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Accuracy and precision of some methods in producing soil erosion maps

Ali Mohammadi Torkashvand and Behzad Kaviani*

Department of Horticultural Science, Rasht Branch, Islamic Azad University, Rasht, Iran

***Corresponding author: m.torkashvand54@yahoo.com**

Abstract

Soil conservation is one of the most strategies for sustainable production of crops. Erosion types mapping is one of the most important and basic methods in erosion and sediment yield studies to determine suitable soil conservation programs. In this study, some methodologies were compared in providing maps of erosion features, in research which took place in the Roodbar basin, Guilan province, Iran at a scale of 1:250,000. The accuracy and precision of three metods were evaluated in producing erosion map types including (A) Integration of land units, rocks erodibility, height and climate layers; (B) Integration of land use, land units, rocks erodibility, height and climate layers; and (C) A photomorphic unit map produced from processed satellite images. Since the large area of basinhas been covered by dense forest, therefore, the accuracy and precision of models were investigated in two methods; with considering forest land use, and without considering forest land use. The greatest accuracy is related to image processing in producing erosion types maps that the difference of accuracy between two models (with and without forest land use) in producing maps of surface, rill, gully and erosion features was 10.1%, 8.5%, 14.2% and 20.1%, respectively. Comparison of ground truth maps of erosion types and working unit maps indicated that the satellite image photomorphic units map provide the best method in producing erosion types maps. It is suggested that satellite images with higher resolution and integration of other layers, such as soil, be investigated to improve accuracy further.

Keywords: Erosion features, GIS, Roodbar basin, RS.

Introduction

Soil is an essential factor in crop production. Soil erosion is an important threat, thus, soil conservation is one of the most strategies for yield production. For conservation of soil, it is needed to provide an erosion map. Most erosion and sediment studies have been carried out to provide a quantitative erosion map (Singh et al., 1992; Martinez-Casanovas, 2003; Ygarden, 2003) rather than to prepare an erosion features map. Erosion types mapping is one of the most important and basic methods in erosion and sediment yield studies to determine suitable soil conservation programs (Mohammadi Torkashvand, 2008). The possibility of using aerial photographs for soil mapping has been recognised for a long time (Goosen, 1967). Commonly, the photographs were used to support conventional geomorphological methods (Stromquist, 1990), and also for direct identification of sheet, rill and gully erosion (Frazier et al., 1983; Stromquist et al., 1985). But, field survey and photo interpretation for erosion mapping at the national scale is time consuming and expensive (Raoofi et al., 2004). The extension of the use of modern spatial information technologies, such as geographical information systems (GIS), digital elevation modeling and remote sensing have created new possibilities for research into improved methods of erosion mapping (Martinez-Casasnovas, 2003) that are economical due to low costs as well as speed (Raoofi et al., 2004). Therefore, this study investigates some methodologies of preparing erosion types maps by integrating effective data layers from GIS, satellite images and data. A few studies have been done in producing erosion features maps, such as GLASOD (Global Assessment Soil Degradation) which divided erosion into four categories: water, wind, physical and chemical factors and prepared a world erosion map at a scale of 1:5,000,000 (Oldeman et al., 1988, 1991). Noble and Fletcher (1984) provided a New Zealand erosion features map at a scale of 1:250,000, with map units obtained from the integration of lithology, soil, slope, erosion, vegetation cover, climate and land use layers, and labelled by the field views. Sirvio et al. (2004) evaluated gully erosion hazard assessments in the Taita Hills, south-east Kenya by the use of geographic information system and airborne digital camera orthomosaics and GIS, and field measurements for large-scale studies, They investigated the distribution and intensity of gully erosion and the main factors affecting gully erosion and its changes during the last 50 years. Raoofi et al. (2004) attempted to recognize and map erosion in the Taleghan basin in Tehran Province by using image processing techniques. Erosion was categorized into rill, gully and no erosion regions by using images from the fusion of ETM^+ bands and Cosmos images. A ground truth map from eroded regions was produced from field observations. Measurements indicated an approximate 80% accuracy for the categorization. Qualitative erosion mapping approaches are adapted to regional characteristics and data availability. Resulting maps usually depict classes ranging from very low to very high erosion risk. There is no standard method for qualitative data integration, and consequently there are many different methods (Vrieling, 2006). Watershed Studies Office of Iran (2000) prepared a design for erosion types maps at the national level at a scale of 1:250,000. The maps integrate data layers of soil, slope, lithology, land type and land use to produce working units maps, but field investigations indicated that this approach is not feasible for the total area of Iran because of time and financial constraints. In Isfahan Province, as a pilot design, Rahnama (2003) investigated the possibility of preparation of a soil erosion features map by aerial photographic interpretation and obtained similar results. He recommended satellite imagery and GIS as a better approach. It seems that the distinct methodology for providing erosion maps with regards to statistical factors has not been done; therefore, the aim of this study is to develop a methodology based on data layers integration with GIS and satellite images processing to improve the accuracy, error and precision of erosion types mapping at the national scale (1:250,000).

