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Full Length Research Paper

Proposing a model for preparation of the soil-water erosion type maps

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Some methodologies were compared in providing maps of surface, rill and gully erosion features, in research which took place in the Jajrood basin, north-east Tehran, Iran. A photomorphic unit map was produced from processed satellite images, and four other maps were prepared by the integration of different data layers, including slope, plant cover, geology, land use, rocks erodibility and land units. Comparison of ground truth maps of erosion types and working unit maps indicated that the integration of land use, land units and rocks erodibility layers with satellite image photomorphic units maps provide the best methods in producing erosion types maps.

Key words: Jajrood basin, geographic information system, remote sensing.

INTRODUCTION

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 we know that 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 and satellite images and data.

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. A few studies have been done in producing erosion features maps, such as GLASOD which divided erosion into four categories – water, wind, physical and chemical – 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.

By applying airborne digital camera orthomosaics and GIS for small-scale studies, and field measurements for large-scale studies, Sirvio et al. (2004) have studied gully erosion hazard assessments in the Taita Hills, south-east Kenya. 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.

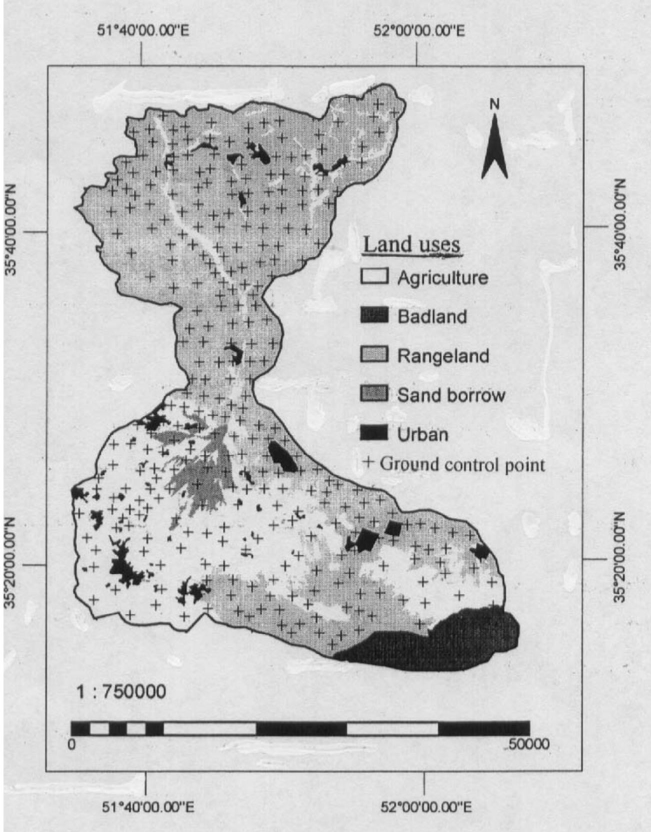

Figure 1. Land Uses in Jajrood basin and the positions of ground control points.

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). Iran Watershed Evaluation and Studies Office (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).

