Assessing the Capability of Satellite Data for Soil Mapping

1- Ali Sarabchi*, 2- Mohammad Hasan Salehi., and 3- Mohammad Amir Delavar 4- Mehdi Naderi

1- Instructor of Soil Science Department, College of Agriculture, Zanjan University,
2-Assistant Professor of Soil Science Department, College of Agriculture, Shahrekord University,
3- Assistant Professor of Soil Science Department, College of Agriculture, Zanjan University,
4- Assistant Professor of Soil Science Department, College of Agriculture, Shahrekord University
* Corresponding author, Postal address: P.O. Box 313 , Zanjan University, Zanjan Province, Iran. Email: Alisarabchi@yahoo.com, Fax: +982412283202 Tel: +982415152236

ABSTRACT

The purpose of this research is to evaluate the potential of using landsat ETM+ data for soil mapping. The study area is located in center of Iran and covers about 1300 ha. The database of studied area was created by introducing topographic map (1:25,000), soil map (1:20,000) and reports and satellite data. After pre-possessing stage, selection of the best informative bands was carried out using optimum index factor (OIF) calculation and principle component analysis (PCA). Results showed that bands TM1, TM4 and TM6-2 contain the highest information and the lowest redundancy. Besides the mentioned bands, TM5 and TM7 were considered for digital image classification. The images were classified using maximum likelihood classifier into seven mapping units. Separability of mapping units examined at 95% confidence level. Comparison of the prepared soil map from satellite data and ground truth showed a relatively high accuracy of 80%. Also, comparison of prepared soil map from satellite data and detailed soil maps prepared using conventional methods showed imagery data could increase the classification and interpretative purity percentage up to 50% and 85%, respectively. The results indicated high potential of imagery data for inventory and increasing the precision of existing soil maps. Therefore, incorporation of high-resolution satellite data for soil survey especially in arid and semi-arid regions is highly recommended.

Keywords: Landsat ETM+ data, Soil mapping, Purity

INTRODUCTION

The objective of soil survey is to study about actual and potential land use management strategies (Rossiter, D.G., 2000). For employment a better strategy for land use management, the soil maps that are prepared through the soil survey should following characteristics (Patrick A. Agbu et al. 1990): (i) Variation in terms of significant soil properties within mapping units should be minimum whereas the variation among mapping units should be maximum. (ii) Effectively characterize the mapping units in terms of significant soil properties. (iii) Grouping the soils that are similar, and then to express accurately the properties of each grouping. According to Western (1978) and Bregt et al. (1992), the quality of a map is a function of reliability, relevance and presentation of the information

Perhaps, the most serious limitation of traditional soil survey process is the assignment of properties derived form typical soil profiles to the entire map unit regardless of the inherited spatial and temporal variability of field soils (Beckett and Webster, 1971; Baker 1978; Bouma et al. 1980; Breeuwsma et al. 1986). Salehi et al. (2003) expressed that although criteria for purity of mapping units have been improved; however, traditional soil mapping approaches are not able to reasonably show the variability of pedons and top soil properties even in a detailed soil map named at series level.

It seems that the capability of imagery data can compensate drawbacks of traditional soil maps. Many researchers applied Landsat TM data for predicting soil properties (Rayan et al., 2000, Campling et al., 2002) or soil classes based on a soil classification system (Lee et al., 1988; Thomas et al., 1999). Dobos et al. (2000) defined digital soil mapping as computer assisted production of a digital map of soil type and soil properties. We believe that the progresses in computer software and satellite data can help to soil surveyors to denote soil surface changes and increase the precision of soil maps. The objective of our research is to study the possibility of soil mapping with integration of ETM+ satellite data, field works, and thematic maps like digital topographic maps and its derivates in Central Iran.

MATERIALS and METHODS

Study Area and Data Collection

The study site locates between 32° 17´ to 32° 20´ N and 51° 3´ to 51° 5´ 3˝ E in the Chaharmahal and Bakhtiari province, Iran and encompasses an area of 1300 ha. Mean annual rainfall is 220 mm and mean altitude of study area is 2100m above the sea level. Main landforms are alluvial plain, outwash and hills. According to U.S. Soil Taxonomy (soil survey staff, 2006) the soil moisture and temperature regimes of the area are Xeric and Mesic, respectively.

