SPATIAL DECISION SUPPORT SYSTEM FOR ARCHAEOLOGICAL APPLICATION: A CASE STUDY FOR KAUNOS ARCHAEOLOGICAL SITE

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GİZEM BAYBAŞ

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submitted by **Gizem BAYBAŞ** in partial fulfillment of the requirements for the degree of **Master of Science in Geodetic and Geographic Information Technologies Department**, **Middle East Technical University** by,

Prof. Dr. Canan ÖZGEN
Dean, Graduate School of **Natural and Applied Sciences**

Assoc. Prof. Ahmet COŞAR
Head of Department, **Geodetic and Geographic Inf. Tech.**

Prof. Dr. H. Şebnem DÜZGÜN
Supervisor, **Mining Engineering Dept., METU**

Assoc. Prof. Zeynep Çizmeli ÖĞÜN
Co-Supervisor, **Archaeology Dept., Ankara University**

Examining Committee Members:

Prof. Dr. Oğuz IŞIK
City Planning Dept., METU

Prof. Dr. H. Şebnem DÜZGÜN
Mining Engineering Dept., METU

Assist. Prof. Dr. Nuray DEMİREL
Mining Engineering Dept., METU

Assist. Prof. Dr. Güliz Bilgin ALTINÖZ
Architecture Dept., METU

Prof. Dr. Fikri KULAKOĞLU
Archaeology Dept., Ankara University

Date:01.02.2013

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name,Lastname: Gizem BAYBAŞ

Signature:

ABSTRACT

SPATIAL DECISION SUPPORT SYSTEM FOR ARCHAEOLOGICAL APPLICATIONS: A CASE STUDY FOR KAUNOS ARCHAEOLOGICAL SITE

BAYBAŞ, Gizem

M. Sc., Department of Geodetics and Geographic Information Technologies

Supervisor: Prof. Dr. H. Şebnem DÜZGÜN

Co-Supervisor: Doç. Dr. Zeynep Çizmeli ÖĞÜN

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Geographically located materials are used by the archaeology to analyze and explain the socio-cultural aspects of ancient life. Thus, Geographical Information Systems (GIS) have started to be used in archaeology for many applications. Although, cooperation of GIS and archaeology is considered as beneficial, it has become insufficient to meet the requirements of archaeologists about excavation study. Therefore, the aim of this thesis is to develop Spatial Decision Support System (SDSS) which includes both the GIS tools and analyses and; analytical modeling capabilities in order to satisfy the needs of archaeologists. Moreover, to develop a specialized system for specific archaeological excavation site is aimed. In this study, Kaunos is selected as a case study area and in order to furnish this aim, firstly, needs of archaeologists working in the excavation study of Kaunos are analyzed. Secondly, GIS tools and analyses are determined which meet the requirements of archaeologists. Finally, SDSS for Kaunos Archaeological Excavation Site is developed. It is composed of four components namely; Database Management, Model Management, Dialog Management and Stakeholder Components. Analyses are conducted under the Model Management Component and results are visualized in Dialog Management Component. Result maps help and assist archaeologists in terms of interpreting and examining the socio-cultural, economical and demographical characteristics of Kaunos.

Keywords: GIS, SDSS, Archaeological Excavation, Excavation Management, archaeological database management systems

ÖZ

ARKEOLOJİK UYGULAMALAR İÇİN MEKANSAL KARAR DESTEK MEKANİZMASI: KAUNOS ARKEOLOJİK KENTİNDEN BİR ÖRNEK

BAYBAŞ, Gizem

Yüksek Lisans, Jeodezi ve Coğrafi Bilgi Teknolojileri Bölümü

Tez Yöneticisi: Prof. Dr. H. Şebnem DÜZGÜN

Ortak Tez Yöneticisi: Doç. Dr. Zeynep Çizmeli ÖĞÜN

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Coğrafi olarak farklı yerlerde bulunan materyaller, eski dönemlerde yaşayan insanların sosyo-kültürel özelliklerini analiz etmek ve açıklamak amacıyla arkeoloji tarafından kullanılmaktadır. Bu nedenle de Coğrafi Bilgi Sistemleri (CBS) birçok arkeolojik uygulamada kullanılmaya başlanmıştır. CBS ve arkeolojinin birlikteliği çok yararlı olarak değerlendirilse de, arkeologların arkeolojik kazı ile ilgili ihtiyaçlarını karşılamada yetersiz kalmaktadır. Bu nedenle, bu tezin amacı, arkeologların ihtiyaçlarına cevap verebilecek, GIS araçlarını, analizlerini ve analitik modelleme yeteneklerini içeren Mekânsal Karar Destek Sistemi geliştirmektir. Bunun yansıra, belirlenmiş bir kazı alanı için özelleşmiş Mekânsal Karar Destek Sistemi geliştirmek de amaçlanmaktadır. Bu çalışma için, Kaunos arkeolojik alanı örnek çalışma alanı olarak seçilmiş ve amacın gerçekleştirilebilmesi için ilk olarak Kaunos kazısında çalışan arkeologların ihtiyaçları analiz edilmiştir. Daha sonra, bu ihtiyaçlara cevap verebilecek GIS araçları ve analizler belirlenmiştir. Son olarak da Kaunos Arkeolojik alanı için Veri tabanı Yönetimi, Model Yönetimi, Diyalog Yönetimi ve Kullanıcı bileşenlerinden oluşan, Mekânsal Karar Destek Sistemi geliştirilmiştir. Analizler, Model Yönetim bileşeni altında yapılarak, Diyalog Yönetim bileşeni altında görsellenmiştir. Analizlerin sonucunda görsellenen haritalar, arkeologların, Kaunos'un sosyo-kültürel, ekonomik ve demografik özelliklerini yorumlamalarında yardımcı olmuştur.

Anahtar kelimeler: CBS, SDSS, Arkeolojik kazı, kazı yönetimi, arkeolojik veri tabanı yönetim sistemleri

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CHAPTER 1

INTRODUCTION

1.1 Introduction

As nearly all disciplines, archaeology deals with the interpretation of geographically located materials (Wheatley and Gillings, 2002). Archaeologists' aim is to analyse and explain socioeconomic life of past human life by using these geographical materials (Kıroğlu, 2003). Hence, Geographical Information System (GIS) becomes a useful tool for archaeologists. Usage of GIS in archaeology dates back almost two decades (Kvamme, 1995). Its usage in this discipline is developing day by day and it is started to be utilized in archaeology for complex analyses rather than just creating database (Dündar, 2009).

For archaeologists, the best way of performing analyses is using recovered and recorded information in dynamic and flexible environment. GIS is one of the most appropriate tools for archaeological analyses. It allows the management of vast quantities of collected data and enables visual representation. Some basic exploratory and statistical investigations can be performed. Moreover, it facilitates the incorporation of all types of information such as archaeological artifacts, environmental factors, modern cultural boundaries etc. (Wheatley and Gillings, 2002).

It is inferred from the literature that GIS is utilized for many reasons in archaeological analyses, generally for ad-hoc problems. Wheatley and Gillings (2002) categorize the aim of GIS usage in archaeology into two groups which are Research and Management (Figure 1.1). Research can be divided into two classes which are Regional Research and Intra-site Studies. Predictive modeling, catchment analysis, viewshed analysis and exploratory data analysis are common applications for regional analysis in archaeological GIS. On the other hand, intra-site studies are directly related to excavation recording especially in 3D. Management, the second common application of GIS in archaeology, consists of two sub-classes which are Database Management (DBM) and Cultural Resource Management (CRM). DBM is related to storage, maintenance and analysis of data both at regional and site base level. For this stage, GIS is used for integrating non spatial data with spatial information. CRM is related to management and protection of the archaeological resource and involves development planning and predictive modeling (Wheatley and Gillings, 2002; Ebert, 2004).

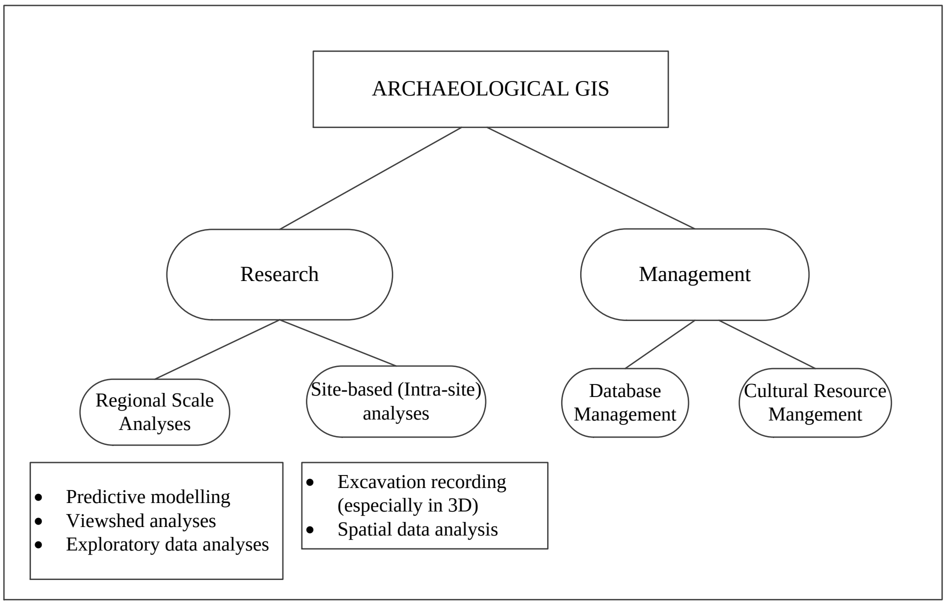


Figure 1.1 Current applications of GIS within archaeology (adapted from Wheatley and Gillings, 2002)

GIS is also used for predictive modeling. Warren (1990) determines predictive modeling as a tool for forecasting unknown places from known patterns or relationships. Due to the requirement of vast amount of data from known locations, predictive models can be established in GIS properly.

Brandt et al. (1992) develop a model in order to find archaeologically sensitive areas in the Netherlands for Regge Valley Region. Similarly, Kuiper and Wescott (1999) utilize GIS to predict potential prehistoric site location in Upper Chesapeake Bay Region, America. Finally, Warren (1990) developed a predictive model for the Western Shawnee National Forest in the Southern Illinois. They all benefit from GIS for the same purpose which is digitizing and organizing the environmental data. Afterwards, they employ statistical properties to obtain the result.

For regional scale, another most common usage of GIS in archaeology is viewshed analysis. “A viewshed is simply the calculation of multiple lines of sight in a 360-degree circle from a single location, specifying all the areas that are visible from a single location.” (Kvamme, 1999, p. 177). It is derived from DEM (Digital Elevation Model) and resultant map indicates visible and non-visible locations from a given location. A further step from viewshed is cumulative viewshed analysis. It represents the sum of individual viewshed.

In the literature viewshed and cumulative viewshed analysis are employed for several reasons. For example, Jones (2006) use viewshed analysis to define whether there is a reason behind the choice of settlement location of Onondaga Iroquois sites. On the other hand, Wheatley (1995), who is among the first researcher working on the cumulative viewshed analysis, examines the spatial organization of long barrows in Avebury and Stonehenge area in the British Isle. Likewise, Lake et al. (1998) perform cumulative viewshed analysis by using GIS in order to determine the distribution of a series of Mesolithic sites on the Isle of Islay in the Inner Hebrides.

Last component of the regional scale analyses is Exploratory Data Analysis (EDA) (Figure 1.1). Behrens (1997) state that EDA is comprehensive statistical properties that provide conceptual and computational tools for discovering patterns to support hypothesis development. It does not contain hypothesis testing but involves multiple mathematical models in order to explore data. Graphical illustration is important aspect for EDA (Williams et al., 1990). Although it is grouped in regional scale analysis by Wheatley and Gillings (2002), it is also used in intra-site analysis.

Studies of Williams et al. (1990) and Kvamme (1996) are the examples of EDA. Williams et al. (1990) try to understand the pattern of site occurrence in the area of Fort Hood Military Area in

Texas. Likewise, Kvamme (1996) examines the debitage distribution of an archaeological area in western Colorado and investigates the patterns.

EDA does not contain hypothesis testing; therefore, pattern classification and modeling issues of the analysis remain incomplete. Hence, in order to prevent this deficiency, spatial data analyses started to be used in archaeology. It contains EDA properties which are visualization and exploration; besides, the hypothesis can be tested with constructed models. Spatial Data Analysis is utilized for archeological investigations of ancient settlement patterns (e.g., in Whitley and Clark, 1985, and Kvamme, 1990). Moreover, Kıroğlu (2003) performs spatial data analyses in his thesis in order to examine the ancient pottery workshops in Datça peninsula, near Reşadiye.

Another component of research is intra-site analyses (Figure 1.1). The subtitle of the site base analyses is excavation recording, especially in 3D environment. Nearly all of the excavation recording implementations include database management. Because archaeological spatial data has a lot of textual information, which is very important for the identification of findings, data recording and management are carried out during the excavation recording process. In other words, there is no strict distinction between excavation recording and database management. Thus, examples for the excavation recording and database management are the same in the literature.

Katsianis et al. (2008) use GIS for documenting the excavation in 3D which is performed for the prehistoric site of Paliembela Kolindros, Greece. Levy and Smith (2007) utilize GIS in order to combine data which they collect during the excavation in Eldom Lowlands Archaeological Site in Jordan. Hugget (2000) records individual artifacts of Symon's Castle. Similarly, Biswell et al. (1995) document archaeological features in Shepton Mallet within GIS. Csaki et al. (1995) perform intra-site documentation and analysis in two fields in Hungary by using GIS.

The second component of the management is Cultural Resource Management (CRM). Tantillo (2007) declares that GIS is a very useful tool in cultural heritage management. Because documentation and monitoring are the key factors in CRM, GIS is appropriate with its capabilities for the preservation. Wide range of information, from macro to micro scale is collected and stored in relational database with spatial information. Moreover, this information can be monitored by GIS. Thus, it becomes a crucial tool for preserving the archaeological heritage.

There are many studies in this field which have been represented at The International Committee for Documentation of Cultural Heritage (CIPA) Symposium since 1999. The main aim for the usage of GIS is to document and to manage the data in order to preserve archaeological heritage (Ardissone and Rinaudo, 2005; Costa et al., 2005; Ientile et al.,2005; Hadjimitsis and Themistokleous, 2007; Katerina et al., 2009). Another trend is creating 3D model of ancient site and publish it via WEB in order to increase the awareness related to the site (Charkiolakis et al., 2007; Shibazaki et al., 2009; Kemeç et al., 2010).

Although site-based scale analysis is rare in the application, regional scale analyses are very common in archaeology. Management also has many implementation examples in the literature. Database management is the first and most common reason for GIS usage in archaeology. Cultural resource managers utilize database management capabilities of GIS as well.

1.2 Objective and Scope of the Thesis

Archaeology examines and interprets the cultures, social orders and political properties of ancient civilizations by using the extant materials. Since these materials are geographically located, they tend to interpret human behavior and material culture in a geographic context. However, this interpretation could not be realized properly by the lack of analysis. As mentioned above, with recent technological developments in archaeology, GIS has started to be utilized for spatial analysis. General trend in its use in archaeology is to analyze one of the problems of archaeological sites. This is insufficient since archaeologists have a lot of questions about site in order to understand the past life of humans (Eren, 2011; Ebert, 2004).

Although, GIS is seen as a crucial tool in archaeology, analytical capabilities of this system in support of archaeological analyses are insufficient. Hence, in order to answer their questions, not only the system which can perform the whole required spatial analyses but also the Spatial Decision Support System (SDSS) containing statistical modeling techniques are needed.

The main aim of this thesis is to propose a conceptual SDSS for Archaeological Excavation which can answer the spatial decision problems of archaeologist by spatial analyses and spatial statistical models. Moreover, the implementation of SDSS for an example archaeological site is aimed. In this study, Kaunos is chosen as a case study area. Firstly, spatial decision problems of archaeologists concerning Kaunos are analyzed. These questions which are listed below are site-based scale and regional scale. Secondly, specific decision analyses are performed to assist the archaeologists while making decisions about Kaunos.

1. Is there any specific type of glass finds? (Site-based scale)
2. Which type of glass finds exist in the Bath? (Site-based scale)
3. How do coins and glasses distribute with respect to time and spatial location in the site? (Site-based scale)
4. Is there any clear relationship between coins and other remains in the region? (Site-based scale)
5. Is there any clear relationship between coins and the type of land use? (Site-based scale)
6. Is the coin distribution affected by the glass distribution in the region? (Site-based scale)
7. Is there any clear difference between coin finds in terms of periods? If exist, which locations are related with the coin finds in the most significant period? (Site-based scale)
8. What are the factors that affect site selection of Kaunians?

CHAPTER 2

BACKGROUND ON SPATIAL DECISION SUPPORT SYSTEMS

2.1 Introduction

Spatial Decision Support System (SDSS) is a new field developed on the basis of Geographical Information System (GIS) and Decision Support System (DSS). In recent years, decision makers are increasingly facing complex spatial problems. In order to solve these problems, they started to use GIS. However, GIS is not enough for solving spatial problems because they do not have analytical modeling capabilities. On the other hand, Decision Support System (DSS) determines the need for a combination of database, interface and model components in order to solve a specific problem. Thus, for dealing with spatial problems, SDSS which is a combination of GIS and DSS, are developed.

Densham (1990) defines the SDSS as a complete system which eases the decision process for complex spatial problems. He also asserts that analytical models, graphical display and tabular reporting capabilities and, expert knowledge of decision makers are combined with database management systems by SDSS. Yan et al. (1999) declare that “SDSS is a new field developed on the basis of GIS and Decision Support System (DSS)” (p.1).

According to Geoffrion (1983), DSS has six characteristics which are listed in Table 2.1 and SDSS can be defined by using them (Table 2.1). However, Densham (1990) says that because of the spatial characteristics of SDSS, they have some additional capabilities like storage of spatial data, representation of complex spatial data, advanced analytical techniques and visualization of the results in a variety of spatial forms (Table 2.1).

Table 2.1 Characteristics of DSS and SDSS (Densham, 1990)

Characteristics of DSS	**Additional capabilities of SDSS**
1. DSS is designed to solve ill-structured problems. Ill-structured problems can be defined as objectives of a decision maker and the problem cannot be fully defined. 2. They have a user interface that is easy to use. 3. Such systems enable the user to combine analytical models and data in a flexible manner. 4. They help the user explore the solution space (the options available) by using the models in the system to generate a series of feasible alternatives. 5. They support a variety of decision-making styles and are easily adapted to provide new capabilities as the needs of the user evolve. 6. Such systems allow problem solving to be both interactive and recursive - a process in which decision making proceeds by multiple paths, perhaps involving different routes, rather than a single linear path.	1. SDSS provides mechanisms for the input of spatial data. 2. They allow the representation of the complex spatial relations and structures that are common in spatial data. 3. They also include analytical techniques that are unique to both spatial and geographical analysis (including statistics). 4. They provide output in a variety of spatial forms including maps and other, more specialized, types.

GIS is mainly used for capturing, storing, retrieving, analyzing and displaying the spatial data. Although GISs are not SDSS, they are main tools of SDSS. SDSS is complete mechanism which includes database management system, analytical and statistical modeling techniques and graphical interface. Database of the system integrates a variety of spatial and non-spatial data and facilitates the use of analytical and statistical modeling techniques. Besides, the graphical interface shows the results of analyses to the decision makers. These capabilities of SDSS distinguish it from GIS (Densham, 1990; Yan et al., 1999).

Sugumaran and Degroote (2011) declare that SDSS has evolved from DSS and GIS. Combined components of GIS and DSS are illustrated in Figure 2.1. A database, a model base and a user interface are three main primary components of DSS. On the other hand, GIS is composed of three major components: a database, a user interface and spatial data creation, analysis, and presentation capabilities (Sugumaran and Degroote, 2011).

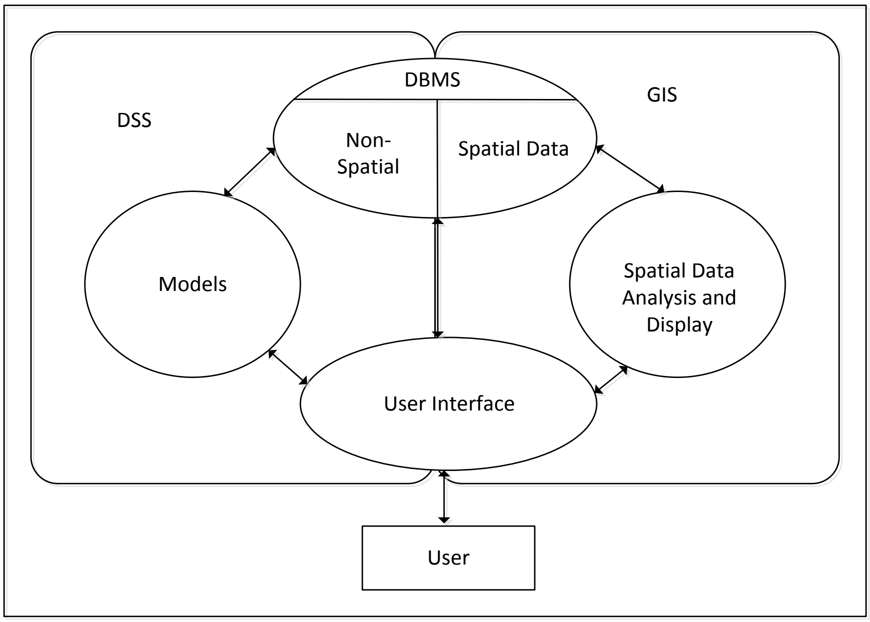


Figure 2.1 Traditional DSS and GIS components (Sugumaran and Degroote, 2011)

The database component of DSS deals with non-spatial data collection, retrieval, management and analysis. Because database component deals with non-spatial data, it does not support cartographic representation, which is essential to spatial decision making. On the other hand, spatial and non-spatial data collection, storage, management, and cartographic display functionalities are furnished by GIS. Besides, database components of both systems provide necessary information to the other components (Sugumaran and Degroote, 2011).

The model base component assists decision makers to access the variety of models easing their decision making process. Statistical, process based, mathematical, and multi-criteria evaluation are some of the examples of models. Traditional DSS is built to use various specific modeling techniques. Although GIS contains some spatial analytical functions, it does not contain any specific analytical modeling capabilities (Sugumaran and Degroote, 2011; Densham 1991).

The user interface component in both GIS and DSS ease the interaction between the user and the computer system. This component is important because interfaces which are not user friendly can negatively affect users. Thus, the usability of the system is also essential for this component in order to satisfy user needs (Sugumaran and Degroote, 2011).

As depicted in Figure 2.1, GIS lacks the necessary modeling capabilities. On the other hand, DSS does not support spatial data analysis and cartographic display functionalities. SDSS has developed in order to utilize the components of both DSS and GIS (Sugumaran and Degroote, 2011).

2.2 Components of SDSS

At the most basic level, SDSS has three main components which are database, model base, and user interface. In the literature the number and the exact description of SDSS components vary. However, Densham (1991) mentions four components: database management, model base management, graphical and tabular report generators and user interface. Besides these components, Sugumaran and Degroote (2011) add two more components which are stakeholder and knowledge management component. They, as well, grouped graphical and tabular report generators and user interface as dialog management component.

According to Densham (1991) Database Management System (DBMS) is the first and the most important component of SDSS. The DBMS must be able to store and manipulate locational, topological and thematic data types in order to support cartographic display, spatial query and analytical modeling. The examples for the spatial data are coordinates, points, lines, polygons; spatial relations between them are topological data. Finally, thematic data are significant attribute data. They are prepared with using the attributes of the data and convert raw data to meaningful data. The users can construct and exploit complex relations between all three types of data with DBMS.

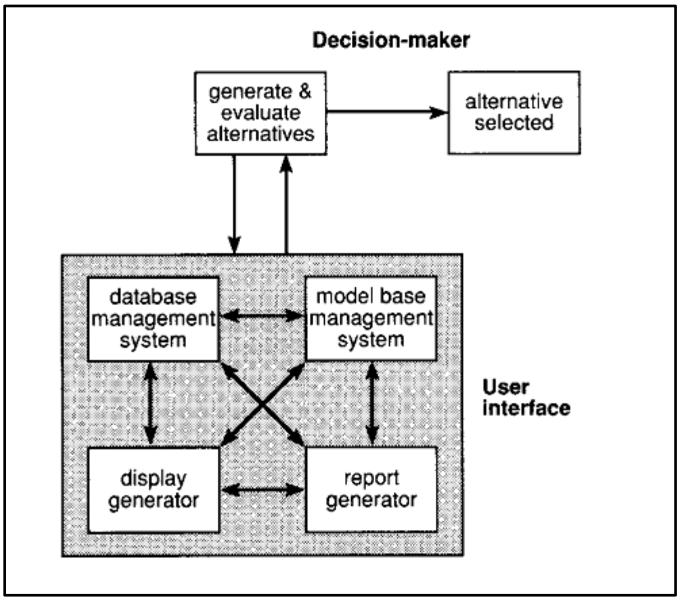


Figure 2.2 A proposed architecture of a SDSS (Densham, 1991)

The second component is model base management system (MBMS) which helps to manage, execute, and integrate different models (Chakhar and Martel, 2004). SDSS needs analytical capabilities in order to investigate the relationships of features in spatial data through various analytical methods. Although GIS has some capabilities for spatial data analyses, it does not provide spatially explicit modeling necessary for complex spatial decision making. Thus, a specific model management component is needed in order to produce new information relevant for decision-making process. In order to generate the model management component of SDSS, developers utilize many spatial modeling techniques. Mathematical models, statistical models, simulation models, prediction models, spatiotemporal models, land suitability models and dynamic models are some of them (Sugumaran and Degroote, 2011).

The third component of SDSS is dialog management which consists of user interface and graphical and tabular report generator. In SDSS, a user interface should be easy to use in order to support effective decision making. Decision makers want to receive information both in tabular and graphical forms. Graphical and tabular report generators produce specialized graphics related to the domain. Because there are two different subjects, the user interface of SDSS needs to contain two types of spaces which are objective space and map space. Objective space shows the parameters, tables and graphics related to analytical model. On the other hand, map space is a cartographic representation of a study area and the output of the model (Densham, 1991).

In Sugumaran and Degrootes' (2011) classification, the fourth component is stakeholders which are experts, developers, decision makers and analysts. In this study, experts and decision makers are explained because they play critical role in the development of SDSS. The experts have detailed knowledge about the spatial problems and they help to define spatial decision problems. Decision makers, who are directly related to experts, provide meaningful interpretation and useful information from the results of the modeling.

Last component is knowledge management and it is an optional component of SDSS. Its purpose is to help users while finding a solution to a specific problem. Moreover, it eases the selection of analytical models.

Malczewski (1997) summarizes the main components of SDSS and its functions which are explained in details as given in Table 2.2. Database management, model base management and dialog management are the key components of SDSS. Stakeholder and knowledge management component are rarely used in SDSS applications.

Table 2.2 Components of SDSS (Malczewski, 1997)

Components	**Functions**		
Database and Management	**Types of Data**	**Logical Data Views**	**Management of Internal and External Databases**
	-locational -topological -attributes	-relational DBMS -hierarchical DBMS -network DBMS -object-oriented DBMS	-acquisition -storage -retrieval -manipulation -directory -queries -integration
Model Base Management	**Analysis**	**Statistics and forecasting**	**Modeling decision makers preference**
	-goal seeking -optimization -simulation	-exploratory spatial data analysis -confirmatory spatial data analysis -geostatistics	-hierarchical structure of goals, evaluation criteria, objectives and attributes -pairwise comparison -multi attribute value/utility -consensus modeling
Dialog Management	**User Friendliness**	**Variety of Dialog Styles**	**Graphical and Tabular Display**
	-consistent, natural language comments -help and error messages -novice and expert mode	-command lines -pull-down menus -dialogue boxes -graphical user interfaces	-visualization in the decision space (high-resolution cartographic displays) -visualization in the decision outcome space (e.g. two and three-dimensional scatter plots and graphs, tabular rapports)

2.3 Technologies for Constructing SDSS

In order to build SDSS, various technologies, techniques and tools are required. There are many kinds of computer programs that can be used for the requirements of SDSS components. For spatial data collection, management, analyses and visualization, GIS programs are very useful. There is a lot of open-source and commercial GIS software (Table 2.3). Most of them have visualization capabilities like cartographic functionality, report generators and chart creation utilities process (Sugumaran and Degroote, 2011).

In order to manage large amount of spatial and nonspatial data, relational database management software is necessary in SDSS application. There are lots of commercial and open source software (Table 2.3). PostGIS (works with PostgreSQL) and ArcSDE (works with multiple relational database management systems such as Oracle and SQL Server) are two examples in order to handle the spatial data in relational databases (Sugumaran and Degroote, 2011).

For model base management component of SDSS, there exist a large number of modeling programs which can handle spatial data (Table 2.3). For example, these are Crime Stat, Fragstats and R (Sugumaran and Degroote, 2011).

As mentioned in the SDSS components, knowledge components are sometimes built in SDSS. However, there are varieties of software that provide some automated intelligence (Table 2.3) (Sugumaran and Degroote, 2011).

Table 2.3 Software for building SDSS (Sugumaran and Degroote, 2011)

Software Category	**Distribution Model**	**Name**
Spatial data collection, management, analysis, and visualization	Commercial	ArcGIS TransCAD MapInfo IDRISI GeoMedia ERDAS Imagine Manifold Smallworld
	Free	GRASS UDig SAMT ILWIS -Open SPRING Quantum GIS SAGA
Data Management System	Commercial	Spatial Query Server Oracle Spatial IBM-DB2 SQL Server 2008
	Free	PostGIS H2Spatial SpatialLite MySQL Spatial
Modeling Related Software	Commercial	S-Plus SPSS MATLAB
	Free	SME openMOdeller R FRAGSTATS
Knowledge Component	Commercial	Jess NetWeaver Criterium DecisionPlus

2.4 Overview of SDSS Applications

In the literature, SDSS is typically used for transportation design, emergency/hazard management, environmental management and land use planning. For example, Arampatzis et al. (2004) develop GIS based decision support system for the analysis and evaluation of different transport policies. For various transportation alternatives, mathematical models are required in order to perform transport network analysis and estimate the impacts of transportation on environmental and energy indicators. For these computational tasks, effective database management and frequently updated database are needed. Thus, they utilize GIS due to its capabilities of spatial data storage, updating, model accessibility and cartographic display of model result. They develop a decision support tool according to the structure illustrated in Figure 2.3.

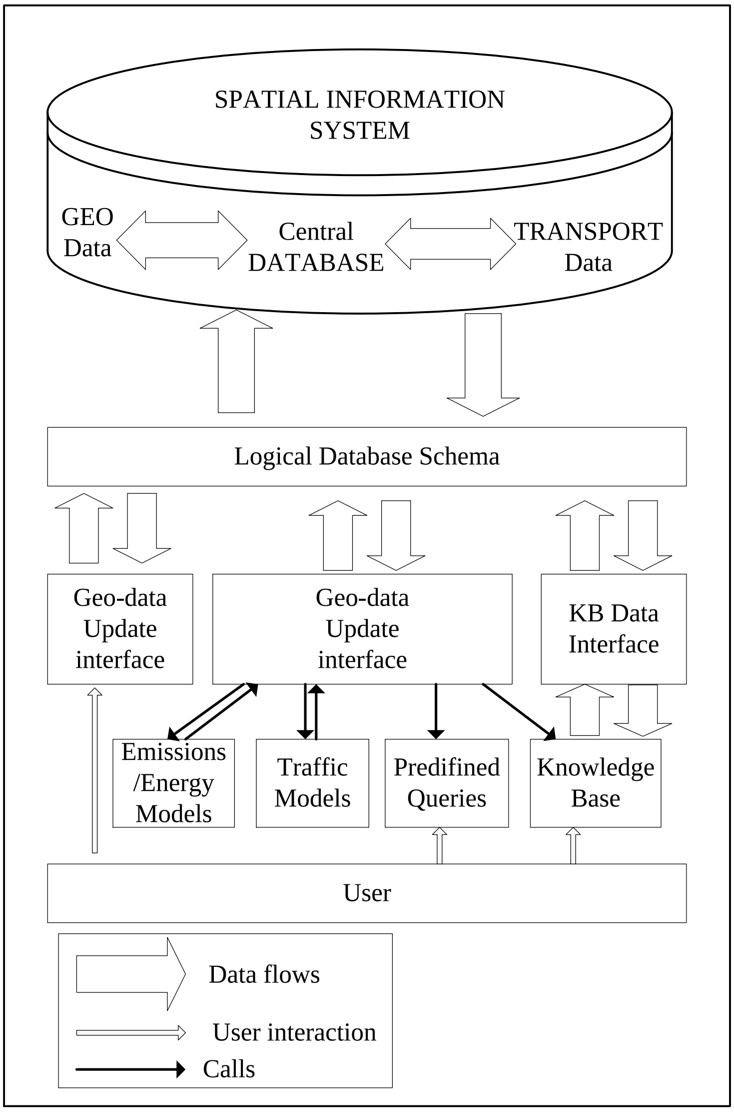
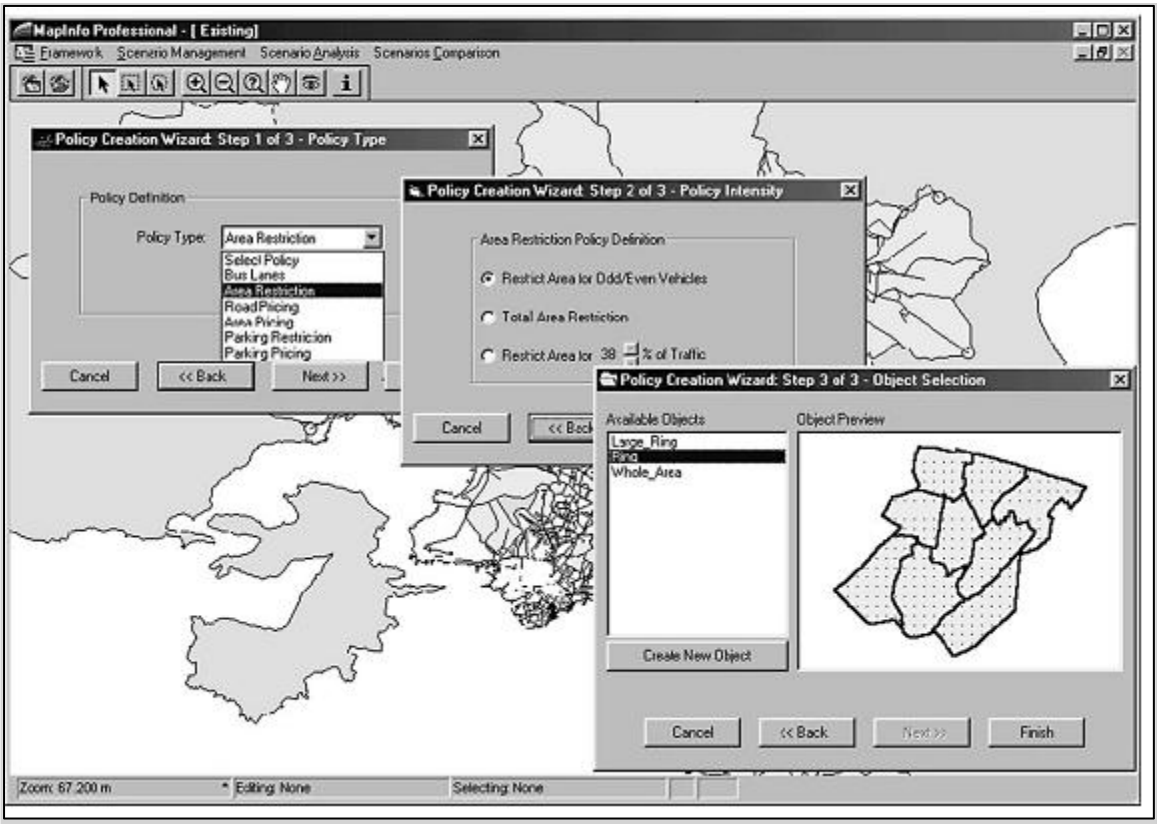


Figure 2.3 Architecture of decision support system (Arampatzis et al., 2004)

MapInfo is used for the central GIS as an intermediate storage space for each scenario parameters and also for the user interface. The tool contains three components. The first component is the database; the second one is a number of mathematical models for traffic assignment as well as for emission and energy consumption estimation and the third one is the presentation of model results through appropriate thematic maps, figures and diagrams. Finally, with this tool, which is shown in Figure 2.4, transportation managers can see different scenarios and assess different alternatives in order to enhance the efficiency of transportation supply.



Policy Type: Area Restriction

Restrict Area for 38 % of Traffic

Figure 2.4 SDSS tool to enhance the efficiency of transportation supply (Arampatzis et al., 2004)

Arentze and Timmermans (2000) develop SDSS for the retail/service planning. They call this system Location Planner which is related to both transportation planning and location decision. They develop the system within three modes. The first one is the model base which includes a different kind of models in which a wide range of problems can be analyzed. The second one is the intuitive mode which supports the impact analysis of plans or market developments. The goal-seeking, third mode, supports the model-based optimization of the spatial configuration of retail or service networks. In order to increase the user interaction, they pay attention to the user interfaces. Maps, graphs and table formats are used for the display and the views are dynamically linked. When one of the parameters is changed, related views are automatically updated. They built the architecture of the system as it is seen in Figure 2.5.

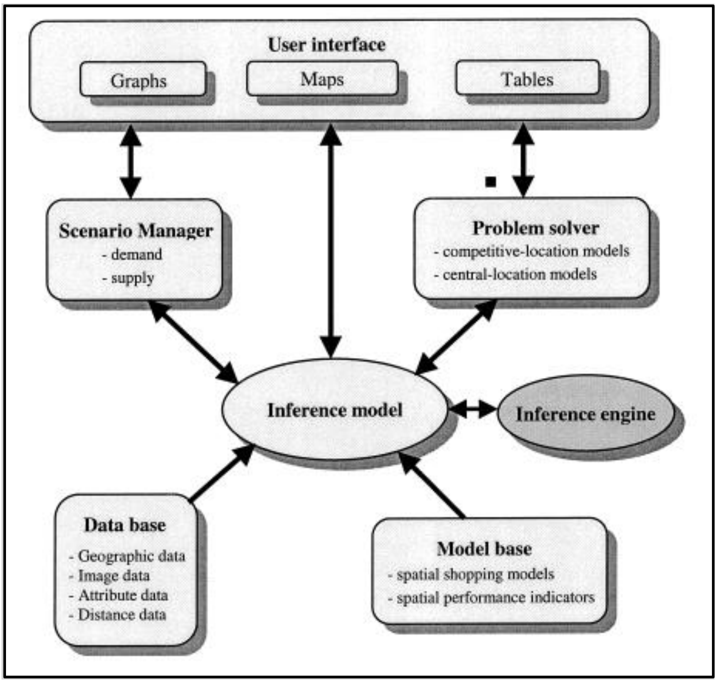


Figure 2.5 Architecture of Location Planner (Arantze and Timmermans, 2000)

As an example for SDSS application in hazard management, Hsu et al. (2011) can be given. They develop GIS based decision support system in Taiwan in order to reduce the typhoon damage. The developed SDSS consist of the basic geographical database, the real time monitoring and forecasting rainfall database, the inundation potential database, and the debris and landslide potential database. The system integrates these databases to help the emergency managers make decisions efficiently. Firstly, the system receives the real-time rainfall data and typhoon path forecasting information. Then the SDSS analyzes the tendency of rainfall and generates the rainfall distribution maps of the latest 1, 3, 6, 12 and 24 hour to display the overall rainfall situations. Secondly, the system predicts the rainfall distribution which is analyzed by the Statistical Models of the system. Thirdly, the system depicts the inundation potential areas and overlaps it with the spatial information layers (major roads, minor roads, rivers etc.). Finally, all of them are combined and visualized in GIS. Emergency managers interpret the results and evaluate the damage.

Other implementations of SDSS are in environmental management. As an example, Elbir et al. (2010) developed GIS based decision support system in order to improve the air quality in Istanbul. The urban air quality management system, which they established, consists of four parts (Figure 2.6). The first part is data collection which contains industrial source specific information. The second part is preparing the emission inventory. The third part is developing a model for predicting urban air quality. Finally, the last part is simulation. After the model is created, different scenarios can be simulated. The developed SDSS assist to determine the air quality in the study area by providing easy access to the software.

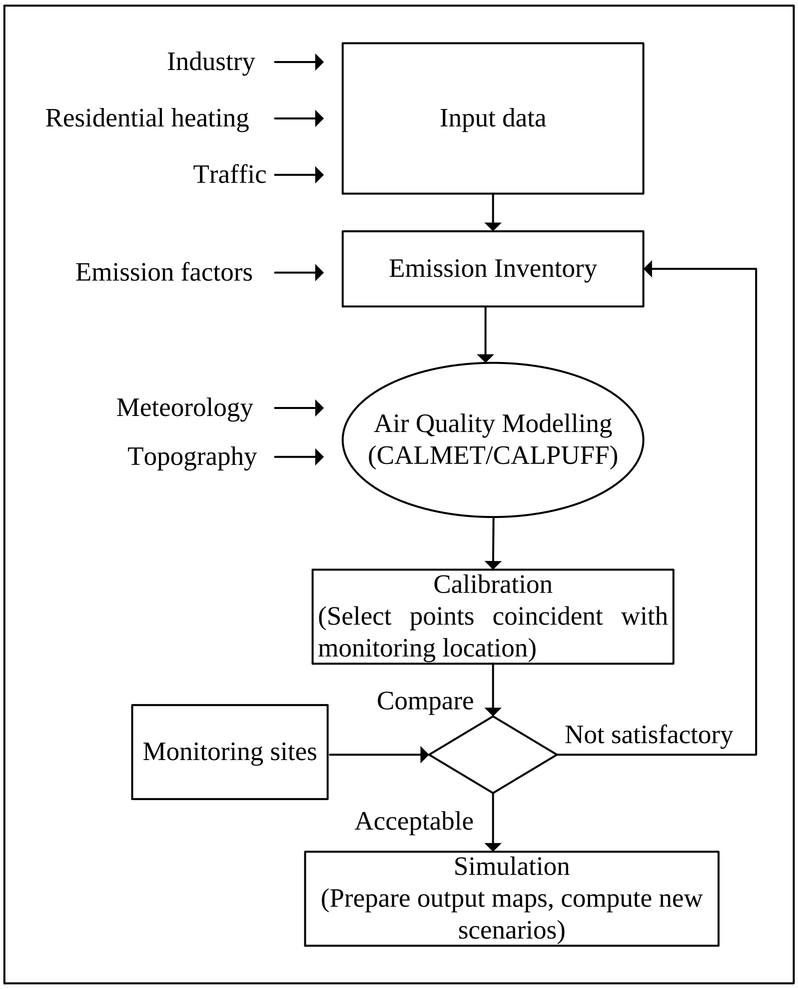


Figure 2.6 SDSS for urban air quality management system (Elbir et al., 2010)

Another example for SDSS in environmental management is the wild-land fire preservation. Guarnieri and Wybo (1995) develop SDSS which includes relational database management system, modeling capabilities, and qualitative modeling (Figure 2.7). This system manages spatial and non-spatial data. Data is stored in GIS and used in modeling programs.

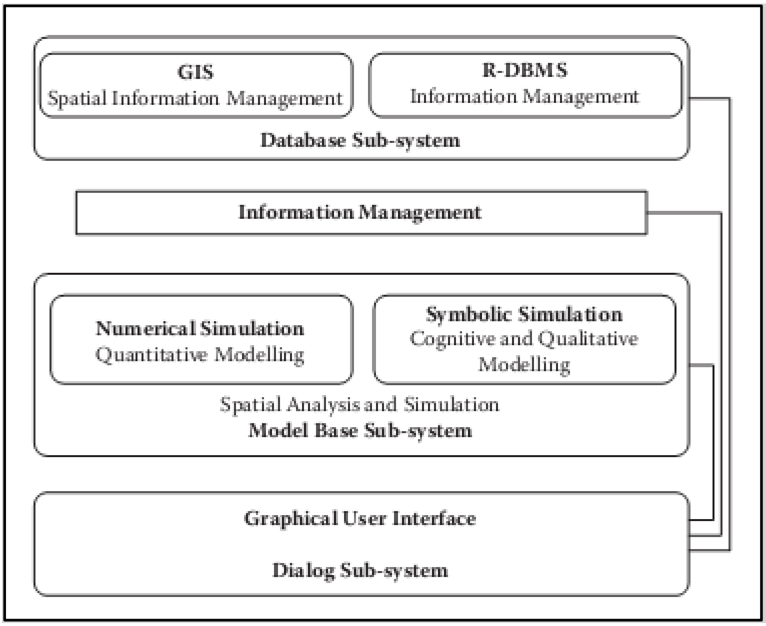


Figure 2.7 Architecture of a wild-land fire SDSS (Guarnieri and Wybo, 1995)

Hey (1998) develop an SDSS, called SSToolbox for the agricultural application. In this system, the main aim is to turn raw site-specific data into agricultural management information. By this way, users can be assisted in terms of making better production decisions. For this aim, he asserts that management, data collection and analysis of the spatial and non-spatial data are important for the SDSS process. In this system, once the data is collected and entered into the system, the user can get the answer to the following questions. *"Exactly where the most variable parts of the fields are located? The user can also set up equations for automatic calculation of fertilizer/chemical applications in the field to remedy any deficiencies found. He/she can quantify the benefits of a particular management decision, such as choice of one seed variety versus another (Hey, 1998:6)."* By this way, users can turn the data into meaningful information so they can make better decisions.

SDSS has not been developed for archaeology, yet. Archaeology studies human cultures in terms of spatial context in order to interpret human behavior in a geographical context. For achieving their aim, archaeologists work with vast bodies of spatial information. GIS is a perfect tool for the storage, management, retrieval and display of this spatial information but it lacks some advanced analytical techniques.

Archaeologists try to produce meaningful information concerning human cultures by examining findings which emerged through the excavations. For instance, they try to find out that findings are belongs to which historical period, in which period this historical site or a place in the site was widely used, why this place is used a lot, why these kind of finds are collected from this place, why this historical site is located here and so on. In fact, they have some hypotheses about these questions. In order to test these hypotheses and to better interpret the results, modeling is required. Besides, the results of these models should be viewed by archaeologists for the meaningful information to be produced. Due to the necessities of all of these techniques in archaeology, SDSS should be developed to support archaeological efforts.

CHAPTER 3

METHODOLOGY AND CONCEPTUAL SDSS DEVELOPMENT FOR ARCHAEOLOGICAL EXCAVATION

3.1 Methodology

In order to develop an SDSS for Archaeological Excavation Site, first of all, needs assessment is performed for determining and addressing the needs of archaeologists. Secondly, based on these needs, decision analyses are defined and SDSS is designed.

Needs Assessment:

Spatial decision problems of archaeologists, concerning the site are analyzed and requirements of archaeologists can be listed as follows:

Needs 1:

Archaeologists want to be stored vast amount of excavation data and archaeological environmental data in spatial context. Excavation data can be the ceramics, bones, coins, sherds, potteries, glasses and tablets. Since spatial location of these findings in the site is important, besides other attribute information, they collect the coordinates of artifact locations during the excavation. Hence, they wish to store excavation data with its detailed attribute information and exact location. Moreover, in order to interpret the archaeological site in its context, they would like to store environmental data like hydrography, soil type, vegetation, geology and topographical information, etc.

Need 2:

Archaeologists, based on the collected data, want to define socio-cultural, economic and demographic characteristics of the site. Hence, they have the spatial decision problems about site characteristics and environmental characteristics (Table 3.1). They wish to answer these questions (Q1,Q2…Q5) with related analysis.

Table 3.1 Spatial decision problems of archaeologists about site with respect to scale

Scale	Questions
Site-based scale questions	**Q1**. How artifacts are distributed with respect to time and spatial location? **Q2**. What is the density distribution of any type of artifact in the site? **Q3**. What are the functions of the buildings? **Q4**. Whether type of artifacts related with the prosperity of site **Q5**. Which factors affect the distribution of artifacts in the site?
Regional scale questions	**Q1**. Is there any relationship between the location of sites and any environmental parameters such as slope, aspect, elevation, distance to water (Kvamme, 1990)? **Q2**. What is the reason of position of monuments if the site has them (Maschner, 1996)? **Q3**. Did villages move to more defensible location considering the two successive periods such as Early to Late Imperial Period (Maschner, 1996)? **Q4**. From which areas did inhabitants of site derive their resources (Tiffany and Abbott, 1982)?

Need 3:

Archaeologists would like to see the results on the maps or with the graphs for interpreting the results. Besides, they state that these illustrated results are a tool from which they can produce meaningful information about characteristics of the site.

After defining the needs of archaeologists, decision analyses and the tools which can meet these demands are determined. These are listed in Table 3.2.

Table 3.2 Tools and decision analysis that meet the needs

Needs of archaeologists			Tools and analysis that meet the needs
Need 1			This requirement of archaeologists can be met with the *GIS software* since it enables to store, edit, retrieve and analyze the spatial data. Besides, *relational database management systems* and related software can be utilized to handle large amount of spatial and non-spatial data.
Need 2	**Site-based scale questions**	**Q1**	First two questions can be answered with the *spatial queries*. In the first question, results should be mapped according to periods.
		Q2	
		Q3	*Point pattern data analysis* and *modeling spatial point pattern* (testing related hypothesis) help to answer this question.
		Q4	In order to analyze these questions, hypothesis testing should be conducted. Methods of *modeling area data* can be utilized to test hypothesis.
		Q5	
	Regional scale questions	**Q1**	This question can be *tested with specific hypothesis* about environmental pattern.
		Q2,Q3	Performing *viewshed analysis* helps to analyze these questions.
		Q4	*Catchment analyses* are performed to meet this kind of questions.
Need 3			In order to visualize the results of analyses, *cartographic display capabilities of GIS* can be used. In addition to the capabilities of GIS software, effective tables and charts can be utilized.

