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Photomorphic Units Map Derived from Processing Satellite Images as a Model in Providing Erosion Types Maps

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Abstract: In this study, the possibility using ETM$^+$ satellite images for providing erosion types maps was investigated. With regards to the lack of visual distinction of surface, rill and small gully erosions on the satellite image after processing, photomorphic units with attention to color, tone, texture, drainage pattern and other image characteristics, were differentiated on color composite by the screen digitizing methods. Photomorphic units map as a model was crossed by ground truth maps of surface, rill and gully erosion; and erosion features map. Results indicated that the greatest accuracy and precision of model is related to providing gully erosion map, although it also is suitable in providing surface and rill erosion maps.

Key words: ETM$^+$, photomorphic units map, soil erosion map

INTRODUCTION

Soil erosion is a serious geo-environmental issue led to land degradation in sub-humid to arid Mediterranean countries (Bou Kheir *et al*., 2006) including parts of Iran. It has both direct and indirect negative impacts: loss of soil, loss of green cover, deterioration of agriculture, desertification and of course, economic reverberations (Khawlie *et al*., 2002). The implementation of effective soil conservation measures has to be preceded by a spatially distributed erosion risk assessment (Moussa *et al*., 2002; Souchere *et al*., 2005) and erosion features assessment and its intensities (Mohammadi-Torkashvand and Nikkami, 2006).

The possibility to use the aerial photographs for soil mapping has been known for a long time (Goosen, 1967). Commonly they 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). Rahnama (2003) investigated the possibility of preparation of soil erosion features map in the parts of Isfahan Province, Iran, by aerial photograph interpretation and concluded that this way is impossible for the total area of Iran because of time and costs. He recommended satellite imagery and GIS for this aim. The extension of the use of modern spatial information technologies, such as Geographical Information Systems (GIS), Digital Elevation Modeling (DEM) and remote sensing, have created new possibilities for research as a key for erosion types mapping (Martinez Casasnovas, 2003) that is economical due to low costs as well as quickness (Raoofi *et al*., 2004).

Most of erosion and sediment studies have been carried out to provide a quantitative erosion map (Singh *et al*., 1992; Martinez-Casanovas, 2003; Ygarden, 2003) and less to preparing erosion features map (Mohammadi-Torkashvand, 2008). Based on the information source of Lansat TM data, colour aerial photographs and ground investigation data, Yuliang and Yun (2002) used remote sensing and GIS techniques for the task of soil erosion types and intensity classification in Shanxi Province during May-July. They provided the reliable data and maps in time to National Water Conservancy Ministry. Shrimail *et al*. (2001) prioritized erosion-prone areas in hills using remote sensing and GIS as a case study of the sukhna lake catchment, northern India. The study indicated that (1) IRS ID

LISSIII data can be used for land use/land cover mapping with a reasonably good (83%) classification accuracy for hydrological and erosion assessment applications and (2) that a simple index-based approach using three main causative factors, i.e., slope, soil and land use/land cover, can give fairly good delineation of erosion-prone areas for prioritizing.

Khawlie *et al*. (2002) for providing a risk map of soil erosion in eastern Mediterranean rugged mountainous areas, Lebanon, applied remote sensing and GIS. They indicated that 36% of the Lebanese terrain is under threat of high-level erosion and 52% of that has been concentrated in the rugged mountainous regions. 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, SE-Kenya. They investigated distribution and intensity of gully erosion and the main factors affecting gully erosion and its changes during the last 50 years within the Taita Hills.

Hajigholizadeh (2005) used the ETM^+ satellite images interpretation method for providing erosion features maps of five basins in Tehran Province, Iran. Results of this research showed that the recognition of surface and rill erosions is very difficult due to image resolution. Therefore, they differentiated gully erosion polygons with low, moderate and high intensity on images and polygons were controlled and corrected by field studies. The synergy of Landsat TM and JERS-1 data by Metternicht and Zinck (1998) studies provided a unique combination that allowed more accurate identification of badlands, slightly eroded areas, miscellaneous land, fallow land and moderately eroded areas, as compared to the results obtained by Landsat TM alone.

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 or erosion risk. There is no standard method for qualitative data integration and consequently many different methods exist (Vrieling, 2006). It appears that the distinct methodology for providing erosion maps and its intensities with regards to statistics factors has not been done; therefore, the aim of this study is to develop a methodology based on satellite images processing with the view of the accuracy, error and precision of erosion types mapping at the national scale (1:250000).

