International
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Journals

African Journal of Soil Science ISSN 2375-088X Vol. 8 (1), pp. 001-008, January, 2020. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Soil mapping approach in GIS using Landsat satellite imagery and DEM data

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Accepted 12 October, 2019

The objective of this study was to create base soil survey maps of the studied lands using Landsat satellite imagery and Digital Elevation Model (DEM) data in a GIS framework. Specific goals were to generate soil maps and to test the usage probability of slope class map overlies colour composite images as a preliminary map for soil survey in a hilly terrain. Surrogate soil-landscape data layers were derived from Landsat satellite imagery and a 10 m DEM. The data were also used to produce 3D-view with slope class boundaries superimposed Landsat image and relief shaded map as a colour map in order to select possible site of soil profile pits and to define physiographic units. Six soil series formed on two different physiographic units were determined, described and sampled. Soil profiles have been classified according to Soil Taxonomy and FAO-Unesco soil map of the World legend classification systems. The methodology was adequate for soil survey and mapping of some types of soils.

Key words: Soil survey, soil mapping, soil classification, GIS, DEM, satellite data.

INTRODUCTION

Soil is a valuable non-renewable resource and exists throughout the World in a broad diversity. Different types of soil exhibit diverse behaviour and physical properties. It provides essential support to ecosystems and to human life and society. Therefore, it is imperative to maintain soil functions and qualities to sustain the ecosystem and the human being (Blum, 1993; De Groot et al., 2002; European Commission, 2006). This alarmed authorities to plan and assess suitable parameters for land uses. It has been recognized that the quality of land suitability assessment and the reliability of land use decisions depend largely on the quality of soil information used to derive them (Mermut and Eswaran, 2001; Bogaert and D'Or, 2002; Salehi et al., 2003; Ziadat, 2007).

Soil surveys are the main information source for sustainable agriculture and land use management. Soil survey mapping units are defined by the soil properties that affect management practices, such as drainage, erosion control, tillage and nutrition, and they involve the whole soil profile (Soil Survey Division Staff, 1993). In Turkey, soil surveys are available only at a small scaled (1:100,000) for most of the country and just a few small part of it has detailed soil maps because of funding limitations and governmental policies, as it is in most of other developing countries.

The traditional methods are expensive and time consuming due to large number of observations. However, advances in computer and information technology have introduced new group of tools, methods, instruments and systems. Rapid developments in new technologies such as Remote Sensing (RS) and Geographic Information System (GIS) provide new approaches to meet the demand of resource related modelling (Mermut and Eswaran, 2001; Salehi et al., 2003).

In recent years thematic mapping has undergone a revolution as the result of advances in geographic information science and remote sensing. For soil mapping archived data is often sufficient and this is available at low cost. Green (1992) stated that integration of Remote Sensing within a GIS database can decrease the cost, reduce the time and increase the detailed information gathered for soil survey. Particularly, the use of Digital Elevation Model (DEM) is important to derive landscape attributes that are utilized in land forms characterization (Brough, 1986; Dobos et al., 2000).

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A DEM is an electronic model of the Earth's surface that can be stored and manipulated in a computer (Brough, 1986) . It provides greater functionalities than the quailtative and nominal characterization of topography. A DEM can be manipulated to provide many kinds of data that can assist the soil surveyor in mapping and giving a quantitative description of landforms and of soil variabilities. By itself the DEM can yield maps of slopes, aspects, rate of change of slope, drainage network on catchments areas (Brough, 1986; Brabyn, 1997). Information derived from a DEM, such as elevation, slope and aspect maps can also be used with the images to improve their capabilities for soil mapping (Lee et al., 1988).

A Study by Hammer et al. (1995) indicated that slope class maps produced from 10 m DEM appear to have great potential use for soil survey and land use planning. Moore et al. (1992) stated that with information on geology and surface deposits a DEM could be used to predict soil types. Bayramin (2001) tested the use of DEM, satellite data, digital geological data to improve mapping efficiency and quality of soil maps and developed a pre model for soil mapping for countries where conventional soil surveys have not been completed yet.