3.1.1 Design of SDSS for Archaeological Excavation Based on Needs

According to the requirements of archaeologist, concerning the defined tools and decision analysis to meet these needs, SDSS for archaeological excavation of the site is proposed (Figure 3.1). It is composed of four main components; Database Management Component, Model Management Component, Dialog Management Component and Stakeholder Component.

The Database Management Component stores both spatial and non-spatial information about archaeological site. According to archaeologist, the main problem is to store and manage vast amount of spatial data. In this component, GIS is utilized for the storage of spatial information. Besides, for the storage of large amount of excavation data, Relational Database Management software is included into the system.

Under the Model Management Component, which is based on Database Management Component, archaeological spatial analyses and spatial data analysis are held. Viewshed analysis, catchment analysis and predictive modeling are the archaeological spatial analysis and these are utilized for analyzing the environmental characteristics of the site. Besides, Model Management Component manages a set of spatial models which interact with the spatial database. Thus, spatial decision problems of archaeologist about archaeological sites are analyzed with spatial analyses and spatial data analyses as well as testing related hypothesis in Model Management Component

The third component is Dialog Management Component that provides user interaction to the system. Cartographic and tabular display capabilities of GIS are commonly utilized in order to provide results to the archaeologists. In addition to the capabilities of GIS, to produce effective reports, tables and charts are utilized.

The last component of archaeological SDSS is stakeholder component. As stated in the previous chapter, categories of stakeholder are decision makers (end user), the analysts, the developers (builders) and the experts. For archaeological SDSS, end users and the experts are archaeologists. They are expert since they have detailed knowledge about the archaeological site. Hence, they address the spatial decision problems of the site. Moreover, according to their feedback, Model Management Component can be improved. On the other hand, they are decision makers as they provide meaningful information about the past life of humans according to the results of spatial analysis and models.

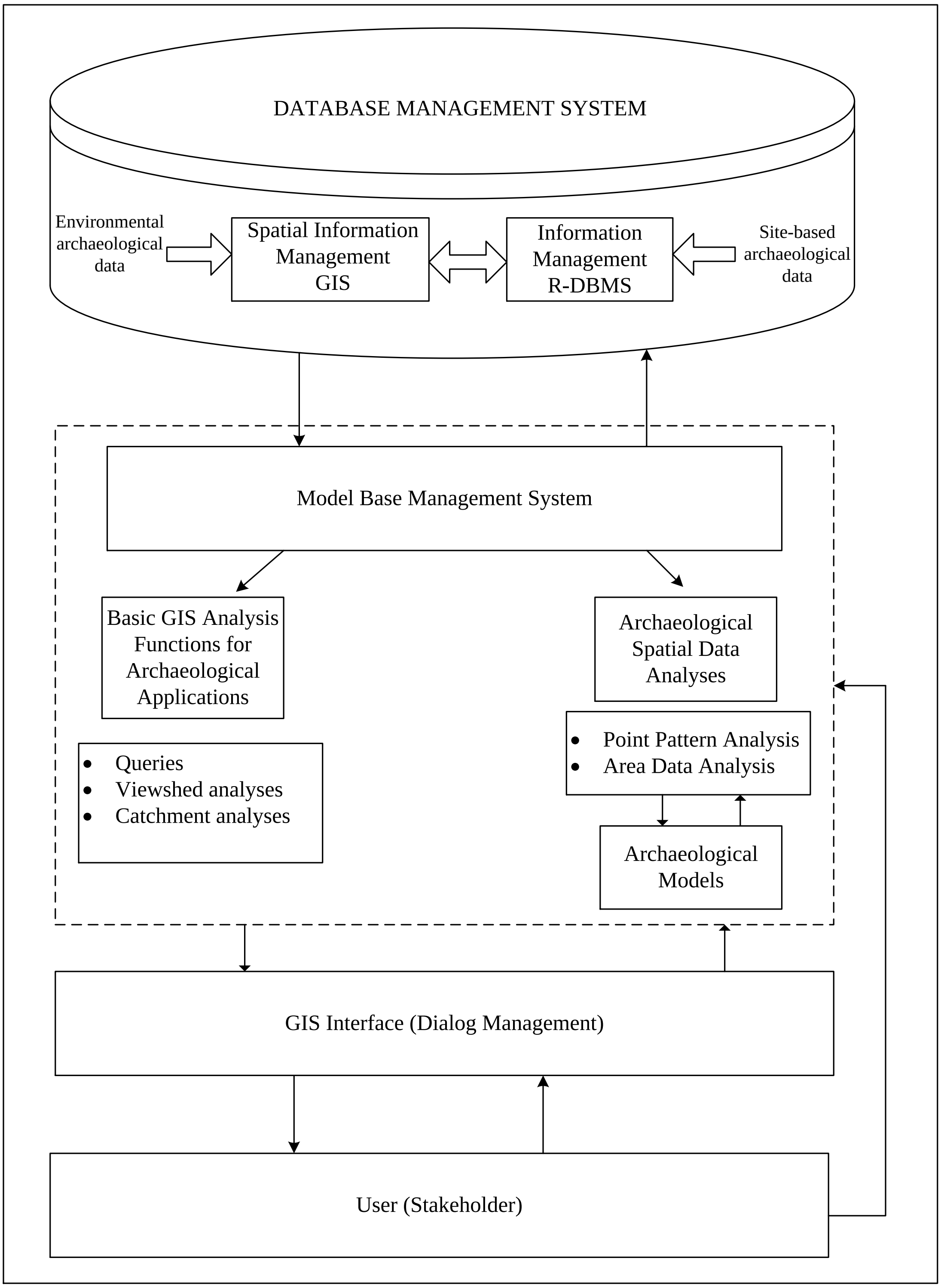


Figure 3.1 Architecture of an archaeological SDSS

3.2 The Database Management Component

It has been emphasized before those archaeology needs of storage and retrieval of multiple data types related to spatial location. Archaeological data consist of regional and site-based context. Generally, environmental data such as elevation, slope, hydrology, soil are regional scale data. This can be contrasted to the data which are collected inside the site; for example, bones, coins, ceramics, stones, buildings have site-based scale. GIS is utilized to manage these large data sets because it can store data ranging from small scale to large scale in its database. Besides, the DBMS component of SDSS can store and manipulate spatial and topological data.

A wide variety of the characteristics of vector feature can be recorded in the attribute tables of GIS. For example, elevation contains height; soil contains type, area and so on. In contrast to environmental data set, site-based data has large amount of non-spatial information. For instance, a coin has its found date, minted name, description, found location and inventory number.

The documentation and the management of archaeological data are essential for the modeling component of SDSS. Thus, besides database of GIS, other database management systems should be used especially for detailed site-based data. These DBMSs, listed before in Table 2.4 are Spatial Query Server, Oracle Spatial, IBM-DB2, SQL Server 2008, PostGIS, H2Spatial, Spatialite, and MySQL Spatial. Comprehensive attributes of site-based data can be stored using one of them by concerning the steps of database design.

According to Ramakrishnan and Gehrke (2003) requirement analysis, conceptual database design and logical database are the steps for a database design. Requirement analysis is the first step of designing a database. For this purpose, what users expect from the database and what they want to store should be clarified. (Ramakrishnan and Gehrke, 2003)

According to the information gathered in the first step, the high level description of data is developed in the second step. Entity-Relationship (ER) Diagram is one of the high level data models employed in the database design (Ramakrishnan and Gehrke, 2003). It is a specialized graphical method that illustrates the relationships among entities in a data model. ER diagram uses symbols (Figure 3.2) which are boxes, diamonds and ovals. Boxes are commonly used to represent entities. Diamonds are normally used to represent relationships and ovals are used to represent attributes (Chapple, 2012).

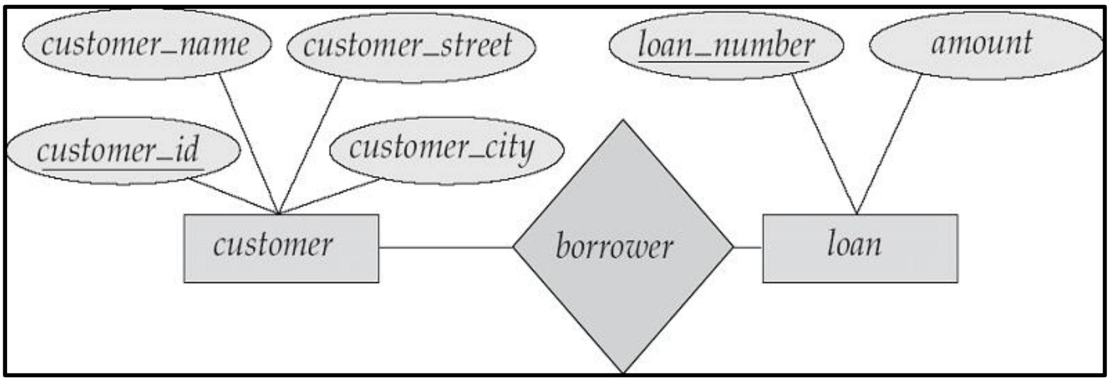
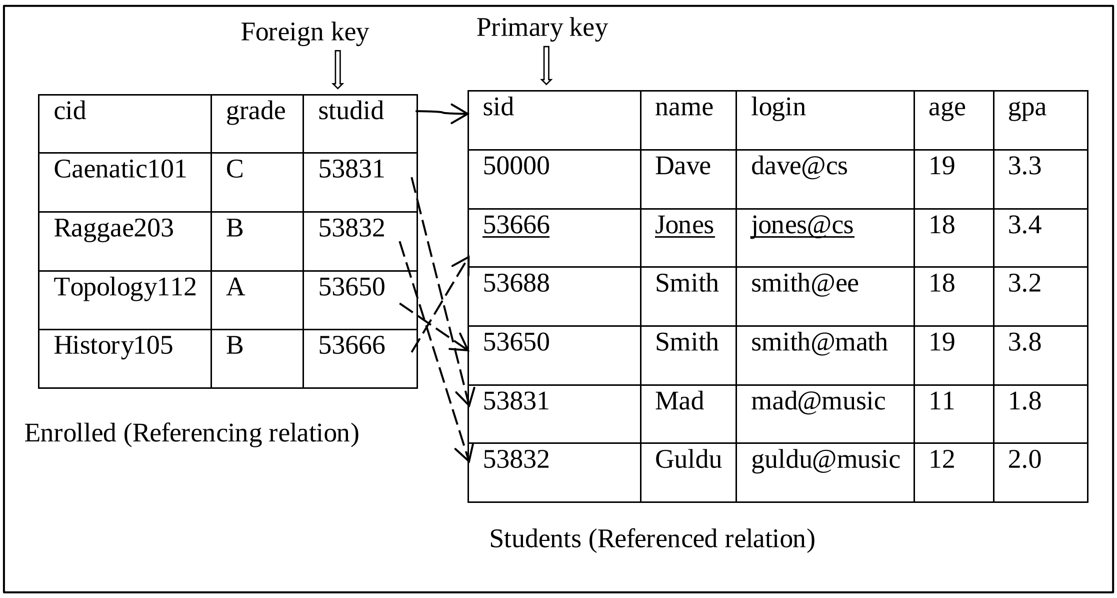


Figure 3.2 An ER Diagram (Introduction to Database Management System Lecture

Moreover, the key constraints specifying how many instances of an entity relate to an instance of another entity are defined on the diagram. It can be one to one, one to many, many to one and many to many relations. These types of relations are explained according to Figure 3.2. In one to one relationship, a customer is associated with at most one loan via a relationship with the borrower and the loan is associated with at most one customer via the borrower. In one to many relationships, a loan is associated with at most one customer via a borrower. However, the customer is associated with several (including 0) loans via the borrower. In many to one relationship, a loan is associated with several (including 0) customers via a borrower though; a customer is associated with at most one loan via the borrower. Finally, in many to many relationship, a customer is associated with several (possibly 0) loans via a borrower and a loan is associated with several (possibly 0) customers via the borrower. The final step of database design is logical database design. In this step, a conceptual database Entity-Relationship (ER) schema is converted into a relational database model (Ramakrishnan and Gehrke, 2003).

A relational database is a set of tables which are called ‘’relations’’. Rows and columns constitute the relations. They are connected to each other by a common key attribute. A key is a unique identifier of a row. Figure 3.3 shows the relational tables of students and the enrolled. Besides, the key columns of relations are illustrated.



cid	grade	studid
Caenatic101	C	53831
Raggae203	B	53832
Topology112	A	53650
History105	B	53666

sid	name	login	age	gpa
50000	Dave	dave@cs	19	3.3
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith@math	19	3.8
53831	Mad	mad@music	11	1.8
53832	Guldu	guldu@music	12	2.0

Figure 3.3 Relational tables of students and enrolled (Ramakrishnan and Gehrke, 2003)

Relational data model is effective in application of SDSS. The major advantages are simple data representation and simplifying the complex queries. The capability of storage of large amount of data supports analyses and eases the analytical modeling. Moreover, it supports the cartographic display and GIS analyses. Briefly, it is an appropriate data model for SDSS.

3.3 The Model Management Component

As it was mentioned before, modeling becomes essential for archaeology. Using comprehensive database of archaeology, Model Management Component of SDSS can be established. Spatial models provide analytical capabilities for SDSS. Locations, attributes and relationship of features in spatial data through various overlays and analytical methods can be examined with spatial models (Sugumaran and Degroote, 2011). GIS provides some analyses and functions but lacks in advanced analytical capabilities. In archaeology, besides the basic GIS analyses, modeling is required. In order to analyze the site and its parts and manage the excavations, the development of a specific model management is needed. Model Management Component can be put into two categories for archaeological applications namely; Basic GIS Analyses Function and Spatial Data Analyses (Figure 3.1).

3.3.1 Basic GIS Analyses Function

Both spatial and non-spatial queries, viewshed analysis and catchment analyses are basic GIS analysis functions for archaeological applications. Although there are not hypothesis testing and modeling processes, these analyses are used for analyzing the site and characteristics of past human culture. For example, viewshed analyses are used for understanding the location choices or analyzing the distribution of archaeological sites. Meanwhile, catchment analysis helps to understand how many lands was used.

3.3.2 Spatial Data Analyses

Spatial data analyses are used when data are spatially located and locations of the features become important in the analysis or interpretation of results (Bailey and Gatrell, 1995). As emphasized before, archaeological data are spatial; therefore, spatial data analyses are used for explanations of spatial arrangement of cultural remains. Using these techniques helps to identify and describe spatial patterns. However, these explanations do not imply that graphical representation is not needed. On the contrary, they are basic elements of models and analysis. In brief, spatial data analysis represents much more detailed information to archaeology (Wheatley and Gillings, 2002).

Spatial data analyses in archaeology can be carried out for point data and area data. Points can be used to represent archaeological sites at regional scale or location of archaeological finds for local scales. These points are visualized as a distribution map and they may represent patterns. However, analyzing patterns with human eye can cause errors. Thus, in order to make a well assertion, point pattern analyses should be performed. The following questions can be investigated with this analysis: Does this set of point locations exhibit any spatial pattern? What form does this pattern take? Are their locations related to each other (Wheatley and Gillings, 2002)?

The second type of data in archaeology is area data. In this type, the site is composed of aerial units with attributes such as ceramics, coins, and glasses and so on. If original locations of findings are not known, data of the finding can be recorded as area data. Maps and visual representations of this kind of data are made easily by using GIS. However, establishing relationship between areal units and their attributes require area data analysis (Wheatley and Gillings, 2002; Bailey and Gatrell, 1995). It is used to test hypotheses for following questions: Is there any relationship between findings and their found location, do these finds have pattern when their associated areas are considered?

3.3.2.1 General Concepts in Spatial Data Analysis

Spatial data analysis concern with the interpretation of data involves accurate description of data which is spatially located. Exploration of patterns and relationships in the data are performed with spatial data analysis. Spatial Data Analysis has 3 steps; visualization, exploration and modeling (Bailey and Gatrell, 1995).

In the visualization process, the data are mapped. Graphical displays of data are appropriate tools for visualization. Exploring spatial patterns and relationships can be done with maps which are created by using GIS (Bailey and Gatrell, 1995).

Exploration is conducted in order to define data in a better way. Thus, it helps to develop hypotheses and appropriate models for the data. As one step further from visualization process, it slightly manipulates the spatial data (Bailey and Gatrell, 1995).

The final step is modeling. Models are the mathematical abstraction of the reality. At this stage, hypotheses, based on visualization and exploration, are tested (Bailey and Gatrell, 1995).

The concept of first order and second order effects of a spatial distribution is also important issue for spatial data analysis. In most of the spatial analyses, the result is affected by one of them. First order effect related to variation in the mean value of the observation. Hence, first order effects reflect the global trend. Second order effect result from the spatial correlation structure or the spatial dependence in the process. Second order effect reflects the local trends in the dataset (Bailey and Gatrell, 1995; Kıroğlu, 2003).

3.3.2.2 Analysis of Point Pattern

Visualization of point pattern analysis is performed by using a dot map. Exploration of spatial point pattern is divided into two categories. The first one is investigating the first order effect. Quadrat and

Kernel estimation is used for analyzing the first order effects. The second one is investigating the second order effects and Nearest Neighbor Distances, and the K Function are used.

In order to test a hypothesis or construct specific models to explain the observed patterns, complete spatial randomness (CSR) is used as a reference pattern. CSR comes from Poisson Process and it says that one event does not depend on others. If CSR is rejected it is obvious that there is a pattern in point data. Thus, CSR is tested for both Quadrat estimation and Nearest Neighbor analyses. According to the result of models, random, clustered or regular pattern in point data is identified (Bailey and Gatrell, 1995).

3.3.2.3 Analysis of Area Data

There are three methods for visualizing area data: proportional symbols, choropleth maps and cartograms. Proportional symbols are superimposed over the areal units. Symbols are proportional to the attribute value of the area. Choropleth maps are obtained by coloring each of the area according to the value of the attribute. Finally, cartograms transform the size of area according to its corresponding attribute value (Figure 3.4) (Bailey and Gatrell, 1995).

The exploration of the area data consists of analyzing the first and second order effects as in point data. The main aim is to determine the proximity measures of the observations related to irregularly shaped areas for area data. A generally used aspect for constituting the proximity measure is the use of (nxn) spatial proximity matrix; W. There are many methods to construct Wij and some of them are depicted below (Bailey and Gatrell, 1995):

$$W_{ij} = \begin{cases} 1 & centroid\ of\ A_j\ is\ one\ of\ k\ nearest\ centroids\ to\ that\ of\ A_i \\ 0 & otherwise \end{cases}$$

$$W_{ij} = \begin{cases} 1 & centroid\ of\ A_j\ is\ within\ distanced\ of\ centroids\ of\ A_i \\ 0 & otherwise \end{cases}$$

$$W_{ij} = \begin{cases} 1 & A_j\ shares\ a\ boundry\ with\ A_i \\ 0 & otherwise \end{cases}$$

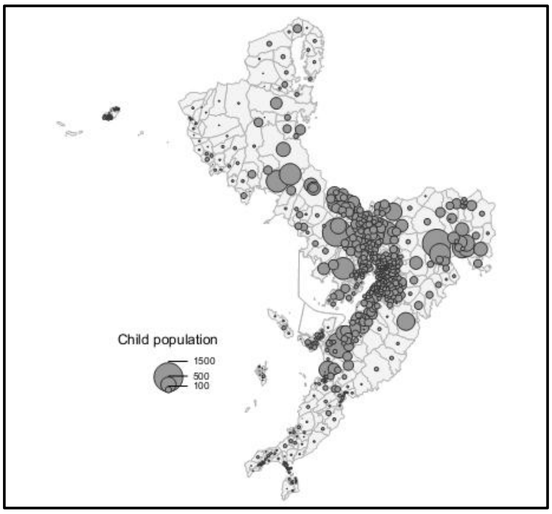
$$W_{ij} = \begin{cases} d_{ij}^{\gamma} & intercentroid\ distance\ d_{ij} < \delta \\ 0 & otherwise \end{cases}$$

After producing spatial proximity matrix, the explorations of first order and second order effects are performed. Spatial Moving Average, Median Polish and Kernel Estimation are the methods for exploring the first order effects. Spatial correlation and correlogram concern with the exploration of second order properties.

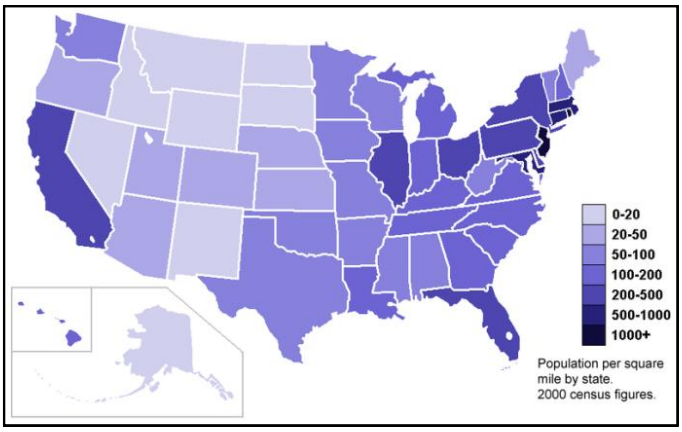
Spatial Moving Average is used for the exploration of attributes' mean values (mean value exploration of the attribute varying across the study region.) Global variation is estimated by predicting the mean value by an average of values in the neighboring areas. Spatial proximity matrix gives weights for neighboring areas. Mean value estimate is given in equation (3.1):

$$\mu_i = \frac{\sum_{j=1}^{n} w_{ij}\, y_j}{\sum_{j=1}^{n} w_{ij}} \tag{3.1}$$

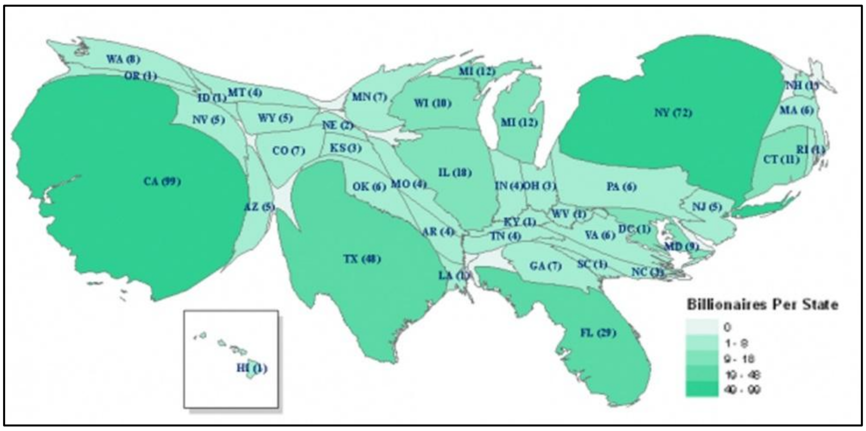
where μ_i is the mean value of the attribute of interest and y_j is the attribute value of the areal units.



(a) (Tanimura et al., 2006)



(b) (Rose, 2009)



(c) (Dempsey, 2012)

Figure 3.4 Proportional symbol (a), choropleth map (b) and cartogram (c)

The second method of exploring the first order effect is Median Polish. It is used to understand global trends in regular grid patterns (Bailey and Gatrell, 1995).

The final method for the first order effect is Kernel Estimation. The Kernel Estimation is mostly used for avoiding the geometry of zones in the study area. Thus, it assumes that each observation zone is associated with an appropriate point location. This point can be the centroid of the study zones or major center of population in that area. According to the results of Kernel Estimation, the visual indication of variation in the intensity over the region can be understood (Bailey and Gatrell, 1995).

The first order effects look for the global variation of data over the study region. However, the second order effects analyze the local variation of area data. Thus, spatial correlation and correlogram explore the spatial dependence of deviations in attribute values from their mean. The measures of spatial autocorrelation are Moran's I and Geary's C. Moran's I is one of the commonly used methods for exploring the spatial autocorrelation. It uses the proximity matrix W and results of Moran's I ranges from -1 to 1. An uncorrelated process has an expected I approximately equal to "0". Negative values of I indicate negative autocorrelation. Positive values indicate positive autocorrelation. Moran's I is given in equation (3.2) (Bailey and Gatrell, 1995):

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(y_i-\bar{y})(y_j-\bar{y})}{[\sum_{i=1}^{n}(y_i-\bar{y})^2][\sum\sum_{i\neq j} w_{ij}]} \quad (3.2)$$

where I is the Moran's I value; n is the number of observation; $y_{i/j}$ is the value at location i and j; $\bar{y}$ is the mean value of attributes and w_{ij} is the spatial proximity matrix.

The second method for exploring the second order effect is correlogram. It is related to spatial autocorrelation which is constructed by calculating spatial autocorrelation at different spatial lags and plotting the correlation values against the lag distances. In case of Moran's I, spatial correlation at lag k is given in the equation (3.3):

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}{}^{(k)}(y_i-\bar{y})(y_j-\bar{y})}{[\sum_{i=1}^{n}(y_i-\bar{y})^2][\sum\sum_{i\neq j} w_{ij}{}^{(k)}]} \quad (3.3)$$

where $W_{ij}^{(k)}$ are the elements of the (nxn) spatial proximity matrix at spatial lag k, W $^{(k)}$. Results show that where the lags of correlogram are larger, the values are highly correlated to each other (Bailey and Gatrell, 1995).

Modeling can be performed with both non-spatial regression and spatial regression models. Non-spatial regression models are linear regressions and can be written as the following equation (3.4):

$$y= b_0+ b_1x_1+\varepsilon \quad (3.4)$$

where y is the dependent variable; x_1 is the independent variable; b_0 and b_1, are the parameters to be estimated, and ε is a random error term, assumed to be normally distributed (Bailey and Gatrell, 1995).

On the contrary, spatial regression models take into account the autocorrelation structure. There are three spatial regression models which are simultaneous spatial regression (SAR), conditional spatial regression (CSR), and moving average (MR). The SAR model is explained since it is used in the developed SDSS (Bailey and Gatrell, 1995).

SAR is used to take weight matrix for spatial autoregression model estimation by Maximum Likelihood, using full matrix methods. SAR assumes that the response at each location i is a function not only of the explanatory variable at i but also of the values of the response at neighboring locations j.

Equation of SAR model is given in the equations of (3.5):

$$Y = X\beta + \rho Wy + \varepsilon$$

$$Y = X\beta + \rho W\ (Y - X\beta) + \varepsilon$$

$$Y = X\beta + \rho WY - \rho WX\beta + \varepsilon \qquad (3.5)$$

$X\beta$ indicates a general trend. $\rho WX\beta$ indicates a neighboring trend.

There is also a local spatial analysis technique which is called as Geographically Weighted Regression (GWR). It is based on the “First Law of Geography”; everything is related to everything else, but closer things are more related. Thus, GWR analyzes spatial variations in relationships and produces different regression coefficient for each area (Yu and Wei, 2004).The output from GWR is a set of statistics that can be mapped and tested, depicting the spatial variation of a relationship. From the results of GWR, local R-square, local estimated regression coefficients, and local t-statistics maps can be produced. (Shoff et al., 2010).

GWR develops the conventionalregression equation. If global regression model is considered, it is written as the given equation (3.6) (Fotheringham et al.,2002):

$$y_i = \beta_0 + \sum\nolimits_k \beta_k x_{ik} + \varepsilon_i \qquad (3.6)$$

where y_i is set of independent variables; $\beta_0$and β_k (k=1,2…,n) are the parameters to be estimated; x_{ik} is the value at the location i and ε_i is a random error term at the location i. GWR rearranges this equation and use local parameters rather than global ones.(GWR uses this traditional equation by allowing local rather than global parameters which are estimated.) Hence, the model can be rewritten as in Equation 3.7.

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{k} x_{ij}\beta_j(u_i, v_i) + \varepsilon_i \qquad (3.7)$$

where x_{ij} is set of observation for i=1,….,n cases and j=1,…,k explanatory variables; y_i is set of independent variables; (u_i, v_i) denotes the location of coordinates and ε_i is random error term (Fotheringham et al.,2002).

3.4 The Dialog Management Component

A key to any successful archaeological SDSS is the development of dialog management component. The outputs of model management component are yielded to the users with this tool. Results can be illustrated with graphs, tables and cartographic displays. The capabilities of GIS software can handle these illustration needs; and the visualization of results is effective with it. Maps are the most useful visualization tools for archaeologists since the advanced spatial statistics results can be easily inferred from them. However, sometimes more specialized graphics and tables may be necessary for the sophisticated spatial statistics in spatial data analysis. Thus, specialized software to build complex graphs can be used along with GIS.

In archaeological SDSS, the development of a user interface can also be beneficial. By this way, users can interactively use the system. SDSS, supporting such capabilities, provides the user with a problem solving environment. However, the system needs expert knowledge about Graphical User Interface (GUI) tools and programming capabilities, so it is beyond the scope of this study.

3.5 The Stakeholder Component

The most frequent users of archaeological SDSS are archaeologists. They are both experts and decision makers. They have detailed information about the archaeological sites and they are capable of producing meaningful information from the output map. Likewise, the hypotheses of the archaeologists can be tested so that the archaeologists can use exact information while analyzing the ancient cultures that lived in the area or any other useful aspects about excavations. Moreover, they find out which parameters should be considered in the models. By the help of their feedback about the existing models, the Model Management Component improves. Thus, archaeological excavations can be evaluated in a systematic way by means of SDSS, and the decision making process for the archaeologists becomes easier.

CHAPTER 4

CASE STUDY

4.1 Case Study

As a case study area, Kaunos archaeological site is chosen for the implementation of the proposed SDSS. Kaunos is situated on the western coast of the Dalyan (Calbis) River, which connects Lake Köyceğiz to the Mediterranean Sea. In the present day it lies within the boundaries of Çandır Village which is opposite to the town of Dalyan (Figure 4.1) (Öğün et al., 2002).

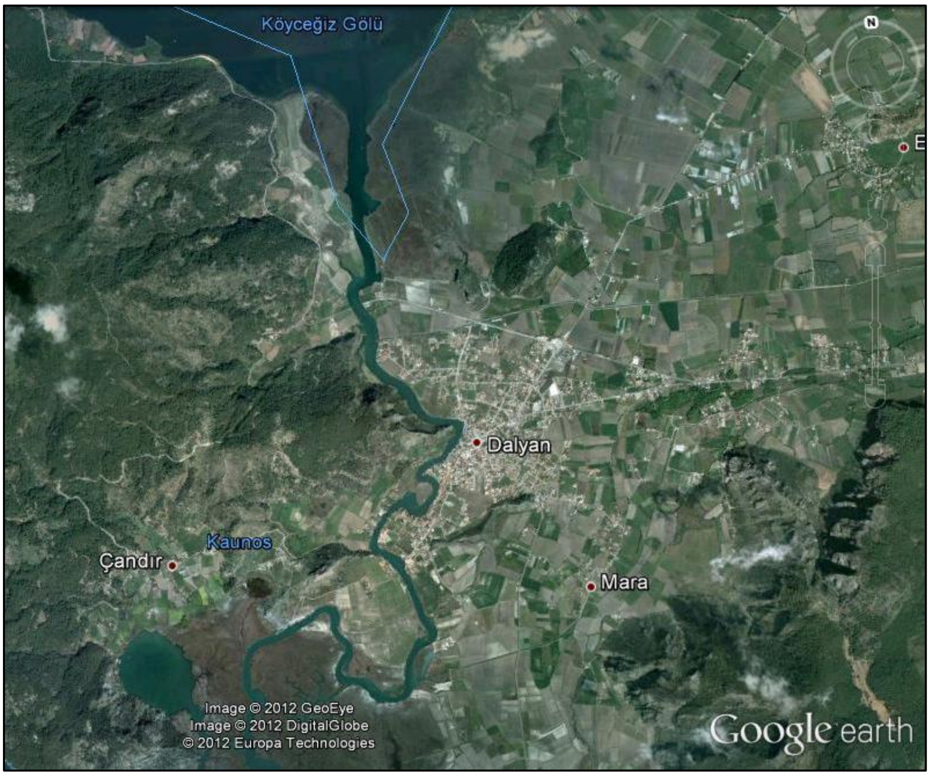


Figure 4.1 Location of Kaunos

The history of Kaunos dates back to 10th century B.C. The first archaeological excavation of the site was undertaken by the leadership of Baki Öğün in 1966. The excavations have been continuing since the year of 2000 (General Directorate of Cultural Heritage and Museums).

The city has two harbours from the Archaic Period until the middle of the Hellenistic Period. One of these harbours is on the southeast, called the Southern Harbour; the other is called the Inner Harbour (currently Suluklu Lake) (Figure 4.2). The Southern Harbour was in use from the foundation of the city and it could not be used mostly due to silting towards the end of the Hellenistic Period. Inner harbour was used till the late days of Kaunos (Öğün et al., 2002).

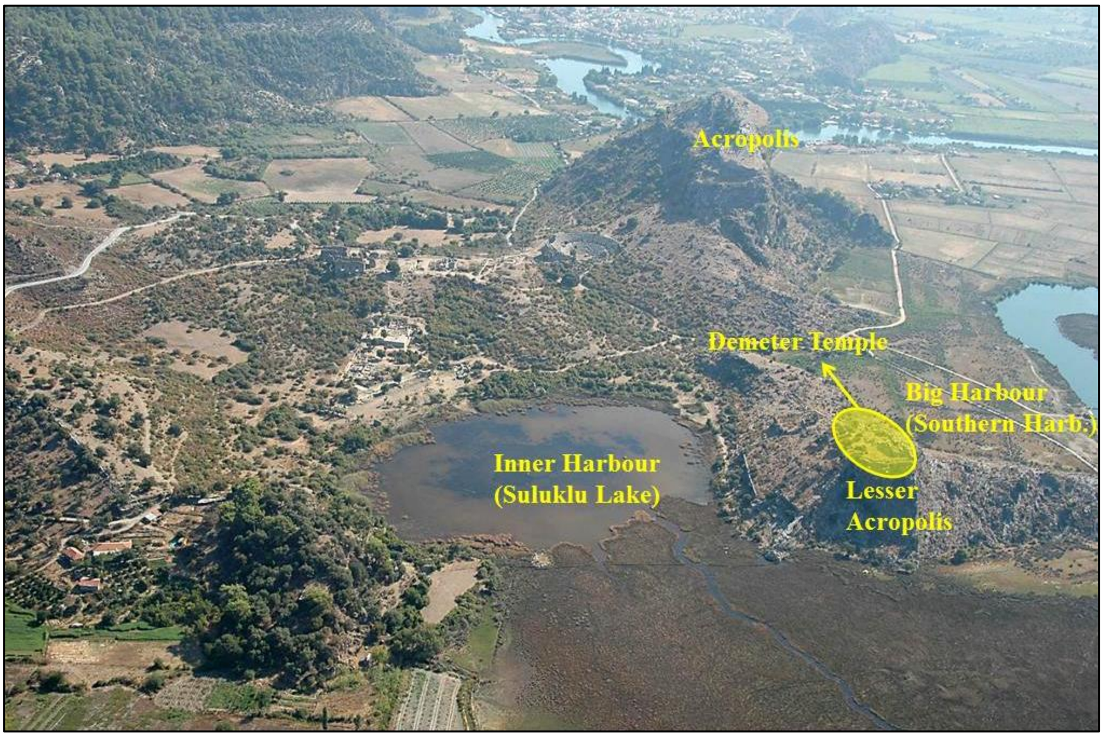


Figure 4.2 Harbours and Acropolis in Kaunos

In the ancient site of Kaunos there are 14 main buildings: Acropolis, theater, Palaestra Terrace, Domed Church, circular building, Temple Terrace, Roman Bath, Sacred Precinct of Apollo, Agora, Stoa, Fountain Building, Monopteros, Roman Basilica and Lesser Acropolis.

Acropolis which is on the northern side of the theatre is 152 m above the sea level (Figure 4.2). On the peak of acropolis, there is an open-air sanctuary. Ceremonies of Basileus Kaunios which were performed under the open sky were carried out in this sanctuary. (Öğün et al., 2002).

The Theater is located on the western side of the Acropolis. Capacity of the theatre is 5000 spectators. The theater oriented through the southwest according to the Anatolian architectural tradition (Figure 4.3). Its plan is drawn in Hellenic tradition and its orchestra has a horseshoe form (Öğün et al., 2002).

Palaestra Terrace is a large square which is located at the center of a Byzantine church (6th century AD). A lot of ceramics, most of which are drinking vessels, shows that the church has existed from the late 6th century BC (Figure 4.3) (Öğün et al., 2002).

1. Theatre
2. Circular Building
3. Palaetra Terrace and Domed Church
4. Roman Bath
5. Temple Terrace
6. Sacred Precinct of Apollo
7. Stoa
8. Fountain Building
9. Agora
10. Monopteros
11. Lesser Acropolis

Figure 4.3Buildings in Kaunos

Circular Building is located at the upper side of Kaunos (Figure 4.3). It is considered as the most important building which is brought to light. According to Vitruvius, streets and the main streets of the city are justified according to the wind by using this platform, where Kaunos is the only example of this system (General Directorate of Cultural Heritage and Museums).

Domed Church was built at the most significant part of the city, nearly at the center of Palaestra Terrace (Figure 4.3). This church is the best preserved ones in Anatolia. (It is one of the earliest and the best preserved examples of this type in Anatolia) (Öğün et al., 2002).

Temple Terrace is built during the second half of the first century BC (Figure 4.3). It is understood from the inscription which is on the column at the western end of the Courtyard *(temenos)* that the temple was dedicated to ***Zeus Soteros*** (Öğün et al., 2002).

Roman Bath in Kaunos is one of the best preserved examples which survived from the Roman Imperial period (Figure 4.3). Bath building consists of large halls. Two of them are warm halls (tepidarium) and two of them are exercise hall (ambulacrum). Moreover, cold room (frigidarium) and sweating room (laconicum) exist (Öğün et al., 2002).

Sacred Precinct of Apollo is located on the lower side of Kaunos. It is thought to be a sacred precinct for the local deity ***Basileus Kaunios*** since votive statue bases and steles are found here. It was used from the beginning of the 4th century BC until the middle of the Roman period. (It must have been a sacred precinct for the local deity ***Basileus Kaunios*** from the beginning of the 4th century BC until the middle of the Roman period) (Figure 4.3). (Öğün et al., 2002).

Agora is established in the Hellenistic Period. Besides the monumental Fountain and Stoa, the excavations reveled that Agora was decorated with many monuments, statues and groups of statues standing on carved stone bases of various forms, throughout centuries (Figure 4.3) (Öğün et al., 2002).

Stoa is lying on the northern side of Agora and was built in the beginning of the third century BC. It is one of the most important buildings of Hellenistic Period in Kaunos. Since it has not got shops in its back wall, it is a promenade Stoa (Figure 4.3) (Öğün et al., 2002).

Fountain Building was built in the middle of the third Century BC. Kaunians used this fountain block through the centuries (Öğün et al., 2002).

The Monopteros was built on the flat area in front of the north-western side of the lesser acropolis (Figure 4.3). It has two main sections: The female statue is found during the excavation and it is thought to be between these columns (Figure 4.4). On the other hand, the lion statue, which stands in the main square of the town of Koycegiz today, thought to have located on the one of the corners of this square (Figure 4.4). This round structure may have served as a funerary monument and can be dated to the first century AD according to evidence of these features (Öğün et al., 2002).

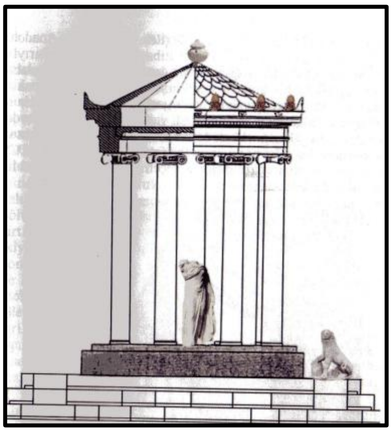


Figure 4.4 Monopteros reconstruction (Öğün et al., 2002)

The second acropolis called **Lesser Acropolis** is located on the eastern side of the Inner Harbour (Figures 4.2 and 4.3). This acropolis was built on the dominant peak having the view of the both harbors. On the peak of this acropolis, at least two temples and one church were built. Lesser Acropolis had an important location in the political history and religious life of Kaunos due to topographical features and strategic location. It was the site of the cult of the fertility Goddess ***Demeter.*** Because numerous votive goods were found at the south-eastern corner of the terrace, it could be said that this terrace played an important role in the *"**Thesmophoria** / fertility festival"* for the women of Kaunos. The Kaunian women met on this terrace every year. They performed the cult of ***"Thesmophoria"*** here for three days so the Goddess provided them with fertility (Öğün et al., 2002).

All of these buildings, harbours, statues and other unearthed objects show that Kaunos was a developed city. It also granted to the history two important peoples – Protegenes, a wall printer, and Dionysodorus, a mathematician. As it was mentioned before, the mother goddess of the biggest and the most important cultivated areas in the Anatolia located in Kaunos as Sacred Precinct of Demeter. Moreover, Carian language was solved by finding a stele written in both Carian and Greek languages.

In the light of this information, it is clear that Kaunos is an important Carian city. The excavation has been taking place since the year of 2000. Hence, in order to assist the archaeologist, the proposed SDSS is implemented for the excavation of Kaunos.

4.2 Design of SDSS for Kaunos Archaeological Excavation

In order to develop an SDSS for Kaunos archaeological excavation, firstly, needs of archaeologists working in the excavation of Kaunos are determined. Secondly, based on these needs decision analyses which are met the requirements of Kaunos archaeologists are defined. Finally, SDSS is designed based on needs.

Needs Assessment:

Requirements of archaeologists working in Kaunos can be listed as follows:

Need 1:

Archaeologists have the city map of Kaunos containing the environmental data about the site. Likewise, archaeologists have the excavation information about the artifacts such as coins and glasses. Hence, they want to store this information with their attributes based on their geographical location. They noted that the number of glass and coin findings is expected to increase, while the more excavation studies proceeds.

Need 2:

Based on the extracted data from site, archaeologists wish to analyze the characteristics of Kaunos. Thus, they have the spatial decision questions (Q1,..., Q7) concerning both regional and site-based scale problems. These are listed in Table 4.1:

Table 4.1 Spatial decision problems of Kaunos archaeologists

Scale	Questions
Site-based scale questions	**Q1.** Is there any specific type of glass finds? **Q2.** Which type of glass finds exist in the Bath? **Q3.** How do coins and glasses distribute with respect to time and spatial location in the site? **Q4.** Is there any clear relationship between coins and other remains in the region? **Q5.** Is there any clear relationship between coins and the type of land use? **Q6.** Is the coin distribution affected by the glass distribution in the region? **Q7.** Is there any clear difference between coin finds in terms of periods? If exist, which locations are related with the coin finds in the most significant period?
Regional scale questions	**Q1.** What is the reason of site selection of Kaunians?

Need 3:

Archaeologists need to see the results of analyses on the site map of Kaunos.

After defining the requirements of archaeologists based on the data of Kaunos, tools and decision analysis are determined to meet these requirements. These tools and analyses are listed as in Table 4.2:

Table 4.2 Tools and decision analyses that meet the needs

Needs of archaeologists			Tools and analysis that meet the needs
Need 1			Spatial data storage and management can be handled with GIS software. Besides, excavation data can be stored Relational Database Management Software.
Need 2	**Site-based questions**	**Q1,Q2,Q3**	The first three questions of archaeologists about site can be answered with queries.
		Q4,Q5,Q6 and Q7	In order to analyze these questions, hypothesis testing should be performed. Hypothesis can be tested using the methods of modeling area data.
	Regional questions	**Q1**	Viewshed analysis can answer this question.
Need 3			Cartographic display function of GIS is utilized to meet this requirement of archaeologists.

Design of SDSS for Kaunos Archaeological Excavation Based on Needs:

SDSS for Kaunos Archaeological Excavation is designed according to the needs of archaeologists. Defined tools and analyses satisfying the requirements are considered. Hence, SDSS for Archaeological Excavation is proposed as in the Figure 4.5. As Figure 4.5 depicts, it is composed of four components. These are Database Management, Model Management, Dialog Management and Stakeholder Components.

The first component, Data Base Management Component, consists of databases which store spatial and textual data namely; GIS and R-DBMS. Environmental spatial data of Kaunos are stored in GIS, meanwhile; excavation data are stored in R-DBMS. The second component, Model Management Component, is based on the first component. It has two basic functions; Basic GIS Analysis Functions for Kaunos and Spatial Data Analysis. Basic GIS Analysis Functions includes Queries and Viewshed Analysis. On the other hand, Spatial Data Analysis contains modeling and hypothesis testing. Spatial decision problems defined by the archaeologists are answered with these decision analyses. The results of the Model Management Component are visualized in Dialog Management Component with the help of GIS. Although Dialog Management Component is a comprehensive tool, in this thesis it only contains the resultant maps and graphical outputs of the models. Finally, the last component is users who are archaeologists working in the excavation of Kaunos. They produce meaningful information about characteristics of site by utilizing the visualized maps and charts. Besides, according to their feedback models can be improved.

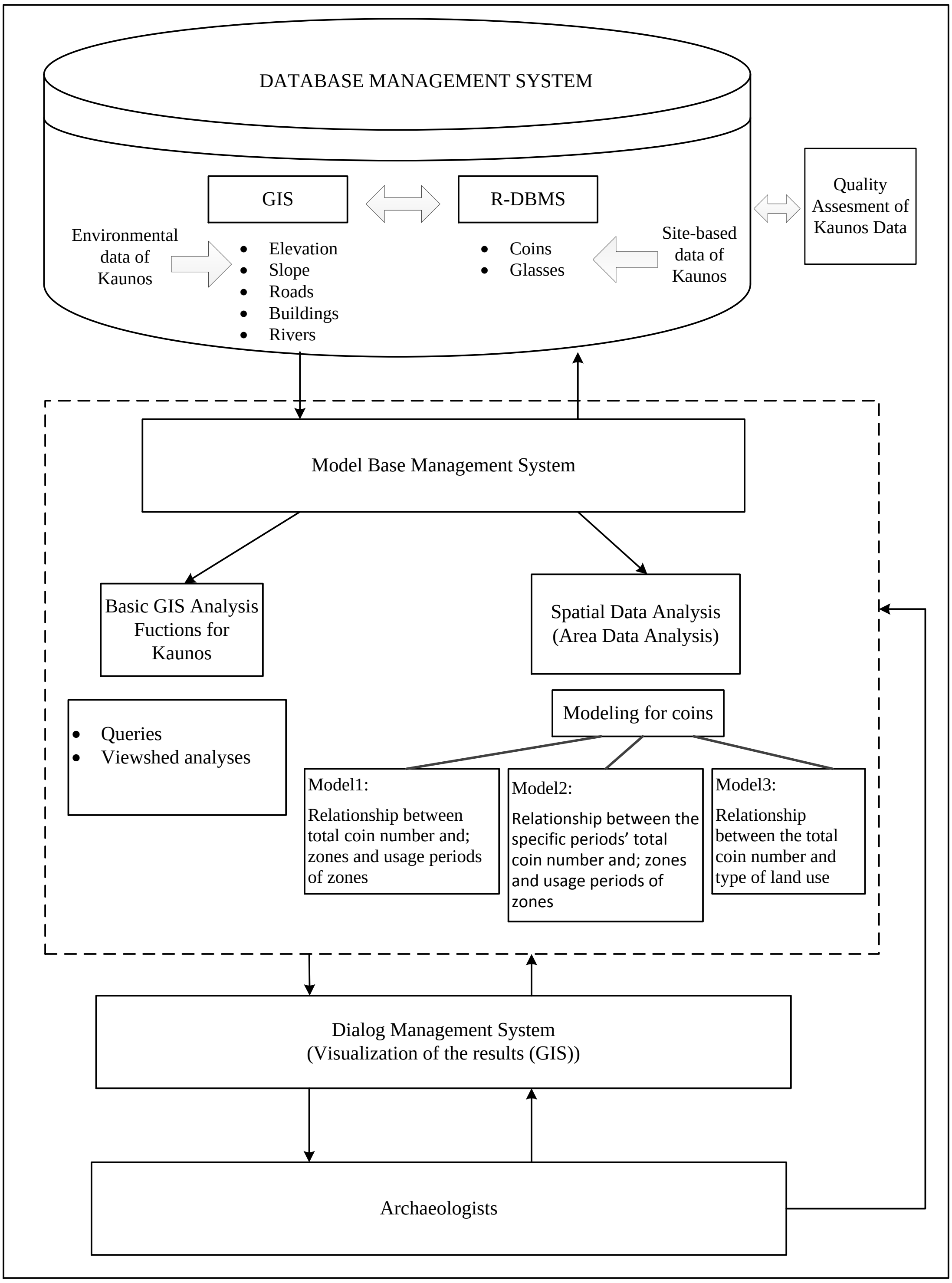


Figure 4.5 Architecture of SDSS for Kaunos archaeological site

4.3 The Database Management Component for Kaunos Archaeological Excavation

In order to develop an SDSS, a database design is the most important step since Model Management Component interacts with the Dialog Management Component.

For Kaunos, the main data is obtained as a map and tabular form from the excavation team. However, since this acquired map is not enough for the visibility analyses, four other maps are obtained from the General Directorate of Land Registry and Cadaster. Maps are 1/5000 scaled maps of Kaunos and the textual data contains information about glass and coins which were found during the excavation in Kaunos (Table 4.3). Hence, data of Kaunos composed of two different scales, regional and site-based scale.

Table 4.3 Raw data of Kaunos

Data	Types	Description	Source
Maps	Raster data	1 / 5000 scaled Kaunos map, 1 / 5000 scaled topographic maps	Excavation team, General Directorate of Land Registry and Cadaster
Coin data	Tabular data	Minted name, minted date, inventory number, found location, information	Excavation team
Glass data	Tabular data	Found location, inventory number, description, detailed description,	Excavation team

These collected data is converted from analogue to digital format by using QGIS and PostgreSQL software. QGIS is utilized for the registration of maps, the capture and the storage of data. On the other hand, PostgreSQL is used for the storage of site-based excavation data, namely coins and glasses. QGIS is selected as a GIS platform for this thesis, since it is an open source, user friendly and developed plug-in can be added and used easily. For example, in order to perform viewshed analysis, plug-ins developed by Şeker (2010) are added to the system. Moreover, it can connect with PostgreSQL and it supports the PostGIS layers created in PostgreSQL. Created database in PostgreSQL can be browsed in QGIS and the queries can be constructed. As relational database management system software, PostgreSQL is used. It has many advantages. One of them is mentioned above that it can connect with QGIS. Another main important characteristic is that "it is open-source relational database management systems on which the PostGIS spatial database can be built" (Huang and Wu, 2008, p.1).

