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Geographic Information System and Remote Sensing: Proposing a Model for Providing Erosion Features Map in Iran at the National Scale

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Abstract: This study in Jajrood sub-basin, North East Tehran, was conducted to investigate some methods for water-soil erosion types mapping by GIS. Four models were used for providing working units' maps by integration of data layers including A. plant cover, geology and slope B. land use, geology and slope C. land use, rocks erodibility and slope and D. land use, rocks erodibility and land units. The surface, rill and gully erosion intensity in the 314 spot were controlled to provide ground truth map from each of these erosion features. Soil erosion type's map obtained from the integration of these truth maps and then this map was crossed by the maps A to D. Results indicated that the integration of land use, rocks erodibility and land units layers is a better model for providing erosion types map than other models from an economic and executive regards. The cross of the map D with the ground truth maps of surface, rill and gully erosions showed the greatest and least accuracy are related to providing gully erosion and erosion features maps, respectively. The greatest precision of model was related to providing gully erosion map (with coefficient of variation 17.8%) and the least precision (with 40.5% coefficient of variations) was related to providing erosion features map. In conclusion, model D is suitable for preparation of gully erosion map no erosion features map. It is recommended that the same study is done in another basin with the different climate and geology.

Key words: Soil erosion, erosion features map, GIS, RS

INTRODUCTION

Soil erosion is a serious geo-environmental issue causing 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, decertification and of course, economic reverberations (Khawlie *et al.*, 2002). Some agricultural and rangeland areas have already declined due to soil erosion. It is necessary to establish soil conservation measures which can reduce land degradation and assure a sustainable management of soil resources. 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 *et al.*, 2005).

The possibility to use the aerial photographs for soil mapping has been known for a long time. 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). But it should be regarded that field survey and photo-interpretation for erosion types mapping at the national scale is time consuming and expensive (Raoofi *et al.*, 2004). In Isfahan province, Rahnama (2003) also concluded similar results in providing erosion types map by aerial photograph interpretation. 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).

Numerous studies have been conducted for providing quantitative erosion maps (Singh *et al.*, 1992; Ygarden, 2003; Martinez-Casasnovas, 2003; Sidorchuk *et al.*, 2003), but has less been regarded to erosion types mapping. 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).

Noble and Fletcher (1984) provided New Zealand erosion features map in 1:250000 scale. Working units had been established by integration of lithology, soil, slope, erosion, plant cover, climate and land use layers and then units regarding to erosion intensities of sheet, rill, gully, tunnel gully, stream bank, Massive and etc. were investigated and labeled by field observations. Khawlie *et al.* (2002) for providing a risk map of soil erosion in Eastern Mediterranean rugged mountainous areas, Lebanon, applied remote sensing and GIS. With steep slopes, torrential rain, improper human interference, run-off is high and water-soil erosion is continuously deteriorating the land cover. Remote sensing can facilitate studying the factors enhancing the process, such as soil type, slope gradient, drainage, geology and land cover. Digital elevation models created from SAR imagery (Shi and Dozier, 1997) contribute significantly to assessing vulnerability of hydric-soil erosion over such a difficult terrain. GIS layers of the above factors are integrated with erosional criteria to produce a risk map of soil erosion. Results indicated that 36% of the Lebanese terrain is under threat of high-level erosion and 52% of that is concentrated in the rugged mountainous regions. Bou Kheir *et al.* (2006) integrated two data layers including erodibility of rocks and soil and potential sensitivity to erosion as a model for providing risk map of soil erosion. The risk map corresponds well to field observations on the occurrence of rills and gullies. In recent researches, integration of data layers has been used in erosion and sediment different studies (Feoli *et al.*, 2002; Navas and Machin, 1997; Bayramin *et al.*, 2003).