Results

According to reasons which will be discussed, accuracy and precision of three methods were evaluated as following:
A) Integration of land units, rocks erodibility, height and climate layers;
B) Integration of land use, land units, rocks erodibility, height and climate layers,
C) Photomorphic unit map produced from processed satellite images.
Since the large area of basin has been covered by dense forest, therefore, the accuracy and precision of every method were investigated in two status: with considering forest land use; and without considering forest land use.

Methods accuracy and precision with considering forest land use

Tables 4 and 5 indicate the accuracy and Root Mean Squared Error (RMSE) of different methods in producing erosion types maps in basin. The greatest accuracy is related to image processing in producing erosion types maps. All methods have the least accuracy in providing an erosion features map, while the greatest accuracy is related to the preparation of a surface erosion map. The photomorphic units map had 90.3% conformity with ground truth map of surface erosion. Of course, the highest accuracy (92.4%) in preparation of gully erosion map is related to working units map C (Photomorphic unit map). In all erosion types maps and erosion features map, RMSE was the least at the photomorphic units map than the layers integration methods. The greatest error was observed in map A obtained at the preparation of gully erosion map and the greatest error of map B was related to erosion features mapping. Table 6 shows the coefficient of variation of different methods in preparing erosion types maps. Every method that has a small coefficient of variation, it has a higher precision. The trend in the coefficient of variation is same to accuracy for different methods.

Methods accuracy and precision without considering forest land use

Tables 4, 5 and 6 indicate the accuracy, error and precision of different methods of producing erosion types maps in basin without considering forest land use. The variation trend of accuracy and error without considering forest land use was same to previous method that forest land use had been considered, but there is a considerable difference between accuracy with and without considering forest land use. The accuracy decreased without considering forest land use. The greatest accuracy is related to image processing in producing erosion types maps that the difference of accuracy between two models (with and without forest land use) in producing maps of surface, rill, gully and erosion features was 10.1%, 8.5%, 14.2% and 20.1%, respectively. Without forest land use, the precision severely reduced that decreasing precision is very greater in the integration of data layers as compared with photomorphic units.

