|--------|-----------|-------------------------------------|
|        | Total x | Total y | Total z |                     |
| 2018   | 12.9    | 11.7    | 8.8     | 16.2 | 0.323 |
| 2019   | 12.5    | 11.2    | 8.9     | 14.3 | 0.301 |

3.2 Analysis of erosion change of Benggang

The figure 2 shows the DEM elevation difference between 2018 and 2019 of Bailu benggang. The monitoring topography of the two periods changed greatly. After one year, the erosion of benggang was further aggravated, most areas have been eroded. The highest was 2.5 m and the lowest was -6.5 m. The height zone from the top to the top of the collapse hill with altitude 200 m vertical direction was the distribution area of the collapse wall, mainly by gravity erosion. The erosion was mainly manifested by slope erosion and gully erosion. All the six colluvium slopes collapsed, of which D collapsed the most. The collapse wall on the east side of D colluvium slopes and piled up on the collapse body. Erosion also occurred on various landslides, mainly in the form of slope erosion. Some slopes had eroded accumulation due to the collapse of the landslides, such as B and D, some slopes had no collapse accumulation due to runoff, and the slopes have eroded, such as A and C. In the catchment area, the erosion ditches were dendritic distribution, and in the upstream of the ditches, the rapid down cutting and side erosion of the ditches are dominant, which made the ditches deepen and widen continuously. In the middle reaches of the channel at the junction of D and E, there was an hourglass mouth. The runoff converges and the channel was cut down rapidly and the depth of the erosion gully is the greatest in this hourglass mouth. Up to the lower reaches of the erosion gully, the terrain was open, the sediment was accumulated and there was no erosion gully. Alluvial fan was formed, and the elevation difference was positive.

In the whole benggang basin, erosion modes were various, and erosion process was changeable. Gravity and hydraulic erosion overlap alternately in time and space, which was the main surface process of gravity-hydraulic composite erosion of avalanche.
4. Discussion
The acquisition of on-site data to quantify sediment movement of single benggang is among the current major challenges of the soil conservation community. This technique might be of great interest regarding study at the single benggang monitor where other methods are too destructive, expensive or time consuming. This acquisition illustrates the temporal resolution that drones can achieve, as well as their capacity to reflect natural phenomenon [16].

Gan County, where the benggang is located, is located in the south part of the Yangtze River. The annual rainy season usually begins at the end of March or the beginning of April. Data from the meteorological and hydrological station in Gan County shows that the rainfall from April 2018 to March 2019 is 1700 mm. The benggang soil mass often occurs after a series of physical processes such as moisture absorption, weight gain and softening of land under heavy rain, and the expansion of benggang is accelerated after heavy rain, which has been confirmed by relevant research [17]. There was a heavy rainfall in the study area on March 5, 2019, which precipitation was 72.8 mm. Through field investigation, several collapses were particularly evident in the study area. If accurate monitoring data and long enough monitoring period can be obtained, the amount of benggang erosion and the total amount of rainstorm during rainy season can be predicted according to the total amount of rainstorm in rainy season by establishing regression equation through statistical analysis.

Comparing the results of the two monitoring, the topographic change of the benggang is obvious during the monitoring period. Benggang erosion is gravity-hydraulic combined erosion. The maximum elevation of the benggang is at the top of the catchment area, and the catchment area will not change significantly under the influence of no man-made destruction. Under the action of hydraulic and gravity, the collapse wall retreats, and traceable erosion occurs at the watershed of the upstream catchment area. The collapse of the wall produces a large number of collapses scattered in the body of the benggang, part of which collapses along with the water flow, part of which accumulates in the body of the benggang to form a collapse heap. Subsequently, under the influence of rainfall and runoff, the collapse heap and erosion gully are re-eroded and accumulated, resulting in the height change of the collapse body. As a result of repeated wetting and drying cycles, soil cracks develop rapidly, which promotes the further development of landslides.
Figure 3. (a) Fresh scars at the headwalls of benggang hill. (b) Collapses on the D collapsing hill and erosional gully. (c) Main channel of benggang and erosional gully

5. Conclusions

In this paper, a typical benggang in Bailu Village, Gan County, Jiangxi Province, South China was taken as the research object. The aerial photographic data were acquired on April 2018 and March 2019. The high-density point cloud data and high-precision DEM data are produced by processing the aerial photographic image of UAV with three-dimensional modeling software Photoscan.