4.3.1 Spatial Database Management System

Being the first part of database management component of SDSS for Kaunos archaeological excavation, GIS helps to capture the data from maps i.e. the generation of spatial information. Figure 4.6 shows the stages of data preparation stages.

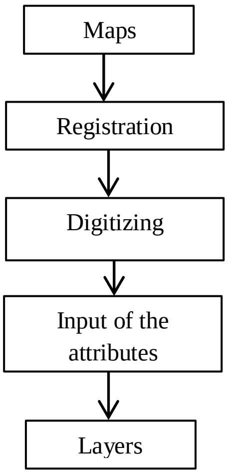
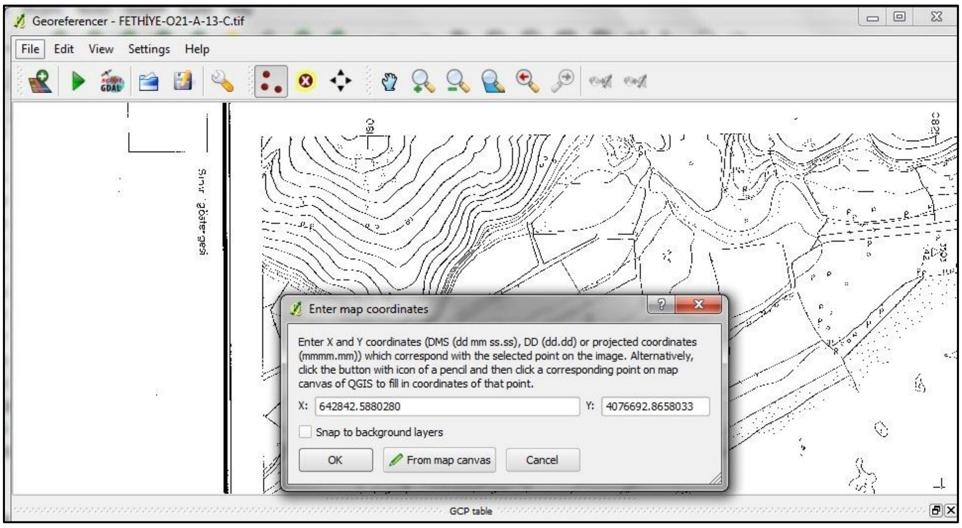


Figure 4.6 Data data preparation stages

Firstly, 1/5000 scaled maps of Kaunos are registered in QGIS by entering the four coordinate points. The map projection type is selected as the Universal Transverse Mercator (UTM ED 50) which is suitable for the mapping purposes in Turkey (Figure 4.7). If the scale of a map is between 1/5000 and 1/250000 or greater than 1/5000 (i.e. 1/1000), UTM is an appropriate projection type.



Enter map coordinates

Enter X and Y coordinates (DMS (dd mm ss.ss), DD (dd.dd) or projected coordinates (mmmm.mm)) which correspond with the selected point on the image. Alternatively, click the button with icon of a pencil and then click a corresponding point on map canvas of QGIS to fill in coordinates of that point.

X: 642842.5880280 Y: 4076692.8658033

☐ Snap to background layers

OK | From map canvas | Cancel

Figure 4.7 Registration interface of QGIS

After the registration step, all the objects on the maps, namely buildings, city walls, roads, river and contours are digitized in QGIS (Figure 4.8). The buildings which are city walls, theater, churches, bath, fountain, stoa, basilica and temples are digitized in detail with their plans (Figure 4.8). Due to the insufficiency of this map for viewshed analysis, the contours are digitized beyond the Kaunos from the maps obtained from the General Directorate of Land Registry and Cadaster (Figure 4.9).

Manual digitizing method is selected for the digitization process. In this method, while tracing on the border of items, the points are captured through the needs. This method is especially appropriate for contours, since if contour line is very curly, the number of clicks can be manually increased in that area. Hence, rough areas are digitized successfully by this way.

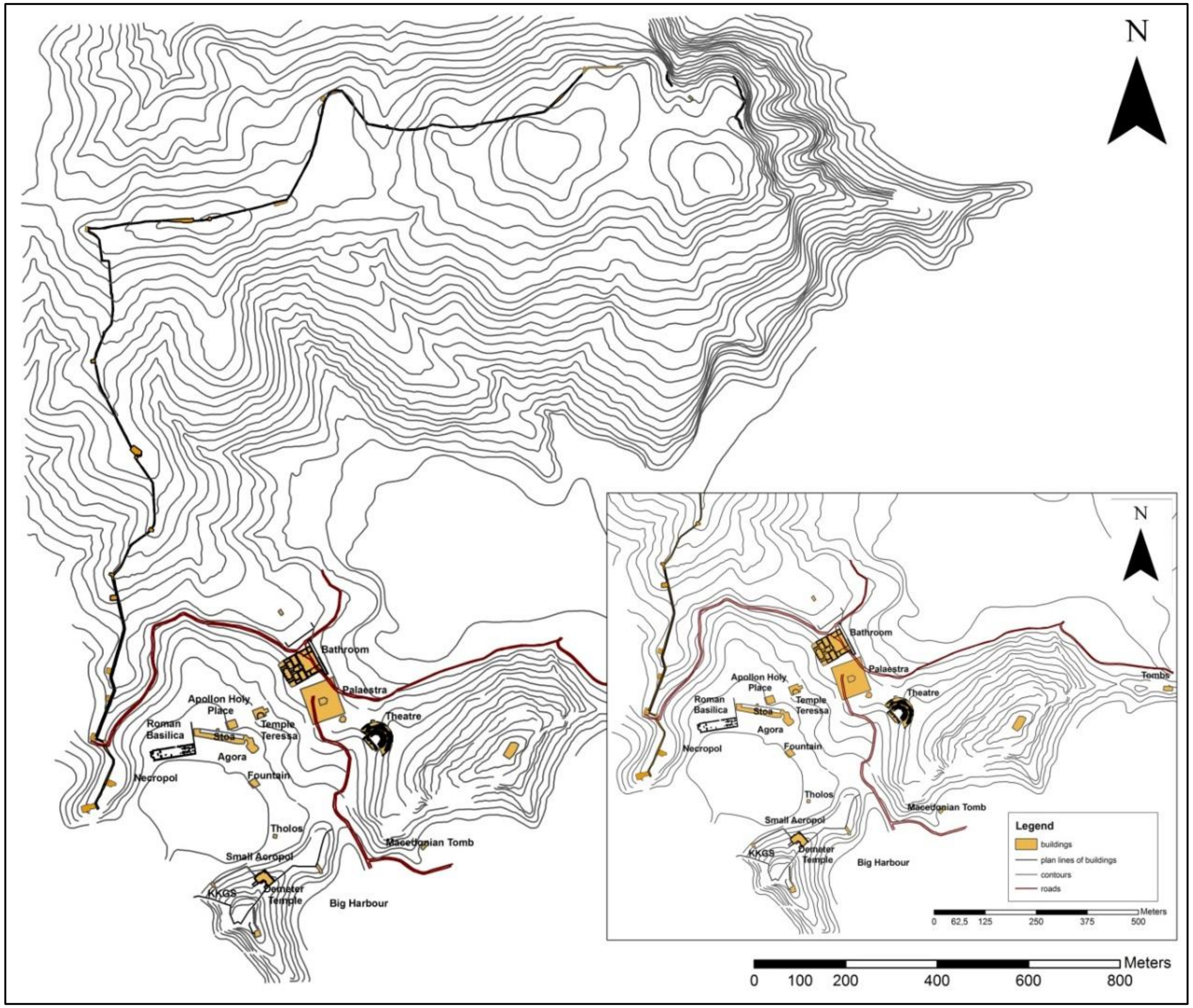


Figure 4.8 Digitized map of Kaunos archeological site

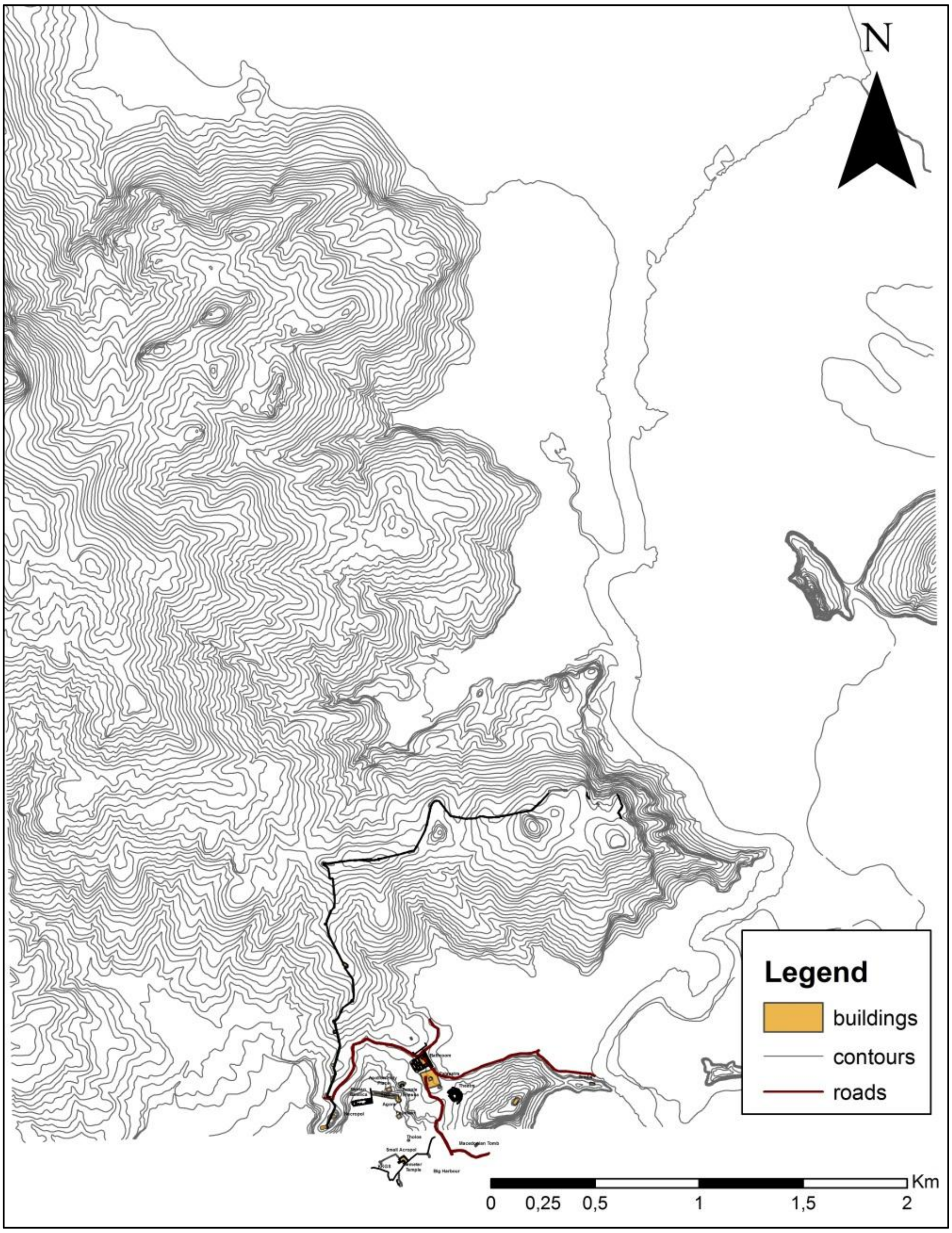


Figure 4.9 Digitized map of Kaunos in regional scale

After digitization, the attribute information of vector features is entered. The database of these buildings consists of identity number (ID), name and era attributes. Contours have ID and elevation attributes. Finally, shape files, i.e. layers, are created. These layers are buildings, transportation (pathways in the historical site are digitized in this layer), river, city wall, plans of the buildings and contours (Table 4.4).

Table 4.4 Data structure of Kaunos

Vector data	Attribute data
Buildings	ID Name · Roman Bath · Measurement Platform (circular building) · Palaesta Terrace · Domed Church · Theatre · Temple Terrace · Fountain · Demeter Temple · Stoa · Roman Bazilica Period
Contours	ID Height
Roads	ID
River	ID Name

In order to analyze site-based decision problems of archaeologists, study area is restricted. Since archaeologists define spatial problems based on coins and glass excavation data, study area is defined as illustrated in the Figure 4.10, which contains the locations of excavation data. In this study area, it is needed to define zones because coordinates of coins and glasses are not known. Hence, attribute information of coins and glasses are stored as area data.

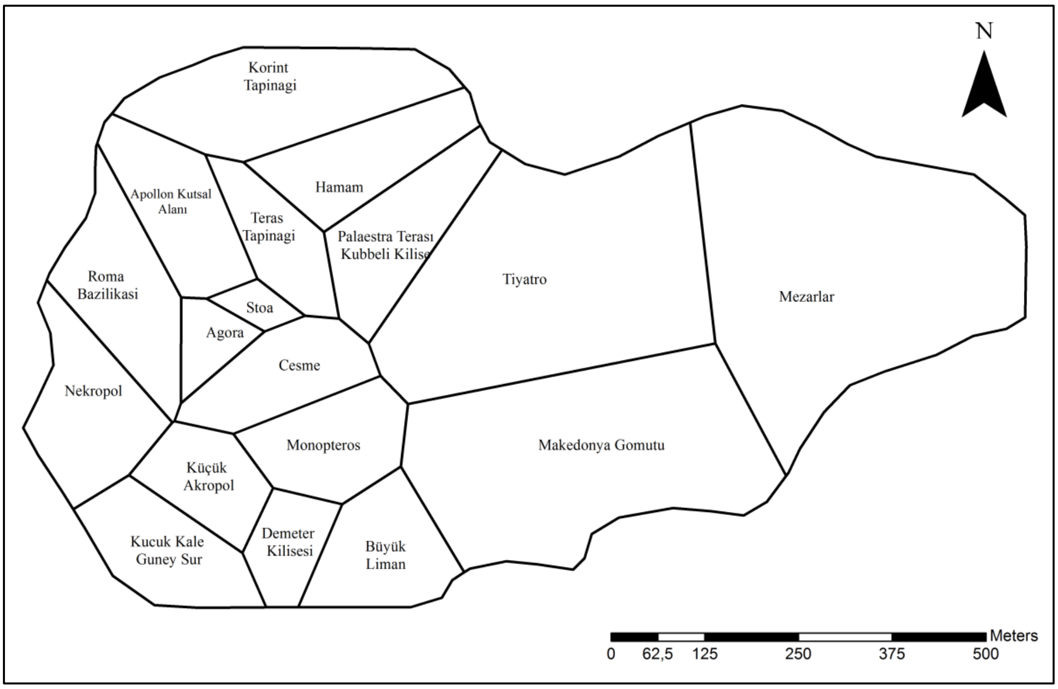


Figure 4.10 Restricted study areas with 18 zones

These zones are created by using the “Create Thiessen Polygons” in ArcGIS 9.3. As different archaeologists have varying perception about the influence area of the structures, using Thiessen Polygons provides a standard location definition in the site. Using this tool of ArcGIS, 18 zones are obtained in which coins and glasses are found. In this data set, the zones have attributes which are total coin number, total glass number, slope, and time of usage interval. Besides, archaeologists state that coins and glass finds in Kaunos belong to six different periods which can be seen from the Table 4.5. Hence, number of coins and glasses are also recorded with respect to periods. Attributes of the zones are listed in the Table 4.6.

Table 4.5 Periods of the remains in Kaunos

Greek Period		**Roman Imperial Period**			**Byzantine Period**
Archaic-Classic Period(1) (BC 7.cen – BC4.cen)	Hellenistic Period(2) (BC 4.cen – BC 1.cen)	Early Imperial Period(3) (BC 1.cen – AD 1.cen)	Mid Imperial Period(4) (AD2.cen-3.cen)	Late Imperial Period(5) (AD 4.cen – 5.cen)	Early Byzantine Period(6) (AD 6.cen – 7 cen)

Table 4.6 Site-based scale data structure of Kaunos

Zones		**Attribute Data**
· **Nekropol** · **Lesser Acropolis** · **Macedonian Tomb** · **Small Castle Southern City Wall** · **Big Harbour** · **Graveyards** · **Roman Bazilica** · **Stoa**	· **Apollon Holy Place** · **Temple Terrace** · **Fountain** · **Monopteros-Tholos** · **Theatre** · **Palaestra-Domed Temple** · **Bath** · **Demeter Temple** · **Korinth Temple** · **Agora**	· Total number of coin · Total number of glass · Total number of coin with respect to each period · Total number of glass with respect to each period · Ratio of number of coins with respect to each period · Ratio of number of glass with respect to each period · Time of usage

4.3.2 Relational Database Management System

In Kaunos, coins and glass findings are studied in detail by the archaeologists. Thus, their attributes are very comprehensive. In order to manage and store this large amount of data, PostgreSQL is used.

In this step of SDSS, the most important aspect is design of database. It is performed according to Ramakrishnan and Gehrke (2003)'s three steps. Requirement analysis is the first step of designing a database and users' demands are determined in this step. Thus, the needs of archaeologists who are working in the excavation study of Kaunos are discussed and defined.

High level description of data which is the theme of second step is developed according to the information gathered in requirement analysis. It is designed for coin and glass database of Kaunos (Figure 4.11). Buildings entity, which is the area data, contains both coins and glasses so ER diagram has two "has" relations. Besides, coins and glasses are related to six periods via ISA ("is a") Hierarchy. The attributes of the coins are inherited to the entities of Archaic-Classic Period, Hellenistic Period, Early Imperial Period, Mid Imperial Period, Late Imperial Period and Byzantine Period by ISA Hierarchy. Information entities are related to coin and glass entities. Besides, as seen from the Figure 4.11, the key constraints are defined on the ER Diagram.

Buildings and coin relation is one to many relation since a coin is associated with at most one building via "has" relation. However, a building is associated with several coins via borrower. Buildings and glass entities have also one to many relation due to same manner. Another constraint is defined between the coin and the information entities. It has one to one relationship because a coin is associated with at most one information via contains relationship and information is associated at most one coin. Glass and information entities have also one to one relation.

As the final step, the ER diagram of coin and glass data are converted into relational tables by using PostgreSQL 9.0. SQL statements are used while creating tables. Meanwhile, constraints are defined.

Spatial information of Kaunos is generated in QGIS, as well as 18 zones. These zones are stored as Thiessen_Orj_Points_Clip.shp which is seen as building relation in ER Diagram. In order to convert ER diagram to relational database schema; firstly, Thiessen_Orj_Points_Clip.shp file is needed to be imported into PostgreSQL. It is imported through the Plugins > PostGIS Shapefile and DBF Loader.

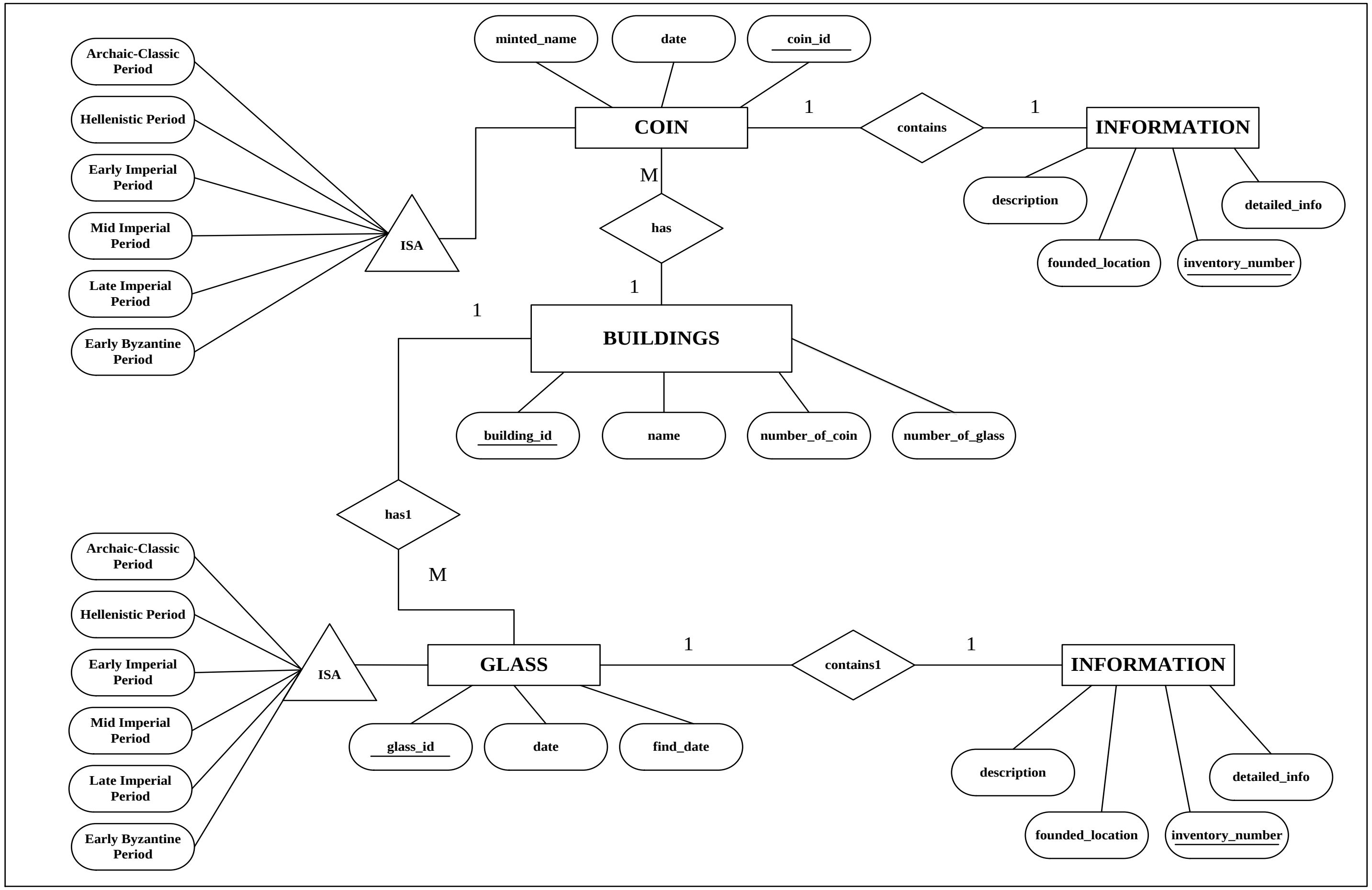


Figure 4.11 ER Diagram of coins and glasses

Secondly, coin entity is converted to relational tables. Since ISA Hierarchy can be stored in different relations, coin has 6 different relational tables. As it can be seen in ER diagram, coin_id is the primary key for coin relational tables. Besides, the foreign key is also coin_id, references to "has" and "contains" relations (Figure 4.12). SQL is as the following for the creation of coin relational table.

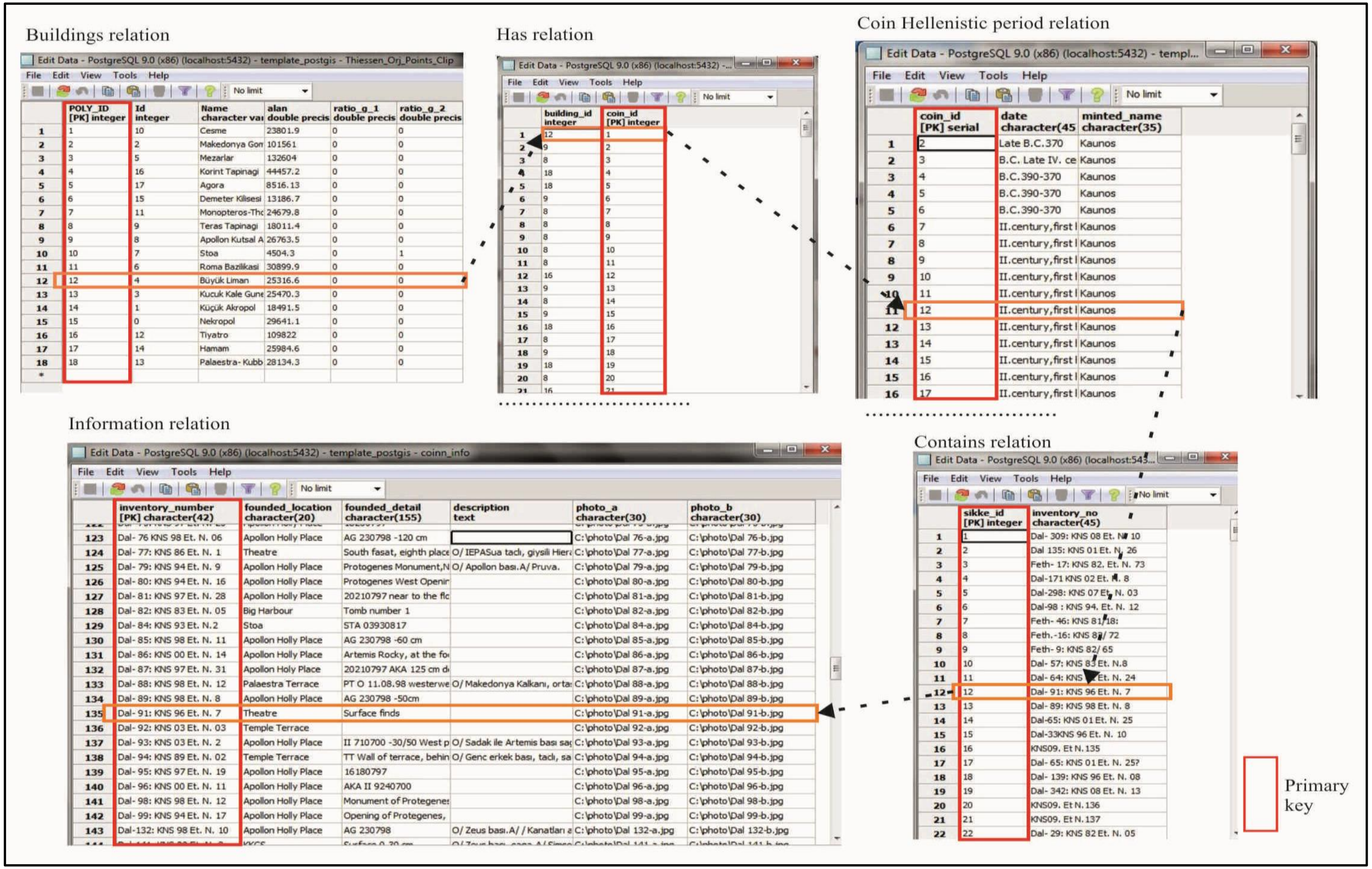
```
CREATE TABLE coinn_arc_classic
(coin_id integer NOT NULL DEFAULT),
date character(45),
minted_name character(35),
CONSTRAINT archaic_classic_coinn_pkey PRIMARY KEY (coin_id),
CONSTRAINT coinn_arc_classic_coin_id_fkey FOREIGN KEY (coin_id)
REFERENCES has (coin_id) MATCH SIMPLE
ON UPDATE CASCADE ON DELETE CASCADE,
CONSTRAINT coinn_arc_classic_coin_id_fkey1 FOREIGN KEY (coin_id)
REFERENCES contains (sikke_id) MATCH SIMPLE
ON UPDATE CASCADE ON DELETE CASCADE)
```

Another important aspect is translating a relationship set to a relation. "Has" relationship has two attributes which are primary keys of coin and buildings entities. Coin_id is again a primary key here and building_id is a foreign key (Figure 4.12). In order to create a "has" relational table SQL is as following:

```
CREATE TABLE has
(building_id integer,
coin_id integer NOT NULL,
CONSTRAINT has_pkey PRIMARY KEY (coin_id),
CONSTRAINT has_building_id_fkey FOREIGN KEY (building_id)
REFERENCES "Thiessen_Orj_Points_Clip" ("POLY_ID")
ON UPDATE CASCADE ON DELETE NO ACTION,
CONSTRAINT has_coin_id_fkey FOREIGN KEY (coin_id)
REFERENCES coinn (coin_id) MATCH SIMPLE
ON UPDATE NO ACTION ON DELETE NO ACTION)
```

Finally, contains relationship and information entities are converted to relational tables. As in the "has" relation, contain relational table is composed of primary keys of coin and information entities. The primary key is sikke_id and the foreign key is inventory_number (Figure 4.12). SQL statement is:

```
CREATE TABLE contains
(sikke_id integer NOT NULL,
 inventory_no character(45),
CONSTRAINT contains_pkey PRIMARY KEY (sikke_id),
CONSTRAINT contains_inventory_no_fkey FOREIGN KEY (inventory_no)
REFERENCES coinn_info (inventory_number)
ON UPDATE CASCADE ON DELETE CASCADE,
CONSTRAINT contains_sikke_id_fkey FOREIGN KEY (sikke_id)
REFERENCES coinn (coin_id)
ON UPDATE CASCADE ON DELETE CASCADE,
CONSTRAINT contains_inventory_no_key UNIQUE (inventory_no))
```



Buildings relation

Edit Data - PostgreSQL 9.0 (x86) (localhost:5432) - template_postgis - Thiessen_Orj_Points_Clip

	POLY_ID [PK] integer	Id integer	Name character var	alan double precis	ratio_g_1 double precis	ratio_g_2 double precis
1	1	10	Cesme	23801.9	0	0
2	2	2	Makedonya Gon	101561	0	0
3	3	5	Mezarlar	132604	0	0
4	4	16	Korint Tapinagi	44457.2	0	0
5	5	17	Agora	8516.13	0	0
6	6	15	Demeter Kilisesi	13186.7	0	0
7	7	11	Monopteros-Thc	24679.8	0	0
8	8	9	Teras Tapinagi	18011.4	0	0
9	9	8	Apollon Kutsal A	26763.5	0	0
10	10	7	Stoa	4504.3	0	1
11	11	6	Roma Bazilikasi	30899.9	0	0
12	12	4	Büyük Liman	25316.6	0	0
13	13	3	Kucuk Kale Gune	25470.3	0	0
14	14	1	Küçük Akropol	18491.5	0	0
15	15	0	Nekropol	29641.1	0	0
16	16	12	Tiyatro	109822	0	0
17	17	14	Hamam	25984.6	0	0
18	18	13	Palaestra- Kubb	28134.3	0	0
*						

Has relation

Edit Data - PostgreSQL 9.0 (x86) (localhost:5432) -...

	building_id integer	coin_id [PK] integer
1	12	1
2	9	2
3	8	3
4	18	4
5	18	5
6	9	6
7	8	7
8	8	8
9	8	9
10	8	10
11	8	11
12	16	12
13	9	13
14	8	14
15	9	15
16	18	16
17	8	17
18	9	18
19	18	19
20	8	20
21	16	21

Coin Hellenistic period relation

Edit Data - PostgreSQL 9.0 (x86) (localhost:5432) - templ...

	coin_id [PK] serial	date character(45	minted_name character(35)
1	2	Late B.C.370	Kaunos
2	3	B.C. Late IV. ce	Kaunos
3	4	B.C.390-370	Kaunos
4	5	B.C.390-370	Kaunos
5	6	B.C.390-370	Kaunos
6	7	II.century,first l	Kaunos
7	8	II.century,first l	Kaunos
8	9	II.century,first l	Kaunos
9	10	II.century,first l	Kaunos
10	11	II.century,first l	Kaunos
11	12	II.century,first l	Kaunos
12	13	II.century,first l	Kaunos
13	14	II.century,first l	Kaunos
14	15	II.century,first l	Kaunos
15	16	II.century,first l	Kaunos
16	17	II.century,first l	Kaunos

Information relation

Edit Data - PostgreSQL 9.0 (x86) (localhost:5432) - template_postgis - coinn_info

	inventory_number [PK] character(42)	founded_location character(20)	founded_detail character(155)	description text	photo_a character(30)	photo_b character(30)
123	Dal- 76 KNS 98 Et. N. 06	Apollon Holly Place	AG 230798 -120 cm		C:\photo\Dal 76-a.jpg	C:\photo\Dal 76-b.jpg
124	Dal- 77: KNS 86 Et. N. 1	Theatre	South fasat, eighth place	O/ IEPASua taclı, giysili Hiera	C:\photo\Dal 77-a.jpg	C:\photo\Dal 77-b.jpg
125	Dal- 79: KNS 94 Et. N. 9	Apollon Holly Place	Protogenes Monument,N	O/ Apollon bası.A/ Pruva.	C:\photo\Dal 79-a.jpg	C:\photo\Dal 79-b.jpg
126	Dal- 80: KNS 94 Et. N. 16	Apollon Holly Place	Protogenes West Openir		C:\photo\Dal 80-a.jpg	C:\photo\Dal 80-b.jpg
127	Dal- 81: KNS 97 Et. N. 28	Apollon Holly Place	20210797 near to the flc		C:\photo\Dal 81-a.jpg	C:\photo\Dal 81-b.jpg
128	Dal- 82: KNS 83 Et. N. 05	Big Harbour	Tomb number 1		C:\photo\Dal 82-a.jpg	C:\photo\Dal 82-b.jpg
129	Dal- 84: KNS 93 Et. N.2	Stoa	STA 03930817		C:\photo\Dal 84-a.jpg	C:\photo\Dal 84-b.jpg
130	Dal- 85: KNS 98 Et. N. 11	Apollon Holly Place	AG 230798 -60 cm		C:\photo\Dal 85-a.jpg	C:\photo\Dal 85-b.jpg
131	Dal- 86: KNS 00 Et. N. 14	Apollon Holly Place	Artemis Rocky, at the fo		C:\photo\Dal 86-a.jpg	C:\photo\Dal 86-b.jpg
132	Dal- 87: KNS 97 Et. N. 31	Apollon Holy Place	20210797 AKA 125 cm d		C:\photo\Dal 87-a.jpg	C:\photo\Dal 87-b.jpg
133	Dal- 88: KNS 98 Et. N. 12	Palaestra Terrace	PT O 11.08.98 westerwe	O/ Makedonya Kalkanı, orta	C:\photo\Dal 88-a.jpg	C:\photo\Dal 88-b.jpg
134	Dal- 89: KNS 98 Et. N. 8	Apollon Holly Place	AG 230798 -50cm		C:\photo\Dal 89-a.jpg	C:\photo\Dal 89-b.jpg
135	Dal- 91: KNS 96 Et. N. 7	Theatre	Surface finds		C:\photo\Dal 91-a.jpg	C:\photo\Dal 91-b.jpg
136	Dal- 92: KNS 03 Et. N. 03	Temple Terrace			C:\photo\Dal 92-a.jpg	C:\photo\Dal 92-b.jpg
137	Dal- 93: KNS 03 Et. N. 2	Apollon Holly Place	II 710700 -30/50 West p	O/ Sadak ile Artemis bası sa	C:\photo\Dal 93-a.jpg	C:\photo\Dal 93-b.jpg
138	Dal- 94: KNS 89 Et. N. 02	Temple Terrace	TT Wall of terrace, behin	O/ Genc erkek bası, taclı, sa	C:\photo\Dal 94-a.jpg	C:\photo\Dal 94-b.jpg
139	Dal- 95: KNS 97 Et. N. 19	Apollon Holly Place	16180797		C:\photo\Dal 95-a.jpg	C:\photo\Dal 95-b.jpg
140	Dal- 96: KNS 00 Et. N. 11	Apollon Holly Place	AKA II 9240700		C:\photo\Dal 96-a.jpg	C:\photo\Dal 96-b.jpg
141	Dal- 98: KNS 98 Et. N. 12	Apollon Holly Place	Monument of Protegenes		C:\photo\Dal 98-a.jpg	C:\photo\Dal 98-b.jpg
142	Dal- 99: KNS 94 Et. N. 17	Apollon Holly Place	Opening of Protegenes,		C:\photo\Dal 99-a.jpg	C:\photo\Dal 99-b.jpg
143	Dal-132: KNS 98 Et. N. 10	Apollon Holly Place	AG 230798	O/ Zeus bası.A/ / Kanatları a	C:\photo\Dal 132-a.jpg	C:\photo\Dal 132-b.jpg

Contains relation

Edit Data - PostgreSQL 9.0 (x86) (localhost:543...

	sikke_id [PK] integer	inventory_no character(45)
1	1	Dal- 309: KNS 08 Et. N. 10
2	2	Dal 135: KNS 01 Et. N. 26
3	3	Feth- 17: KNS 82. Et. N. 73
4	4	Dal-171 KNS 02 Et. N. 8
5	5	Dal-298: KNS 07 Et. N. 03
6	6	Dal-98 : KNS 94. Et. N. 12
7	7	Feth- 46: KNS 81/18:
8	8	Feth.-16: KNS 82/ 72
9	9	Feth- 9: KNS 82/ 65
10	10	Dal- 57: KNS 83 Et. N.8
11	11	Dal- 64: KNS [illegible] Et. N. 24
12	12	Dal- 91: KNS 96 Et. N. 7
13	13	Dal- 89: KNS 98 Et. N. 8
14	14	Dal-65: KNS 01 Et. N. 25
15	15	Dal-33KNS 96 Et. N. 10
16	16	KNS09. Et N. 135
17	17	Dal- 65: KNS 01 Et. N. 25?
18	18	Dal- 139: KNS 96 Et. N. 08
19	19	Dal- 342: KNS 08 Et. N. 13
20	20	KNS09. Et N. 136
21	21	KNS09. Et N. 137
22	22	Dal- 29: KNS 82 Et. N. 05

Figure 4.12 Relational tables of coins

The primary key of information entity is inventory_number (Figure 4.12) and it is converted to relational table with the following SQL statement:

```
CREATE TABLE coinn_info
(inventory_number character(42) NOT NULL, founded_location character(20), founded_detail
character(155), description text, photo_a character(30),photo_b character(30),
CONSTRAINT coinn_info_pkey PRIMARY KEY (inventory_number))
```

Relational tables of glass entities are created in the same way as with coin entities.

4.4 Model Management Component for Kaunos Archaeological Excavation

Model Management Component of Kaunos' SDSS has two parts. These are Basic GIS Analysis Functions for Kaunos and Spatial Data Analyses Functions (Area Data Analyses). As determined in the methodology, Basic GIS Analyses for Kaunos are queries and viewshed analysis. These analyses are performed in order to explain site characteristics of Kaunos. The second part of the Model Management Component is area data analysis. In this section, hypotheses are constructed to answer spatial decision problems of archaeologists.

4.4.1 Basic GIS Analysis Functions for Kaunos

Basic GIS Analysis Functions are queries and viewshed analysis.

Queries:

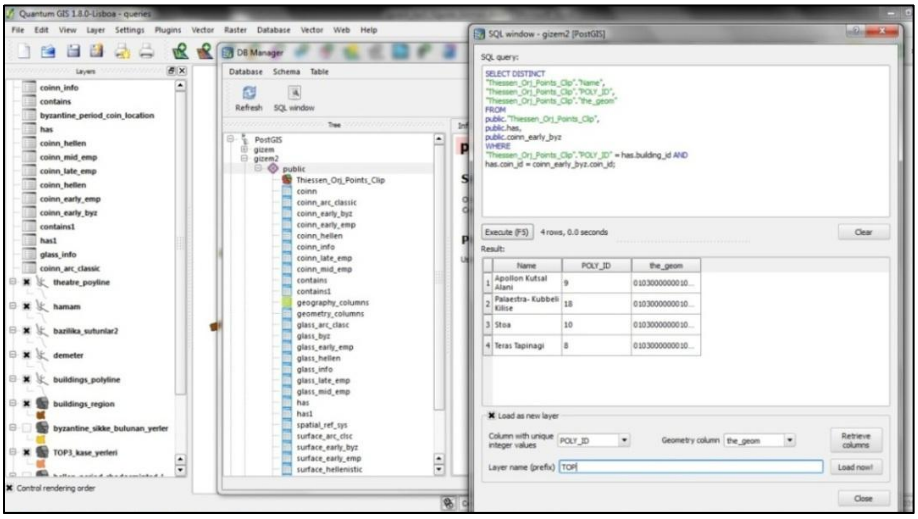
The queries are performed in order to answer the questions of archaeologists related with database. According to their demands both non-spatial and spatial queries required to be performed. Spatial queries are performed for the following questions of archaeologists:

- Where are the Byzantine Periods' coins found?
- In Hellenistic Period, where are the coins which are minted by the king having the highest number of coin?

The non-spatial queries are:

- What is the number of coins according to the minted name in each period?
- Is there any specific type of glass finds? If exist where are they found?
- Which type of glass findings exist in the Bath?

SQL in DB Manager tool of QGIS 1.8.0 is used to perform queries. This tool connects the PostGIS with PostgreSQL where database is created. Because of geometry column, i.e. being spatial database, spatial queries can be performed by adding the query result as a new layer (Figure 4.13).



SQL query:

```
SELECT DISTINCT
"Thiessen_Orj_Points_Clip"."Name",
"Thiessen_Orj_Points_Clip"."POLY_ID",
"Thiessen_Orj_Points_Clip"."the_geom"
FROM
public."Thiessen_Orj_Points_Clip",
public.has,
public.coinn_early_byz
WHERE
"Thiessen_Orj_Points_Clip"."POLY_ID" = has.building_id AND
has.coin_id = coinn_early_byz.coin_id;
```

4 rows, 0.0 seconds

Result:

	Name	POLY_ID	the_geom
1	Apollon Kutsal Alani	9	010300000010...
2	Palaestra- Kubbeli Kilise	18	010300000010...
3	Stoa	10	010300000010...
4	Teras Tapinagi	8	010300000010...

☒ Load as new layer

Column with unique integer values: POLY_ID

Geometry column: the_geom

Layer name (prefix): TOP

Figure 4.13 DB Manager tool of QGIS

Since archaeologists would like to see the locations of last periods' coins, following query is performed. As the Figure 4.14 shows coins are found in those areas namely Apollon Holy Place, Stoa, Temple Terrace and Palaestra Terrace.

```
SELECT DISTINCT
“Thiessen_Orj_Points_Clip”.”Name”,
“Thiessen_Orj_Points_Clip”.”POLY_ID”,
“Thiessen_Orj_Points_Clip”.”the_geom”
FROM
public.”Thiessen_Orj_Points_Clip”,
public.has,
public.coinn_early_byz
WHERE
“Thiessen_Orj_Points_Clip”.”POLY_ID” = has.building_id AND
has.coin_id = coinn_early_byz.coin_id;
```

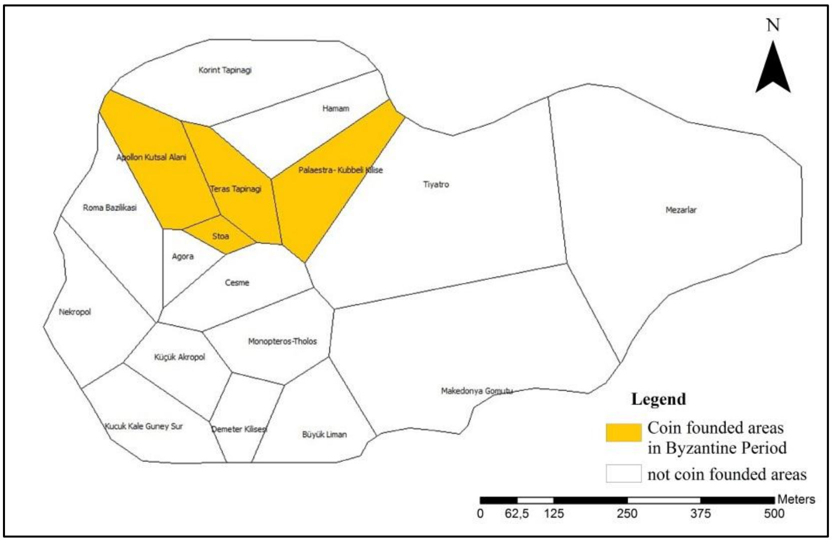


Figure 4.14 Thematic map of coin found areas in Byzantine Period

In Hellenistic Period, according to demands of archaeologists, locations of coins, which are minted by the king who minted the most coins, are found. According to result of following SQL statement, Kaunos was minted the highest number of coin in this period and these coins are found from Apollon Holy Place, Temple Terrace, Stoa, Palaestra, Korinth Temple, Theatre, Big Harbour and Graveyards.

```
SELECT DISTINCT
“Thiessen_Orj_Points_Clip”.”Name”,
“Thiessen_Orj_Points_Clip”.”POLY_ID”,
“Thiessen_Orj_Points_Clip”.”the_geom”,
oin_hellen.minted_name
FROM
public.”Thiessen_Orj_Points_Clip”,
public.has,
public.coinn_hellen
WHERE
“Thiessen_Orj_Points_Clip”.”POLY_ID” = has.building_id AND
has.coin_id =coin_hellen.coin_id and
coin_hellen.minted_name=’Rhodos’
```

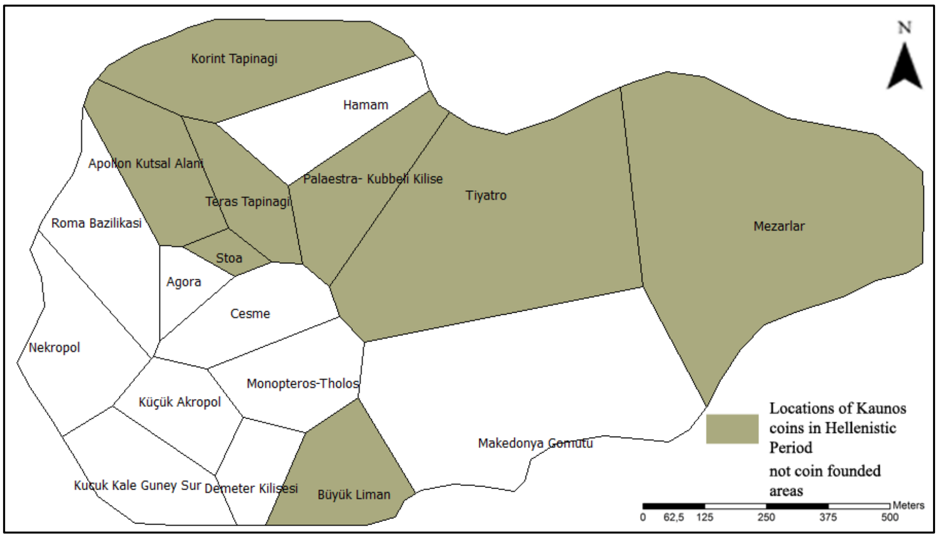


Figure 4.15 Thematic map of location of coins minted by Rhodos in Hellenistic Period

The attribute queries are implemented in PostgreSQL and the results of some queries are illustrated with graphs or tables. For the first question which is “What is the number of coins according to minted name in each period?” SQL statement is:

```
SELECT DISTINCT minted_name,
COUNT (*) AS count
FROM public.coinn_arc_classic
GROUP BY minted_name;
```

In this statement, FROM part is updated according to six periods relations and the results are illustrated in Figures 4.16 to 4.21. As seen from the figures, Hellenistic Period has the highest number (126) of coins and it is followed by Early Byzantine Period (50), nearly half of them are Heraclius’s coins. The third period is Mid Imperial with the value of 37 coins and Late Imperial Period follows this period with 34 coins. Early Imperial Period is in the fifth order and it has totally number of 15 coins most of which are minted by Rhodes. Finally, in Archaic Classic Period, there were just 3 coins found, minted by Kaunos and Rhodos.