Database of the study area was constructed by collecting digital topographic maps (1:25,000), existing detailed soil map (1:20,000) and reports (the information of 85 soil profiles; Salehi et al. 2003), aerial photographs (1:20,000) and Landsat (ETM+) digital imagery data. The satellite data obtained on 2 July 2001, including reflectance TM bands (TM1-TM5 and TM7), thermal bands (TM6-1 and TM6-2) and panchromatic band (TM8). Image processing was performed using ILWIS 3.3 (Integrated Land and Water Information System, developed by ITC, 2007).

Preparing of Digital Soil Map

Preparing of digital soil map was carried out in three stages. At first, the satellite data were georeferenced using topographic map (1:20,000) and GPS (Garmin 12XL) during preliminary field work with minimum possible error. In the second stage, the best informative bands were selected by considering statistical characteristics of them and calculating of optimum index factor (OIF) and principle component analysis (PCA).

Considering of different soil forming factors showed the topography have a major impact on soil variability. Thus, the study area was divided based on major landforms into three units, including hill (H), alluvial plain (P) and outwash (O), by using topographic map and digital elevation model (DEM).

In third stage, A supervised image classification approach and maximum likelihood algorithm was performed by introducing the pixels related to 46 sites covering the major physiographic units as training area. The training sites were determined by considering physiographic units, DEM, depth of A horizon and its properties like percent of sand, silt and clay, organic matter content, $CaCO_3$ equivalent and soil surface gravel percentage (data not shown) and were addressed to the false color composite (obtained from best informative bands) of the area. Feature spaces were considered during introduction of training sites. Because of different spectral behavior of training sites in three main units (H, O and P), each units were divided into several subunits (spectral classes). By considering mean and standard deviation of each subunits, separability of different spectral classes were examined at 95% confidence intervals and the importance of informative TM bands for separation and distinguishing of different spectral classes were determined. The supervised classified image divides the study area into several spectral units, which were considered as soilscape/soil map units. The resulted map was smoothed by post classification filtering. Thus individual pixels and the resulted units which cover areas less than 1.6 ha (minimum legible area (MLA) according Soil Survey Manual, 1993) were merged into main units.

At post classification stage, A confusion matrix was elaborated by crossing known samples as ground truth (major taxons at soil series level in each spectral unit) and the classified image, to evaluate accuracy of classification performance. In this study, besides saved information of soil profiles and observation points in database, 12 profiles were excavated and described in unsampled areas and were used as ground truth.

Comparison of Digital and Traditional Soil Map

The new soil map (NSM) was assessed by calculating taxonomic and interpretation purities and compared with the traditional soil map (TSM). The taxonomic purity of the dominant soil in each map unit at family and series levels was determined and compared with the traditional soil map. To find interpretive purity, percentages of the dominant taxon and soils similar to dominant taxon in each map unit were combined. In this study, similar soils were marginally outside the limits of the particle size and/or mineralogy classes defined in soil control section at family level for dominant taxon.

RESULTS and DISCUSSION

Band Selection

Table 1, shows the results of OIF calculation. The table indicates that the thermal bands have important role in soil inventories. According to Alavi Panah et al. (2001), thermal bands have a key role for studying different soils in arid and semiarid zones; therefore application of these bands improves the accuracy of classification in such regions. According to Table 1, optimum index factor (OIF) calculations indicate the most informative bands are TM1, TM4 and TM6-2. Besides bands TM1, TM4 and TM6-2, we applied bands TM5 and TM7, which are emerged in the second and third ranks. Therefore, TM1, TM4, TM5 and TM6-2, and TM7 were selected for image classification.

Table1. OIF values of TM bands combinations.