METHODS

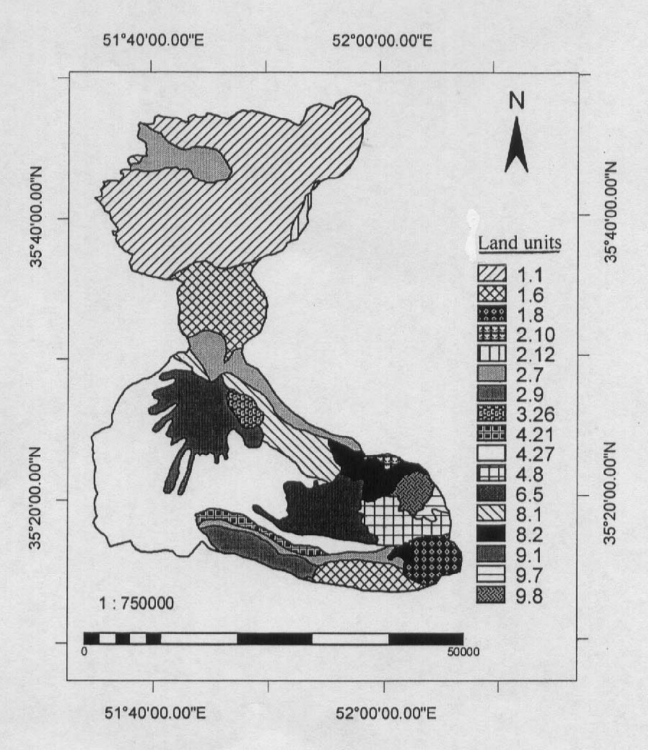

Figure 2. Land uses in Jajrood basin and the positions of ground control points.

The Jajrood sub-basin, with 162,558 ha between 51°34′E and 52°6′E, 35°13′N and 35°48′N, was considered for the investigation of erosion features. It extends from north-east to south-east Tehran Province, Iran. The highest and the lowest heights of the basin are 3000 m and 867 m, respectively. The Jajrood River originating in the northern Miegoon region and in the northern Varamin region flow into alluvial plains. Land types include rangeland, bad lands, sand mine, agricultural land and urban regions (Figure 1). Basic land units in the major part of basin are 1.1, 1.6, 2.7, 4.27, 6.5, 8.1 and 9.7 that Figure 2 indicates land units map. Within the basin, different lithic units include pyroclastic stones, tuffs, andesite, shale, conglomerate, gypsum and limestone. Quaternary deposits are also in the major part of the southern basin, particularly in the Varamin plain (covering 47.8% of the area of the basin). The climate, according to the De Martonne method, is sub-humid, semi-arid and arid in the northern, central and southern regions, respectively. The majority of rain and snow (75 to 85%) falls between November and April, and the rest comes from autumn, winter storms and spring showers.

The maps used, such as topographic, geologic, plant cover type and land unit maps, were scanned and georeferenced. A digital elevation model was prepared using 1:50,000 topographic digital data, and the derived slope map was classified into eight slope classes – 0 to 2%, 2 to 5%, 5 to 8%, 8 to 12%, 12 to 20%, 20 to 40%, 40 to 70% and >70% based on Mahler's (1979) classification;

land use was derived using ETM$^+$ a satellite image and rocks erodibility layer based on Feiznia (1995). Figures 3 and 4 shows the slope map and rocks sensitivity to erosion map, respectively. According to their sensitivity to erosion, the rocks were categorized into the following five classes:

(1) Very sensitive: lithology such as salt, shale, siltstone, mudstone, gypsum covering 20.3% of the basin area.

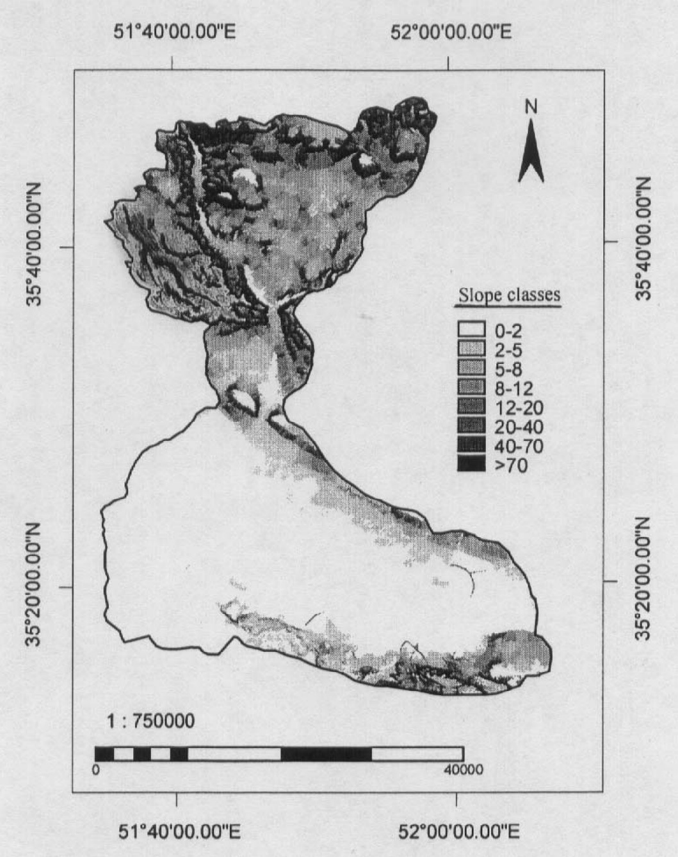

Figure 3. Slope map in Jajrood basin.