Navas *et al.* (2005) used GIS to integrate the information derived from an automated land evaluation system that, in turn, identified the erosion risk of areas by combining data on various soil properties and physiographic and bioclimatic factors. According to the map of erosion risks generated for the Arnás catchment's, southern Pyrenees, there were three distinct areas with different soil erosion features where fallout ^{137}Cs was used to assess the soil redistribution pattern. Therefore, in this research, methodologies of preparing this map are investigated by integrating effective data layers in the environment of Geographic Information Systems (GIS). 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. The research reflects the advantages of integration of RS and GIS techniques, which is worth popularizing and applying. 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.

The aim of this study is to develop a methodology based on data layers integration in GIS for providing water-soil erosion types map and its intensities at the national scale (1:250000).

MATERIALS AND METHODS

Jajrood sub-basin has been considered as study basin with 162558 ha area that its location is 51°34′ and 52°6′ eastern longitude and 35°13′ and 35°48′ northern latitude, in the north-east Tehran province, Iran, during years 2004-2005. Land covers were rangeland, badland, sand borrow, agriculture land and urban regions. In basin, different lithic units exist including pyroclastic stones, tuffs, andesite, shale, conglomerate, gypsum and limestone. Also, quaternary deposits have covered in the vast part of south basin particularly in Varamin plain. Climate according to Demartonne method (Scientific Bulletin of Climatological Research Institute, 2004) is sub-humid in the narrow ribbon of basin north and semi-arid in the parts of north and central of basin. From central parts to south of basin, climate is arid.

Preparation of data layers: Maps of land use, geology, plant cover, topography and land units (at the 1: 250000 scales) were scanned and georeferenced. From topographic layer, at first, digital elevation model and then slope layer was provided according to Mahler (1979) classification. Rocks erodibility layer base on Feiznia (1995) classification from geology layer was prepared.

Preparation of working units maps: Four models applied for preparation of working unit's maps that derived from integration of data layers including:

A: Plants cover, lithology and slope layers
B: Land use, lithology and slope layers
C: Land use, rocks erodibility and slope layers
D: Land use, rocks erodibility and land units layers

Selection of data layers was regarding exploratory studies in Kan sub-basin (Mohammadi Torkashvand *et al.*, 2005). After this, these models are called models A, B, C and D (Fig. 1).

Processing the remote sensing data (ETM+ Satellite Images, path 164-35, 2002) was done by ILWIS 3.2 Academic software that briefly including: selection of best