Discussion

Based on previous studies it has been distinguished to use land units layer instead of slope layer (Mohammadi Torkashvand and Nikkami, 2008; Mohammadi Torkashvand and Hghighat, 2009). The slope layer is an important data layer in integration with other data layers. In quantitative erosion maps, the slope layer is a basic layer (Singh et al., 1992; Feoli et al., 2002; Essa, 2004) and in qualitative erosion maps, such as landslide maps (Bayramin et al., 2003; Esmali and Ahmadi, 2003) and erosion risk maps (Khawlie et al., 2002). However, when the slope layer is used to produce erosion features maps, as it establishes a large number of units in a small area. Large numbers of working units increase the expense of map preparation. In maps at a scale of 1:250,000, representation of small working units is difficult and results in map confusion, and low quality (Mohammadi Torkashvand, 2008). In general, regarding the quality of results and economic and practical concerns, integration of land use, rocks erodibility, land units, height and climate as a method with other two methods including the integration of rocks erodibility, land units, height and climate layers; and photomorphic units models as working units maps applied for preparing of erosion features maps. Shrimali et al. (2001) also indicated that a simple index-based approach using three main causative factors, ie, slope, soil and land use/land cover, can give fairly good delineation of erosion-prone areas for prioritization. When the land units layer was integrated with four data layers, the accuracy and precision of method increased in producing erosion featuers map than another integrated layers method (integration of land units, rocks erodibility, height and climate layers), because this reduces the diversity of erosion intensity, consequently, it increases the accuracy and precision of maps. It seems that the units of erosion features map had a further conformity with the working units derived from integrating land units, land use, rocks erodibility, height and climate than another method of layers integration. The accuracy and precision of models decreased without forest land use due to increase in diversity of erosion intensity. Forest are homogenous lands with the view of erosion that usually do not show obvious erosion feature. The photomorphic units map and integration of land units and rocks erodibility layers had the most and the least accurate results with minimum and maximum accuracy in both methods (with and without forest land use), respectively. The use of photomorphic units derived from visual interpretation of satellite images with careful consideration of color, tone, texture, drainage patterns and other image characteristics, is suitable for studying surface features (Alavi Panah, 2004). This provides homogeneous data over large regions with a regular revisit capability, and can therefore greatly contribute to regional erosion assessment (King and Delpont, 1993; Siakeu and Oguchi, 2000). Investigations showed that photomorphic unit maps had good conformity compared with the ground truth maps of gully and surface erosions. Nejabat (2003) also provides indirect detection of surface erosion on ETM^+ satellite images in part of Fars Province, Iran. He calculated 68%

Table 1. The classification of soil surface erosion intensity.

Extent in field Intensity class	<5	5-25	25-50	50-75	>75
1	-	Low	Moderate	Severe	Severe
2	-	Low	Moderate	Severe	Very severe
3	Low	Moderate	Sever	Very severe	Very severe

Intensity classes 1-3 with regard to 1 or more of below characteristics: 1: Good plants cover than region potential, no detectable deposition or erosion
2: Moderate plants cover than region potential, deposited soil around plant with thickness less than 10 cm, crust with thickness less than 1 cm
3: Weak plants cover than region potential, deposited soil around plants with thickness higher than 10 cm or roots exposed to air, crust with thickness higher than 1 cm. No surface erosion: S_0, Low: S_1, Moderate: S_2, Severe: S_3, Very severe: S_4

Table 2. The classification of soil rill erosion intensity.

Area (%) of rill erosion in a working unit Rills distance (m)	5-25	25-50	50-75	>75
<3	Moderate	Severe	Very severe	Very severe
3-25	Low	Moderate	Severe	Very severe
25-100	Low	Low	Moderate	Severe
100-500	-	Low	Low	Moderate

No rill erosion: R_0, Low: R_1, Moderate: R_2, Severe: R_3, Very severe: R_4

Table 3. The classification of soil gully erosion intensity.

Gully Depth (cm)	Gullies distance (m) erosional activity	<25	25-50	50-150	150-500	>500
30-150	1*	Severe	Moderate	Low	-	-
	2**	Severe	Severe	Moderate	Low	-
	3***	Very severe	Severe	Moderate	Low	-
50-500	1	Severe	Severe	Moderate	Low	-
	2	Very severe	Severe	Moderate	Low	-
	3	Very severe	Very severe	Severe	Moderate	Low
>500	1	Very severe	Severe	Moderate	Low	-
	2	Very severe	Very severe	Severe	Moderate	Low
	3	Very severe	Very severe	Very severe	Severe	Moderate

*Sustainable gullies that erosional activity exist at the less than 10% of its length, **Gullies that have erosional activity at the 10-50% of its length
***More than 50% of gullies length exist erosional activity, No gully erosion: G_0, Low: G_1, Moderate: G_2, Severe: G_3, Very severe: G_4

