GULLY EXTRACTION AND MAPPING IN KAJOO-GARGAROO WATERSHED – COMPARATIVE EVALUATION OF DEM-BASED AND IMAGE-BASED MACHINE LEARNING ALGORITHM

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KEY WORDS: Gully erosion, UAV photogrammetry, DTM, orthophoto, machine learning, manual digitizing, and image classification.

ABSTRACT:

Monitoring and mapping eroded lands by gully erosion is an essential step to control gully networks. Advances in remote sensing and aerial photography have enabled users to capture data with variant temporal and spatial resolution that is needed in different fields. In addition, introducing different types of unmanned aerial vehicles (UAV) enabled to carry imaging payload. The orthophoto and digital elevation model (DTM) produced from aerial images taken by Aeria-X camera mounted on Sensefly eBee-X drone was employed to identify and map eroded areas by gully in Kajoo-Gargaroo watershed in Chabahar, south-eastern part of Iran. Digitizing gully boarders manually is a tiring and time-consuming process for the operators. Maximum likelihood algorithm as one of the machine learning algorithm was also used to classify orthophoto in order to extract gully borders in the study area. In this study a new algorithm based on analysing geometric features and clustering of the DTM was used to map gullies automatically. The results of the proposed method and machine learning algorithm were compared with the manually digitized gully map. Quantitative evaluation demonstrates that our proposed method reaches better overall accuracy compared to machine learning algorithm with the increase of 7.2 percent in overall accuracy.

1. INTRODUCTION

Like other natural resources, soil needs to be carefully maintained. As one of the most important parts of the ecosystem production cycle, soil is considered as a resource that provides the ideal conditions for producing foods and appropriate habitat for growing population. It also helps to preserve the biodiversity in natural environments (Brevik et al. 2015; Nikolaidis and Ragnarsdottir, 2015). The erosion can impact soils particularly agricultural lands by decreasing their fertility (Dai et al. 2015; Seutloali and Beckedahl, 2015). In traditionally plowed farms, the mean and median erosion rates are considered as 3.94 and 1.54mm respectively. Unfortunately, the soil production rates are one or two orders lower than these mentioned rates (Montgomery, 2012; Prosdocimi et al. 2016).
Gully erosion is one of the most remarkable land degradation processes in different parts of the world (Monsieurs et al. 2015) because (1) as a significant sediment source in different environments, (2) connect and transfer runoff and sediment from upstream to downstream rapidly, (3) accelerate drainage interflow and water tables and reduce soil moisture (4) destructs infra- structure, roads and residential areas (Hayas et al. 2017). The remained sediment of eroded gullies through water erosion causes soil loss of 10-94 % (Poesen et al. 2003).
Monitoring gully erosion is done by different approaches including using historical evidence such as aerial photos, satellite images, unmanned aerial vehicles (UAV) (Chen et al. 2019), and field surveying. Time series of gully maps shows the extent and direction of gully erosion in a watershed. As historical evidence such as aerial photos and images are less time and budget consuming, hence most recent studies focused on this type of study.
The process of gully mapping is known as such helpful procedure to analyze and monitor the eroded soils. The extracted gully maps can be used to assess the development of erosion in the future (Chen et al. 2019). While plenty of methods have been used to assess eroded features by gullies, drones have been extremely used due to their possibility in monitoring gully erosion in recent years. Although using the unmanned aerial vehicles (UAV) has accelerated the accuracy