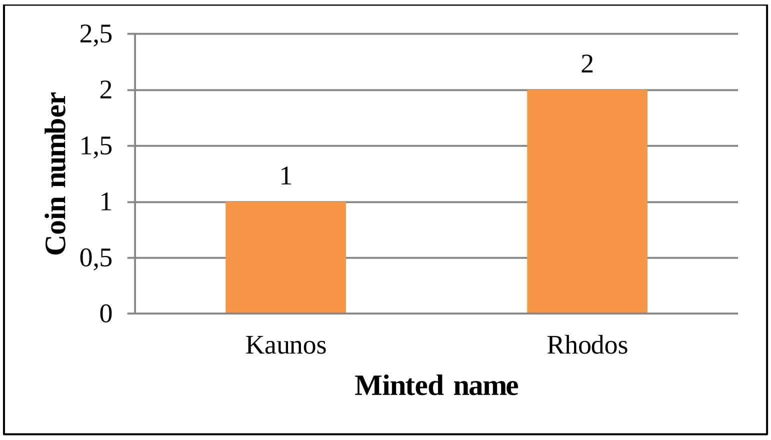


Figure 4.16 Archaic Classic Period coin number according to minted names

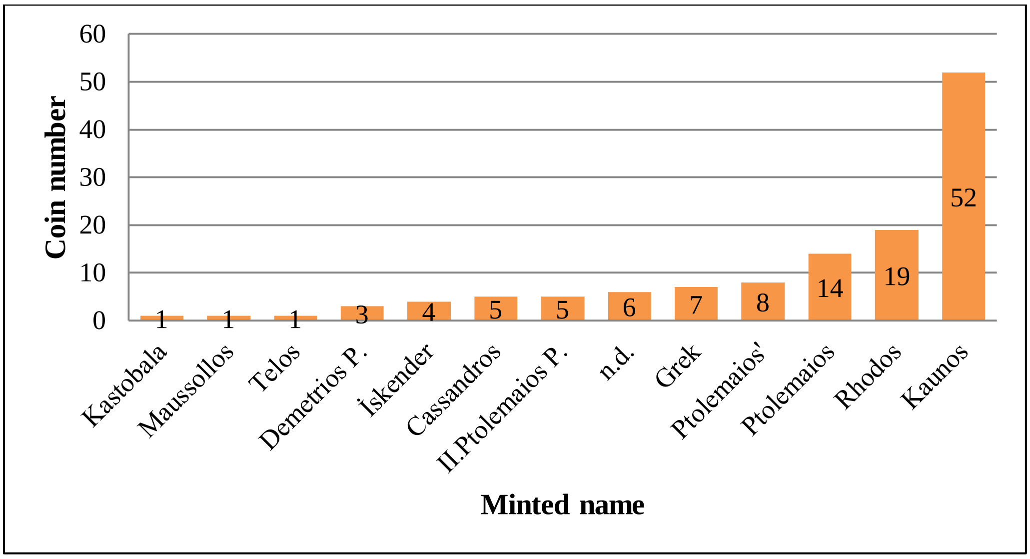


Figure 4.17 Hellenistic Period coin number according to minted names

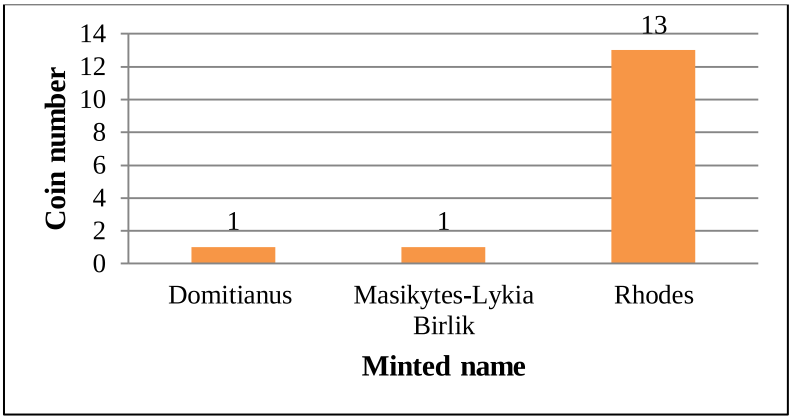


Figure 4.18 Early Imperial Period coin number according to minted names

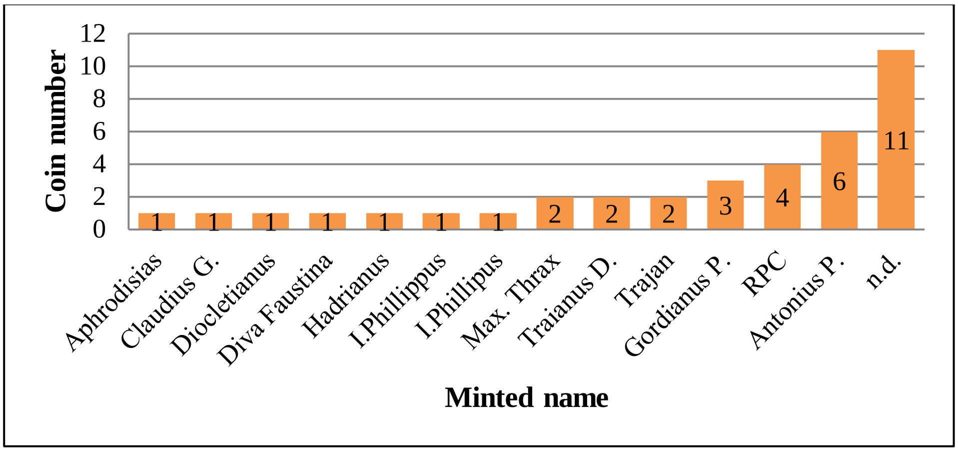


Figure 4.19 Mid Imperial Period coin number according to minted names

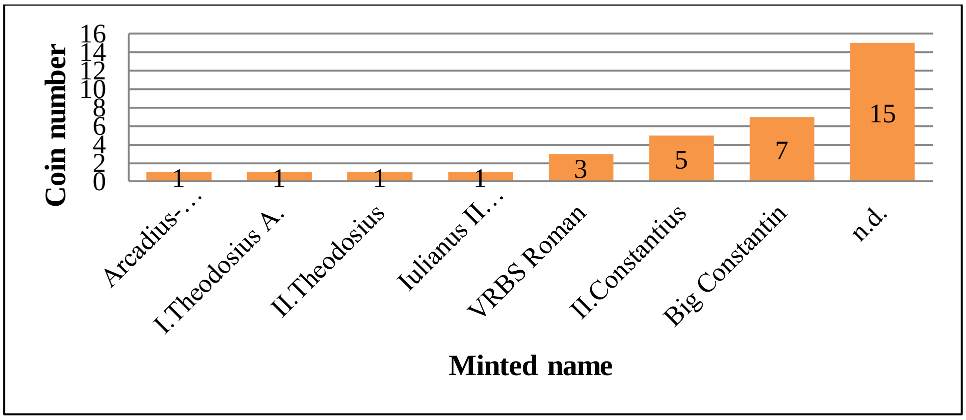


Figure 4.20 Late Imprial Period coin number according to minted names

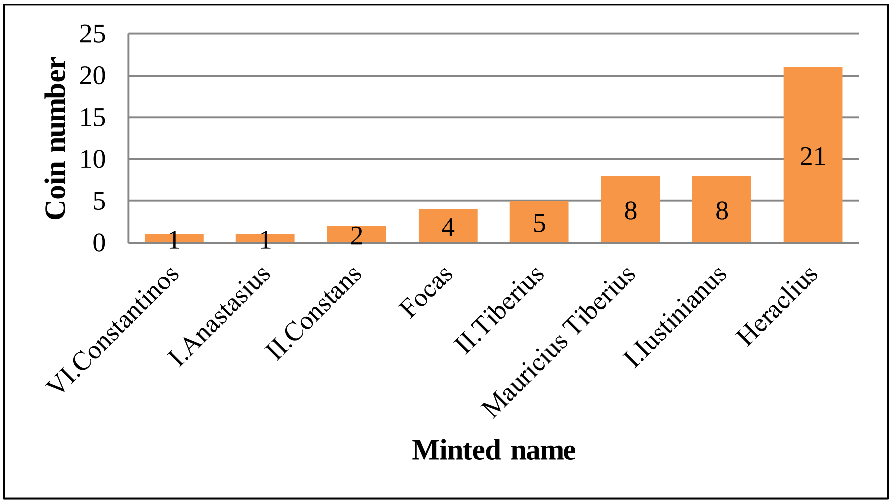


Figure 4.21 Early Byzantine Period coin number according to minted names

Secondly, in order to analyze whether there exist any different type of glass finds, SQL statement is written like that:

```
SELECT DISTINCT description,founded_location
FROM public.glass_info
GROUP BY description,founded_location;
```

Result table (Table 4.7) shows that there are two different type of glass, “Aryballos” and “Oinochoe”. Aryballos is a perfume bottle and it is found from Temple Terrace. Although archaeologists expect to find this type of artifacts from the bath, they say that because of the land sliding, it is found from the nearest location of bath, which is Temple Terrace. On the other hand, Oinoche is a type of bottle that is used for the wine service and found in Stoa.

Table 4.7 Different type of glass finds and found location

description	**found_location**
Aryballos	Temple Terrace
Oinochoe	Stoa

Finally, in order to analyze the type of glass findings that are found from bath, SQL statement is written as follows:

```
SELECT DISTINCT "glass_info"."description", "glass_info"."founded_location"
FROM public.glass_info
WHERE founded_location='Bath';
```

According to result of this statement, it is seen that just a flat bowl is found from Bath (Table 4.8).

Table 4.8 Type of glass finds found in Bath

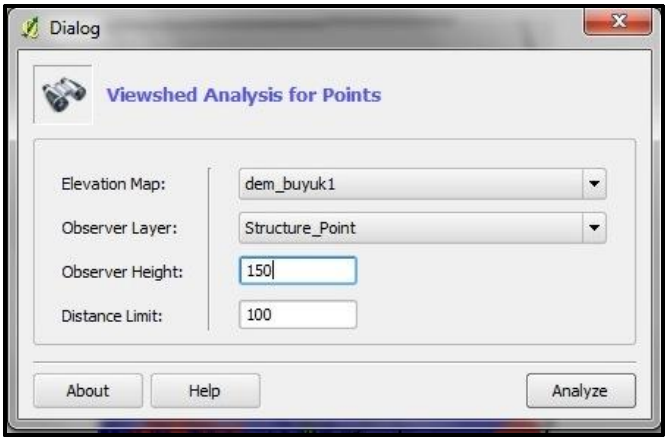
description	**found_location**
Flat bowl	Bath

Viewshed Analyses:

As it is explained in the literature section, viewshed analyses are utilized to explain site selection criterions of ancient civilization. Whether a selection of this area contains a reason behind it or not can be examined by viewshed analysis. In this manner, archaeologists’ question in regional scale can be answered with viewshed analysis.

In this study, viewshed analyses are conducted by using two types of methods. These are cumulative viewshed and visibility analyses. Cumulative viewshed is the summation of visibility analyses performed from various selected points. In this thesis, it is utilized in *path based* and one of the *point based* viewshed analysis. On the other hand, visibility analysis defines visible and non-visible areas from the defined points and it was utilized in point based visibility analyses.

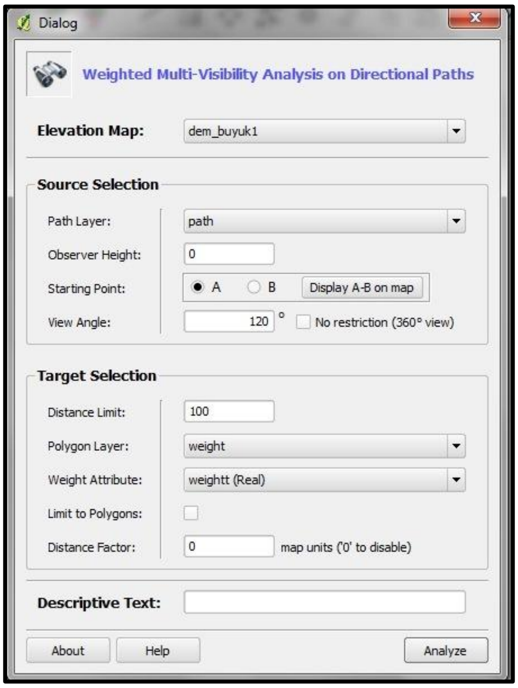
Two plug-ins, which were developed for QGIS by Şeker (2010), are used to perform the viewshed. The names of plug-ins are “Viewshed Analysis for Points” and “Visibility Analysis”. In the first one, as seen in the Figure 4.22, the observer height and the distance limit are defined. If one point is selected in observer layer, the resultant map consists of binary code whereas if more than one point is selected, it gives Digital Number (DN) according to the times of visibility.



Elevation Map: dem_buyuk1
Observer Layer: Structure_Point
Observer Height: 150
Distance Limit: 100

Figure 4.22 Interface of Viewshed Analysis for Points

Visibility analysis is realized with using the interface shown in the Figure 4.23. In this analysis, weights can be assigned to the defined areas with polygons which are thought to be important. For the present investigation, this parameter is not used and therefore the weight values are not defined. Resultant maps are the same as multiple point based visibility analyses. They give DN numbers to the areas according to how many times the areas are seen.



Elevation Map: dem_buyuk1
Path Layer: path
Observer Height: 0
Starting Point: ● A ○ B
View Angle: 120 ° ☐ No restriction (360° view)
Distance Limit: 100
Polygon Layer: weight
Weight Attribute: weightt (Real)
Limit to Polygons: ☐
Distance Factor: 0 map units ('0' to disable)
Descriptive Text:

Figure 4.23 Interface of Visibility Analysis

Point Based Viewshed Analyses

Point based viewshed analyses are performed from the points defined by the archaeologists. These points are generally selected on the buildings. Measurement platform, Acropolis and Demeter Temple are the observation points. Besides, the visibility and the cumulative viewshed analyses are performed for the observation towers on the city wall.

The observers' height, selected as 165 cm, and each analysis are performed both for the extent of 1000 m and 3000 m.

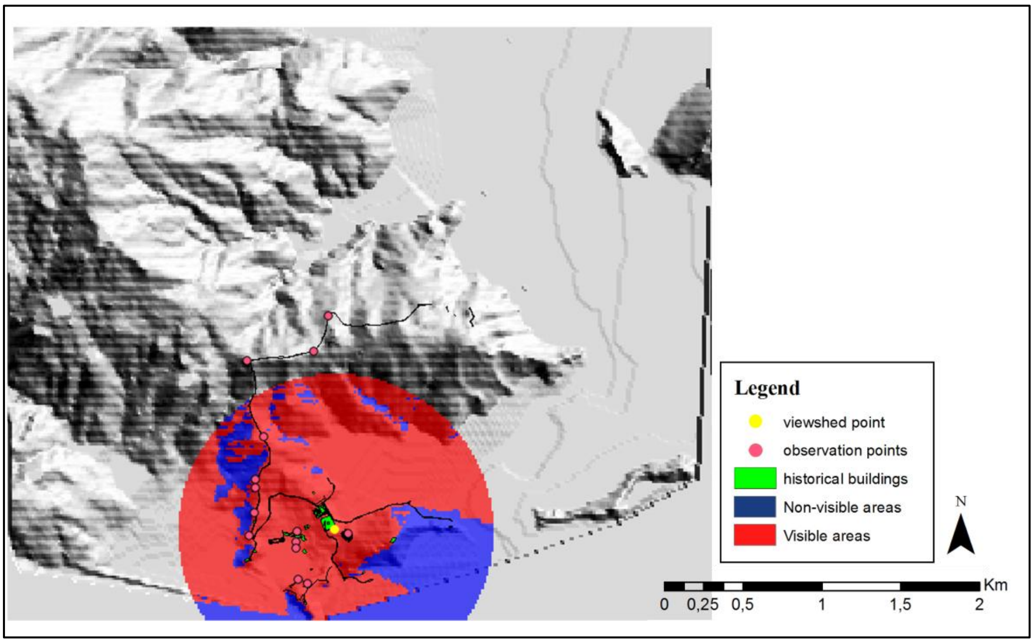


Figure 4.24 Viewshed analysis from measurement platform (1000m)

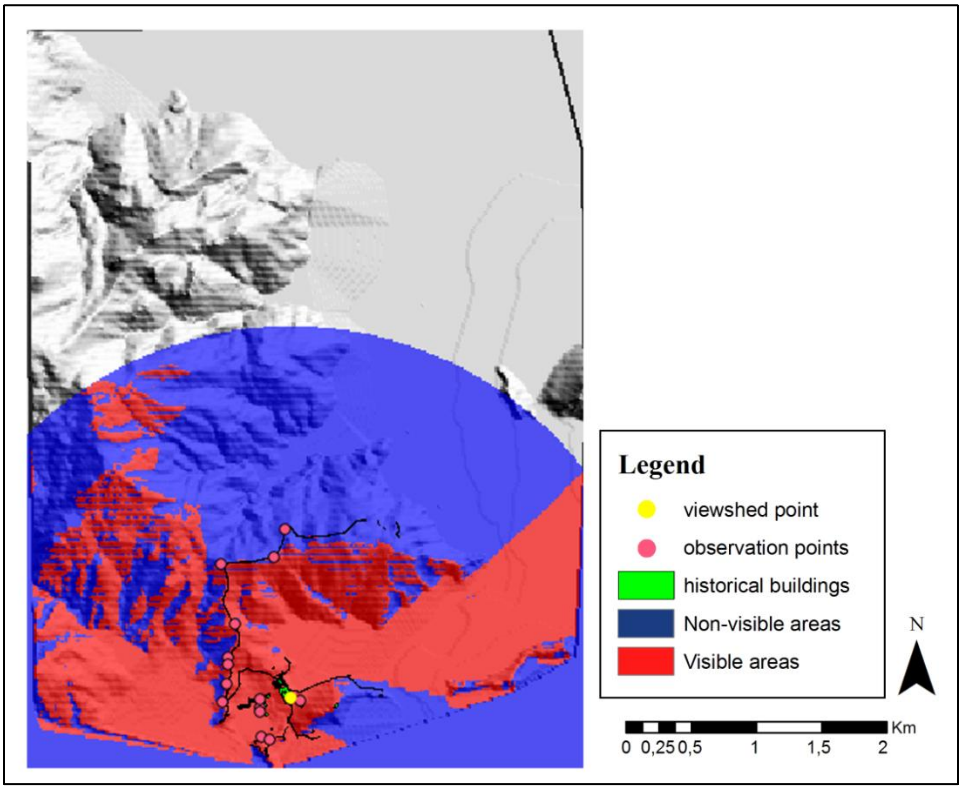


Figure 4.25 Viewshed analysis from measurement platform (3000m)

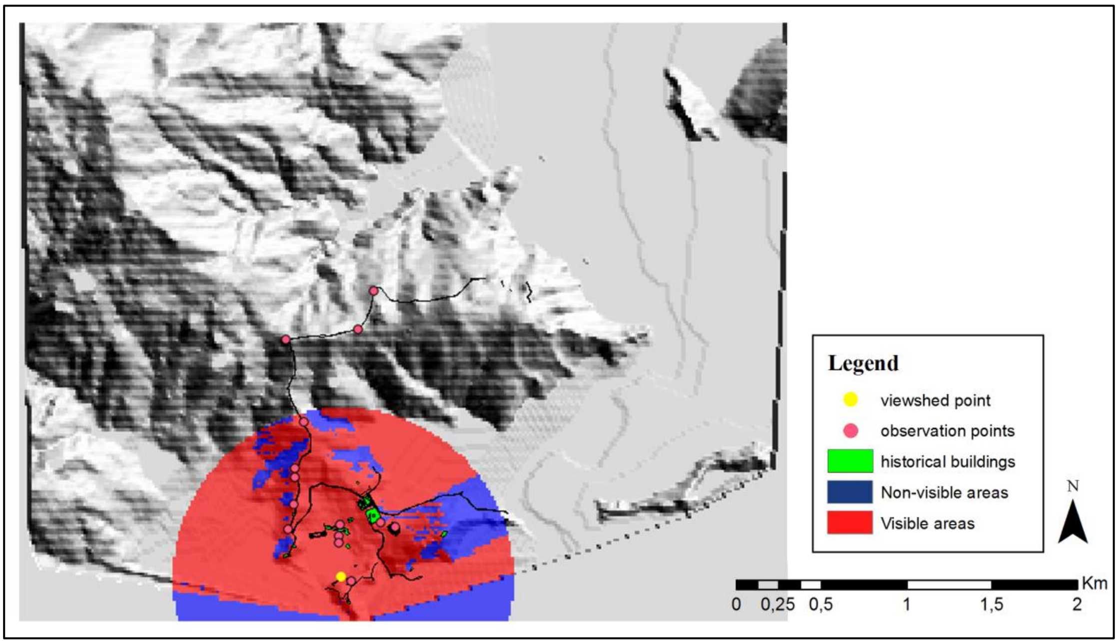


Figure 4.26 Viewshed analysis from Acropolis (1000m)

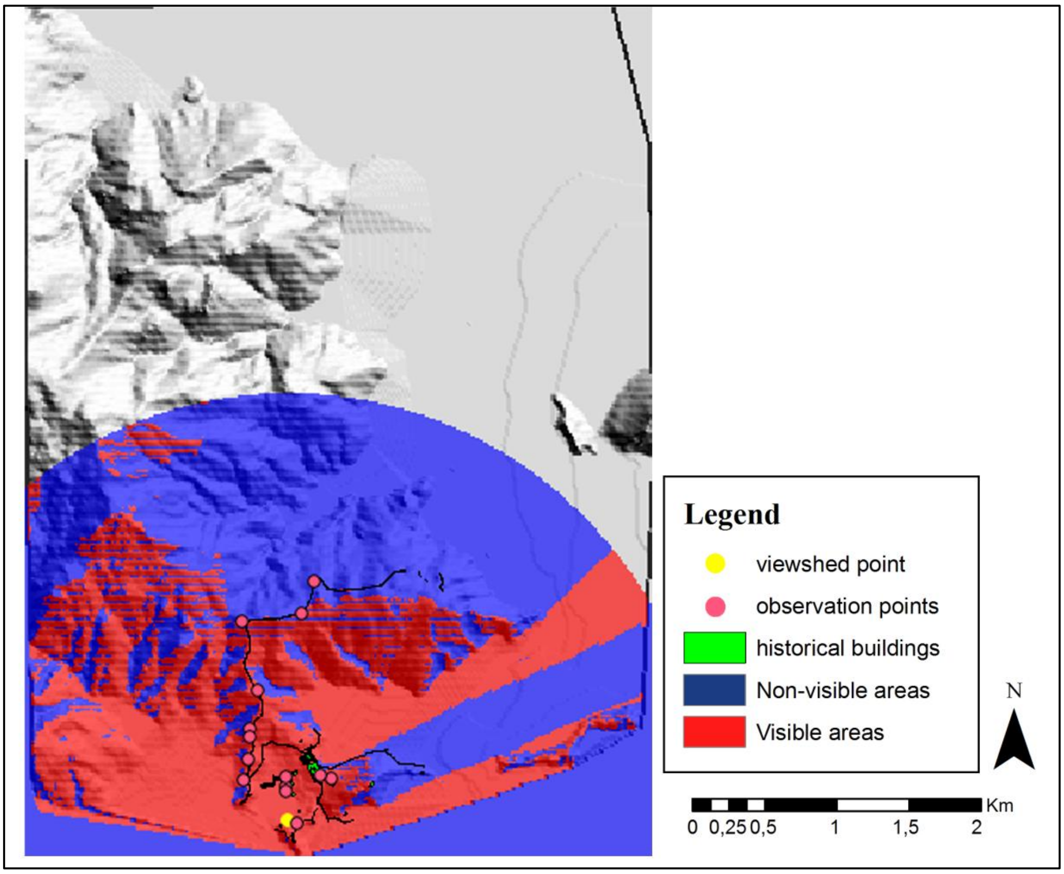


Figure 4.27 Viewshed analysis from Acropolis (3000m)

Results of viewshed analyses performed from the measurement platform are presented in Figures 4.24 and 4.25. The inside of Kaunos, i.e the inside of the city wall, is mostly visible and some areas outside of the city wall can be seen from the observation point.

The results of Acropolis viewshed are nearly the same as the measurement platform. Here, inside of the Kaunos can be seen as well. However, in the eastern side of some parts of the area, which is behind the small castle, the south city wall cannot be seen because it is located on the hill (Figure 4.26 and 4.27).

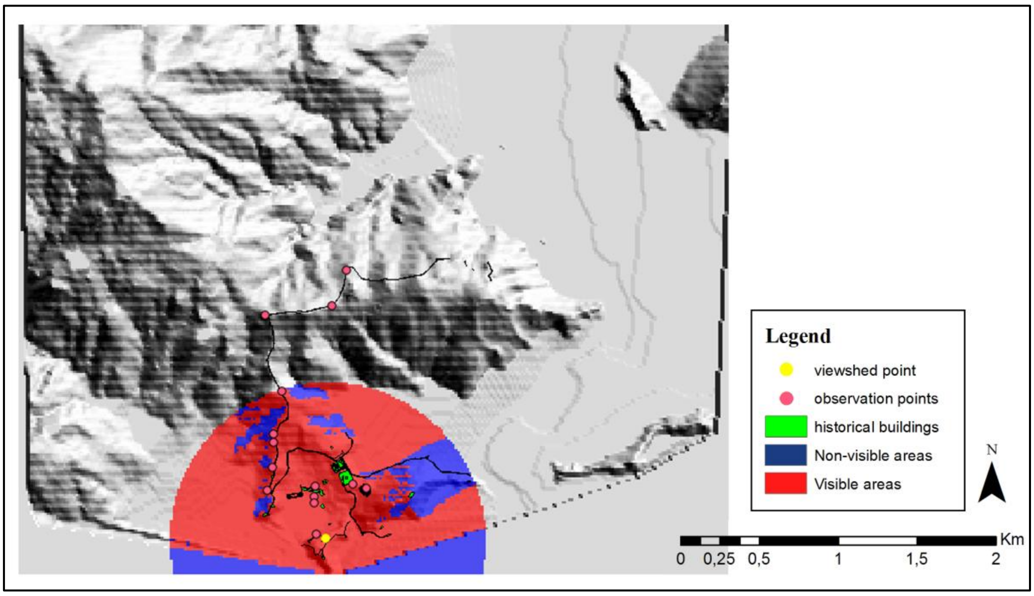


Figure 4.28 Viewshed analysis from Demeter Temple (1000m)

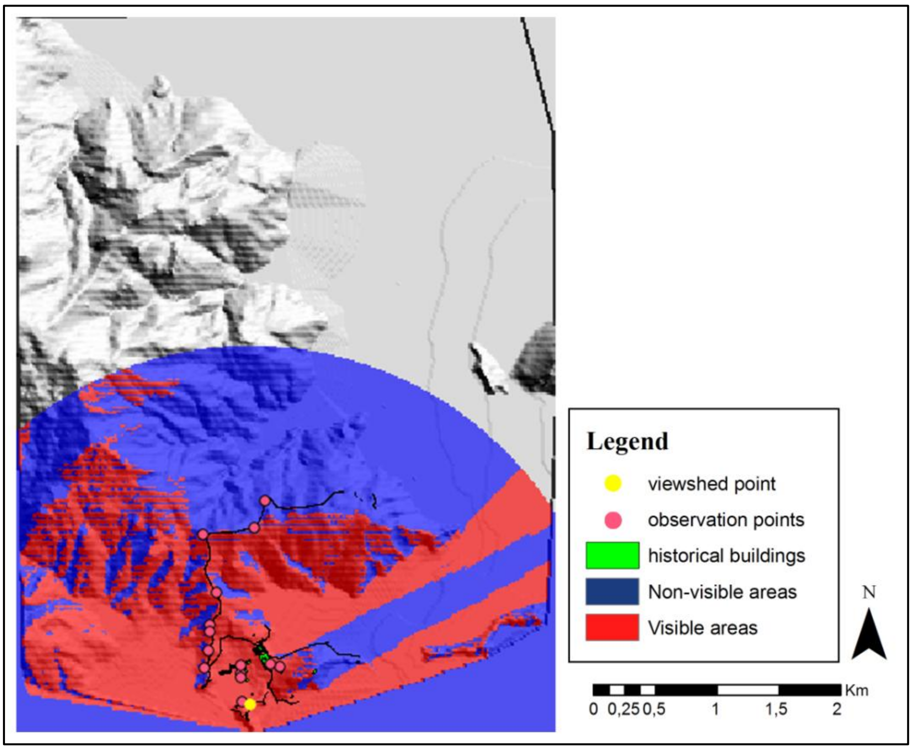


Figure 4.29 Viewshed analysis from Demeter Temple (3000m)

The visible areas from Demeter Temple are seen in Figure 4.28 and 4.29. The resultant maps are similar to the results of Acropolis.

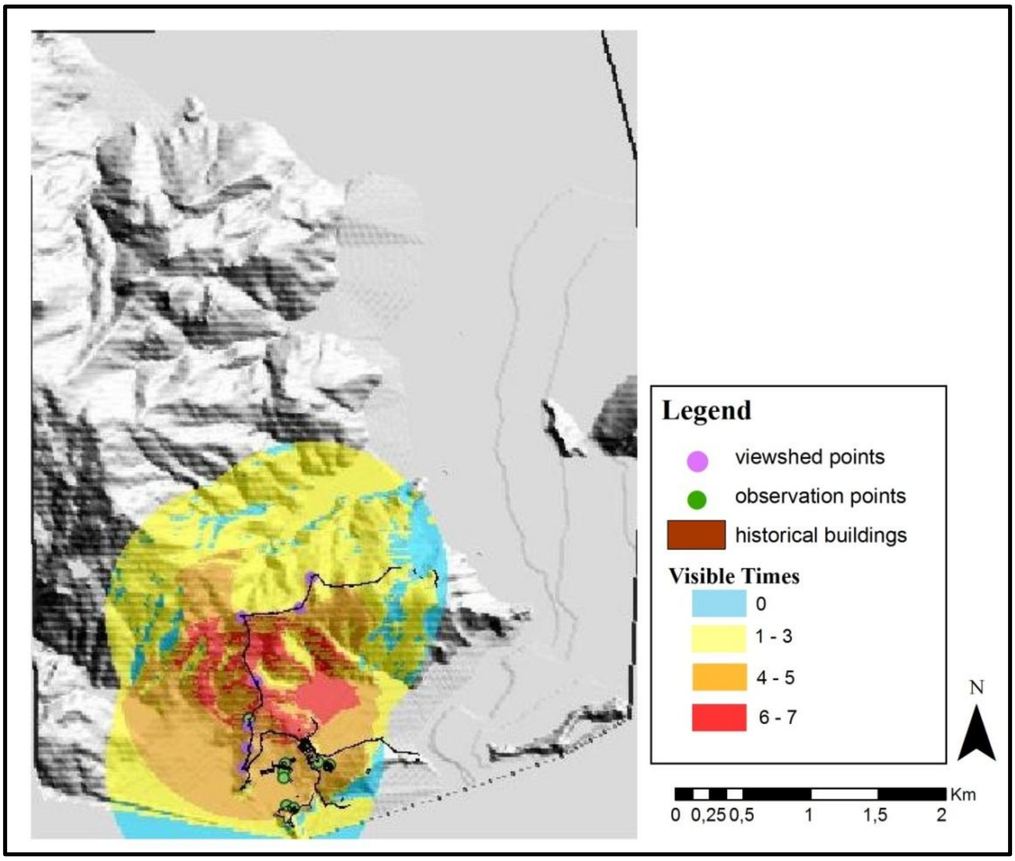


Figure 4.30 Viewshed analysis from tower of city wall (1000m)

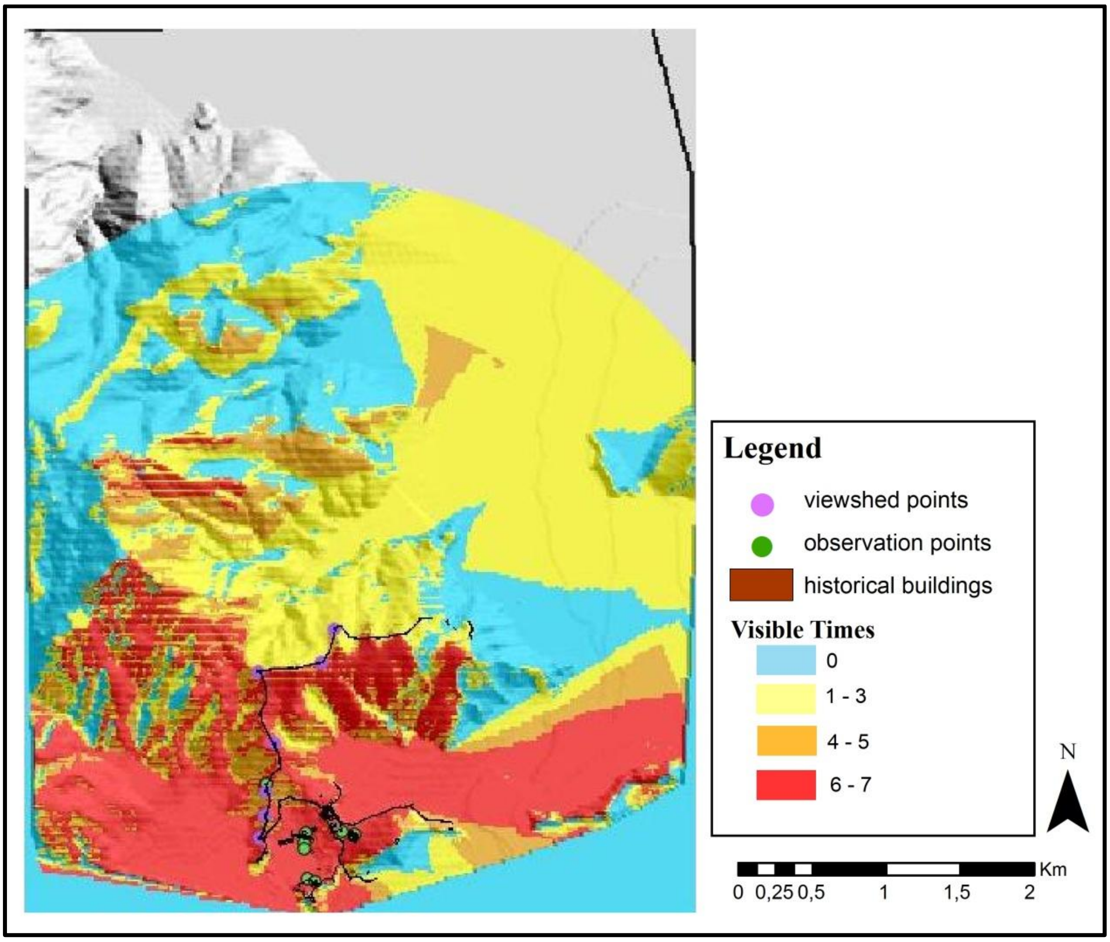


Figure 4.31 Viewshed analysis from tower of city wall (3000m)

Finally, the viewshed analysis is carried out for seven points which are on the tower of the city wall (Figure 4.30 and 4.31). Blue areas in the figures represent the areas that are not visible, whereas the red areas mostly show the places that can be seen from the points on the city wall.

Path Based Viewshed Analyses:

Path based viewshed analyses are performed from the coastline of harbor, west city wall, north city wall and the rest of the city wall. As point based viewshed analyses, these are performed for 1000 m and 3000 m extent. The observers' height is again selected as 165 m.

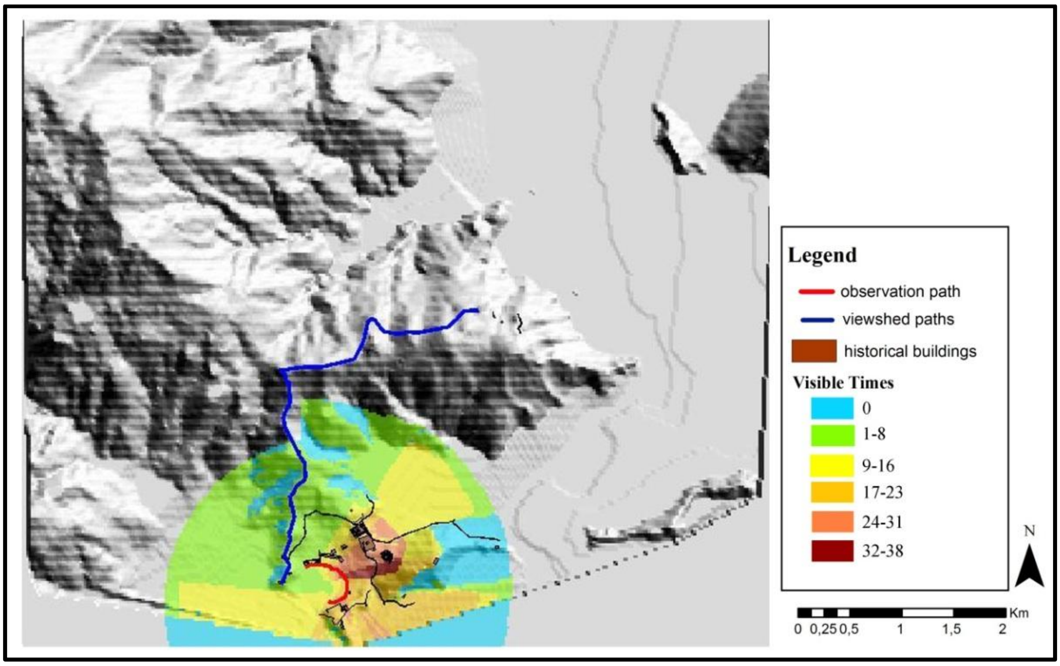


Figure 4.32 Viewshed analysis from coastline of harbor (1000m)

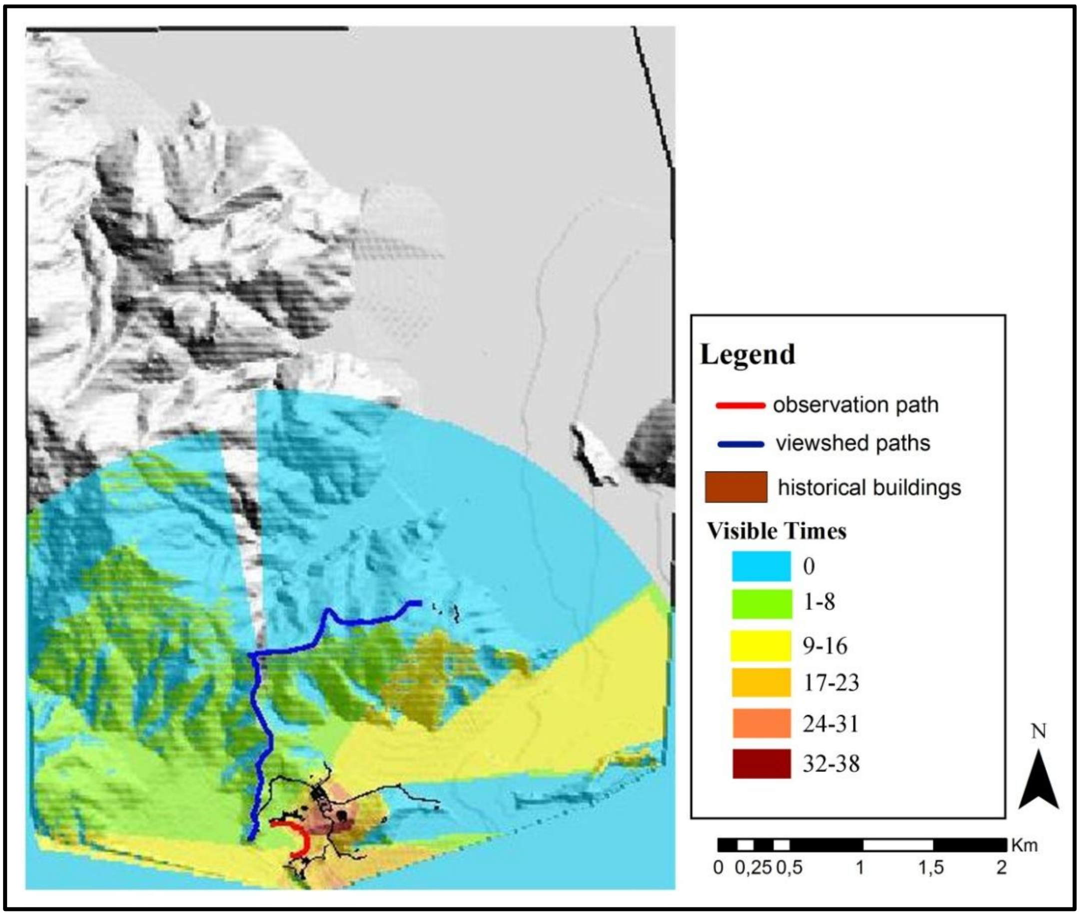


Figure 4.33 Viewshed analysis from coastline of harbor (3000m)

Brown areas in Figures 4.32 and 4.33 are the most visible ones from the observation path which is the coastline of harbor. Inside of Kaunos where buildings are located can be seen commonly. Outside of the city wall is not seen due to the elevation.

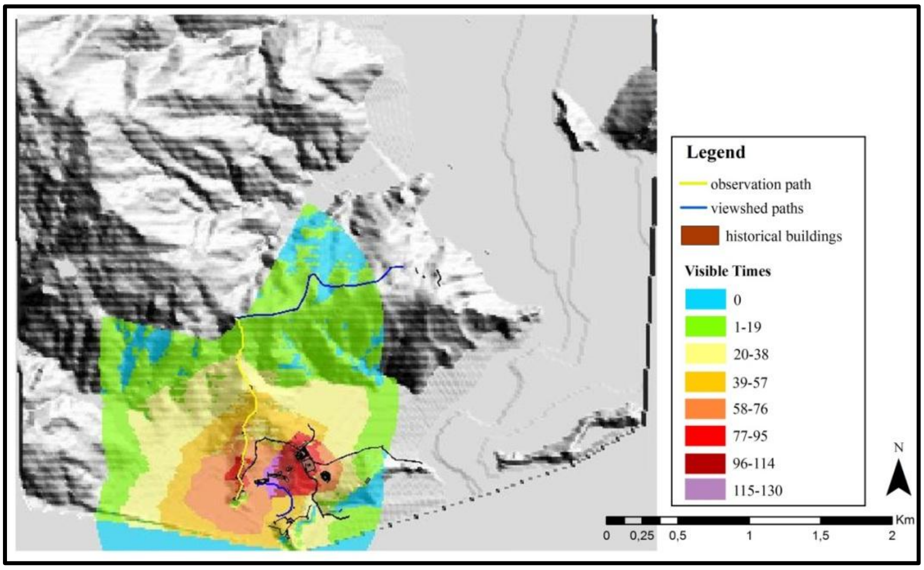


Figure 4.34 Viewshed analysis from west city wall (1000m)

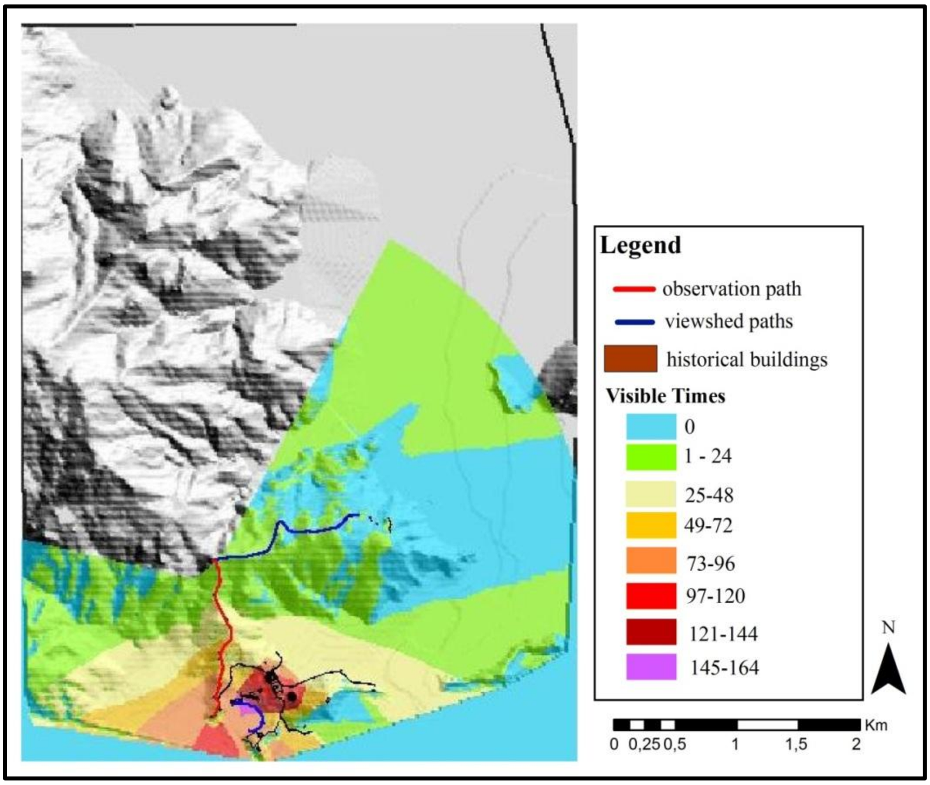


Figure 4.35 Viewshed analysis from west city wall (3000m)

Secondly, the path based viewshed analysis is performed from the path of the west city wall. In Figure 4.34, purple areas represent the most seen places, brown and red areas are commonly visible from the defined path. The inside and the vicinity of the Kaunos are commonly visible (Figure 4.34 and 4.35).

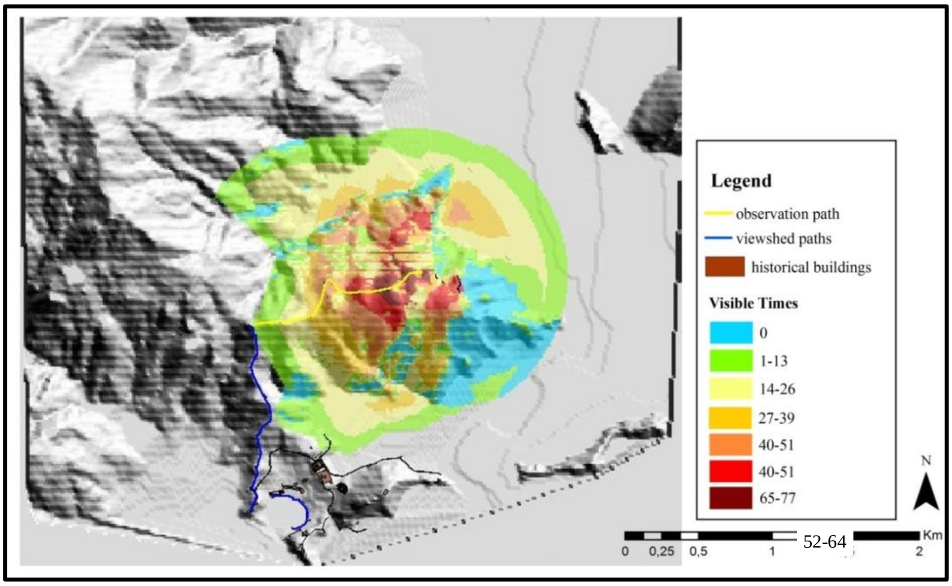


Figure 4.36 Viewshed analysis from north city wall (1000m)

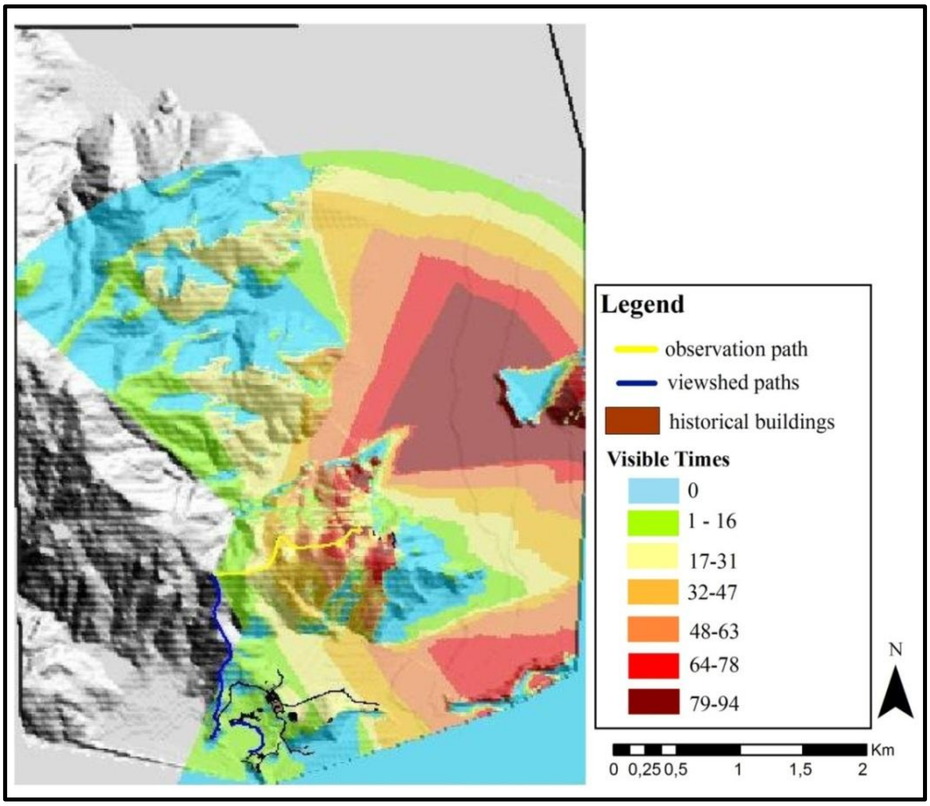


Figure 4.37 Viewshed analysis from north city wall (3000m)

Areas visible from the northern city wall are outside of Kaunos. Especially the side of Dalyan River is visible from the path of the northern city wall (Figure 4.36 and 4.37). This can be related to the fact that this area was used as harbour in ancient times. Thus, people could avoid the attacks which might have come from the sea.

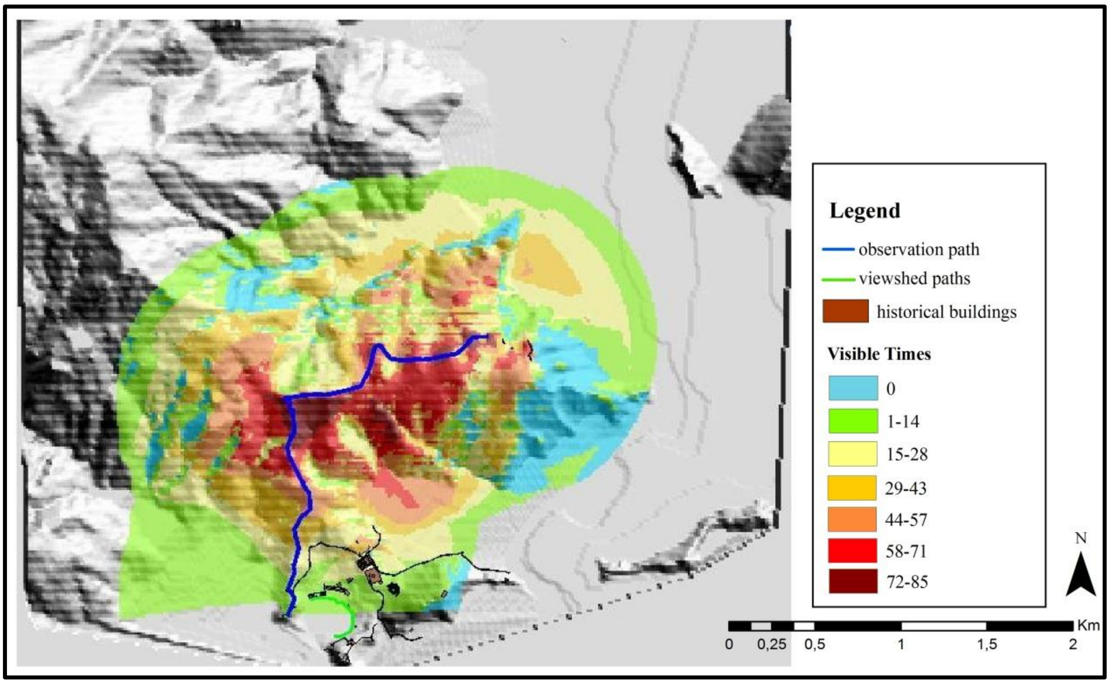


Figure 4.38 Viewshed analysis from whole city wall (1000m)

Finally, the path based viewshed analysis is performed from the whole city wall (Figure 4.38). Blue areas in Figure 4.38 are those which are not seen from anywhere of the wall. The mostly seen areas are situated far from buildings. This may be the reason for the surveillance of enemy.

