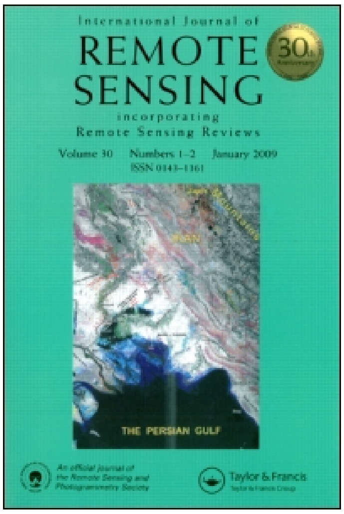

International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713722504

How geographical information systems and remote sensing are used to determine morphometrical features of the drainage network of Kastro (Kasatura) Bay hydrological basin

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Online Publication Date: 01 January 2009

International Journal of Remote Sensing
Vol. 30, No. 7, 10 April 2009, 1737–1748

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How geographical information systems and remote sensing are used to determine morphometrical features of the drainage network of Kastro (Kasatura) Bay hydrological basin

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Geographical information systems (GIS) and remote sensing have applications in many fields, but have a strikingly important use in studies related to drainage network morphometry. The data source that is produced from GIS contributes greatly to examination of the drainage features of the site under investigation and to the acquisition of numerical data. In order to demonstrate the application potential of GIS and remote sensing, the hydrology of the Kastro Gulf River, which is connected to Kırklareli and the boundaries of the Vize area, has been examined. The data source for this study consisted of a 1 : 25 000 scaled topographical map, 25 September 1987 Landsat Thematic Mapper, 2 July 2000 Landsat Enhanced Thematic Mapper and 25 June 2006 Advanced Spaceborne Thermal Emission and Reflection Radiometer images of satellite and terrain observation. Analysis of the data was performed with the benefit of Arc GIS 9.1 and Erdas 8.5 software. Three-dimensional analysis and spatial analysis modules, which are important for the determination of networks, have also been used. By use of the obtained splitting quantity of the Sultanbahçe and Elmalı brooks, which are streams within the basin, hydrographic data such as drainage density, stream frequency and stream length have been evaluated and analysed by means of GIS and remote sensing.

1. Introduction

Since the 1990s, geographical information systems (GIS) and remote sensing have offered a sophisticated system of generating, storing and analysing geometric and semantic information about spatial elements. The application of GIS and remote sensing to drainage network morphometry studies nowadays offers users and researchers a variety of facilities via the numeric and textual database created. One of those facilities enables the identification of a drainage network, and the quantification of its characteristics to be carried out precisely and accurately. Furthermore, by means of the database created through GIS and remote sensing technology, splitting degree, drainage density, stream frequency and stream length, as well as hydrographic data, can all be calculated and a database produced. GIS and remote sensing can also be used effectively for updating and monitoring spatial analysis of the morphometric, parametric databases of river basins etc. GIS and remote sensing have excellent potential for drainage network studies, as will be demonstrated, and some fundamental subjects, such as drainage type, stream frequency (F_u), splitting ratio and quantity (R_b), which support and further strengthen the studies, will also be evaluated. The hydrological basin of Kastro

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International Journal of Remote Sensing
ISSN 0143-1161 print/ISSN 1366-5901 online
http://www.tandf.co.uk/journals
DOI: 10.1080/01431160802639533

Bay within the Vize region in Kırklareli province, Turkey, was chosen for the purpose (figure 1).

2. Data and method

Data sources for this study on identifying morphometric characteristics of a catchment drainage network are: topographic maps of 1 : 25 000 scale, 25 September 1987 Landsat Thematic Mapper (TM), 2 July 2000 Landsat Enhanced Thematic Mapper (ETM) and 25 June 2006 Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) very near infrared (VNIR) images of satellite field inspection. The topographic maps chosen as the base of the study were processed by screen digitization in order to be used in GIS environments and then geometrically corrected with Erdas 8.5 imaging software (UTM, ED50, zone 35). ArcGIS 9.1 was used as the GIS software and 3-dimensional analysis and spatial analysis modules were used for data input and analysis.

3. Catchment area pattern

Kastro Bay hydrological catchment area is composed of two sub-catchment areas and its water-storage. The water-storage capacity derives from a total catchment area of 79.852 km^2 (figure 1). Its total linear length is 12.25 km and its width is 8.417 km. Height varies between 0 and 450 m. The study area comprises Pre-Permian, Permian, Trias, Tertiary and Quaternary units. Of these, Trias Mahya Schist has the largest area with a spatial value of 25.521 km^2. This is followed by Quaternary Thrace formation with a spatial value of 16.245 km^2, Trias Şermat quartzite with a spatial value of 15.210 km^2 and Permian Kızılağaç metagranite with a spatial value of 10.224 km^2. Slope values vary between 6% and 59%. Aspect directions of topographic surfaces are mostly towards the northwest and north.