Mora-Vallejo et al. (2008) applied digital soil mapping in a 13,500 km^2 study area in South-eastern Kenya with the main aim to create a reconnaissance soil map to assess clay and soil organic carbon contents in terraced maize fields. Soil spatial variability prediction was based on environmental correlation using the concepts of the soil forming factors equation. The results were confirmed by cross-validation and provide a significant improvement compared to the existing soil survey.

Debella-Gilo and Etzelmüller (2009) used a DEM of 25 m grid resolution to derive terrain attributes to model the relationship between WRB-1998 soil groups and terrain attributes and predict the spatial distribution of soil groups in Vestfold County of South-eastern Norway. Elevation, flow length, duration of daily direct solar radiation, slope, aspect and topographic wetness index were found to be the most significant terrain attributes correlating with the spatial distribution of the soil groups.

Moreover, many researches indicated optimistic results on using digital data for soil surveys (Moore et al., 1993; Odeh et al., 1994; Boer et al., 1996; Dobos et al., 2000; Gessler et al., 2000; Wilson and Gallant, 2000; Bishop and McBratney, 2001; Park et al., 2001; Zhu et al., 2001; Florinsky et al., 2002; Park and Burt, 2002; Ziadat et al., 2003; Ziadat, 2005; Bishop et al., 2006; Liu et al., 2006; Castrignano et al., 2009), and numerous complements related to the satellite data enriched with topographic information for mapping natural resources have been reported by many researchers (Frazier and Cheng, 1989; Bhatti et al., 1991; Dinç et al., 1992; Dobos et al., 2000; Odeh and McBratney, 2000; Ryan et al., 2000; McBratney et al., 2003; Ziadat et al., 2003; Dobos et al., 2006; Lagacherie et al., 2007; Hartemink et al., 2008; Liberti et al., 2009).

The main goal of this research was to use digital elevation model (DEM) and Landsat TM imagery for a detailed soil survey work in a hilly terrain, as an alternative and improved method for mapping soil patterns. A 3D view of the landscape is generated to visualize the soil and landform relationships. The final soil map of this study was intended to analyze agricultural productivity and to prepare the land capability and irrigation suitability classification maps of the studied area.

MATERIALS AND METHODS

The study area is located on between 28° 12' 30" and 28° 15' 00" E, and 40° 14' 00" and 40° 17' 30" N in the Northwest part of Bursa province, Turkey (Figure 1) and covers an area about 850 ha. The area has a Mediterranean type climate with annual precipitation around 700 mm (Anonymous, 2006), most of which occurs from December to May and possesses mesic soil temperature and xeric soil moisture regime according to Soil Taxonomy (Soil Survey Staff, 1999). The mean annual temperature is about 14.50°C (Anonymous, 2006). Elevation in the study area varies from 230 to 30 m above sea level and generally decreases from South to North. Agriculture is the main land use in the area and sparse forest lands and orchards are the other land cover types. The major agricultural crops are wheat, maize, sunflower, pea and watermelon.

Integrated land and water information system (ILWIS 3.2) was used to develop a GIS framework for the spatial analysis and image processing software (ERDAS Imagine 8.2) was used for image analysis. Topographic maps scaled at 1:25,000, Landsat TM satellite data (August 1998) and soil map of the Bursa province, scaled at 1:100,000, produced by General Directorate of Rural Service of Turkey in 1995, were used for this study. The selection of the scene was based on the minimization of the vegetation cover and low cost. Thus, the selected scene had less vegetation cover, minimal effect of surface roughness and the very low soil moisture content. The remotely sensed data and soil maps were geometrically rectified to a common Universal Transverse Mercator (UTM) coordinate system optimally enhanced and histogram matched to be comparable during the visual interpretation through ERDAS software. The root mean square error (RMSE) for the rectified image was < 0.5 pixel.