(2) Sensitive: lithology such as limestone, dolomite, sandstone, coal-bearing covering 14.1% of the basin area.
(3) Moderately sensitive: lithology such as limestone and marl, sandstone with phosphatic layers, lava and pyroclastics covering 2.3% and Quaternary deposits covering 51.4% of the basin area (Quaternary deposits have been considered as a separate class)
(4) Resistant: lithology including diorite covering 0.06% of the basin area.
(5) Very resistant: lithology including andesite, dacite, basalt, gabbro, middle and upper tuff members and quartizite on top covering 11.8% of the basin area.

Seven methods were used to prepare working unit maps, of which four methods were used to integrate different data layers including: (a) plant cover type, geology and slope, (b) land use, geology and slope, (c) land use, rocks sensitivity to erosion and slope, and (d) land use, rocks sensitivity to erosion and land unit layers. The other three methods were based on: (e) land units, (f) sensitivity of rocks to erosion, and (g) image photomorphic unit maps. Selection of the data layers was carried out after exploratory studies in Kan sub-basin (Mohammadi-Torkashvand et al., 2005). Slope, plant cover type, geology, land use and land unit are important factors in soil-water erosion features.

Image processing included radiometric correction, selecting the best bands for making color composites with regard to O.I.F., 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.

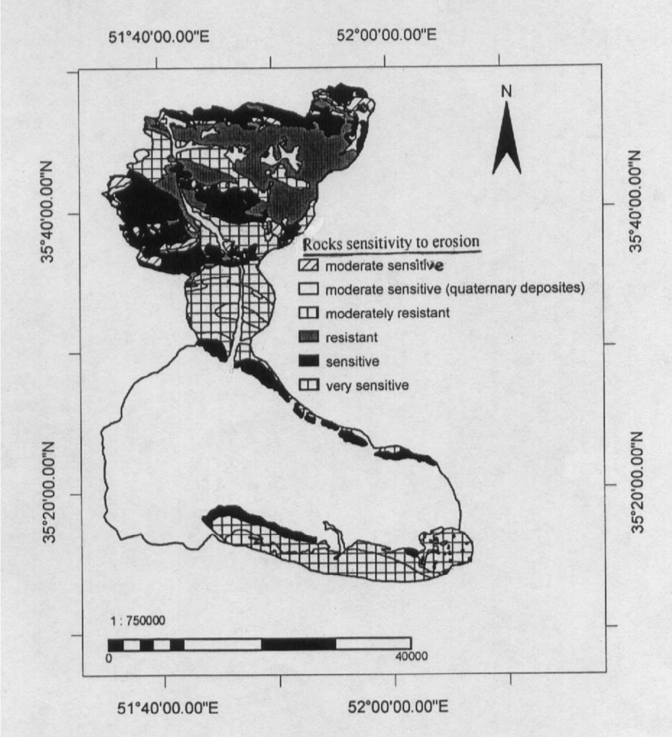

Figure 4. Rocks sensitivity to erosion map in Jajrood basin.

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).