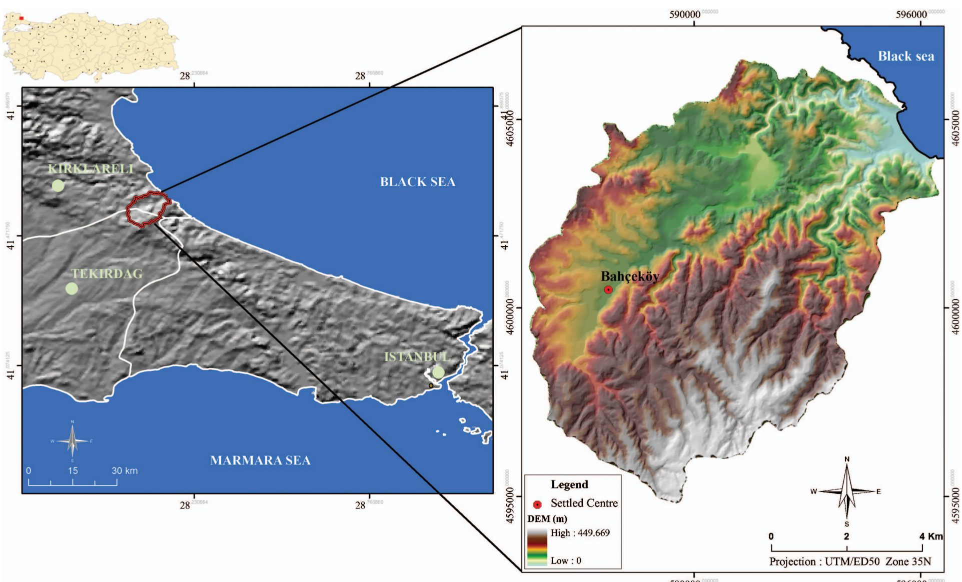

Figure 1. Location of the study area.

Table 1. Degree of splitting index formulas.

Splitting ratio and quantity (R_b) (i=index)				
i1 R_b	i2 R_b	i3 R_b	i4 R_b	i5 R_b
$\frac{\sum N_u(\mathrm{i}1)}{\sum N_u(\mathrm{i}2)}$	$\frac{\sum N_u(\mathrm{i}2)}{\sum N_u(\mathrm{i}3)}$	$\frac{\sum N_u(\mathrm{i}3)}{\sum N_u(\mathrm{i}4)}$	$\frac{\sum N_u(\mathrm{i}4)}{\sum N_u(\mathrm{i}5)}$	$\frac{R_b(\mathrm{i}1+\mathrm{i}2+\mathrm{i}3+\mathrm{i}4)}{4}$

4. Morphometry of the drainage network

GIS and remote sensing have played an important role in the examination of the characteristics of streams and stream systems that lead essentially to the erosion of the catchment area, consequently contributing to studies related to the morphometric characteristics of catchment drainage networks. First, the streams shown on the topographic map were digitalized and second a database was created to support the study. Thirdly, catchment areas of two main streams that flow into Kastro Bay were separated from one another, and certain morphometric characteristics were evaluated for the area (tables 1–3).

4.1 *Drainage type*

Streams were classified according to Strahler's (1964) method in the GIS environment (figure 2). When a recently-created stream system begins to develop, it splits into first-order tributaries (segments) and then continues with second and third order and further sub-divisions, with an increasing frequency. Degrees of splitting of streams (R_b) within sub-catchments and catchment areas were digitalized and classified by Strahler's (1964) method. The results of the evaluations, analyses based on the created database, showed that the degrees of splitting in the area studied were determined as 3.8, 6, 1.8, 5, 4.1 (tables 1 and 3). Notably, catchment areas under structural control showing parallel-sub-parallel characteristics have degrees of splitting of 4 and more. The same is not exactly true of sub-catchments when evaluated in the light of this information, but the two main streams within the catchment area, the Sultanbahçe stream and the Elmalı stream, show

Table 2. Morphological parameters and mathematical definitions (Verstappen 1983, Strahler 1964, Özdemir 2006).

Morphological parameters	Formula	Definition
Total number of stream segments (N)	(ΣN_u)	Denotes total number of stream segments available in the basin
Total length of stream segments (L)	(ΣL)	Denotes total length of stream segments available inside the basin
Splitting ratio and quantity (R_b)	$R_b=N_u/N_{u+1}$	Obtained by the ratio of any number of sequences available in the basin to a number of sequences higher than itself
Drainage density (D_d)	$D_d=\Sigma L/A$	Obtained by dividing the total length of sequences available in the basin by the area of the basin (km km^{-2})
Stream frequency (F_u)	$F_u=\Sigma\ Nu/A$	Obtained by dividing the total number of sequences available in the basin by the area of the basin

Table 3. Drainage network morphometric characteristics.