A DEM was generated with 10 m spatial resolution based on the topographic maps and this data was used to generate a slope map of the study area. The DEM data and the slope class map of the study area were shown on the Figures 2 and 3 respectively. After eliminating the speckle effects by smooth filtering a vector map of the slope classes was produced by screen digitizing. The produced vector format slope class map was overlaid to colour composite Landsat image of the studied area to delineate soil boundaries and other land features by visual interpretation. A 3D perspective view map and a hill shade relief map were generated using the DEM. A 3D presentation of the landscape is required to visualize the soil and landform relationships. Thus, a colour hill shade relief map with slope classes was produced by overlying the final maps in order to select possible site of soil profile pits and to define physiographic units (Figures 4 and 5). After extensive fieldwork and sampling the soil profiles, 27 mapping units were determined. The soil series and their important phases were slope, texture, depth and stoniness which were considered as basic mapping units. Henceforth, final soil map, scaled at 1:25,000 was produced after the final field checking and so the preliminary soil map (scaled at 1:100,000) was corrected. Soil profiles were described and sampled according to Soil Taxonomy (Soil Survey Staff, 1999, 2006) and Schoeneberger et al. (2002). Necessary analysis for classifying and

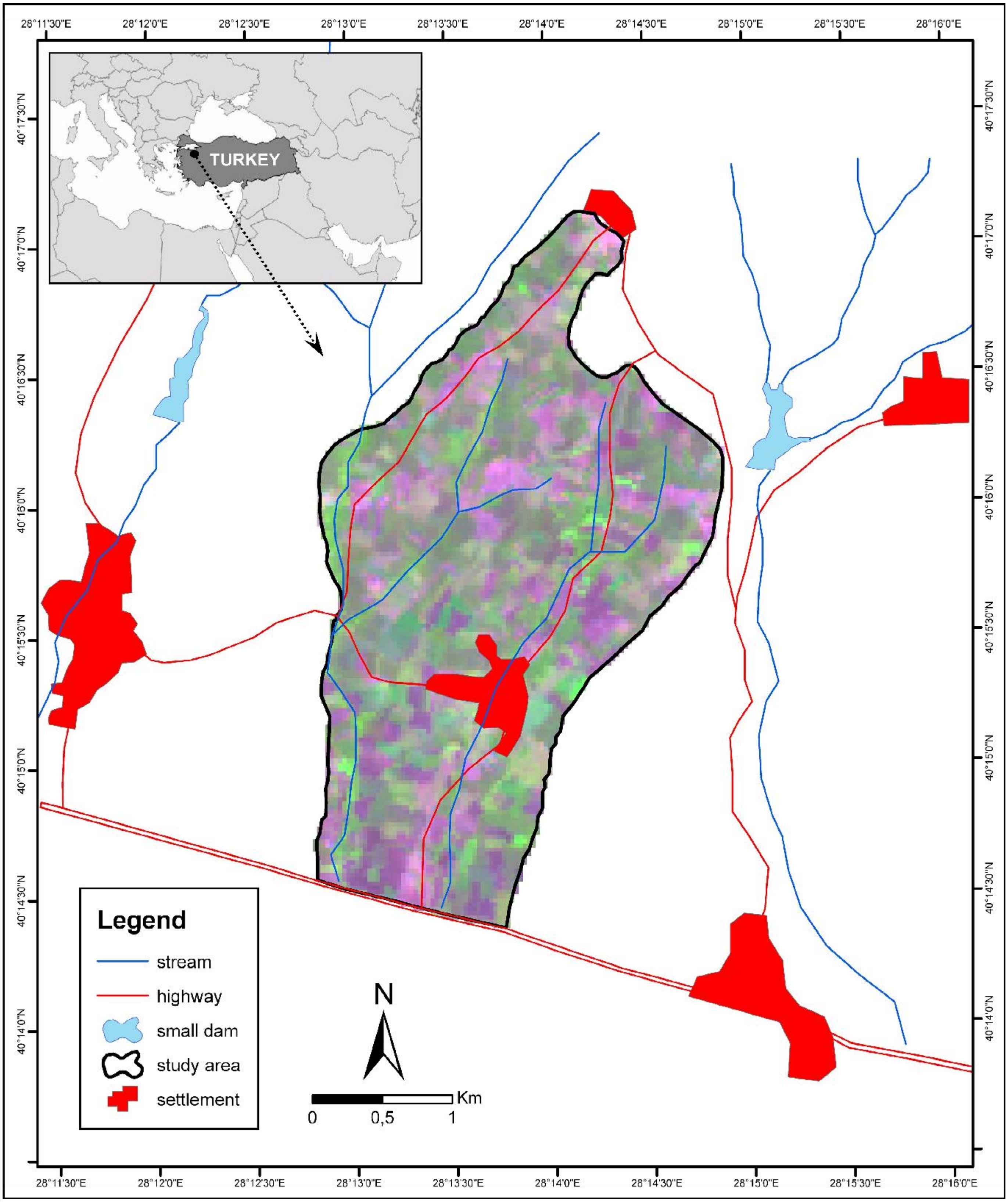

Figure 1. Location map of the study area and false colour composite of Landsat TM image (band 543 as RGB).

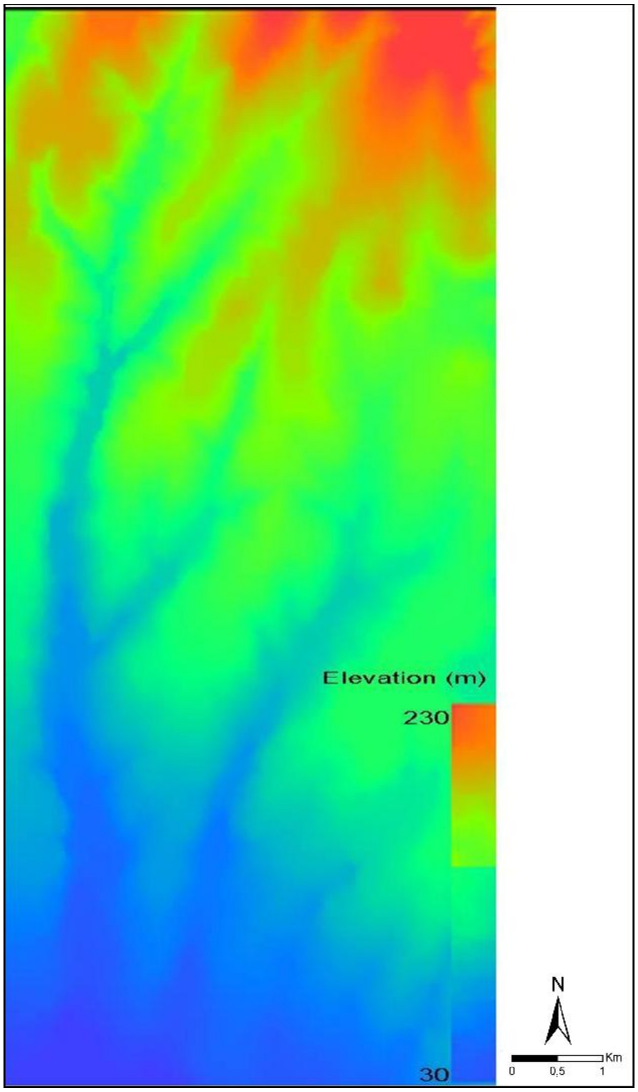

Figure 2. Digital elevation model (DEM) of the study area and surroundings.

determining physical and chemical properties were done according to Burt (2004). On the basis of morphological and physicochemical characteristics, the soil profiles classified according to Soil Taxonomy (Soil Survey Staff, 1999, 2006) and FAO-Unesco soil map of the World legend (FAO-Unesco, 1974, 1990) classification systems.

RESULTS AND DISCUSSION

With the detailed soil survey and mapping works at the study area, six soil series formed on two different physio-graphic units were identified and mapped in 27 mapping units. Mainly the studied soils were formed on neogene clay lime deposits at the eroded upland physiographic units and the others formed on holocene colluvial deposits at the lowland physiographic units. Most of the soils are shallow and a few were very deep, with textures ranging from SCL to C. Limitations such as salinity, sodicity and surface fragments (rocks and stones) were not determined in the study area. However, agricultural potential of the soils was restricted by the steep slope, shallow soil depth and high amount of $CaCO_3$ content of the sub-surface horizons. Organic matter contents were generally low and decreased with the depth, but it was high or moderate level in lands newly deforested for agricultural use.