In this study, erosion features are soil–water erosion types including surface, rill, gully and channel erosion. Different methods were incorporated for the classification of surface, rill, gully and channel erosion severity, such as those in Flugel et al. (2003), Flugel et al. (1999), Refahi (2000), Boardman et al. (2003), and Sirvio et al. (2004), and the classifications are based on experience (Mohammadi Torkashvand et al., 2005). A total of 314 points on the color composite images has been considered for field investigation by classified randomized sampling. Figure 1 shows the positions of these points. A primary polygon was determined for each control point 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, gully and channel 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, gully and channel erosion features were prepared. Figure 5 indicates the rill erosion map in the Jajrood basin. The map of the erosion features was obtained from the combination of the surface, rill, gully and channel erosion maps. Erosion features maps were combined with working unit maps to investigate the ability of each method to separate erosion features. Equation 1 was used to investigate each method's accuracy:

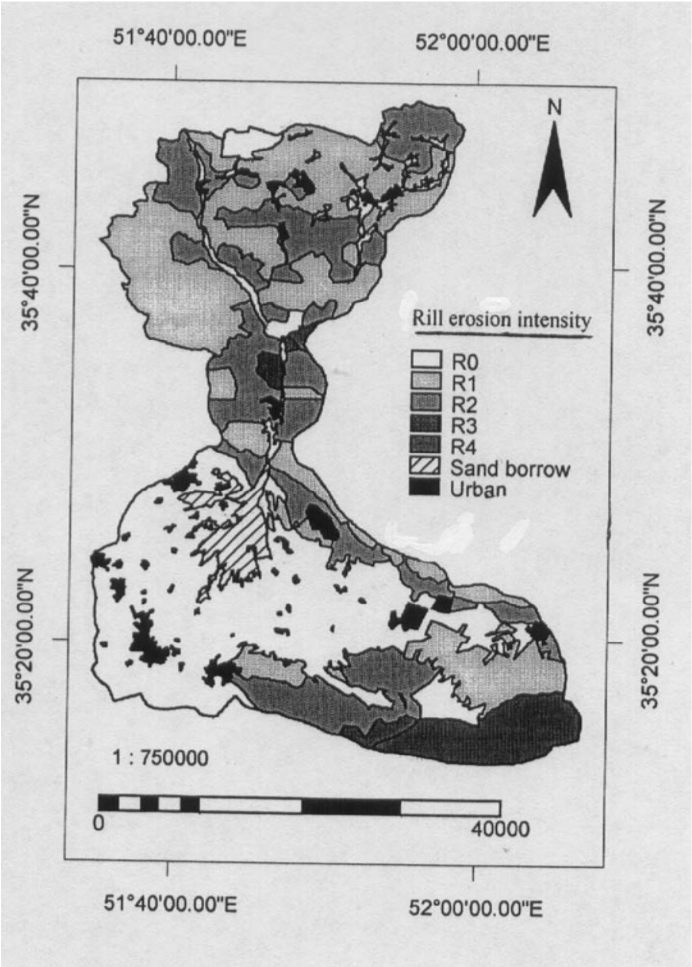

Figure 5. Truth map of rill erosion in Jajrood basin.

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

where A is the map accuracy or map conformity, $Z^*_{(x_i)}$ is the actual condition (%) in working units area (ha), and c_i is the maximum area of each working unit that is uniform compared to actual conditions (%). The root mean square errors were computed using Equation 2:

$$RMSE = ((\sum_{i=1}^{n} (Z_{(x_i)} - Z^*_{(x_i)})^2)/n)^{\frac{1}{2}} \quad (2)$$

where RMSE is the root mean squared (RMS) error of the working unit accuracy and $Z_{(x_i)}$ is the working unit area (ha) that is uniform.

The precision of each method was investigated by applying the working unit accuracy coefficient of variation (Equation 3):

$$CV = (S / \overline{X}) * 100 \quad (3)$$

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

RESULTS

Table 1 indicates the integrated results of different data layers. The largest and the smallest numbers of working units were related to maps "a" and "d", respectively, and most of the polygons in maps "a", "b" and "c" covered small areas which could not be included on 1:250,000 maps due to cartographic limitations. The largest and smallest accuracy are in maps "a" and "c", with 68.3% and 53.4%, respectively. The difference in accuracy between maps "a", "b" and "d" is small, but is significant with map "c". Although map "c" has a low accuracy, its precision is greater in providing an erosion types map (that is a high coefficient of variation). A ground truth map of erosion types, when compared with map "g", indicates that the uniformity in photomorphic units of the erosion features is greater than that obtained from other methods. On this map erosion features are completely uniform in some units, even those of a large area. According to reasons which will be discussed, map "d" derived from the integration of land units, land use and rocks erodibility layers as a working units map was compared with three more maps included maps "e", "f" and "g". Maps "d", "e", "f" and "g" are land units, rocks erodibility, photomorphic units and integrated layers methods, respectively. Figure 6 indicates the accuracy of different methods of producing erosion types maps. The least and the greatest accuracy are related to rocks erodibility and image processing, respectively, in providing all erosion types maps, although integrated layers and image processing methods have the same accuracy in preparing a gully erosion map (89.0% versus 89.8%). All methods have the least accuracy in providing an erosion types map, while the greatest accuracy is related to the preparation of a gully erosion map. The photomorphic units map had 72% conformity with ground truth. The difference between the rocks erodibility and other methods is considerable.