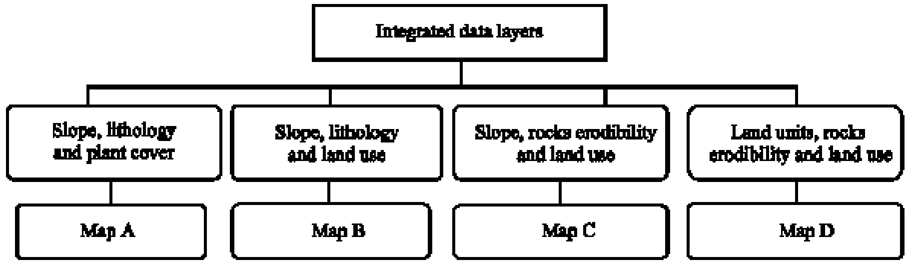

Fig. 1: Integrated data layers and working units maps A, B, C and D

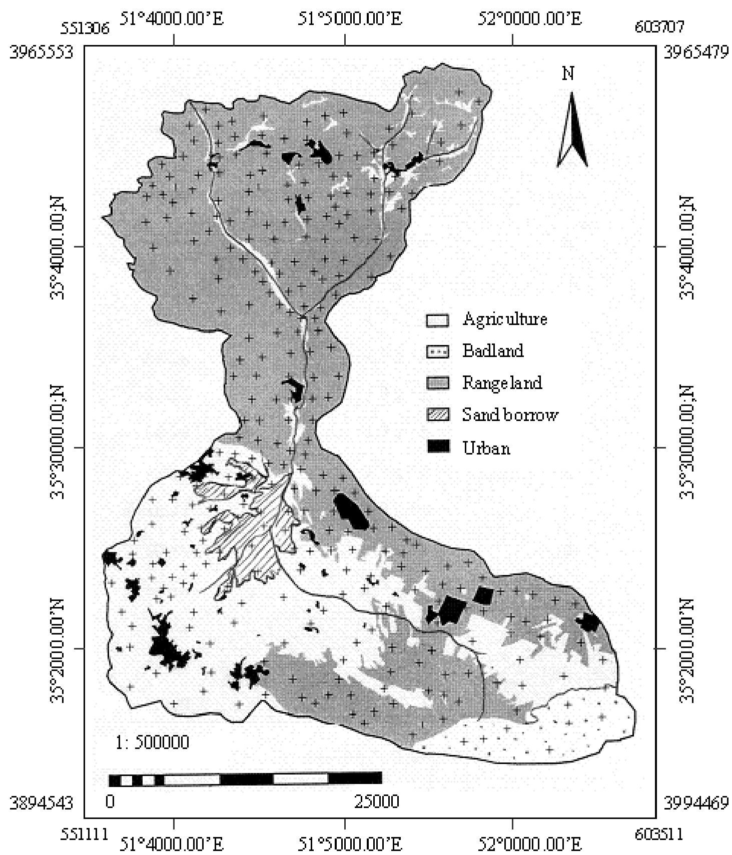

Fig. 2: The position of ground control points (+) in Jajrood sub-basin

bands for making color composite with regards to OIF, making principal components 1, 2 and 3, resampling spectral bands and principal components to georeference of panchromatic band by nearest neighbor method, making different color composite by using spectral bands, linear stretching and filtering in different stages for preparation of color composite. Finally, all color composites were compared and the best color image was selected for distinction of erosion features. From DEM, hill shade layer was prepared and overlayed on color composite to derive 3-D view.

Field practices: Different methods were incorporated for classification of soil erosion type's severities (Flugel *et al.*, 1999; Refahi, 2000; Boardman *et al.*, 2003; Sirvio *et al.*, 2004) and experiences and expertise considerations (Mohammadi Torkashvand *et al.*, 2005). Numbers of 314 points have been considered on color composite image for field investigations (Fig. 2). With regards to lack visual distinction of surface and rill erosions, small and medium gullies on satellite images, a photomorphic unit with attention to drainage patterns and also other characteristics such as color, tone and texture, were differentiated on color composite by screen digitizing method (Daeles and Antrop, 1977) as a polygon was determined for each of control point. The intensities each of erosion types was investigated in these ground control points and then frontiers each of polygon were corrected with due attention to field views for every one of the surface, rill and gully erosions. Modified polygons were marked with regards to intensities each of erosion features in field. Polygons that had same intensity were together combined and ground truth maps of surface, rill and gully erosions were prepared. Erosion type's map derived from integration of surface, rill and gully erosions maps. This map was crossed by working units' maps to investigate the ability each of method on separating soil erosion type's intensities. Equation 1 was used for investigating method's accuracy.

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

That A is map accuracy or map conformity with actual conditions (percent), $Z^*_{(xi)}$ is working units' area (ha) and C_i is maximum area of each working unit that is uniform in compared to actual conditions (percent). Root mean squared error of working units' accuracy was computed by Eq. 2.

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

That $Z_{(xi)}$ is working units' area (ha) that is uniform in actual conditions. The precision each of method by Eq. 3 was obtained.

$$CV = \frac{S}{\overline{X}} 100 \qquad (3)$$

That CV and S are coefficient of variation and standard deviation of working units' accuracy, respectively and $\overline{x}$ is method accuracy (A in Eq. 1).

RESULTS

In layers integration models, the most and least numbers of working units are related to models A and D, respectively (Table 1). Most polygons of models A, B and C have small area which is not possible to be presented in the maps 1:250,000 maps due to cartographic limitations. Table 2 presents the accuracy and error of data layers integration models in distinguishing soil erosion type's intensities. According to this Table 2, the highest and the least accuracy belong to models A and C that is 68.3 and 53.4%, respectively. The accuracy difference between models A, B and D is not considerable, but it is significant with model c. It should be regarded that model c has the greatest precision (high coefficient of variation).

