The Determination and Comparison of the Hydrological Properties of Basins from Topographic Maps, DTM and SRTM DEMs. A Case Studyof Part of the Roman Water Supply System (Thrace, Turkey)

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Abstract. Geographic Information Systems (GIS) play an important role in the study of drainage network morphometry. Data that is produced and supplied with GIS contribute a great deal for the understanding of the drainage features of a specific region. Different types of data can be used to determine and compare different catchment areas. In this study, basins of the Mandıra River within the boundaries of the Çatalca District of Istanbul (in Thrace) have been investigated. These basins are also hydrologically related to the Roman and Byzantine water supply system passing through this region. The data source types consisted of 1:25000 scale digital topographic maps, Digital Terrain Model (DTM) and Shuttle Radar Topography Mission (SRTM -3 arcsecond) . The Arc Hydro tool of Arcinfo 9.3 and River Tools 2.4 softwares were used to analyse the data and the Strahler method was applied in order to determine hydrographic data, such as drainage density, stream frequency, stream length, and its profile to the length. Consequently it was observed that among three different types of data, DTM provided the best solution for determining the hydrological properties of the basins**.**

Keywords. Roman Water Supply System, DTM, SRTM, Topographic Maps, Drainage Network.

Introduction

The study focuses on the region of Thrace, west of the city of Istanbul. From the fourth to the twelfth centuries C.E. this was one of the principal water sources for a complex network of aqueduct channels leading to the Byzantine city. The system was developed in response to the increasing size of the late Roman city from the fourth century C.E. and like all Roman aqueducts relied on a gravity fed system of water conduits fed by springs along its course. By the time of fullest extent in the fifth and sixth centuries the system of channels was nearly 500 km in length one of the astonishing achievements of civil engineering known from the ancient world. [3] [6].

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The application of GIS and remote sensing for the study of drainage network morphometry offers users and researchers a variety of facilities via the numeric and textual databases 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, it is possible to calculate splitting degree, drainage density, stream frequency and stream length, as well as hydrographic data. DEMs have an important role to determine these properties. GIS and remote sensing can also be used effectively for updating and monitoring the spatial analysis of the morphometric and parametric databases of river basins etc.

1. Study Area

The study area was located within the borders of the Çatalca district of the Istanbul province in the Marmara Region between UTM/WGS84 /Zone35N, Max. West: 596779, Max. East: 612308, Max. North: 4581857, and Max. South 4564727 coordinates (Figure 1). The study area has a perimeter of 58.071 km and a surface area of 158.391 km^2; the north–south length of the study area is 18.685 km, and the east–west length is 14.281 km. The elevation of the study area varies between 70 and 360 m, with a mean of 201.85 m.

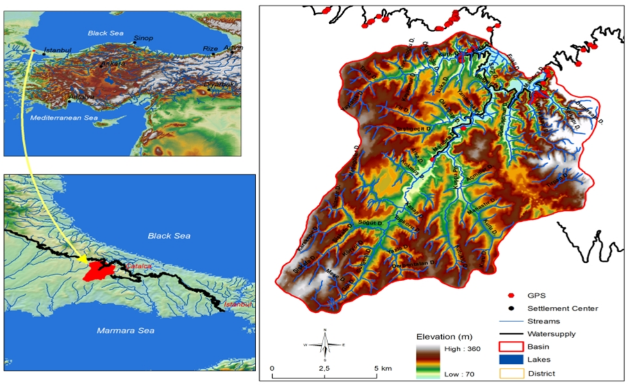

Figure 1. Location of study area.

2. Data and Method

The available data comprise the results of archaeological field survey and GPS measurements, IKONOS images, SRTM data, DTM and 1: 25000 digital topographic maps. The volume and flow of the water within discrete basins relating to the system are calculated using River Tools 2.4 and ArcHydro GIS software. This provides a better understanding of the potential discharge of the river systems and their potential contribution to the water supply system.

2.1. Determination of Drainage Properties

For hydrologic applications the DTM of the study area was obtained with a grid interval of 10 m by using 1:25 000 scale digital topographic data. River Tools software was used to generate drainage network properties from the DTM. Also, drainage network properties of the study area are determined from 1:25000 manually digitized topographic maps. Streams were classified in the GIS environment according to Strahler's (1964) method (Figure 2) . Moreover, River Tools software was used to generate drainage network properties from SRTM DEM (3 arcsecond). The higher the precision of the DTM, the more realistic the rivers are, otherwise, large flat areas will produce an unnatural drainage network [7].