When the viewshed analyses are investigated, both path based and point based, critical areas can be seen from the observation location. The inside of the city wall as well as some parts outside of the wall can be visible from the points which are selected as observation location. Moreover, as it can be seen from the results of path based viewshed analyses (Figures 4.32-4.38), the side of river which used to be a harbour in the past times is particularly visible.

4.4.2 Spatial Data Analyses of Area Data

As it can be understood from the site-based questions of archaeologists which are specified in Section 4.2.1, they want to analyze spatial pattern or trends of the coins collected over a set of areas.

With area data analysis, spatial variations in the coins and glass variables can be analyzed, in terms of spatial arrangement of measurement areas. Moreover, relationship between coins, spatial arrangement of zones and other attributes, which are recorded for each zone such as glasses, time of usage intervals etc., can be determined with statistical models of area data analysis.

Hence, in order to answer the following spatial decision problems of archaeologists, firstly, visualization of the coin and glass data is made.

1. Is there any clear relationship between coins and other remains in the region?
2. Is there any clear relationship between coins and the type of land use?
3. Is the coin distribution affected by the glass distribution in the region?
4. Are there any differences among coin findings in the periods? If there are any differences in the periods, which locations are related to the coin findings in the most significant period?

Secondly, explorations in order to explore first and second order effects are performed. Finally, statistical models are constructed to test hypothesis developed from exploration and visualization.

Visualization of Coin and Glass Data in Kaunos:

Coin and glass data are visualized in terms of total values and values according to periods. As seen in Figure 4.39, most of the coins that were found belong to Hellenistic Period. In Apollon Holy Place, Temple Terrace, Agora and Stoa, the total number of coins is high and excluding Archaic-Classic Period, coins were found throughout all the periods. This shows the continuity in these areas. Especially, Hellenistic Period and Early Byzantine Period have the largest values in these areas. Coin findings in Archaic-Classic Period are very rare.

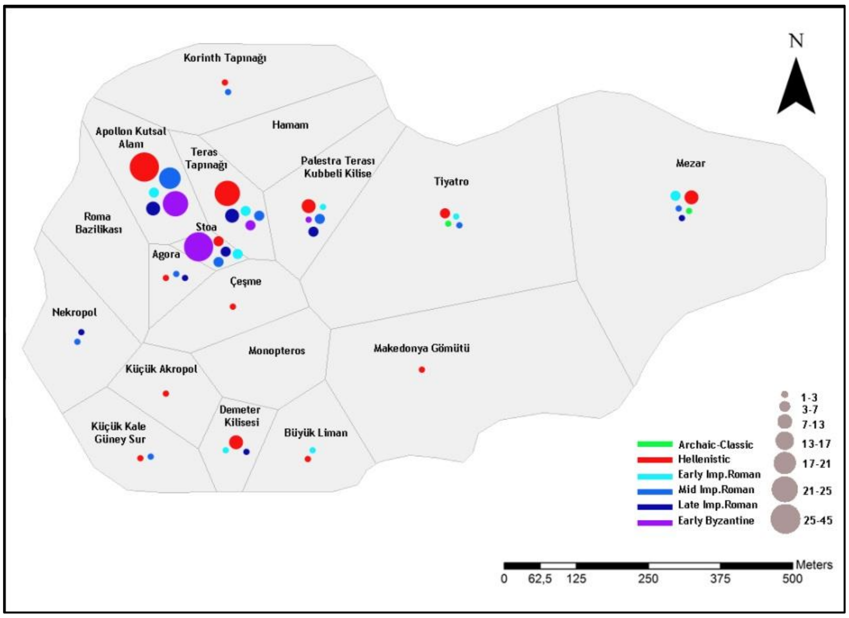


Figure 4.39 Coin map in terms of period

The glass findings in Stoa, Temple Terrace, Monopteros and Graveyard are rich (Figure 4.40). As distinct from the coin distribution, glass findings are common during the periods of Early and Late Imperial. It is noticeable that although there are no coins in Monopteros, there is a plenty of glass found in this zone whereas there is no glass in Apollon Holly Place. This might show that the relationships between the glass and the coin findings may not exist.

However, Kulakoğlu stated that artifacts should be evaluated with its environment. When the coin findings in the adjacent areas of Monopteros are investigated, small numbers of coins are found which belong to the Hellenistic Period (Figure 4.39). Hence, archaeologists infer that coins may not be found in Monopteros (personal communication, January 14, 2012).

On the other hand, glass findings are densely found in the adjacent areas of Apollon Holy Place (Figure 4.40). Thus, archaeologists infer that this area should be studied in detail.

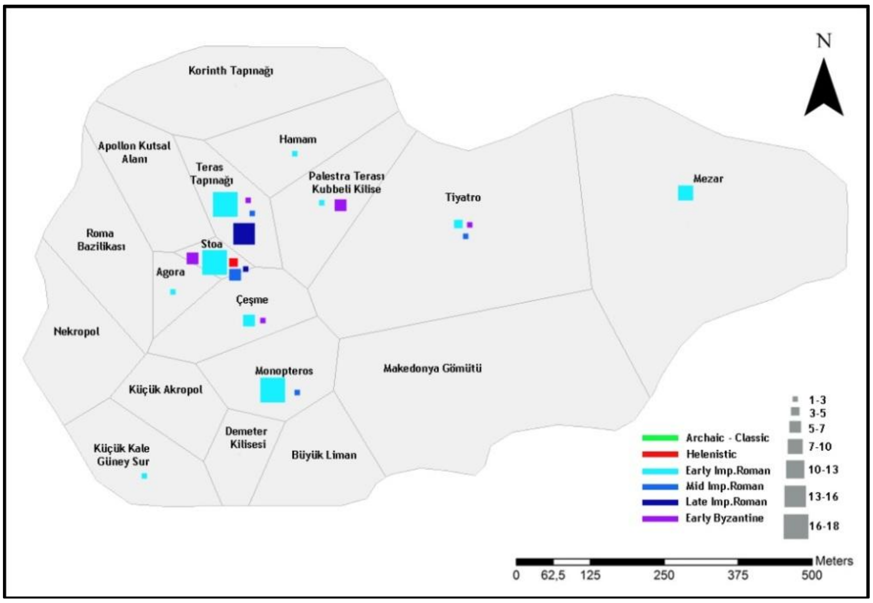


Figure 4.40 Glass visualization map in terms of period

In order to simplify the statistical analysis, ratios according to the sum of coin and glass numbers in each period are obtained. The ratios of coin and glass findings are mapped using the choropleth maps considering periods in order to visualize the distribution of these findings with respect to time and spatial location. These maps are summarized in Figure 4.41 and 4.42 and illustrated in Appendix A.

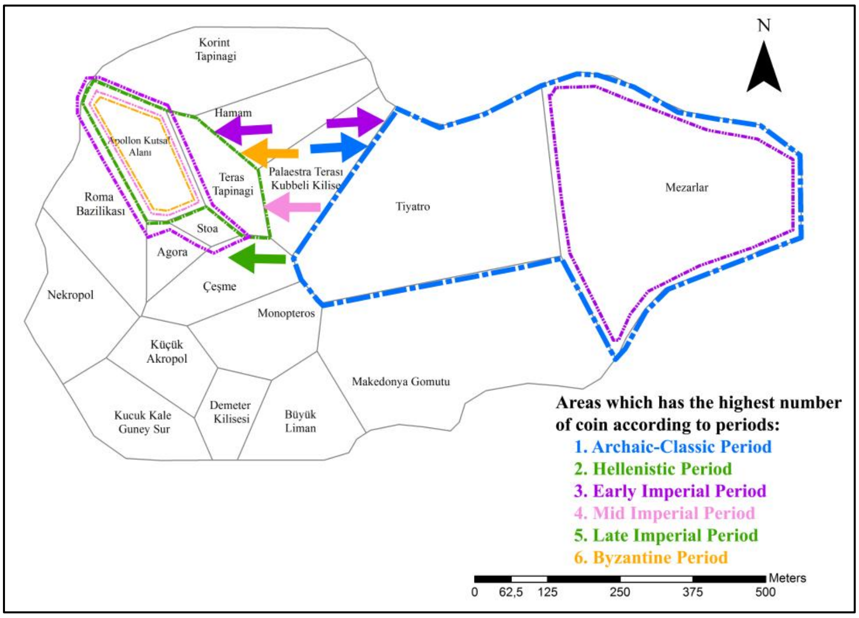


Figure 4.41 Ratio of coin finds according to periods

As seen in Figure 4.41, in the Archaic-Classic Period, coin findings are rich in the north eastern part of the study region. However, in the Hellenistic Period, mostly coins were found in the north western side, in Apollon Holy Place and Temple Terrace. Early Imperial Period is mixture of the first two periods. Coin ratios are high in the zones of Apollon Holy Place, Temple Terrace and Tombs. In Mid Imperial Period, coin ratio is high just in the Apollon Holy Place. Coin density location in Late Imperial Period is similar with Hellenistic Period. In Byzantine Period, coin ratio is high in the north western part of the study region, too.

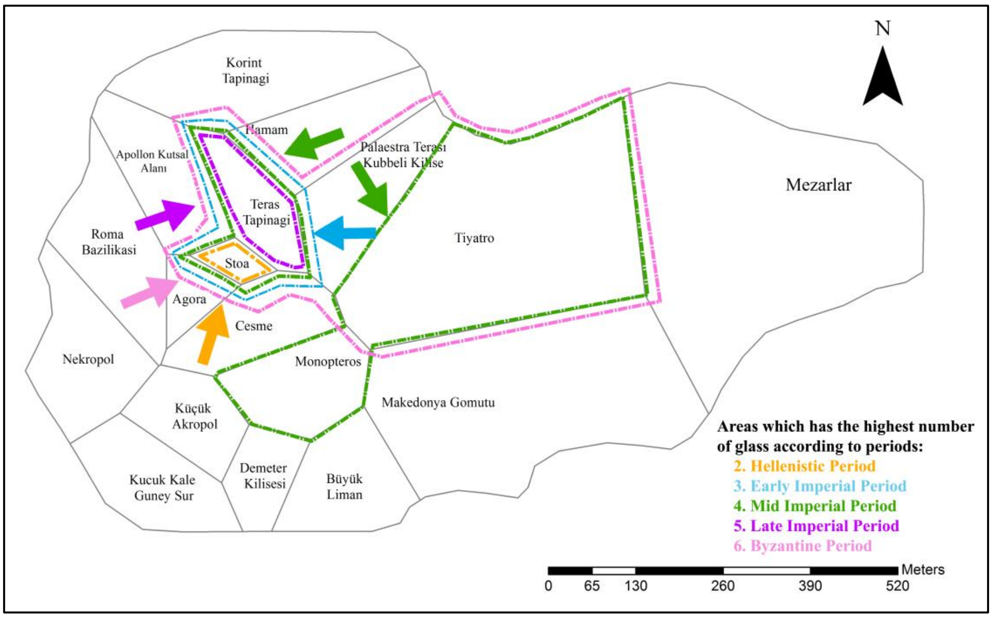


Figure 4.42 Ratio of glass finds according to periods

As seen in Figure 4.42, there are no glass findings in the Archaic Classic Period. In the Hellenistic Period, glass findings are rich in Stoa. Besides, in Early Imperial Period, glass findings were commonly found in Stoa and Temple Terrace. When the Mid Imperial Period is considered, glasses were found also in the zones of Monopteros and Theatre. However, in the Late Imperial Period, glass ratio is high in the Temple Terrace. In Early Byzantine Period, glasses are rich at the center of the study region.

In order to analyze, whether coin and glass distribution related to slope and aspect of the region, slope and aspect maps of the region are created.

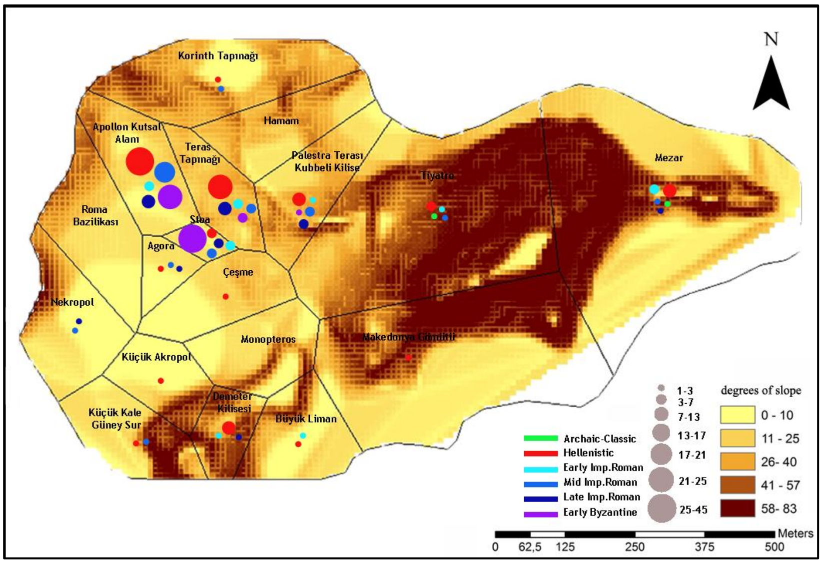


Figure 4.43 Slope and coin distribution

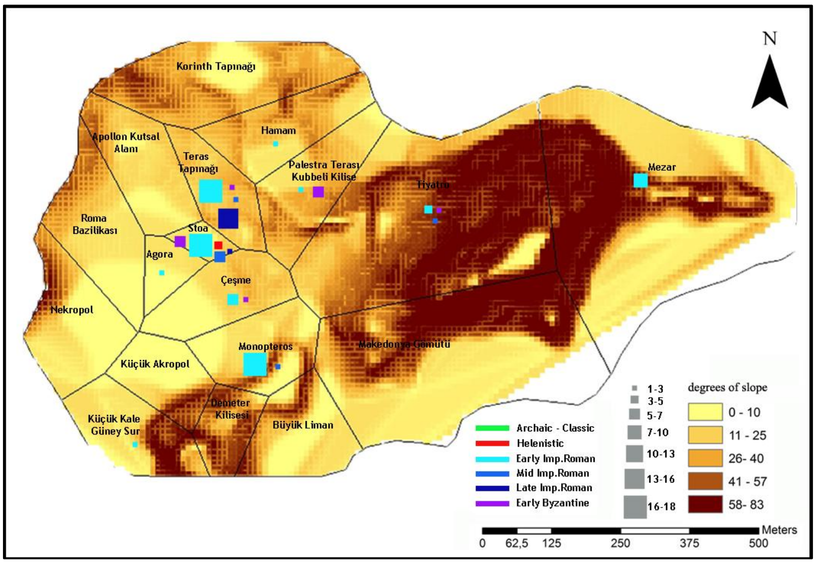


Figure 4.44 Slope and glass distribution

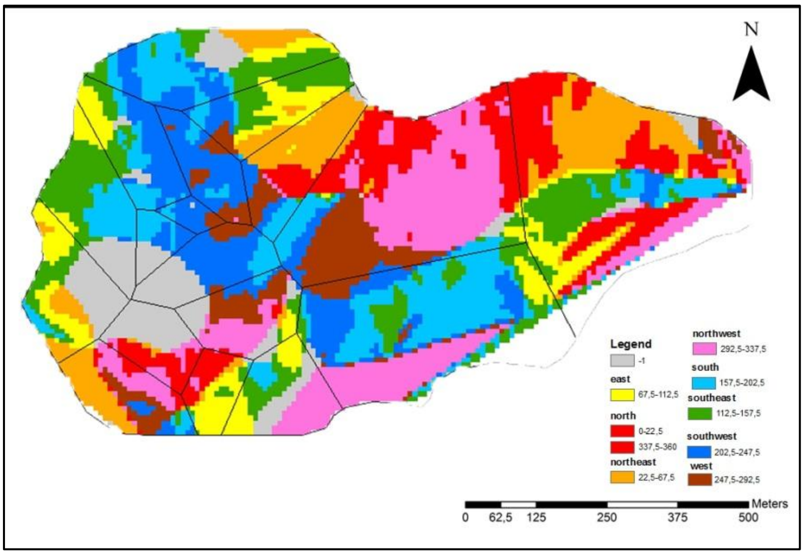


Figure 4.45 Aspect map of the region

As seen in Figures 4.43 and 4.44, although coin and glass distribution is rich in the flat areas, they were also found in the rough areas. Thus, it can be said that the slope does not affect coin and glass distribution in the study region. When looking at Figure 4.45, it is visible that coin and glass distribution do not depend on aspect.

Exploration of Area Data in Kaunos:

In order to estimate the global trends and the variations in the area data, how the mean value of the attribute varies across the study region is investigated. Spatial moving average is applied for both coin and glass ratios in terms of six periods. Resultant maps are summarized in Figure 4.46 and 4.47 and illustrated in Appendix B. The global trend is analyzed for the coin and glass findings according to the periods. The global trend is analyzed by using Spatial moving averages. In the Equation 3.1, for the proximity matrix, common boundary-based matrix is used.

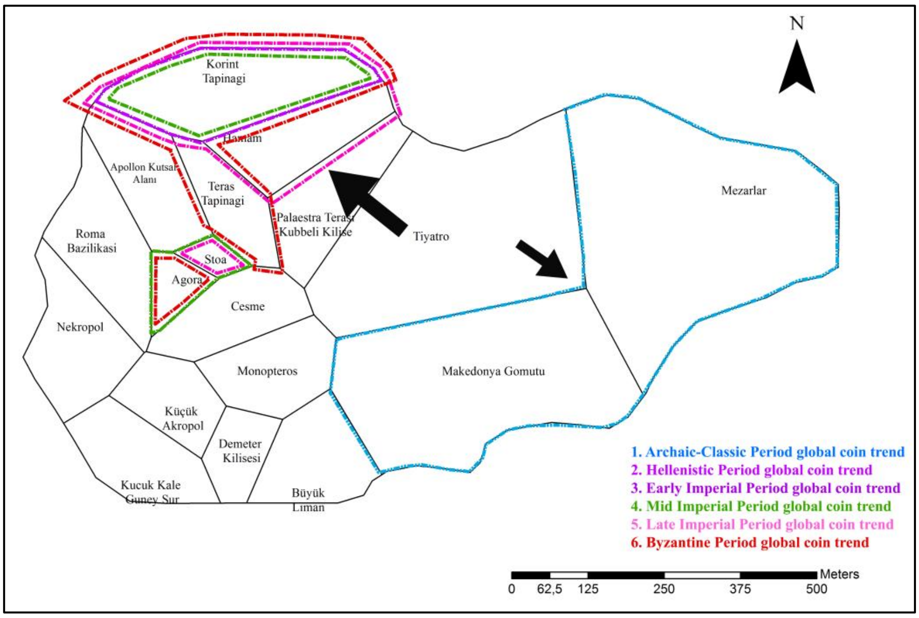


Figure 4.46 Global trend in coin distribution

In the Archaic-Classic Period, trend in the coin distribution proceeded through the eastern side of the study region (Figure 4.46). On the other hand, for the rest of the five periods, global trend is through the north-western side.

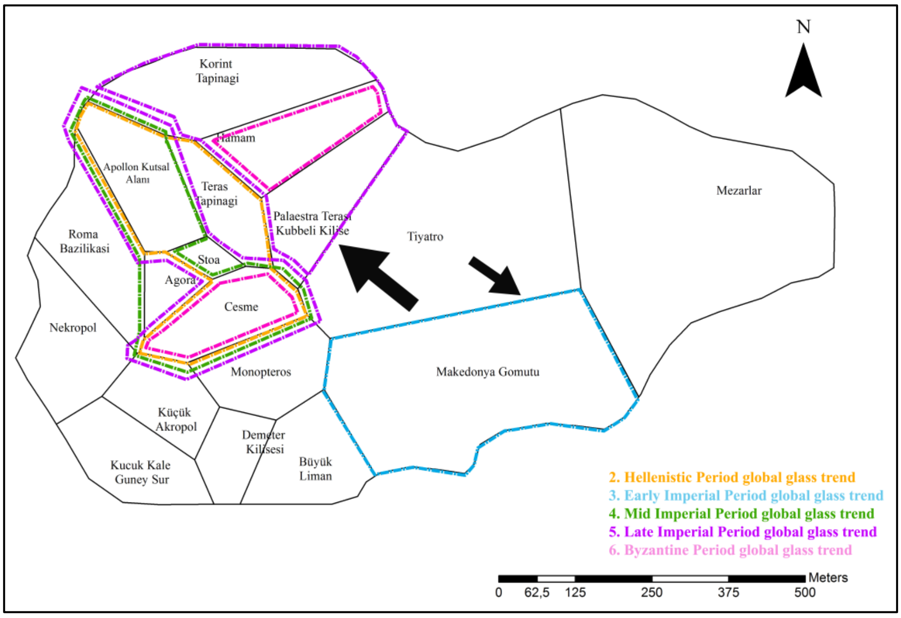


Figure 4.47 Global trend in glass distribution

As seen in Figure 4.47, only in Early Imperial Period trend is through the south-eastern side of the region. The rest of the five periods, trend is through the north-western side.

In the area data analysis, kernel estimation is not used as a common approach. Instead of storing the information about the entire area, areas associated with some appropriate point locations are used for storage. This point can be the centroid of the area. Here, in this case, it is concluded that building zones from measurement points via Thiessen polygons, attribute information are stored in the centroid of the built zones. Bandwidth is 30 m. The clusters of coins according to the periods can be seen in the Figures 4.48- 4.53.

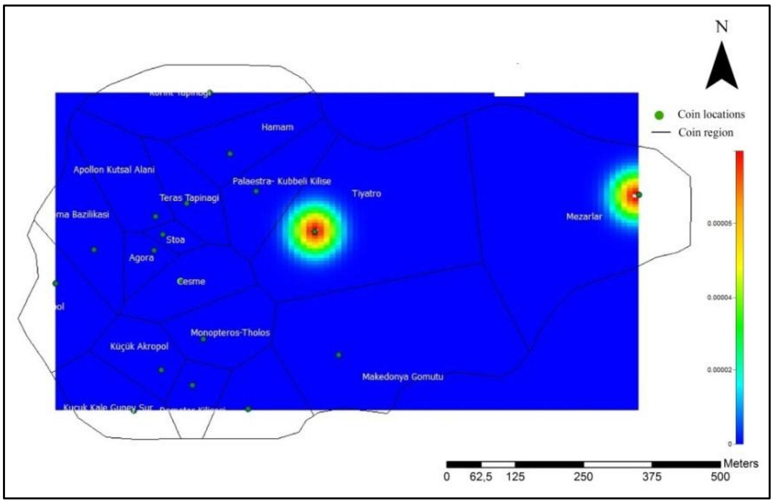


Figure 4.48 Archaic Classic Period-Kernel Estimation

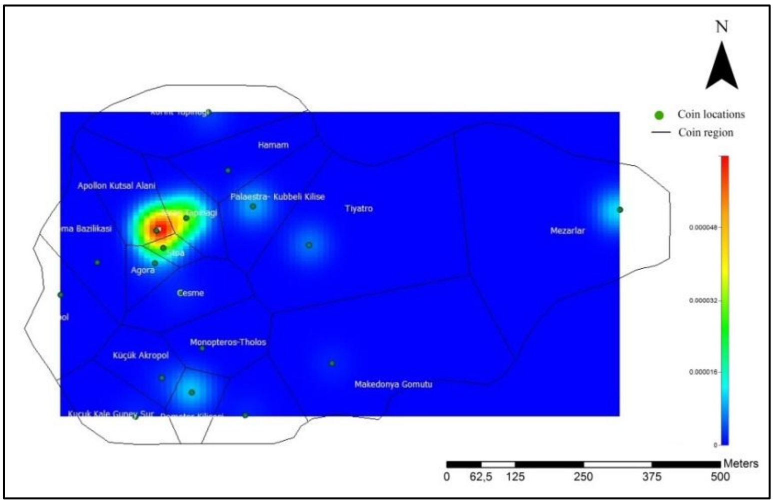


Figure 4.49 Helenistic Period-Kernel Estimation

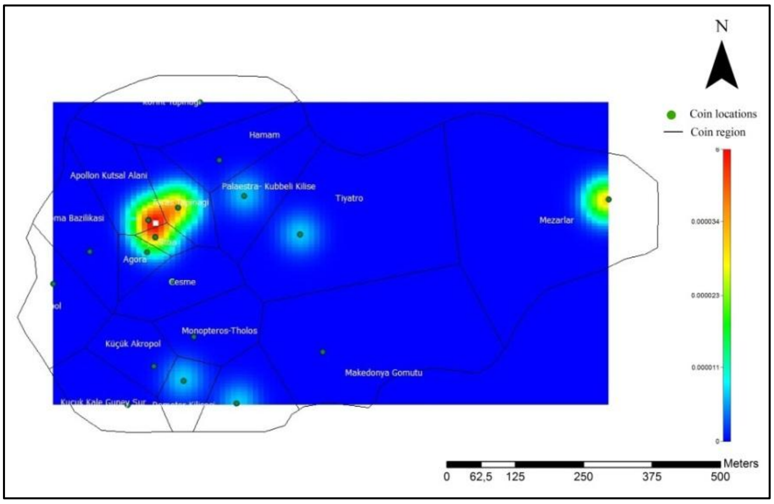


Figure 4.50 Early Imperial Period-Kernel Estimation

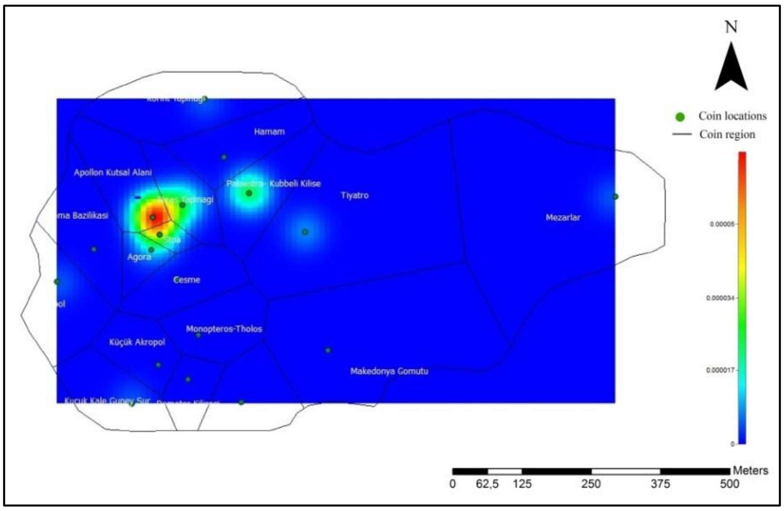


Figure 4.51 Mid Imperial Period-Kernel Estimation

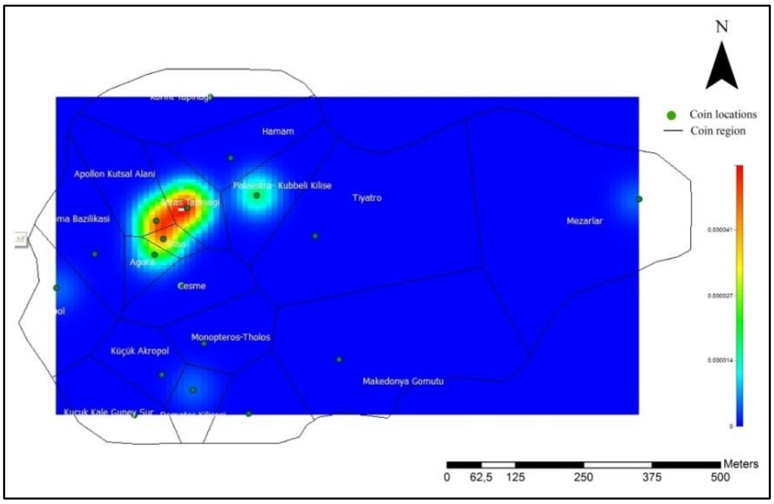


Figure 4.52 Late Imperial Period-Kernel Estimation

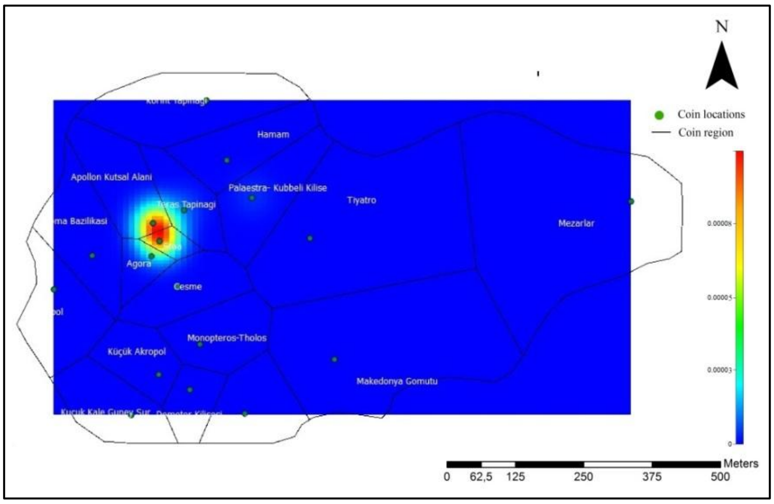


Figure 4.53 Early Byzantine Period-Kernel Estimation

In order to analyze second order effects in the study area, Moran's I (spatial autocorrelation) values are calculated for different spatial lag distances; 2, 4, 6 and 8. Spatial autocorrelation values are plotted against the lag distances.

High numbers of coin findings are located in closer zones with similar percentages. In small lags, there are I values close to 1 and after lag 4, it is clearly getting smaller. Until lag 8, there is positive spatial autocorrelation whereas after lag 8, there is negative and small spatial autocorrelation (Figure 4.54).

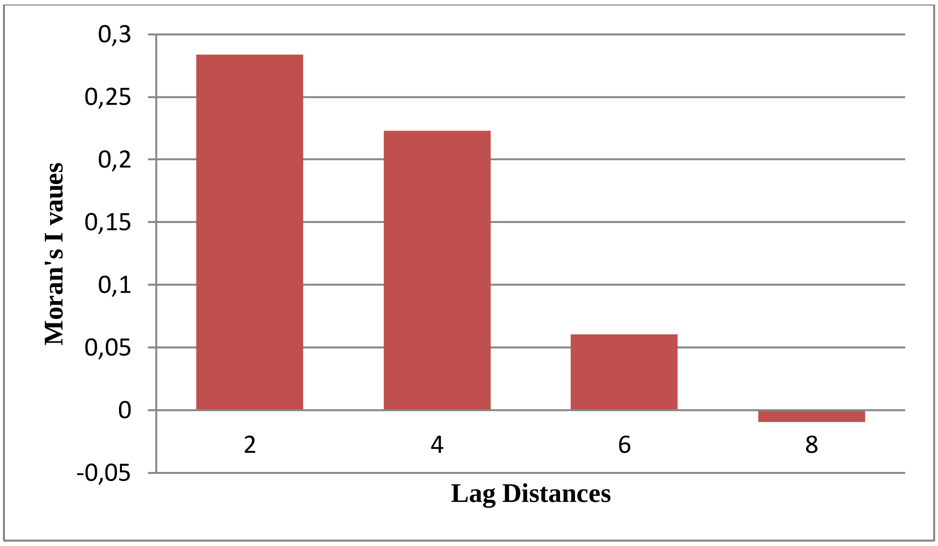


Figure 4.54 Moran's I for coin

Similarly, at a small distance, there is clustering in the glass distribution. However, in the lag 4, there is negative correlation, which means that at the small distances there might be no glass findings around clusters of glass. It shows small and positive spatial autocorrelation in lag 6 while in the lag 8, there is, again, negative spatial autocorrelation (Figure 4.55).

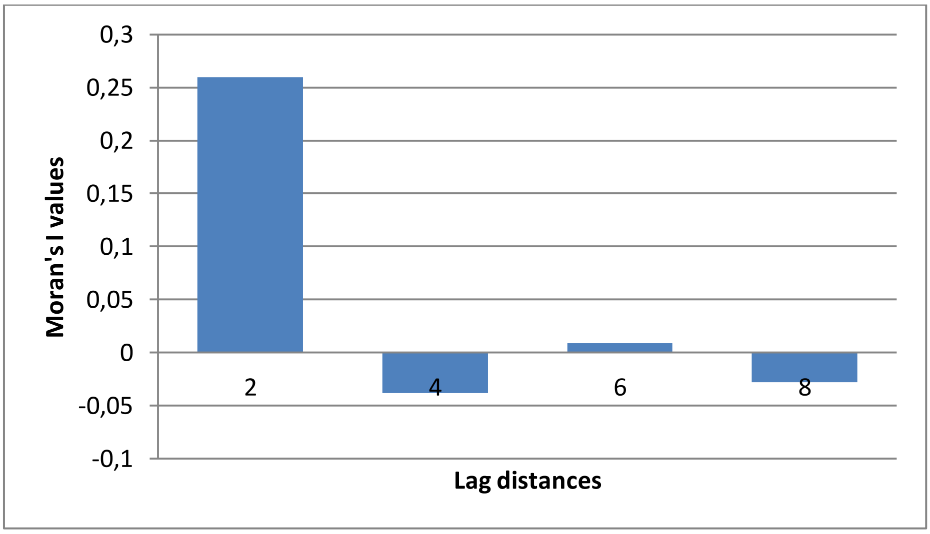


Figure 4.55 Moran's I for glass

Modeling of Area Data in Kaunos

In order to establish relationship between coins and other specified parameters, modeling is required. In this case, three models are constructed and, non-spatial (Multiple Linear Regression-MLR) and spatial regression (Spatial Auto Regression-SAR and Geographically Weighted Regression-GWR) are performed. The data set of Kaunos for the regressions is composed of the dummy variables for each zone and each type of land and scale variables.

Dummy coding is a way of representing the categorical variables (male, female etc.) using only zeros and ones. For example, if it is needed to be measured religiosity, there might be the categories of Muslim, Jewish, Catholic, Protestant etc. However, these categories cannot be included in the regression analysis. Hence, categories of religiosity are represented using zeros and ones by dummy coding (Field, 2009).

In this study, dummy coding is used to represent whether a zone has coin or not. Moreover, dummy representation is preferred because independent and dependent variables are the same which were coin number. Firstly, the number of dummy variables is calculated. There were 18 zones so there would be 17 dummy variables. The reason for it, there should be a baseline group in order to eliminate the redundancy. Hence, the baseline category is selected as Monopteros.

After defining the dummy variables for zones, dummy variables for type of land use are created. First of all, which areas are related to which type of land use is determined. Monopteros, Demeter Temple, Small Castle Southern City Wall, Apollon Holy Place, Temple Terrace and Korinth Temple constitute the Holy Place. Trade Area is composed of Big Harbour, Nekropol and Lesser Acropolis. Graveyard has the areas of Macedonian Tomb and Graveyards. Theatre, Fountain, Agora, Roman Basilica and Bath compose the Socio-Cultural Areas. Secondly, dummy variables are created for the type of land use.

In the data set, besides dummy variables, there are scale variables which are slope, time of usage of each zone (yy) and glass ratio. Scale variables represent numerical measures. For example, a scale ranking of 1 to 5 would be a scale variable. Three models are selected to test the hypotheses about coin finds in Kaunos.

The first model deals with the effect of 18 zones on the coin finds. This helps answering how remains and usage periods of zones affect the coin findings. The second model is related to the same effect; however, it deals with specific period of the coin distribution. This reveals differences between periods related in terms of these factors. The last model aims to explore whether the type of land use significantly affects the coin findings.

By utilizing R, MLR analysis is conducted and then SAR is used to analyze the spatial auto regression. Finally, GWRs are performed to analyze the spatial variations in relationships. Besides, it explores the spatial non-stationarity for the given global bandwidth and the chosen weighting scheme.

Model 1:

In order to answer which parameters (other remains, glass findings, time of usage of each zone) affect coin findings, following model is constructed:

$$\begin{aligned} coin\ total = {} & b_0 + b_1 kucukd + b_2 makd + b_3 kkd + b_4 blimand + b_5 romad + \\ & b_6 stoad + b_7 akad + b_8 ttd + b_9 cesmed + b_{10} monopd + b_{11} tiyatrod + \\ & b_{12} palaestrad + b_{13} hamamd + b_{14} demeterd + b_{15} korinthd + b_{16} mezard + \\ & b_{17} agorad + b_{18} nekropold + b_{19} slope + b_{20} yy + b_{21} glassratio + \varepsilon_i \end{aligned} \quad (4.1)$$

In the equation (4.1), coin total is the number of total coin findings in the study area, **xxxd (kucukd,makd,…,nekropold)** is a set of dummy variables which depict whether a zone has coin findings or not. Table 4.9 shows the dummy variables and original name of related zones in order to clarify the name of variables.

Slope is average slope value of the zone; **yy** is usage period of the zones and **glassratio** is the ratio of "number of glass finds per each zone / number of total glass finds" and $b_i$is the coefficient of the predictors.

Table 4.9 Dummy variables of zones

Dummy Variables	**Original Zone Names**	
kucukd	Kucuk Akropol	Lesser Acropolis
makd	Makedonya Gomutu	Macedonian Tomb
kkd	Kucuk Kale Guney Sur	Small Castle Southern City Wall
blimand	Buyuk Liman	Big Harbour
romad	Roma Bazilikazı	Roman Basilica
stoad	Stoa	Stoa
akad	Apollon Kutsal Alanı	Apollon Holy Place
ttd	Teras Tapinagi	Temple Terrace
cesmed	Cesme	Fountain
monopd	Monopteros	Monopteros
tiyatrod	Tiyatro	Theatre
palaestrad	Palaestra+ Kubbeli Kilise	Palaestra + Domed Temple
hamad	Hamam	Bath
demeterd	Demeter Kilisesi	Demeter Temple
korinthd	Korint Tapinagi	Korinth Temple
mezard	Mezarlar	Graveyards
agorad	Agora	Agora
nekd	Nekropol	Nekropol

To avoid multicollinearity problems, the correlation diagram of the independent variables is analyzed and correlation table can be seen in Appendix C. As seen from the table, slope and kkd is correlated and glassratio is correlated to stoad and ttd. Therefore, statistically insignificant variables (slope and glassratio) are dropped.

After that, in order to find most effective model, stepwise method is used. The rest of the independent variables are added and the most affecting ones are selected. Consequently, the model for total number of coin findings is:

$$coin\ total = b_0 + b_1 stoad + b_2 akad + b_3 ttd + b_4 palaestrad + b_5 demeterd + b_6 mezard + b_7 yy + \varepsilon_i \quad (4.2)$$

The regressions using these variables (4.2) are conducted in R project. MLR, SAR and GWR models are performed and the results are compared.

Model 1 - MLR Method Results

MLR results are given in the Table 4.10. The parameter estimated in model 1, akad (Apollon Holy Place) has the highest value which is 86.925. Occurrence of coins in the zones of Stoa and Temple Terrace has nearly same contribution to the number of total coin findings.

Table 4.10 MLR method significance results of model 1

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.5317	0.4842	-1.098	0.297872
stoad	38.9253	1.2230	31.827	2.21e-11 ***
akad	86.9253	1.2230	71.073	7.41e-15 ***
ttd	39.9253	1.2230	32.644	1.72e-11 ***
palaestrad	13.9253	1.2230	11.386	4.78e-07 ***
demeterd	5.5769	1.1285	4.942	0.000586 ***
mezard	8.2738	1.3543	6.109	0.000114 ***
yy	8.2579	1.2041	6.858	4.41e-05 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.033 on 10 degrees of freedom
Multiple R-squared: 0.9989, **Adjusted R-squared: 0.9982**
F-statistic: 1342 on 7 and 10 DF, p-value: 4.769e-14

Since the model has 99.89% fit, the independent variables which are zone dummy variables are seen as white in Figure 4.56.

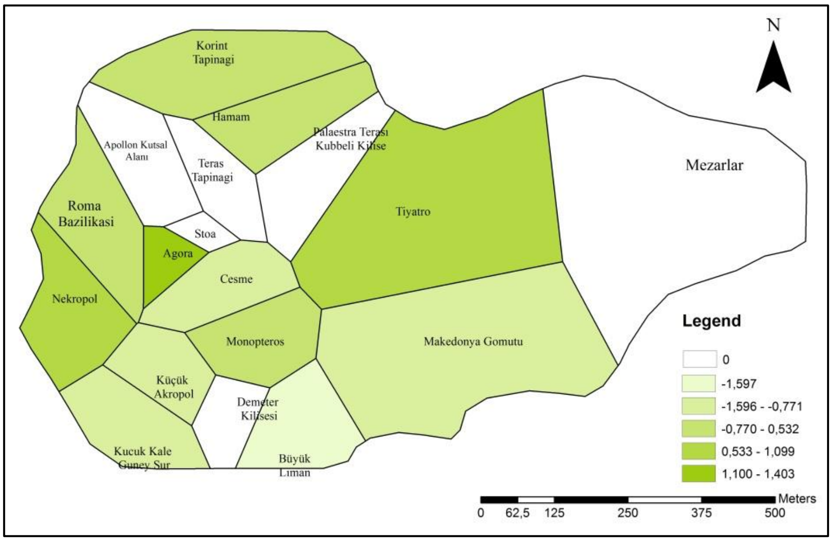


Figure 4.56 Residuals of model 1 according to MLR method

Residuals of MLR are mapped and results show that the distribution is random. Positive values scattered as well as negative values.

Model 1 – SAR Method Results

In order to incorporate spatial variability spatial regression, SAR is applied with the same dependent and independent variables. As in the MLR results, the highest parameter estimate belong to akad (Apollon Holy Place) (4.11).

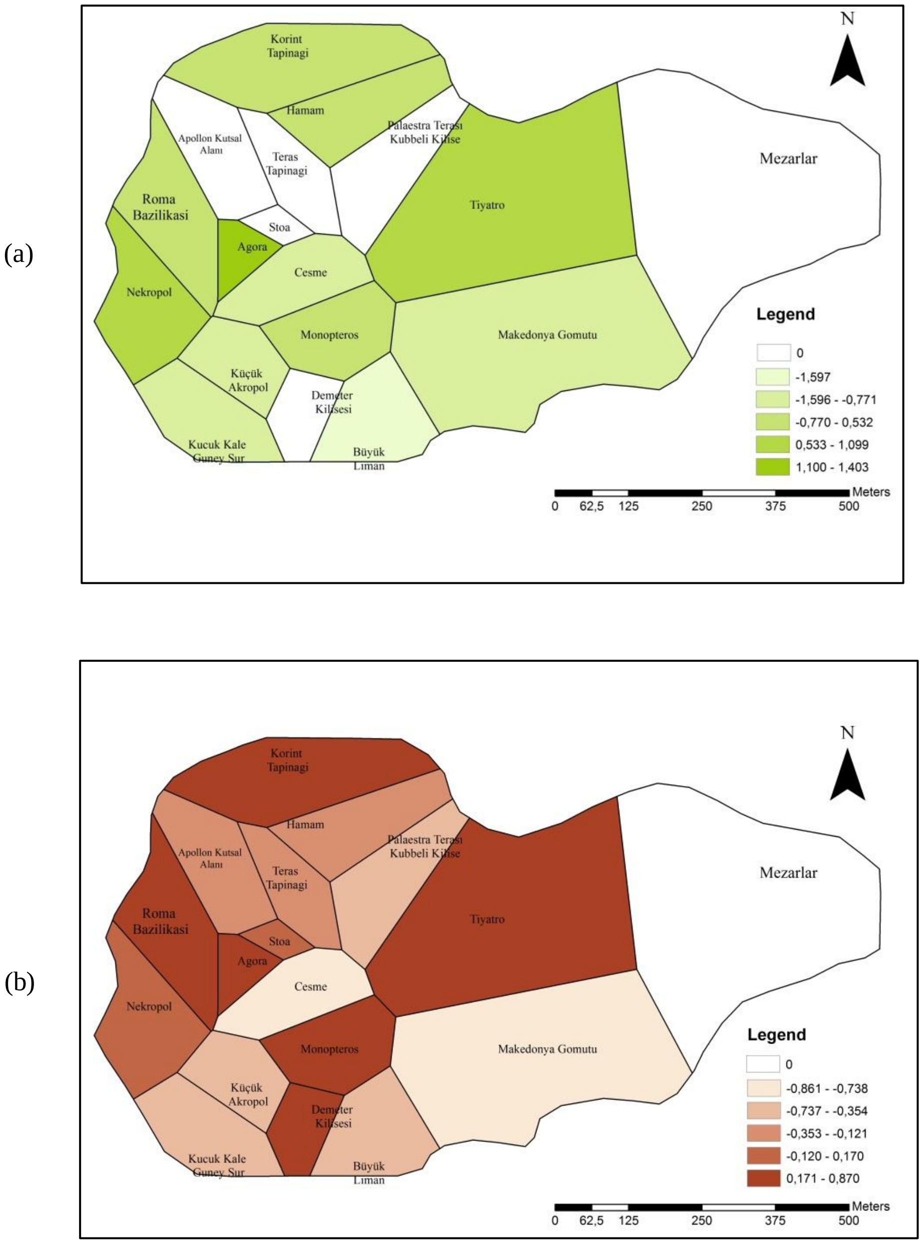


Figure 4.57 Residuals of model 1 according to SAR model (a) and comparison with MLR method (b)

When the residual maps of Model 1 are investigated (Figure 4.57), the residuals which are obtained from SAR method are smoother than the residuals obtained from MLR method. Although there are no errors in the Apollon Holly Place, Terrace Temple, Stoa, Tombs, Demeter and Palaestra Terrace according to MLR method, SAR method calculates the errors for these areas because of the weight matrix.

Table 4.11 SAR method significance results of model 1

	Estimate	Std. Error	zvalue	Pr(>|z|)
(Intercept)	-0.063	0.215	-0.293	0.770
Stoad	40.457	0.677	59.789	< 2.2e-16
Akad	88.074	0.622	141.559	< 2.2e-16
ttd	39.783	0.598	66.519	< 2.2e-16
palaestrad	15.207	0.617	24.656	< 2.2e-16
demeterd	4.120	0.516	7.978	1.554e-15
mezard	9.448	0.767	12.325	< 2.2e-16
Yy	6.990	0.556	12.570	< 2.2e-16

Lambda: -1.0185 LR test value: 8.7166 p-value: 0.0031532

Log likelihood: -16.48543

ML residual variance (sigma squared): 0.24589, (sigma: 0.49587)

Number of observations: 18, Number of parameters estimated: 10

AIC: 52.971, **R square: 0.9995594**

Model 1 – GWR Method Results

In order to explore geographically varying relationships between dependent variables and independent variables, GWR are performed. GWR applies the weighting function to each of the observations and calculates a weighted regression for each point.

GWR results of Model 1 are summarized in Table 4.13. It gives the weights (sum.w), local intercept estimate (X.Intercept), GWR coefficients (yy, stoad, akad, ttd, palaestrad, demeterd, and mezard), residuals (gwr.e), predicted values (pred) and local R^2. Moreover, the t values of the coefficients are mapped and it can be seen in Appendix E. Coefficient values are mapped to see if coefficient values vary over space (Figure 4.58- 4.64).

Moreover, in order to compare the global model (MLR and SAR) with the GWR, “LMZ.F3GWR.test” is made (Fotheringham et al., 2002). Result of this test is an ANOVA table (Table 4.12). This test is significant, since F (8, 10) =3.07 < 3.30, p<0.05.

Table 4.12 ANOVA

	Df	**Sum of Squares**	**Mean Squares**	**F value**
OLS Residuals	8.00000	10.6810		
GWR Improvement	0.22982	0.7697	3.3491	
GWR Residuals	9.77018	9.9113	1.0144	3.3015

Improvements in the AIC values support the significance of GWR. AIC value of SAR is **52.971.** On the other hand, AIC value of GWR is **48.57106**. Difference between the two values is 52.971-48.57106= **4.40** which is greater than 3. This shows that there is significant difference between the models (Fotheringham et al., 2002).

Table 4.13 GWR method results of model

	sum.w	X.Intercept.	Yy	Stoad	akad	Ttd	Palaestrad	demeterd	mezard	gwr.e	pred	localR2
Fountain	16,684	-0,515	8,207	38,949	86,949	39,949	13,949	5,591	8,308	-0,947	1,947	0,999017
Macedonian Graveyard	13,974	-0,634	8,415	38,902	86,902	39,902	13,902	5,585	8,219	-0,891	1,891	0,998828
Graveyard	13,771	-0,604	8,461	38,834	86,834	39,834	13,834	5,527	8,142	0	16	0,998950
Korinth Temple	15,360	-0,490	8,318	38,836	86,836	39,836	13,836	5,499	8,172	0,163	2,837	0,999142
Agora	16,743	-0,500	8,191	38,947	86,947	39,947	13,947	5,585	8,309	1,405	3,595	0,999046
Demeter Temple	16,090	-0,531	8,152	39,010	87,010	40,010	14,010	5,640	8,380	0,000	10	0,998937
Monopteros	16,332	-0,535	8,204	38,972	86,972	39,972	13,972	5,613	8,331	0,535	-0,535	0,998961
Terrace Temple	16,387	-0,501	8,263	38,891	86,891	39,891	13,891	5,543	8,238	0	46	0,999086
Apollon Holy Place	16,360	-0,488	8,224	38,908	86,908	39,908	13,908	5,553	8,264	0	93	0,999096
Stoa	16,673	-0,504	8,224	38,925	86,925	39,925	13,925	5,569	8,280	0	45	0,999056
Basilica	16,546	-0,490	8,184	38,942	86,942	39,942	13,942	5,579	8,305	0,490	-0,490	0,999069
Big Harbour	15,391	-0,562	8,186	39,013	87,013	40,013	14,013	5,650	8,376	-1,531	3,531	0,998874
South City Wall	16,245	-0,511	8,131	39,006	87,006	40,006	14,006	5,632	8,380	-0,741	2,741	0,998980
Akropol	16,530	-0,511	8,150	38,991	86,991	39,991	13,991	5,621	8,361	-0,934	1,934	0,998992
Nekropol	16,497	-0,495	8,150	38,975	86,975	39,975	13,975	5,605	8,345	0,865	1,135	0,999035
Theatre	14,414	-0,597	8,486	38,809	86,809	39,809	13,809	5,506	8,111	0,960	7,040	0,998972
Bath	15,126	-0,509	8,379	38,806	86,806	39,806	13,806	5,482	8,130	0,509	-0,509	0,999128
Palaestra	15,198	-0,533	8,395	38,816	86,816	39,816	13,816	5,495	8,137	0	20	0,999080

For Model 1, according to the results of MLR method, significant independent variables are Apollon Holy Place, Temple Terrace, Stoa, Demeter Temple, Graveyard and Palaestra and the time of usage. Thus, the coefficient results of these independent variables which are obtained from GWR are analyzed.