With regards to the results of data layers integration, model d has suitable been distinguished than models A, B and C Totally, regarding results and economic and executive regards, integration of land use, rocks sensitivity to erosion and land units as a method as working units map applied for preparing of surface, rill and gully erosion features maps.

Accuracy: Figure 3 shows the accuracy of model d in preparing erosion features maps. The greatest and least accuracy is related to preparation of gully erosion map that working units have 89% conformity with field actual conditions. Accuracy is approximately similar for providing surface and rill erosions map. The least accuracy is related to providing erosion features map.

Table 1: Number of units in working units' maps

Working units' map	Crossed data layers	Working units' area (km^2) < 0.1	0.1-1	1-10	10-100	> 100	Total No. of working units
		No. of working units					
A	Slope, plant cover and lithology	302	286	296	17	1	902
B	Slope, land use and lithology	175	137	96	27	1	436
C	Slope, land use and rocks sensitivity	39	64	33	12	2	149
D	Land units, land use and rock sensitivity	12	23	26	22	3	86

Table 2: Accuracy, coefficient of variation (precision) and RMSE of crossed layers as working units' maps

Working units' map	Crossed data layers	Accuracy (%)	Error (%)	Accuracy coefficient of variation (%)	Root mean squared error (ha)
A	Slope, plant cover and lithology	68.3	31.7	34.8	1686.8
B	Slope, land use and lithology	67.4	32.6	40.1	716.0
C	Slope, land use and rocks sensitivity	53.4	46.6	30.9	1933.8
D	Land units, land use and rock sensitivity	66.6	33.4	36.5	1732.5

Table 3: 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	15.9	18.6	20.6	44.8
Rill	0.9	37.6	21.9	39.6
Gully	5.7	6.1	15.9	72.3
Erosion Features	39.9	15.5	6.0	38.6

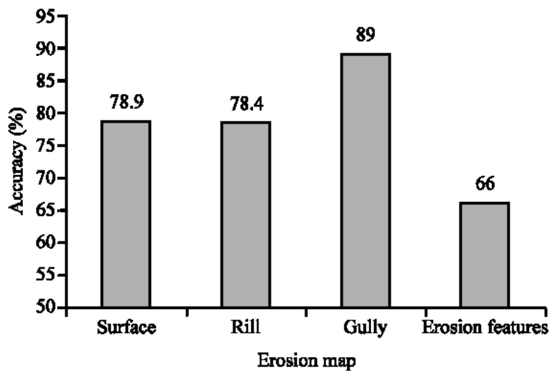

Fig. 3: The accuracy of model D in providing different erosions maps

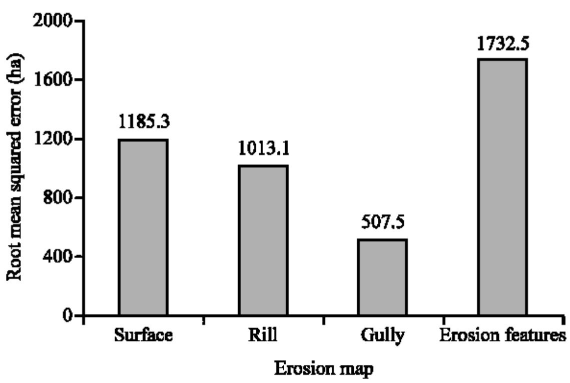

Fig. 4: The root mean squared error of model D in providing different erosions maps

It can approximately tell that working units had not the accuracy less than 50% for preparing rill erosion map, but the greatest area is related to providing erosion features map (39.9%). In providing gully erosion map, 72.3% area of working units had the accuracy more than 90%. Least area of working units in accuracy more than 90% is related to providing erosion features map (Table 3).