(a)

Parameters	Area (km^2)	Stream segment orders					Total number of stream segments	Total length of stream segments (km)
Catchment area		i1	i2	i3	i4	i5	(Σ N_u)	(Σ L)
S.Bahçe stream	51.49	148	35	5	3	1	192	130.70
Elmalı stream	27.51	61	19	4	2	–	86	67.46
Combined areas	79.00	209	54	9	5	1	278	198.16

(b)

	Degree of splitting					Drainage density	Stream frequency
Equation	$R_b = \frac{N_u}{N_{u+1}}$ (1)					$D_d = \frac{\sum L}{A}$ (2)	$F_u = \frac{\sum N_u}{A}$ (3)
Catchment area	i 1	i 2	i 3	i 4	i 5		
S. Bahçe stream	4.2	7	1.6	3	3.9	2.53	3.72
Elmalı stream	3.2	4.7	2	3.3		2.45	3.12
Combined areas	3.8	6	1.8	5	4.1	2.50	3.51

parallel-sub-parallel drainage network characteristics (table 3 and figure 3). The streams in the area of study were monitored via ASTER 2003 VNIR satellite images and it was eventually determined that visually the drainage type is both parallel and sub-parallel (figure 4).

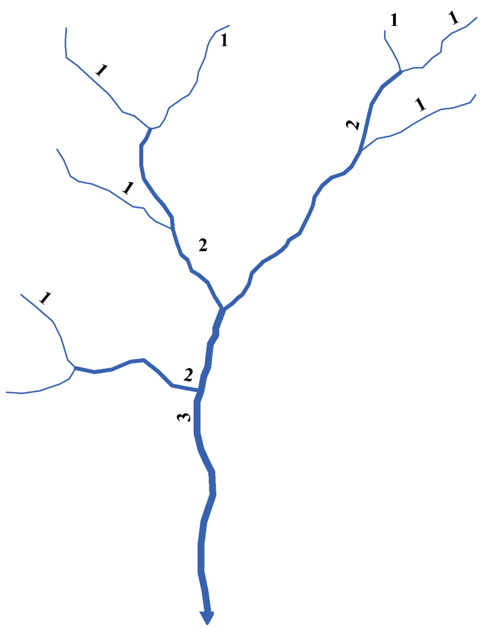

Figure 2. Calculation technique for degree of splitting.

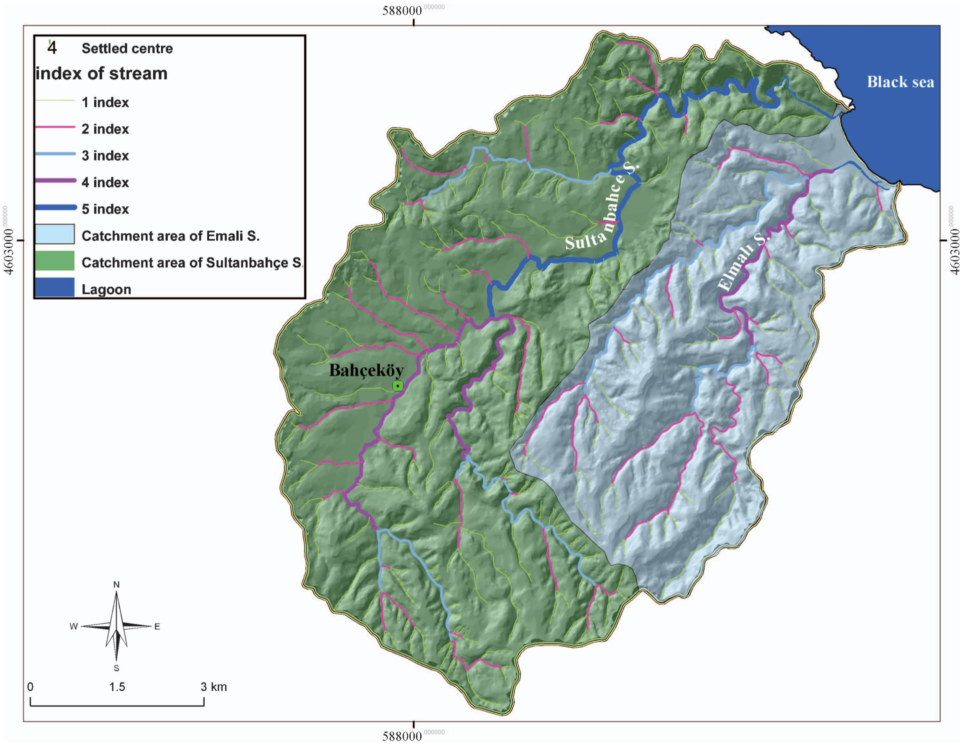

Figure 3. Stream system, sub-catchment for the study area.