Table 1. The accuracy and error of working units maps in the Jajrood sub-basin.

Working units map	Crossed data layers	Accuracy (%)	Coefficient of variation (%)	Root mean squared error (ha)	Total number of working units
A	Slope, plant cover and lithology	68.3	34.8	1686.8	902
B	Slope, land use and lithology	67.4	40.1	716	436
C	Slope, land use and rocks sensitivity	53.4	30.9	1933.8	149
D	Land use, rock sensitivity and land units	66.6	36.5	1732.5	86

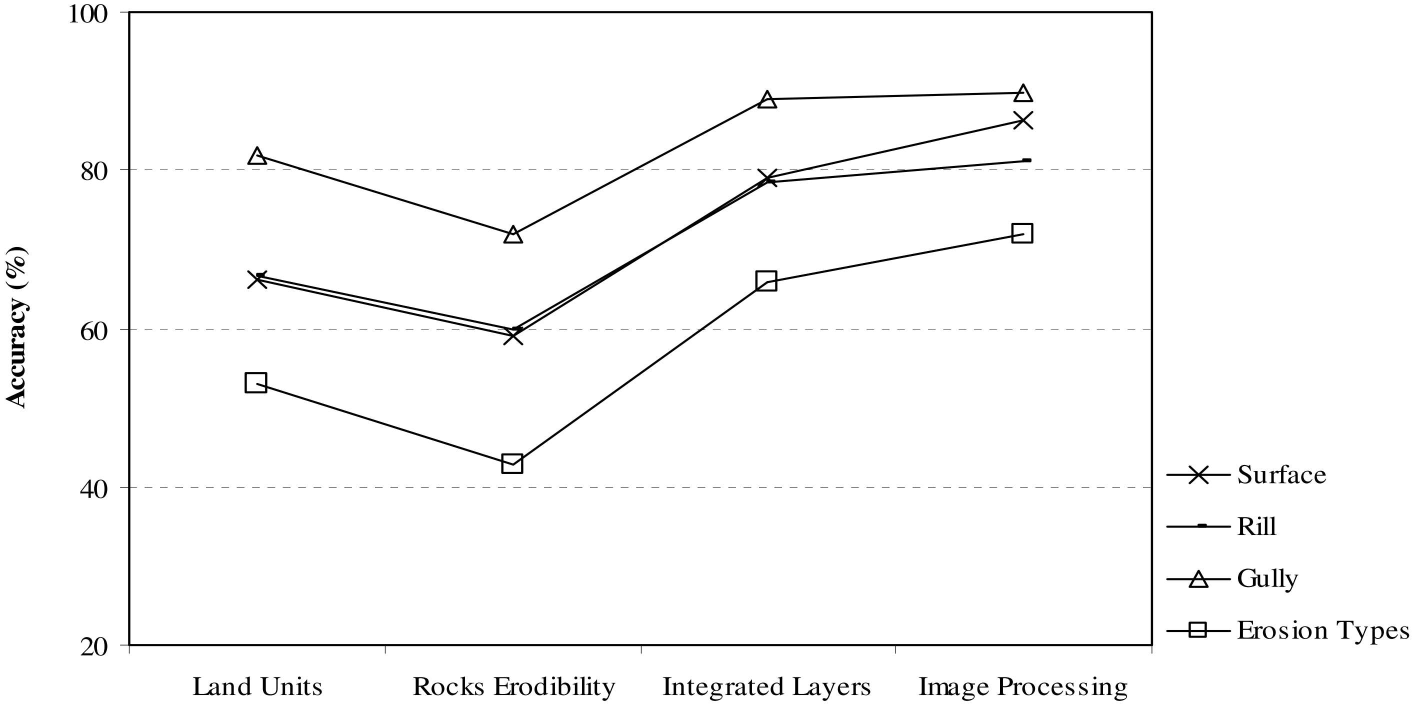

Figure 6. Accuracy of different methods in providing erosion types maps.