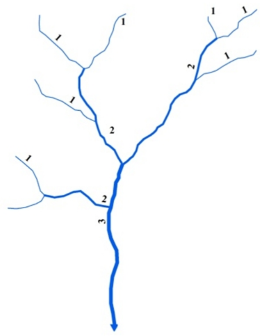

Figure 2. Calculation technique of Strahler method.

After DTM and SRTM DEM were selected, the sinks and peaks heights on the DTM were corrected in order to eliminate interruption of the river network [11] (Figure 3). The D8 method was used to determine natural flow directions. There are eight valid output directions relating to the eight adjacent cells into which water flow could travel. This approach is commonly referred to as an eight direction (D8) flow model and follows an approach presented in Jenson and Domingue 1988 [5]. The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell. The distance is determined between cell centers. Another model generated by using the DTM and SRTM DEM in hydrologic studies is the flow accumulation model obtained from the flow direction model (Figure 4). Water flow directions are identified from the DTM, a SRTM DEM and a water flow directions model is created accordingly. Starting from the top right corner on the water flow directions model, the flow accumulation values are calculated cell by cell. If a cell does not receive a flow from another cell, its value will be zero (Figure 4). Each grid cell (pixel) on the DTM and SRTM DEM has a numeric value. The flow from the cell can only be to one neighbouring cell with a lower altitude value. There are eight possible directions for each cell. Figure 4 shows the possible flow directions from cell 50 and the values to be assigned to cell 50 in the new water flow direction model. These values define the flow directions in software operating under GIS. Accordingly, if flow is to the right of cell 50, the flow direction value of cell 50 will be 8; and if flow is to the left of cell 50, the flow direction value will be 4; and if flow is to the bottom of cell 50, the flow direction will be 2 [5]. The filled DTM and SRTM data were used to generate flow directions (Figure 5).

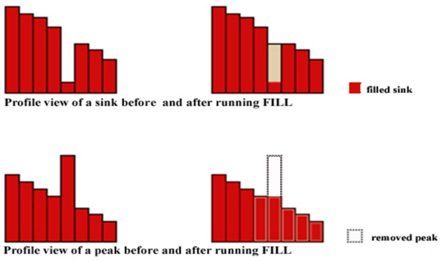

Figure 3. Editing peaks and sinks in DTM and SRTM DEM.

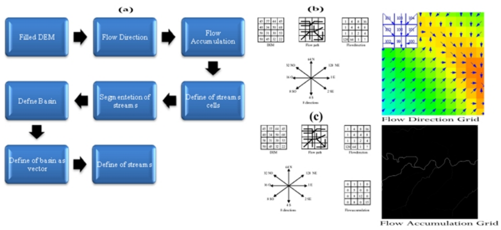

Figure 4. Steps of the stream which is generated from the DTM and SRTM DEM.

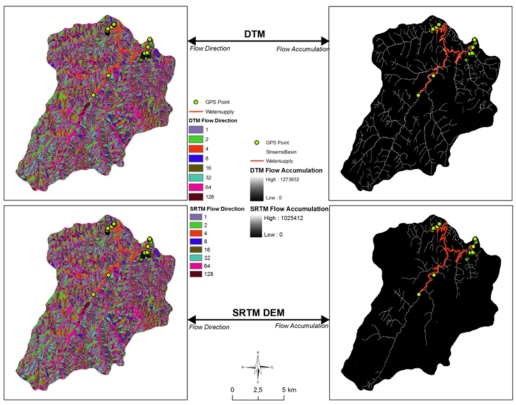

Figure 5. Flow direction and flow accumulation of DTM and SRTM.

3. 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 of all, the streams shown on the topographic map were digitized and then a database was created to support the study. Then, certain morphometric characteristics were evaluated for the area (Table 1, Table 2). Also, using River Tools software morphometric characteristics were determined from DTM and SRTM DEM (Table 3, Table 4).

3.1 Drainage Type

Streams were classified according to Strahler's [10] method in the GIS environment. 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 digitized and classified by Strahler's [9] [10] method. As a result of the evaluations, analyses based on the created database showed that the degrees of splitting generated from topographic maps of the study area, could be determined to varies between 3.28 and 6.0 (Table 1 and Table 2). However, splitting ratios generated from DTM vary between 4.0 and 4.88 and similarly splitting ratios generated from SRTM DEM vary between 4.14 and 6.0.