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of studies by taking very high resolution aerial photos, but there is still some deficiencies in monitoring studies (Peter et al. 2014; Stoecker et al. 2015; Wang et al. 2016).
To extract and map gullies from aerial photos and satellite imagery, a variety of methodologies and approaches are utilized, including manual digitizing, machine learning based methods, and heuristic algorithms (Noto et al. 2017). Visual interpretation of aerial photos has been used to produce gully maps before enormous advances in image processing methods and the introduction of scientific approaches to gully extraction such as object-based image analysis, image classification, and deep learning (d'Oleire-Oltmanns et al. 2014).
While the simplest method for mapping gullies from optical sources such as orthophoto and satellite images is the manual digitizing, it also suffers from high similarity of river banks and bare soil with the gully area. The need for strong focus is tiring operators. In addition, it is really time consuming. So using machine learning methods to automate the process could lead to map gullies quickly and precisely.
Although there might be some challenges in gully extraction procedure using manual digitizing method (McInnes et al. 2011; Zhang et al. 2015,) the resulted dataset can be used as useful dataset to evaluate semi-automated and automated extracted gullies. While, it is clear the appropriate results would be accessible if all exterior boundaries of gully features are accurately digitalized. (Korzeniowska et al. 2018; Yang et al 2017).
By introducing new technologies like drones, plenty of automatic gully extraction methods based on aerial photos were proposed. These mentioned methods were being developed based on pixel-based and object-based algorithms (Seutloali et al. 2016; Vrieling et al. 2007; Knight et al. 2007). Also, other products like Digital terrain models can be used to identify and extract gully boundaries. Image gradation detection and terrain visibility analysis are known as methods that have been developed based on using DTM to extract gully boundaries.
This study was aid to monitor gully erosion in the south east part of Iran in Kajoo-Gargaroo watershed which is located in Sistan and Balouchestan province. To extract and mapping gullies in the study area, the photogrammetry techniques were used to collect images, produce DTM and orthophoto. The manual digitizing method was used to extract gullies from orthophoto. The resulted data from this method was used as reference map to evaluate the results of two different semi-automatic approaches. The procedure of this study is shown in the figure (1). The study area, methods, results and conclusion of this study will be presented in the following sections.

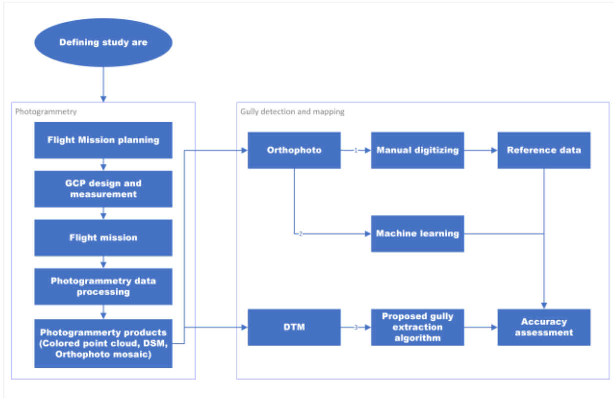

Figure 1. The workflow of this study

2. MATRIALS

2.1 Study area

Study area is the part of Kajoo-Gargaroo watershed which is located in Chahbahr county, Sistan and Balouchestan province, southeast of Iran. It lies between the latitudes of 25°31′17″–26°10′13″ N and the longitudes of 60°19′19″–61°21′34″ E). The selected area is around 21500 hectares. Figure (2) shows the study area map. The minimum and maximum elevation of this area are -10 and +20 meter. The average slope of the area is 2.6 percent. The average of annual precipitation is 103 mm. Maximum and minimum temperatures are 35°C and 21°C.
The gullies have grown in size across a sizable portion of the study area, in the recent years, which is close to 21000 hectares. These expanded gullies have caused plenty of issues and damages to land use and land cover of the study area. The huge amount of soil has eroded related to this natural phenomenon.