The RMS error of the working units accuracy illustrated in Figure 7 shows a minimum error in the image interpretation method. A considerable increase in RMS error is seen for the rocks erodibility method in providing all erosion types maps. Despite its accuracy, this method is not suitable for preparation of erosion features maps due to the large error. The error of the integrated layers and image processing methods is the same in preparing erosion types maps, although the error of the integrated layers is a little less than that of image processing in preparing gully erosion maps (507.5 ha versus 996.3 ha).

Figure 8 shows the coefficient of variation of different methods in preparing erosion types maps. Every method that has a small coefficient of variation has higher

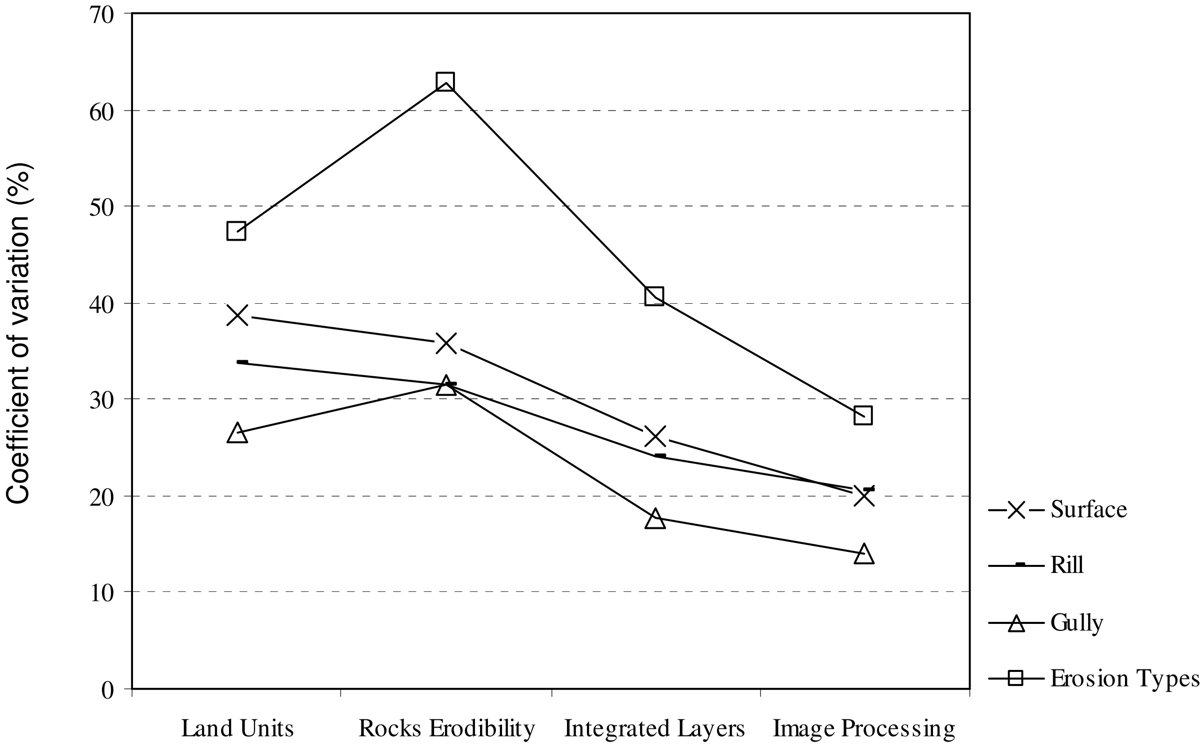

Figure 7. Precision (coefficient of variation) of different methods in providing erosion types maps.