accuracy when the ground truth map of surface erosion was compared with the photomorphic units map. In the Taleghan basin in Tehran Province, Iran, a gully erosion map (direct image obtained from the fusion of ETM^+ bands and Cosmos image) with a ground truth map indicated approximately 80% accuracy (Raoofi et al., 2004). Visual interpretation usually provided good results and, despite intensive development of numerical interpretation approaches, it is still popular. It is used mainly for erosion mapping of large areas in third-world countries (Tripathi and Rao, 2001; Sujatha et al., 2000). Raoofi et al. (2004) determined that gully erosion maps derived from visual interpretation of Cosmos images with ground truth mapping had 80% conformity. In conclusion, the investigations indicated that differentiating photomorphic units in satellite imagery makes more uniform units available for use as working units in erosion features studies in both methods i.e. with and without forest land use. On national scales, representation of small working units is difficult and results in map confusion, and low quality. Therefore, use of the slope layer to produce an erosion features map in four models established a high number of units within a small area. A large number of working units, unit replication and increasing numbers of field control points are the most important factors affecting map preparation costs. The model derived from the integration of rocks erodibility, land use and land units layers was better than other models. This model, as the second most precise method, is especially applicable in providing surface erosion maps with 84.2% accuracy with considering forest land use. It is suggested that satellite images with higher resolution and integration of other layers, such as soil, be investigated to improve accuracy further. This study was carried out in a basin with a variety of climates and land uses, and the results compared with previously published methods.

Materials and methods

Studing basin

The Roodbar sub-basin with 102898 ha between 49°15´ E and 49°51´ E, 36°43´ N and 37°02´ N was considered for the investigation of erosion features. It extends to south of Guilan Province, Iran, in central part of Alborz mountains. Land uses include poor and moderate rangeland, orchards, dense and sparse forest, agriculture land and urban regions. Basic land units (and components) in the major part of basin are 1.1.1, 1.1.4, 1.2, 1.2.1, 1.2.3, 1.7, 2.1.3 and 3.2.2. Within the basin, different lithic units include pyroclastic stones, tuffs, andesite, shale, conglomerate, gypsum and limestone. The climate, according to the De Martonne method is sub-humid and humid in the southern and northern regions, respectively.

The preparation of working units maps

Based on digital elevation model prepared from 1:50,000 topographic digital data, 25.6% and 46.5% of basin area have a height range in 500-750 m and 750-1000 m. Fig. 1 shows the height map of basin. Land use was derived using ETM^+ a satellite image and rocks erodibility layer based on Feiznia (1995). Figs. 2, 3 and 4 indicate climate, land use and rocks erodibility maps. According to their sensitivity to erosion, the

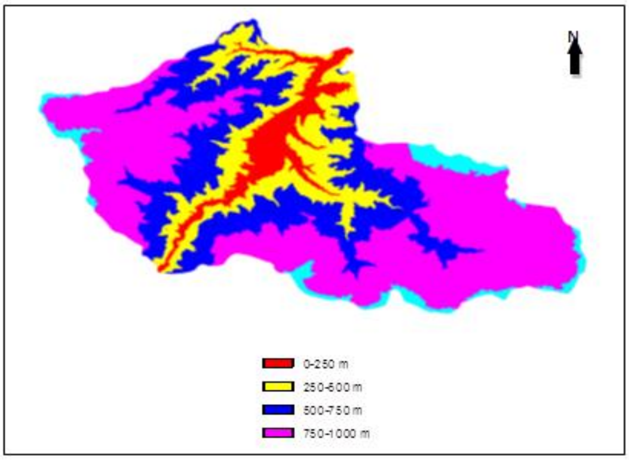

Fig 1. The height map of Roodbar sub-basin.

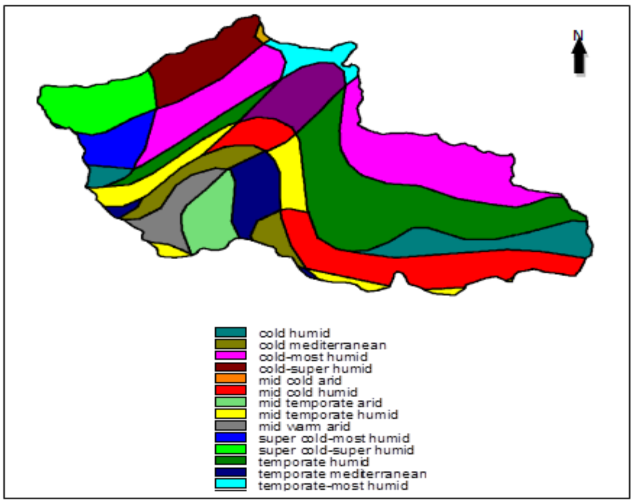

Fig 2. The climate map of Roodbar sub-basin.