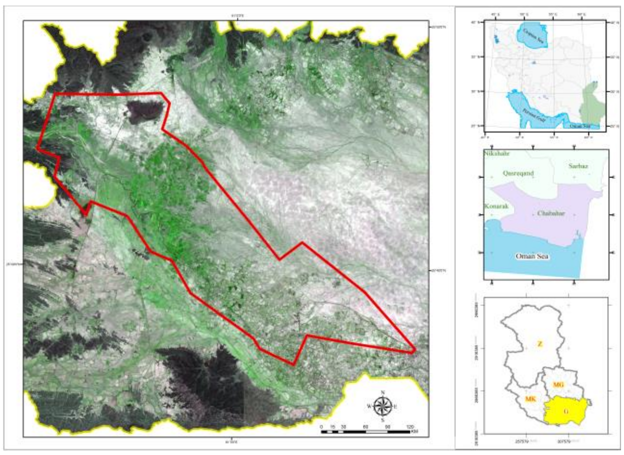

Figure 2. The location of the study area

Figure3. The gully erosion in the study area

2.2 Methods

2.2.1 Drone photogrammetry

For a wide range of research involving the landform, an accurate digital terrain model (DTM) is a crucial input. Land surveying, global navigation satellite system (GNSS) receivers, photogrammetry, and radar-grammetry are just a few of the equipment and techniques that can be used to gather 3D data to produce the DTM. One can choose the best approach based on the project's price, accuracy, speed, and other requirements and constraints.
Photogrammetry, a method for creating maps and 3D data using overlapped aerial pictures, was invented in the 1900s, developed during the First and Second World Wars, and gained popularity following the Second World War (Gosh, 1981). With the introduction of new data capturing and processing technology, photogrammetry continued to advance. In the 20th century, photogrammetry was revolutionized and made more accessible to consumers and applications because of satellite technology and unmanned aerial vehicles (UAVs) or drones. There are several uses for low-cost, non-metric camera-equipped drones, which are readily accessible on the market. Drones are used in a variety of fields, in addition to traditional surveying, mapping, photogrammetry, and cadastral mappings, such as agriculture, environmental monitoring, intelligence, surveillance, and reconnaissance, as well as engineering and cultural heritage (Colomina and Molnia, 2014).
By providing additional products like an orthophoto mosaic and colored point clouds as well as having the ability to operate in challenging conditions, photogrammetry expands the options for mapping (Saadatseresht et al. 2015). In contrast, to traditional photogrammetry projects, where the flight operating and processing teams often work individually, drone mapping projects require that the entire process be managed at once (Jiménez-Jiménez et al. 2021).
Choosing the best drone and its payload, which may include a camera system, GNSS receiver, IMU, or other additional sensors, as well as preparing the mission, enable the entire process to meet the project's requirements accurately. Multirotor, fixed wing, and hybrid systems are the different types of drones (Vergouw et al. 2016).
Technically, photogrammetry projects might use any sort of drone, with all of its advantages and disadvantages. The primary advantage of fixed-wing drones over multirotor is their lengthy flight times, which result in a larger coverage area during a single flight.

2.2.2 Operational mission

The photos in the present project were taken using a Sensefly eBee X fixed-wing drone and a Sensefly Aeria X camera. Since its founding in 2009, Sensefly has specialized in the design and manufacturing of fixed-wing drones. The following table contains the drone and camera's specifications. The photography for larger projects is sped up by the eBee X's lengthy flying time (approximately 60 minutes operational with an Aeria X camera based on our experience). Global shutter technology, which is a feature of the Aeria X camera, results in less motion blur at higher drone cruise speeds. Hence, higher quality of final products is the result of this combo.

Manufacturer	Sensefly
Type	eBee X
Maximum flight time	Up to 90 minutes
Maximum flight range	Standard: 37 km Endurance: 55 km
GCP	Not required (using PPK/RTK)
Hand launch	Yes
Landing	Automatic linear landing

Table 1. Sensefly eBee X fixed-wing drone specifications

Figure4. Sensefly eBee X fixed-wing drone

Sensor	APS-C
RGB lens	F/2.8-16 18.5mm (35mm equivalent: 28 mm)
RGB resolution	6000×4000
RGB shutter	Global Shutter 1/30 – 1/4000s
ISO range	100 - 6400
FOV	75°

Table 2. Sensefly Aeria X camera specifications

Figure5. SenseFly Aeria X camera

2.2.3 Gully extraction

Due to the numerous variables in gully size, shape, age, and region, several distinct techniques were utilized to create gully maps at the same time (Arabameri et al. 2020).

Based on training samples that are fed into the algorithm or automatically discovered, classification algorithms assist users in identifying homogenous regions.

The study area was separated into four main blocks, and within each major block, several smaller segments depending on the items were segregated to reduce the processing time for image processing. The maximum likelihood method was used to categories images after the investigation of supervised classification algorithms. Water, soil, vegetation cover, asphalt, and gullies were listed as the key classes. Pure components of each class served as the source of the training samples.

Although using image classification techniques are beneficial for mapping gully branches, but they cannot be utilized to automatically extract gully branches. Therefore, utilizing new approaches that are developed based on using UAV photos, multi-temporal images and DTM can be useful to map gullies. (Zhou and Chen, 2011; Marzolff and Poesen, 2009).

DTM as one of the significant spatial products can be used to determine topographic relief information and extract some morphological data related to of the study area. (Dai et al. 2015). It is clear that the higher resolution of the DTM, the more detailed data and accurate results of processing.