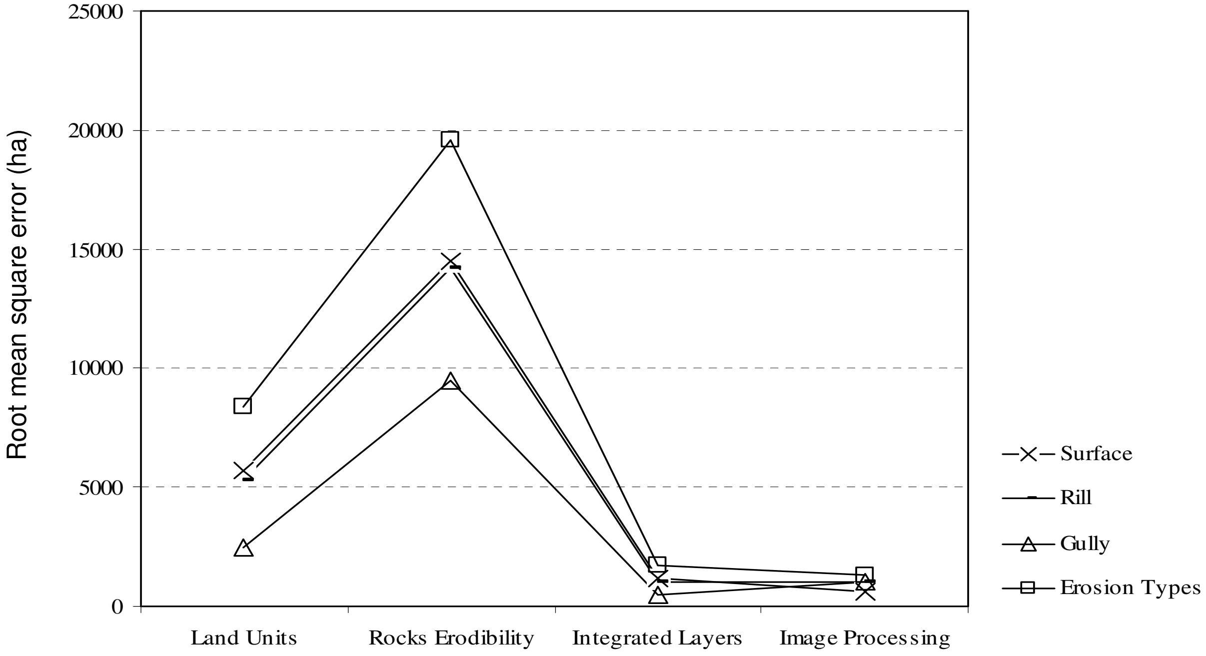

Figure 8. Root mean squared error of different methods in providing erosion types maps.

precision. The trend in the precision trend is similar with accuracy for different methods. The difference in precision between integrated layers and image processing methods in providing erosion types maps and surface erosion maps is compared with the difference in accuracy.

Table 2. Percentage of working units' area compared with the basin area in different accuracies.

Kind of erosion map	Working units' map	Method	< 50	50 to 70	70 to 90	> 90
Surface	D	Layers integration	15.9	18.6	20.6	44.9
	E	Land units	26	42.3	2.5	29.2
	F	Rocks erodibility	24.4	64.7	11.8	0.067
	G	Images processing	5.6	15.9	17.4	61
Rill	D	Layers integration	0.85	37.6	21.9	39.6
	E	Land units	26.8	42.9	2.5	27.7
	F	Rocks erodibility	21	78.9	-	0.07
	G	Images processing	-	25.9	51.8	22.3
Gully	D	Layers integration	5.7	6.1	15.9	72.3
	E	Land units	7.4	22.8	11.6	58.2
	F	Rocks erodibility	-	71.1	-	28.9
	G	Images processing	3.1	6.4	36.5	54
Erosion features	D	Layers integration	39.9	15.5	6	38.6
	E	Land units	69.2	0.5	5.9	24.4
	F	Rocks erodibility	49.8	50.1	-	0.07
	G	Images processing	18.9	21.7	44.4	15

The percentage of working units and basin areas with different accuracies is shown in Table 2. The greatest area with accuracy >90% in all erosion maps is related to the layers integration method, while the lowest area with accuracy <50% is related to the image processing method. For the working units of the integration layers method for the preparation of an erosion features map, 38.6% of their area has an accuracy of >90% (compared to 15.0% for the image processing method), but only 6.0% of their area has an accuracy of 70 to 90%. This area is 44.4% for the image processing method.

