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Simulating Hydrological Patterns and Potential Irrigable Agricultural Lands Using Remote Sensing and GIS¥

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Abstract

It was aimed to determine potentially irrigable lands of Canakkale province using Digital Elevation Model (DEM). DEM were obtained by digitizing 1:25000 scaled topographic maps to investigate the terrain features. Hydrologic analysis was conducted using ArcHydro module that attached with ArcGIS software. Flow directions, flow accumulations, catchment grids, catchment polygons, drainage lines and drainage points were delineated. In order to determine water bodies and agricultural lands, Land Use and Land Cover (LULC) map was generated using Landsat TM 5 image. According to the results, 206 catchments were identified within study area. Among these catchments, water found to be cumulated on 47 catchments within 27 natural or man-made water collection units. It was seen that water would be able to transfer from these units to 136 catchments. The agricultural lands within these catchments with land use capability class value varying 1-3, and slope values varying 0-8%, defined as Potentially Irrigable Lands in this study (131016 ha).

Keywords: ArcHydro, catchment, irrigable lands, digital elevation model, landsat TM, Canakkale

Hidrolojik Yapı ve Potansiyel Sulanabilir Tarım Alanlarının Uzaktan Algılama ve CBS Yardımıyla Simülasyonu

Özet

Çalışmada Çanakkale ilinin potansiyel sulanabilir tarım alanlarının Sayısal Yükseklik Modeli (SYM) yardımıyla belirlenmesi amaçlanmıştır. SYM, 1:25000 ölçekli topografik haritaların sayısallaştırılmasıyla elde edilmiştir. Hidrolojik analizler ArcGIS yazılımı ArcHydro modülü kullanılarak yürütülmüştür. Akım yönleri, akım birikimleri, havza hücreleri, havza poligonları, drenaj yolları ve drenaj noktaları belirlenmiştir. Su ve tarımsal alanların belirlenmesi için Landsat TM 5 görüntüsü kullanılarak Arazi Kullanım ve Bitki Örtüsü (AKBÖ) haritası oluşturulmuştur. Sonuçlara göre, çalışma alanı içerisinde 206 havza olduğu tespit edilmiştir. Bu havzalar arasından suyun 47 havza üzerinde, 27 doğal veya insan yapımı su toplama ünitesinde biriktiği bulunmuştur. Suyun bu ünitelerden 136 havzaya iletilebildiği görülmüştür. Söz konusu havzalar içerisinde bulunan tarım alanlarından arazi kullanım kapasitesi değeri 1-3 ve eğim değerleri %0-8 arasında değişen tarımsal alanlar, çalışmada Potansiyel Sulanabilir Alanlar olarak tanımlanmıştır (131016 ha)

Anahtar kelimeler: ArcHydro, havza, sulanabilir alan, sayısal yükseklik modeli, landsat TM, Çanakkale

Introduction

Since catchments are considered as natural boundaries of hydrological systems, catchment scaled water resources plannings are required for an appropriate management (Meric, 2004). In this context, topographic maps can be used in catchment-scaled hydrological analysis. Furthermore, the usage of computer based methods including Digital Elevation Models (DEM)

¥: This research was based on a part of Melis Inalpulat's (Sacan) M.Sc. thesis provides rapid and reliable results (Mark, 1983; O'Callaghan and Mark, 1984; Rinaldo et al., 1998; Xu et al., 2001; Maidment, 2002). Computation of flow directions is considered as the first step of computer based catchment delineation. Understanding of water movement provides a correct investigation of water and terrain interactions.

Geographic Information Systems (GIS) plays a key role in hydrologic modelling because of its ability to relate hidrological data with Land Use and Land Cover (LULC) status and many other positional features. The role of land cover maps derived from satellite imagery is considerably important in regional, national, and even global scales for hydrological investigations (Cihlar, 2000; Homer et al., 2004; Vogelmann et al., 2004). Landsat images are widely used for LULC determination.

The aim of this study was to simulate hydrologic properties, and potentially irrigable agricultural lands of Canakkale using LULC maps derived from Landsat imagery and ArcHydro tools of ArcGIS software.