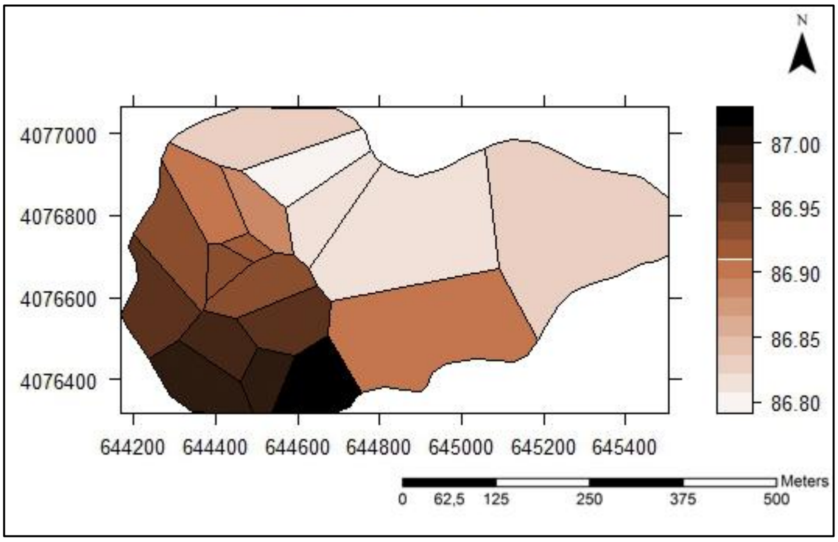


Figure 4.58 Coefficients maps of Apollon Holy Place independent variable-Model1

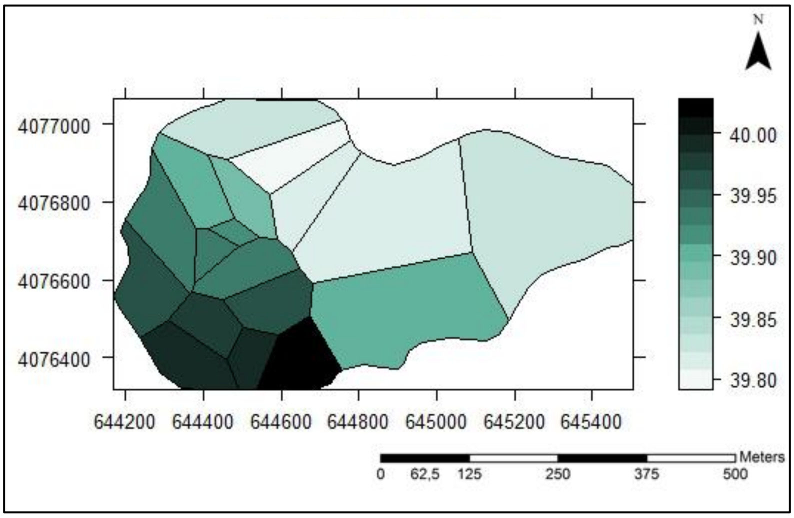


Figure 4.59 Coefficients maps of Temple Terrace independent variable-Model1

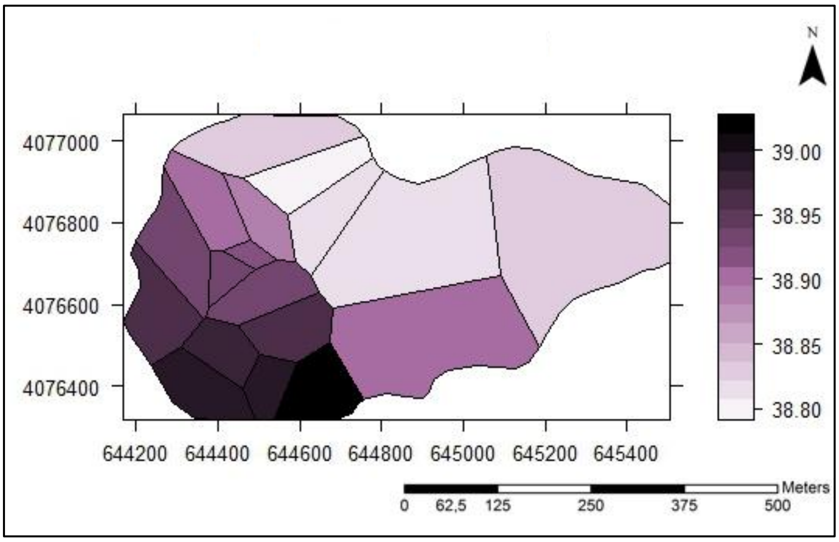


Figure 4.60 Coefficients maps of Stoa independent variable-Model 1

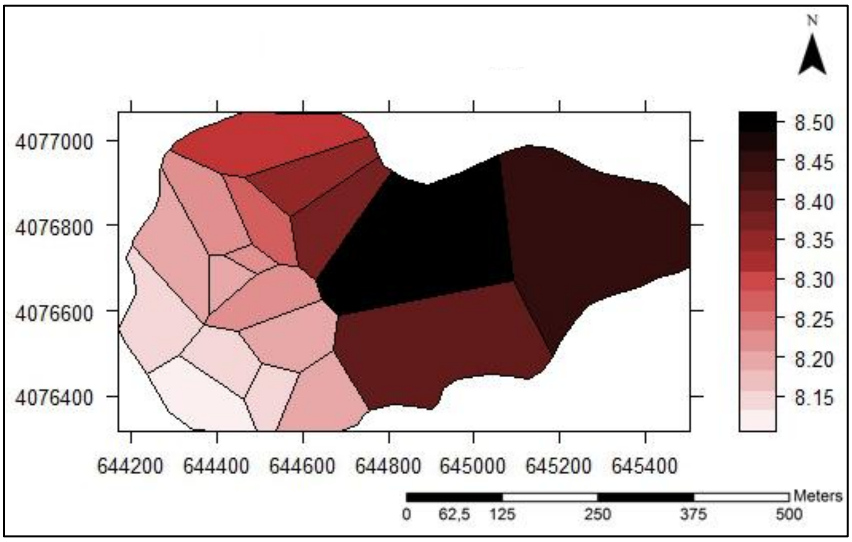


Figure 4.61 Coefficients maps of time of usage independent variable-Model 1

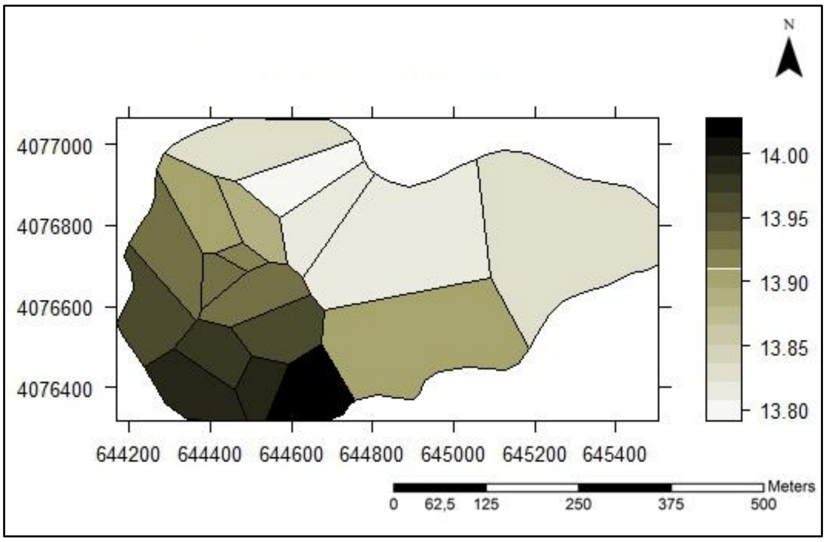


Figure 4.62 Coefficients maps of Palaestra independent variable-Model1

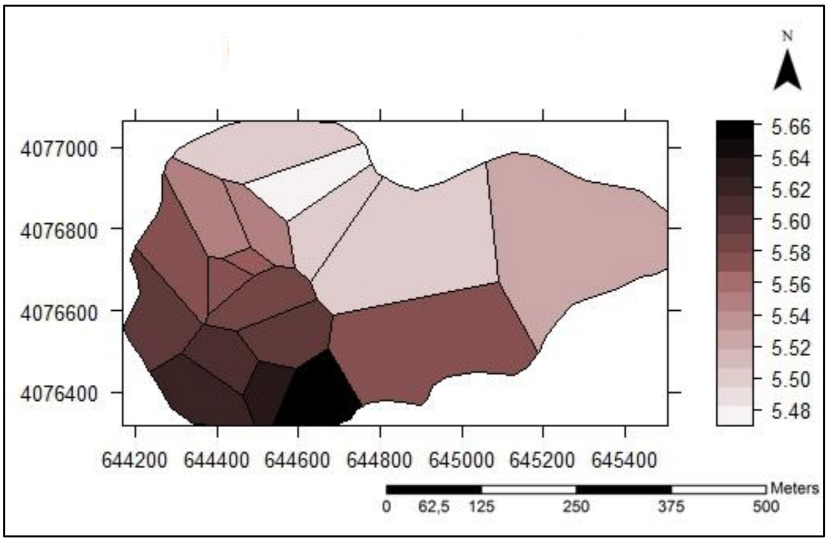


Figure 4.63 Coefficients maps of Demeter Temple independent variable-Model1

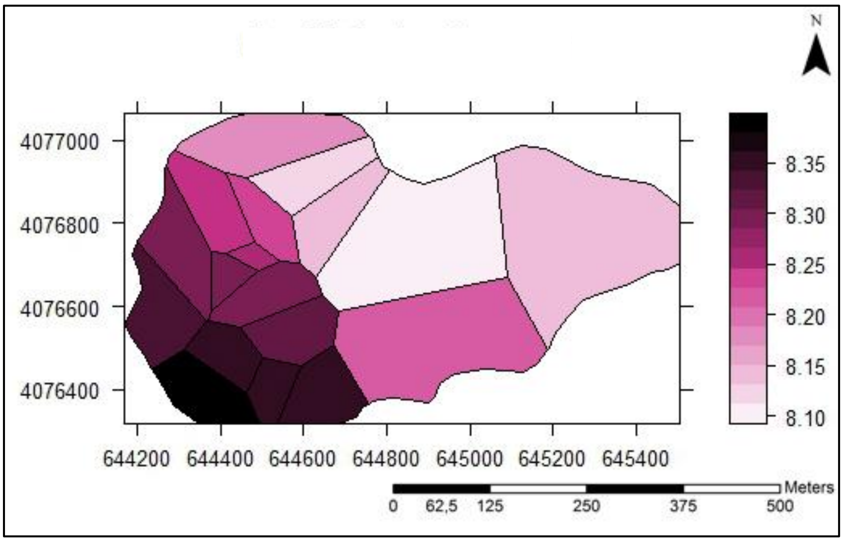


Figure 4.64 Coefficients maps of Graveyard independent variable-Model1

The coefficients of Apollon Holy Place have higher values than others. The relationship between the dependent variable and each significant predictor are mapped in local zones by using GWR coefficient maps. The coefficients are all positive and higher values show higher parameter estimates in the zones (Figure 4.58- 4.64).

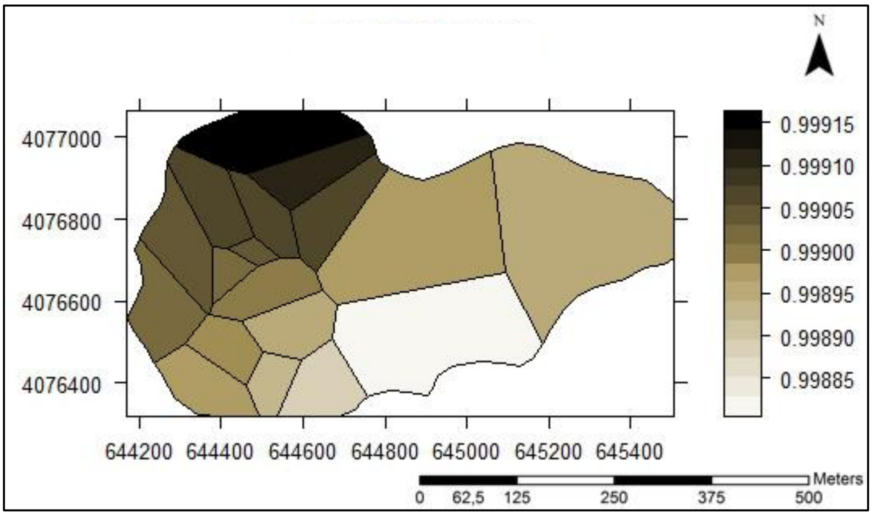


Figure 4.65 Local R Square of model 1 according to GWR method

In order to see in which locations GWR predict well, local R square values are mapped (Figure 4.65). Local R square values range between 0 and 1 and indicate how well the local regression model fits the observed independent values. Very low values indicate that the local model is performing poorly in those zones. When looking at Figure 4.65, R^2 values are high in south-western part of the region which means that GWR predicts well in these zones. It fits the max of 99.91% which is nearly same as with the model 2.

MLR and SAR Regression are applied to all of the data and give a global measure of the relationships. However, GWR produces local measures of the importance of various predictors that can be mapped and compared. As the map of MLR and GWR are different, this shows the spatial variation in local zones or, in other words, spatial heterogeneity (Figure 4.66).

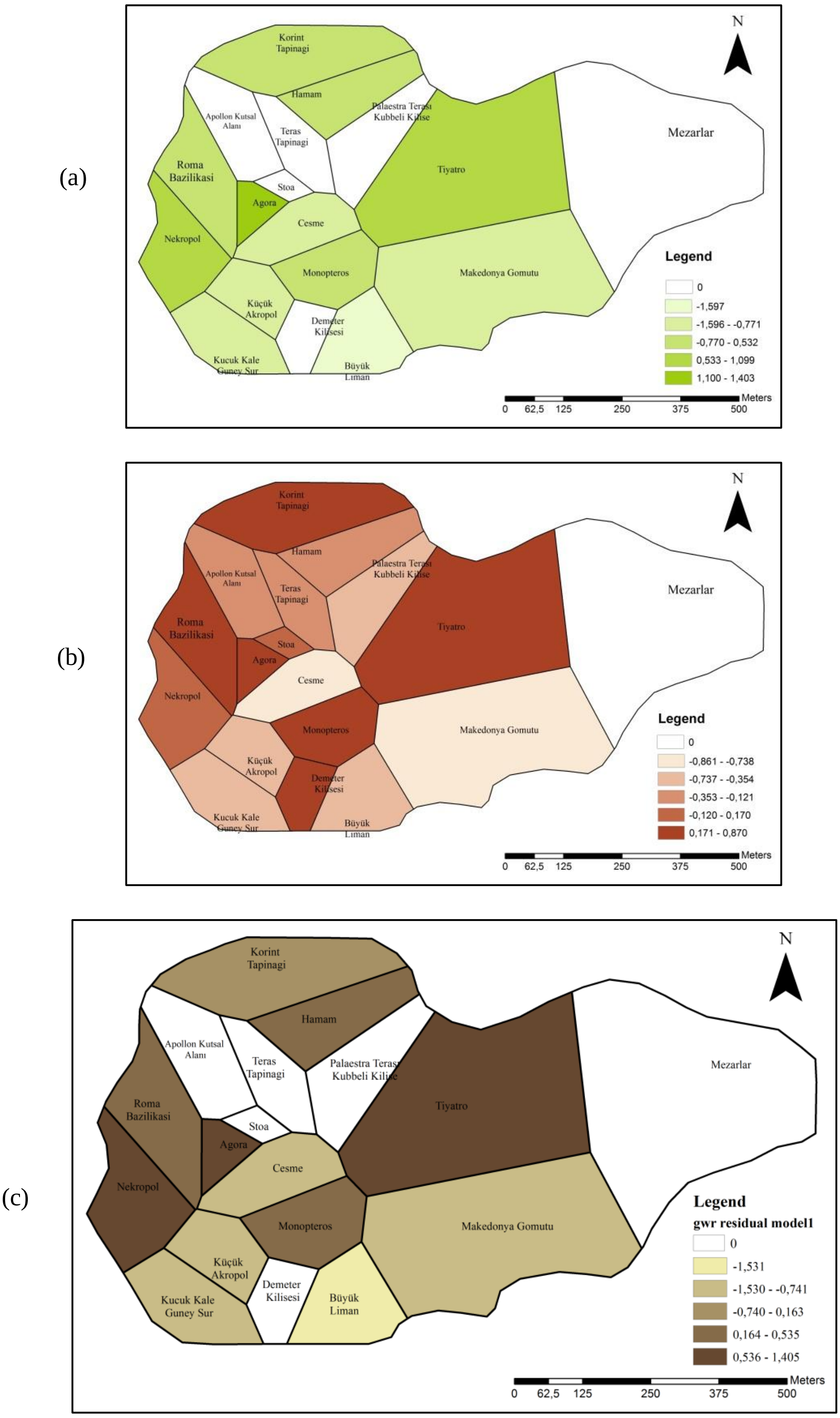


Figure 4.66 (a) Residuals of MLR (b) Residuals of SAR (c) Residuals of GWR according to Model 1

Model 2:

In this model, any clear differences between total numbers of coin findings in terms of periods are investigated. As in the Model 1, firstly correlated independent variables are eliminated (Appendix C). Secondly, the most affected independent variables are selected using stepwise method. Finally, in order to compare each period following model are performed:

$$coin\ total_{\underset{Period}{xxx}} = b_0 + b_1 stoad + b_2 akad + b_3 ttd + b_4 palaestrad + b_5 demeterd + b_6 mezard + b_7 yy + \varepsilon_i \quad (4.3)$$

In the equation 4.3, **xxx** is the name of the period and independent variables are the same as with Model 1. This model is conducted for each period to compare the periods. When look at the R^2 values of these models, it is seen that model for explaining the total coin number of the Early Byzantine Period fits 100% (Table 4.14).

Hence, in order to find which locations are related with the coin values in most significant period, coin values in Hellenistic Period are chosen as dependent variable (R^2=0.998, %99.8 fit).

Table 4.14 R^2 values for periods

	R^2
Archaic Classic Period	0.565
Hellenistic Period	0.998
Early Imperial Period	0.964
Mid Imperial Period	0.983
Late Imperial Period	0.962
Early Byzantine Period	1

Model 2 – MLR Model Results

In order to define the relationship between coin values in the Hellenistic Period, zones and usage period of the zones, following model is established:

$$coin\ total_{\underset{Period}{Hellenistic}} = b_0 + b_1 stoad + b_2 akad + b_3 ttd + b_4 palaestrad + b_5 demeterd + b_6 mezard + b_7 yy + \varepsilon_i \quad (4.4)$$

MLR results are given in the Table 4.15. According to the values of estimated parameters, akad (Apollon Holy Place) has the highest contribution to the number of total coin findings. Besides, there is significant relationship between the coin values in the Hellenistic Periods and the areas of Apollon Holy Place, Stoa, Temple Terrace, Palaestra, Demeter Temple, Graveyard and also; time of usage same as in Model 1.

Table 4.15 MLR model significance results of model 2

	Estimate	Std.Error	t value	Pr(>|t|)
(Intercept)	-0.2421	0.2101	-1.152	0.27602
stoad	2.8937	0.5307	5.452	0.00028 ***
akad	41.8937	0.5307	78.936	2.60e-15 ***
ttd	18.8937	0.5307	35.599	7.26e-12 ***
palaestrad	3.8937	0.5307	7.336	2.49e-05 ***
demeterd	5.7308	0.4897	11.703	3.70e-07 ***
mezard	5.0566	0.5877	8.604	6.19e-06 ***
Yy	4.1855	0.5225	8.010	1.16e-05 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4485 on 10 degrees of freedom

Multiple R-squared: 0.999, **Adjusted R-squared: 0.9984**

F-statistic: 1487 on 7 and 10 DF, p-value: 2.859e-14

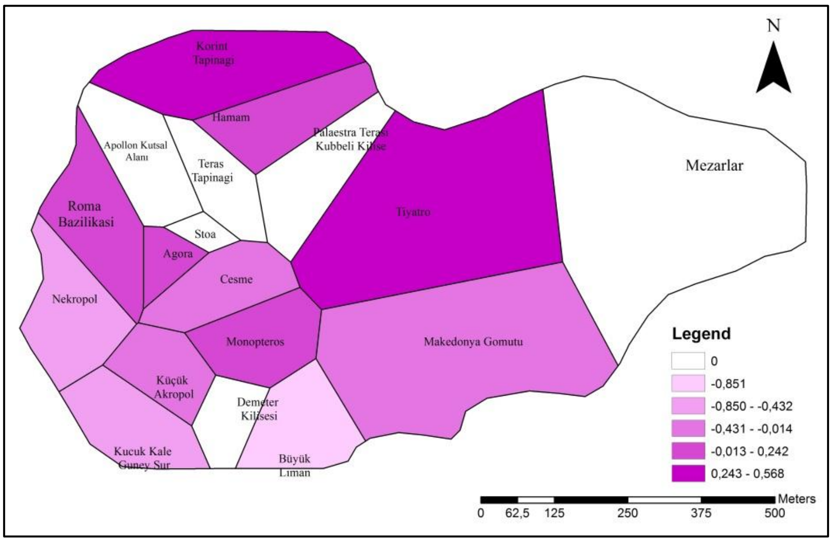


Figure 4.67 Residuals of model 2 according to MLR method

Residuals of MLR of Model 2 are mapped and results show that the distribution is random (4.67). Distributions of residuals are similar to Model 1, but values are smaller. This means that predictors are better explains the coin values for the Hellenistic Period.

Model 2 – SAR Method Results

SAR method is applied using the same dependent and independent variable with MLR method.

Table 4.16 SAR model significance results of model 2

	Estimate	Std.Error	z.value	Pr(>|z|)
(Intercept)	-0.21858	0.14296	-1.5290	0.1263
stoad	2.88105	0.41610	6.9239	4.394e-12
akad	41.94172	0.38157	109.9182	< 2.2e-16
ttd	18.93956	0.40450	46.8227	< 2.2e-16
palaestrad	4.08855	0.38401	10.6470	< 2.2e-16
demeterd	5.25628	0.35349	14.8698	< 2.2e-16
mezard	5.13829	0.45838	11.2097	< 2.2e-16
Yy	4.18998	0.37456	11.1863	< 2.2e-16

Lambda: -0.53615 LR test value: 0.45997 p-value: 0.49764

Log likelihood: -5.586647

ML residual variance (sigma squared): 0.099532, (sigma: 0.31549)

Number of observations: 18

Number of parameters estimated: 10

AIC: 31.173, R^2: 0.9991452

As seen from the Table 4.16, this model explains slightly better than MLR method. R^2 value is higher than the MLR which means that spatial location affects the distribution.

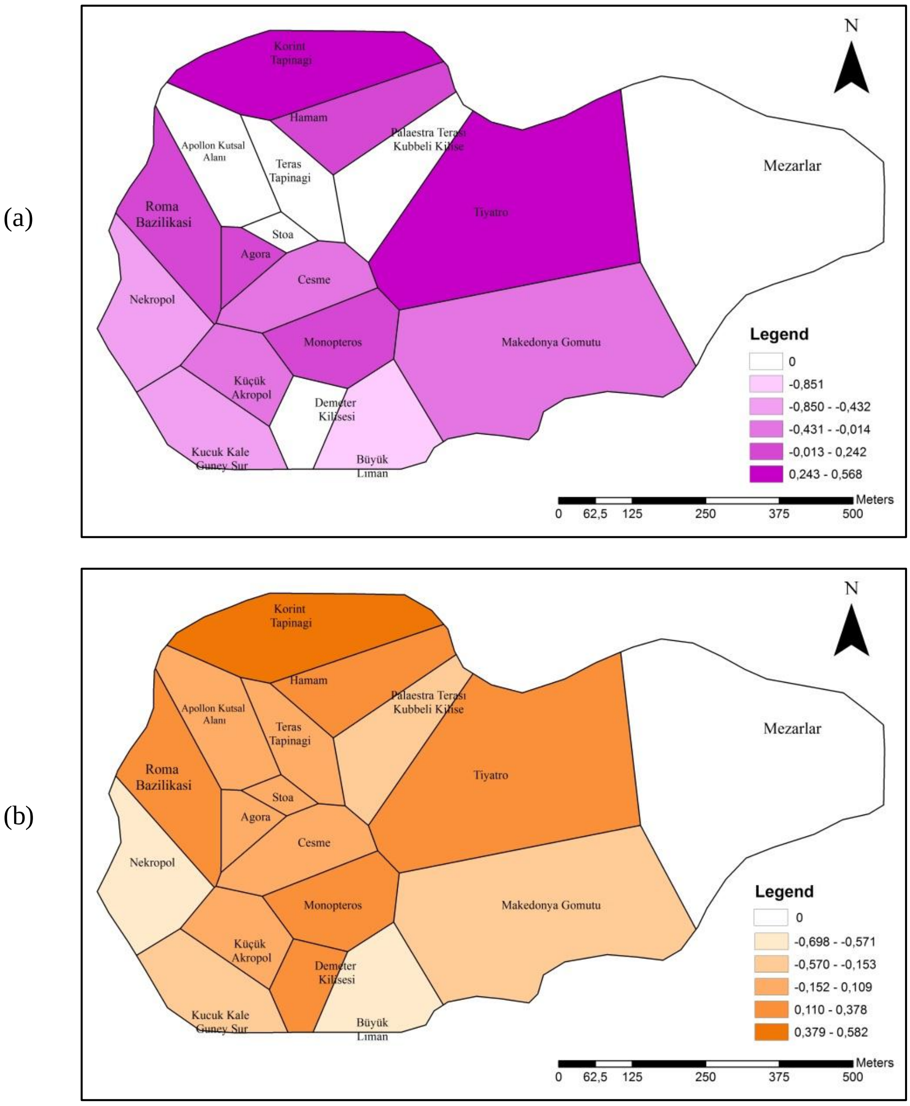


Figure 4.68 Residuals of model 2 according to SAR model (a) and comparison with MLR method (b)

When residual map of SAR method compared to MLR method, some clusters are observed (Figure 4.68). Similar values located in the nearer areas**.**

Model 2-GWR Method Results

GWR results of Model 2 are summarized in Table 4.18. It gives the weights (sum.w), local intercept estimate (X.Intercept), GWR coefficients (yy, stoad, akad, ttd, palaestrad, demeterd, and mezard), residuals (gwr.e), predicted values (pred) and local R^2. Coefficient values are mapped to see if coefficient values vary over space (Figure 4.69- 4.75). T values of each independent variable are also mapped (Appendix E).

Similar to Model 1, in order to compare the global model (MLR and SAR) with the GWR, "LMZ.F3GWR.test" is made (Fotheringham et al., 2002). Result of this test is an ANOVA table (Table 4.17). This test is significant, since F (8, 10) =3.07 < 4.563, p<0.05.

Table 4.17 ANOVA

	Df	Sum of Squares	Mean Squares	F value
OLS Residuals	8.00000	2.01131		
GWR Improvement	0.22982	0.19497	0.84835	
GWR Residuals	9.77018	1.81634	0.18591	4.5633

Difference between the AIC values is bigger than 3. This supports the significance of GWR (GWR AIC: 18.02776, SAR AIC: 31.173).

Model 2- GWR Method Results

Results of the GWR method are summarized in Table 4.18. The relationship between the coin dependent and each significant predictor is mapped by using GWR coefficient maps.

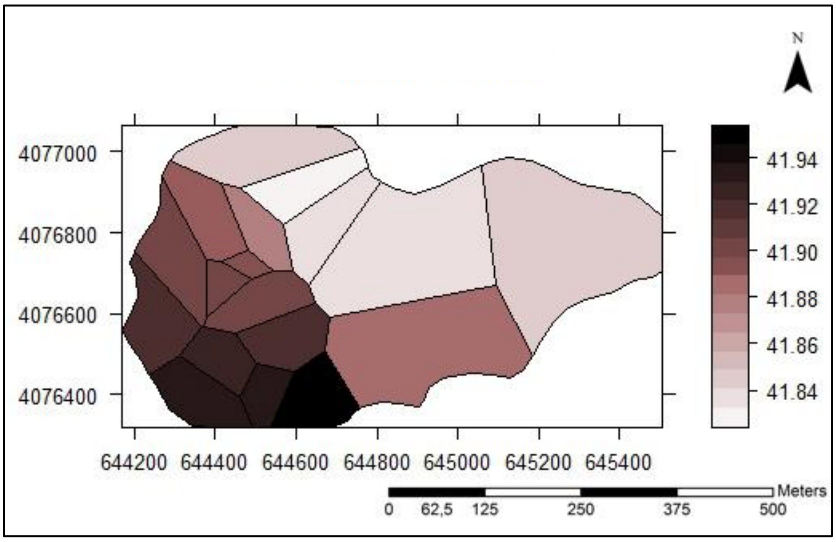


Figure 4.69 Coefficients maps of Apollon Holy Place independent variable- Model 2

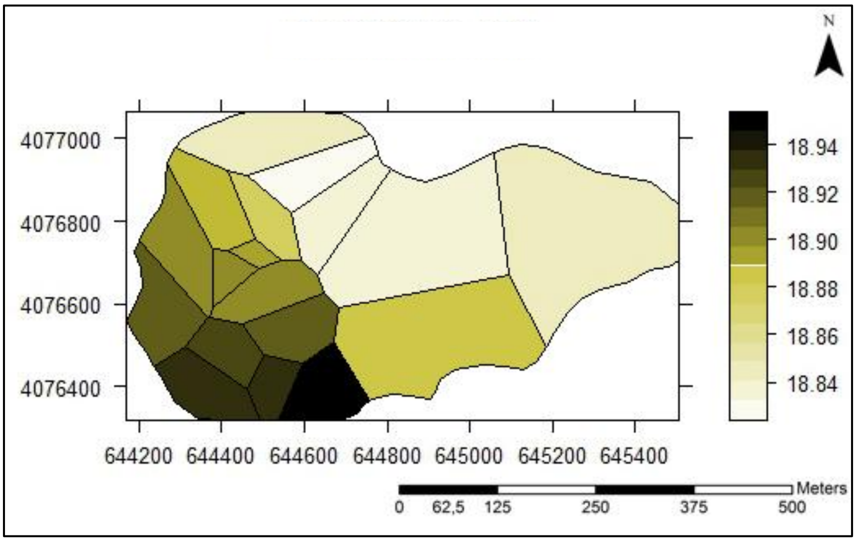


Figure 4.70 Coefficients maps of Temple Terrace independent variable- Model 2

Table 4.18 GWR results of model 2

	sum.w	X.Intercept.	stoad	Akad	ttd	palaestrad	demeterd	mezard	yy	gwr.e	pred	localR2
Fountain	16,684	-0,236	2,912	41,912	18,912	3,912	5,743	5,081	4,154	-0,010	1,010	0,9991
Macedonian Gravey.	13,974	-0,249	2,883	41,883	18,883	3,883	5,725	5,041	4,208	-0,013	1,013	0,9990
Graveyard	13,771	-0,241	2,844	41,844	18,844	3,844	5,693	4,994	4,247	0	9	0,9991
Korinth Temple	15,360	-0,220	2,848	41,848	18,848	3,848	5,691	5,004	4,216	0,534	1,466	0,9993
Agora	16,743	-0,235	2,911	41,911	18,911	3,911	5,742	5,080	4,155	0,157	1,843	0,9992
Demeter Temple	16,090	-0,244	2,944	41,944	18,944	3,944	5,769	5,119	4,125	0	8	0,9991
Monopteros	16,332	-0,240	2,925	41,925	18,925	3,925	5,753	5,096	4,144	0,240	-0,240	0,9991
Terrace Temple	16,387	-0,228	2,880	41,880	18,880	3,880	5,717	5,043	4,185	0	22	0,9992
Apollon Holy Place	16,360	-0,229	2,889	41,889	18,889	3,889	5,724	5,054	4,176	0	45	0,9992
Stoa	16,673	-0,232	2,899	41,899	18,899	3,899	5,732	5,065	4,167	0	6	0,9992
Basilica	16,546	-0,234	2,907	41,907	18,907	3,907	5,739	5,076	4,158	0,234	-0,234	0,9992
Big Harbour	15,391	-0,247	2,946	41,946	18,946	3,946	5,771	5,120	4,127	-0,816	1,816	0,9990
South City Wall	16,245	-0,242	2,942	41,942	18,942	3,942	5,767	5,117	4,125	-0,408	1,408	0,9991
Akropol	16,530	-0,241	2,934	41,934	18,934	3,934	5,761	5,108	4,133	0,001	0,999	0,9991
Nekropol	16,497	-0,238	2,925	41,925	18,925	3,925	5,753	5,097	4,141	-0,590	0,590	0,9992
Theatre	14,414	-0,233	2,832	41,832	18,832	3,832	5,683	4,982	4,251	0,407	3,593	0,9991
Bath	15,126	-0,217	2,832	41,832	18,832	3,832	5,678	4,986	4,232	0,217	-0,217	0,9992
Palaestra	15,198	-0,221	2,839	41,839	18,839	3,839	5,685	4,994	4,228	0	7	0,9992

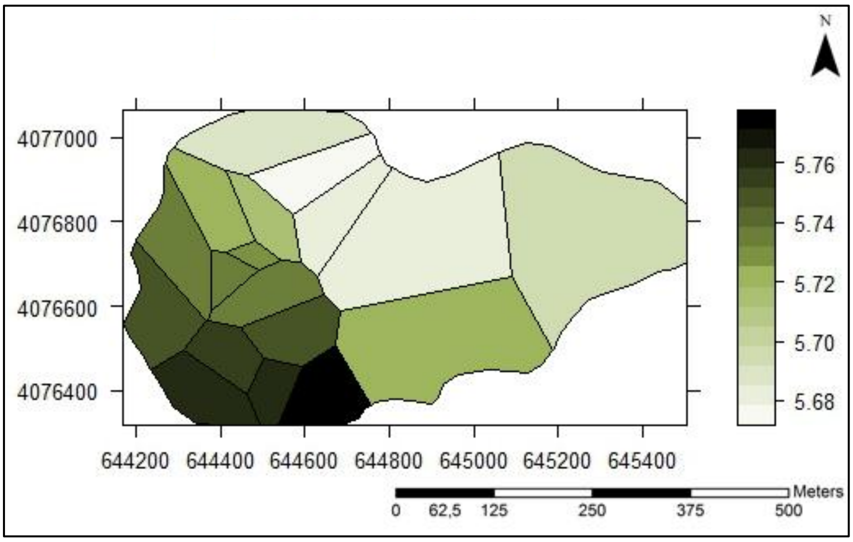


Figure 4.71 Coefficients maps of Demeter Temple independent variable- Model 2

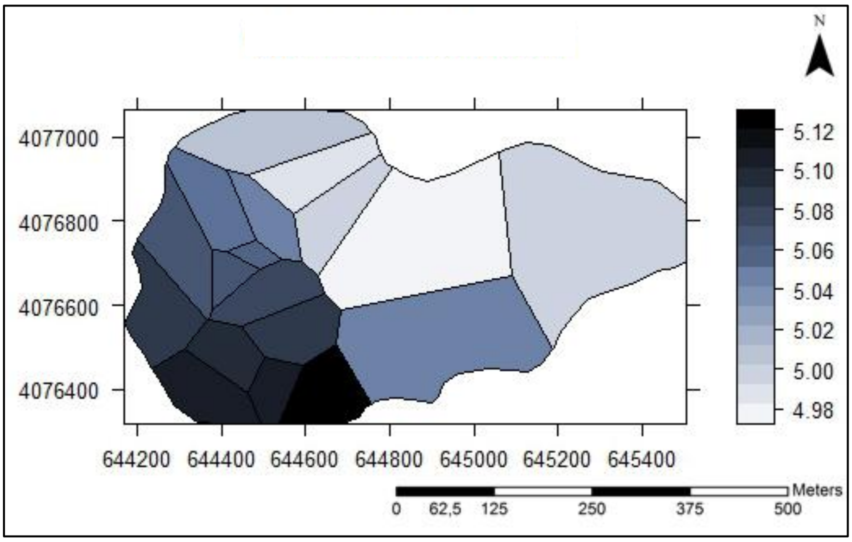


Figure 4.72 Coefficients maps of Graveyard independent variable- Model 2

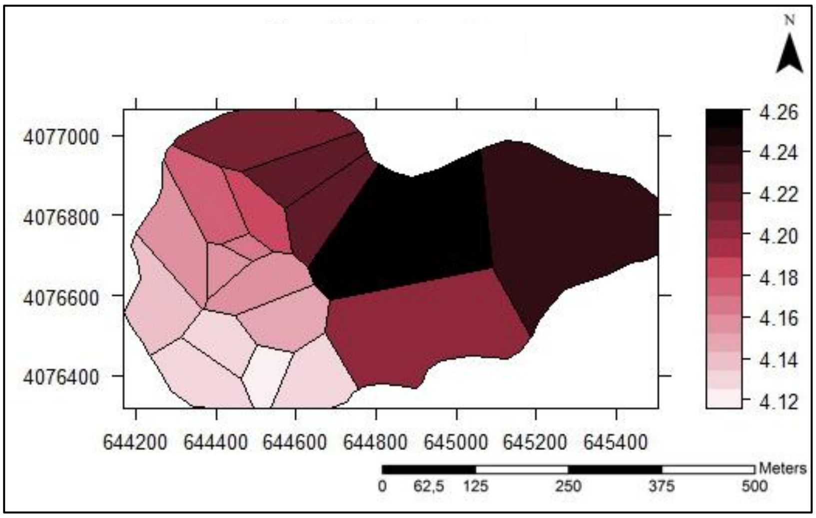


Figure 4.73 Coefficients maps of Time of Usage independent variable- Model 2

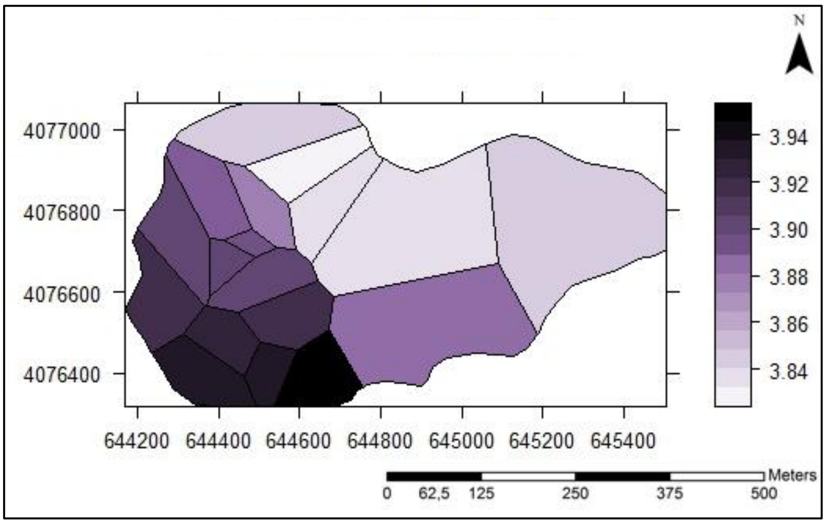


Figure 4.74 Coefficients maps of Palaestra independent variable- Model 2

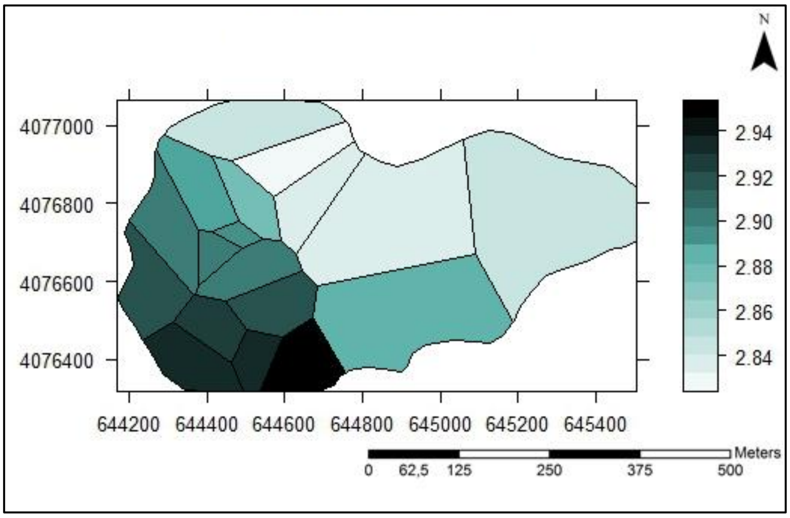


Figure 4.75 Coefficients maps of Stoa independent variable- Model 2

As it is seen in Figures 4.69-4.75, there is a positive relationship between each predictor and the independent variable. Higher values show higher parameter estimates in the zones.

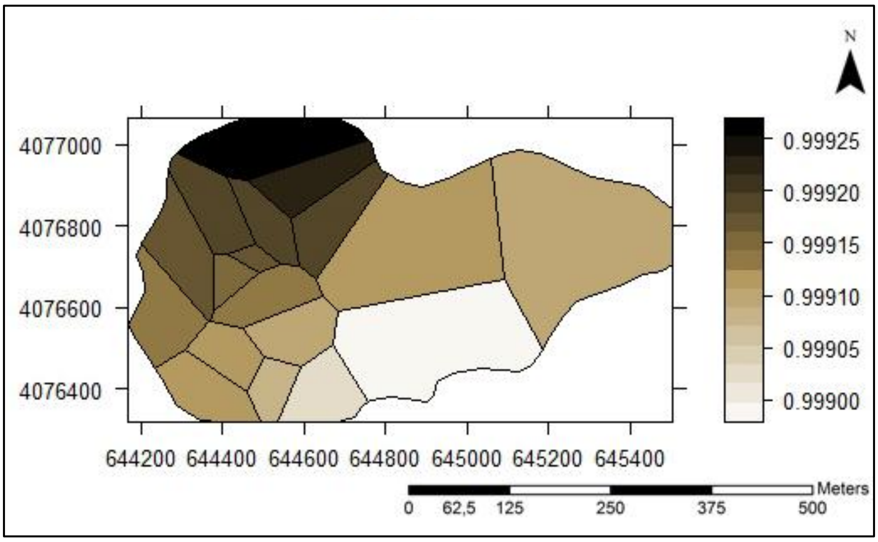


Figure 4.76 Local R Square of model 2 according to GWR Method

The Local R^2 values are mapped to see where GWR predicts well. In Figure 4.76, R square values are high in the south-western part of the region which means that GWR predicts well in these zones. This map is close to the Local R^2 map of Model 1. However, the min and max values do not vary in a great range. It fits the max of 99.9%.

MLR and SAR Models are applied to all the data and give a global measure of the relationships. However, GWR produces local measures of the importance of various predictors that can be mapped and compared. As the residual maps of SAR and GWR are different, it can be concluded that there is a spatial variation (heterogeneity) in the local zones (Figure 4. 77). SAR method for Model 2 slightly differs from the one for Model 1.

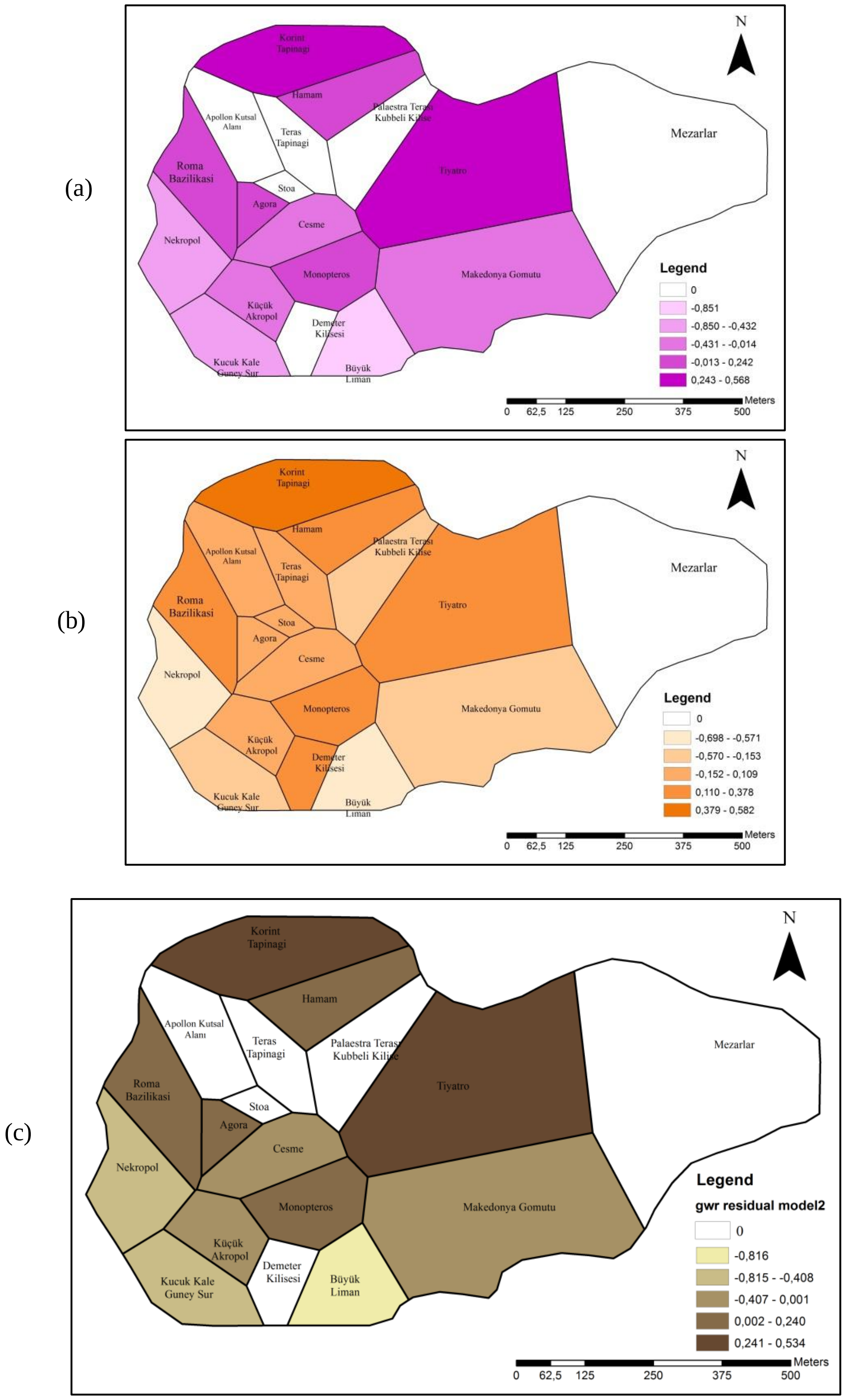


Figure 4.77 (a) Residuals of MLR (b) Residuals of SAR (c) Residuals of GWR according to Model 2

Model 3:

This model is constructed to understand whether the coin findings is affected by the type of land use. Hence, the model in Equation 4.4 is constructed.

$$coin\ total = b_0 + \ b_1 holydd + b_2 traded + b_3 graved + b_4 socioculturald + b_5 glassratio + b_6 yy + \ \varepsilon_i \tag{4.4}$$

In the equation 4.4, coin total is the number of total coin finds in the study area. **xxxd (holyd, traded, graved, socioculturald)** is a set of dummy variable which depict the type of land use as follows:

> **holyd** is 1 if the area is belong to one of the holy places which are Monopteros, Demeter Temple, Small Castle Sothern City Wall, Apollon Holy Place, Temple Terrace or Korinth Temple; otherwise 0,
>
> **traded** is 1 if the area is belong to one of the trade places which are Big Harbour, Nekropol or Lesser Acropolis; otherwise 0,
>
> **graved** is 1 if the area is belong to one of the tomb area which are Macedonian Tomb or Graveyards; otherwise 0,
>
> **socioculturald** is 1 if the area is belong to one of the socio cultural area which are Theatre, Fountain, Agora, Roman Basilica or Bath; otherwise 0.

glassratio is the ratio of "number of glass finds per each zone / number of total glass finds" and **yy** is usage period of the zones. Finally, b_i is the coefficient of the predictors.

In order to avoid multicollinearity, correlations are analyzed. Since socio-cultural place and holy place are significantly correlated, the socio-cultural place is eliminated (Table 4.19). After that, using the stepwise method, independent variables which explain the model in a better way are selected.

The regression using these variables is conducted in R project. MLR, SAR and GWR regression methods are performed and the results are compared.

Table 4.19 Correlation Results of Model 3

		hollyplace	Sociocultural	trade	glassratio	slope	coincentury
hollyplace	Pearson Correlation	1	-,564*	-,357	,160	-,084	,166
	Sig. (2-tailed)		,015	,146	,526	,741	,509
	N	18	18	18	18	18	18
Socio-cultural	Pearson Correlation	-,564*	1	-,316	,094	-,333	-,139
	Sig. (2-tailed)	,015		,201	,712	,177	,584
	N	18	18	18	18	18	18
Trade	Pearson Correlation	-,357	-,316	1	-,282	,129	-,207
	Sig. (2-tailed)	,146	,201		,258	,609	,410
	N	18	18	18	18	18	18
Glassratio	Pearson Correlation	,160	,094	-,282	1	-,192	,376
	Sig. (2-tailed)	,526	,712	,258		,446	,124
	N	18	18	18	18	18	18
Slope	Pearson Correlation	-,084	-,333	,129	-,192	1	,016
	Sig. (2-tailed)	,741	,177	,609	,446		,950
	N	18	18	18	18	18	18
coincentury	Pearson Correlation	,166	-,139	-,207	,376	,016	1
	Sig. (2-tailed)	,509	,584	,410	,124	,950	
	N	18	18	18	18	18	18

*. Correlation is significant at the 0.05 level (2-tailed).