4.2 *Stream frequency* (F_u)

Stream frequency is defined as the number of stream beds of sub-catchment areas and their tributaries within the area studied per unit catchment area (Verstappen 1983). It is calculated by division of the total number of stream segments within the catchment area (ΣN_u) by the total catchment area (equation 3). Areas of high frequency showed impermeable field characteristics, sparse flora, high relief characteristics, and low relief characteristics (Hoşgören 2004). Vaporization in lower parts of forests is smaller than on naked ground because of the fact that there is less sunlight and lower temperatures in such areas, relative humidity is higher and wind speed is lower (Hoşgören 2004). This reduces loss of water by vaporization of waters available in lower parts of forests. In areas where the vegetation is dense, however, some of the rainfall is captured by the leaves and roots of plants and is therefore prevented from joining running waters: this would have a negative impact on running water frequency. Furthermore, plants tend to use underground water through their root systems and encourage penetration, exerting a negative impact on the stream.

When the stream frequency of the sub-catchment is examined, stream frequencies of the sub-catchment of the Sultanbahçe and Elmalı streams are found to be 3.72 and 3.12 respectively (table 3). It is understood from this that both streams have similar stream frequency levels. Catchments of both streams, however, are distinguished by their structural characteristics: the catchment area of the Sultanbahçe stream has a lower permeability compared with that of the Elmalı stream. Visible and near

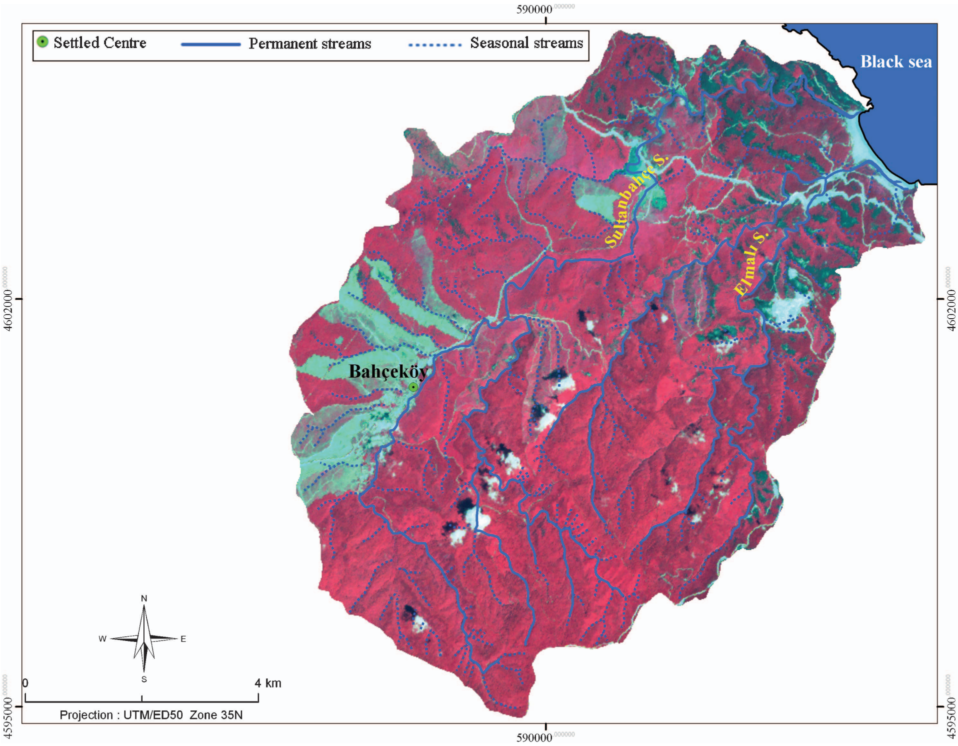

Figure 4. Streams monitored on ASTER 2003 VNIR satellite image.

infrared images (4,3,2, bands; 0.52–0.76 μm) of the 1987 Landsat TM and 2000 Landsat ETM satellite images taken at different times have been used to determine the effect of the plant cover on stream frequency (figure 5). When the satellite images were examined, it was observed that, especially in 1987, there was more plant cover destruction in the Sultanbahçe stream sub-catchments (figure 5). This plant cover situation has been influential in stream frequency values over the years.