Bands composition	OIF value
TM6-2, TM1, TM4	42.5
TM6-2, TM4, TM7	36.43
TM6-2, TM1, TM5	35.99
TM6-2, TM1, TM7	33.89
TM6-1, TM1, TM	32.37
TM6-2, TM3, TM4	32.37

Based on suggestions of Masul et al. (1990), results from principle component analysis (PCA) can be used for image classification. They suggested four bands that have maximum eigenvectors in the first principle component, are useful. Therefore, beside of OIF calculation principle component analysis (PCA) was applied for band selection. The results of principle component analysis indicate that TM1, TM3, TM6-2 and TM7 have maximum eigenvectors in the first principle component, respectively (Table 2). Therefore the results of PCA highly confirm OIF results. The results correspond to the findings of other workers in arid and semi-arid zones. Al-Bakri (2000) and Ziadat et al. (2003) recommended TM1, TM5 and TM7 combination for mapping soils in arid and semi-arid zones.

Table 2.The eigen values for nine principle components

		TM Bands								
		TM1	TM2	TM3	TM4	TM5	TM6-1	TM6-2	TM7	TM8
Principal components	PC1	0.510	0.300	0.506	0.152	0.203	0.329	0.740	0.512	0.213
	PC2	-0.112	0.088	-0.025	0.021	-0.096	0.156	0.481	-0.071	-0.009
	PC3	0.405	0.430	0.477	0.175	-0.533	0.021	0.015	-0.294	0.012
	PC4	0.039	0.100	-0.077	0.748	0.055	-0.028	-0.008	-0.475	0.458
	PC5	-0.641	-0.291	0.574	0.176	-0.327	-0.089	-0.067	0.128	0.088
	PC6	-0.084	0.010	0.328	0.123	0.430	-0.002	-0.002	-0.481	-0.674
	PC7	-0.139	0.140	0.168	0.575	0.359	-0.001	-0.006	-0.436	0.532
	PC8	-0.585	0.776	-0.211	0.095	0.028	0.018	-0.024	-0.010	-0.011
	PC9	0.032	0.019	-0.001	0.008	0.002	0.491	-0.870	0.870	0.00

Separability of Training Sites

Considering of feature spaces (data not shown) indicated that the studied area can be divided into several subunits or spectral classes including H1, H2, P1, P2, P3, Agri., O1 and O2. Agir. was a cultivated area and merged into the appropriated unit by considering its attributed profile description. Figure 1 shows separability of different spectral classes at 95% confidence intervals. According to Figure 1, bands TM5 and TM6-2 could be able to separate classes H1 and H2. Band TM5 could differentiate class H2 from other spectral classes. Spectral class O1 could be separated from classes O2, P1, P2 and P3 using TM1. Classes O1 and O2, which are varied in gravel content (Table 3) could be differentiated using visible and infrared bands (Figure 1). Class P1 with the lowest surface gravel (Table 3) expresses higher radiation in the thermal band. Overlaying of single standard deviations of units P2 and P3 indicates hardly discrimination of these features by single bands.

