GEOARCHAELOGICAL INVESTIGATION OF CENTRAL ANATOLIAN CARAVANSERAIS USING GIS

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Approval of the Graduate School of Natural and Applied Sciences.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

GEOARCHAELOGICAL INVESTIGATION OF CENTRAL ANATOLIAN CARAVANSERAIS USING GIS

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This study comprises analysis of geological, geomorphological constraints that played role in the site selection of caravanserais. In order to do this, 15 caravanserais located along a route from Nevşehir-Aksaray-Konya to Beyşehir were used. The data used in the study include a caravanserai database, lithological maps, and digital elevation model of the area. GIS analyses performed in the study are proximity, visibility, and probability distribution (PDA). The first step is the generation of the ancient trade route which is used as a reference in other analysis. Results of the analysis indicate that the average distance between consequent caravanserais is 10 km. PDA suggests that there should be two more caravanserais between Beyşehir - Yunuslar and one caravanserai between Obruk - Sulatnahanı hans. Caravanserais are very close to a water source but not at their immediate vicinity. Groundwater is not considered in this study; dominant water sources are streams, springs and lakes. Their visibility tested in an area of 78 km^2 shows a great variation suggesting that visibility is not considered during the site selection. Ignimbrite, limestone and marble are preferred rocks types although other rocks such as clastic rocks are exposed in closer distances.

Key words: Caravanserai, Geoarchaeology, GIS, probability distribution analysis (PDA), ancient trade routes.

ÖZ

ORTA ANADOLU KERVANSARAYLARININ COĞRAFİ BİLGİ SİSTEMLERİ KULLANILARAK JEOARKEOLOJİK İNCELEMESİ

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Bu çalışma kervansarayların yerlerinin seçiminde rol oynamış jeolojik ve jeomorfolojik etmenlerin analizini kapsar. Nevşehir-Aksaray-Konya ve Beyşehir arasında ki 15 kervansaray bu amaçla analiz edilmiştir. Kullanılan veri setleri kervansaray konumu, kullanılan malzemenin tipi gibi faktörlerle, jeoloji haritaları, ve sayısal arazi modeli içermektedir. Derlenen bu veriler kullanılarak değişik CBS analizleri yapılmıştır. Bu analizler göstermiştir ki; tüm kervansaraylar mutlaka bir su kaynağına yakın fakat hemen bitişiğinde kurulmamışlardır, ve kervansarayların görünebilirlikleri yer seçiminde önemli bir etmen olarak gözükmemektedir.

Bunlara ek olarak, yapılan analizler göstermiştir ki kervansaraylar arasındaki ortalama mesafe 10 km'dir. Yapılan analizler ayrıca göstermiştir ki Beyşehir ile Yunuslar ve Obruk ile Sulatnahanı arasında olmak üzere en az 2 kervansaray daha bulunmalıdır. Bu kervansarayların olası pozisyonları bu tez sırasında geliştirilmiş olan olasılık dağılım analizi (ODA) tekniği kullanılarak belirlenmiştir.

Anahtar kelimeler: kervansaray, jeoarkeoloji, CBS, olasılık dağılım analizi (ODA), antik ticaret yolları.

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CHAPTER 1

INTRODUCTION

1.1. Purpose and Scope

Caravanserais are monumental structures built throughout Anatolia along the trade routes. Most of them belong to Seljuk period and used in the later centuries. Although neither database nor reliable information exists on the number of caravanserais, it is estimated that several hundreds of them were in use existed during 12-13th centuries.

Caravanserais are conventionally studied by art historians in Turkey and focus on their architecture, age and related features. In most of these studies a restoration plan or a use for tourist attraction (as restaurant or museum etc) is suggested.

These structures, although today mostly exist stand alone and isolated, belong to a complicated network and are positioned with a certain pattern. This aspect of the caravanserais is relatively not considered in the studies carried out. For this reason, there are several questions not answered about caravanserais. Investigation of the caravanserais from earth science point of view would contribute a lot to understand some details of caravanserai design system.

The purpose of this study is to investigate geoarchaeological characteristics of caravanserais to shed light on various aspects of these structures. In this approach, it is expected to answer some questions that will help to understand the system behind caravanserais. Examples of these questions are:

- What is the distance between two neighbor caravanserais (true distance measured on topography rather than plan distance)
- During the selection of a caravanserai site, is it planned to hide the structure or is it intended to see it from a certain distance

- What is the importance of water resources in the selection of a caravanserai site
- How important is the distance to the source rock used in the construction of caravanserai
- How can the location of an unknown or totally destroyed caravanserai be predicted

In order to answer these questions three disciplinary tools will be used in this study. These are geological background (particularly on the rock types and water sources), topographic parameters and GIS applications.

The scope of the thesis is limited with following aspects:

- The study will be based on the caravanserais that exist between Beyşehir and Nevşehir in Central Anatolia. This line is known to be one of the most populated routes.
- Architectural and historical aspects of caravanserais will not be considered.
- Caravanserais will be dealt as points; therefore, their internal structure, size and other dimensional characteristics will not be used.

The study in general will be a methodological work that will introduce an approach to study caravanserais as a population rather than individual structures. This approach is assumed to be applied to other caravanserais located along other routes across Anatolia.

1.2. Method of Study

The study is carried out starting with the literature survey, and continued with the preparation of the caravanserai database and the data layers. The database is acquired using the existing information from the literature, and completed with the fieldwork.

In the preparation of data layers, the Shuttle Radar Topographical Mission (SRTM) data is used as Digital Elevation Model (DEM) extraction, 1/500.000

scale geological maps of MTA are used for the geology layer, and 1/250.000 and 1/100.000 scale topographical maps of General Command of Mapping are used for the extraction of the recent roads and water sources, respectively.

In the digitization process of the recent road and geology layer, Able Software R2V is used to convert raster data into vector format. After these office works, a field work program is planned in order to complete the missing parts of the database and to verify the accuracy of the information from the literature, to obtain precise GPS coordinates of the caravanserais, and other field observations related to characteristics of the caravanserais. After the completion of the database and data layers TNTmips v6.2 software is used for all kinds of GIS analyses.

CHAPTER 2

PREVIOUS WORKS

Previous studies are categorized into two groups. In the first group, studies about distribution and architecture of caravanserais are presented. The second group is generally related to the topics about the GIS analyses used in this study.

2.1. Studies about the Architectural Aspects of Caravanserais in the Region

The literature about the architectural studies about caravanserais can be grouped into two as books, and M.Sc. and Ph.D. theses.

The main studies concerning the architectural properties of caravanserais in the form of books is as follows:

One of the first broad studies about caravanserais is by Erdmann (1961), 13th Century Anatolian Caravanserais. He made a classification of caravanserais with respect to the sizes of their hall and court. According to this classification he investigated all caravanserais one by one and provided information about certain properties such as their location, brief description, dimensions, construction system, stone carving, and founder and building date. Additionally, he investigated some structural elements of caravanserais such as the mosque, bath and the water supply. He also mentioned about their preserved conditions and prepared a detailed plan of all these caravanserais.

Another study is of Asatekin *et al.* (1996), Along Ancient Trade Routes, Seljuk Caravanserais and Landscapes in Central Anatolia. They investigated general characteristics of landscape, vegetation, and some geological aspects as well as the history, and the architecture of some caravanserais and villages in the region. By combining all these information, they developed some policies for the conservation and continuation of the Anatolian historical heritage.

Bektaş (1999) studied the Seljuk Caravanserais and made a proposal regarding their protection and use. He also introduced the functions of caravanserais, types of caravanserais, all kinds of recent and ancient roads in Anatolia and gave information about some of the caravanserais on these routes.

Studies performed as theses are as follows:

Çankaya (1995) approached to the subject from different point of view in his M.Sc. Thesis. He evaluated the Anatolian Seljuk period hans and caravanserais in order to be used in touristic purposes. He examined all Anatolian Seljuk period caravanserais in terms of their position and dimensions. The main purpose of the study was to investigate the feasibility of caravanserais that can be restored and revitalized in a cost efficient way. Therefore, the study dealt mainly with the cheap restorability of the caravanserais and determination of the ones that can be revitalized via restoration.

Karaoğlu (1998) studied the restoration of the Kızılören Han near Konya in her M.Sc. Thesis. She described the general properties of the Han, examined the architecture of the building and its elements, and then proposed o method for restoration.

Another M.Sc. Thesis about hans and caravan roads in Kayseri and in its surroundings is conducted by Çeliker (1998). He investigated the ancient routes passing from Kayseri, and prepared a list about the condition of hans and categorized into three groups as; the ones in good condition, ones that are partly destroyed, and the ones that are totally destroyed.

Aktemur (1999) studied the stone ornamentations on the Kayseri buildings belonging to Anatolian Seljuk period as a M.Sc. Thesis. He described different types of ornamentations on these buildings, and the techniques used in the ornamentation.

Yılmaz (2001) carried out a study about the Kültepe writings in her Ph.D. thesis. She attempted to find out the possible routes for the caravan roads with the help of these writings. But she concluded that the main theme of these writings was about trade life, so there was no clue about the routes neither about the settlements nor how ancient trade people spend the night along the route that might help to delineate the ancient routes.

Önge (2004) studied the restoration of Zazadin Han located near Konya as a M.Sc. Thesis. He described the architecture of the building and its surroundings. He made a comparison of the Zazadin han with some other hans and proposed a project for restoration.

2.2. Studies about GIS Analyses

There are a number of GIS analyses developed, and thousands of different articles about these analyses published in the literature. Therefore, only the previous studies about GIS analyses, related to this thesis will be summarized. These are visibility analysis, and the watershed analysis.

2.2.1. Visibility (Viewshed) Analysis

The earliest work related to visibility analysis dates back to the times of first generation computers. For example Amidon and Elsner (1968) developed a methodology to map the areas visible from a point using computers.

Goodchild and Lee (1989) discussed the problems related to visibility and coverage on topographic surfaces.

Along with the developments in the computer technology and Geographical Information Systems softwares, visibility analyses and the accuracy assessment of the produced viewsheds have gained acceleration by the end of 1980's. Especially in the 1990's a number of different techniques have been developed using different approaches and data structures.

Fisher (1991) is the first who tested the accuracy of the produced viewshed. In his research he found out mainly two factors affecting the accuracy of a viewshed: (1) 30m resolution DEMs prepared by USGS are served with an error up to RMSE=15m which causes a large amount of error in the application of visibility analysis. (2) The viewshed algorithm itself is very sensitive to small deflections which cause the analysis to be inaccurate. Considering all these drawbacks, he introduced the probable viewshed concept (Fisher, 1995) in which the output is not a binary map. Instead, it is a probability map in which the value of pixels ranging between 0 and 1. Therefore, 0 indicates absolutely invisible areas while 1 indicates definitely visible areas. The value between 0 and 1 corresponds to probability of visibility. After the computation of the probable viewshed map, he carried out some overlay operations in which the products can be used in landscape planning.

Sorensen and Lanter (1993) proposed that the errors in viewsheds are not only from the inaccuracies in DEM but also from the nature of raster data structure, and they developed two algorithms to reduce the errors. These two algorithms, the vector analysis method, and the sub-cell binary analysis, reduces or eliminates the data-structure induced viewshed errors.

Using raster data structure, Cohen-Or *et al.* (1995) developed a methodology for determination of visible and invisible sites from a point using Digital Terrain Maps, in which the idea is arisen from the need of fast and efficient computation. They performed some vector calculations in order to detect the hidden points on a curve and generated an algorithm which the arithmetical operations are minimum.

A different application of visibility analysis is introduced by Lake *et al.* (1998). They applied the visibility analysis to find out whether the archaeological sites on Rhinns of Islay located at positions of better visibility compared to other potential sites in the area. For faster computation, they gave a new form to the existing GIS software GRASS, for the calculation of automated cumulative viewshed analysis.

Lee and Stucky (1998) aimed to integrate the viewshed analysis with the least cost path analysis using Digital Elevation Models. The least-cost path analysis includes several factors such as the distance between the starting point and destination point, the slope angles, etc. They applied the analyses on four different paths, which are designed for different purposes. The first path is the “hidden path” having minimum visibility, which can be used for military purposes. The results of the analysis showed that, these kinds of paths tend to stay away from high elevations. The second one is the “scenic path” where the path has maximum visibility. It is designed in order to have panoramic views during a journey. The results showed that they tend to be in valleys where the surrounding can be seen more completely. Other two paths, “strategic path” and “withdrawn path” have properties between those two, except that the withdrawn path has no slope restriction so that it is suitable for the pipelines. They compared the results with Euclidean paths in order to create a standard to test the efficiency of the paths.

2.2.2. Watershed Analysis

GIS is an important and powerful tool in the computation of watersheds. There are a number of studies covering different applications of watershed analysis as well as the techniques to improve the analysis. The first computer based studies about the subject started in 1988 with the measurement of catchment area from digital elevation models by using FORTRAN program (Martz and De Jong, 1988). Among the many studies about GIS based watershed analysis, the study of Garbrecht and Martz (1996) worth to mention here. They studied the flat surfaces in DEM which is relatively very difficult task, to improve the automated drainage analysis and to develop an algorithm to modify the flat surfaces in DEM, in order to get more realistic and topographically consistent drainage patterns.

Nowadays watershed analysis became one of the standard tool-box for most GIS softwares.

CHAPTER 3

GENERAL INFORMATION ABOUT STUDY AREA

3.1. Location of Study Area

The study area is located at the central part of Anatolia (Turkey), along the main highway that runs almost east to west between Beyşehir and Nevşehir. The area is a 310 km strip, covering an area of 10 km from each side of the recent road. This road is believed to coincide with the ancient caravanserai route. The strip starts at the center of Beyşehir, and passes through major cities Konya and Aksaray, and ends at the center of Nevşehir (Figure 3.1).

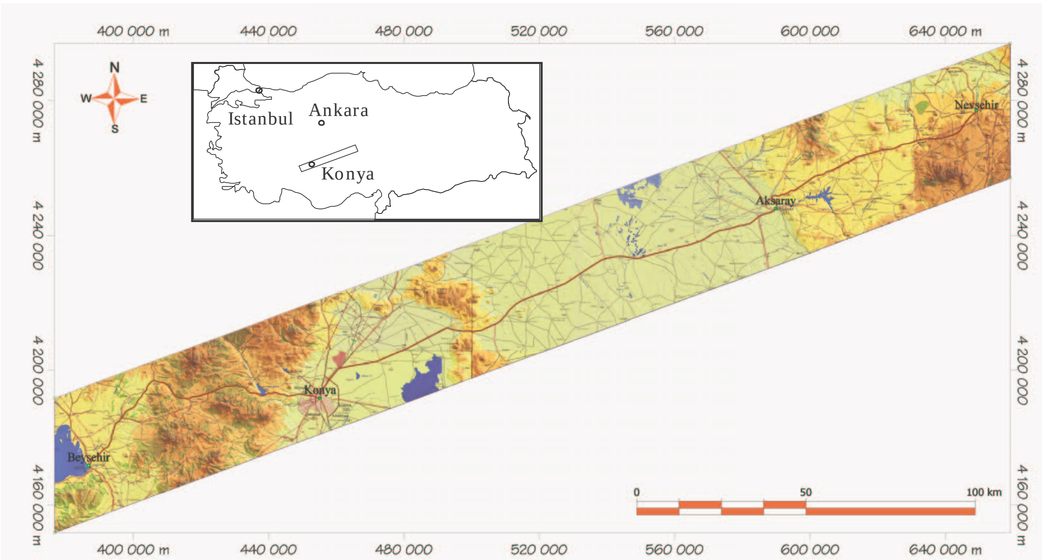


Figure 3.1: Location map of the study area.

3.2. Regional Geology

Major geological rock units in the region can be divided into four associations. These units relatively from east to west are represented by the Kırşehir Block, Cappadocian Volcanic Province, Neogene-Quaternary deposits of the Tuz Gölü and Konya plains, and the Tauride Carbonate Platform units. The major structures in the region are the dextral Eskişehir and Tuz Gölü Fault Zones (Figure 3.2). The geological characteristics of these units are briefly explained below.

The Kırşehir Block (also referred to as Central Anatolian Crystalline Massif; Göncüoğlu *et al.*, 1990) is represented by various Paleozoic to Late Cretaceous carbonates and clastics metamorphosed to low to medium grades in places, and medium to high grade Paleozoic metamorphic rocks exposed mainly in the south (Göncüoğlu *et al.*, 1990). All of these units are thrusted over by the Late Cretaceous ophiolites and subsequently all of these lithologies were intruded by the Late Cretaceous to Paleocene granitoids. The lithologies of the Kırşehir Block were seldom used as construction material for the caravanserais.

Cappadocian Volcanic Province (CVP) is 300 km long in E-W direction and about 60 km wide in N-S direction. It is developed within the Kırşehir Block during the Neogene to Quaternary and is also exposed within the horst-like highs within the alluvial plains of Tuzgölü and Konya basins (Toprak *et al.*, 1994). It comprises mainly the Neogene mafic (basaltic) to felsic (rhyolitic) lava flows, various pyroclastic units and intercalated fluvio-lacustrine associations. The latest eruption in the CVP is thought to occur during ancient times as evidenced by drawings on the walls of pre-historic Çatalhöyük settlement. The ignimbrites of the CVP are extensively used for the construction of caravanserais, particularly between Kayseri to Aksaray, as being light to carry and soft enough to give a certain shape and a good insulator for sound or heat.

The Tuzgölü Basin is one of the largest Neogene basins in Turkey and is delimited and controlled by the Tuz Gölü Fault Zone in the east and SE branches of the Eskişehir Fault Zone in the west. The Konya Alluvial Basin is developed within the Tauride Carbonate Platform units and is surrounded by horst-like highs along which the platform units are exposed. Since the area is covered by alluvial deposits, there is no potential source rock used during the construction of caravanserais.