4.3 *Splitting ratio and quantity (*$\mathbf{R_b}$*)*

The number of narrow, deep and youthful valleys within the catchment areas increases with increasing degrees of splitting in the catchment area found between the first index and the second index. It is surplus to the degree of splitting between the highest index and preceding index (equation 1). It is calculated from the fact that the degree of splitting of first-order streams in sub-catchments of the Sultanbahçe stream is rather higher than those of the Elmalı stream (table 3). Moreover, the total numbers of stream segments within the mentioned area (ΣN_u) are 192 and 86 for Sultanbehçe and Elmalı streams, respectively. Consequently, the total number of stream segments within the catchment area is 278. When we analyse the total number of segments, we find that the streams are forming narrow, deep and youthful valleys within this sub-catchment (Akar *et al.* 2006). Remote sensing technology gives the researcher an opportunity to make visual analyses regarding splitting quantities. The visible bands of 1987 Landsat TM satellite images (3, 2, 1 bands; 0.45–0.69 μm) were used in order to achieve this. When figure 6 was analysed the splitting ratio and

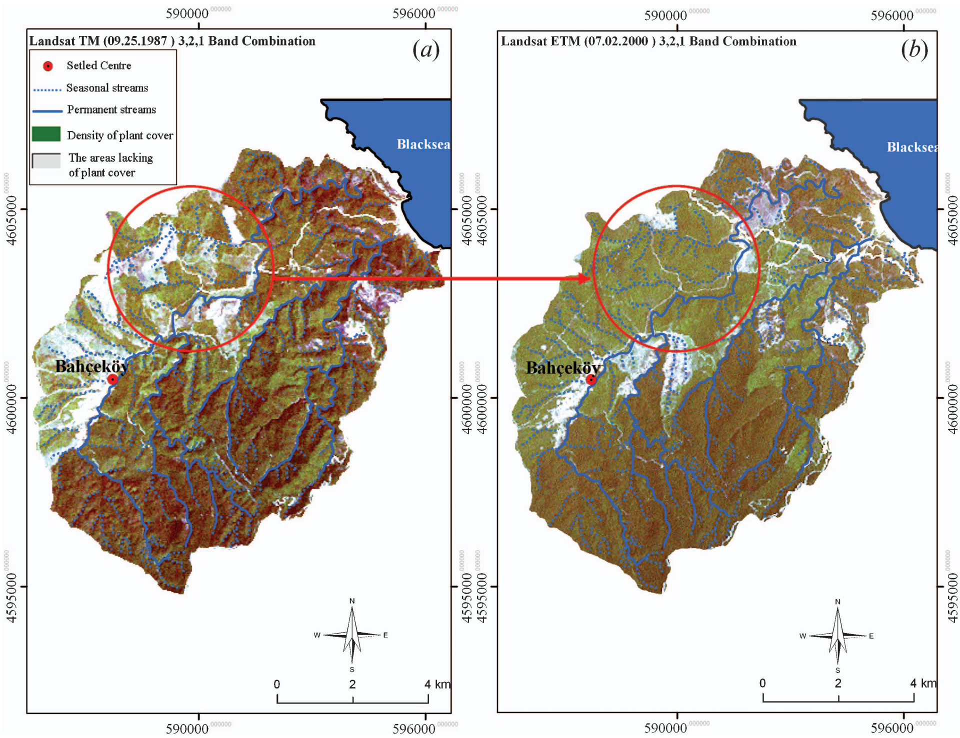

Figure 5. Determination of changes in plant cover through use of (*a*) 1987 Landsat TM and (*b*) 2000 Landsat ETM satellite images.

quantity of the Sultanbahçe stream sub-catchment was seen to be higher than that of the Elmalı sub-catchment (figure 6).

4.4 *Drainage density* (D_d)

Drainage density is a measure that shows the degree of catchment area partitioned by the stream. It is calculated by division of the total length of the segments (ΣL) by the catchment (A), as stated in formula (2) (Hoşgören 2004). Furthermore, being the result of sundry factors controlling surface flow, drainage density influences both sediment and outflow of water within catchment areas. We can enumerate the factors that determine the density of drainage as permeability characteristics of the field, its infiltration capacity, sparsity and density of the flora, relief characteristics and climatic factors (Morisawa 1968, Baker *et al.* 1988).

According to evaluations of sub-catchments, the drainage density of the Sultanbahçe stream is 2.53, and this shows us that the loss arising from lithologic structure and vegetation cover is relatively less in this sub-catchment. When, however, we take into consideration the evaluation of the Elmalı stream sub-catchment, density is relatively low and its water loss is higher compared with the Sultanbahçe stream. Rainfall fails to have direct contact with running waters in those segments of the field of study where the vegetation is dense. Through its roots, the vegetation absorbs a significant proportion of the water available to running waters, and this has a negative impact on drainage density. Running waters are capable of benefiting more from surficial running in those segments where surficial running is high.