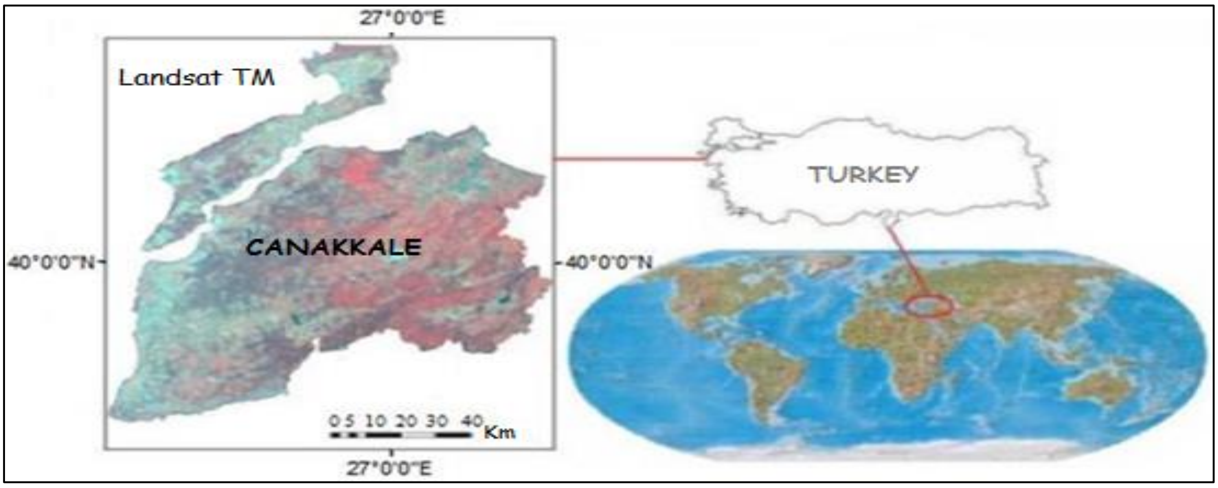

Figure 1. The location of study area

Materials and Methods

Study area

The study was conducted in Canakkale province, located between 25° 40´- 27° 30´ E and 39° 27´- 40° 45 N (Canakkale Governorship, 2010) (Figure 1). The study area has a perimeter of 810 km and covering approximately 8660 km^2 area. Elevation values vary from 0 to 1741 m (Figure 2) above the sea level and topographic structure is complex.

A major part of the area is covered by forests and the natural vegetation of the area mostly comprises of pine trees (*Pinus brutia* Ten., *Pinus nigra*), oak trees (*Quercus petraea* spp.) and beech species (*Fagus orientalis* spp.). Agriculture have a significant role in economic activities; tomato (*Solanum* spp.), wheat (*Triticum* spp.), maize (*Zea mays* L. ssp.), and olive (*Olea europaea*) varieties are main products that cultivated in province.

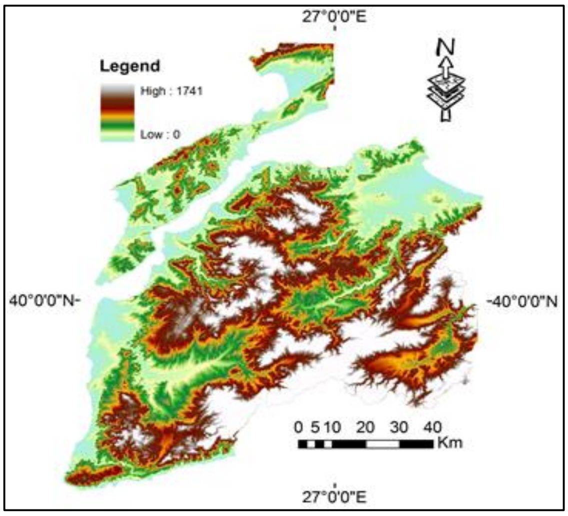

Figure 2. DEM of study area

Image processing

Landsat TM image (5 July, 2007) (Figure 1) was used to determinate LULC status of study area. Prior to the study, the imagery was geometrically corrected. Image rectification and classification procedures were performed using Erdas Imagine

(9.1) software. The rectified image was exposed to supervised classification. There are many different methods for implementation of supervised classification. However, the most widely-used algorithm, the maximum likelihood method (Jensen, 2005) were used in study.