Obtaining a very high resolution DEM is essential in order to achieve a reliable, precise and accurate restitution of elevation and its derivatives. Photogrammetry can be of great use in water and soil conservation. As computer capacities are increasing and photogrammetric software are continuously improving, this technique opens a way towards an improvement in the acquisition of field data.

The distribution map of collapse deposits was obtained by ArcGIS raster calculation, which more clearly expressed the accumulation and erosion of the collapse body, and the results achieved the desired research purposes.

Unmanned aerial vehicle tele photogrammetry technology can be used to obtain multi-temporal and high-precision data of benggang erosion characteristics without causing damage to benggang, which can provide reference for monitoring of benggang erosion.

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References

[1] Luffman, I.E., Nandi, A., Spiegel, T. (2015) Gully morphology, hillslope erosion, and precipitation characteristics in the Appalachian Valley and Ridge province, south-eastern USA. J. Catena., 133:221-232.
[2] Ji, X., Huang, Y.H., Lin, J.S., et al. (2019) Sensitivity assessment method of collapsed gully occurrence in granite region of South China based on niche-fitness. J. Journal of China Agricultural University., 22(10):159-168.
[3] Zeng, Z.X., Huang, S.M. (1980) China Physiography (Geomorphology). China Science Publishing, Beijing.
[4] Xu, J.X. (1996) Benggang erosion: the influencing factors. CATENA., 27(3-4), 0-263.
[5] Feng, M.H., Liao, C.Y., Li, S.X., et al. (2009) Investigation on status of hill collapsing and soil erosion in southern China. J. Yangtze River., 40(8):66-68, 75.

[6] Zhou, H.Y., Li, H.X. (2017) The study on soil disintegration characteristics and its influence factors of collapsing wall in the collapsing hill erosion region of Southern China. J. Journal of Soil and Water Conservation., 31(1):74-79.

[7] Liu, X.L., Zhang, D.I. (2015) Temporal-spatial analyses of collapsed gully erosion based on three-dimensional laser scanning. J. Transactions of the Chinese Society of Agricultural Engineering., 31(4):204-211.

[8] Liu, X.L., Zhang, D.I. (2015) Study on Erosion Process of Collapsing Hill and Gully by Three-dimensional Monitoring: An Example of Liantanggang in Wuhua County of Guangdong Province. J. Journal of Soil and Water Conservation., 29(1):26-31.

[9] Du, Y., Li, S.X., Ding, S.W., et al. (2015) Study of CORS-RTK combined with GIS in Collapsing gully monitoring of southeast of Hubei Province. J. Yangtze River., 46(12):87-90.

[10] Lin, X.R. (2018) Study on soil erosion of slope run off plot based on slope Photogrammetry. Fujian Agriculture and Forestry University, Fuzhou china.

[11] Cai, Z.J. (2016) Study on the Collapsing Hills and Gullies of Survey and Evaluation based on RS/GIS. Guangxi Teachers Education University, Guilin china.

[12] Eltner, A., Baumgart, P., Mass, H., et al. (2015) Multi-temporal UAV data for automatic measurement of rill and interrill erosion on loess soil. J. Earth Surface Processes&Landforms., 40(6):741-755.

[13] Cook, K.L. (2017) An evaluation of the effectiveness of low-cost UAVs and structure from motion for geomorphic change detection. J. Geomorphology., 278:195-208.

[14] Song, Y.J. (2015) Analysis of the Geo-morphological Features of Collapsing Hill Development in Gan County of Jiangxi Province. J. Subtropical Soil and Water Conservation., 27(3):29-35.

[15] Liao, K.T., Song, Y.J., Zhang, J.S., et al. (2017) UAV remote sensing technology in the application of the orchard construction of soil and water conservation. J. Science of Soil and Water Conservation., 15(5):135-141.

[16] Koh, L.P., Wich, S.A. (2012) Dawn of drone ecology: low-cost autonomous aerial vehicles for conservation. J. Trop.Conserv., 5:121-132.

[17] Lin, J.N., Huang, Y.H., Zhang, D.B., et al. (2013) Influence of soil moisture content on shear characteristics of Benggang. J. Journal of Soil and Water Conservation., 27(3):55-58.