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Investigation of Some Methodologies for Gully Erosion Mapping

Ali Mohammadi Torkashvand
Islamic Azad University-Rasht Branch, Rasht, Iran

Abstract: The aim of this study is to investigate the accuracy, error and precision of some models for providing erosion types map in Jajrood sub-basin, north-east Tehran, Iran. Seven models were applied for providing working units maps that four models were prepared by the integration of different data layers. Other models were photomorphic units map derived from processing satellite images, land units map and rocks erodibility map. Gully erosion intensity in 314 spots was investigated to provide the ground truth map. This map was crossed by the different working units' maps. Results indicated that the integration of land use, rocks erodibility and land units layers is a better model than other models of data layers integration from an economic and executive regards. Accuracy for this model and photomorphic units map was 89.8 and 89.0%, respectively. The least coefficient of variation (14.1%), consequently, the highest precision was related to photomorphic units' map. Land units and rocks erodibility models, because of their low accuracy and precision, are not suitable for providing gully erosion map. That is why the best model is photomorphic units map.

Key words: GIS, gully erosion map, RS, soil erosion

INTRODUCTION

Gully erosion is a serious geo-environmental issue causing land degradation. It causes damages to vulnerable agricultural lands, water pollution by soil particles and chemicals and mudflows which may affect urban areas (Poesen and Hooke, 1977). In contrast to the effort during the last decades to investigate sheet (inter-rill) and rill soil erosion processes, relatively few studies have been focused on quantifying and/or predicting gully erosion (Martinez Casasnovas, 2003). Gullies can develop as enlarged rills, but their genesis is generally more complex, involving sub-surface flows and sidewall processes (Bocco, 1991). The geographic distribution of gullies is one of the most important information required for soil conservation. Large gully systems have received much attention from researchers using modern geospatial analysis (Tabatabaei, 2000; Zinck *et al*., 2001; Martinez Casasnovas, 2003; Martinez Casasnovas *et al*., 2004).

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). But it should be regarded that field survey and photo interpretation for gully 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 (DEM) and remote sensing, have created new possibilities for research as a key for gully erosion mapping (Martinez Casasnovas, 2003) that is economical due to low costs as well as quickness (Raoofi *et al*., 2004).

Gully erosion is a serious problem in many parts of the world and particularly in Iran, because of climate, lithology, soils, relief and land use/cover characteristics. Iran Watershed Evaluation and Studies Office (2000) prepared a design for providing erosion types map at the national level (scale-1:250000). They integrated data layers of soil, slope, lithology, land type and land use for providing working units map, but field investigations had indicated that this way is impossible for the total area of Iran because of time and costs. In Isfahan province as a pilot design, Rahnama (2003) investigated the possibility of preparation of soil erosion features map by aerial photograph interpretation and concluded similar results. He recommended satellite imagery and GIS for this aim.

Sirvio *et al*. (2004) have investigated gully erosion hazard assessments in Taita Hills, SE-Kenya, applying airborne digital camera orthomosaics and GIS for small-scale studies and field measurements for large-scale studies. Detection of distribution and intensity of gully erosion and main factors affecting gully erosion were investigated within Taita Hills and changes during the last 50 years. Raoofi *et al*. (2004) categorized rill and gully erosions in Taleghan basin-Tehran province by using visual interpretation of images derived from the fusion of ETM+ bands and Cosmos image. Also a map of ground truth from eroded regions was provided by using Cosmos image as well as visual interpretation and field observations. Measurements had indicated an approximate 80% accuracy for the categorization. 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.

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; Sidorchuk *et al*., 2003) and less to preparing an erosion features map. 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 gully erosion map and its intensities with regards to statistics factors such as accuracy, precision and error, have not been done. The aim of this research is to develop a methodology based on data layers integration in GIS and satellite images processing for providing gully erosion map at the national scale (1:250000).

MATERIALS AND METHODS

The Jajrood sub-basin with 162,558 ha located 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 northeast to southeast Tehran province, Iran. The highest and the lowest height of the basin are 3000 and 867 above msl, 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. Basin lithology 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). 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.

Necessary maps such as topographic, geology, plant cover type and land units were scanned and georeferenced. Digital Elevation Model (DEM) was prepared by 1:50,000 topographic digital data, classified slope map-the DEM-derived slope map was classified into eight slope (percent) classes 0-2, 2-5, 5-8, 8-12, 12-20, 20-40, 40-70 and >70 based on Mahler (1979) classification, land use was derived using ETM^+ satellite image and rocks erodibility layer based on Feiznia (1995). According to their sensitivity to erosion, the rocks were categorized into the following five classes: very sensitive, sensitive, moderately sensitive, resistant and very resistant.