The main classes considered to be in LULC map are Forests, Grazing Lands, Agricultural Lands, Water Surfaces, and Residential Areas. The classification accuracy was assessed according to Congalton and Green (1999). Assessment was performed by checking total 200 equalized random reference points; 40 points for each class, and Google Earth imagery was used as reference image.

$$s = \arctan\left(\frac{\Delta z}{d}\right) \tag{1}$$

where; *s* is slope, Δz elevation difference between two grids, and *d* is distance (*d* varies according to direction: for North, South, West and East 1, otherwise √2).

Figure 3. Streamline determination using Formosat imagery

Hydrological simulations

Hydrologic analysis was conducted using ArcHydro (1.3) module of ArcGIS software. The stream network and DEM are required to determine catchments in ArcHydro analysis. However, there was no stream indicative map available for the study area. Thus, stream lines were formed in vector format using Formosat imagery (8 m spatial resolution) as underlay (ArcGIS 9.3) (Figure 3). The DEM was generated by digitizing 1:25000 scaled topographic maps (Figure 2). Because the precision of DEM affects the accuracy of extraction of hydrological parameters, the sinks and peaks were removed by DEM reconditioning prior to the analysis to obviate the discontinuity in drainage network (Jenson and Dominique, 1988; Wise, 2000; Bastawesy et al., 2008). Following the DEM reconditioning, flow directions were determined. Eight direction (D8) algorithm was used to calculate the flow directions. This approach depends on a basic premise that water flows downhill. Water will flow from a cell towards one of the eight cells surrounding it, according to direction of steepest descent (O'Callaghan and Mark, 1984; Jenson and Domingue, 1988; Martz and Garbrecht, 1992). Flow directions can be calculated using following formula (1) (Burrough et al., 1998):

Flow accumulations were computed as grids that contain the accumulated number of cells upstream of a cell, for each cell in the input grid calculated according to the formula (2) (Burrough et al, 1998; Lüscher et al., 2010):

$$S(c_i) = S(c_i) + \sum_{u}^{n} (c_u) \tag{2}$$

where *ci* is the raster cell with value *S(ci)* and where *∑(cu)* is the sum of all upstream elements draining to *ci*.

Catchment boundaries were delineated by identifying areas that draining into each stream link using flow accumulation grid. In other words, area that water flows into a certain section of the stream network, defining the catchments of each stream.

Drainage lines were extracted from DEM as denoted in the existing procedures in literature (Tarboton et al., 1991; Maidment, 2002). Unlike a flow accumulation map, stream channel map shows; if a cell either belongs to a stream channel or not. A treshold modified from Brandly (1997) required to calculate stream channels (3):

If (upstream elements >= 25*) then streams*=true;
else streams=false. (3)

Extraction of drainage lines using DEM is based on the principle that water flows from higher to lower elevation and it was assumed that the losses of interception, evapotranspiration, and infiltration to groundwater are not considered (Ozdemir and Bird, 2007).

Potentially irrigable agricultural lands

Where the elevation of a dam is above the agricultural lands, this elevation difference supplies irrigation without requiring energy. In this study, definition of irrigable lands is restricted for agricultural fields that elevation difference supports irrigation. Based on this restriction, locations of water collecting units were identified to determinate the irrigable lands in study area. The positions of water bodies were localized using 'water' class of LULC map and DEM. It was assumed that water will flow from these units throughout drainage network and will lead to catchments that drainage path passes through.