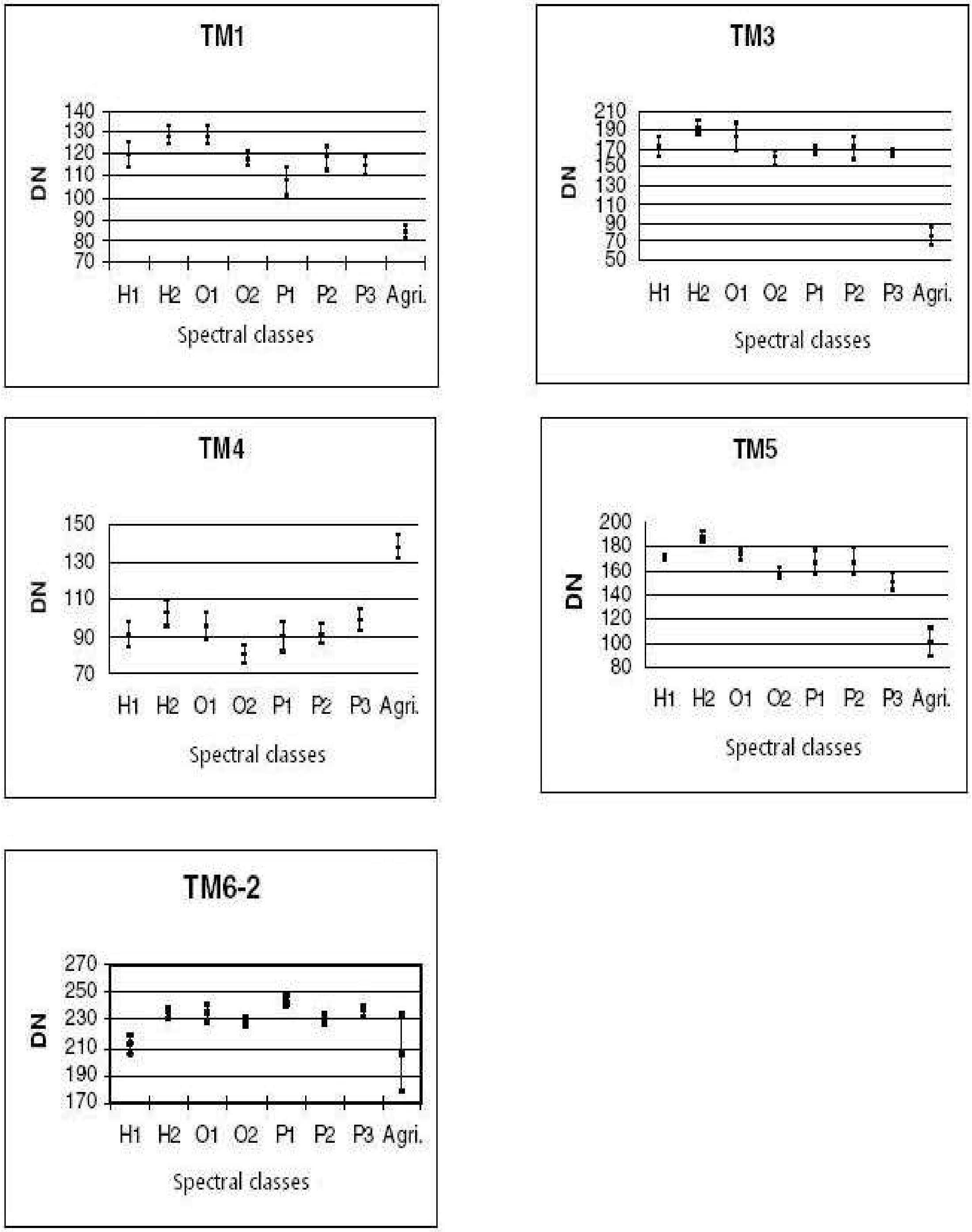

Figure 1. separability of different spectral classes at 95% confidence intervals

We hope using multispectral bands and maximum likelihood approach, which considers the probability of membership of pixels for each class aid to optimize differentiation of these features. Training areas of alluvial plains P1, P2 and P3 are varied in gravel and $CaCO_3$ equivalent content (Table 3) and in the feature space plot of TM5-TM7 these units are separated efficiently.

Table 3. Some physical and chemical characteristics of A horizons of training areas

Spectral class	Soil surface characteristics in spectral classes (soil mapping units)					
	Land form	Texture	$CaCO_3$ (%)	Gravel (%)	Organic matter (%)	Depth of A horizon (cm)
P3	Alluvial plain	Clay loam	10-20	14-28	0.4-0.7	20
P2	Alluvial plain	Loam- silty clay loam	19-43	21-57	0.7-0.9	20
P1	Alluvial plain	Clay loam- silty clay	10-25	2-11	0.7-0.9	20
H1	Hill	Clay loam	23-36	30-35	0.95-1.1	20
H2	Hill	Loam	37-51	25-35	0.7-0.8	20
O1	Outwash	Loam	19-30	45-65	0.6-0.9	15
O2	Outwash	Clay loam	15-30	25-45	0.95-1.12	15

Evaluation of Image Classification Accuracy

For classification assessment, a confusion matrix was formed and the classified image and the field verified samples of different classes not used for training were compared (data not shown). The results show maximum class accuracy is 91.2% and belongs to class O2 and minimum accuracy is for H1 (71.6%). The overall classification accuracy is 80%.