Clustering and segmenting DTM can be helpful to determine and extract gully boundaries based of differences between digital numbers of DTM pixels that are represents the elevation. (Dai et al. 2015). The natural breaks classification that was proposed by Jenks as a method to data clustering, was used to classify DTM results. In this method, the average deviation of each class should be minimized from the mean of the classes and maximum the deviation of each class from the mean of other groups. By reducing the variance within classes and maximizing the variance between them, the method is used to determine the best arrangement of values in different classes.

According to the mentioned method, there are some natural turning points and breaking points that are highly significant in natural sequences like between depth point of gullies and the edge of it that is located in the higher altitude. Following this statistically remarkable sections in natural data like DTM can be leaded in dividing some groups of data with similar properties. (Dai et al. 2015).

While the study area is located in the flat plain and there are no significant altitude changes, the gully branches that has situated in lower than the main surface, were accurately been identified and clustered on DTM using Jenks method. While, the depth of the gully branches is different and can be varied especially in some parts of the study area that are not affected by gully erosion seriously, the final clustering result must be checked and revised to increase the accuracy of clusters and extracted braches. Finally, the binary raster which is calculated with gully and non-gully values is produced. The final vectored map must be compared to reference one to evaluate the results accuracy.

3. RESULTS

3.1 Photogrammetry results

The eMotion software was used for photogrammetric mission planning in this project. 34 flight sorties and 5 days were required to complete the aerial photography for the project. With an average GSD of 6 cm, the aerial photos were collected with 80% forward and 60% side overlap. 184 ground control points (GCP) throughout the study area were measured using GNSS receivers and the RTK technique. Shamim continuously operating reference station (CORS) a network that offers the RTK corrections. Based on the IRG 2016 geoid model of Iran,

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the elevations of GCPs are corrected for geoid height (Saadat et al. 2016).

Using Agisoft Metashape software, photogrammetric processing was carried out to produce the colored point cloud, digital surface model (DSM), and an orthophoto mosaic. As the eBee X supports direct georeferencing (DGR) technology, it enables users to produce the products without using the GCPs. In addition, the GCPs are measured to ensure precision and control of the process. 160 points are chosen to complement the aerial triangulation computations, and 24 points are left out of the processing to serve as checkpoints for the evaluation of the findings. The results of aerial triangulation for the project area in DGR and using GCP scenarios are shown in table (3). The outcomes of the DGR study utilizing ground measurements show how this technology can be used in the real world.

		Scenario1 (DGR)	Scenario2 (AT with GCPs)
No. of GCPs		0	160
No. of check points		184	24
GCP error	X error (cm)	-	6.6
	Y error (cm)	-	7.1
	Z error (cm)	-	10.4
Check point error	X error (cm)	9.1	6.7
	Y error (cm)	10.4	7.4
	Z error (cm)	31.3	17.8

Table 3. The results of aerial triangulation for the project area in DGR and using GCP scenarios

When the GCPs were taken into account, the findings revealed an improvement of around 3 and 13 cm in the horizontal and vertical accuracy. The second scenario's results were used in the current project to manufacture the products, but the results showed that one may delete the GCP measurements or reduce the number of GCPs to the absolute minimum required to certify and assess the results, as well as dependent on the project needs.

3.2 Gully extraction results

Depending on changes of the gully morphology, some newly created gully branches with intricate shapes were precisely digitized. In areas with distinct boundaries, high correspondence between automatic extraction and manual digitizing may be seen clearly. Clear borders facilitate manual digitizing using shaded reliefs. (Shruthi et al. 2011). The map of very small gullies was produced by manually digitizing techniques since they are easily identified visually on the UAV orthophotos. These most accurate findings, which can be used as reference data to evaluate the accuracy of classified images. The results of manually digitized gullies are shown in figures (6) and (7). The Maximum likelihood that is known as one of the commonly adopted classification method for various applications was used to classify and label pixels of orthophoto. Gullies, especially those that are filled in water or covered with plant, are easily distinguished from the surrounding soil and may be recognized remarkably from the objects and materials in their immediate surroundings.