Model 3- MLR Method Results

In order to analyze the relationship between the total coin number and the type of land use, Model 3 is established as follows. In this model only time of usage is significant independent variable (p<0.05).

$$coin\ total = b_0 + b_1 holydd + b_2 traded + b_3 grave + b_4 glassratio + b_5 yy + \varepsilon_i \qquad (4.5)$$

Table 4.20 MLR method significance results of model 3

	Estimate	Std.Error	T.Value	Pr(>|t|)
(Intercept)	-10,44	11,201	-0,932	0,3696
glass_ratio	36,179	62,952	0,575	0,5761
Yy	40,714	17,713	2,298	0,0403*
Hollyd	13,097	11,709	1,119	0,2852
Traded	-1,464	15,103	-0,097	0,9244
Graved	-8,971	17,384	-0,516	0,6152

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 21.03 on 12 degrees of freedom

Multiple R-squared: 0.4718, **Adjusted R-squared: 0.2518**

F-statistic: 2.144 on 5 and 12 DF, p-value: 0.1296

As it is seen from the Table 4.20, the highest coefficient value belongs to the time of usage. When residuals are mapped, positive and negative values are randomly scattered over the study region (Figure 4.78).

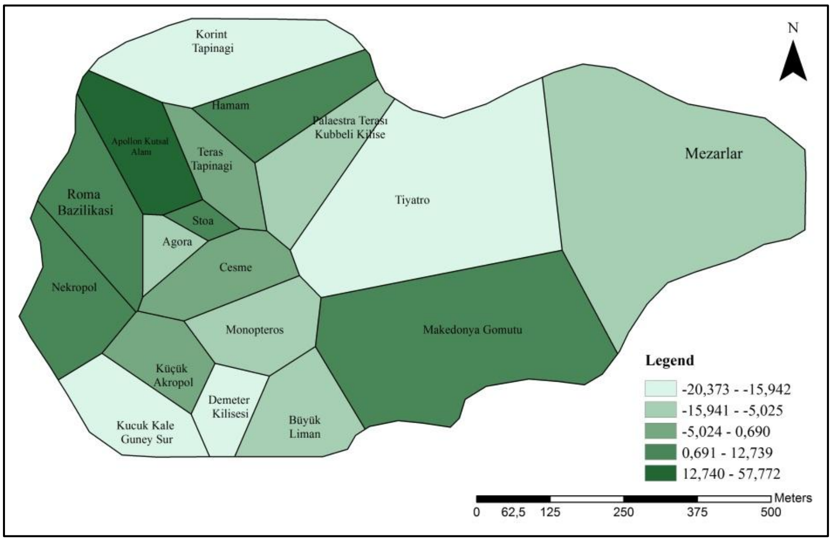


Figure 4.78 Residuals of model3 according to MLR Model

Model 3- SAR Method Results

SAR method is also applied to the Equation 4.5 and results show that again only the time of usage is significant predictor (4.21).

Table 4.21 SAR method significance results of model 3

	Estimate	Std.Error	Z.Value	Pr(>|z|)
(Intercept)	-11,0962	9,6589	-1,1488	0,250639
glass_rati	21,0315	49,6545	0,4236	0,671888
Yy	40,2841	13,3554	3,0163	0,002559
Hollyd	13,0519	9,8595	1,3238	0,185573
Traded	2,5659	12,4683	0,2058	0,836955
Graved	-3,1133	14,0945	-0,2209	0,825181

Lambda: 0.24079 LR test value: 0.52101 p-value: 0.47041

ML residual variance (sigma squared): 281.04, (sigma: 16.764)

Number of observations: 18, Number of parameters estimated: 8

AIC: 168.91, **R Square 0.4964761**

The value of R^2 increased in SAR method when compared to MLR method. When compared the residual maps of MLR and SAR method, distribution of the error values over the study region are similar (Figure 4.79).

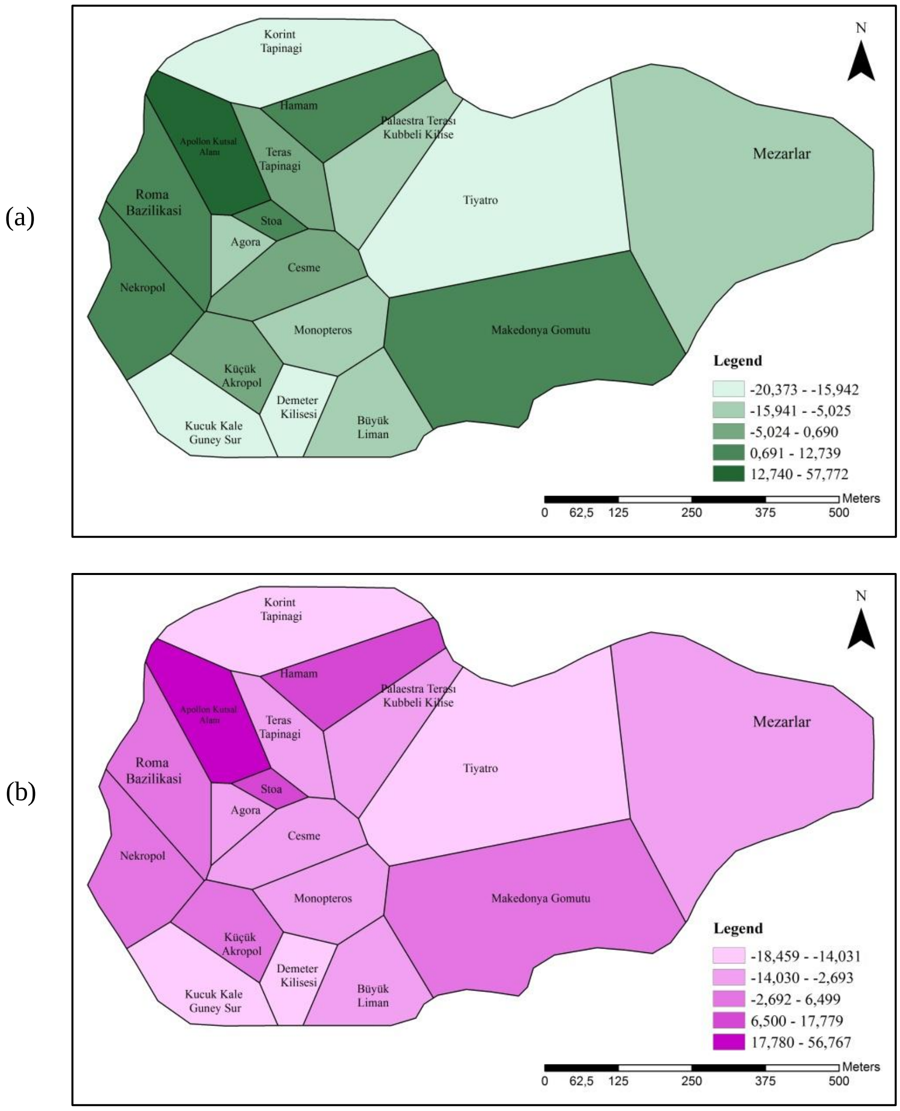


Figure 4.79 Residuals of model 2 according to SAR model (a) and comparison with MLR method (b)

Model 3- GWR Method Results

GWR results of Model 3 are summarized in Table 4.23. It gives the weights (sum.w), local intercept estimate (X.Intercept), GWR coefficients (glass_ratio, yy, holyd, traded, graved), residuals (gwr.e), predicted values (pred) and local R^2. Coefficient values are mapped to see if coefficient values vary over space (Figure 4.80) and also maps of t values are produced (Appendix E).

Moreover, “LMZ.F3GWR.test” is also made in order to compare the global model (MLR and SAR) with the GWR (Fotheringham et al., 2002). Result shows that this test is not significant, since F (6, 11) =3.09 > 2.519, p<0.05 (Table 4.22). This means that relationship between dependent and independent variable do not vary geographically.

Table 4.22 ANOVA

	Df	Sum of Squares	Mean Squares	F value
OLS Residuals	6.0000	5306.3		
GWR Improvement	0.8251	832.2	1008.55	
GWR Residuals	11.1749	4474.1	400.37	2.519

Table 4.23 GWR method results of model 3

	sum.w	X.Intercept.	glass_ratio	Yy	hollyd	traded	graved	gwr.e	pred	localR2
Fountain	14,015695	-12,129625	35,380959	45,996250	12,463808	-1,452176	-4,853218	-2,438298	3,438298	0,584274
Macedonian Gravey.	13,650817	-10,176286	46,346327	36,587965	12,466747	-1,145189	-6,154144	6,354040	-5,354040	0,553106
Graveyard	13,277472	-9,882794	41,310463	36,970671	13,624343	-1,305160	-7,653393	-6,739321	22,739321	0,548618
Korinth Temple	14,173214	-11,023869	26,657091	44,502609	14,921655	-1,720742	-9,228817	-18,698829	21,698829	0,564453
Agora	14,669554	-11,938272	29,600159	47,328619	12,946734	-1,634746	-6,739184	-7,022039	12,022039	0,577994
Demeter Temple	13,931884	-11,531969	44,873627	42,165787	10,671727	-1,163276	-5,263014	-14,439231	24,439231	0,567865
Monopteros	13,262466	-12,010968	45,836192	42,717502	11,018231	-1,099330	-3,554051	-5,882692	5,882692	0,580397
Terrace Temple	14,082954	-11,630457	25,738357	46,641405	14,676500	-1,769435	-7,430702	-1,565907	47,565907	0,575658
Apollon Holy Place	14,173415	-11,665231	23,123971	47,986257	14,273697	-1,832565	-8,621246	52,002529	40,997471	0,572362
Stoa	14,038630	-12,050236	27,294248	47,844991	13,789800	-1,718988	-6,165315	11,131854	33,868146	0,582487
Basilica	14,607570	-11,733940	26,569734	47,666638	13,263175	-1,728092	-8,196371	11,733940	-11,73394	0,572855
Big Harbour	13,646467	-11,137442	48,060453	39,700084	10,803922	-1,068261	-5,067307	-5,644339	7,644339	0,562982
South City Wall	14,259625	-11,567747	39,264568	44,112072	11,124901	-1,346802	-6,537557	-15,594628	17,594628	0,568183
Akropol	14,390158	-11,816300	38,518219	44,961627	11,252631	-1,356308	-5,921193	0,684121	0,315879	0,573155
Nekropol	14,756218	-11,635368	31,869450	46,200500	12,262222	-1,570989	-7,748129	5,966257	-3,966257	0,570571
Theatre	13,626898	-10,134408	41,443635	37,347878	13,998019	-1,289679	-6,831894	-17,965300	25,965300	0,555414
Bath	13,919992	-10,888296	29,464018	42,977534	15,165027	-1,646931	-8,337357	10,593655	-10,59365	0,565153
Palaestra	14,042735	-10,849429	33,857304	41,537975	14,748333	-1,522680	-7,233708	-5,089536	25,089536	0,567097

The relationship between the coin dependent and significant predictor are mapped in the zones by using the GWR coefficient maps.

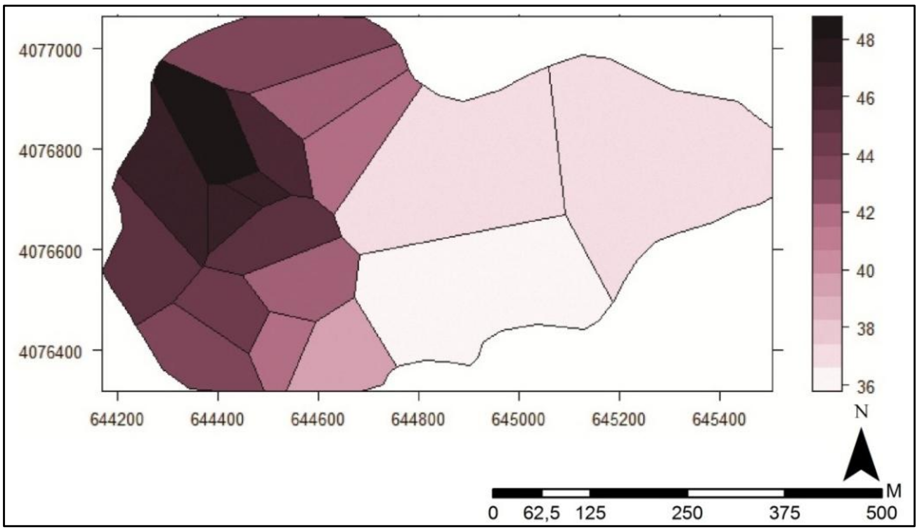


Figure 4.80 Coefficients maps of time of usage independent variable- Model 3

There is a positive relationship between each predictor and the outcome. Higher values show higher parameter estimates in the zones. (Figure 4.80).

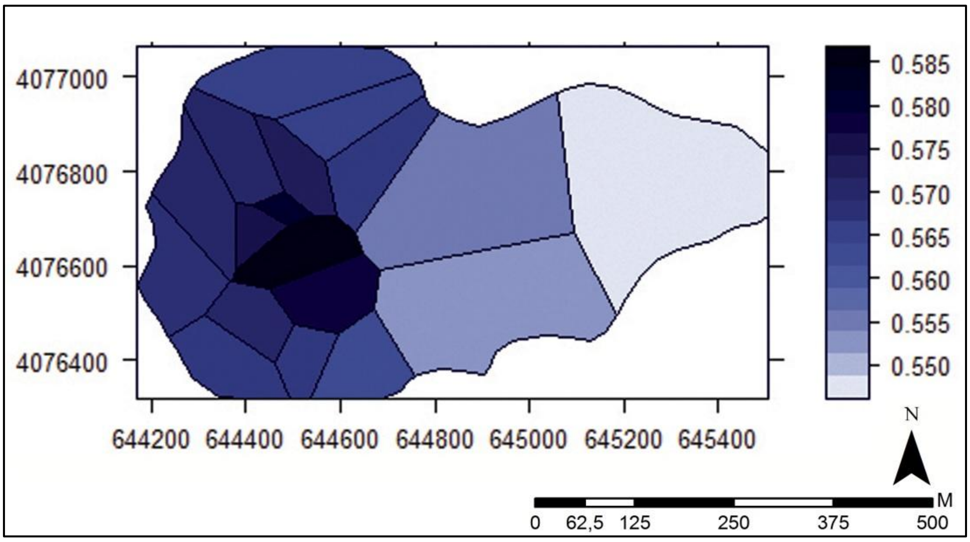


Figure 4.81 Local R Square of model 3 according to GWR Method

In model 3, R^2 values are as high as other models. The model fits in the center of the region. It is fixed at the max of 58.5% (Figure 4.81).

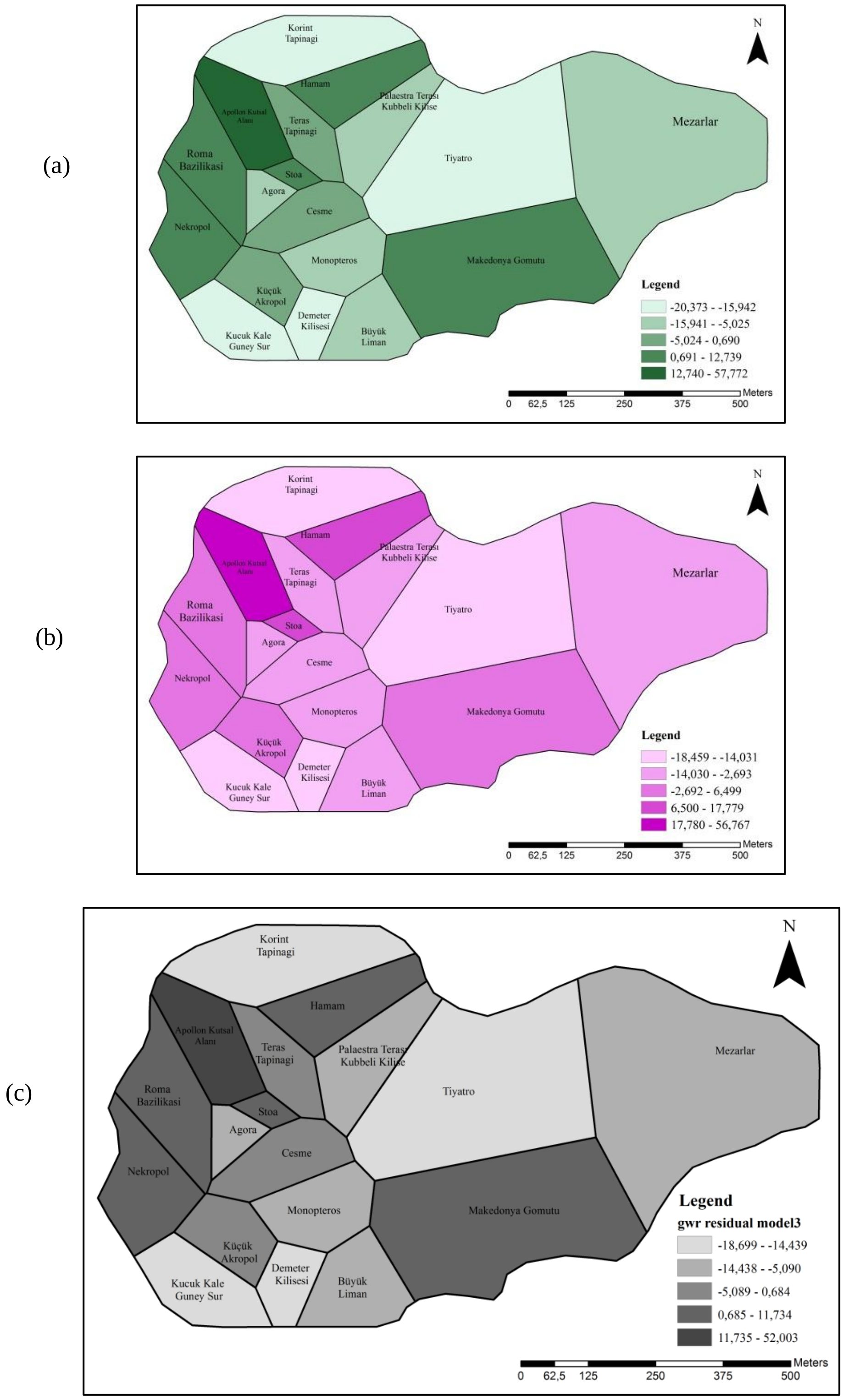


Figure 4.82 (a) Residuals of MLR (b) Residuals of SAR (c) Residuals of GWR according to Model 3

The global and the local pictures of this model are similar according to these parameters (4.82). Therefore, there might be no variation across the region when these parameters are used.

4.5 Stakeholder Component of SDSS for Kaunos Archaeological Site

Archaeologists, who are working at the excavation site of Kaunos, are the users of SDSS for Kaunos. They belong to both expert and decision maker classes of stakeholders because they have detailed information about the site as well as they use the system for making the decisions.

As experts, they collect data from Kaunos and tell about their preferences concerning what kind of data should be stored in DBMS. According to their demands, GIS database and R-DBMS are created. Moreover, they advise from which points and paths the viewshed analysis should be performed. In addition, they help to define queries. Finally, for the modeling, they contribute to the development of hypotheses.

As decision makers, with special queries, they can see the simplified information from the detailed database. Besides, the thematic maps which are created according to the attribute queries are helpful for their studies. They understand the location selection of Kaunos with viewshed analysis. Finally, the hypotheses about the coin findings are tested with the spatial data analyses of area data in Kaunos.

These analyses help archaeologists in defining the socio-cultural life of Kaunians. The pattern analysis of coin findings enables them to determine in which periods which areas were commonly used. Additionally, which parameters are related to the foundations of coins is identified. Hence, the characteristics of Kaunos are defined. The illustrated maps and tables are very useful tools for archaeologists. They make their decisions and reach the exact results about Kaunos by benefiting from the thematic maps and tables.

CHAPTER 5

RESULTS AND DISCUSSIONS

Today, SDSS is being used in many fields, such as natural resource management, environmental pollution, agriculture, transportation etc. in order to deal with complex spatial problems. However, as it can be seen in the literature section, it has not been developed for the archaeology. However, archaeological data is spatial and archaeologists have spatial decision problems about site characteristics. Therefore, in this thesis, a Spatial Decision Support System is proposed for an archaeological application and implemented to specific archaeological site, Kaunos. According to the view of archaeologists, it has been very useful and the results of every component help to analyze the characteristics of Kaunos. SDSS for Kaunos archaeological application is developed according to requirements defined by the archaeologist working in Kaunos. Hence, decision analyses are determined to meet the requirements.

Results of Queries

First of all, resultant maps, graphs and tables of queries help archaeologists to infer various characteristics of Kaunos. They interpret the results of the first query which is “Where are the Byzantine Periods’ coins found?” as Kauninans used commonly Apolon Holy Place, Temple Terrace and Palaestra in the last period. This result also may lead them to excavate this part of the site in order to find some artifacts belong to the Early Byzantine Period.

Second query is about to find the location of the coins which are minted by the king who minted the most coins in the Hellenistic Period. According to the results of this query, they say that economic situation most probably was the best in the period of Kaunos in the Hellenistic Period. Besides, zones, which are mapped in the Figure 4.15, are the areas in which flow of currency is high excluding the Tombs. They state that because of the tradition of burying the dead, number of coins is high in the Tombs. They especially select the Hellenistic Period, since the highest numbers of coins are found in this period.

They also interpret the results of attribute queries which are:

- Is there any specific type of glass finds? If exist where are they found?
- Which type of glass finds exist in the Bath?

According to the type of glass, archaeologists make interpretation about social classes of Kaunians. They state that perfume bottles are sign that Bath is used by the high social classes. However, in the database, since these kinds of findings are not enough and also just one of the glass findings’ location is recorded as Bath, they could not be sure. Therefore, they may decide to excavate Bath and its vicinity in detail.

Result of Viewshed Analysis

Viewshed analyses are performed in order to define the location choice of Kaunos. Being a regional scale analyses, viewshed analyses are performed by using the wide range of digitized maps of Kaunos. Firstly, the analyses are performed from points and the results are illustrated in the Figures from 4.24 to 4.31. The amounts of visible and non-visible areas are seen in the Table 5.1.

Table 5.1 Amount of visible and non-visible areas from defined points

	1000m		3000m	
	m^2	km^2	m^2	km^2
Measurement Platform	19653	0,1965	5654093	5,654
Agora	1962819	1,963	5285034	5,285
Akropol	1578617	1,579	4916426	4,916
Demeter	1531383	1,531	5283904	5,284

When the distance is selected as 1000 m, nearly 2 km^2 areas can be seen. Moreover, when the distance parameter is selected as 3000 m, nearly 5 km^2 areas can be viewed. If the result maps of visibility analyses and the amount of visible areas are considered together, the significant amount of areas are visible. Besides, when location of the city walls, which surrounds the Kaunos archaeological site on the high mountain from north and south, and its domination over the important areas are considered, it can be concluded that Kaunos was located in a safe area. As it is seen from the selected observation path and points, there could be surveillance arranged for the threats coming from outside of the city wall and the sea.

Result of Spatial Data Analysis

Spatial Data Analyses are performed to analyze site-based spatial decision problems of archaeologists. Especially, exploratory techniques and models, which are used to analyze the global and local effects on the distribution of coin findings, assist archaeologist while producing the information about Kaunos.

Coin and glass values are visualized in terms of time and spatial location in the visualization part of Spatial Data Analysis (Appendix A, Figure 4.41and Figure 4.42). Archaeologists observe from these maps that number of coin findings in Tomb is decreasing through the last periods. According to them, it may be the case that the tradition of burying the dead of Kaunians has changed throughout the periods. Another result is again related with defining the policies of excavation. The Apollon Holy Place is needed to be studied in detail. The main reason is that, although there are many glass findings in the adjacent areas, the Apollon Holy Place has not got any glass findings.

When archaeologists look at the distribution of the mean values over the site (Appendix B), they explain the global trend, which proceed through the south western part of the site, with the development side of the city. This is also supported with the distribution of the coins and glasses according to periods (Appendix A).

After exploring the coin and glass distribution, statistical models are established to analyze the questioned relationships between the coin values and other parameters. Followings are the site-based scale questions of archaeologist:

Table 5.2 Site-based decision questions of archaeologists and models to analyze them

Decision questions	Models
1. Is there any clear relationship between the coins and other remains in the region?	Model 1 (Equation 4.2)
2. Is there any clear relationship between the coins and the type of land use?	Model 3 (Equation 4.5)
3. Is the coin distribution affected by the glass distribution in the region?	Model 3 (Equation 4.5)
4. Are there any clear differences among coin findings in the periods? If there are any differences in the periods, which locations are related to the coin findings in the most significant period?	Model 2 (Equation 4.4)

Three models are constructed to analyze these relationships and MLR, SAR and GWR analyses are performed for each model.

In order to answer the question one, Model 1 is used as in Equation 4.2. According to MLR and SAR results, all of the independent variables are significant (Table 5.2). Hence, it can be said that the zones which are Stoa, Apollon Holy Place, Temple Terrace, Palaestra Terrace, Demeter Temple, Graveyards are related with the coin values. Archaeologist state that this is the expected case, since when the distribution of the coin and glass values are investigated, these areas are very dense (Figure 4.39 and 4.40). This density may show that these areas are commonly used by the Kaunians throughout the periods. Therefore, relationship between the coin values and these areas are very clear.

Besides global regressions, GWR is performed for the Model 1. Relationship between the predictors and outcomes vary over the study area according to GWR results. ANOVA test result shows that this model is significant (Table 4.12). Hence, it is concluded that there is spatial-non stationary when these parameters are used.

Spatial variations in the relationship between the coin values and each predictor are represented in Figures 4.58-4.64. There are positive relationships and when the time of usage predictor is excluded, other independent variables shows strong relationship in the south western part of the site. On the other hand, the relationship between the coin value and usage period of the zones are strong in the north western part of the site. Maps of t values of Model 1 encourage since t values are positive (Appendix E).

In order to analyze the question four which is “Are there any clear differences among coin findings in the periods? If there are any differences in the periods, which locations are related to the coin findings in the most significant period?”, R^2 values of the models specified in the equation 4.3 are compared and it is concluded that the Archaic-Classic Period is different from other periods. This period has the smallest R^2 value (Table 4.12).

In order to define the relationship between the most significant periods’ coin values and the locations, model in the equation 4.4 is established. Results are similar with Model 1 (Table 5.2). Therefore, it can be said that the coin values in the Hellenistic period are related with the locations of Stoa, Apollon

Holy Place, Temple Terrace, Palaestra Terrace, Demeter Temple, Graveyards. Archaeologists state the same comment for this result as in Model 1.

Spatial heterogeneity is also tested with GWR for Model 2. There is a significant spatial variation in the relationship between the Hellenistic Period coin values and predictors. Positive and strong relationships also exist in the same regions of the site as in Model 1.

Table 5.1 Results of whole MLR methods significant variables

	(Intercept)	stoad	akad	ttd	palaestrad	demeterd	mezard	yy
MLR1(t)	-1.098	31.827	71.073	32.644	11.386	4.942	6.109	6.858
LM Pr(>ItI)	0.297872	2.21e-11 ***	7.41e-15 ***	1.72e-11 ***	4.78e-07 ***	0.000586 ***	0.000114 ***	4.41e-05 ***
SAR1(z)	-0.293	59.789	141.559	66.519	24.656	7.978	12.325	12.570
Pr(>|z|)	0.770	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	1.554e-15	< 2.2e-16	< 2.2e-16
	(Intercept)	stoad	akad	ttd	palaestrad	demeterd	mezard	yy
MLR2(t)	-1.152	5.452	78.936	35.599	7.336	11.703	8.604	8.010
LM Pr(>ItI)	0.27602	0.00028 ***	2.60e-15 ***	7.26e-12 ***	2.49e-05 ***	3.70e-07 ***	6.19e-06 ***	1.16e-05 ***
SAR1(z)	-1.5290	6.9239	109.9182	46.8227	10.6470	14.8698	11.2097	11.1863
Pr(>|z|)	0.1263	4.394e-12	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
	(Intercept)	Glass_Ratio	yy	Holy Place	Trade	Graveyard		
MLR3(t)	-0,93	0,58	2,30	1,12	-0,10	-0,52		
LM Pr(>ItI)	0,37	0,58	0,0403*	0,29	0,92	0,62		
SAR1(z)	-1,1488	0,4236	3,0163	1,3238	0,2058	-0,2209		
Pr(>|z|)	0,250639	0,671888	0,002559	0,185573	0,836955	0,825181		

Question two and three is modeled with Model 3 (Equation 4.5). According to results of MLR and SAR, only time of usage is significantly related with the coin values. There is no any relationship between the type of land use and the total number of coins. Archaeologists expect that the trade areas may show the relationship. They conclude that these areas, called as trade areas, may not be the locations that coins are interchanged. They also stated that however; these areas should be studied in detail.

Spatial heterogeneity is also investigated for the Model 3. However, ANOVA table shows that the results of GWR are not significant (Table 4.22). Besides, T values of the independent variables exclude time of usage are very low. T values of trade areas and graveyard are negative as well (Appendix E). Therefore, there is not spatial variation in the relationship between predictors and outcome.

Limitations of the Study

The limitations of this study should also be discussed. Firstly, there are some constraints concerning the viewshed analysis. A basic concern is the difference between the topography of the area. Since digital elevation model of the ancient life cannot be created, viewsheds are constructed as if there are no changes in the landscape. Another concern is the tree problem. Because whether the site has trees or not in the ancient life cannot be known, viewsheds are performed under the assumptions that there are no trees.

Secondly, although spatial decision problems of archaeologists are analyzed with spatial analyses, there are some deficiencies. As stated in Section 4.4, coordinates of the coin and glass values are not known. Because of this problem, some socio-economic and cultural properties of Kaunos cannot be fully defined. Archaeologists say that if this information exists, it can be understood that the found coins are public findings or belongs to someone. Moreover, social classes of Kaunos can be identified. Another problem is that the number of coins and glass findings are very few so analyses cannot be conducted properly.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

The use of Spatial Decision Support System (SDSS) has grown dramatically due to its ability to provide various tools for solving spatial decision problems. When spatial decision problems of archaeologists, which are asked in order to examine and interpret different characteristics of ancient civilizations, are analyzed, it is figured-out that SDSS is the best tool to help them. Therefore, in this thesis, an SDSS is proposed for archaeological applications. The proposed SDSS is implemented for the archaeological excavation site of Kaunos to demonstrate the use of proposed SDSS.

The developed SDSS meets the requirements of archaeologists with its components. Database Management Component provides the storage of excavation data such as coin and glass information in R-DBMS and storage of spatial information in GIS software. Model Management Component contains basic GIS analyses functions and also spatial modeling tools in order to analyze the site-based and regional scale questions that archaeologists works on about Kaunos. The results of analyses are visualized in the Dialog Management Component. These illustrated results are found useful by the archaeologists. In User Component, archaeologists are included into the system in terms of interpreting the characteristics of Kaunians by utilizing the visualized results of analyses.

The most important advantage of an archaeological SDSS is that it incorporates modeling and analysis capabilities with database management system so that decision questions of archaeologists, which cannot be answered only by the GIS analysis, can be analyzed.

Second advantage of this system is to incorporate the archaeologists to the system. By this way, they can interpret socio-cultural, economic and political characteristics of Kaunians and the output map of analyses. For example basic GIS analysis functions helps to analyze social classes of Kaunians, specific characteristics of coin and glasses and also location selection criteria of Kaunians.The relationship between coins and other specified parameters are modeled by using the spatial data analysis methods. According to the results of the models, archaeologists produce information about use of locations in terms of periods, relationships between the number of coins and locations, relationship between the number of coins and type of land use etc.

This developed system is different from the past applications about spatial analyses in archaeology. Examples in the literature utilize GIS software in order to meet only one of the requirements of archaeologists. For example, in Elaiussa Sebaste, GIS is used to organize and to retrieve the regional survey and excavation data or in order to analyze location selection criteria in Onondaga Iroquois sites, viewshed analysis are performed with GIS etc. However, the proposed SDSS not only provide the GIS functions to archeologist but also other analytical tools, which are not exist in the GIS software, for making better decisions. Moreover, since it has the modeling capabilities besides GIS analysis, the whole decision questions of archaeologists about the site are analyzed within SDSS.

In this study, developed SDSS is used by the archaeologists through the produced maps, charts and graphs. They produce meaningful information about Kaunos by interpreting them. Besides, during the course of developing the system, their knowledge is utilized. However, Dialog Management Component of an SDSS should provide the user interface requiring coding of the user interfaces, which lacks in the implementation of the proposed SDSS. Decision makers are involved in the system through these interfaces. Densham (1991) states that the user interface of SDSS needs to represent two spaces; objective space and map space. Objective space shows the parameters of an analytical model. On the other hand, output of the models and cartographic representation of the results constitute the map space. These kinds of interface provide archaeologists easy to select data, make queries, model parameters and analyses of the results. Hence, if user interfaces are developed for the non-expert users of archaeologists, use of the system will be more effective than the current developed system. Hence development of the user interfaces by coding in appropriate programming languages are recommended for further study.

Although developed system can perform many analysis and test related hypotheses, some of the characteristics of Kaunos could not be defined. This is because of the deficiencies in the excavation data. In order to develop successful SDSS for archaeological excavation, archaeologists should collect the excavation data with coordinate information. Moreover, if findings such as coins, glasses or tablets are found inside the buildings, their location should be signed on the sketch of the building.

Another most important aspect is that as more artifacts are found, the more the characteristics of the site can be analyzed. In Kaunos, socio-cultural and economic properties of the site cannot be fully analyzed due to existence of only coin and glass findings data. Therefore, archaeologists should collect ceramics, potteries and tablets from the site during the survey. Models can be created more specifically with these values. For example, archaeologists say that colored ceramics and mines (such as gold) are related with the prosperity and the quality of life. Based on this hypothesis, the relationship between the prosperity of the regions in the site, colored ceramics and mines can be modeled.

Another important aspect for the data collection is about regional scale data. Maps of archaeological site should be obtained in digital format. Besides, in order to reveal the location characteristics of that period objectively, topographical maps belong to the related historical period tried to be obtained.

In conclusion, the proposed decision support system is used to reveal the characteristics of Kaunos by analyzing the decision questions of archaeologists with GIS analyses and the spatial data analyses as well as hypothesis testing. Using GIS software, the system meets the requirements of archaeologists with its four main components. Therefore, the proposed decision support system assists archaeologists and eases both the excavation and post excavation processes of the site.

The improvement of the following issues for further research will allow enhancement of the proposed archaeological SDSS:

- Collection of more comprehensive excavation data with better spatial detail (such as containing the ceramics, tablet)
- involvement of more detailed attribute information related to the findings
- development of more sophisticated models using more comprehensive excavation data and its detailed attribute information

development of user interface in Model Management Component.