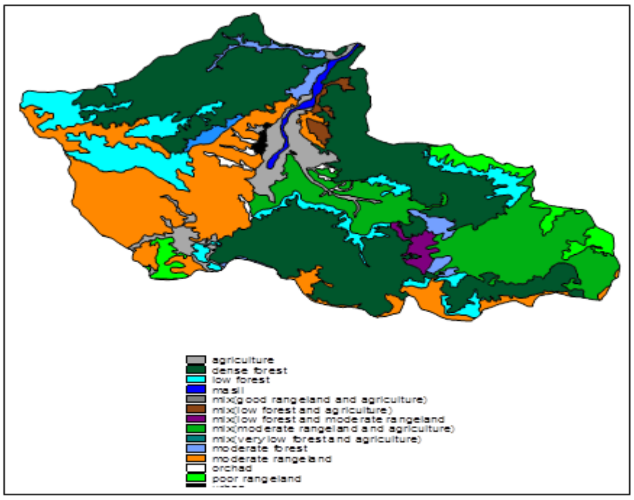

Fig 3. The land use map of Roodbar sub-basin.

rocks were categorized into the following five classes: sensitive, moderately sensitive, nearly resistant and resistant. The soil erosion status of an area depends upon the regional conditions of the area, such as climate, soil condition, land use/land cover, topography, population density, etc. Therefore, to assess the erosion hazard of the area a range of evaluation criteria, objectives and attributes should be identified with respect to the problem situation (Rahman and Saha, 2008). Based on previous studies in Kan sub-basin and Jajrood sub-basin (Mohammadi Torkashvand et al., 2005; Mohammadi Torkashvand and Nikkami, 2008, Mohammadi Torkashvand and Haghighat, 2009), rocks sensitivity to erosion (rocks erodibility), land use, land units (components), height and climate were selected for data layers integration in compared with photomorphic units map. Two maps obtained from the integration of data layers included: 1. Integrating rocks erodibility, land use, height and climate layers as *working units map no. 1;* and 2. Integrating rocks erodibility, land use, land units, height and climate layers as *working units map no. 2*. Image processing included radiometric correction, selecting the best bands for making color composites with regard to O.I.F. (Optimum Index Factor), making principal components 1, 2 and 3, resampling spectral bands and principal components to panchromatic bands, georeferencing by the nearest-neighbor method, making different color composites using spectral bands, and linear stretching and filtering in different stages for preparation of color composites. All color composites were compared and the best color image was selected to distinguish erosion features. From digital elevation modeling, a hill shade layer was prepared and overlaid on a color composite with the possibility of generating a 3-D image. Because of the lack of visual distinction of surface, rill and small gully erosion on the satellite images, photomorphic units with attention to color, tone, texture, drainage pattern and other characteristics were differentiated on color composites by screen digitizing methods (Daeles and Antrope, 1977) and was prepared photomorphic units map as *working units map no. 3*.

The preparation of ground truth maps of erosion types

In this study, erosion features were soil-water erosion types including surface, rill and gully erosion. Different methods were incorporated for the classification of surface, rill and gully erosion severity, such as those in Flugel et al. (1999), Refahi (2000), Boardman et al. (2003), Sirvio et al. (2004), and Mohammadi Torkashvand et al. 2005. Tables 1, 2 and 3 indicate the classification of soil surface, rill and gully erosion insities, respectively. A total of 652 points on the color composite images has been considered for field investigation by classified randomized sampling. Fig. 5 shows the positions of ground control points. For producing ground truth maps of erosion types, a primary polygon was determined for each control point (652 points) with respect to image characteristics. The magnitude of erosion in each erosion feature was investigated in these ground control points and then frontiers of each primary polygon were corrected with attention to the field views for each surface, rill and gully erosion feature. Modified polygons with regard to the intensity of each erosion feature in the field were marked. Polygons with the same intensity were combined and ground truth maps of surface, rill and gully erosion features were prepared. Figs. 6, 7 and 8 indicate the surface, rill and gully erosions maps in the Roodbar basin. The map of the erosion features was obtained from the combination of the surface, rill and gully erosion maps.