DISCUSSION

Investigation of the four models derived from data layer integration indicates that three models, "a", "b" and "d", have the same accuracies, but "d" has less precision than "a" and "b". A slope layer was included in models "a", "b" and "c". In other studies, 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 addition to accuracy and precision, economic and practical aspects are very important factors in preparing erosion features maps on a national scale (Rahnama, 2002).

Large numbers of working units, replication of units and increasing numbers of field control points are the most important factors affecting the cost of map preparation. On the other hand, it is natural to have more uniformity in small units than in large ones, resulting in greater accuracy in maps "a" and "b" than in maps "c" and "d". On the whole, regarding the quality of results and economic and practical concerns, integration of land use, rocks sensitivity to erosion and land units as a method with other three method including "e", "f" and "g" as working units maps applied for preparing of erosion features maps. Maps "d", "e", "f" and "g" are land units, rocks erodibility, photomorphic units and integrated layers methods, respectively.

Investigations showed that the photomorphic units maps and rock sensitivity maps had the most and the least accurate results with minimum and maximum RMS error, respectively. Nejabat (2003) also provides indirect detection of surface erosion on ETM$^+$ satellite images in part of Fars Province, Iran. He calculated 68% 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).

A land units map has also shown the same results of using a rocks erodibility map in preparing erosion types maps. These maps have large units, but they are not homogenous with the view of surface, rill and gully erosion intensity. Increasing the unit area causes an increase in the diversity of erosion features intensity due to the effect a greater number of variables has on these erosion features, consequently, accuracy, error and precision of these maps reduce. Using these two maps (land units and rocks erodibility), by Mohammadi-Torkashvand and Nikkami (2006) for preparing erosion features maps, has not been shown to be asuitable method. Therefore, in addition to economic and practical regards, accuracy and precision are important in producing erosion features maps. It has been suggested that processing ETM$^+$ images will distinguish surface, rill and gully erosion, but this processing did not show surface and rill erosion in small and medium sized gullies. Hajigholizadeh (2005) also produced surface, rill and gully erosion maps for five basins in Tehran province, Iran, from visual interpretation of images. He concluded that recognition of these types of erosion is very difficult due to the resolution of the images, and that direct detection of surface and rill erosion from ETM+ images is not possible. For large gullies in Central Brazil, Vrieling and Rodriguez (2004) found that optical ASTER imagery provides better a depiction of gully shape than ENVISAT ASAR data, when compared to QuickBird images. With the current availability of high-resolution data collecting satellites such as IKONOS and QuickBird, options for detecting and monitoring individual small-scale features have increased, although these have not yet been reported in the literature. 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.

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 (Alavipanah, 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 gully erosion ground truth maps. Integration of land units, land use and rocks erodibility layers established units with greater conformity than the gully erosion maps compared with rill and surface erosion maps. It appears that gully erosion intensity is more influenced by land units, land use and rocks erodibility than surface and rill erosion. When only land unit and rocks erodibility maps were used to produce erosion features maps, accuracy and precision were low, but the maps derived from the integration of these maps with a land use layer had greater accuracy and precision. This reduces the diversity of erosion intensity to increase accuracy and precision of the maps.

Conclusion

The investigations indicated that land units and rocks erodibility methods, taking into consideration accuracy, error and precision, are not suitable methods for preparing erosion features maps, although land units maps can be used for providing approximate gully erosion maps. Differentiating photomorphic units in satellite imagery makes more uniform units available for use as working units in erosion features studies. 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 gully erosion maps with 89% accuracy.

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.

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