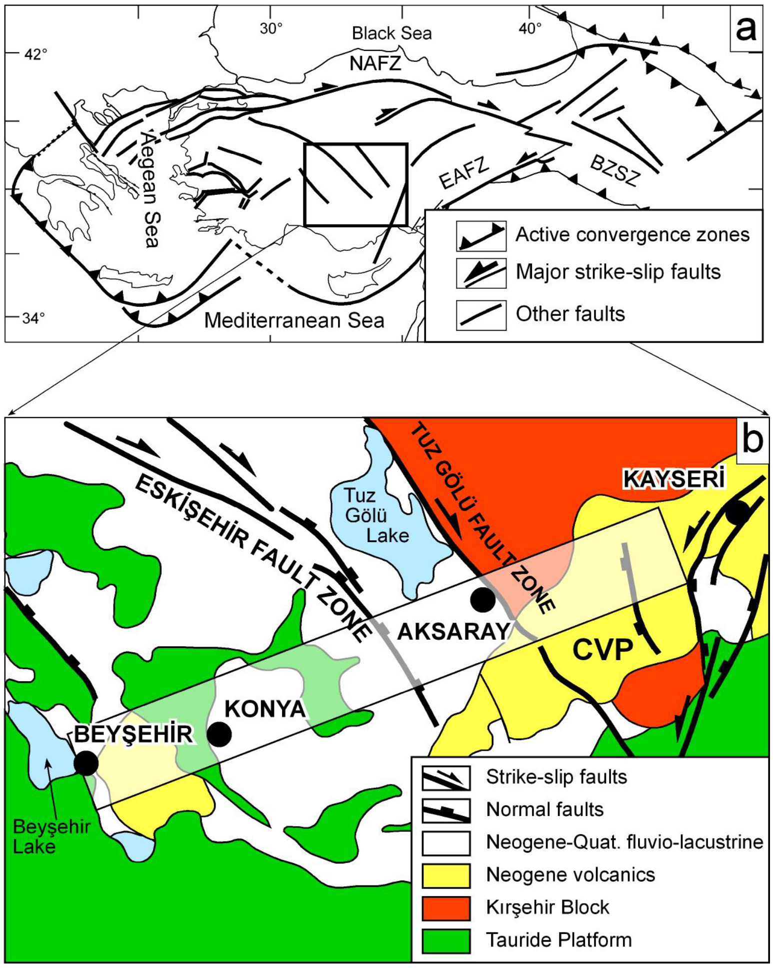


Figure 3.2: a) Outline tectonic setting of the Eastern Mediterranean area. BZSZ: Bitlis-Zagros Suture Zone, EAFZ: East Anatolian Fault Zone, NAFZ: North Anatolian Fault Zone. **b)** Simplified regional geological map of the study area (modified from Toprak *et al.* 1994). Rectangular fainted box indicates the study area.

The Tauride Carbonate Platform units are resented by various Paleozoic to Late Cretaceous neritic limestones and clastics in the lesser amount. These carbonates are generally medium to thick bedded, relatively very good construction materials as having similar properties to marbles. Therefore, they were often used for the pillars, carved for ornamentations all around the main gates, and used as thrust or beams in the windows or openings. The other lithologies in the region are Neogene volcanics and fluvio-lacustrine associations similar to the CVP, and located to the west of Konya. These lithologies were also extensively used in the caravanserais located between Konya to Beyşehir. For example, the main construction material of Kuruçeşme Han is the conglomerates and sandstones of Neogene fluvio-lacustrine origin.

CHAPTER 4

DATA

The data used in the study is introduced in this chapter. The data are organized into two categories as the attribute database and the data layers and is explained below in two sections.

The data layers include the route maps, DEM, and lithology map that are used in the GIS analyses.

4.1. Attribute Database

In this study, 15 caravanserais between Beyşehir in the west and Nevşehir in the east are analysed. These are, from west to east, Yunuslar Han, Kuruçeşme Han, Kızılören Han, Altınapa Han, Horozlu Han, Zazadin Han, Akbaş Han, Katrancı Han, Obruk Han, Sultanhanı, Ak Han, Ağzıkara Han, Öresin Han, Alay Han, and Sünnetli Han (Figure 4.1). Most of the caravanserais, as known from the literature (http://www.turkishhan.org), are younger than the enclosing settlements. Some of them even today are observed as isolated structures. But, the four major settlements namely Beyşehir, Konya, Aksaray, and Nevşehir are older than caravanserais that are present in them. So, for the four major cities, a caravanserai is assumed to be located at the historical city center, to be used in some of the GIS operations in terms of position, but they are not observed in the field to be included to the database.

For each caravanserai, five attributes exist in the database (Table 4.1), which are grouped into three categories. These are position, date of construction, and construction material.

TOTALLY DESTROYED		
Yunuslar Han	Kuruçeşme Han	Kızılören Han
TOTALLY DESTROYED		
Altınapa Han	Horozlu Han	Zazadin Han
TOTALLY DESTROYED		
Akbaş Han	Katrancı Han	Obruk Han
		
Sultanhanı	Akhan	Ağzıkarahan
		
Öresinhan	Alayhanı	Sünnetli Han

Figure 4.1: General views of the caravanserais in the study area.

Table 4.1: Attribute table of caravanserais

	Caravanserais	Position			Date of Construction*	Construction material
		x	y	z		
1	BEYŞEHİR	386845	4171799			
2	Yunuslar Han	405160	4196073	1246	---	---
3	Kuruçeşme Han	418785	4192363	1376	1207-1210	Clastic rocks + Limestone
4	Kızılören Han	426576	4194872	1555	1205-1206	Clastic rocks + Limestone
5	Altınapa Han	438769	4193845	1243	1201 or before	---
6	KONYA	454730	4189581			
7	Horozlu Han	458524	4198322	1014	1249	Limestone + Andesite
8	Zazadin Han	471726	4206466	1001	1236-1237	Marble + Limestone + REC
9	Akbaş Han	493950	4211950	1006	Undated	---
10	Katranci Han	506900	4218507	1020	---	---
11	Obruk Han	516088	4225339	1005	1245-1250	Limestone + REC
12	Sultanhani	547891	4233656	946	1229	Marble + Limestone
13	Ak Han	568145	4238967	927	1253-1254	---
14	AKSARAY	589871	4247929			
15	Ağzıkara Han	599559	4256030	1164	1231-1237	Ignimbrite
16	Öresin Han	604996	4258908	1177	1270 or later	Ignimbrite
17	Alay Han	618131	4264414	1252	1190 or before	Ignimbrite
18	Sünnettli Han	631409	4268087	1242	---	---
19	NEVŞEHİR	649159	4276969			

REC: Recycled construction material; * source: http://www.turkishhan.org

4.1.1. Position

The position refers to the geographical location of each caravanserai. The position data are collected during the field survey by using GPS, since the coordinates are the first requirement for all kinds of GIS operations. Elevation data (z values) are obtained from DEM, because of the low vertical precision of conventional GPS. To accomplish this, first, each caravanserai is overlaid on DEM by using their x and y values collected in the field, then, corresponding z values are collected by a transfer function. In addition to this, as Altınapa Han is submerged under the waters of Altınapa Dam in 1967 (http://www.turkishhans.org), its coordinates (x, y, z) are determined from the 1/100.000 scale topographical maps prepared prior to the construction of the dam in 1963.

4.1.2. Date of Construction

One of the primary goals of this thesis is to understand the rationale behind the position of the caravanserais and the distance between successive caravanserais. In order to unravel the “statistically hidden” rule behind the position and distance of caravanserais, the construction dates are important for the statistical consistency of the data. As seen in Table 4.1., the caravanserais in the study area are constructed within the same century. Therefore, same conditions, rules and rationale are existed during the construction of all caravanserais. In other words, having very close dates for the construction of the caravanserais implies that they are part of a same system and they can confidently be used for statistical analysis.

4.1.3. Construction Material

Nine out of 15 caravanserais, the lithologies of the construction material, lithologies of ornamentations especially around the gates, pillars and thrusts were analyzed wherever preserved in-situ. The remaining 6 caravanserais were either completely destroyed or reconstructed. These data are used for estimation of source of the construction material and its distance to the caravanserais.

Some caravanserais are built out of one single rock type, whereas some others contain two or more rock types (Figure 4.2). In some caravanserais (eg. Zazadin and Obruk han) almost half of the rock pieces are derived from older structures. These materials are referred to as “recycled” (REC) material in this study. There is no information on the source of such material.

Alayhan – Rocks: Ignimbrite

Zazadin han – Rocks: Limestone + marble + REC

Figure 4.2: Two distinct types of construction materials used in caravanserais. Above: Single rock type, Below: multiple rocks including recycled (REC) material.

4.2. Data Layers

These layers include ancillary data that are used to determine certain parameters of the caravanserais. Ancillary data utilized in this study are ancient trade route maps, lithology map, and digital elevation model.

4.2.1. Route Maps

Route maps include the recent roads, and available ancient trade routes. The study area is known to be located over the famous “Silk Road” that provided transportation of goods between Europe and Far East (Figure 4.3). According to the literature, the Silk Road in Anatolia is divided into two branches as northern and southern branch (Figure 4.4). The northern branch follows a route from Sivas to Black Sea and the southern branch, part of which is the topic of this study, follows a route heading to Antalya and İzmir via Konya and Beyşehir.

None of these roads are delineated precisely in the literature. Generally, the route is described and illustrated as a belt connecting the ancient major trade centers rather than a well-defined path. Besides, some researchers only mention the names of the settlements that might be along the route. The existing maps (Figure 4.4) have a scale about 1/5.000.000, which is not sufficient for the purpose of this study. Therefore, the recent roads are digitized from georeferenced 1/250.000 scale scanned maps of General Command of Mapping (Figure 4.5). In addition to this, a detailed ancient route map is generated as described in the analyses section.

Figure 4.3: General trend of the Silk Road over which the study area is located.

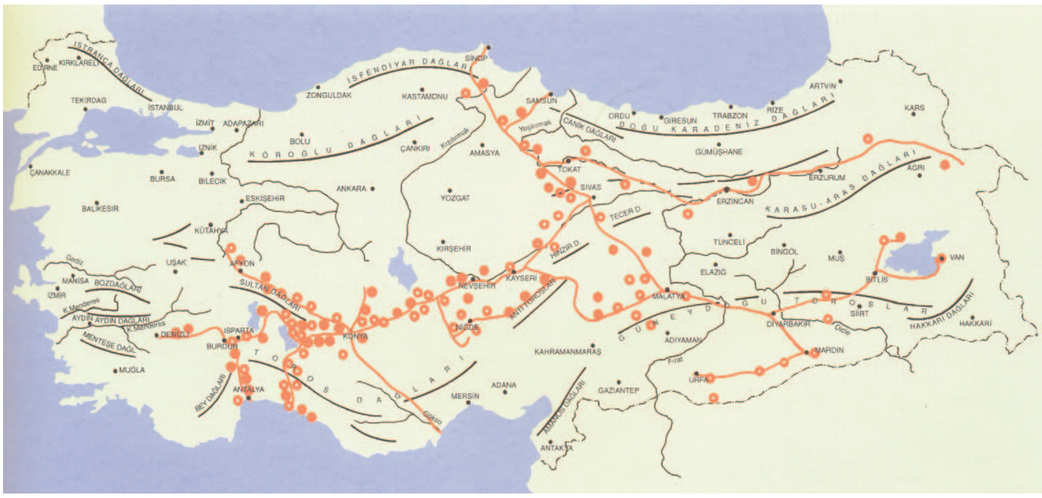


Figure 4.4: Map showing the Seljuk caravanserais and caravan roads (from Bektaş, 1999). Note that the southern branch is passing through Kayseri and Konya.

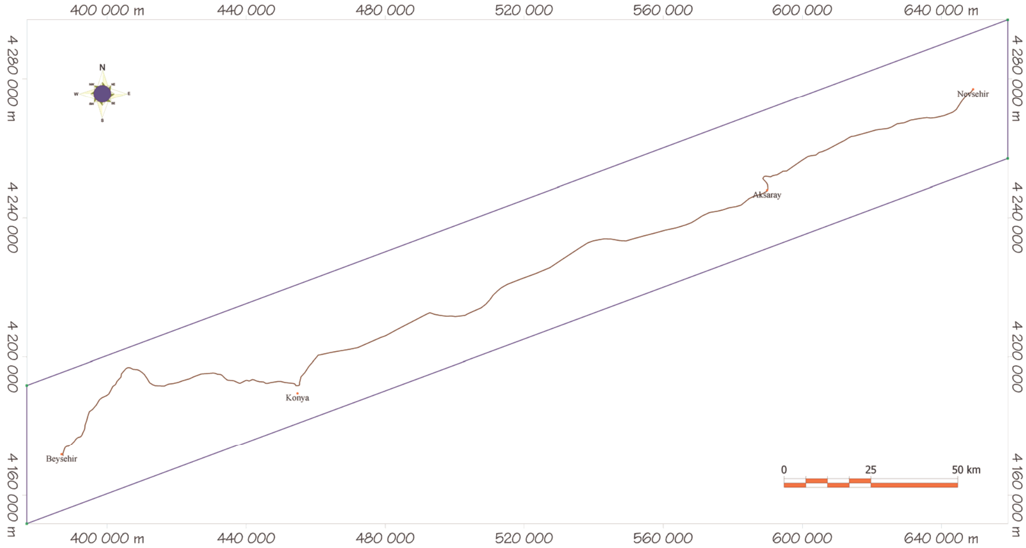


Figure 4.5: Recent road between two endpoints of the route used in this study. The road is digitized from 1/250.000 scale topographical maps and used throughout this study.

4.2.2. Lithology Map

This layer is used in the "distance to rock type analysis" in order to understand the relation between the construction material of the caravanserai and the rocks in the vicinity. It is generated by digitization of 1/500.000 scale geological maps prepared by the General Directorate of Mineral Research and Exploration (MTA) of Turkey. The geological maps of MTA is produced regarding the ages of the units first, and then subdivided by defining the corresponding lithologies. Since the ages of the units are not important in this study, the layer is produced only by considering the lithologies and special emphasis was given to the lithologies which have potential to be used as a construction material as evidenced by the field observations. The construction of this layer includes reclassification of similar lithologies, regardless of their ages. In the study area, there are 59 different types of units in the MTA map (Figure 4.6). After the reclassification process they are decreased down to 6 new classes (Figure 4.7).

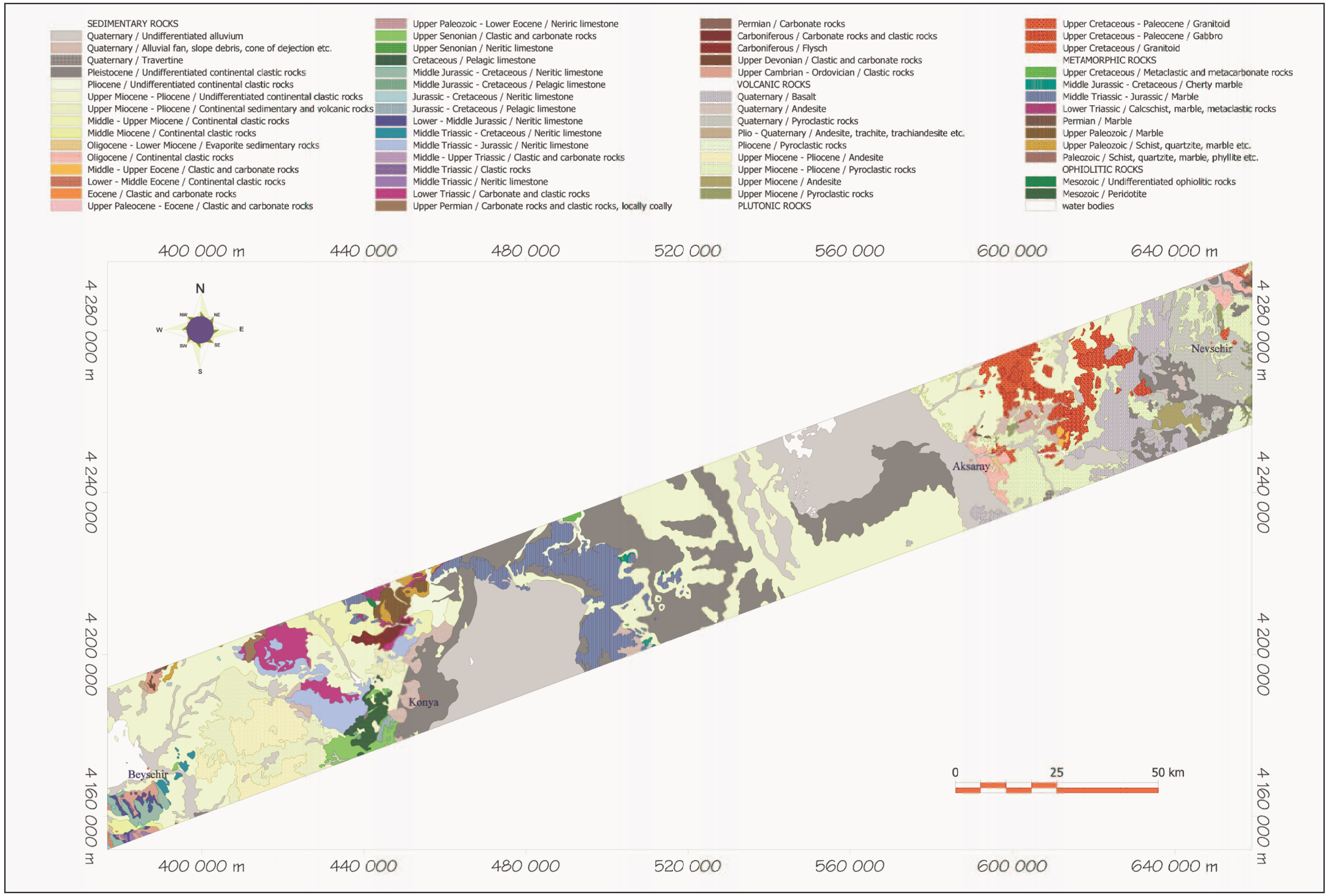


Figure 4.6: Digitized original 1 / 500.000 scale lithological map (MTA 2003).