Seven methods were used to prepare working units' maps of which four methods were 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 units' 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 through exploratory studies in Kan sub-basin (Mohammadi-Torkashvand *et al*., 2005). Slope, plant cover type, geology, land use and land unit are the important factors in the formation of the soil-water erosion features.

Image processing included radiometric correction, selecting best bands for making colour composite with regards to the OIF, 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 colour composites were compared and the best color image was selected for the distinction of erosion features. From DEM, a hill shade layer was prepared and overlayed on a color composite that obtained 3-D view possibility. Regarding the lack of visual distinction of small and moderate 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 Antrop, 1977).

Different methods were incorporated for classification of gully erosion severity such as Flugel *et al*. (1999), 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). A total of 314 points has been considered on color composite images (for field investigation) by classified random sampling. Figure 1 shows the positions of these points.

A primary polygon was determined for each control point regarding image characteristics. The intensity of

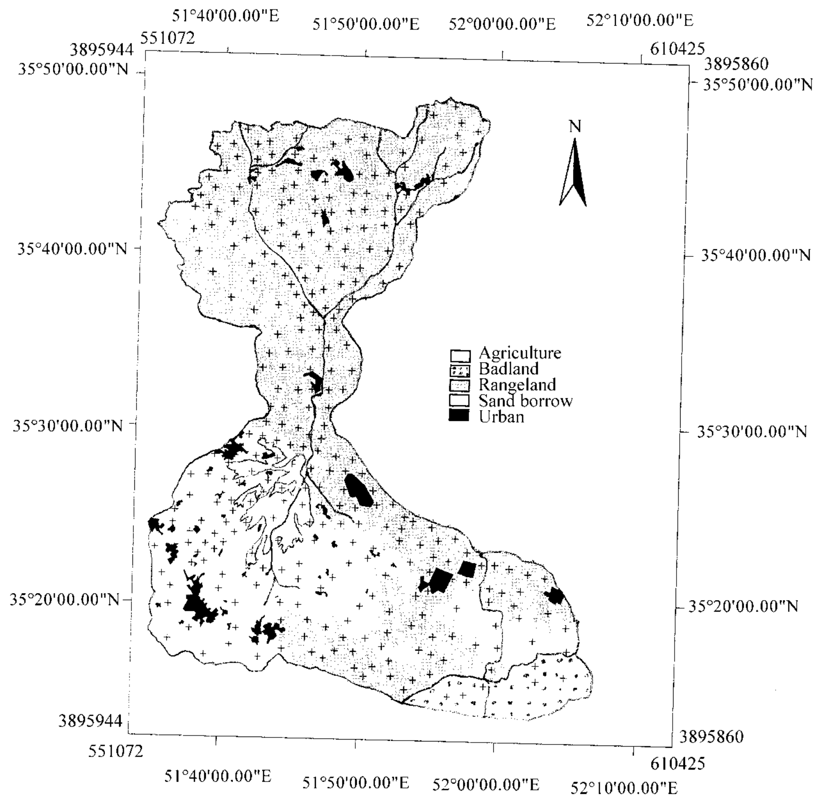

Fig. 1: The position of ground control points (+) in Jajrood sub-basin

Table 1: Classification of gully erosion intensity

Gully depth (cm)	Erosional activity	Gullies distance (m) <25	25-50	50-150	150-500	>500
30-150	1*	Sever	Moderate	Low	-	-
	2**	Sever	Sever	Moderate	Low	-
	3***	Very sever	Sever	Moderate	Low	-
50-500	1	Sever	Sever	Moderate	Low	-
	2	Very sever	Sever	Moderate	Low	-
	3	Very sever	Very sever	Sever	Moderate	Low
>500	1	Very sever	Sever	Moderate	Low	-
	2	Very sever	Very sever	Sever	Moderate	Low
	3	Very sever	Very sever	Very sever	Sever	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

gully erosion was investigated in these ground control points and then frontiers of each polygon were corrected with due attention to field views (Table 1). Modified polygons were marked with regards to the intensity of gully erosion in field. Polygons with same the intensity were combined together and ground truth map of gully erosions was prepared. This map has been crossed by working units' maps to investigate the ability each of models on separating gully erosion intensities. Equation 1 was used for investigating each of models accuracy.