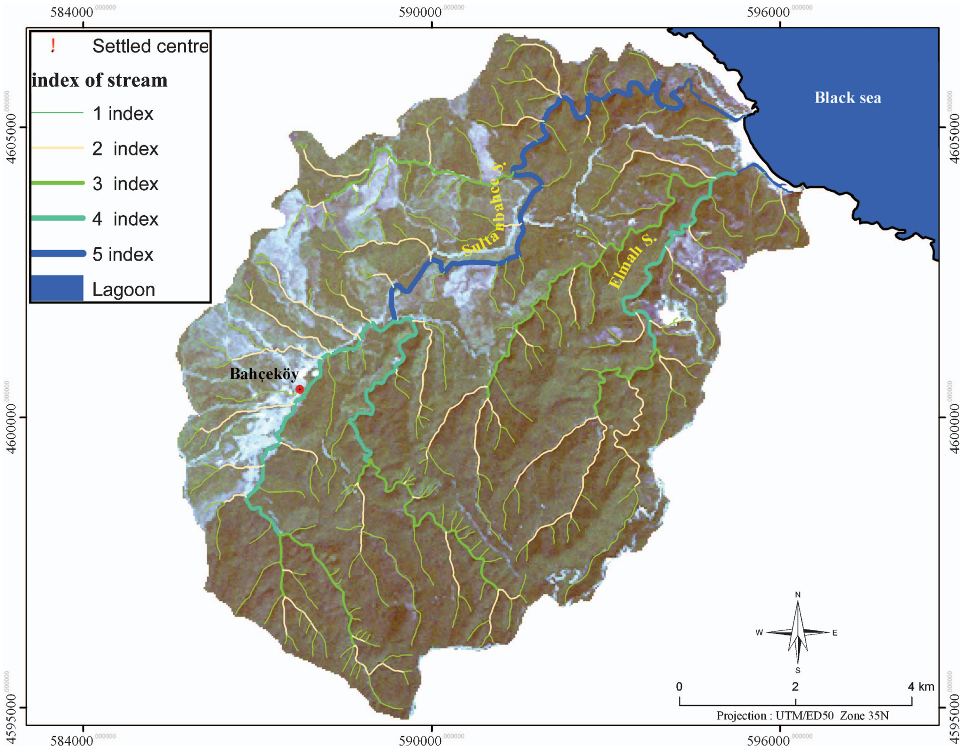

Figure 6. 1987 Landsat TM satellite image showing the stream splitting quantity of the study area.

5. Hypsometric curve

The hypsometric curve describes the distribution of elevations across an area of land. A useful attribute of the hypsometric curve is that drainage basins of different sizes can be compared with each other because area and elevation are plotted as functions of total area and total elevation. That is, the hypsometric curve is independent of differences in basin size and relief (Keller and Pinter 2003). The total catchment area is shown as A. Its length is shown as h. Relative area (a/A) is shown with the formula ($h/H=1$) for the maximum length and for the minimum length ($h/H=0$) (Bilgin 2001; table 4). First, contour curves and elevation points, generated by GIS 9.1 software,

Table 4. Calculation method of hypsometric curve.

Height (m)	H (m)	a (m^2)	A (m^2)	h/H	a/A
0	450	81 642297	81 642 297	0.00	1.00
50	450	78 808 971	81 642 297	0.11	0.97
100	450	71 923 012	81 642 297	0.22	0.88
150	450	54 978 763	81 642 297	0.33	0.67
200	450	35 860 551	81 642 297	0.44	0.44
250	450	23 785 386	81 642 297	0.56	0.29
300	450	13 503 294	81 642 297	0.67	0.17
350	450	4 868 223	81 642 297	0.78	0.06
400	450	628 279	81 642 297	0.89	0.01
450	450	700	81 642 297	1.00	0.00

were transformed into a Triangulated Irregular Network (TIN), producing an irregular triangular network through a hybrid model between tessellation and vectorial representation by means of a 3-dimensional analysis module (Wilson and Gallant 2000).

The created TIN model was transformed into a raster format and subsequently a digital elevation model (DEM) was created from it. These raster data have made an effective contribution to the conversion of 50 m elevation zones into m^2 in the way that was required for generation of the hypsometric curve of the catchment area: when the latter is analysed, it is seen that it demonstrates a slightly concave pattern (figure 7), and this shows us that the catchment area is experiencing a mature stage. According to the analysis results, the erosion power and capability of the streams within the study area would be reduced, and, as a result, the possibility of the formation of a narrow, deep valley would be decreased.