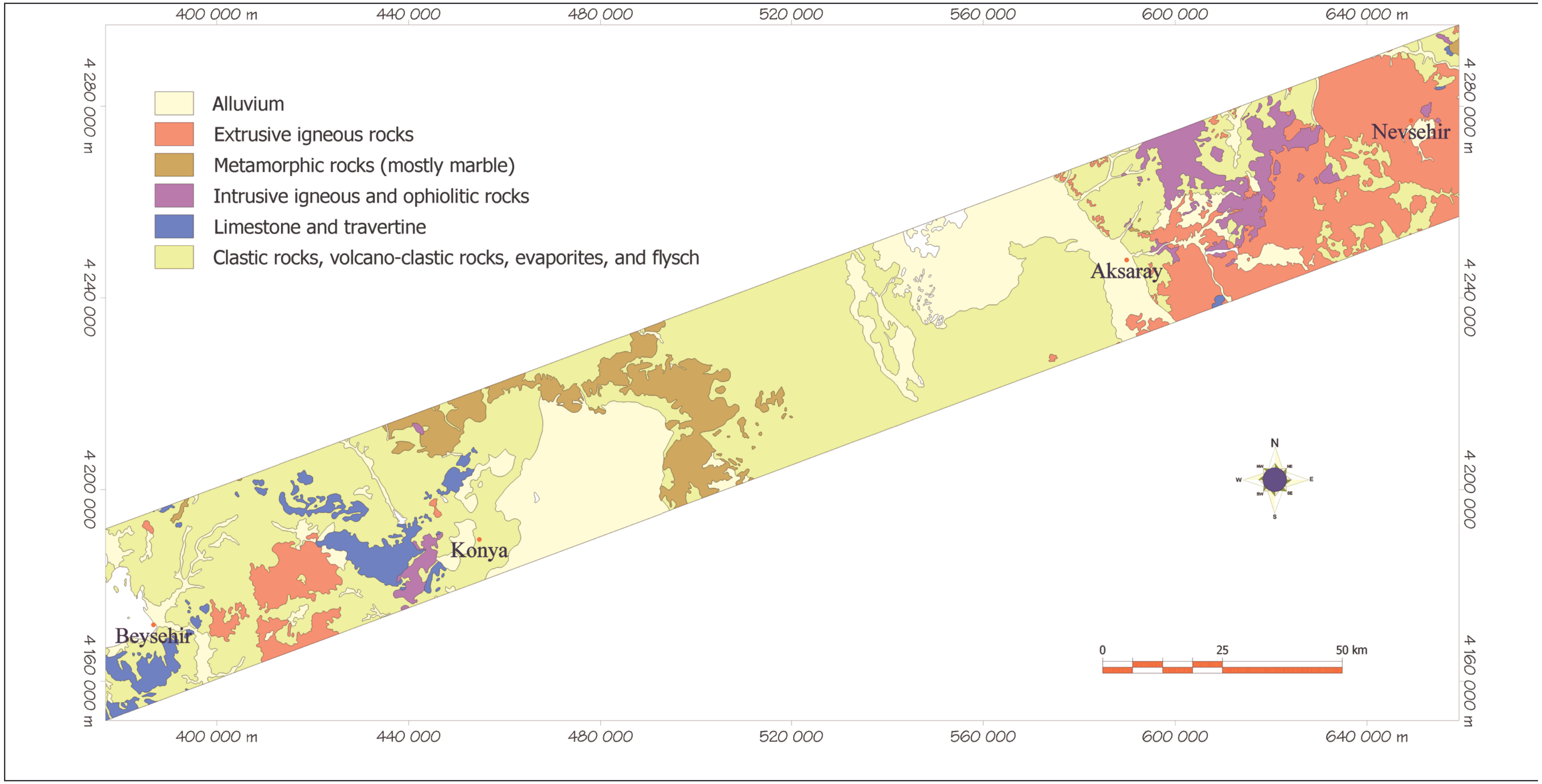


Figure 4.7: 1 / 500.000 scale reclassified lithological map of the area.

4.2.3. Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) is the digital representation of a topographic surface in raster form. It can be used in various earth oriented subjects including geology, geomorphology, geotechniques, climatology, hydrology, transportation, geoarchaeology, navigation etc. In this thesis, DEM is used to investigate the topographical properties of the study area, to perform visibility and proximity analysis, and to compute the flow paths. It is also used as one of the input layers in the generation of the ancient route map.

The DEM used in this study is SRTM (Shuttle Radar Topographical Mission) data (Figure 4.8**)** and is obtained from USGS (United States Geological Survey). SRTM data is spaceborne radar images converted into elevation units using interferometeric techniques. For full account of SRTM, USGS web site (http://srtm.usgs.gov/) is referred. The topographic elevation data is processed to create files covering 3-arcseconds corresponding to approximately 70.3m*92.5m ground resolution.

The study area is subdivided into three distinct zones considering the characteristics of the topography. This subdivision is based on the roughness and local relief variations over the surface. Such subdivision is important for morphometry dependent GIS analyses. For example, map and true distance in the flat areas will not vary significantly contrary to rough areas. Also, the parameters related to viewshed and watershed analysis are controlled by the roughness of topography. Relief maps and the profiles along the axes of these subdivisions are illustrated in Figure 4.9.

The first subdivision is the westernmost part of the area and covers the section between Beyşehir to Konya. It is a rough and mountainous region with an internal relief ranging between 1100-2100 m. (Figure 4.9a).

The second subdivision is the middle part of the study area and is represented by a flat area bounded by Meram Fault on west and Tuz Gölü Fault on east. It has gentle and uniform slope towards east, with an elevation range between

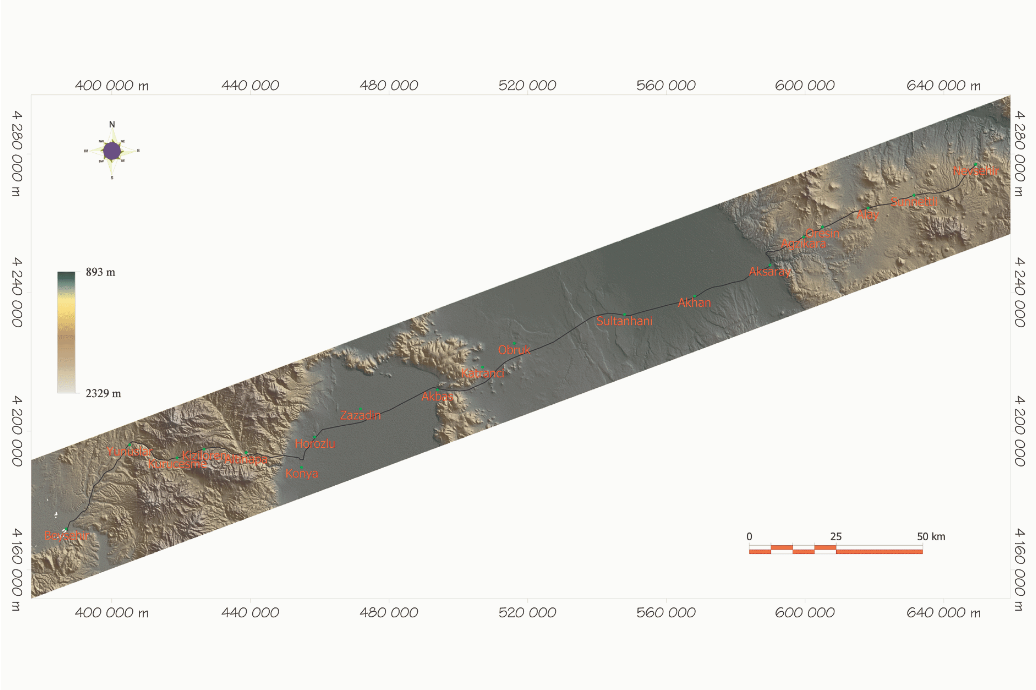


Figure 4.8: Recent road and positions of the caravanserais are overlaid onto color coded relief shaded Digital Elevation Model of the study area.

950-1050 m. with an exception of a narrow topographical high reaching up to 1350 m. that is separating Konya plain in the west and Tuz Gölü plain in the east (Figure 4.9b).

The eastern part starts from the center of Aksaray in the west, and ends at Nevşehir in the east. The division line between eastern and middle areas corresponds roughly to the Tuz Gölü Fault Zone around Aksaray. This area is also relatively rough; however internal changes in its relief and also its absolute relief are less than the westernmost part (Figure 4.9c).

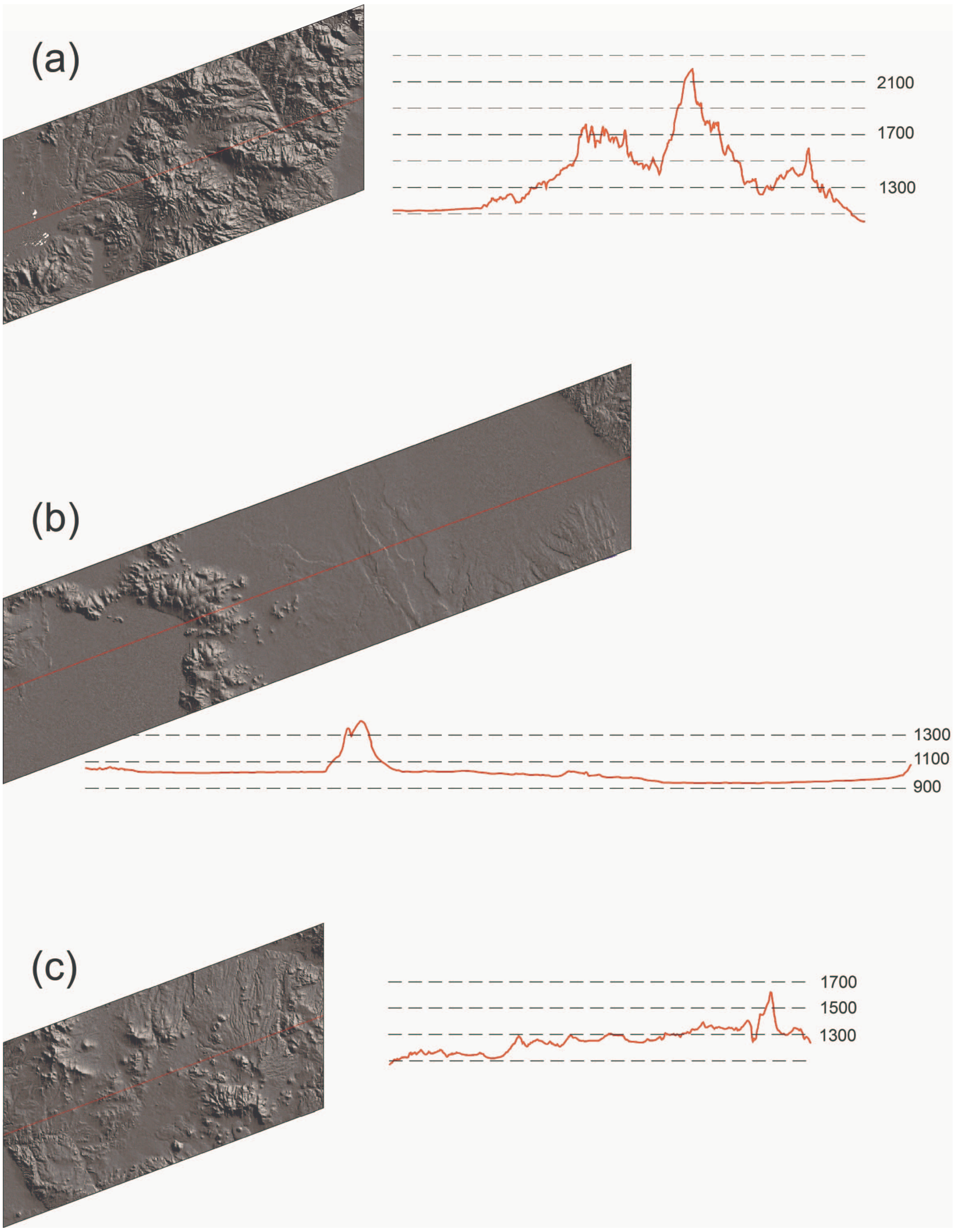


Figure 4.9: Relief maps for western (a), central (b), and eastern (c) subdivisions of the study area. The profiles are taken along the red lines.

4.2.3.1. Accuracy of SRTM

According to SRTM website, the specifications of SRTM data are as follows; C-band Radar beam were used for 30 m x 30 m spatial sampling with <=16 m absolute vertical height accuracy, <= 10 m relative vertical height accuracy, and <=20 m absolute horizontal circular accuracy. All accuracies are quoted at the 90% level. In addition to this, the accuracy of local SRTM data can also be verified suing the following statistical test using digitized 1/25.000 scale topographical maps of the area of interest. A feasible accuracy assessment of SRTM can be performed by optimally selecting 28 (Figure 4.10) randomly but evenly distributed points from the topographical maps keeping the 8 of the points on the edges and the corners (Falorni *et al.* 2005). Since the accuracy of this study is well below the accuracy of the SRTM data, it is thought that no accuracy assessment is needed for this study.

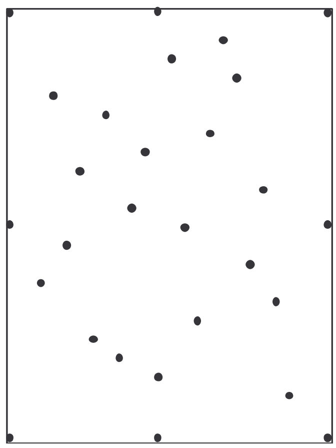


Figure 4.10: Sampling points to assess the accuracy of SRTM. 4 points should be selected from the corners, 4 from the edges, remaining 20 points should be selected randomly in the map and corresponding to the contours of the 1/25.000 scale reference map.

CHAPTER 5

GIS ANALYSES

This chapter introduces four analyses carried out using the caravanserai database and related ancillary data. These analyses are as follows:

1. Generation of Ancient Route map
2. Proximity analysis, which is applied for;
    - ➢ distance between two neighbor caravanserais,
    - ➢ distance to source lithology,
    - ➢ distance to water sources
3. Visibility (Viewshed) analysis

5.1. Generation of Ancient Route Map

In this study, a hypothetical position for the ancient route is determined, based on the following assumptions:

1. Caravanserais lie right next to the ancient route.

2. The ancient people have chosen the shortest distance and avoided steep slopes as much as possible.

3. The routes used in the past have evolved and almost coincides with the recent routes, however, they may be locally modified by tunnels, bridges, and leveling in recent times.

Therefore, the resultant output ancient route map should fulfill the conditions above. In the route generation process, three data layers are used. These are 1) the caravanserai database including their geographical position, 2) DEM obtained from SRTM and 3) the recent road map in 1/250.000 scale. The caravanserai database is used to pursue the first assumption while DEM is used for finding optimum path considering least relief change along track and the recent road map is used to pursue the third assumption. All these data layers are overlaid and an output map is generated manually from their visual display (Figure 5.1).

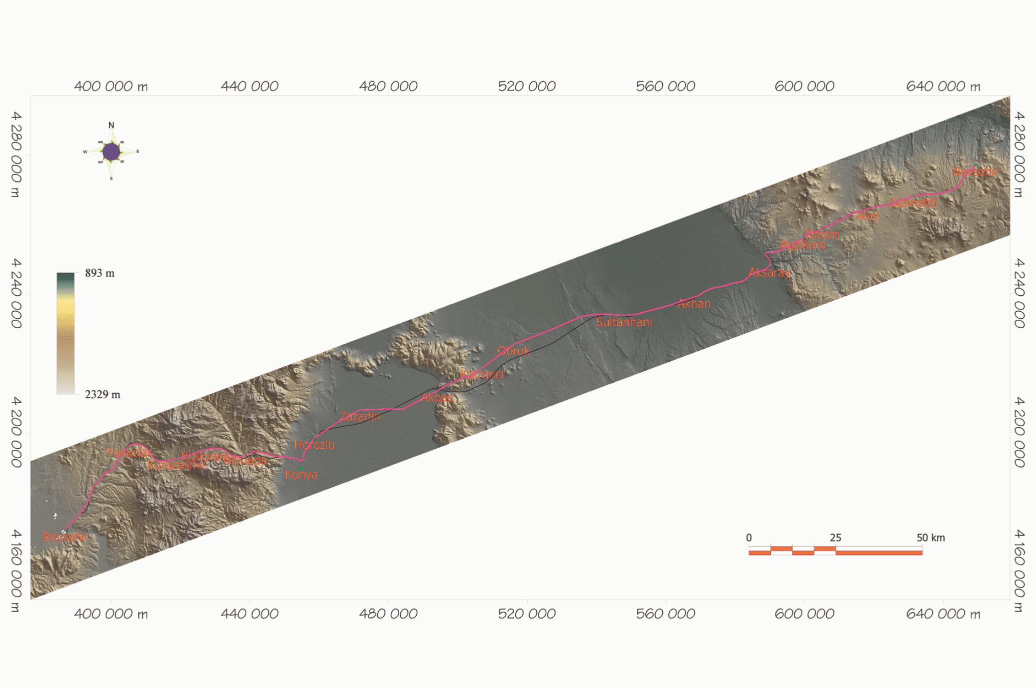


Figure 5.1: Ancient route map (pink) generated by using recent road (black), DEM, and position of caravanserais.

Visual comparison of ancient and recent road indicates that:

- Two roads coincides almost 100 % in the western (Beyşehir to Konya) and eastern (Aksaray to Nevşehir) subdivisions. These regions are represented by relatively rough and mountainous topography. This similarity suggest that there is not much alternative for the selection of route.

- In the central part, however, between Konya and Aksaray where the surface is flat, certain differences are observed between two roads. The differences occur around Zazadin, Katrancı and Obruk caravanserais. Amount of shift is about 5 km for Zazadin and Katrancı and 4 km for Obruk caravanserais. Direction of shift is consistent in all; the recent road is located to the south of ancient one.

5.2. Proximity Analyses

Proximity analysis is one of the standard operations in GIS analyses. It is defined as the closeness of one item to another (Burrough and McDonnell, 1998). In this study, proximity analysis is used to examine the distance relations between; 1) each consequent caravanserai, 2) construction material of the caravanserai to its nearest source lithology, 3) caravanserai to a water source. In this respect, GIS offers numerous ways of proximity analysis techniques. The ones which are used in this thesis are discussed in detail in the relevant sections below.

5.2.1. Distance between Consequent Caravanserais

It is generally accepted that, the distance between each consequent caravanserai should not exceed 1 day with a loaded camel. The purpose of this analysis is to examine the distance relations, later to be used in the prediction of the location of the missing caravanserais along the route, in Chapter 6.

The distance concept can be handled in three ways; the straight line distance (as the crow flies), the map distance (2D), and the true distance (3D). The straight line distance is calculated by direct measurement of the distance between two points without considering the curvatures and relief changes. For the other two methods, mainly 2 sets of data, the positions of caravanserais, and the path are used. So, the measurements are performed by direct point to point calculations without any further operation or query. However, for the true distance calculations, DEM is also used as an additional layer to take into account the elevation values. In the map distance measurements, only the map length of a path is considered, whereas the true distance calculations considers the curvature of the path as well as the increments introduced by the relief changes (Figure 5.2).

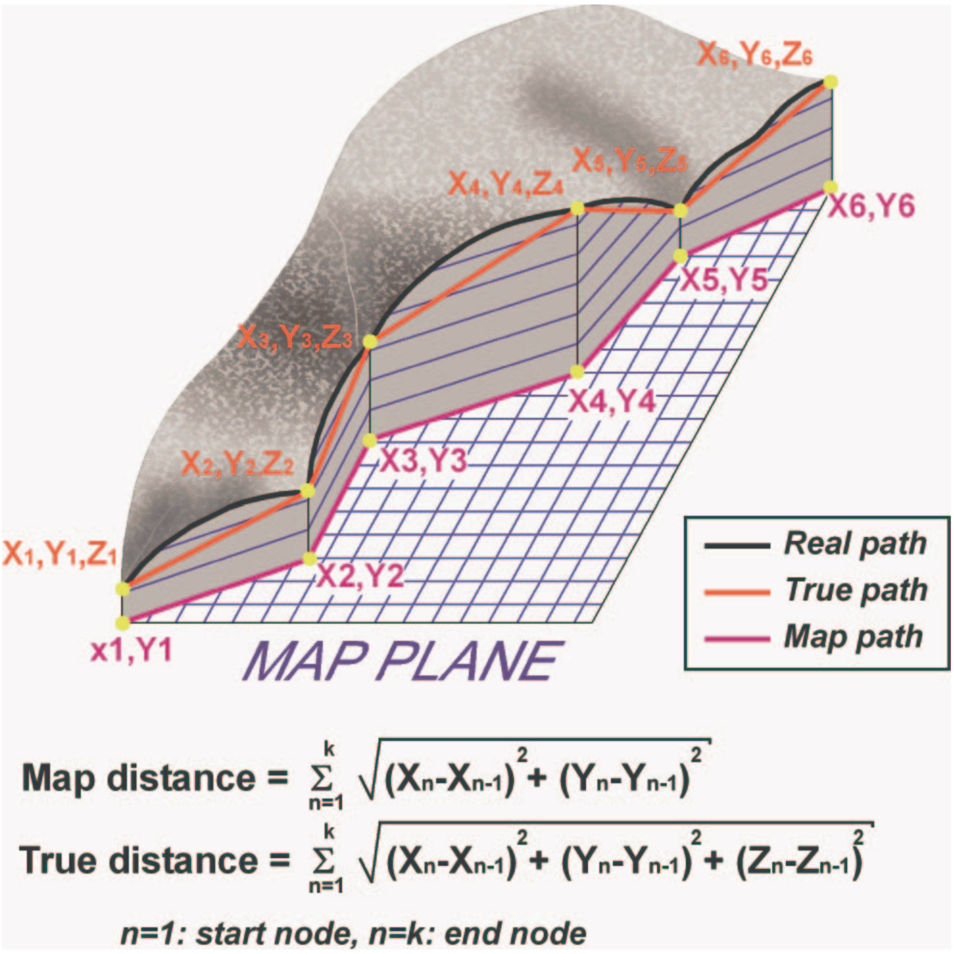


Figure 5.2: The logic of the calculation of map and true distance.