MATERIALS AND METHODS

ETM^+ satellite images (path 165-34) relate to 2002 year were used for the investigation of erosion features at the Jajrood sub-basin with 162,558 ha located between 51°34′ E, 52°6′ E, 35°13 N and 35°48′ N. This basin extends from northeast to southeast Tehran Province, Iran. The highest and the lowest height of basin are 3000 and 867 m, respectively. The Jajrood river originating in the northern Miegoon region and in the northern Varamin entered in alluvial plains. Land covers were rangeland, badland, sand borrow, agriculture land and urban regions. Basic land units in the great parts of basin are 1.1, 1.6, 2.7, 4.27, 6.5, 8.1 and 9.7. Within the basin, different lithic units include pyroclastic stones, tuffs andesite, shale, conglomerate, gypsum and limestone. Also, Quaternary deposits have covered in the major part of the southern basin particularly in the Varamin plain (47.8% of area basin). Climate according to the Demartonne method is sub-humid, semi-arid and arid in the northern, central and southern regions, respectively. The majority of rain and snow (75-85%) falls between November and April and the rest corresponds to Autumn and Winter storms and spring showers.

Image processing included radiometric correction, selecting best bands for making color composite with regard to the Optimum Index Factor, making principal components 1, 2 and 3, resampling spectral bands and principal components to the panchromatic bands, georeferencing by the nearest neighbour method, making different colour composites using the spectral bands and linear stretching and filtering in different stages for preparation of colour composites.

Finally, all color composites were compared and the best color image was selected for the distinction of erosion features. For this mean; principal components 2 and 3 with panchromatic band were combined by HIS method to differentiate green, red and blue wavelengths, then from those a color composite was created by RGB method. This color composite and also another color composite of RGB5-3-1 were used in providing photomorphic units map. Regarding the lack of visual distinction of surface, rill and small gully erosions on the satellite image, photomorphic units with attention to color, tone, texture, drainage pattern and other images characteristics, were differentiated on color composite by the screen digitizing methods (Daeles and Antrope, 1977), consequently, 76 photomorphic units as working units were differentiated. Off course, from DEM, a hill shade layer was prepared and overlayed on a color composite that obtained 3-D view possibility.

In this study, erosion features are soil-water erosion types including surface, rill and gully erosions. Different methods were incorporated for classification of surface, rill and gully erosion severity such as Flugel *et al.* (2003), Refahi (2000), Boardman *et al.* (2003) and Sirvio *et al.* (2004) and the series of changes are based on experience and expertise considerations (Mohammadi-Torkashvand *et al.*, 2005). The magnitude of erosion in each erosion feature was investigated in 314 ground control points and with due attention to the field views for every one of the surface, rill and gully erosions for every ground control point, a polygon was determined. Then, polygons with regard to the intensity of each erosion features in the field, were marked. Polygons with same the intensity were combined together and ground truth maps of surface, rill and gully erosions were prepared. Figure 1 indicates the position of ground control points with land uses in Jajrood basin. Figure 2 also shows the truth map of rill erosion.