The CEC was generally found high because of high clay contents and clay type. The base saturation percentage was high and often close to 100 % with the Ca^{+2}+Mg^{+2} occupying more than 95% of the exchange site. Average soil properties for the upper 30 cm of the main soil types are given in Tables 1 and 2. Soil profiles investigated in the area have *ochric*

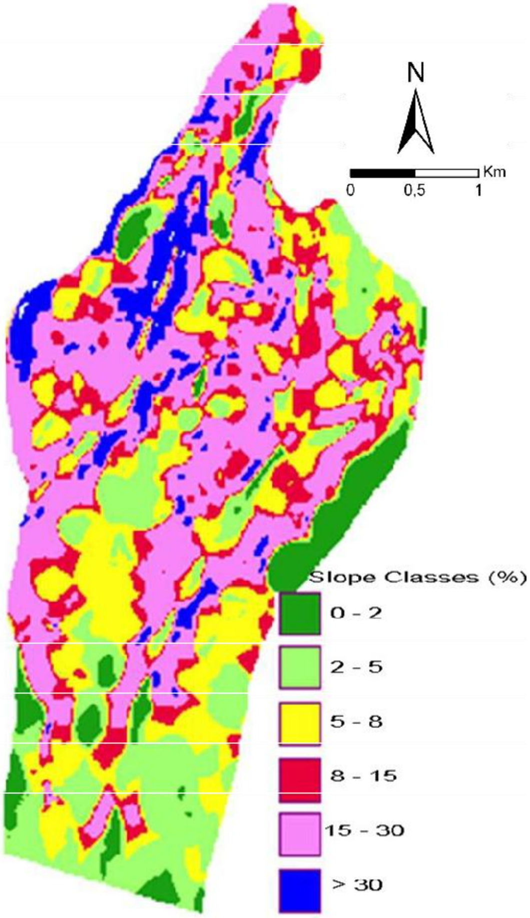

Figure 3. Slope class map of the study area.

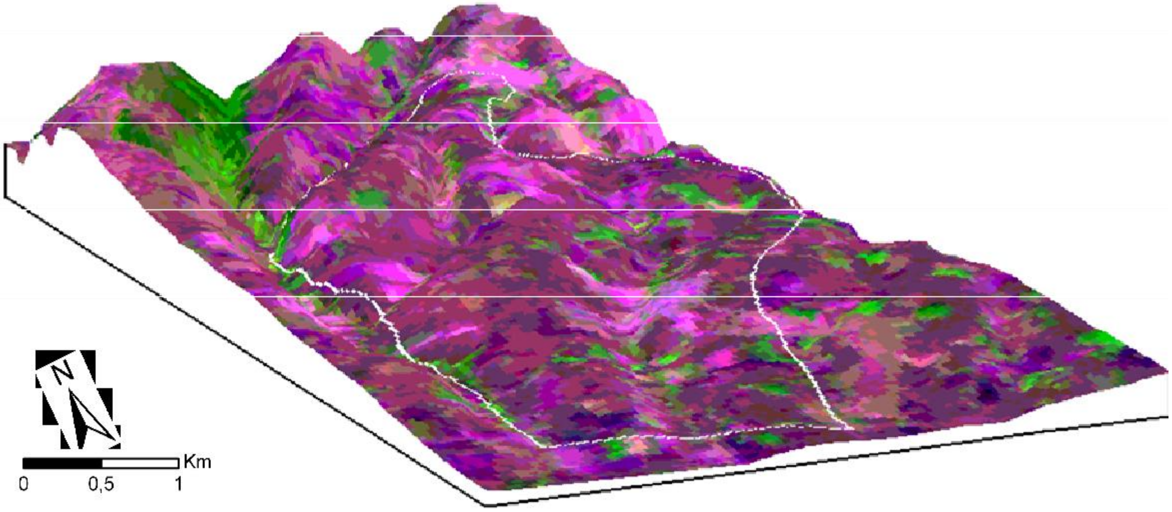

Figure 4. 3D view of the study area and Landsat imagery as a colour map.