In the study, the path is divided into 18 segments based on the position of caravanserais, in order to be able to observe the discrepancies between different types of measurements in each segment. Each segment, therefore, corresponds to the distance between two caravanserais. These segments are measured in terms of straight line distance, map distance and true distance. The straight line distance is measured by constructing lines using the x and y coordinates of each caravanserai as starting and ending points of the line segment. The lengths of the lines are the straight line distances between each consequent caravanserai. The map distance is equal to the length of the path, which is calculated automatically by the program. For true distance calculations, the x, y, and z values of random points on the path are recorded on an Excel sheet and the true distances are calculated using the formula in Figure 5.3. The results of the calculations and the profiles along each path are depicted in Table 5.1.

Table 5.1: Results of the distance calculations between caravanserais. Profiles show the elevation of the traveled path between two endpoints.

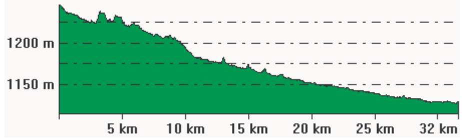
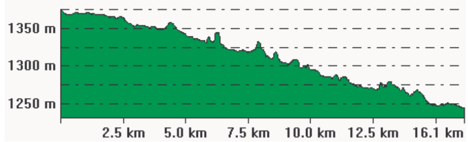
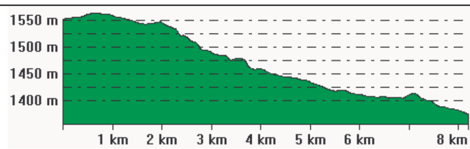
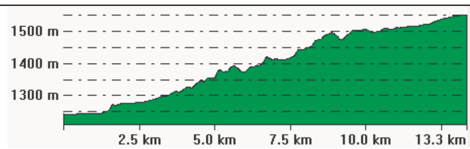
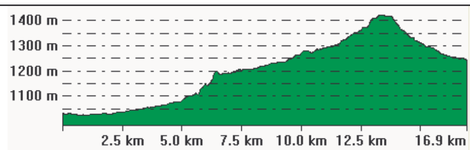
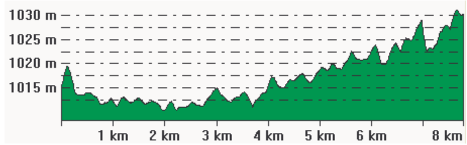
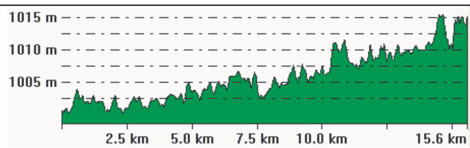
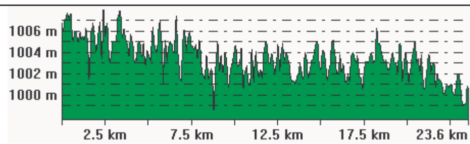
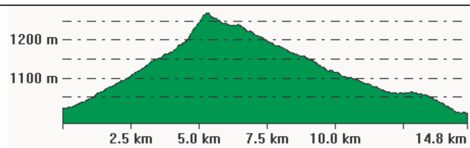
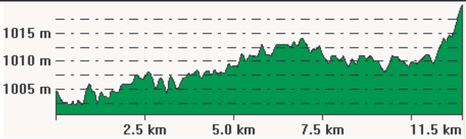
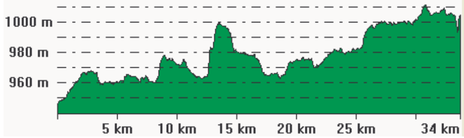
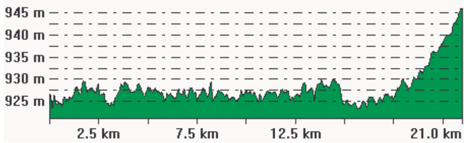
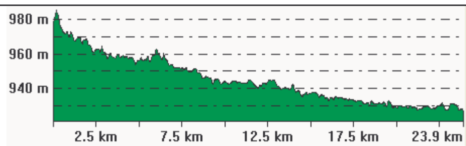
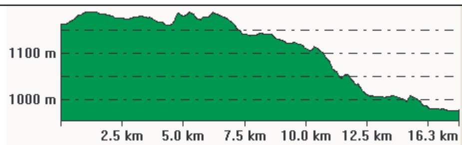
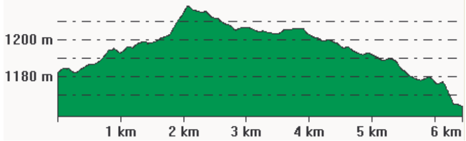
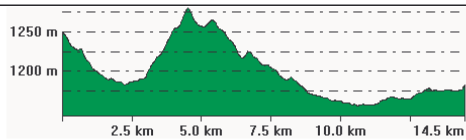
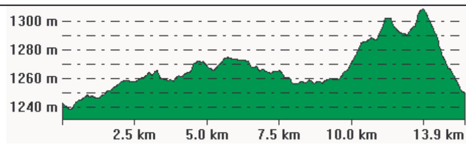
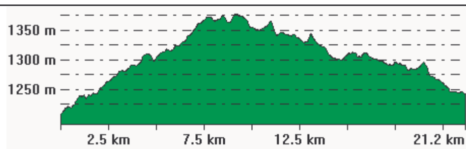
	Straight Line Distance (km)	Map Distance (km)	True Distance (km)	Profile
Beyşehir - Yunuslar	30.408	31.505	31.511	
Yunuslar - Kuruçeşme	14.121	15.960	15.978	
Kuruçeşme - Kızılören	8.185	8.205	8.213	
Kızılören - Altınapa	12.236	13.253	13.278	
Altınapa - Konya	16.095	16.763	16.799	
Konya - Horozlu	7.541	7.926	7.927	
Horozlu - Zazadin	15.512	15.522	15.524	
Zazadin - Akbaş	22.891	23.578	23.581	
Akbaş - Katrancı	14.515	14.831	14.846	

Table 5.1 (continued)

Katrancı - Obruk	11.445	11.445	11.446	
Obruk - Sultanhanı	32.873	33.457	33.463	
Sultanhanı - Akhan	20.939	21.004	21.005	
Akhan - Aksaray	23.502	23.912	23.915	
Aksaray - Ağzıkara	12.629	16.257	16.270	
Ağzıkara - Öresin	6.152	6.250	6.254	
Öresin - Alay	14.242	14.417	14.427	
Alay - Sünnetli	13.777	13.911	13.916	
Sünnetli - Nevşehir	19.848	21.194	21.207	
TOTAL	**296.911**	**309.390**	**309.560**	

The results of calculations are used to evaluate the travel distances found by different methods (Table 5.2). The difference between “straight line distance” and “map distance” range from 0 to 3628 m. The average difference is 693 m. Considering the locations of caravanserais in the study area is can be concluded that the difference is maximum in rough topography and minimum in flat areas. The difference for Aksaray-Ağzıkara segment is exceptionally higher than all others because this segment has a “V” shaped route. All other differences are due to expected undulations over the route.

The differences between “map distance” and true distance”, on the other hand, are calculated to be between 1 and 36 m with an average of 9.4 m. These differences correspond to the third dimension along the route. Considering the low values obtained from these differences, it can be concluded that steep slopes (which are responsible for the difference) are avoided during the selection of the route.

Table 5.2: Comparison of travel distances for different calculation methods.

Segment	Distance differences	
	Straight line distance minus map distance	**Map distance minus true distance**
Beyşehir - Yunuslar	1097	6
Yunuslar - Kuruçeşme	1839	18
Kuruçeşme - Kızılören	20	8
Kızılören - Altınapa	1017	25
Altınapa - Konya	668	36
Konya - Horozlu	385	1
Horozlu - Zazadin	10	2
Zazadin - Akbaş	687	3
Akbaş - Katrancı	316	15
Katrancı - Obruk	0	1
Obruk - Sultanhanı	584	6
Sultanhanı - Akhan	65	1
Akhan - Aksaray	410	3
Aksaray - Ağzıkara	3628	13
Ağzıkara - Öresin	98	4
Öresin - Alay	175	10
Alay - Sünnetli	134	5
Sünnetli - Nevşehir	1346	13
Average	693,3	9,4

For the whole route from Beyşehir to Nevşehir, the total difference between the straight line distance and the map distance is 12.5 km, whereas it is only 170 m between the map and the true distances. Thus, the major factor that affects the path length is the curvature of the path, not the relief changes along the path. The possible reasons for such a small difference in map and true distance can be the nature of the terrain as well as the second assumption of section 5.1. Since the discrepancy between the map distance and true distance values is very small as compared to the ground resolution of DEM, for the sake of easiness, the map distance is used throughout the study.

5.2.2. Distance to Source Lithology

The field studies indicated that the construction materials of most of the caravanserais are mostly obtained from nearby lithologies. Therefore, the main purpose of distance to rock type analysis is to examine whether availability of construction material affected the position of the caravanserai. The analysis is based on finding the nearest source rock to the point feature i.e. caravanserai, and to examine the other rock types in the surrounding. To achieve this goal, buffering technique is used within the concept of proximity.

Buffering is the computation of an area with a specified distance which is called the buffer zone (Chang, 2002). The first step of the analysis is to measure the nearest distance between the lithological boundary of the source rock, and the caravanserai, from the visual display. Then, circular buffer zones are constructed for each of the obtained measurement to check if there are any other unnoticed intersections with another polygon having the same lithology. After the buffer size is set for each caravanserai, other rock types within the buffer zone are examined. Therefore, for each caravanserai, different buffer zones are computed on the reclassified geological map.

This analysis is carried out for 8 caravanserais. Because the building stones for 6 caravanserais are not known. These are Yunuslar, Altınapa, Akbaş, Katrancı, Akhan and Sünnetli. In addition to these, Ağzıkara caravanserai is located on its source rock; therefore, there is no need to carry out an analysis for this.

Kuruçeşme caravanserai is located within alluvium (Table 5.3, Figure 5.3). The rocks used in the construction are clastic rocks and limestone. The nearest exposures of these rocks are 409 and 1929 m, respectively. Although volcanic rocks are also exposed in the vicinity of the caravanserai, these rocks are not preferred as construction material.

Kızılören caravanserai is located over clastic rocks (Table 5.3, Figure 5.3). The structure is made up of clastic rocks and limestone. Therefore, the analysis for this caravanserai is carried out for limestone. The nearest limestone outcrop is at a distance of 323 m to the north.

Table 5.3: Results of the analysis carried out for source rock investigation.

Caravanserai	Settled within	Use of NIS	Rock used in the structure	Distance to Source Rock	Other Rocks In Buffer Zone
Kuruçeşme	Alluvium	No	Clastic rocks, Limestone	409 m to clastics 1929 m to limestone	Volcanic rocks
Kızılören	Clastics	No	Clastic rocks, Limestone	on its source (clastics), 323 m to limestone	---
Horozlu	Clastics	No	Limestone, Volcanics	7140 m to limestone 12176 m to andesite	Clastic rocks
Zazadin	Alluvium	Yes	Marble, Limestone	9928 m to marble 17417 m to limestone	Clastic rocks
Obruk	Clastics	Yes	Marble	4304 m to marble	Clastic rocks
Sultanhanı	Clastics	No	Marble	32302 m to marble	Volcanic rocks Clastic rocks
Öresin	Alluvium	No	Ignimbrite	864 m to ignimbrite	Intrusive rocks
Alay	Intrusive	No	Ignimbrite	1283 m to ignimbrite	Intrusive rocks

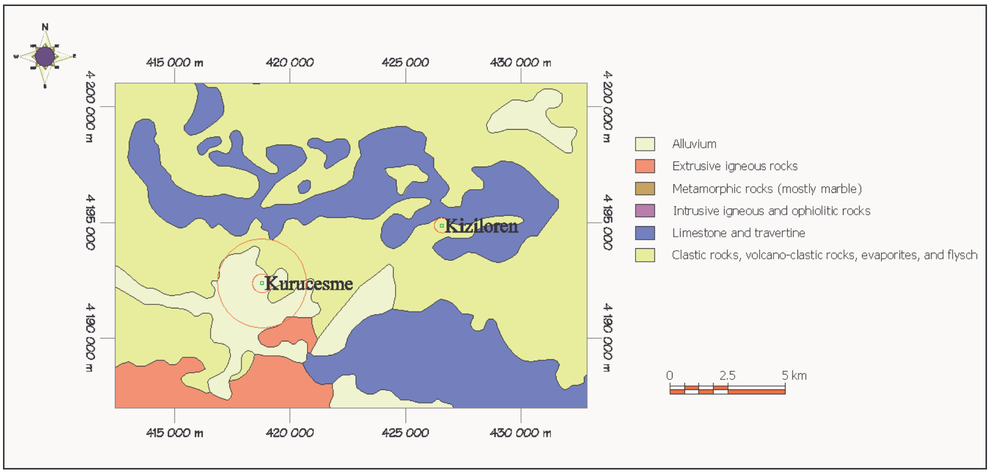


Figure 5.3: Source rock analyses for Kuruçeşme and Kızılören caravanserais.

Horozlu caravanserai is located within the clastic rocks (Table 5.3, Figure 5.4). Rock units used in the structure are limestone and volcanic rocks. The distances to the sources of these rocks are 7.14 km for the limestone to the northwest and 12.176 km for the volcanic rocks to the west of the caravanserai.

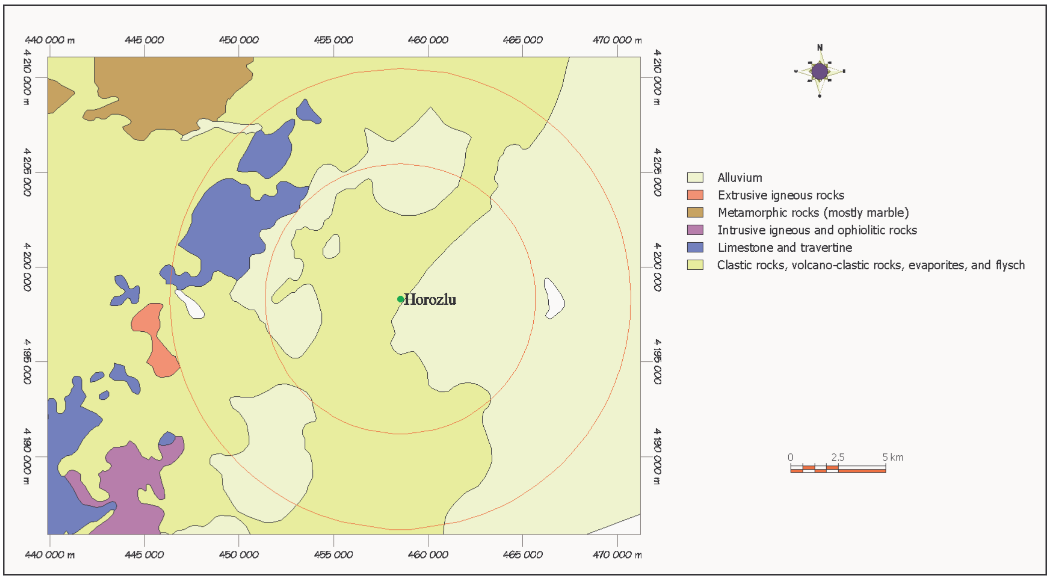


Figure 5.4: Source rock analysis for Horozlu caravanserai.

Zazadin caravanserai is located within alluvium (Table 5.3, Figure 5.5), and marble and limestone are the construction materials. The nearest exposures of these rocks are at distances of 9928 m for marble to the north, and 17417 m for the limestone to the west of caravanserai. Clastic rocks are not used in the structure although they are the nearest rock type to the caravanserai.

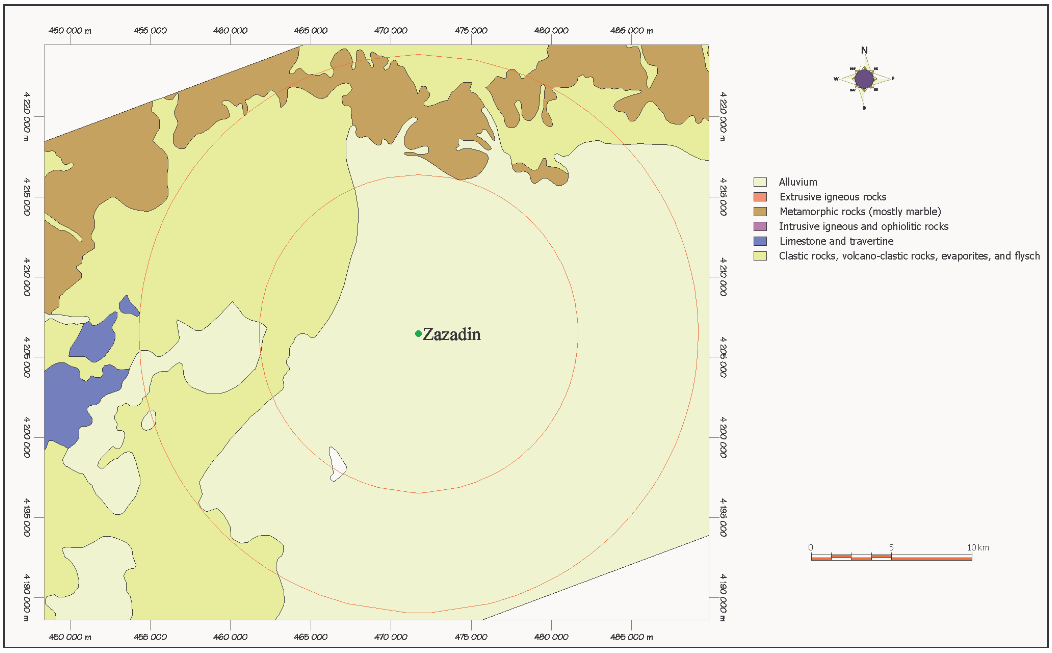


Figure 5.5: Source rock analysis for Zazadin caravanserai.