Figure 6. The result of manually digitized gullies as reference map

Results of a supervised classification in the research area are shown in the figure (7) and (8). The gully branches are different in their length, width, depth and cover. The result shows that if gully branches contain water bodies, the borders can be clearly identified, which aids in the automatic mapping of gully branches. It also seems straightforward to extract outline border of gully branches completely that are covered by dense vegetation cover. Comparing the classification map to the ground truth data is necessary to quantitatively evaluate classification accuracy. Hence, the error matrix was created to compare the classification findings to the actual data in order to evaluate the result accuracy (Lu and Weng, 2007; Rwanga(Brevik, Cerdà et al. 2015) and Ndambuki, 2017) should be added). The results of accuracy assessment of image classification are shown in the table (4). The overall accuracy of image classification was estimated to be 82.3 % and Kappa Coefficient of 0.76 show the reasonable accuracy of classified image.

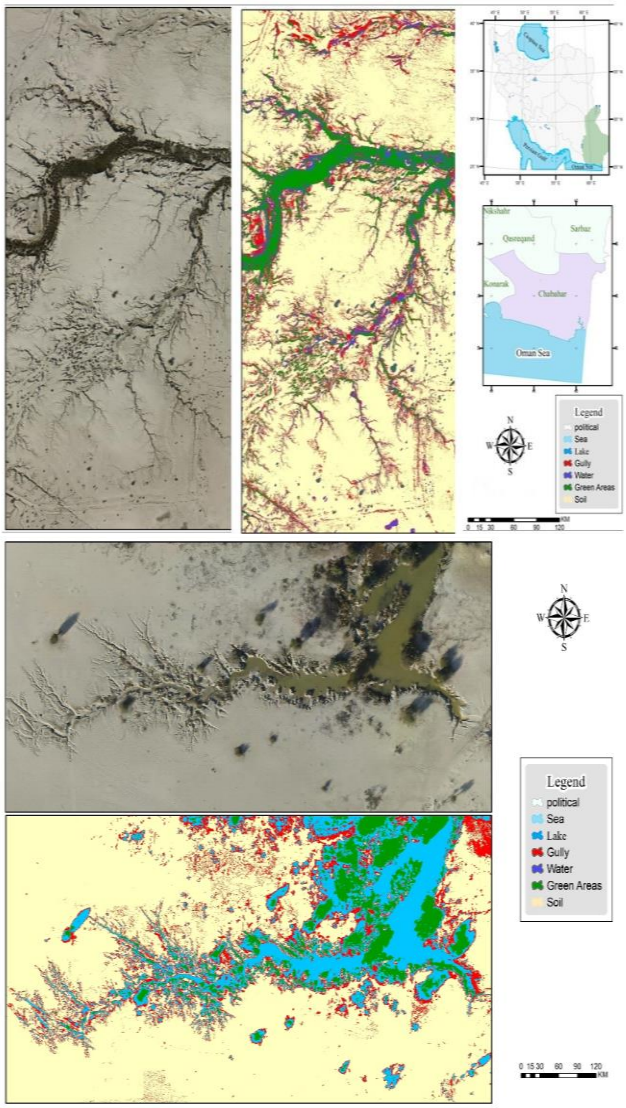

Figure 7. The result of classified gullies with machine-based learning

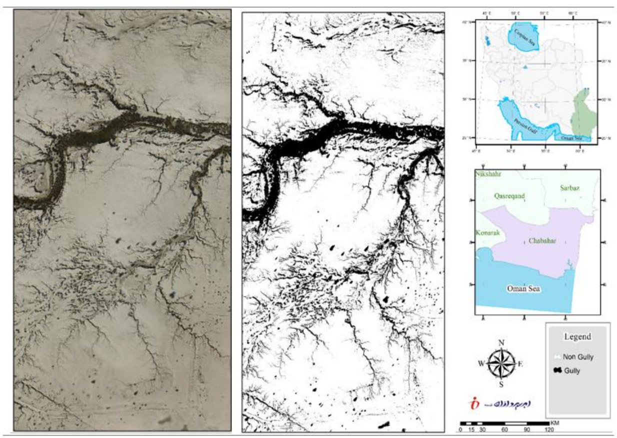

Figure 8. The binary result of classified gullies with machine-based learning method

Method	Class	Producer Accuracy (percent)	User Accuracy (percent %)
Machine Learning	Non- Gully	87.31	84.85
	Gully	68.61	93.70
	Overall Accuracy	82.3	
	Kappa Coefficient	0.76	

Table 4. The results of accuracy assessment of image classification

Using some heuristic algorithms can provide accurate results that are helpful to map gully erosion in large eroded regions. By using the Clustering and segmenting DTM, some pure gully branches that are not entirely covered by any vegetation and water, may be distinguished from their surrounding areas. Some results of DTM analysis and detecting uncovered gully branches from their surrounding are shown in the figure (9). It is obvious that compared to classified images, the procedure of gully extraction does not depend on land use and land cover seriously. There results also show that the connectivity between extracted gully branches is more reasonable that it reduces the editing and modifying final results.