5.1 *Hypsometric integral (*H_i*)*

A simple way to characterize the shape of the hypsometric curve for a given drainage basin is to calculate its hypsometric integral (H_i). The integral is defined as the area under the hypsometric curve (Turoğlu 1995). The hypsometric integral for the catchment area was calculated using histogram data from a DEM generated for the catchment area (figure 8). A hypsometric integral indicates a youthful topography (figure 9(*a*)). An intermediate value of the Hypsometric integral and a sigmoidal-shaped hypsometric curve indicate a mature stage of development (figure 9(*b*)). Further development to the old-age stage will not change the value of the integral, unless high-standing erosional remmants are preserved (figure 9(*c*)). The hypsometric integral is calculated using formula (4) (Mayer 1990). The hypsometric integral of the catchment area is 0.436. This value proves the fact that the area is in a mature stage (Keller and Pinter 2003).

$$\boldsymbol{Hi} = \frac{mean\ elevation - minimum\ elevation}{maximum\ elevation - minimum\ elevation} \quad \boldsymbol{Hi} = \frac{196.52 - 0}{450 - 0} = 0.436 \tag{4}$$

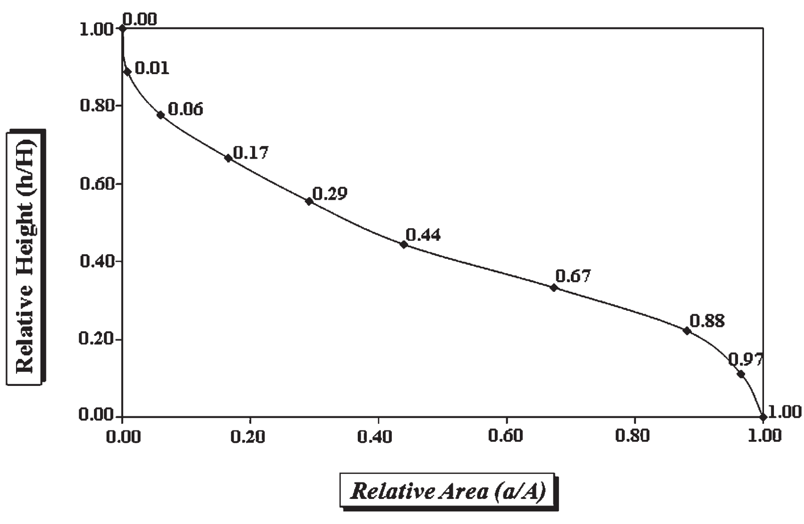

Figure 7. Hypsometric curve of the study area.

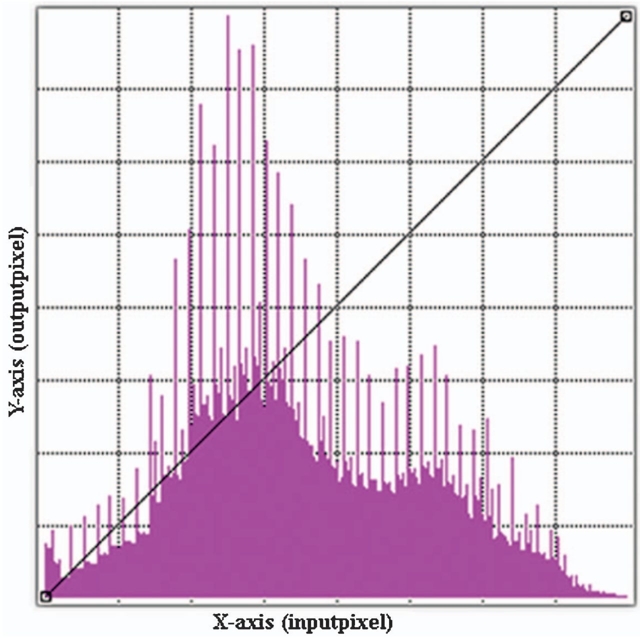

Figure 8. Histogram of the DEM of the study area.

The *Hi* value demonstrates that the Kasatura Bay Catchment area is at the final stages of its maturity. It also demonstrates that the Kasatura Bay Catchment area has been eroded very much by running waters.