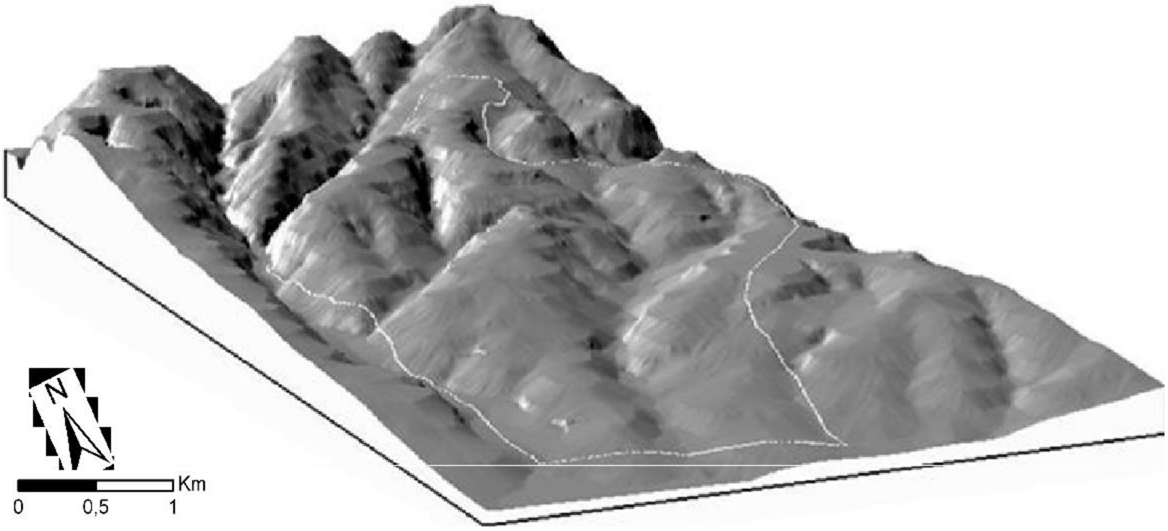

Figure 5. Hillshade relief map of the study area and 3D perspective view.

Table 1. Some important chemical properties for the main soil groups in the study area (average values for the upper 30 cm).

Soil classification	pH	Water soluble total salt (%)	C.E.C. (cmol kg^{-1})	Exchangeable cation (cmol kg^{-1}) Na^{+}	K^{+}	Ca^{2+}+Mg^{2+}	CaCO$_3$ (%)	Organic Matter (%)
Typic Xerorthents	7.82	0.05	31.25	0.30	0.75	30.20	37.00	0.65
Pachic Calcixerolls	7.74	0.08	39.72	0.42	0.80	38.50	22.00	2.50
Typic Xerochrepts	7.25	0.05	20.86	0.59	0.27	20.00	10.00	0.70
Vertic Xerochrepts	6.40	0.09	40.64	1.50	1.02	38.12	0.20	1.75
Typic Calcixererts	7.40	0.10	37.41	0.50	1.44	35.47	1.50	1.50
Chromic Haploxererts	7.92	0.08	34.74	0.47	0.75	33.52	9.80	1.45

Table 2. Some important physical properties for the main soil groups in the study area (average values for the upper 30 cm).

Soil classification	Particle size distribution (%)			Texture	Bulk density	Field capacity	Wilting point	Available water
	Sand	Silt	Clay	class	(g cm^{-3})	(cm^{3} water cm^{-3} soil)		
Typic Xerorthents	36.20	30.20	33.60	CL	1.32	0.32	0.19	0.13
Pachic Calcixerolls	34.00	30.20	35.80	CL	1.31	0.33	0.20	0.13
Typic Xerochrepts	54.20	24.40	21.40	SCL	1.42	0.24	0.13	0.11
Vertic Xerochrepts	33.10	24.00	42.90	C	1.28	0.37	0.24	0.13
Typic Calcixererts	24,60	23,90	51,50	C	1.24	0.43	0.29	0.13
Chromic Haploxererts	26.70	28.20	45.10	C	1.26	0.39	0.25	0.14