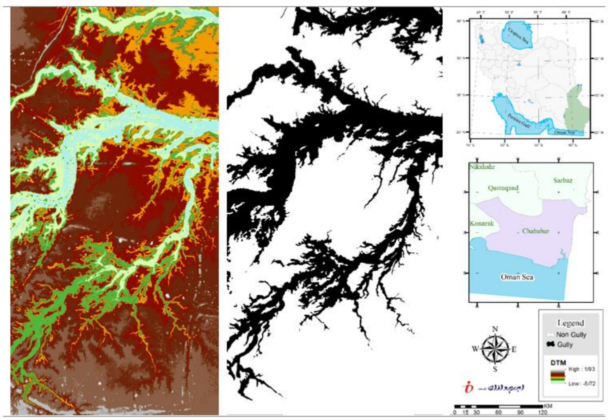

Figure 9. The binary result of extracted gullies with heuristic algorithms

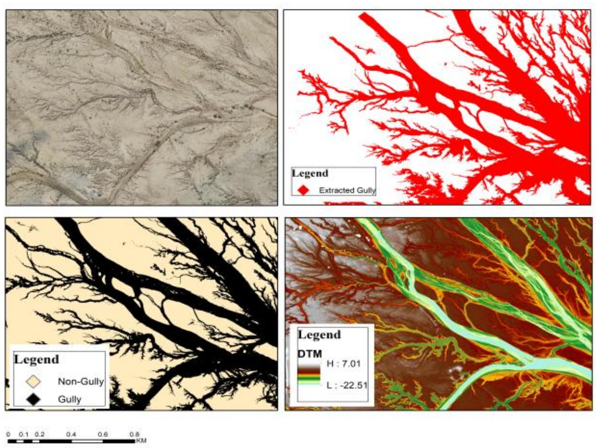

Figure 10. The binary result of extracted gullies with heuristic algorithms

The results of accuracy assessment of the above mentioned heuristic algorithm are shown in the table (5). The overall accuracy of image classification was estimated to be 89.5 % and Kappa Coefficient of 0.82 show the reasonable accuracy of classified image.

Method	Class	Producer Accuracy (percent)	User Accuracy (percent %)
DEM-based image extraction	Non- Gully	85.42	87.64
	Gully	80.45	94.56
	Overall Accuracy	89.5	
	Kappa Coefficient	0.82	

Table 5. The results of accuracy assessment of heuristic algorithms

4. CONCLUSION

This study used image processing tools, visual interpretation, manual digitizing, and heuristic algorithms to examine the viability of gully extraction methods from UAV photographs. The orthophoto image mosaic of the study area with spatial resolution of 5 cm were used to map and visual interpretation of gully phenomenon in the study area. Although manual digitization might produce a considerably higher degree of spatial accuracy in the gully extraction process and can be used as a reference data to assess the accuracy of study, it is clear that mapping the entire study area takes a lot of effort and time. In addition, visual interpretation by operators may result in some inaccuracies because gully branches and river tributaries have certain similar characteristics particularly in branches that are not as deep as main gully branches.

The results of using machine learning based methods shows that the more gully branches are covered by water and vegetation covers, the more they can be recognized and extracted from UAV photos precisely. In addition, the accuracy assessment of image processing was deemed to be at an acceptable level, and the image classification approach is advised for research of this nature. Although, image processing in the large study areas is considered as time-consuming procedure.

In spite of the acceptable levels of image processing accuracy, the results of image classification can be remarkably improved by using digital elevation models and other spatial products that are produced based on aerial photos. Using DTM particularly in areas with significant elevation variations can be quite useful to detecting and extracting gully branches. Using heuristic algorithms to recognizing and extracting gully boundaries showed that if high resolution DTMs are clustered precisely based on height differences between deepest point of each gully branch and its surface, it leads to map branches perfectly. While, using this method can improve the gully mapping procedure in terms of time and operating labors, but as all other spatial projects, the final binary results should be modified particularly in gully head cats that are not deep enough.

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