Table 4. The accuracy of methods (%) in providing erosion types maps with and without forest land use.

Map \ Erosion type	With forest land use				Without forest land use			
	Surface	Rill	Gully	Erosion features	Surface	Rill	Gully	Erosion features
1*	85.4	74.6	81.2	68.8	65.2	48.2	58.4	46.6
2**	86.1	76.1	82.8	75.4	72.1	49.6	66.2	47.2
3***	92.0	84.5	92.4	82.2	80.2	72.1	78.2	62.1

*Integration of the land use, rocks erodibility, height and climate, *rocks erodibility, height and climate,***Photomorphic units.

Table 5. The Root Mean Squaed Error (RMSE) of methods in providing erosion types maps with and without forest land use.

Map \ Erosion type	Surface	Rill	Gully	Erosion features
1*	152.2	312.6	426.2	408.6
2**	94.1	115.1	174.2	292.6
3***	54.6	78.6	110.4	92.8

*Integration of the land use, rocks erodibility, height and climate, **Integration of the land use, land units, rocks erodibility, height and climate
***Photomorphic units.

Table 6. The Coefficient of Variations (precision) of methods in providing erosion types maps with and without forest land use.

Map \ Erosion type	With forest land use				Without forest land use			
	Surface	Rill	Gully	Erosion features	Surface	Rill	Gully	Erosion features
1*	20.6	29.6	26.4	37.2	41.7	46.8	35.0	65.8
2**	18.8	28.2	20.6	36.0	33.2	44.2	36.0	62.3
3***	21.2	24.6	21.0	30.4	25.6	40.4	29.1	50.4

*Integration of the land use, rocks erodibility, height and climate, **Integration of the land use, land units, rocks erodibility, height and climate
***Photomorphic units.

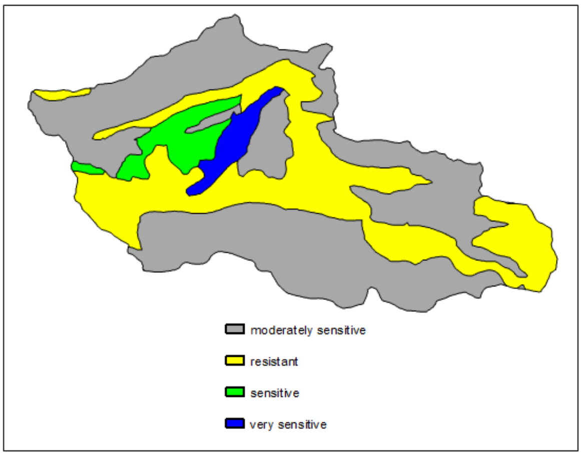

Fig 4. The rocks erodibility map of Roodbar sub-basin.

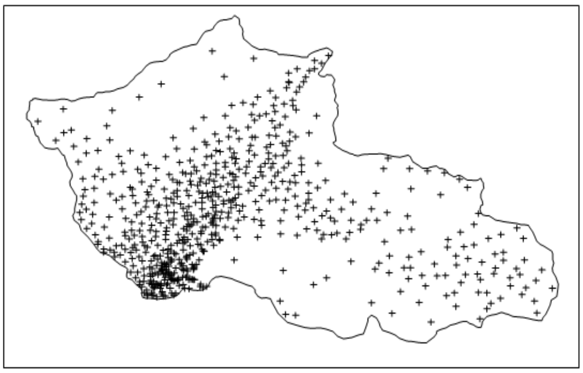

Fig 5. The positions of ground control points in studying basin.