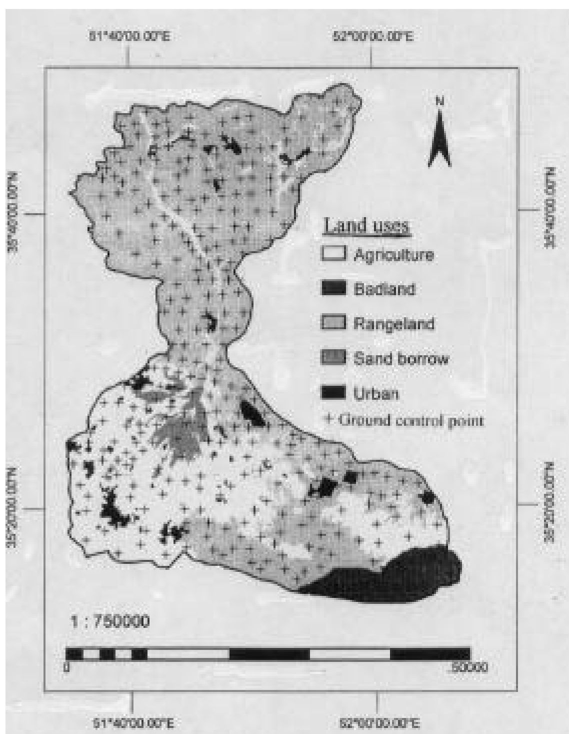

Fig. 1: Land Uses in Jajrood basin and the positions of ground control points

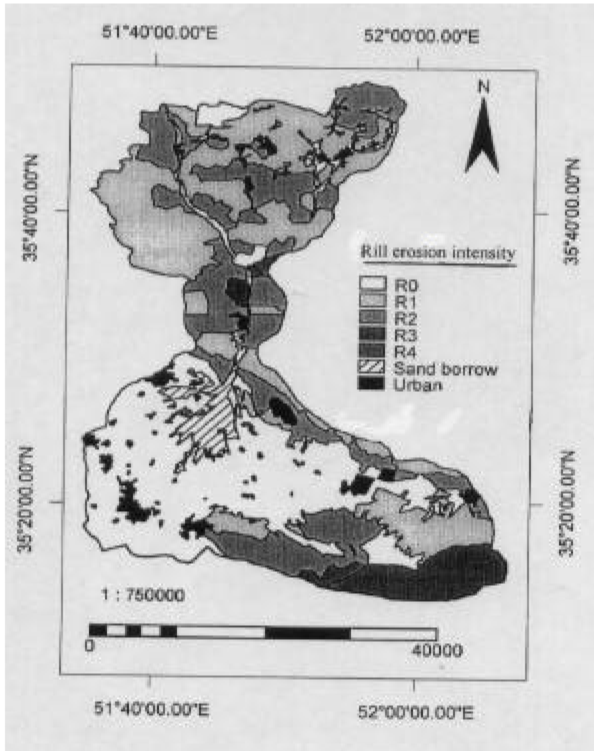

Fig. 2: Truth map of rill erosion in Jajrood basin

The erosion features map obtained from integration of the surface, rill and gully erosions maps. Erosion types maps and erosion features map were crossed by photomorphic units map to investigate the ability of this map (as a model) on separating erosion features. Equation 1 was used for investigating model accuracy:

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

where, A is model accuracy or map conformity with actual condition (percent), $Z^*_{(xi)}$ is working units' area (ha) and C_i is maximum area of each working unit that is uniform compared to actual conditions (percent). Root Mean Squared Errors of (RMSE) working units accuracy were computed by Eq. 2.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} \left[Z_{(x_i)} - Z^*_{(x_i)} \right]^2}{n}} \quad (2)$$

where, RMSE is Root Mean Squared Error of working units' accuracy and Z_{xi} is working units' area (ha) that is uniform in actual condition. The precision of method was investigated by applying the working units accuracy coefficient of variation (Eq. 3).

$$CV = \frac{S}{\bar{X}} \times 100 \quad (3)$$

where, S is working units accuracy standard deviation and $\bar{X}$ the model accuracy.

RESULTS AND DISCUSSION

Table 1 indicates the results of the photomorphic units map cross by erosion types maps. The greatest accuracy of model (photomorphic units' map) is related to providing gully erosion map that is approximately 90%. Accuracy is 86.4 and 81.0% in preparation of the surface and rill erosions maps, respectively. The lowest accuracy of model, also, is related to providing erosion features map (72%).

While accuracy difference of model in providing surface and rill erosion maps was 5.4%, model precision difference (working units' accuracy coefficient of variation) in preparing two above erosion types is only 0.5%. Thus, RMSE of model for providing surface and rill erosions maps is 652.0 and 1019.5 ha, respectively. This point is important that the model accuracy and precision in providing gully erosion map, respectively 3.4 and 5.8% is more than surface erosion map, but RMSE of model in preparing surface erosion map is greater than gully erosion map. The highest CV and error (RMSE) is related to providing erosion features map.

The working units' area percentage in comparison with the basin area in different accuracies is calculated and shown in Table 2. Any area of working units in rill erosion map has accuracy less than 50%. The greatest areas of working units with the accuracy more than 90% are related to surface erosion map (61.0%) and gully erosion map (54.0%). The greatest and the least areas of working units respectively with accuracy less than 50% and more than 90% is in providing erosion features map.