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

where, A is model 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 comparison to the actual conditions (per cent). Root mean squared error of working units' accuracy (RMSE) was computed by Eq. 2.

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

where, $Z_{(xi)}$ is working units' area (ha) that is uniform in actual condition. The precision each of models was obtained by Eq. 3.

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

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

RESULTS

In layers integration models, the most and the least numbers of working units are related to models a and d, respectively. Most polygons of models a, b and c have a small area which is not possible to be presented in the maps 1:250,000 due to cartographic limitations. Least numbers of units' is related to rocks erodibility and land units maps, but the units' area is great (Table 2). In all models, less than 10% of working units area exist in the accuracy less than 50%. In the high accuracy (more than 90%), the greatest area of working units is related to model a. Least area of working units in the accuracy more than 90% is related to model f. Only 54.0% of working units area in model e i.e., photomorphic units map, have the accuracy more than 90% that is less than data layers integration models (Table 3).

The greatest and the least accuracy are related to models a and b that is 68.3 and 53.4%, respectively. The difference of accuracy between models a, b, c, d and e is not considerable, but it is significant with models f and g. Cross of seven working units' maps and ground truth map with the view of root mean squared error are shown at Table 4. Results indicated the greatest error is related to model g that RMSE is 9480.8 ha with very considerable difference as compared with other methods. In data layers integration models, RMSE is least for model a and then model d. Also, model f has a high error (2466.1 ha).

Table 4 shows the coefficient of variations of working units' accuracies (CV), that a high coefficient of variation i.e., low precision. The greatest precision is related to model e that had obtained from satellite images interpretation. Least precision is also related to models f and g. In data layers integration methods, model c had the least precision.

Table 2: Number of units in the working units' maps of the Jajrood sub-basin

Working units map (Model)	Working unit No.	Units area (km^2) <0.1	0.1-1	10-Jan	10-100	>100
a	902	352	335	296	17	1
b	436	175	137	96	27	1
c	149	39	44	29	-	2
d	86	12	23	26	22	3
e	17	-	-	3	10	4
f	6	-	-	1	1	4
g	76	-	2	37	36	1

Table 3: Percentage of working units' area compared with the basin area in different accuracies

Model	Accuracy 50>	50-70	70-90	90<
a	-	3.40	5.20	91.4
b	2.3	3.60	7.80	86.3
c	5.2	4.90	11.3	78.6
d	5.7	6.10	15.9	72.3
e	7.4	22.8	11.6	58.2
f	-	71.1	-	28.9
g	3.1	6.40	36.5	54.0

Table 4: Accuracy, error and precision in different methods

Working units' map	Accuracy (%)	RMSE* (ha)	Accuracy coefficient of variation (%)
a	92.6	462.5	15.4
b	90.4	868.2	14.8
c	90.2	646.4	18.2
d	89.0	507.5	17.8
e	82.0	2466.1	26.5
f	71.9	9480.8	31.4
g	89.8	996.2	14.0

DISCUSSION

In addition to accuracy and precision, economic and executive matters are very important factors in preparing soil erosion features map in the national scale (Rahnama, 2003). 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) and also, in providing qualitative erosion maps such as land slide map (Bayramin *et al.*, 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. On the other hand, it is natural that the small units have more uniformity in comparison with large ones causing more accuracy in models a and b as compared to other models, although this difference is not considerable between models a, b, c, d and e. Off course, models that derived from layers integration have same precision, approximately.

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). Therefore, pay attention to low difference accuracy and precision between layers integration models and also economic and executive matters importance, map d has been distinguished as the better working units map for providing erosion gully map in 1:250000 scales as compared with other data layers integration methods.

Rocks erodibility and land units maps are having large units, but those are not homogenous with the view of gully erosion intensity. Increasing units' area is caused to increase the diversity of gully erosion intensity due to more variables affect on this erosion feature. Consequently, accuracy, error and precision of these maps reduce that this subject is more for rocks erodibility map. Using these two maps, by Mohammadi-Torkashvand and Nikkami (2006) for providing erosion features map, suitable methods have not also been distinguished. Therefore, not only economic and executive regards are important for providing erosion features mapping, but also, accuracy and precision have importance.

Previously, it had been talked that processing ETM^+ images for distinguishing gully erosion intensities were done, but this processing was not caused distinction of small and medium gullies. 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. For large gullies in Central Brazil, Vrieling and Rodrigues (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). Raoofi *et al*. (2004) distinguished that gully erosion map derived from visual interpretation of Cosmos images with ground truth map had 80% conformity.