Comparison of Some Mapping Precision Parameters in New and Traditional Soil Maps

Comparison of taxonomic purities of new soil map and traditional soil map at soil family level shows that the purities of mapping units for the digital soil map varies between 40% and 59% while these values range from 27% to 60% for the traditional soil map. Taxonomic purities of dominant soils in the digital soil map at soil series level range from 40% to 50% whereas for the traditional soil map such purities range from 19% to 33.5%, respectively (Figure 2). This shows that results obtained by the digital soil map are closer to the expected criteria of American Soil Survey Manual (1993).

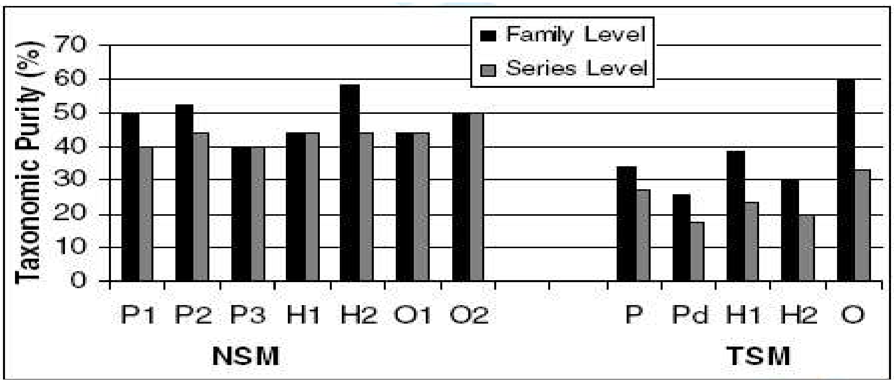

Figure 2. Taxonomic purity in map units of NSM and the TSM at family and series levels.

Interpretative purity is considered as a reliability index of soil maps (Beckett and Webster, 1971; Bie and Beckett, 1973; Marsman and De Gruijter, 1986). The results indicate that interpretive purities of mapping units for the new soil map vary between 60 and 85 percent while these values for the traditional soil map were range between 40% and 75% (Figure 3). Consequently, the definition of the mapping units according to interpretive purity instead of taxonomic purity can be used for increasing the reliability of soil maps.

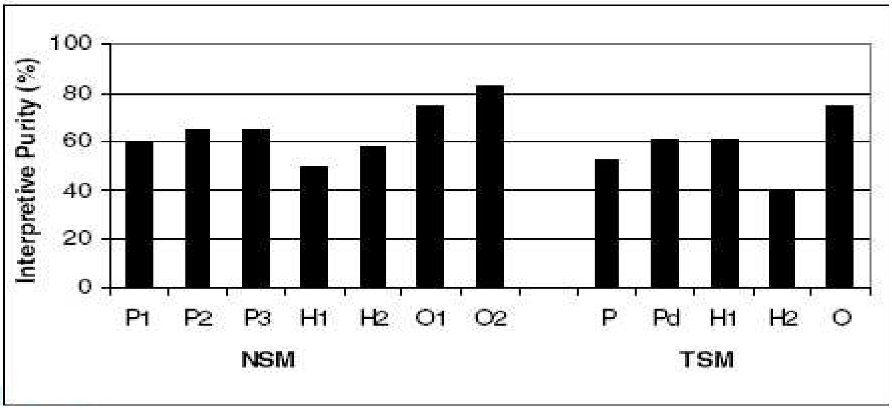

Figure 3. Interpretive purity in map units of the NSM and the TSM

CONCLUSION

The results indicate high potentials of Landsat ETM+ data for differentiation soil mapping units in arid or semi-arid soils with no or sparse vegetation. Possible inventory of new mapping units using satellite data promise improving the quality of traditional soil maps. By Integration of satellite imagery data, field works, digital elevation models and with employment of geographic information systems may facilitate soil mapping in arid and semi-arid zones.