Root mean squared error: Results that are related to root mean squared error of model d are shown in Fig. 4. This index also shows that model has the least error for preparing gully erosion map as compared with other erosions. RMSE trend for providing different erosions map is following: Gully < rill < surface< Erosion features. Therefore, model has the greatest error in preparing erosion features map that RMSE is 1732.5 ha.

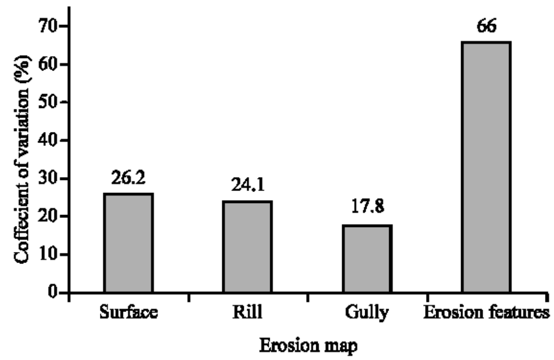

Fig. 5: The coefficient of variation (precision) of model D in providing different erosions maps

Precision: The greatest precision of model is related to providing gully erosion map, because have the least coefficient of variations (Fig. 5). Least precision of model with 40.5% coefficient of variations is related to providing erosion features map. Precision trend approximately is same with accuracy trend, with this difference that providing rill erosion map has a few more precision as compared with surface erosion map preparation.

DISCUSSION

Comparison of the four models a, b, c and d indicated that three models a, b and d have the nearly same accuracy, but the model d has a less precision as compared with the models a and b. In the models a, b and c, slope layer has applied. In the different studies, the slope layer is an important data layer in the integration of data layers. For providing quantitative erosion maps, slope layer is used as a basic layer (Singh *et al*., 1992; Feoli *et al*., 2002; Essa, 2004) and also, in providing qualitative erosion maps such as land slide map (Bayramin *et al*., 2003; Esmali and Ahmadi, 2003) and erosion risk map (Khawlie *et al*., 2002). But it should be regarded when the slope layer was used for providing erosion features map, it establish the high number of units with the small area. High numbers of working units, unit's replication and increasing field control points are the most important factors affecting on the map preparation expenses. In the 1:250,000 scales, representation of small working units is difficult and results in map confusion, color eating piecemeal and low quality (Mohammadi Torkashvand *et al*., 2005).

In addition to accuracy and precision, therefore, economic and executive matters are the very important factors in preparing erosion features map in the national scale (Rahnama, 2003). On the other hand, it is natural that the small units have more uniformity in compared with large ones causing more accuracy in maps a and b as compared to map D, although this difference was not considerable.

Therefore, pay attention to low difference accuracy between layers integration models and also economic and executive matters importance, model d has been distinguished as the better working units map for providing water-soil erosion map in 1:250000 scales in compared to other data layers integration models. In this model from land units' layers was used instead of the slope layer for the integration with the rocks erodibility and land use layers. Bou Kheir *et al.* (2006) also for providing risk map of soil erosion in Lebanon applied two data layers including erodibility of rock and soil and potential sensitivity to erosion. Shrimail *et al.* (2001) for prioritizing erosion-prone areas in hills, a cumulative erosion index computed from the rating given to the some main causative factors among them soil erodibility and land cover.

It seems when one of the erosion features has been considered, alone, accuracy is more as compared with erosion features. It is natural to increase the diversity in erosion type's intensities, consequently, decrease accuracy. Results indicated that the integration of land units, land use and rocks sensitivity layers establish working units with more uniformity with the view of gully erosion than surface and rill erosions. Model precision was low for preparing erosion features map. Surface and rill erosions

CONCLUSION

In conclusion, it seems that the model d is suitable for preparation of gully erosion map but had low accuracy and precision in providing erosion features map, consequently, it is not proposed. It is proposed to investigate the other method of data layers integration. It is also recommended to evaluate the different methods in a basin with climate, geology and various land use to differ from Jajrood sub-basin.

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