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 (Alavipanah, 2004). Therefore, regarding drainage pattern, physiographic and other properties on color composite image, was prepared the photomorphic units map. 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's map had the great conformity as compared with gully erosion truth map.

CONCLUSION

In the 1:250,000 scales, representation of small working units is difficult and results in map confusion, color eating piecemeal and low quality. Therefore, when the slope layer is used for providing erosion features map in four models, it established 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. The model derived from the integration of rocks erodibility, land use and land units layers were better than other models.

Comparison of accuracy, error and precision of this model with the land units and rock sensitivity maps and photomorphic units' map showed that differentiating photomorphic units in satellite imagery makes more uniform units for using as working units in gully erosion studies. As the second precise method, data layers integration, with same accuracy (89%) is applicable in providing gully erosion map. It is suggested that integration of other layers and satellite images with higher resolution were investigated for this aim.

REFERENCES

Alavipanah, S.K., 2004. Application of Remote Sensing in the Earth Sciences (Soil). University of Tehran Press, Tehran, Iran.

Allan James, L., D.G. Watson and F.H. William, 2007. Using LiDAR data to map gullies and headwater streams under forest canopy: South Carolina, USA. Catena, Article, Corrected Proof, (In press).

Bayramin, I., O. Dengiz, O. Baskan and M. Parlak, 2003. Soil erosion risk assessment with ICONA model, case study: Beypazari area. Turk. J. Agric. For., 27: 105-116.

Boardman, J., A.J. Parsons, R. Holland, P.J. Holmes and R. Washington, 2003. Development of badlands and gullies in the Sneeuberg, Great Karoo, South Africa. Catena, 50 (2-4): 165-184.

Bocco, G., 1991. Gully erosion: Processes and models. Prog. Phys. Geogr., 15 (4), 392-406.

Daeles, L. and M. Antrop, 1977. The extraction of soil information from remote sensing documents. Pedologic, 27: 123-190.

Feiznia, S., 1995. Rocks resistant to erosion in Iran different climates. J. Iran Nat. Res., 47: 95-116.

Feoli, E., L.G. Vuerich and W. Zerihun, 2002. Evaluation of environmental degradation in northern Ethiopia using GIS to integrate vegetation, geomorphological, erosion and socio-economic factors. Agric. Ecosyst. Environ., 91 (1-3): 313-325.

Flugel, W.A., M. Marker, S. Moretti, G. Rodolfi and H. Staudenrausch, 1999. Soil erosion hazard assessment in the Mkomazi river catchment (Kwazulu/Natal-South Africa) by aerial photo interpretation. In: Zentralblatt fur geologie und palaontologie. Teil I, 3 (4): 641-653.

Frazier, B.E., D.K. Mc Cool and C.F. Engle, 1983. Soil erosion in the palouse: An aerial perspective. J. Soil Water Cons., 38: 70-74.

Goosen, D., 1967. Aerial photo interpretation in soil survey. Soil Bulletin. 6. FAO, Rome.

Hajigholizadeh, M., 2005. Capability using high resolution satellite images in distinguishes some erosion features in Tehran province, Iran. In: The Proceeding 3rd Erosion and Sediment National Conference. Soil Conservation and Watershed management Research Institute, Tehran, Iran.

Iran Watershed Evaluation and Studies Office, 2000. A design for providing Iran erosion features map at 1:250000 scale. Under Ministry for Education and Research, Ministry of Jihad-e-Agriculture, Iran.

Khawlie, M., M. Awad, A. Shaban, R. Bou Kheir and C. Abdallah, 2002. Remote sensing for environmental protection of the Eastern Mediterranean rugged mountainous areas, Lebanon. ISPRS J. Photogrammetry Rem. Sens., 57: 13-23.

King C. and G. Delpont, 1993. Spatial assessment of erosion: Contribution of remote sensing, a review. Remote Sens. Rev., 7: 223-232.

Mahler, P.J., 1979. Manual of Land Classification for Irrigation. Soil Institute of Iran Publications, No. 205.

Martinez-Casasnovas, J.A., 2003. A spatial information technology approach for the mapping and quantification of gully erosion. Catena, 50 (2-4): 293-308.

Martinez-Casanovas, J.A., M.C. Ramos and J. Poesen, 2004. Assessment in sidewall erosion in large gullies using multi-temporal DEMs and logistic regression analysis. Geomorphology, 58: 305-321.