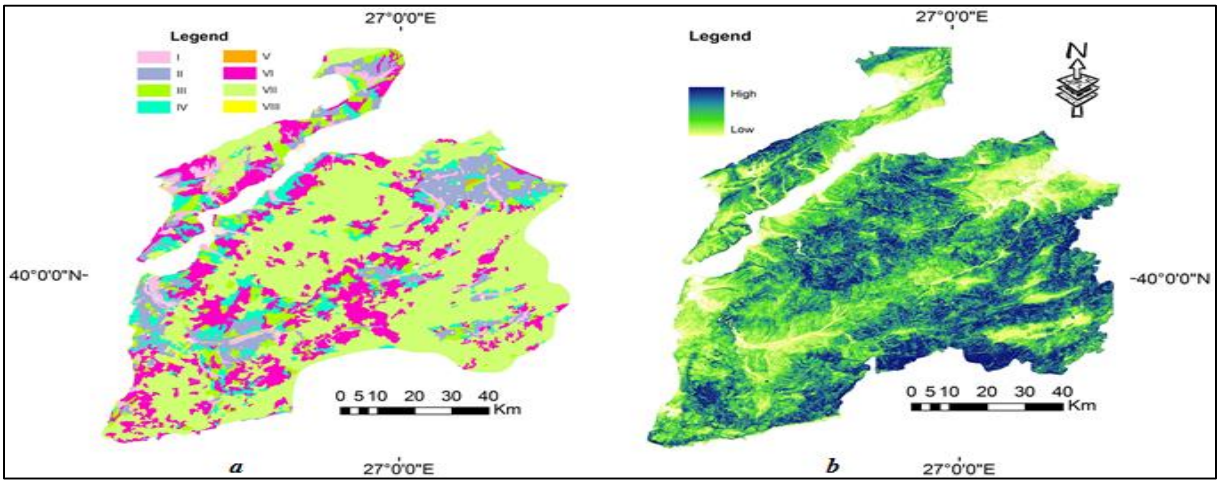

Figure 4. a. Land use capability classes, **b.** Slope map derived from DEM

These catchments were isolated from the others as a new layer and converted into raster format to enable the interrogation with LULC, soil and slope maps for geospatial analysis. In decisional process, Land use capability class value between 1-3, and maximal slope value 8% were selected as criteria that defines the potentially irrigable agricultural lands. In other words, if elevation of water units are higher than agricultural lands with maximum values of land use capability class 3 and slope 8%, then its irrigable.

Criteria equation transformed into the following function using the thresholds :

$$I=A(e_{w,a}, luc, s)$$

$$\text{where } e_w>e_a,\ luc=<3 \text{ and } s\ s=<8\%$$

I : Irrigable
A : Agriculture
e_w : Elevation of dams, ponds etc,
e_a : Elevation of agricultural lands
luc : Land use capability class
s : Slope

The Soil map was digitized from Turkish Ministry of Agriculture soil maps (Figure 4-a), and slope map was derived from DEM (Figure 4-b). All Geospatial analysis conducted using ArcGIS 9.3 software.

Results

LULC classification

Classification results showed that a significant part of study area was covered by forests as it mentioned before (40.9%). Since Canakkale is one of the most important provinces for agricultural production, agriculture class own a big portion in LULC status (39.6%). Grazing lands, residential areas and water surface classes covers an area of 17.2%, 1.4% and 0.5% respectively. 27 water accumulation units were stated.