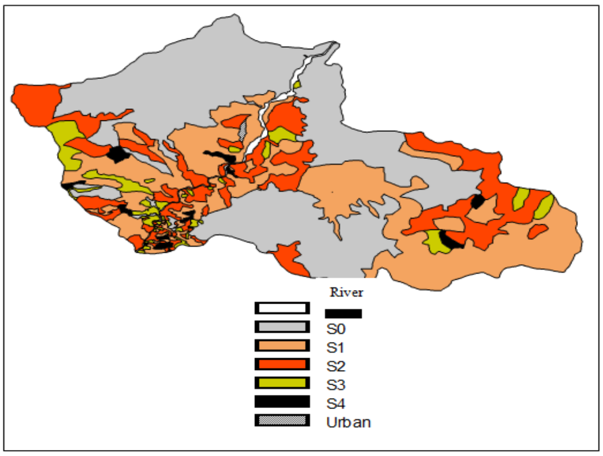

Fig 6. The ground truth map of surface erosion in the Roodbar sub-basin.

The calculation of accuracy and precision of methods

Erosion types maps were combined with working unit maps 1-3 to investigate the ability of each method to separate erosion features in two methods: 1. with considering forest land use, and 2. without forest land use. Equation 1 was used to investigate each method's accuracy:

$$A = \left(\sum_{i=1}^{n} Z*_{(x_i)}\, c_i\right) / \left(\sum_{i=1}^{n} Z*_{(xi)}\right) \qquad (1)$$

Where; A is the map accuracy or map conformity, $Z^*_{(xi)}$ is the actual condition (%) in working units area (ha), and C_i is the

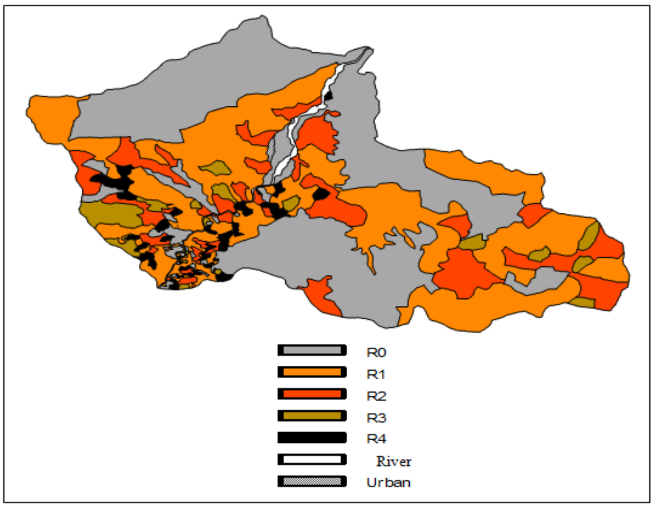

Fig 7. The ground truth map of rill erosion in the Roodbar sub-basin.

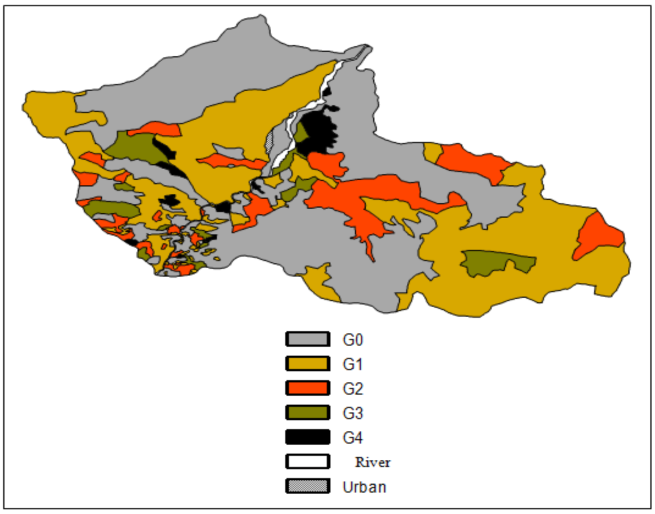

Fig 8. The ground truth map of gully erosion in the Roodbar sub-basin.

maximum area of each working unit that is uniform compared to actual conditions (%). The precision of each method was investigated by applying the working unit accuracy coefficient of variation (Equation 2):

$$CV = (S / \overline{X}) * 100 \qquad (2)$$

Where; S is the working unit accuracy standard deviation and $\overline{X}$ is the method accuracy.

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