Obruk caravanserai is located within clastic rocks (Table 5.3, Figure 5.6). The caravanserai, however, is built using limestone. The limestone exists in the steep walls of the karstic depression nearby but there is no information if the rocks used in the structure are quarried from this site. The nearest rock to the caravanserai is marble at a distance of 4304 m located on the south.

Sultanhanı caravanserai is located over the clastic rocks (Table 5.3, Figure 5.7). The rock types used in the construction of the structure is marble. The nearest source rock is situated 32302 m to the southwest of the caravanserai. The clastic rocks over which the caravanserai is built, and volcanic rocks which are closer than marble are not used in the construction.

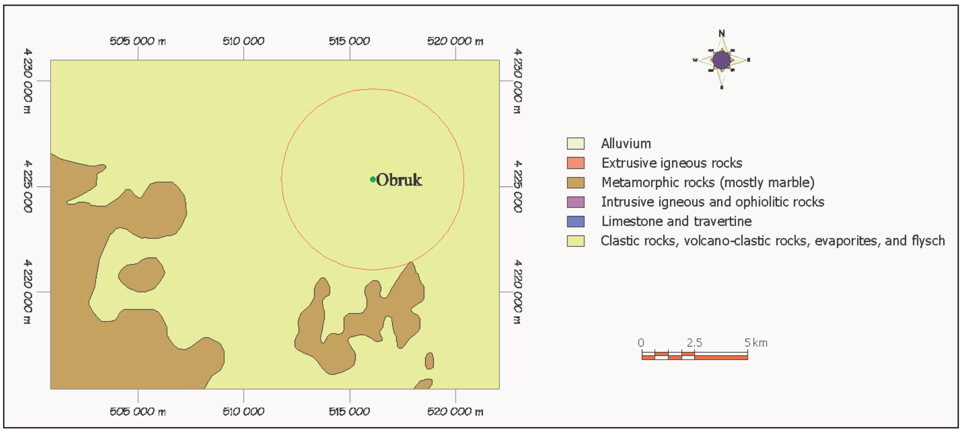


Figure 5.6: Source rock analysis for Obruk caravanserai.

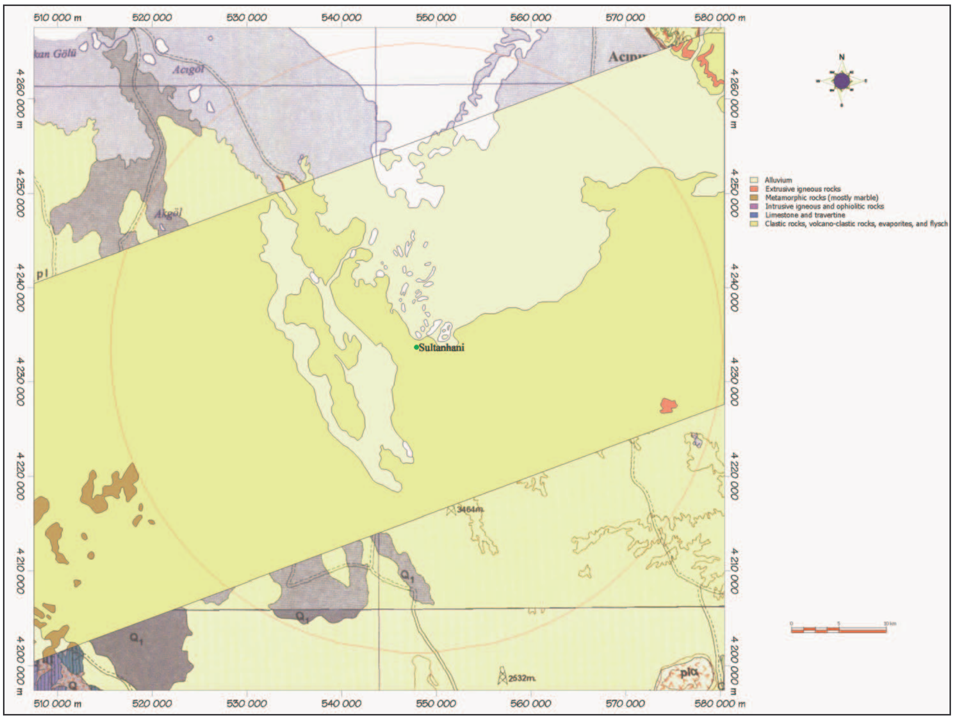


Figure 5.7: Source rock analysis for Sultanhanı caravanserai.

Öresin caravanserai is located on the alluvium (Table 5.3, Figure 5.8). Ignimbrite is the only rock type used in the construction of the building. The nearest ignimbrite outcrop is 864 m situated southeast of the caravanserai. Intrusive rocks are not used in the structure although they are closer than ignimbrites.

Alayhanı caravanserai is located within intrusive rocks (Table 5.3, Figure 5.8). The structure is totally built of ignimbrite. The nearest ignimbrite exposure is 1283 m to the east of caravanserai.

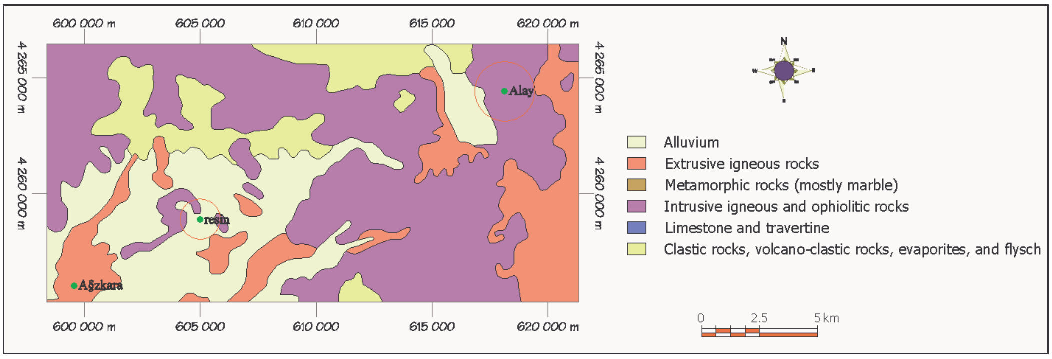


Figure 5.8: Source rock analysis for Öresin and Alayhanı caravanserais.

Following conclusions can be derived on the construction material of the caravanserais, based on the source rock analyses:

- Out of 9 caravanserais, only one caravanserai (Ağzıkara Han), and partly a second one (Kızılören Han) is situated on its source lithology. The others are carried from 8 km far on average. So, the presence of a source rock did not effect the position of the caravanserais in the study area. However, the uses of certain rocks in the structures which are further than the rocks in the buffer zone indicate that the selection of rock material is important during the construction.
- In four of the caravanserais (Kızılören, Horozlu, Obruk, and Sultanhanı), although the rock type that they are settled in is suitable for construction (clastic rocks), there is a specific preference on marble and limestone.

- Intrusive rocks are never used as construction material despite their closeness and wide spread occurrence to the caravanserais in the eastern part.
- Ignimbrite is the only rock type used alone in three eastern caravanserais (Ağzıkara, Öresin and Alayhanı).

5.2.3. Distance to a Water Source

This analysis is performed to understand the effect of availability of water source on the site selection of the caravanserai. Streams and springs are the widespread and expected water resources to exist in any area. Field studies, however, indicated that other water sources such as lakes (Figure 5.9) and ground water (Figure 5. 10) are also used in caravanserais.

In this study, however, the term “water source” stands for the surface waters (streams, lakes, ponds, and springs) that occur at certain places over the earth’s surface and can be detected by either field studies or map analysis. Therefore, the ground water that can exist anywhere and is accessed by water-wells, and the water channels are not included in the study.

There are two approaches to test the importance of closeness of a water source: manual and automated flow path computation. The manual part covers only the digitization of the existing sources; whereas the automated one uses the DEM of the study area, to determine the possible flow paths, the flow accumulations, the watersheds etc. So, both methods are applied in the thesis, to remove the errors that may come out from the dried out, unmarked sources from manual analysis, or extra sources marked by the program from automated analysis.

Figure 5.9: Water pond (karstic depression) near Obruk caravanserai used as water source.

Figure 5.10: Water well near Zazadin caravanserai.

5.2.3.1. Manual Delineation of Flow Paths

In the manual delineation of flow paths, the buffering technique is used, same as the one discussed in the previous section, to determine the distance between each caravanserai and the potential water sources such as existing springs, lakes, streams etc. The streams are classified as permanent or seasonal based on the 1/100.000 scale topographical maps. The potential water sources in the neighborhood of each caravanserai that are present in these maps are digitized manually. Summary of the analysis is given in Table 5.4. The whole data are shown in Figure 5.11 for all caravanserais separately.

Table 5.4: Summary of the manually derived water sources (1: permanent stream, 2: seasonal stream, 3: spring, 4: lake)

Caravanserai	Nearest distance to a water source (m)	Type of the source	Explanations
Yunuslar	168	1	The major stream is on the south of caravanserai
Kuruçeşme	507	1, 3	In addition to stream, there are 3 springs on the south at a distance of 1-1.5 km
Kızılören	317	2, 3	There is a major stream 1349 m away, and several springs to the south (the nearest one is 1579 m away)
Altınapa	452	1, 3	The spring is on the south and the stream is 456 m away on SW
Horozlu	---	---	No water sources nearby
Zazadin	---	---	No water sources nearby
Akbaş	565	2	Structure is next to a scarp, so, they must have been used wells. There is also one seasonal stream 950 m on the south
Katrancı	400	2	Structure is next to a scarp, so, they must have been used wells. There is also one seasonal stream 1195 m apart.
Obruk	162	4	---
Sultanhanı	573	3, 4	There is a second spring and a lake, 665m and 702 m away, respectively.
Akhan	1720	2	There is a second seasonal stream on the south, 2139 m away.
Ağzıkara	130	1, 3	There are a number of springs in its surrounding.
Öresin	115	1	It is a major stream flowing in N-S direction
Alay	162	2	---
Sünnetli	586	1	The stream is fed by 3 springs nearby.

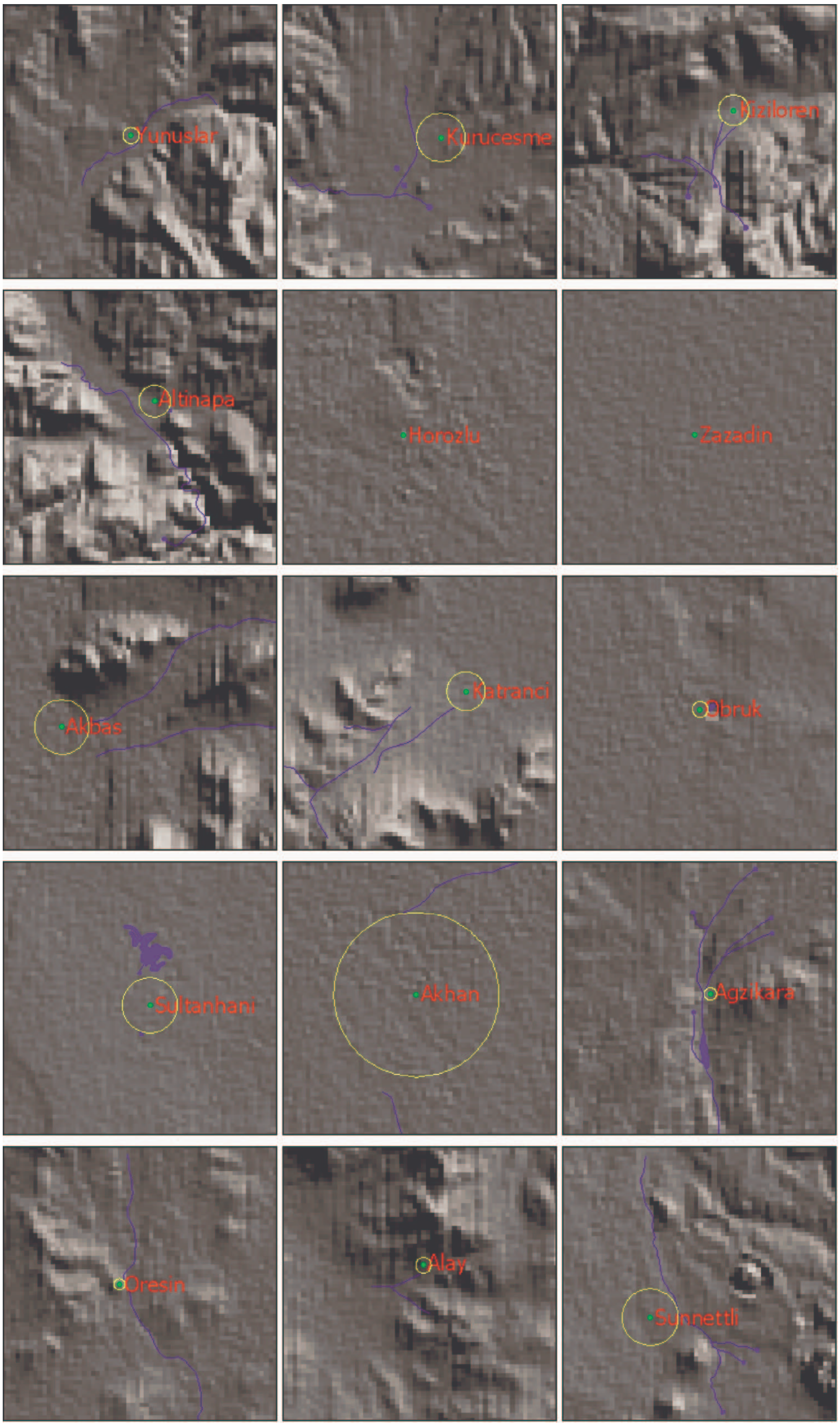


Figure 5.11: Nearest water sources for caravanserais shown on the DEM of the area. Streams, springs, and lakes are illustrated by blue lines, points, and polygons, respectively.

The results of the analysis are as follows:

1. Except two, the caravanserais are located near to a water source within a distance of at most 1720m.
2. For two caravanserais (Horozlu and Zazadin), no surface water can be identified.
3. Six caravanserais (Yunuslar, Kuruçeşme, Altınapa, Ağzıkara, Öresin, and Sünnetli) are located nearby a permanent stream. The average distance to the source for these caravanserais is 326 m.
4. For 5 of the caravanserais (Kuruçeşme Han, Kızılören Han, Altınapa Han, Sultanhanı, and Ağzıkara Han) there is more than one potential water source nearby.
5. None of the caravanserais are any closer than 115 m to a water source.

5.2.3.2. Automated Flow Path Delineation

A watershed is defined by the area that is drained by a river and its tributaries. Watershed analysis is the delineation of drainage basins and topographic features such as stream networks, by using DEMs. The first step of the analysis is to remove the depressions from the elevation raster, which may occur because of the errors in the DEM (Chang, 2002). The watershed process computes the local directions of flow (flow direction raster), and the gradual accumulation of water (flow accumulation raster) moving downslope across the landscape. From these intermediate results, the process then computes the stream network and the boundaries between watersheds (http://www.microimages.com/freestuf/). Since the aim of this study is to find out the dried out, unmarked, extra marked sources; and to suggest an alternative source for the caravanserais which does not have any water source nearby, it is presumed that, to concentrate on the standard flow paths would be sufficient within the framework of this study.

In the output maps, the lines in the flow paths vector represent the computed network of actual and potential stream channels that drain each watershed. (http://www.microimages.com/freestuf/).

There are three parameters that control the output map of a standard flow path vector object. These are outlet, inlet, and branch. In a watershed process, the number of upstream cells that contribute the flow are the first to be calculated. Then, these accumulation values are used to generate flow path vector, by tracing flow paths upstream, beginning with the highest accumulation values where streams reach the boundaries of the area. The outlet parameter sets a threshold to the flow accumulation to initiate the flow on the edges of a raster. So, the parameter adjusts the number of paths for the small watersheds around the periphery of the DEM. The inlet parameter determines the furthest upstream (the last cell) in a branch. A flow path terminates when the flow accumulation value for the next upstream cell falls below the inlet parameter value. The branch parameter controls the splitting of flow paths at potential junctions between tributaries. A branch flow path is created when the flow accumulation value at the mouth of the tributary is greater than the branch parameter value (http://www.microimages.com/freestuf/).

For the study area, the expected number of streams is very few when the topographic characteristics of the 2nd subdivision (mentioned in section 4.2.3.) of the terrain are considered. This fact is also evident from the field observations. Therefore, the flow path parameters are set in order to minimize the potential flow paths in the region, which would result in more realistic drainage patterns.

The result of the automated analysis is given in Figure 5.12 for the whole study area. Details of this output will be illustrated in the next section. A visual analysis of the available 1/100.000 scale topographical map indicates that near Horozlu and Zazadin, no recent surface water source is present, although they are located along potential flow paths obtained from automated method (numbers 6 and 7 in Figure 5.12). Since automated method is based on subtle changes in topography, presence of a potential surface water source for these caravanserais is ambiguous.