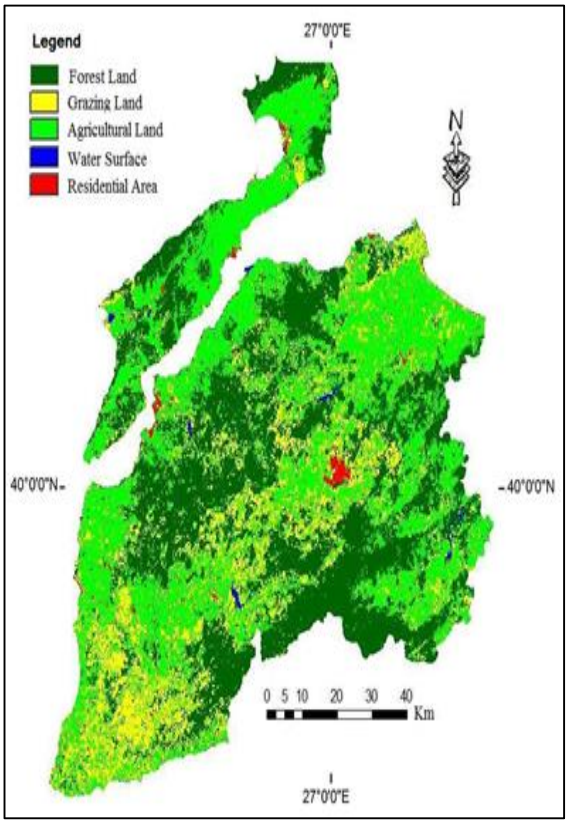

Figure 5. Landsat-derived LULC map of study area

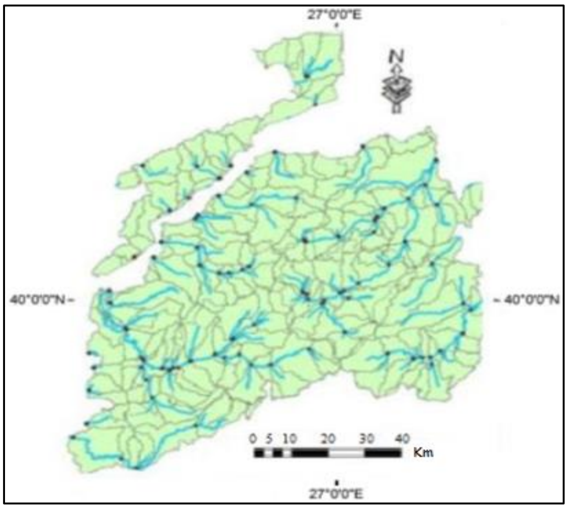

Figure 6. Display of catchments, drainage lines and drainage points

The accuracy of classification is found to be 86.80% with Kappa statistic of 85.2% and user's accuracy of individual classes ranged from 82 to 88% and producer's accuracy ranged from 83 to 87%. Figure 5 shows the LULC map which was derived from Landsat imagery. Classification results; as percentages [% (ha/ha)] and hectares (ha) given in Table 1.

Table 1. Results of image classification

Lulc Class	Area %	ha
Forest Land	40.9	354038.13
Grazing Land	17.2	153167.58
Agricultural Land	39.6	342544.32
Water Surface	0.5	43314
Residential Area	1.4	11997

Hydrologic properties and irrigable lands

Using computer based technologies integrated with satellite based remotely sensed data provides catchment polygons, drainage networks, and drainage points to be constituted automatically. In this study, it was found that there are 206 catchments in Canakkale region. The maximum, minimum and mean values of catchment areas are given in Table 2. Catchment boundaries, drainage lines and catchment drainage points can be seen in Figure 7.

Result of geospatial analysis showed that 131016 ha agricultural lands were found to be the potentially irrigable lands in Canakkale province (Figure 7).

Consequently, spatial hydrological characteristics of Canakkale province were studied using DEM and GIS functions. According to results, 131016 ha of irrigable lands were detected. However, Canakkale Provincial Directorate of Food, Agriculture and Livestock (2010) was reported that the irrigable lands covers approximately 110000 ha area in Canakkale province.

Table 2. Catchment properties

Catchment Property	Maximum	Minimum	Mean
Catchment Area (Km^2)	232.39	0.23	42.58
Catchment Length (Km)	124.78	1.91	40.15

These differences may come up with the lack of detailed soil properties and etc. These data should be evaluated to determinate actual irrigable agricultural areas.

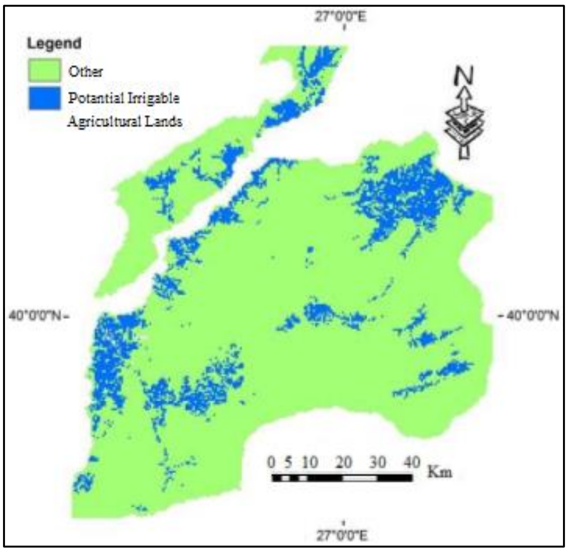

Figure 7. Potential irrigable agricultural lands

In conclusion, it was seen that catchment polygons, drainage networks, and irrigable lands could be displayed using GIS and remote sensing technology, with a practical, time saving and relatively economic approach.

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