and *mollic* surface horizons and some of them have *cambic* horizon as a sub-surface horrizon. Based on morphological properties and physicochemical analysis, soils were classified as Entisol, Mollisol, Inceptisol and Vertisol according to Soil Taxonomy (Soil Survey Staff, 1999, 2006) and as Eutric Leptosol, Haplic Calcisol, Calcaric Cam-bisol, Eutric Vertisol, Calcic Vertisol according to FAO-Unesco soil map of the World legend (FAO-Unesco, 1974, 1990) classification systems (Table 3).

In the Entisols, only *Ochric epipedon* existence was identified. The clay contents of the Vertisols in the area were generally close to 50%. They are especially rich in smectitic clay minerals reason to form cracks in summer time. *Ochric epipedon* with cambic horizon was found in

Table 3. The classification of the soils according to Soil Taxonomy (Soil Survey Staff, 1999, 2006) and FAO-Unesco (1974, 1990) classification systems.

Order	Suborder	Great group	Subgroup	FAO-UNESCO
Entisols	Orthents	Xerorthents	Typic Xerorthents	Eutric Leptosol
Mollisols	Xerolls	Calcixerolls	Pachic Calcixerolls	Haplic Calcisol
Inceptisols	Ochrepts	Xerochrepts	Vertic Xerochrepts	Haplic Calcisol
			Typic Xerochrepts	Calcaric Cambisol
Vertisols	Xererts	Haploxererts	Chromic Haploxererts	Eutric Vertisol
		Calcixererts	Typic Calcixererts	Calcic Vertisol

the Inceptisols. Moreover, there is no other horizon definition except mollic epipedon formed on the surface of the Mollisols. It is also suggested that all soil profiles are still in developing phase. Over all we found the soils are very high in clay and $CaCO_3$ contents, but very low in organic matter. They also have very weak structure to be used for agricultural purposes. Hence, we strongly recommend that close attention should be paid for the soil cultivation, irrigation system and time regarding the soil type.

The major photo-interpretation elements such as land forms, relief, slope etc. are the cornerstones of the both monoscopic and stereoscopic interpretation of satellite images as well as aerial photographs for delineation of soil boundaries. The disadvantages caused by the absence of stereovision of the Landsat images during the image interpretation for soil survey were eliminated by using slope classes map and shaded relief map derived from 10 m DEM. Viewing the topographic and satellite data together provided an opportunity to look at the same soil mapping units in both formats at the same time.

The results showed that, the slope classes map from 10 m DEM overlie Landsat images can easily be used for soil survey with extensive ground truth where there are proven close relationships between soils and topography and soils are situated hilly terrain. But in flat areas the contour lines alone did not enable easy interpretation of soil variations. 3D view with slope classes boundaries overlaid Landsat images and shaded relief map as a colour map, can be used to define physiographic units, to select possible site of soil profile pits and to distinguish distribution of the soils. A 3D viewing of the landscape helps the visual interpretation of images and the understanding of relationships between landscape elements. Even though topography is a crucial factor in the spatial distribution of soils, cannot explain everything itself.

Most importantly, close attention must be given to land surveys and profile descriptions as well. Therefore, the prediction could be improved if information regarding the other soil forming factors is included with extensive field works. Besides, the soil survey efficiency can be increased by using large scaled geological map, high resolution satellite data or black and white aerial photographs and others. It further showed that digital terrain analysis plays a strong role in digital soil mapping and provides a high level of topographic detail. Landsat TM satellite imagery (bands 5, 7) has a good potential for responding to differences in soil properties and hence the separation of soil types.

For long term productivity, soils must have a good and right soil management. Depending on this, soil survey works become more important spontaneously (Özsoy and Aksoy, 2007) . The results proved that using RS and GIS technologies and integrating DEM, satellite data and ancillary data are very powerful tool for soil survey and the GIS based softwares are user friendly and can easily be support necessary procedures for soil survey and mapping works.

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