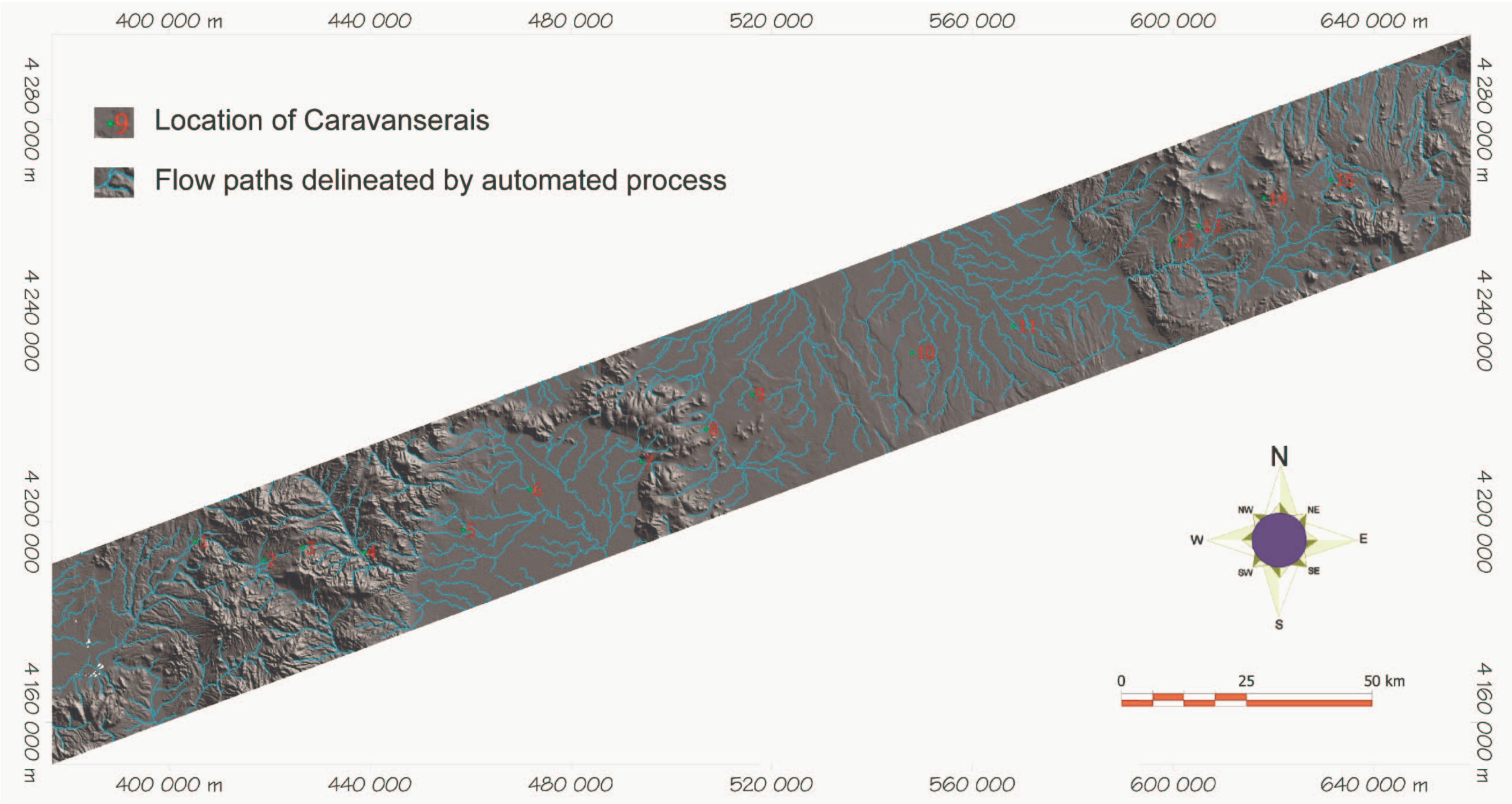


Figure 5.12: Standard flow paths in the study area extracted automatically.

5.3. Correlation of Automated Derived Flow Paths and Present Water Sources

An overlay operation is performed for the outputs of manual and automated analysis to check the overlapping sources. It is thought that, the overlapping water sources indicate the water sources that were present in ancient times and still active presently. In addition, it also indicates the adequacy of the selected parameters for the generation of the automated flow paths.

The overlay analysis of recent and automatically determined water sources indicates that, the water sources for the 10 caravanserais out of 13 have almost exact match (Figure 5.13 A-J). The remaining two of the 3 caravanserais are located next to lakes / ponds (Figure 5.13 K-L) and the last one (Figure 5.13 M) is located within a very small gully which was not detected in the automated method. In addition, no recent water source is present next to two caravanserais (Figure 5.13 O&N) for which no correlation is possible.

Exact matching of the recent and automated flow paths has two main implications; 1) the used parameters for the automated method are appropriately selected and 2) there is no major climatological change since the construction of the caravanserais so that water regime has not changed significantly. However, this needs further study.

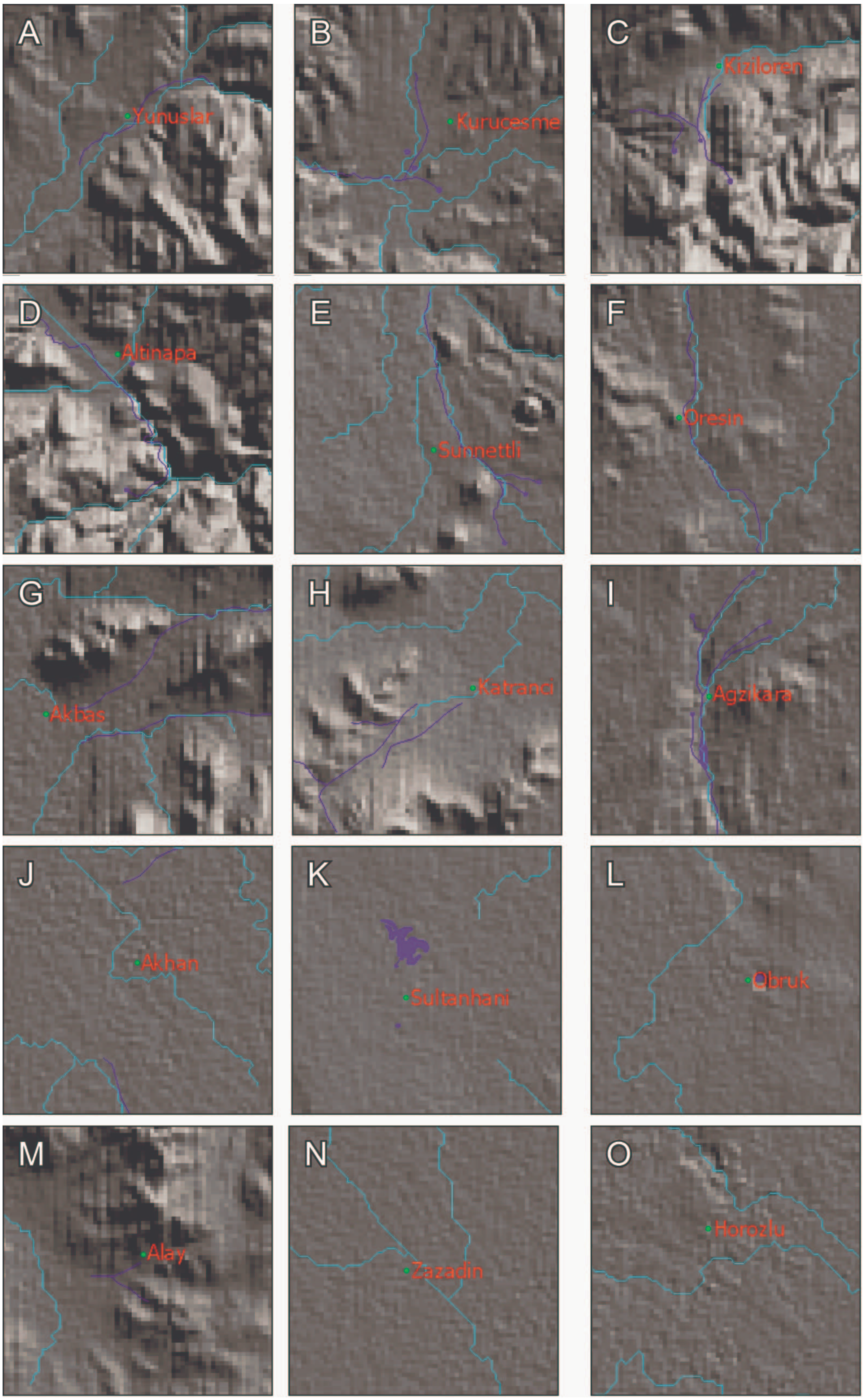


Figure 5.13: Overlay of automated (cyan) and recent (blue) surface water sources.

5.4. Visibility (Viewshed) Analysis

Visibility analysis is the determination of areas of terrain that can be seen from a particular point on a terrain surface. All visible surfaces on the map are called the viewshed (Heywood *et al.*, 1998). In the computation of the viewshed analysis, two input data sets are required. The first set is the point data set, composed of one or more viewpoints. The second set is a DEM on which, the visible and invisible terrain is determined from the previously determined point data set (Chang, 2002). The analysis is based on tracing a ray (line-of-sight) from the location of observer to each possible target location on the terrain and back to the observation point. The higher elevations on the path of the line will form an obstacle for the surfaces behind them (Figure 5.14). By repeating the ray-tracing procedure in all directions a viewshed map will be produced (Heywood, *et al.*, 1998). The output map will be a binary map consisting of visible (1) and invisible (0) parts. For large distances the curvature of earth and the transparency of the atmosphere should be taken into consideration (Burrough and McDonnell, 1998).

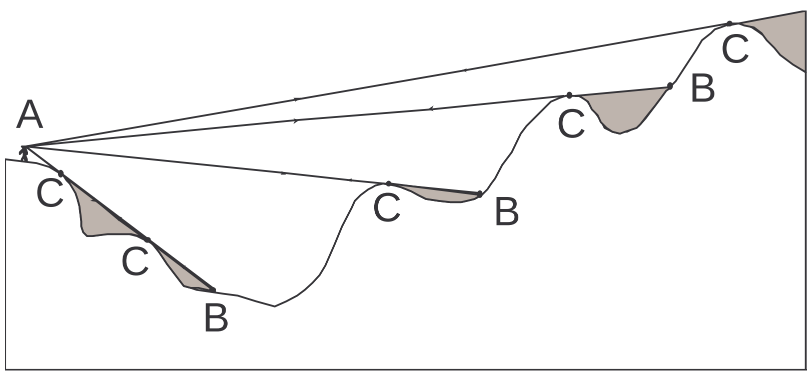


Figure 5.14: 2-D visualization of concept of visibility analysis modified from Davis, 2001. [AB]: Line from observation point to the target. [AC: Ray from observation point to the obstacle.

In this thesis, this analysis is carried out to find out from which distance a caravanserai become visible. Therefore, this analysis will help to understand whether there was an attempt to hide the caravanserai or not.

There are three main parameters that affect the result of the viewshed; the location of the viewpoint, the viewing azimuth, and the viewing radius (Chang, 2002). For the first parameter, the location of each caravanserai is used as viewing point. The heights of the traveler and the caravanserai are set as 2m. above the ground.

The second parameter, viewing azimuth, sets a horizontal angle limit to the view. By this limit, the user can calculate the visibility only for a certain range. In this study, no limit is defined and the viewing azimuth is selected as 360°. Therefore, the total visibilities from the surrounding areas will be examined.

The last parameter, the viewing radius, defines the distance for which the visibility analysis will be carried out. Since the visibility distance is limited by the nature of the human eye and the atmospheric effects (haze), this radius is chosen as 5 km.

The analysis is performed for each caravanserai by computing radial buffer zones, where the center of the circle is the location of the caravanserai. The results of the analyses are illustrated in Figure 5.15. Each circle in the figure is for one caravanserai that covers an area with a radius of 5 km. The caravanserais located at the center of the circle. Grey shade over the image is the visible surface (viewshed) for this caravanserai. Colored image at the background is the DEM of the area. The line that passes through the center is the ancient route, which is usually in E-W direction. Areas and distances in the analysis are quantified and shown in Table 5.5.

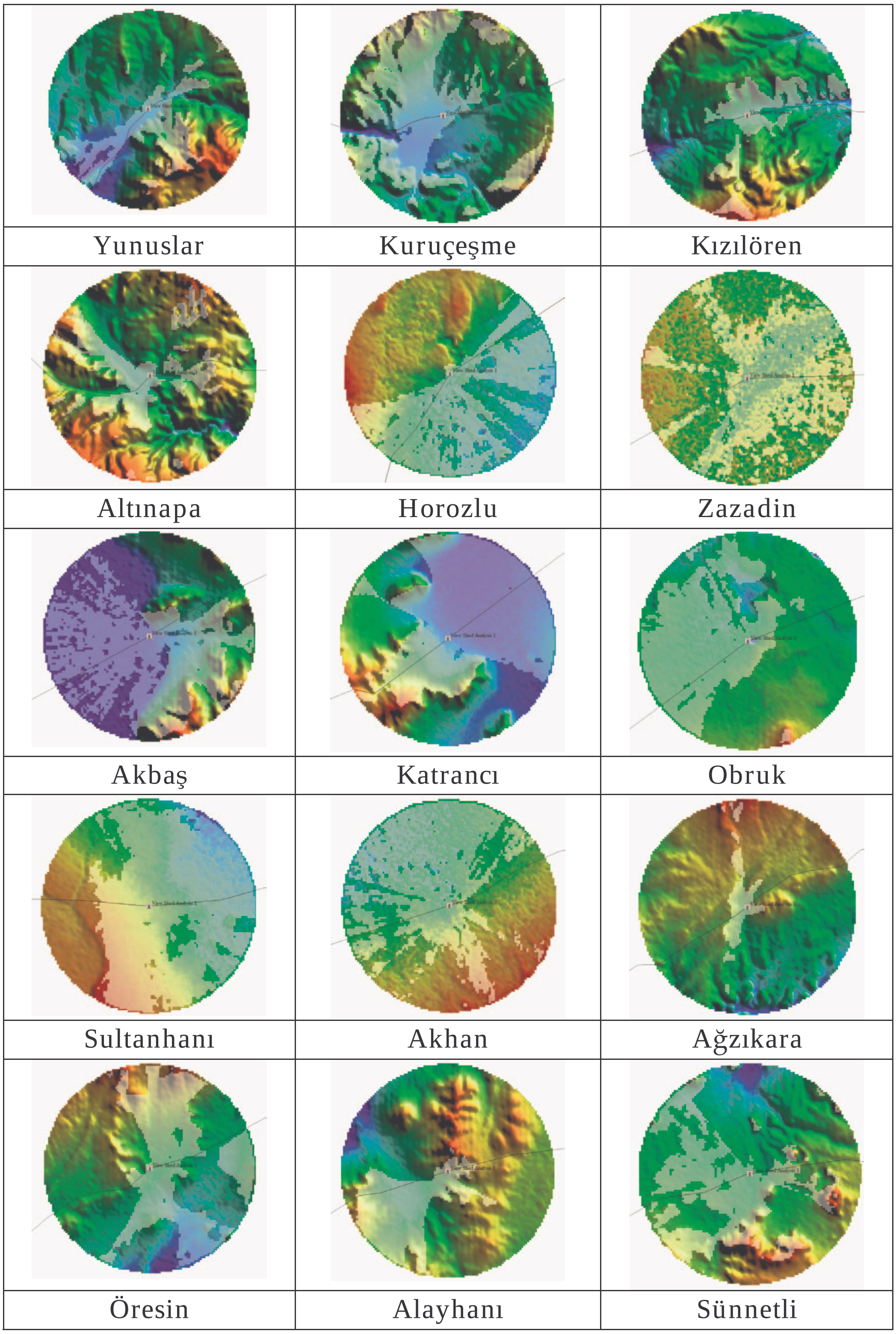


Figure 5.15: Results of viewshed analyses. Each circle stands with one caravanserai with 360° viewing azimuth and 5 km viewing radius. Grey shaded areas over the DEM are visible areas from caravanserais.

Table 5.5: Numerical results of the viewshed analysis. (**Areal visibility:** Percentage of the area visible in the circle, **Visibility from E and W:** The length and the percentage of distance visible from caravanserai along the ancient route towards east end west, respectively)

Caravanserai	**Areal Visibility**	**Visibility from E**		**Visibility from W**	
	%	km	%	km	%
Yunuslar	17,4	1,35	27,0	4,76	95,2
Kuruçeşme	41,3	1,42	28,4	2,26	45,2
Kızılören	13,1	0,64	12,9	0,67	13,5
Altınapa	18,6	3,21	64,2	1,94	38,8
Horozlu	40,3	2,51	50,2	4,98	99,6
Zazadin	47,3	4,78	95,6	1,47	29,4
Akbaş	50,6	1,72	34,4	4,81	96,2
Katrancı	56,3	4,93	98,6	4,81	96,2
Obruk	39,9	1,35	27,0	4,92	98,4
Sultanhanı	68,5	4,94	98,8	2,31	46,2
Akhan	49,2	0,85	17,0	3,89	77,8
Ağzıkara	05,2	0,36	7,14	0,99	19,9
Öresin	34,3	2,75	55,0	1,21	24,2
Alayhan	19,5	1,39	27,8	4,44	88,8
Sünnetli	29,9	2,27	45,4	4,75	95,0

Areal visibility of the caravanserai ranges from 5.2 to 68.5 % with an average of 35.4 %. Since the whole area in one circle corresponds to 78.54 km^2 ($\pi * r^2$) the average visible area is about 45 km^2. Seven caravanserais in the central part of the area between Konya and Nevşehir (Horozlu to Akhan) have larger percentages ranging from 39.9 to 68.5. Four western caravanserais (Yunuslar to Altınapa) and four eastern caravanserais (Ağzıkara to Sünnetli) have percentages ranging from 13.1 to 41.3 and from 05.2 to 34.3, respectively.

A caravanserai will be approached either from east or from west along the route during the travel. Therefore, the extraction of the information about the viewshed in these two directions will be an important contribution. This information is given in the table both as the length (for 5 km) and its percentage separately for the eastern and western directions.

For the eastern direction, the minimum and maximum distances are 360 and 4940 m, respectively, with an average of 2298 m. Three caravanserais in the central part (Zazadin, Katranci and Sultanhanı) are visible from a distance more than 4700 m. Three caravanserais that are not visible within the last one km are Kızılören, Akhan and Ağzıkarahan.

For the western direction, the minimum and maximum distances are 670 and 4980 m, respectively, with an average of 3214 m. Seven caravanserais are visible from a distance more than 4 km (Yunuslar, Horozlu, Akbaş, Katrancı, Obruk, Alayhan and Sünnetli). Two caravanserais with minimum visibility are Kızılören (670 m) and Ağzıkara (990 m).

Two caravanserais, Kızılören and Ağzıkarahan, have visibility distances less then 1 km. All others in either one or two directions have long visible distances which is good evidence against the suggestion that they are put out of sight. For example, Katrancı caravanserai is visible for more than 4 km in both directions.

CHAPTER 6

PREDICTION OF LOCATION OF MISSING CARAVANSERAIS ALONG THE ROUTE

As mentioned previously, it is presumed that there are relatively well defined geological and topographical constraints that controlled the location of the caravanserais. In order to test this, first the distances between the caravanserais are analyzed.

The analyses started first with determining the distances between the existing caravanserais. It is found that, there is no fixed distance between the caravanserais (Table 5.1 neither in the map distance nor in the true distance). Form this, it is concluded that there exist hidden (yet unknown) rules which can be unraveled via statistical means. In order to discover this rule, a statistical methodology is developed as explained below.

6.1. Statistical Test for Caravanserais Distances

The minimum distance encountered is approximately 6 km. This is observed between Öresin and Ağzıkara caravanserais, which is an exception among other distances. The other and relatively frequent values are 8, 10, 13, 14, 15, 16, 21, 23 and more than 30 km. Using this information, a probability analysis is performed, starting from 8 km to 36 km, with 2 km increments. Since the increments are multiples of 2, it, evidently, will add bias to the analysis. In order to avoid the bias and also include the minimum observed distance, 7 km which is an odd number is also used in the analysis.

It is assumed that for each selected number (i.e. modulation number in km) the probability of presence of caravanserais increases from zero to 1 linearly, starting from the beginning until the chosen distance is reached. The end point will serve a new starting point for the next successive distance along the path (Figure 6.1). This procedure is repeated for each number mode. After the completion of the calculations and determination of probabilities, the probability values for each point along the path are added and divided by the number of runs (number of modulators) which is 16 for this analysis.