Accuracy and precision of model (photomorphic units map) in providing erosion features was less than when use this model for preparation of surface, rill or gully erosions map, alone. This can be due to increase in diversity of erosion types intensity led to decrease the accuracy and precision of model. This diversity is also caused that the more areas of working units have accuracy less than 50%. Mohammadi-Torkashvand (2008) applied some models of data layers integration in GIS for providing erosion types maps and concluded that models have a more accuracy and precision in providing surface, rill and gully erosion maps than the preparation of erosion features map. In data layers integration, accuracy was 66.6%, while in this study is 72.0% by using photomorphic units' map.

It seems differentiating photomorphic units with regards to the different factors such as drainage pattern led to increase in accuracy and precision of model in providing gully erosion map. In differentiating photomorphic units, off course, only large gullies were detectable, but this subject in

Table 1: Accuracy, coefficient of variation (precision) and root mean squared error of model in providing erosion types maps

	Kind of erosion map			
Index	Surface	Rill	Gully	Erosion features
Accuracy (%)	86.4	81.0	89.8	72.0
Coefficient of variation (%)	19.9	20.4	14.1	28.3
RMSE (ha)	652.0	1019.5	996.2	1287.4

Table 2: Working units area (in terms of percent as compared with basin area) in different accuracies for providing different erosions maps

	Accuracy (%)			
Kind of erosion map	<50	50-70	70-90	>90
Surface	5.6	15.9	17.4	61.0
Rill	-	25.9	51.8	22.3
Gully	3.1	6.4	36.5	54.0
Erosion features	18.9	21.7	44.4	15.0

differentiating photomorhic units increases the accuracy of model. Allan James *et al.* (2007) investigated the ability of the ALS (Airborne Laser-Scanning) topographic data to identify headwater channels and gullies for two branching gully system in frosted areas and to extract gully morphologic information. Regarding results, at the gully network scale, ALS data had provided accurate maps-the best available- with robust detection of small gullies except where they are narrow or parallel and closely spaced. For large gullies in Central Brazil, Vrieling and Rodriguez (2004) found that optical ASTER imagery provided better description of gully shape than ENVISAT ASAR data, when compared to QuickBird image. With the current availability of high-resolution satellites such as IKONOS and QuickBird options for detecting and monitoring individual small-scale features have increased, although not yet reported in literature. The visual interpretation provided usually good results and despite of 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).

For providing gully erosion map, coefficient of variations also is low i.e., accuracy variations of working units is more uniform than surface and rill erosion map and erosion features map. Both surface erosion and rill erosion weren't detectable on satellite images, but photomorphic units map has a great accuracy in providing these erosion maps particularly surface erosion map. Hajigholizadeh (2005) also for providing surface, rill and gully erosion maps in five basins in Tehran Province, Iran, by using images visual interpretation, concluded that recognition of surface, rill and small gully erosion is very difficult with due attention to images resolution. Direct detection of surface and rill erosion with regards to ETM^+ resolution is not possible. In Nejabat (2003) studies, indirect detection of surface erosion on TM satellite images in the part of Fars Province, Iran, was investigated. He calculated 68% accuracy when the ground truth map of surface erosion was compared with photomorphic units' map. In the Taleghan basin in Tehran Province, Iran, a gully and rill erosion map (direct detection on image obtained from the fusion of ETM^+ bands and Cosmos image) was compared with a ground truth map indicated an approximate 80 percent accuracy (Raoofi *et al*., 2004).

Mohammadi-Torkashvand (2008) reported that the integration of land use, land units and rocks erodibility layers as a model in providing surface, rill and gully erosion maps had accuracy 78.9, 78.4 and 89.0%, respectively. Accuracy difference between data layers integration model and photomorphic units model in providing gully erosion map is low (89.0 versus 89.8%), but it is considerable for rill erosion map and especially surface erosion map. This can be due to more dependency of gully erosion to land use, land units and rocks erodibility than surface and rill erosion those are surface features of soil erosion. Using photomorphic units derived from visual interpretation of satellite images with due attention color, tone, texture, drainage pattern and other images characteristics, is a suitable method 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.

CONCLUSION

In general, it seems that this model (photomorphic units map) is suitable in providing gully erosion map. Thus, regarding earlier studies (Mohammadi-Torkashvand *et al*., 2005; Mohammadi-Torkashvand, 2008) in this basin, using photomorphic map as a model is better than data layers integration in preparation of the surface, rill erosion maps; and erosion features map. It is proposed that satellite images with higher resolution were investigated for this aim.

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