3.2 Stream Frequency (Fu)

Stream frequency is defined as the number of stream beds in the sub-catchment areas and their tributaries within the area studied per unit catchment area [12]. It is calculated by the division of the total number of stream segments within the catchment area ($\sum N_u$) by the total catchment area. Areas of high frequency showed impermeable field characteristics, sparse flora, high and low relief characteristics [11]. Evaporation in lower parts of the forest is smaller than on open ground because there is less sunlight and lower temperatures in such areas, relative humidity is higher and wind speed is lower [11]. This reduces water loss by way of evaporation of water 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 stream frequency generated from topographic maps of the sub-catchment is examined, the stream frequencies of the sub-catchment can be illustrated to be 2.61 (Table 2). When stream frequency generated from DTM is examined the resulting figure is 7.28 (Table 3), whereas by contrast the stream frequency generated from the SRTM DEM is 2.81 (Table 4).

3.3 Splitting Ratio and Quantity (Rb)

The number of narrow, deep and youthful valleys within the catchment areas increases with increasing degrees of splitting. This is found to be between the first index and second index and is surplus to the degree of splitting between the highest index and preceding index. Splitting ratios which were generated from topographic maps vary between 3.28 and 6.0. However, splitting ratios which were generated from the DTM vary between 4.0 and 4.88. These values vary between 4.14 and 6.0 when generated from SRTM DEM in the catchment area. In addition GIS technology gives the researcher an opportunity to make visual analyses regarding splitting quantities (Figure 6 -7) based on IKONOS pan-sharpened images.

3.4 Drainage Density (Dd)

Drainage density is a measure that shows the degree to which a catchment area is partitioned by a stream and it can be calculated by the division of the total length of the segments (∑L) by the catchment (A), as stated in formulas in tables[1][8] . Furthermore, being the result of a range of factors controlling surface flow and drainage density which can influence both the sediment and the outflow of water within catchment areas. We can enumerate the factors that determine the density of drainage as the permeability characteristics of the field, its infiltration capacity, sparsity and density of the flora, relief characteristics and climatic factors [4]. When the drainage density is generated from topographical maps the resulting value is 1.87. When drainage density is generated from DTM and SRTM DEM the values are 9.63 and 7.61 respectively in the catchment area.

Table 1. Degree of splitting index formula.

Splitting ratio and quantity (R_b) (i=index)						
i1 R_b	i2 R_b	i3 R_b	i4 R_b	i5 R_b	i6 R_b	i7 R_b
∑ Nu(i1) / ∑ Nu(i2)	∑ Nu(i2) / ∑ Nu(i3)	∑ Nu (i3) / ∑ Nu (i4)	∑ Nu(i4) / ∑ Nu (i5)	∑ Nu(i5) / ∑ Nu (i6)	∑ Nu(i6) / ∑ Nu (i7)	R_b (i1+i2+i3+i4) / 6

Table 2. Morphometric parameters of drainage network derived from topographic maps.

Basin Name	Area (km²)	Stream Orders					Total Stream Orders	Total Stream Orders Length (km)
		O1	O2	O3	O4	O5	(∑ N_u)	(∑ L)
Mandıra Streams	158.331	296	90	21	6	1	414	296.225

Basin Name	Splitting Ratio					Drainage Density	Stream frequency
Mandıra Streams	$R_b = \frac{N_u}{N_{u+1}}$ (1)					$D_d = \frac{\sum L}{A}$ (2)	$F_u = \frac{\sum N_u}{A}$ (3
	O1	O2	O3	O4	O5		
Mandıra Streams	3.28	4.28	3.50	6	4.26	1.87	2.61

Table 3. Morphometric parameters of drainage network derived from DTM.

Basin Name	Area (Km²)	Streams Order							Total Stream Orders	Total Stream Orders Length (km)
		O1	O2	O3	O4	O5	O6	O7	(∑ N_u)	(∑ L)
Mandıra Streams	158.331	8786	1797	404	89	20	4	1	11104	1,525.594

Basin Name	Splitting Ratio							Drainage Density	Stream Frequency
	$R_b = \frac{N_u}{N_{u+1}}$ (1)							$D_d = \frac{\sum L}{A}$ (2)	$F_u = \frac{\sum N_u}{A}$ (3)
	O1	O2	O3	O4	O5	o6	O7		
Mandıra Stream	4.88	4,44	4.53	4,45	5	4	4,55	9.63	7.28

Table 4. Morphometric parameters of drainage network derived from SRTM DEM.