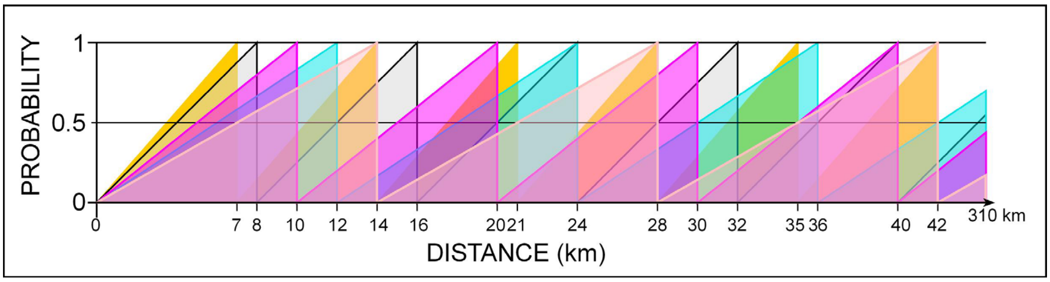


Figure 6.1: Linear probability distribution for some selected repeat cycles (distances). In the analysis, except 7 km, starting from 8 km to 36 km, 2 km increments are used, which make 16 runs.

In order to determine the probabilities, the path segment between Beyşehir to Nevşehir is divided into 100 m interval points. Then the probabilities are distributed according the selected path length (see Table. 6.1). It is important to note that selection of 100 m point interval is based on the spatial resolution of the SRTM data which is slightly less than 100 m and for the sake of easy calculation.

It is obvious that the starting end of the path (west or east) will add bias. For example if the western end of the route (Beyşehir) is chosen for the beginning point, first 36 km (the largest modulation number) interval will have the largest bias (Figure 6.2) and same applies for the eastern beginning case. In order to overcome this bias, the same analysis is repeated taking the eastern end (Nevşehir) as the beginning point (Figure 6.3). Then, the probability values for western and eastern beginning cases are calculated for each point and divided by two (Figure 6.4). After this operation it is thought that bias is eliminated to some extend, and its results are used for further analysis.

Table 6.1: Probability determination method for each 100 m spaced point along the route. Note that 16 modulation numbers are used.

Points for 7 km	Probability for 7 km	Points for 8 km	Probability for 8 km	Points for 10 km	Probability for 10 km	...	Points for 36 km	Probability for 36 km	Probability Sum / 16
0.10	0.1/7	0.10	0.1/8	0.10	0.1/10	...	0.10	0.1/36	2.56/16
0.20	0.2/7	0.20	0.2/8	0.20	0.2/10	...	0.20	0.2/36	2.72/16
0.30	0.3/7	0.30	0.3/8	0.30	0.3/10	...	0.30	0.3/36	2.88/16
...	...	...	...	...	...	...	...		
6.80	6.8/7	7.80	7.8/8	9.80	9.8/10	...	35.80	35.8/36	6.624/16
6.90	6.9/7	7.90	7.9/8	9.90	9.9/10	...	35.90	35.9/36	6.704/16
7.00	7.0/7.0	8.00	8.0/8.0	10.00	10/10	...	36	36/36	6.816/16
0.10	0.1/7	0.10	0.1/8	0.10	0.1/10	...	0.10	0.1/36	5.904/16
0.20	0.2/7	0.20	0.2/8	0.20	0.2/10	...	0.20	0.2/36	6.000/16
0.30	0.3/7	0.30	0.3/8	0.30	0.3/10	...	0.30	0.3/36	6.112/16
...	...	...	...	...	...	...	...	...	
end		end		end			end	end	end

The resultant probability values indicated that maximum value is 0.63 and the highest frequencies occur around 0.55 (Figure 6.5). There is drastic decrease of frequencies for the values more than 0.57. Therefore it is thought that the probability values equal or greater than 0.57 might indicate a possible location of a caravanserai.

Using the distance values equal of greater than 0.57 the probability values are calculated on the map. It is found that the minimum distance between caravanserais is about 5 km and maximum distance about 20 km. After this step, the resultant distances and measured distances between the known caravanserais are plotted (Figure 6.6) It is observed that both graphs are resembling to each other and they are highly correlated with a correlation coefficient of 0.979 (Table 6.2).

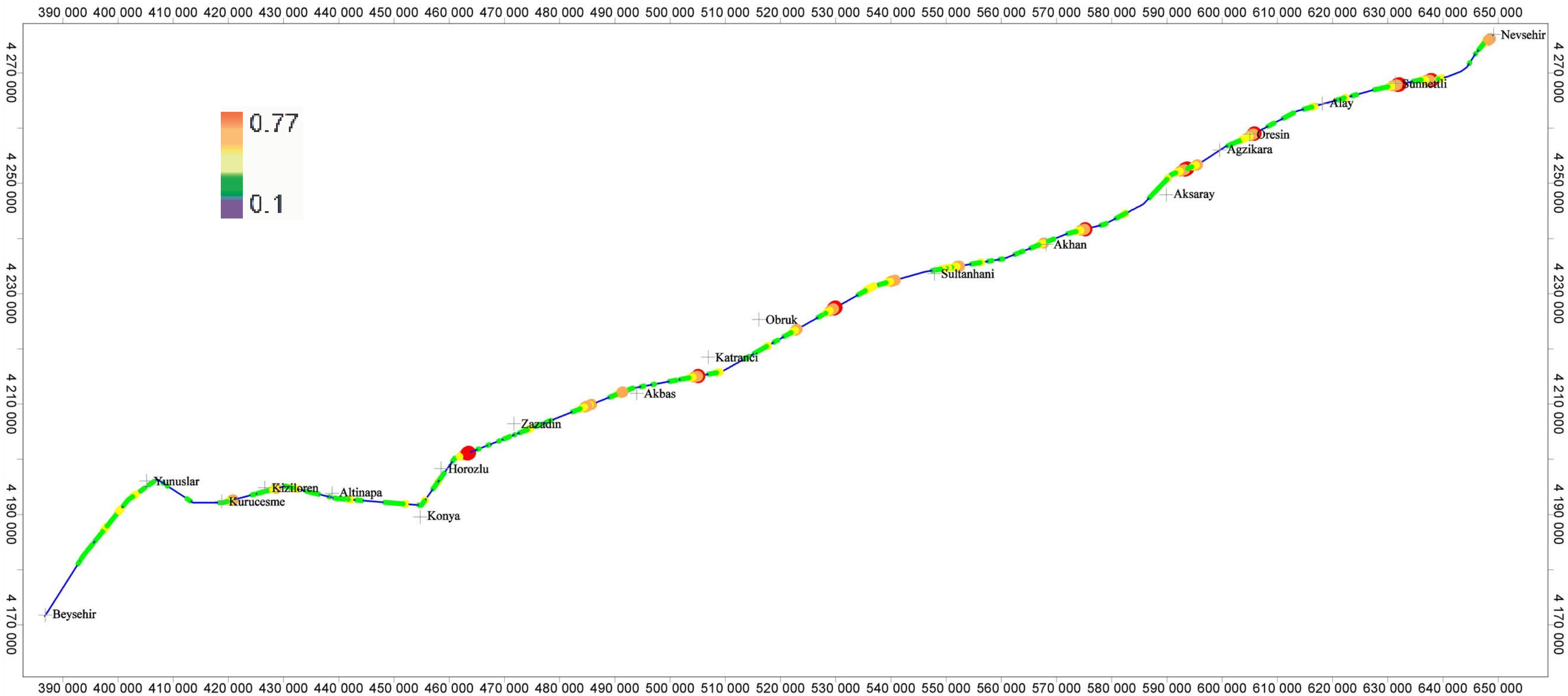


Figure 6.2: Probability distribution for the western beginning case, i.e. analysis started from Beyşehir. Probability range is between 0.1 to 0.77.

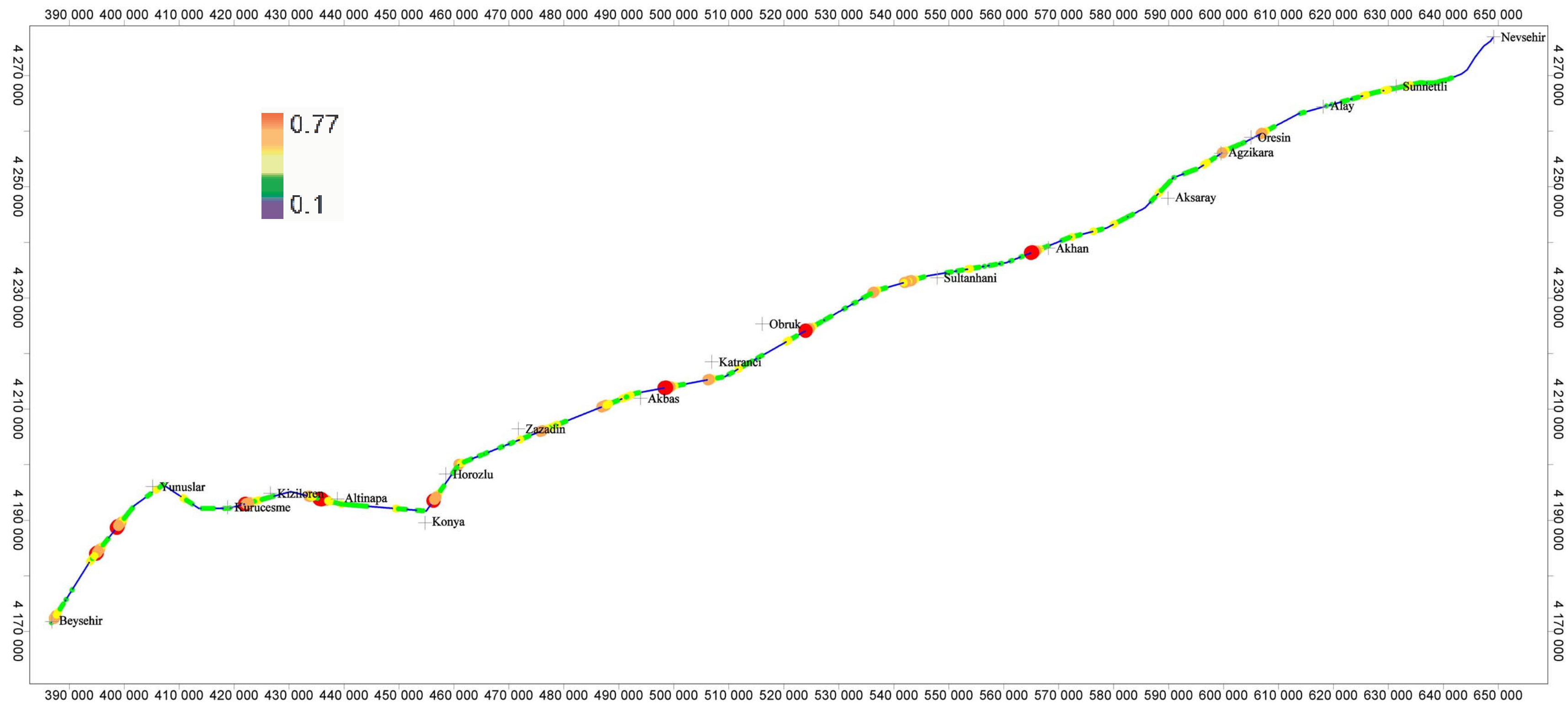


Figure 6.3: Probability distribution for the eastern beginning case, i.e. analysis started from Nevşehir. Probability range is between 0.1 to 0.77.

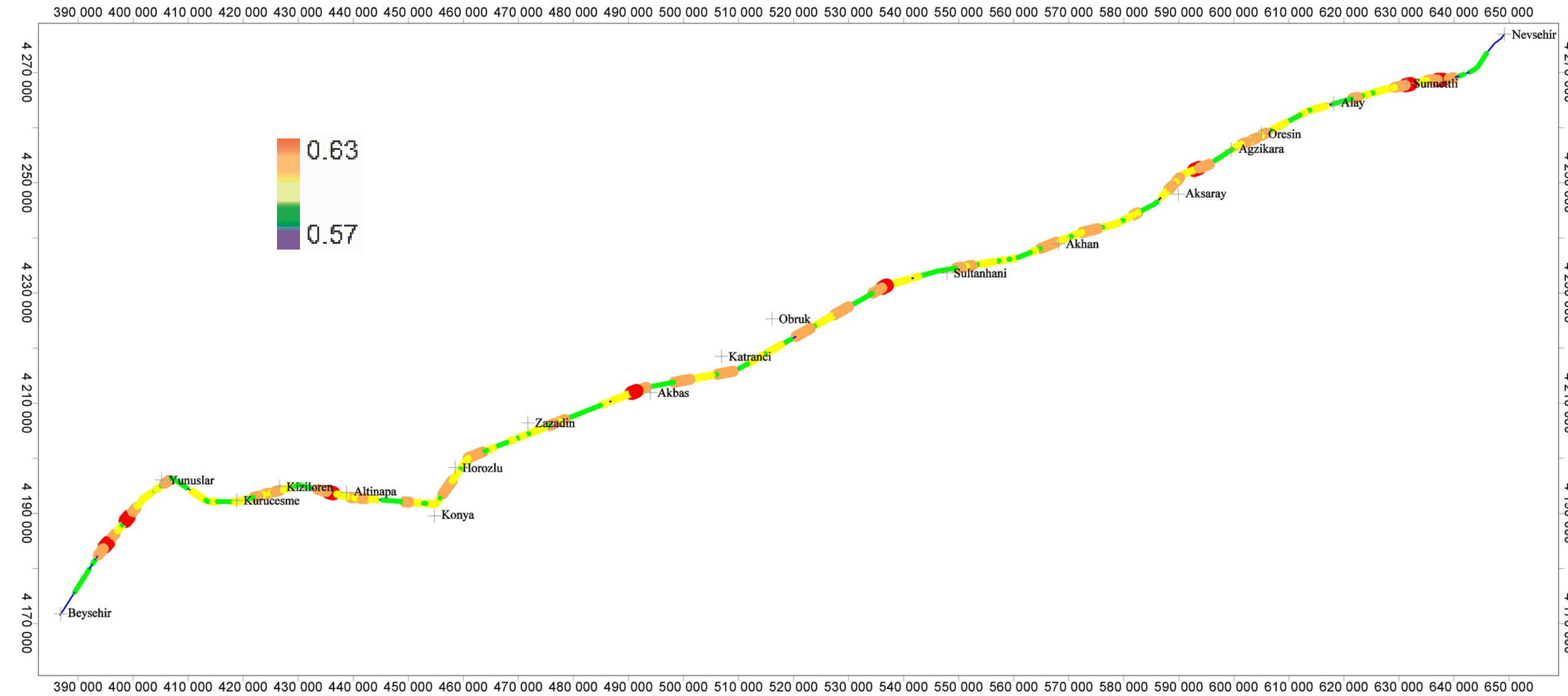


Figure 6.4: Normalized probability distribution along the route, i.e. the western and the eastern beginning cases are averaged. Note very high probabilities between Beyşehir -Yunuslar and Obruk-Sultanhani caravanserais. Probability range is between 0.57 to 0.63.

Table 6.2: Correlation of measured distances from the known caravanserais and obtained (calculated) distance values.

		OBTAINED
	N (number of items)	18
MEASURED	Pearson Correlation	0,979

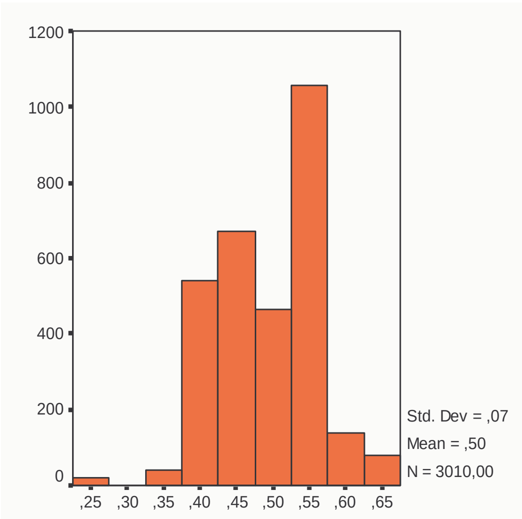


Figure 6.5: Histogram of calculated probabilities for the locations of the caravanserais. The mod is 0.55 and there is a major drop at 0.57.

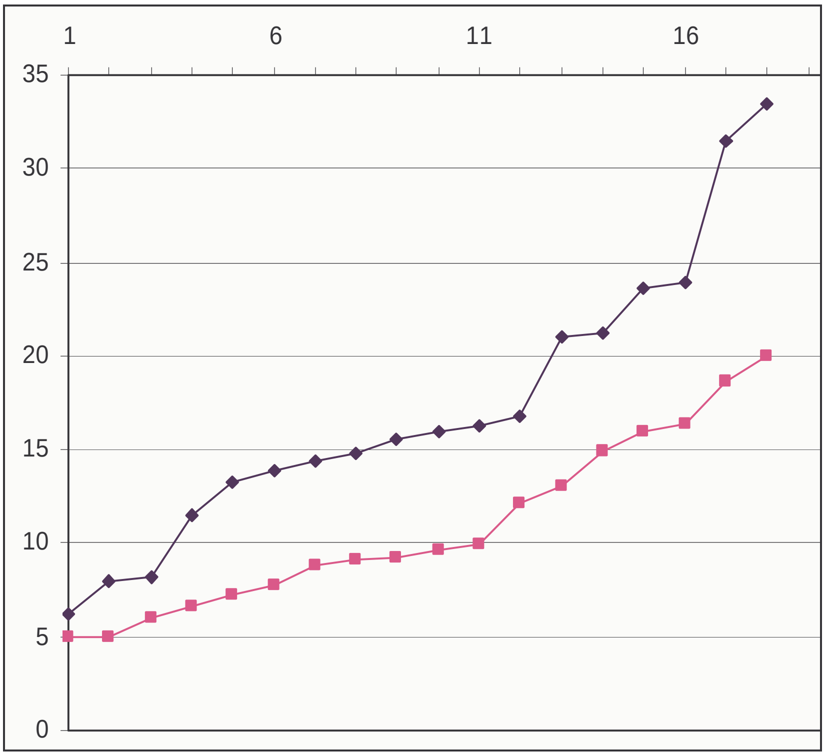


Figure 6.6: Graph showing the distances between the successive caravanserais for the known (blue) and calculated (magenta) values. X-axis: caravanserai number, Y-axis: distance value in kilometers. Note that before plotting, the values were sorted according to distance value. Therefore, X-axis indicates only its sequence in the data file.

6.2. Recurrence Distance of Caravanserais and Potential Sites for Unknown Caravanserais

A frequency analyses is performed in order to pursue one of the main objectives of this study, the recurrence distance between each successive caravanserai. It is found that the optimum distance between successive caravanserais is about 15 km according to the distance data from known caravanserais (Figure 6.7). This value is found to be 10 km according to proposed method.