REFERENCES

Alavi Panah, S.K., M. De Dapper, R. Goossens and M. massoudi. 2001. The use of TM thermal band for land cover/land use mapping in two different environmental conditions of Iran. J. Agric. Sci. Technol., Vol. 3: 27-36.

Al-bakri, J. T. 2000. Remote Sensing Techniques for Environmental Monitoring of Semi arid Zones of Jordan. Ph.D Thesis, Cornfield University.

Baker, F.G. 1978. Variability of hydraulic conductivity within and between nine Wisconsin soil series. Water Resour. Res., 14: 103-108.

Beckett, P.H.T., R. Webster. 1971. Soil variability: a review. Soil Fert., 34: 1-15.

Bie, S.W. and P.H.T. Beckett. 1973. Comparison of four independent soil series by air photo interpretation, Paphos area (Cyprus). Photogrammetria 29,189-202.

Bouma, J., De Loat, P.J.M. Van Holst and Th. J. Van De Nes. 1980. predicting the effect of changing water table levels and associated soil moisture regimes for soil survey interpretations. Soil Sci. Soc. Am. J., 44:797-802.

Breeuwsma, A., J.H.M. Wosten, J.J. Vleeshoumer, A.M. Van Slobbe and J. Bouma. 1986. Derivation of land qualities to assess environmental problems from soil survey. Soil Sci. Sco. Am. J., 50:186-190.

Breget, A.K., J. J. Stoorvogel, J. Bouma and A. Stein. 1992. Mapping ordinal data in soil survey: A Costa Rican example. Soil Sci. Soc. Am. J., 56: 525-531.

Campling, P., A. Gobin, and J. Feyen. 2002. Logistic modeling to spatially predict the probability of soil drainage classes. Soil Science Society of America Journal Vol. 66:1390-1401.

Dobos, E., E. M. Micheli, F. Baumgardener, L. Biehl, and T. Helt. 2000. Use of combined digital elevation model and satellite radiometric data for soil mapping. Geoderma 97:367-91.

ITC. 2007. ILWIS 3.3 For windows. The Netherlands.

Marsman, B.A. and J.J. De Gruijter. 1986. Quality of soil maps: a comparison of survey methods in a sandy area. Soil Surv. Pap. 15 (Stiboka, Wageningen, Netherlands, 103p).

Mausel, P.W., W.J. Karmer, and J.K. Lee. 1990. Optimum bands selection for supervised classification of multi spectral data. Photogarmetric Eng. and Remote Sensing, Vol. 59, No. 1, pp: 55-60.

Patrick A., Agbu, Donald J., Fehrenbacher and Ivan J., Janson. 1990. Statistical comparison of SPOT spectral maps with field soil maps. Soil Sci. Soc. Am. J., 54: 812-818.

Rossiter, D.G. 2000. Methodology for Soil Resource Inventories 2nd Revised Version. International Institute for Aerospace Survey and Earth Science (ITC).

Ryan, P. j., N. J. McKenzie, D. O'Connell, A. N. Loughhead, P. M. Leppert, D. Jaequier, and L. Ashton. 2000. Integration forest soils information across scales: spatial prediction ofsoil properties under Australian Forest Ecology and Management 138:139-157.

Salehi, M. H., M. Karimian Egbal and H. Khademi. 2003. Comparison of soil variability in a detailed and a reconnaissance soil map in central Iran. Geoderma, 111: 45-56.

Soil survey division staff. 1993. Soil Survey Manual, 3th edition, USDA-SCS, Govt. Print Office, Washington, D.C.

Soil survey staff. 2006. Keys to Soil Taxonomy. United States Department of Agriculture, Soil Conservation Service, p. 326.

Western, S. 1978. Soil survey contracts and quality control. Clarendon Press, Oxford, England. p. 284.

Ziadat, F.M., J.C. Taylor and T.R. Brewer. 2003. Merging landsat TM imagery with topographic data to aid soil mapping in Badia region of Jordan. Journal of Arid Environments. (54): 527-541.