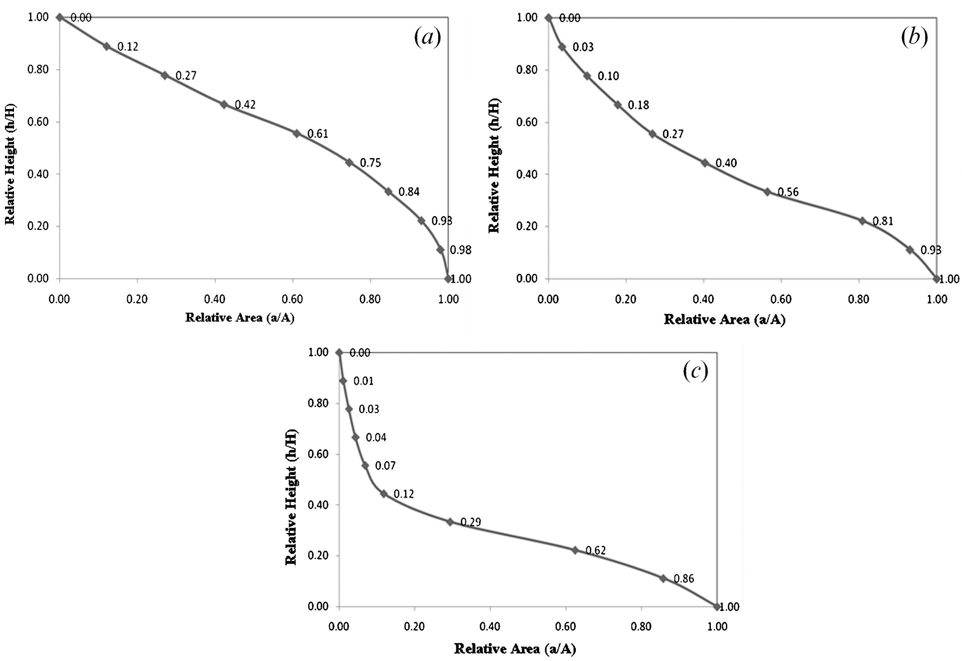

Figure 9. Three examples of different values of the hypsometric curve and hypsometric integral. (*a*) Youthful (H_i=0.745), (*b*) mature (H_i=0.450), (*c*) old-age stage (H_i=0.150).

6. Conclusions

GIS and remote sensing methods have been used in various scientific disciplines, thanks to recent developments and their acceleration during the last few years. This study benefited from the facilities offered by GIS and remote sensing. Drainage network and morphometric analysis require very comprehensive and very wide research, covering many features. That is why it is not possible to show all analyses here. According to analysis results, Kastro Bay hydrological basin is mainly at the mature stage. Erosion activities of the streams therefore decrease. The drainage pattern of the studied area demonstrates parallel and sub-parallel characteristics. Drainage density shows differences in the sub-catchment levels. The drainage density of the Sultanbahçe stream basin is 2.53. The Elmalı stream basin's drainage density is 2.45. The drainage density of the Sultanbahçe stream sub-catchment is higher than that of the sub-catchment of the Elmalı stream: this difference is based on geological, geomorphological and flora cover characteristics. Furthermore, human activity in the study area affects the characteristics of the streams. Flora cover deformation has a particular effect on the drainage network characteristics.

The hypsometric integral for the catchment area was calculated using histogram data from a DEM generated for the catchment area. The hypsometric integral of the catchment area is 0.436. This value proves the fact that the area is at a mature stage. The stream frequency of Sultanbahçe stream basin is 3.72. Elmalı stream basin's stream frequency is 3.12. The same is not exactly true of sub-catchments when evaluated in the light of this information, but the two main streams within the catchment area, the Sultanbahçe stream and the Elmalı stream, show parallel-sub-parallel drainage network characteristics. The results of the evaluations (analyses based on the created database) showed that the degrees of splitting in the area studied were determined as 3.8, 6, 1.8, 5, 4.1.

When the stream frequency of the sub-catchment is examined, stream frequencies of the sub-catchment of the Sultanbahçe and Elmalı streams are found to be 3.72 and 3.12, respectively. It is understood from this that both streams have similar stream frequency levels. Catchments of both streams, however, are distinguished by their structural characteristics: the catchment area of the Sultanbahçe stream has a lower permeability compared with that of the Elmalı stream. Visible and near infrared images (4, 3, 2, bands; 0.52–0.76 μm) of the 1987 Landsat TM and 2000 Landsat ETM satellite images, taken at different times, have been used to determine the effect of the plant cover on stream frequency. Moreover, the total numbers of stream segments within the mentioned area (ΣN_u) are 192 and 86 for Sultanbehçe and Elmalı streams, respectively. Consequently the total number of stream segments within the catchment area is 278. When we analyse the total number of segments, we find that the streams are forming narrow, deep and youthful valleys within this sub-catchment. Remote sensing technology gives the researcher an opportunity to make visual analyses regarding splitting quantities. The visible bands of the 1987 Landsat TM satellite images (3, 2, 1 bands; 0.45–0.69 μm) were used in order to achieve this. When figure 6 was analysed the splitting ratio and quantity of the Sultanbahçe stream sub-catchment was seen to be higher than that of the Elmalı sub-catchment.

The analysis carried out by GIS and remote sensing methods helps us to determine the characteristics of the drainage system digitally and confidently. As this study shows, spatial analysis with GIS and remote sensing methods is quantitative and trustworthy.

Acknowledgments

I would like to thank Professor D. Maktav, Assistant Professor A. Ertek, research assistant H. Ozdemir, engineer C. Uysal and TUBITAK (The Scientific and Technological Research Council of Turkey) for their contributions to this study.

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