In order to determine the potential sites of unknown caravanserais, the obtained probabilities and known caravanserais were overlaid. Keeping in mind the recurrence intervals obtained from both methods, 3 potential points are determined that might correspond to unknown caravanserais. Two of the sites are located between Beyşehir and Yunuslar, and the other site is between Obruk and Sulatnahanı hans (Figure 6.8). For these sites, distance to water source analysis is also performed and it is found that they are just next to streams. Presence of water source nearby further supports the potential of presence of caravanserais in these sites.

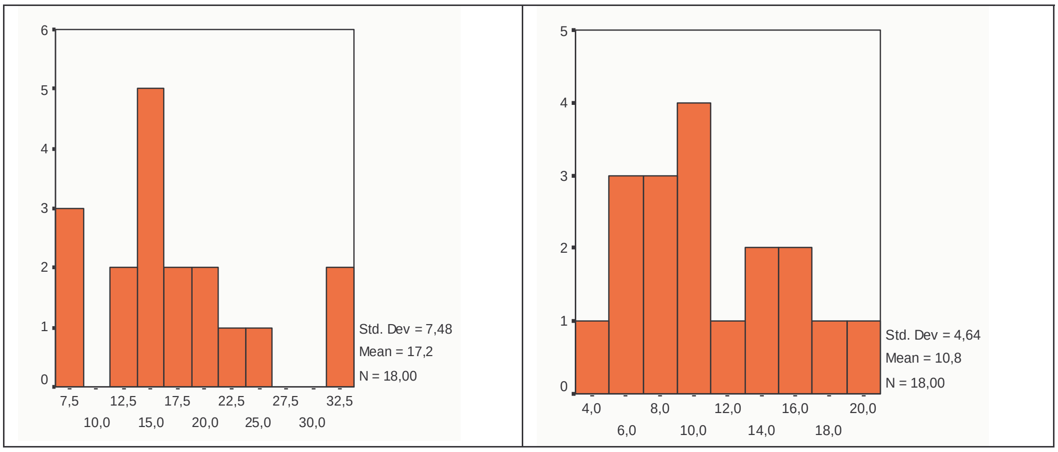


Figure 6.7: Histograms of the distances between successive caravanserais. a) for the known caravanserais and b) for the calculated distances. Note that Mod from known caravanserais is 15 km and it is 10 km for the calculated distances.

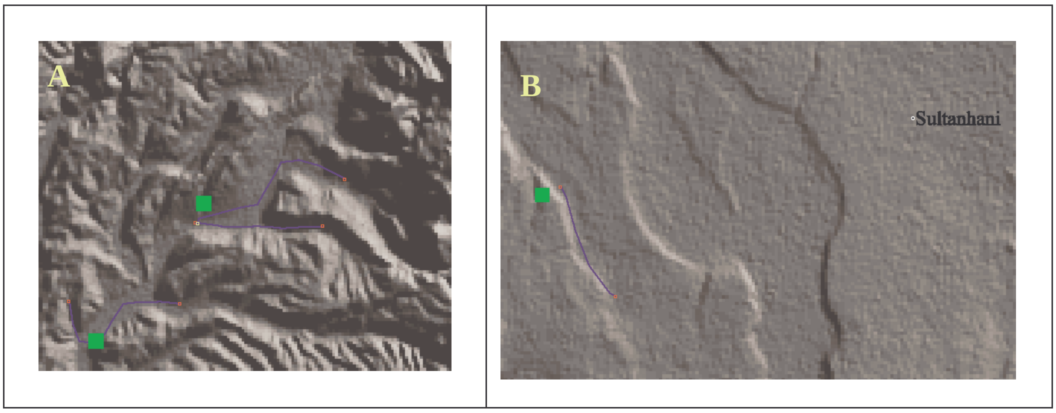


Figure 6.8: Possible locations of unknown caravanserais determined in this study. A) between Beyşehir and Yunuslar, B) between Sultanhanı and Obruk caravanserais. Note that they are located right next to surface water sources.

CHAPTER 7

DISCUSSION AND CONCLUSION

7.1. Generation of Ancient Trade Route

Generation of the ancient caravanserai route is a necessity because the accuracy of some analysis such as the computation of the distances between successive caravanserais and visibility analysis are carried out using this route. The route is generated using coordinates of the caravanserais, the DEM of the area the route of the recent road. Three assumptions explained in Chapter 5.1 are made to decrease the alternatives of the ancient route to be determined on the DEM.

Accuracy of the generated route can be increased by use of ancillary data such as historical bridges, milestones (if any), and caravan stop locations (temporary resting places). Although these features are mentioned in the literature, there is no information on their location. Other morphological obstacles such as dried up lakes and marches, or any restricted regions along the route can also play an important role to modify the route particularly for the flat area between Konya and Nevşehir.

The route delineated in this study indicates that the ancient and the recent roads greatly coincide in the eastern and western parts of the area which are characterized by mountainous and relatively rough topography. In the central part, between Konya and Aksaray, on the other hand, a shift of 4-5 km is noticed at two localities, in the vicinity of Obruk and Zazadin caravanserais.

7.2. Proximity Analysis

Proximity analysis is carried out for three aspects of caravanserais. Several aspects of these analyses are discussed below.

7.2.1. Distance between Caravanserais

Distances between caravanserais are considered to be determined according to daily travel distances. Therefore, the distances between them should be expected to have a homogeneous distribution. Although there is not an agreed daily distance, literature states that the daily travel distance for a caravan ranges between 20 to 30 km. The analyses carried out in this study, however, indicate that there is a great variation in the distances. The minimum and maximum values are found to be 6254 (Ağzıkara-Öresin) and 33463 m (Obruk-Sultanhanı), respectively although average distance is 17198 m.

Following reasons may explain the variation of the distance between successive caravanserais:

- Some of the caravanserais along the route might have been eliminated which is frequently mentioned in the literature. One of the most supporting evidence for this is presence of clear-cut stones in the buildings of some villages that are supposed to be derived from the now eliminated caravanserais. Therefore, if all eliminated or destroyed caravanserais could be included in the database, a more uniform distribution would be obtained.

- Some caravanserais although seem to exist along the suggested route may actually belong to another route that runs in different direction. Two examples of such caravanserais are Horozlu and Öresin which have minimum distances. The distance between Horozlu and Konya is 7927 m; the distance between Öresin and Ağzıkara is 6254 m. These distances are much less than any expected daily distance. The case of Horozlu caravanserai is investigated to test the distance (Figure 7.1). If Horozlu is excluded from the route the distance between Konya and Zazadin will be about 23 km (it may even drop to 22 km due to the curvature of route) which is still a daily travel distance. Therefore, it is logical to claim that Horozlu may belong to another route in a different direction and is not used in Konya-Aksaray route.

- The travel distances for the winter and summer periods should be different due to variation in the daylight duration. Daylight duration for Konya is computed to be 15 hours 4 minutes in June 21st and 10 hours 7 minutes in December 21st indicating about one-third longer time for summer period. Therefore, it is probable that the use of the caravanserais had different travel patterns in different seasons and that the system is more complicated than assuming a uniform distance between two neighbor caravanserais.

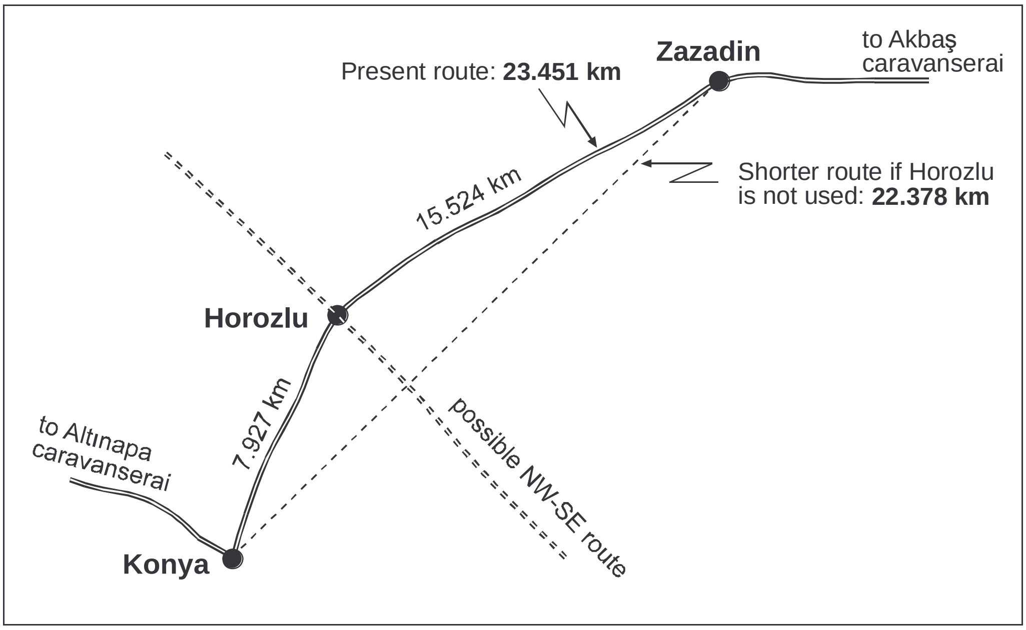


Figure 7.1: Position of Horozlu caravanserai between Konya and Zazadin. This caravanserai is questioned if it can belong to another route in different direction.

7.2.2. Distance to Rock Type

The rock types used as building stone in caravanserai and the lithology map of the area are used to investigate the use of rocks in caravanserais. The rock types are known only in eight caravanserais. The lithology map used in the analysis is prepared from 1:500.000 scale geological map of MTA.

The procedure of the investigation is composed of three steps

1. the rocks used in the caravanserais are transferred to the database
2. the distance to the exposures of these rocks are computed using the lithology map and a circle (buffer) with the radius of this distance is drawn the caravanserai being at the center
3. other rocks that exist in the buffer are noted

The analyses carried out for the rock material used in the caravanserais involve the comparison of the rocks in the structure with the rocks in vicinity and the distance to the rock source. The results indicated that certain rock types are not used in some caravanserais although they are closer than the ones used. Examples of these rocks are volcanic rocks for Kuruçeşme and Sultanhanı; clastic rocks for Horozlu, Zazadin and Obruk; and Intrusive rocks for Öresin and Alayhan. The conclusion, therefore, is that the distance to the source rock is not an important factor for the site selection of the caravanserai and that the preferred rock type is used even if it is at a greater distance.

A more detailed lithology map will produce better results. This detail is related with the scale and the description of the rocks exposed in the area. A mapping is not performed in this study considering the size of the area. However, field studies to certain areas can contribute to correlation of the rocks in the field with the rocks used in the caravanserais. Petrographic analysis may be useful for this correlation. Aerial photographs can be used to identify ancient quarries.

7.2.3 Distance to Water Source

There are several types of water sources used in caravanserais. Among these sources the ground water is known to be used in Zazadin and Katrancı caravanserais as evidenced by the wells in the vicinity of the buildings. Ground water, however, is not considered in the analysis in this study. Because it is not a surface feature and it can exist anywhere at different depths. Therefore, other surface water sources (streams, springs and lakes) are used to calculate the distances.

Six caravanserais are located near to permanent streams and others to seasonal streams, springs or lakes. The lake near to Obruk caravanserai is a typical example of the importance of water in the selection of site. Presence of multiple water resources indicate that it is not necessary to base on only one source. None of the caravanserais is closer than 100 m that may imply that they avoided locating the caravanserai in flood plain.

7.3. Visibility Analysis

Visibility analysis is carried out for one pixel that represents the caravanserai. The analysis is first performed for a circular area of 5 km radius. Then the visibility for two certain directions to the east and west of the caravanserai along the ancient route are computed.

The results indicate that selection of 5 km search radius is a correct decision because none of the caravanserais is visible from 5 km. The maximum visible distance is 4.98 km for the eastern direction of Zazadin caravanserai. Three caravanserais (Kızılören, Akhan and Ağzıkara) have distances less than 1 km in one or both directions.

A general conclusion of the analysis is that the visibility of the caravanserais and the general characteristics of the terrain are consistent with each other. Flat area between Konya and Aksaray yield larger visibility distances while the eastern (Aksaray-Nevşehir) and western (Beyşehir-Konya) caravanserais have relatively lower visible distances.

Variation and inconsistency in the visibility analysis may lead to the interpretation that there is no tendency to hide the caravanserai nor there is an attempt to locate it somewhere visible from long distances. To extract more information on the visibility, a further analysis can be carried out to compare the visibility of a site with other neighbor points around the site. For example, visibility of all points within a circular buffer zone (caravanserai being at the center) can be computed and correlated with the visibility of the caravanserai. By this analysis, an exact answer about the selection of the site can be given whether there is an attempt to locate the caravanserai in this specific place within the buffer zone.

7.4. Prediction

Prediction of caravanserais is an important analysis that will produce concrete results and contribute to related studies. The prediction of the sites is performed by Probability Distribution Analysis which is newly developed in this study. The results of the analysis suggest several sites along the route (Figure 6.4). Three of these sites are located between the caravanserais that have maximum distances in the area. These are Beyşehir-Yunuslar (two predicted sites) and Obruk-Sultanhanı (one predicted site). The location and the evaluation of these predicted sites are illustrated in Figure 7.2.

Beyşehir-Yunuslar route is divided into three segments if the predicted sites are considered (Figure 7.2-A). The distances between caravanserais in this case are 15, 7 and 9.5 km. Accordingly, the distances between the caravanserais along the Beyşehir-Konya route range from 7 to 16.8 km.

The third predicted caravanserai between Obruk and Sultanhanı divides the route into two segments with the distances of 21.5 and 12 km (Figure 7.2-B). By the addition of this caravanserai the minimum and maximum distances would be 7.9 and 23.9 km along the Konya-Aksaray route.

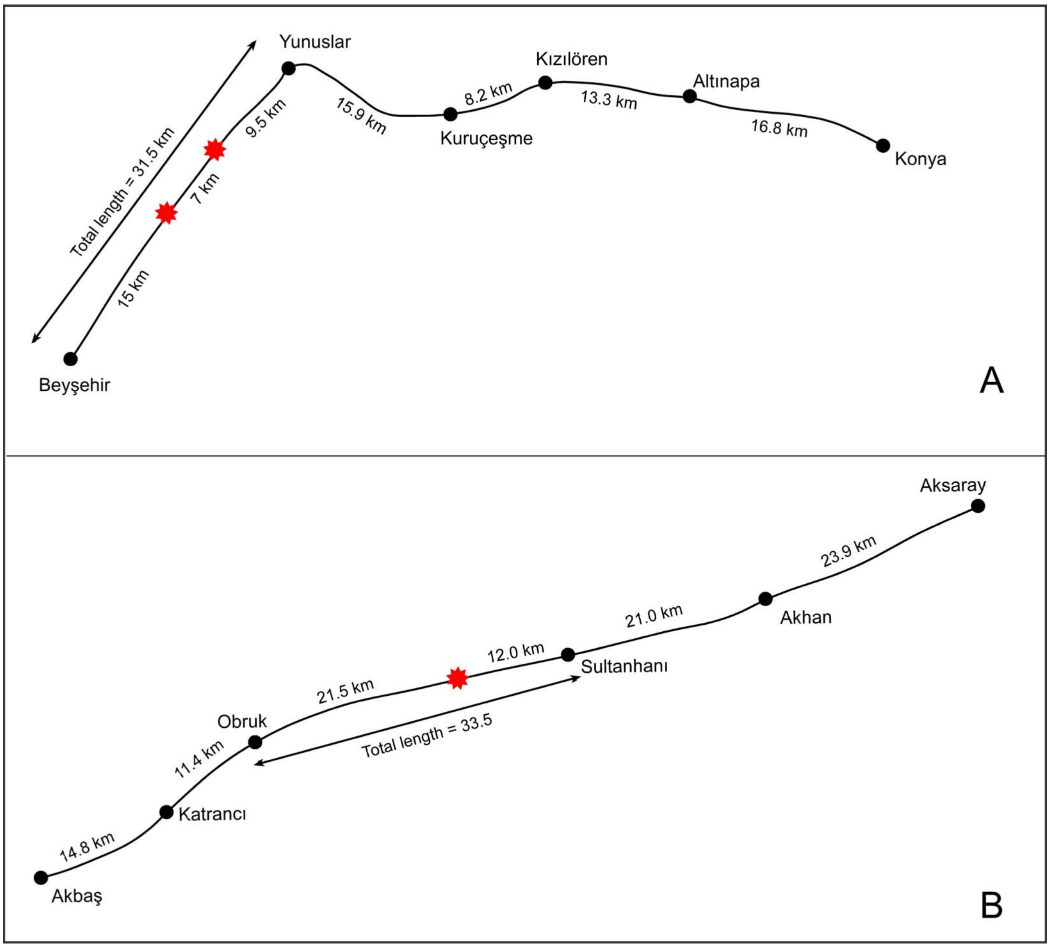


Figure 7.2: Location map showing the position of the predicted caravanserais and the modified distances between consequent caravanserais.

CHAPTER 8

RECOMMENDATIONS

The most important contribution of this thesis is to introduce an approach that will answer some questions on the nature, use and site selection of caravanserais. Two aspects of this approach are the use of: 1) geographic information systems (GIS), and 2) ancillary data such as rock type, water sources and topography.

Use of the GIS, although not a new technology, is believed to be used for the first time by this thesis for the caravanserais. The use here, however, is limited to certain aspects of the caravanserais and should be extended further including other ancillary spatial data on the caravanserais.

Following investigations can be suggested for the further studies:

- Orientation of the caravanserais is not analyzed in this study because of the limited data. This analysis can be carried out with a larger data set that can contribute to understand if the structures are oriented in relation to topography or main road or defense etc.
- Distance to rock source analysis is based on the geological maps available. No particular field work is carried out to justify the results. Field studies including petrographic and geochemical analysis will help for a better understanding on the use of the rock sources and locating the ancient quarries from where the rock material was provided for the caravanserais.
- Distances between the caravanserais found in this study should be tested for daily travel distance. This test is not made here because there not an optimum daily distance agreed in the literature. The daily distance will greatly differ in the summer and winter times (almost with one-third)

that will also affect the type of the caravanserai as “winter caravanserai” or “summer caravanserai”.

- The caravanserais used in this study belong to a straight route between Beyşehir and Nevşehir. Delineation of other routes that cross this one is very important particularly in order to identify if some caravanserais do not belong to this one. Horozlu is given an example in this study that may belong to a NW-SE route. Therefore, further studies should be performed on a set of caravanserais that belong to more than one route.
- Size and internal structure of the caravanserais are not considered in this study. Size can lead to understand the function of the caravanserai, for example, if it is located at the junction of two routes or if it is used only for winter seasons. Comparison of the internal structure by GIS, on the other hand, can help to recognize a different aspect of the caravanserai.
- Visibility analysis in this study is carried out only for one pixel that corresponds to the site of the caravanserai. An analysis carried out for the neighbor pixels can contribute to quantify the selection of the site.

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