Mohammadi-Torkashvand, A., D. Nikkami and M. Esfandiari, 2005. Investigation of methodology for preparing erosion features map, case study: Tehran Kan-Sologhan basin. In the Proceeding for 3rd Erosion and Sediment National Conference. Soil Conservation and Watershed management Research Institute, Tehran, Iran.

Mohammadi-Torkashvand, A. and D. Nikkami, 2006. Erosion features map: A basic map for soil sustainable management. In: The Proceeding of Soil, Environment and Sustainable Development National Conference. Water and Soil Engineering College, Tehran University, Tehran, Iran.

Poesen, J.W.A. and J.M. Hooke, 1997. Erosion, flooding and channel management in Mediterranean environments of Southern Europe. Prog. Phys. Geogr., 21: 157-199.

Rahnama, F., 2003. International design for providing erosion features map in the part of Isfahan province, Iran. Workshop of modern technologies designs (GIS-RS) in soil conservation. Soil Conservation and Watershed Management Research Institute, Tehran, Iran.

Raoofi, M., H.Gh. Refahi, N. Jalali and F. Sarmadian, 2004. A study of the efficiency of digital processing methods of satellite images to map and locate soil erosion. Iran. J. Agric. Sci., 35 (4): 797-807.

Refahi, H.Gh., 2000. Soil Erosion by Water and Conservation. 2nd Edn. Tehran University Publications, Tehran, Iran.

Siakeu, J. and T. Oguchi, 2000. Soil erosion analysis and modelling: A review. Trans. Jap. Geomorphol. Union, 21 (4): 413-429.

Sidorchuk, A., M. Marker, S. Moretti and G. Rodolfi, 2003. Gully erosion modeling and landscape response in the Mbuluzi catchment of Swaziland. Catena, 50 (2-4): 507-525.

Singh, G., R. Babu, P. Narain, L.S. Bhushan and I.P. Abrol, 1992. Soil erosion rates in India. J. Soil Water Conserv., 47 (1): 97-99.

Sirvio, T., A. Rebeiro-Hargrave and P. Pellikka, 2004. Geo-information in gully erosion studies in Taita hills, SE-Kenya, preliminary results. In: The Proceedings of the 15th Africa Association of Remote Sensing of Environment Conference. Nairobi, Kenya.

Stromquist, L., B. Lunden and Q. Chakela, 1985. Sediment sources, sediment transfer in a small Lesotho catchment-A pilot study of the spatial distribution of erosion features and their variation with time and climate. South Afr. Georgr. J., 67: 3-13.

Stromquist, L., 1990. A Multilevel Approach to Soil-erosion Surveys. Examples from the Lesotho lowlands. In: Monitoring soil loss at different observation levels-Case studies of soil erosion in the Lesotho Lowlands, Stromquist, L. (Ed.). UNGI Uppasala University, Uppasala.

Sujatha, G., R.S. Dwivedi, K. Sreenivas and L. Venkataratnam, 2000. Mapping and monitoring of degraded lands in part of Jaunpur district in Uttar Pradesh using temporal space borne multispectral data. Int. J. Rem. Sens., 21: 519-531.

Tabatabaei, S.M.R., 2000. Investigation of gully erosion changes trend in Khoozestan province by using GIS and satellite imagery. In: The Proceeding of 2nd Erosion and Sediment National Conference. Soil Conservation and Watershed Management Research Institute, Tehran, Iran.

Tripathi, N.K. and A.M. Rao, 2001. Investigation of erosion on Hope Island using IRS-ID LISSIII data. Int. J. Rem. Sens., 22: 883-888.

Vrieling, A. and S.C. Rodrigues, 2004. Erosion assessment in the Brazilian Cerrados using multi-temporal SAR imagery. Proceedings of the Envisat and ERS Symposium. SP-572, ESA, Salzburg, Austria (2004).

Vrieling, A., 2006. Satellite remote sensing for water erosion assessment: A review. Catena, 65 (1): 2-18.

Ygarden, L., 2003. Rill and gully development during an extreme winter runoff event in Norway. Catena, 50 (2-4): 217-242.

Zinck, J.A., J. Lopez, G.I. Metternicht, D.P. Shrestha and L. Vasquez-Selem, 2001. Mapping and modeling mass movements and gullies in mountainous areas using remote sensing and GIS techniques. Int. J. Applied Earth Obser. Geoinform., 3 (1): 43-53.