Basin Name	Area (Km²)	Streams Order						Total Stream Orders	Total Stream Orders Length (km)
		O1	O2	O3	O4	O5	O6	(∑ N_u)	(∑ L)
Mandıra Streams	158.331	2742	504	112	27	6	1	3392	1.206,497

Basin Name	Splitting Ratio						Drainage Density	Stream Frequency
	$R_b = \frac{N_u}{N_{u+1}}$ (1)						$D_d = \frac{\sum L}{A}$ (2)	$F_u = \frac{\sum N_u}{A}$ (3)
	O1	O2	O3	O4	O5	O6		
Mandıra Stream	5.44	4.50	4.14	4.50	6	4.91	7.61	2.81

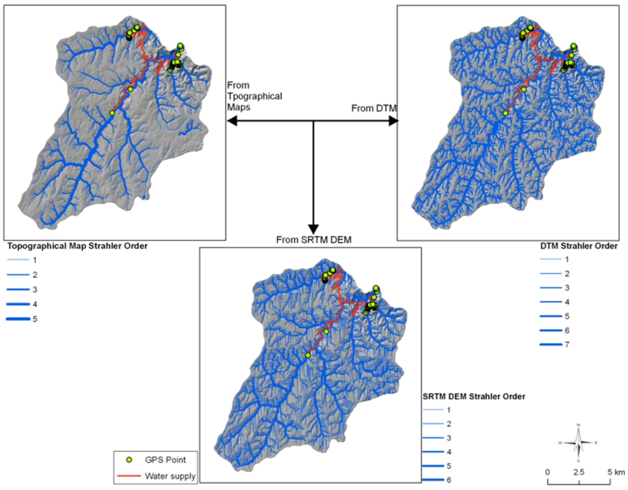

Figure 6. Drainage network from topographic maps, DTM and SRTM DEM.

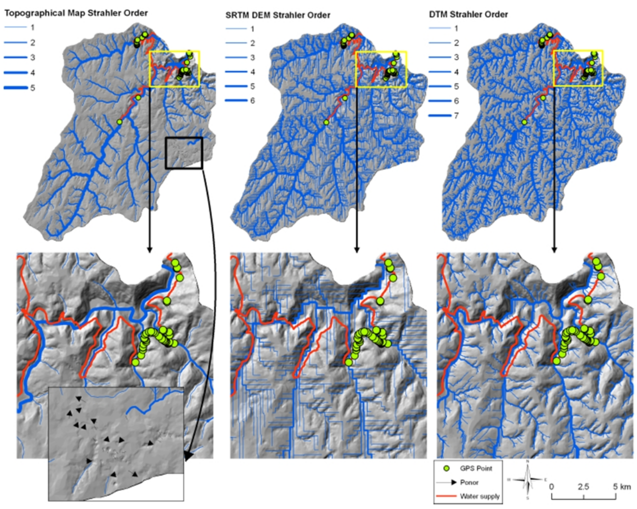

Figure 7. Drainage networks from topographic maps, DTM and SRTM DEM with Roman Water Supply System in the catchment.

Conclusions

In this study, drainage networks properties were acquired from topographic maps, DTM and SRTM DEM to model the hydraulic properties of the catchment area. According to the analysis of the drainage network those morphometric features generated from the DTM provide the best results for modeling the catchment area. The SRTM DEM and topographic maps respectively provide drainage network morphometric features of a lower accuracy. The drainage network generated from the

DTM has a higher stream frequency and drainage density value. Moreover, the drainage network generated from the DTM has higher stream order and total stream order length than the others. Also the accuracy of the DEMs can be important to determine drainage network morphometric features. Dolines in the study area show that the area has rich groundwater resources [2]. This is one of the reasons why the Roman Water Supply system passed along this line. When we investigate the results of stream frequencies, drainage densities and drainage network morphometric properties generated from topographical maps, DTM and SRTM DEM it becomes apparent that there is enough water capacity in this catchment area capable of providing a significant boost to the passing channels of the main aqueduct line. In previous fieldwork in the valley of the Kurşunlugerme Stream we were able to identify the two main higher and lower aqueduct channels running across the great fifth-century aqueduct bridge but in addition it was possible to identify a number of supplementary channels fed by local streams and springs [3]. This study of the regional drainage network provides important insights to undertsand the potential of these streams and aquifers of one of the ancient world's greatest building achievments.

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