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APPENDIX A

Ratio of Coin and Glass Values with Respect to Periods

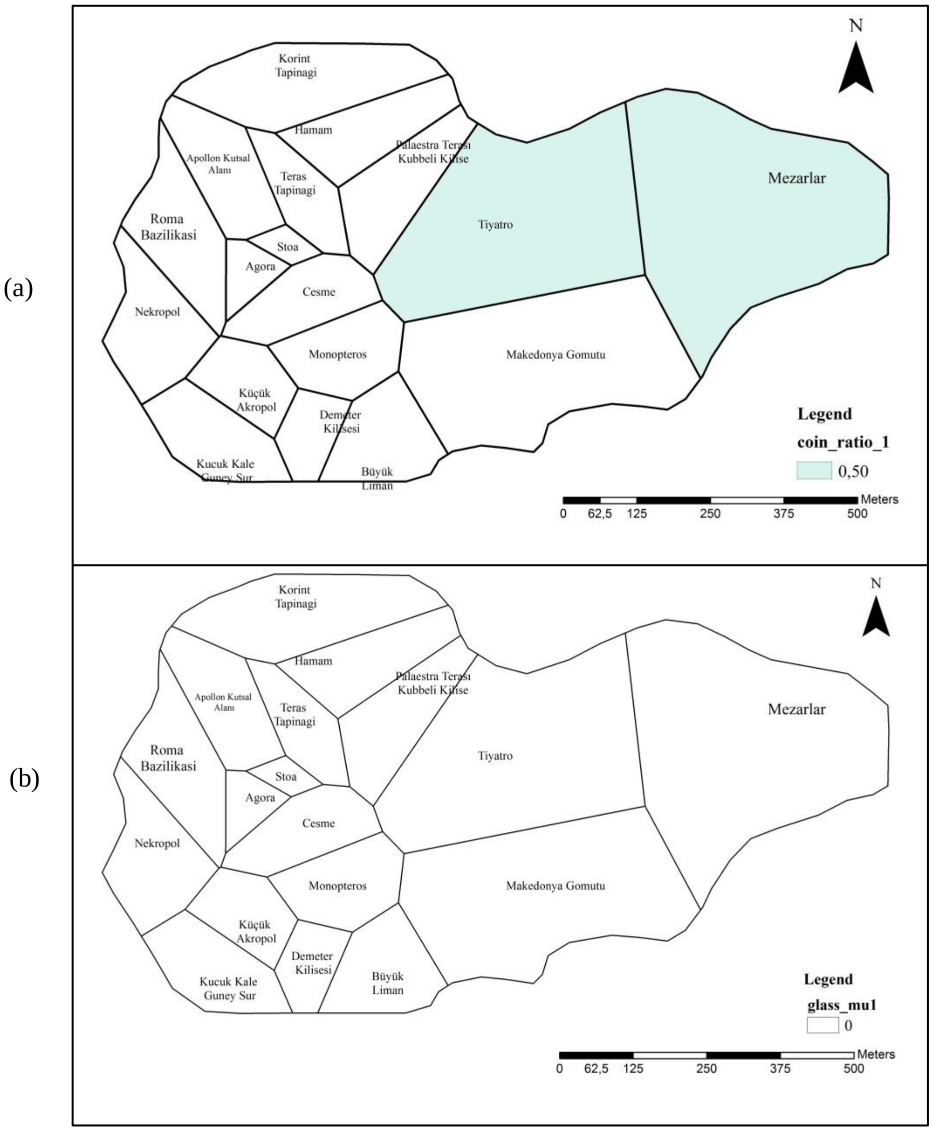


Figure A.1 Coin (a) and glass (b) ratios in Archaic-Classic Period

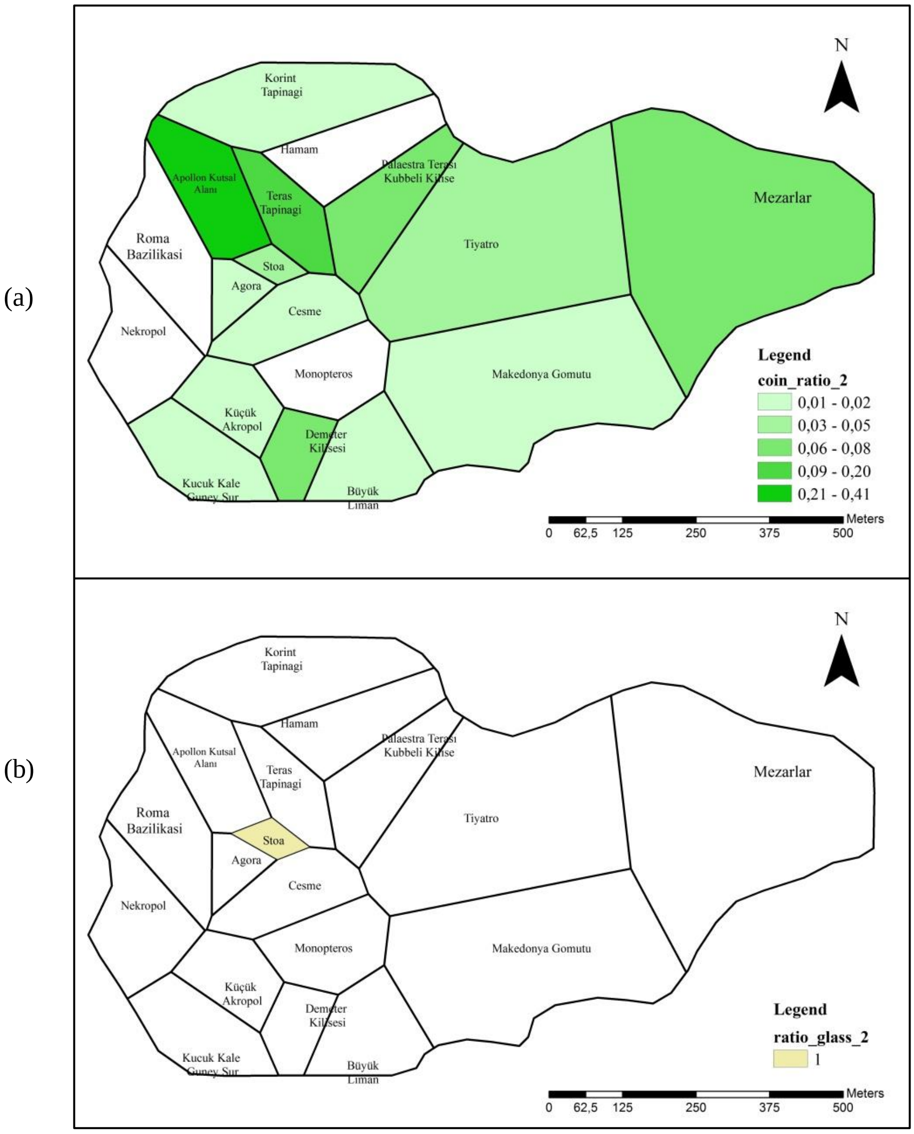


Figure A.2 Coin (a) and glass (b) ratios in Hellenistic Period

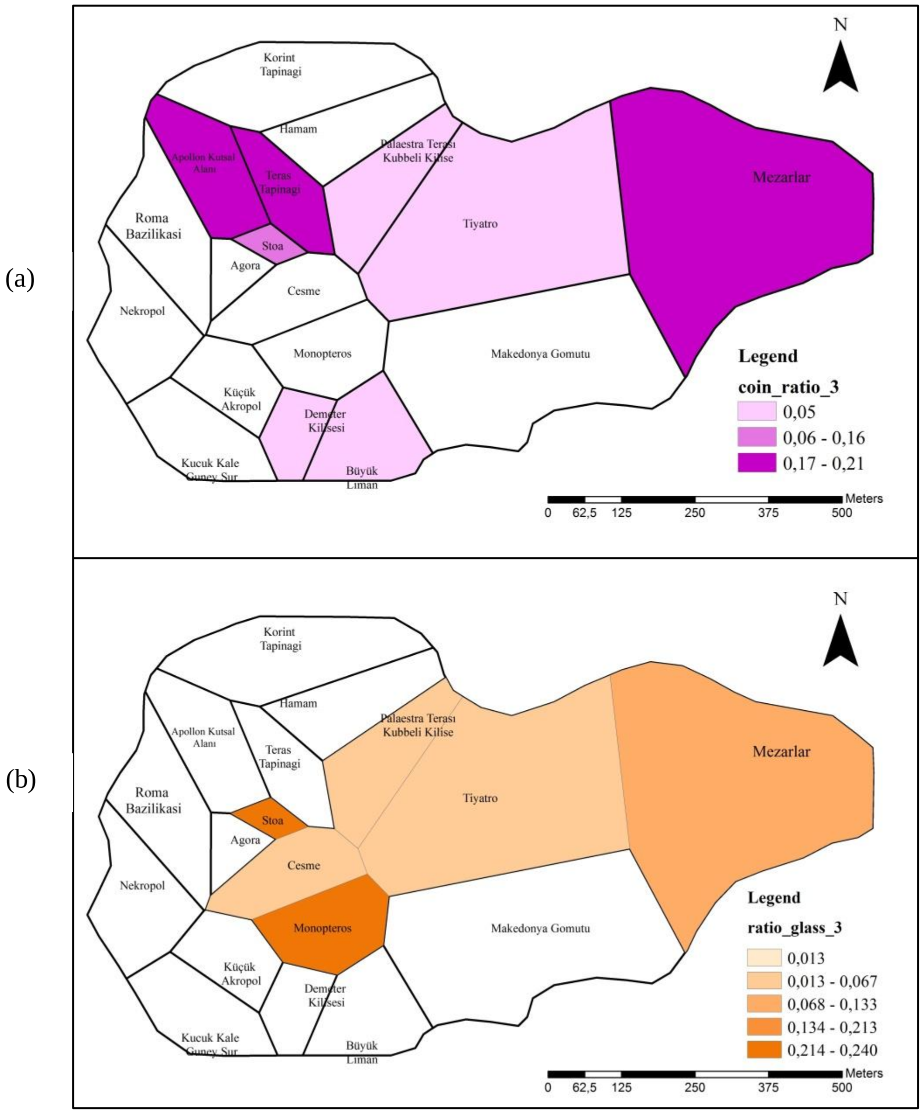


Figure A.3 Coin (a) and glass (b) ratios in Early Imperial Period

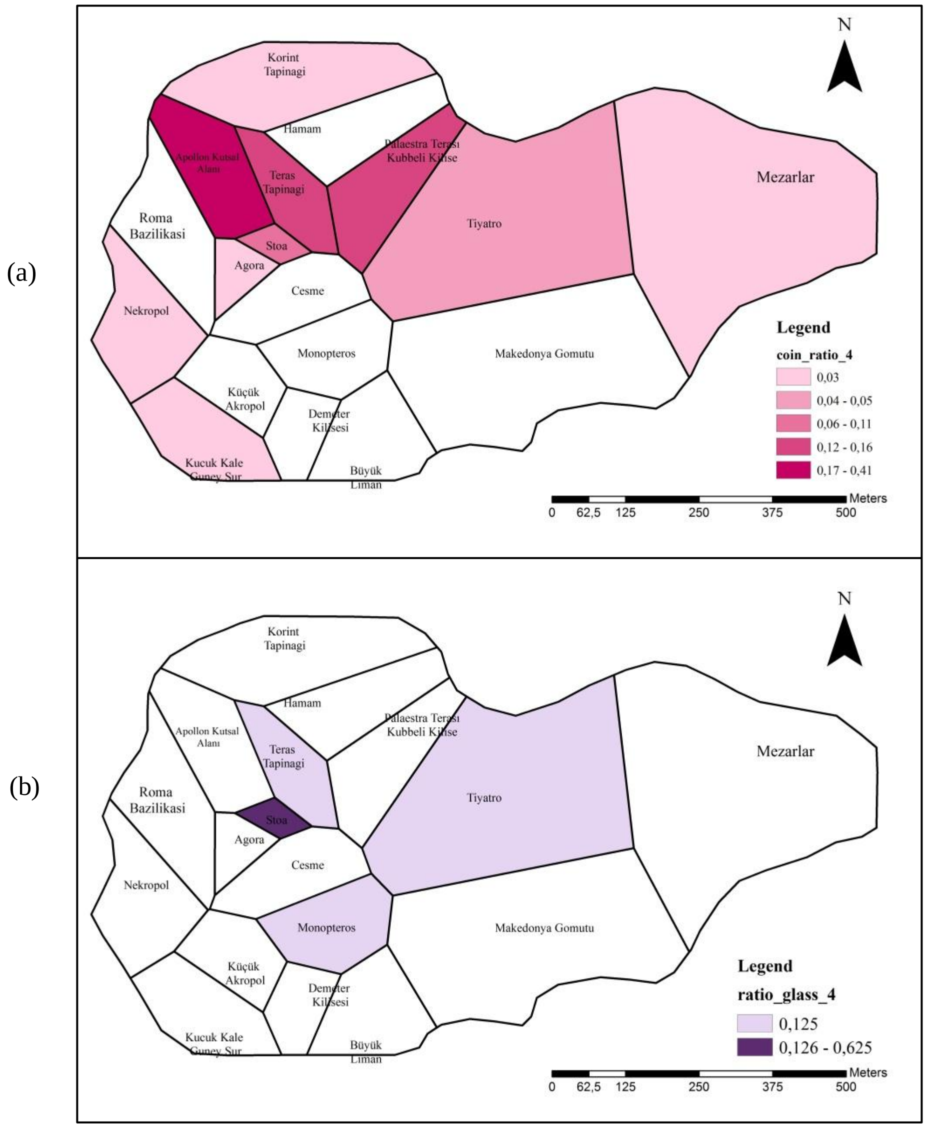


Figure A.4 Coin (a) and glass (b) ratios in Mid Imperial Period

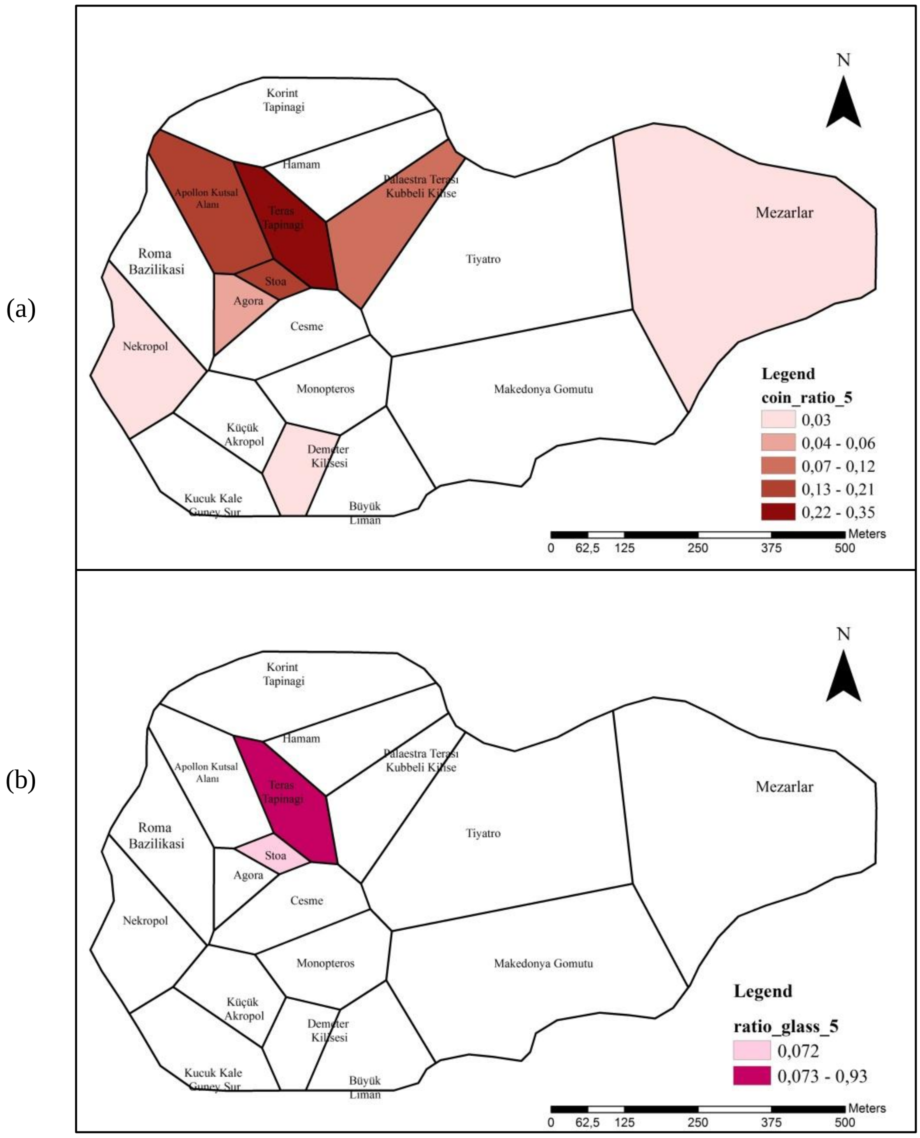


Figure A.5 Coin (a) and glass (b) ratios in Late Imperial Period

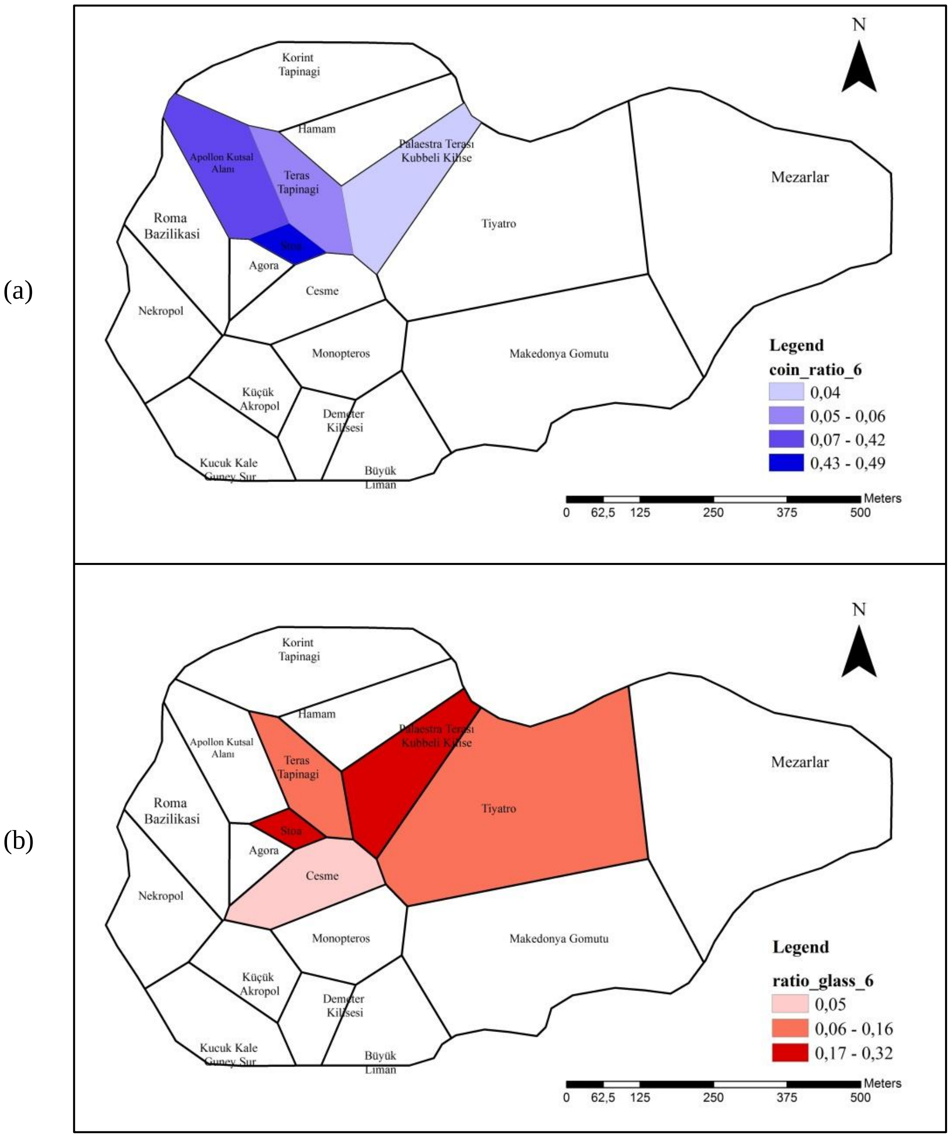


Figure A.6 Coin (a) and glass (b) ratios in Early Byzantine Period

APPENDIX B

Spatial Moving Average Maps of Coins and Glasses with Respect to Periods

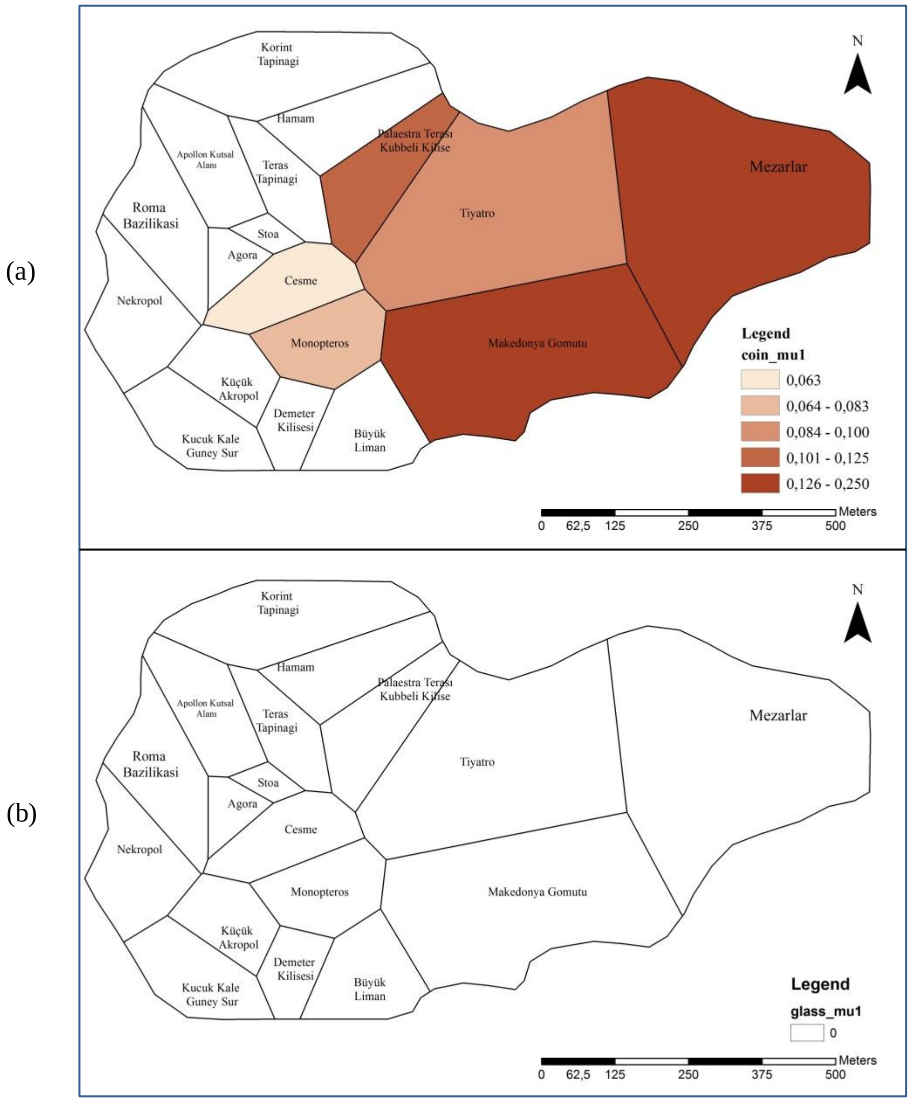


Figure B.1 Coin (a) and glass (b) μ values in Archaic-Classic Period

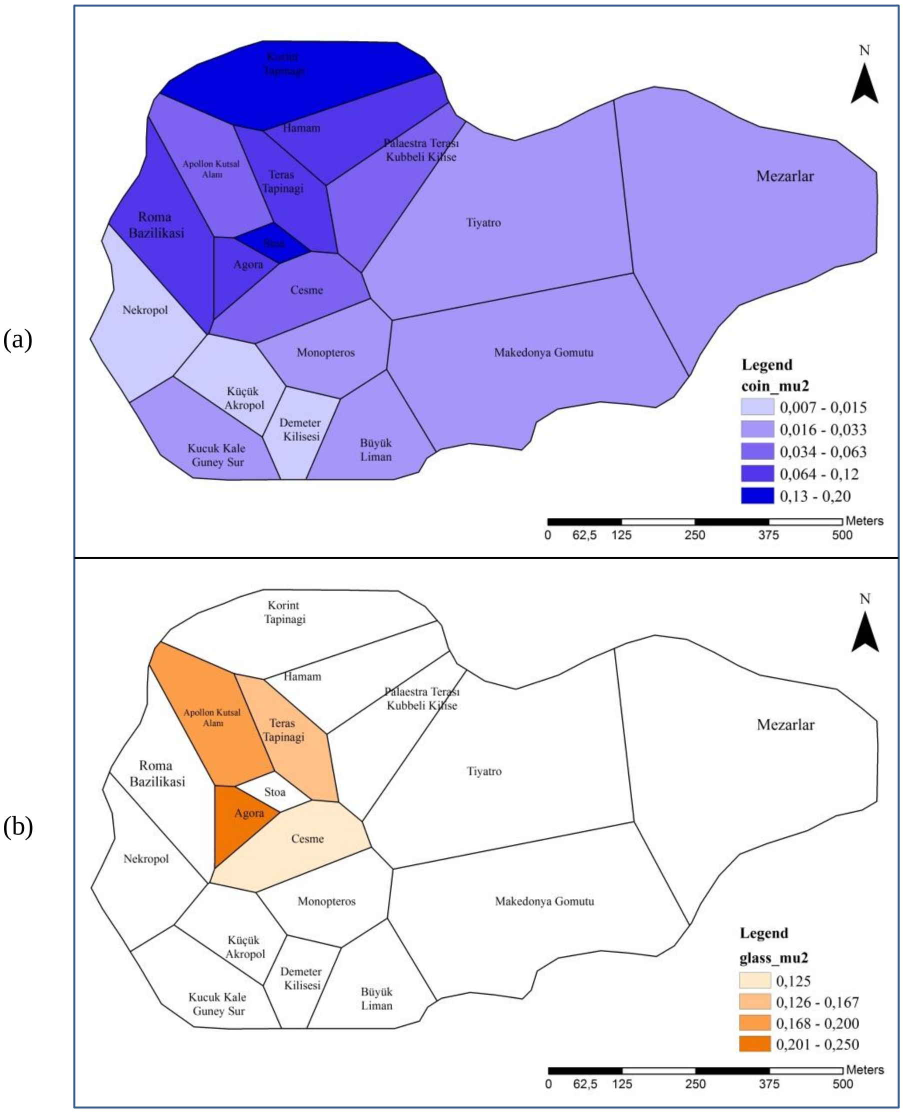


Figure B.2 Coin (a) and glass (b) μ values in Hellenistic Period

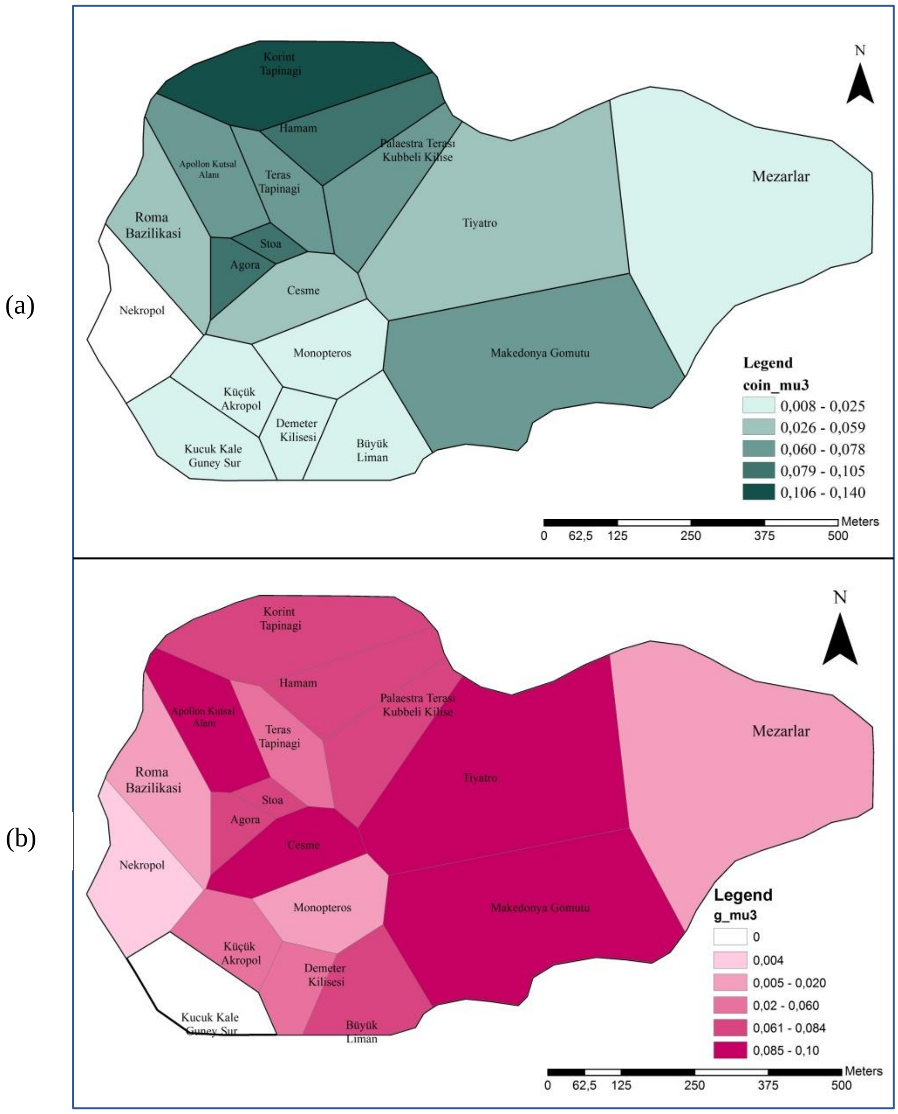


Figure B.3 Coin (a) and glass (b) μ values in Early Imperial Period

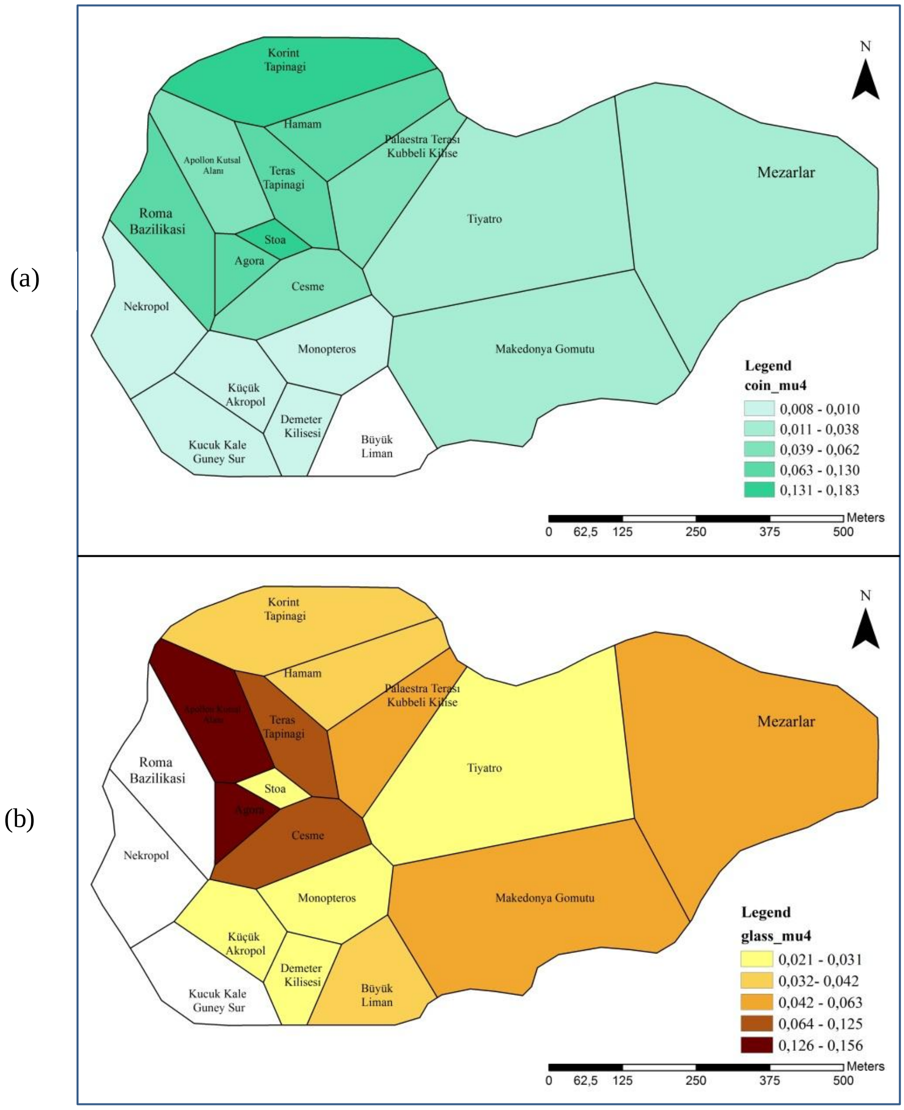


Figure B.4 Coin (a) and glass (b) μ values in Mid Imperial Period

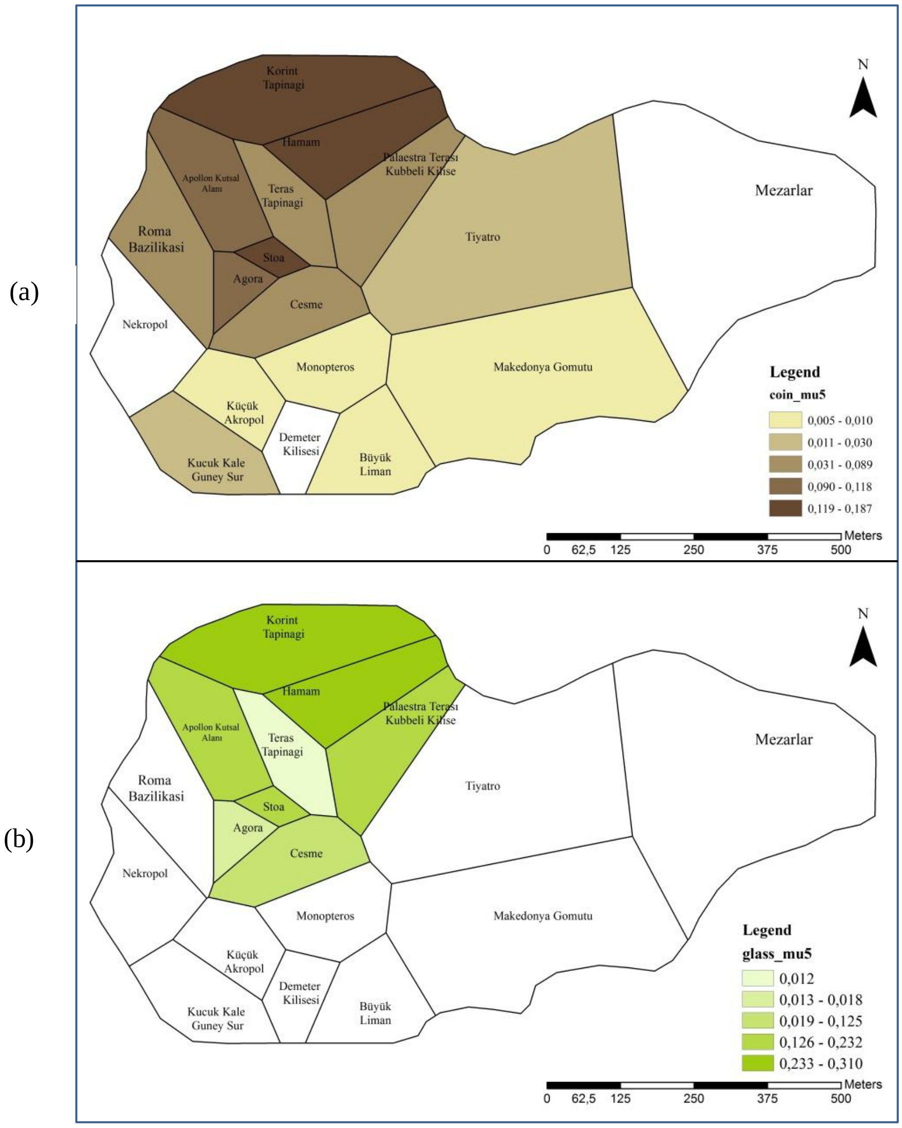


Figure B.5 Coin (a) and glass (b) μ values in Late Imperial Period

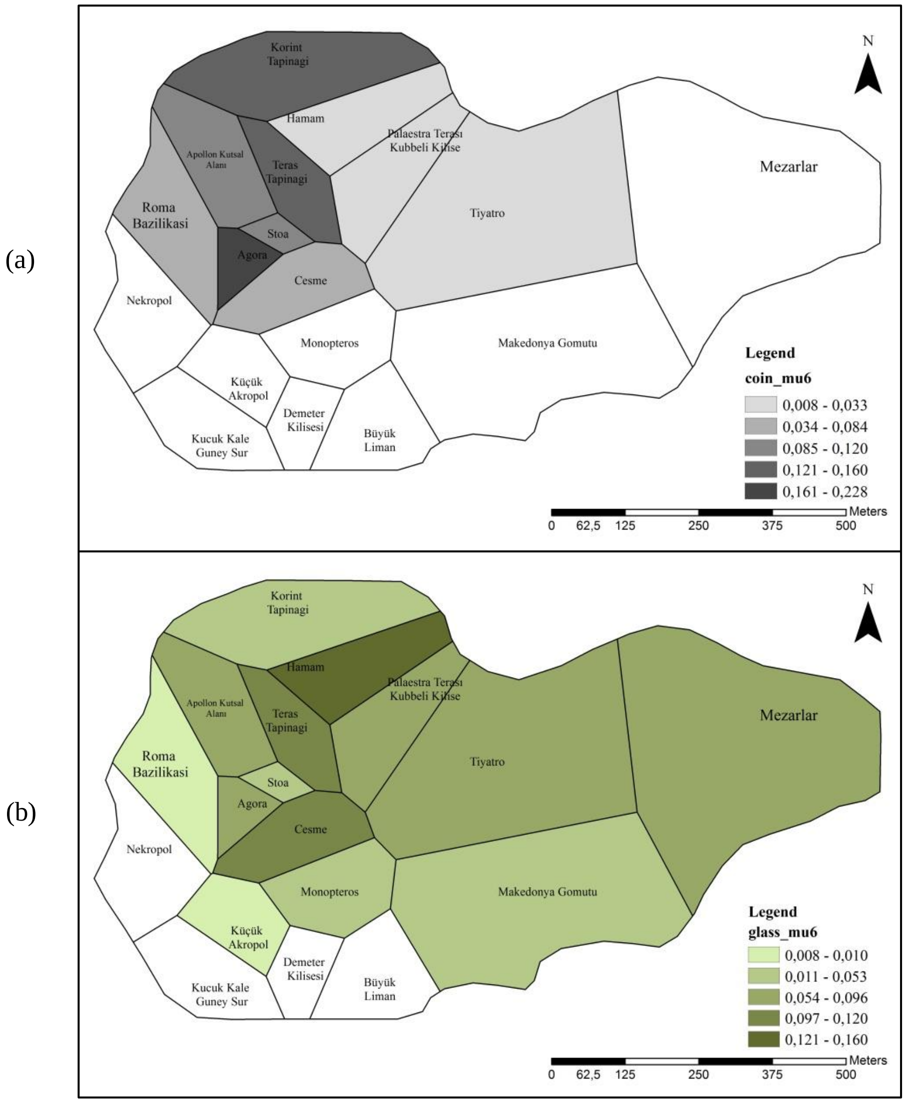


Figure B.6 Coin (a) and glass (b) μ values in Early Byzantine Period

APPENDIX C

Correlation diagram of independent variables

Table C.1 Correlation diagram of independent variables

		slope	coincentury	Glassratio	nekropolD	kucukakropolD	makedonyagomutuD	KucukkaleguneysurD	BuyuklimanD	MezarlarID	RomaBazilikasıD	StoaD	AKAD	TerastapınagıD	CesmeD	TiyatroD	PalaestraD	HamamD	DemeterD	KorinthD	AgoraD
Slope	Pearson Correlation	1	,016	-,192	,156	,353	,331	,497*	-,299	,322	-,197	-,172	-,267	-,079	-,153	,035	-,076	-,013	,194	-,299	-,186
	Sig. (2-tailed)		,950	,446	,536	,150	,179	,036	,228	,193	,433	,496	,284	,754	,545	,890	,764	,961	,440	,228	,460
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Coincentury	Pearson Cor	,016	1	,376	-,216	-,138	-,138	-,060	,017	,406	-,372	,251	,251	,251	-,138	,328	,251	-,372	,095	-,060	,017
	Sig. (2-tailed)	,950		,124	,389	,584	,584	,812	,946	,095	,129	,316	,316	,316	,584	,183	,316	,129	,708	,812	,946
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Glassratio	Pearson Cor	-,192	,376	1	-,153	-,153	-,153	-,130	-,153	,078	-,153	,610**	-,153	,610**	-,014	,009	,055	-,130	-,153	-,153	-,130
	Sig. (2-tailed)	,446	,124		,545	,545	,545	,608	,545	,758	,545	,007	,545	,007	,956	,972	,828	,608	,545	,545	,608
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
nekropolD	Pearson Cor	,156	-,216	-,153	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,536	,389	,545		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table C.1 Correlation diagram of independent variables (Cont'd)

kucukakropolD	Pearson Cor	,353	-,138	-,153	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,150	,584	,545	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
makedonyagomutuD	Pearson Cor	,331	-,138	-,153	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,179	,584	,545	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
KucukkaleguneysurD	Pearson Corr	,497*	-,060	-,130	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,036	,812	,608	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
BuyuklimanD	Pearson Cor	-,299	,017	-,153	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,228	,946	,545	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
MezarlarID	Pearson Cor	,322	,406	,078	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,193	,095	,758	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table C.1 Correlation diagram of independent variables (Cont'd)

RomaBazilikasıD	Pearson Cor	-,197	-,372	-,153	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,433	,129	,545	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
StoaD	Pearson Cor	-,172	,251	,610**	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,496	,316	,007	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
AKAD	Pearson Cor	-,267	,251	-,153	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,284	,316	,545	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
TerastapınagıD	Pearson Cor	-,079	,251	,610**	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,754	,316	,007	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
CesmeD	Pearson Cor	-,153	-,138	-,014	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,545	,584	,956	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table C.1 Correlation diagram of independent variables (Cont’d)

TiyatroD	Pearson Cor.	,035	,328	,009	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059	-,059	-,059	-,059
	Sig. (2-tailed)	,890	,183	,972	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
PalaestraD	Pearsıon Cor.	-,076	,251	,055	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059		1	-,059	-,059	-,059	-,059
	Sig.(2 tailed)	,764	,316	,828	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
HamamD	Pearson Cor	-,013	,-037	-,130	-,059	,-059	,-059	,-059	,-059	,-059	,-059	-,059	,-059	-,059	,-059	,-059	,-059	1	,-059	-,059	-,059
	Sig.(2 tailed)	,961	,129	,608	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
DemeterD	Pearson Cor	,194	,095	-,153	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059	-,059
	Sig.(2 tailed)	,440	,708	,545	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817	,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
KorinthD	Pearson Cor	-,299	-,060	-,153	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1	-,059
	Sig.(2 tailed)	,228	,812	,545	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817		,817
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18

Table C.1 Correlation diagram of independent variables (Cont'd)

AgoraD	Pearson Cor	-,186	,017	-,130	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	-,059	1
	Sig.(2 tailed)	,460	,946	,608	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	,817	
	N	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18		18	18

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX D

Dummy coding tables

Table D.1 Dummy coding tables for zones

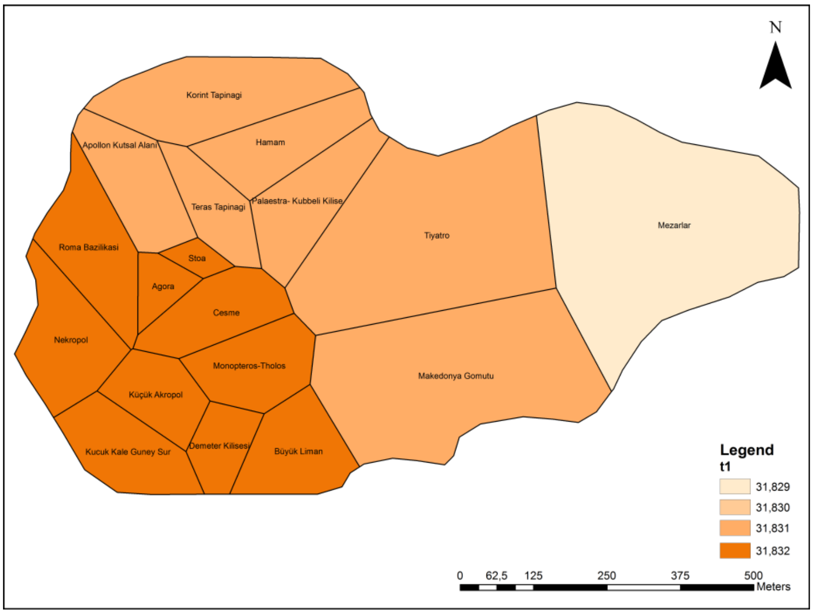
	Dummy Variables																
	Nekd	Kucukd	makd	kkd	blimand	Mezard	romad	stoad	akad	ttd	cesmed	tiyatrod	palaestrad	hamad	demeterd	korinthd	agorad
Cesme	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Makedonya Gomutu	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mezarlar	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Korint Tapinagi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Agora	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Demeter Kilisesi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Monopteros-Tholos	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teras Tapinagi	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Apollon Kutsal Alani	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Stoa	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Roma Bazilikasi	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Buyuk Liman	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Kucuk Kale Guney Sur	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Kucuk Akropol	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nekropol	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tiyatro	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Hamam	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Palaestra- Kubbeli Kilise	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0

Table D.2 Dummy coding tables for type of land use

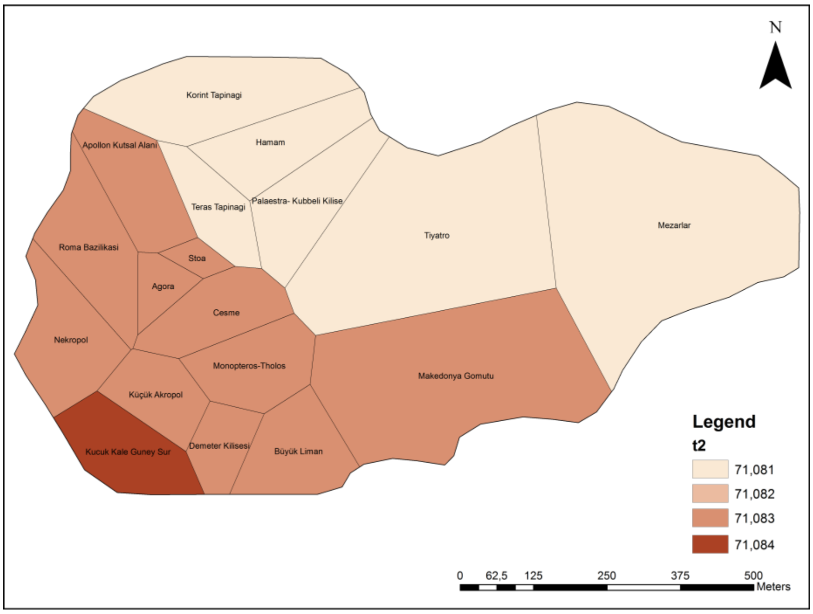
Name	graveyard	hollyd	traded
Cesme	0	0	0
Makedonya Gomutu	1	0	0
Mezarlar	1	0	0
Korint Tapinagi	0	1	0
Agora	0	0	0
Demeter Kilisesi	0	1	0
Monopteros-Tholos	0	1	0
Teras Tapinagi	0	1	0
Apollon Kutsal Alani	0	1	0
Stoa	0	0	0
Roma Bazilikasi	0	0	0
Buyuk Liman	0	0	1
Kucuk Kale Guney Sur	0	1	0
Kucuk Akropol	0	0	1
Nekropol	0	0	1
Tiyatro	0	0	0
Hamam	0	0	0
Palaestra- Kubbeli Kilise	0	0	0

APPENDIX E

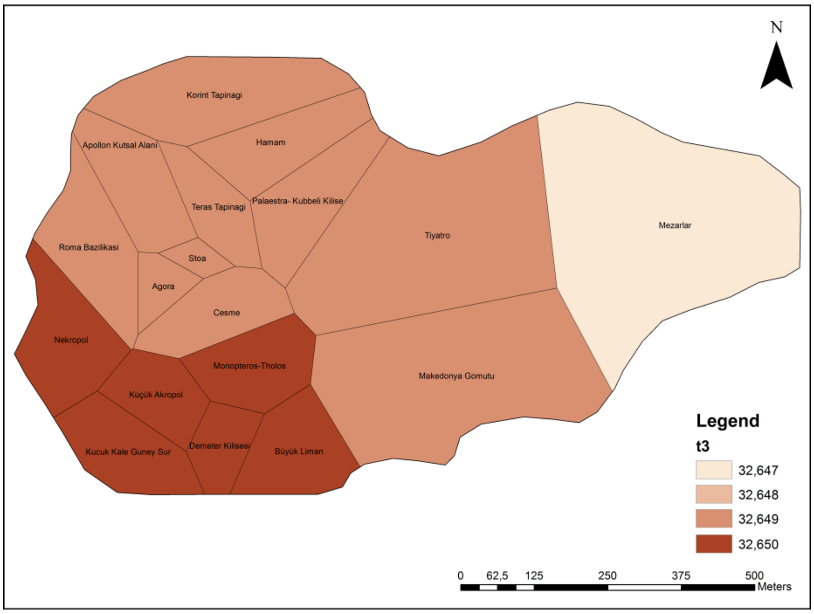
t values of GWR –Model 1, Model 2 and Model 3



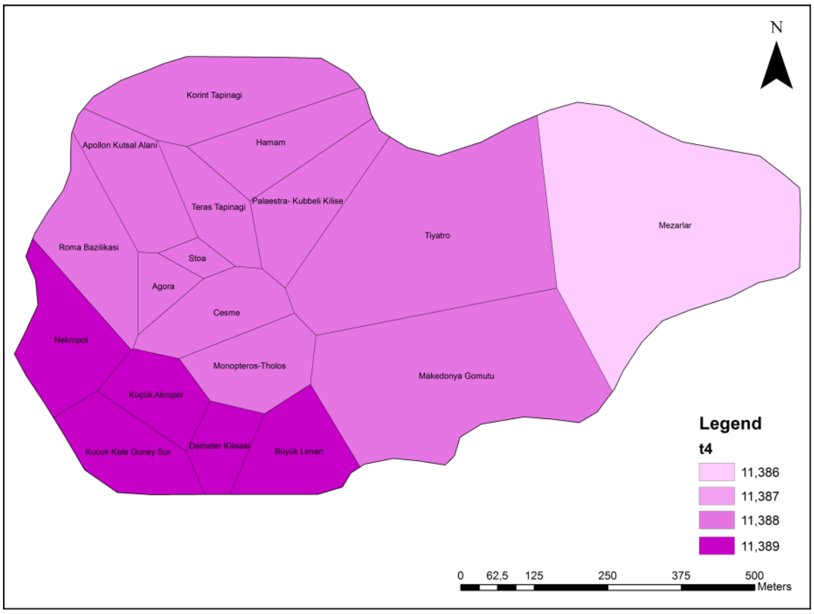
E1: t values of the Stoa coefficients - Model 1



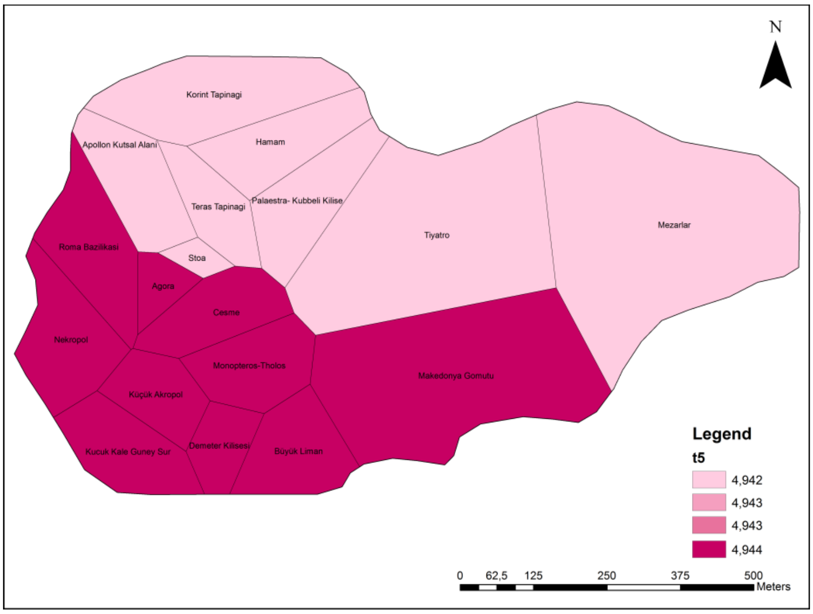
E2: t values of Apollon Holy Place - Model 1



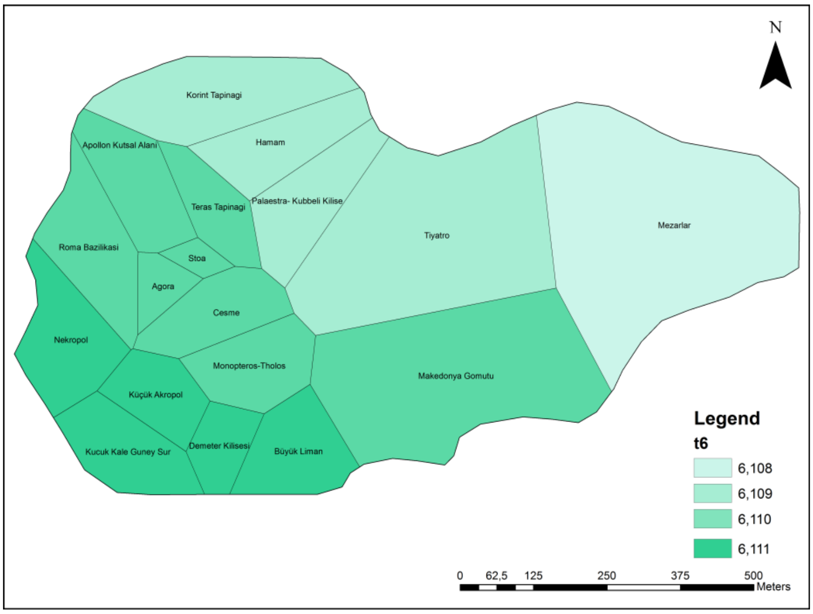
E3: t values of Temple Terrace – Model 1



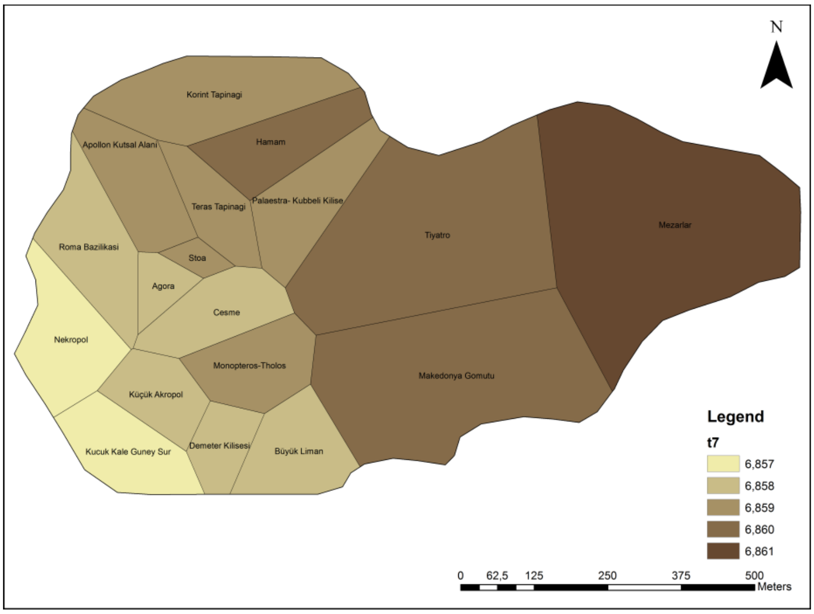
E4: t values of Palaestra – Model 1



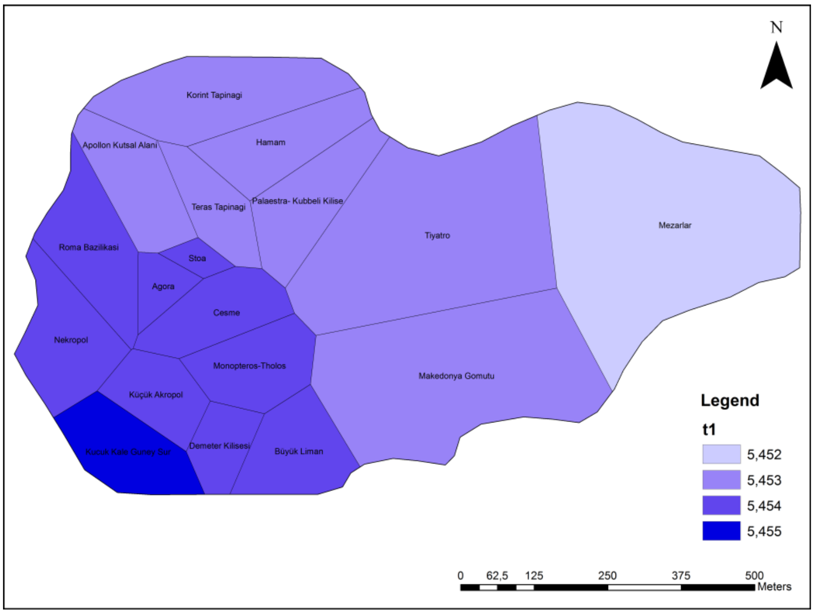
E5: t values of Demeter Temple – Model 1



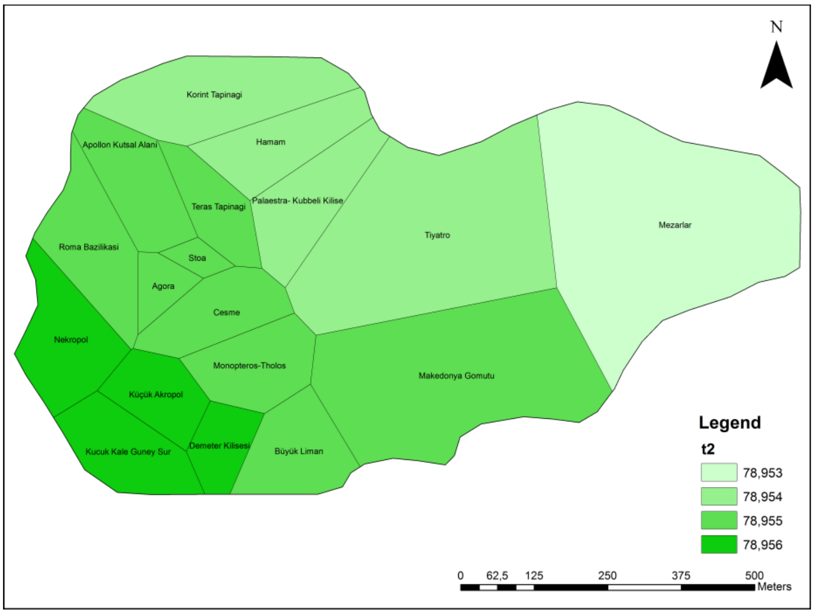
E6: t values of Graveyard – Model 1



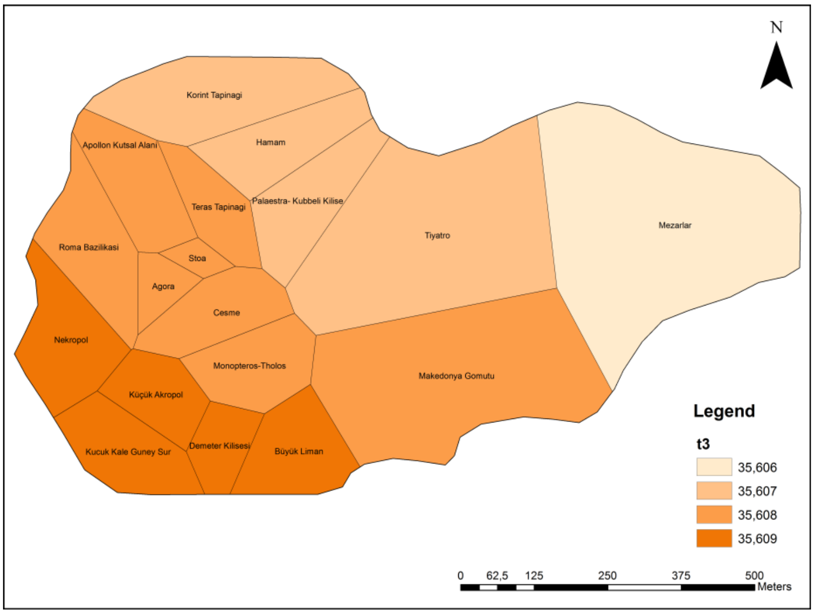
E7: t values of time of usage – Model 1



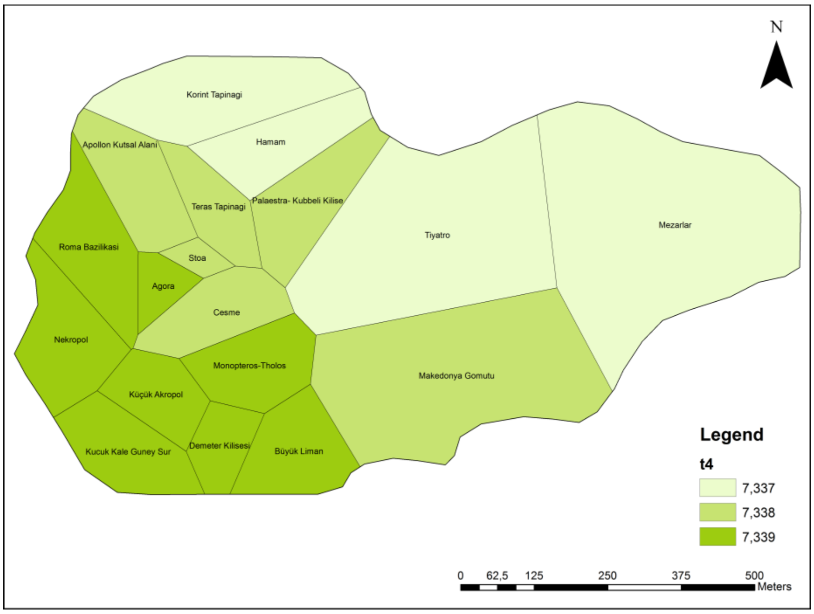
E8: t values of the Stoa coefficients - Model 2



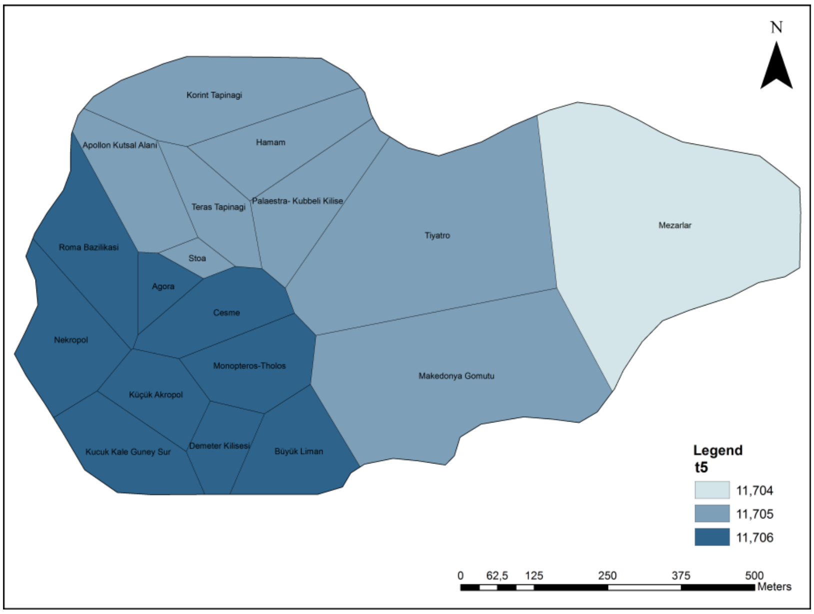
E9: t values of Apollon Holy Place - Model 2



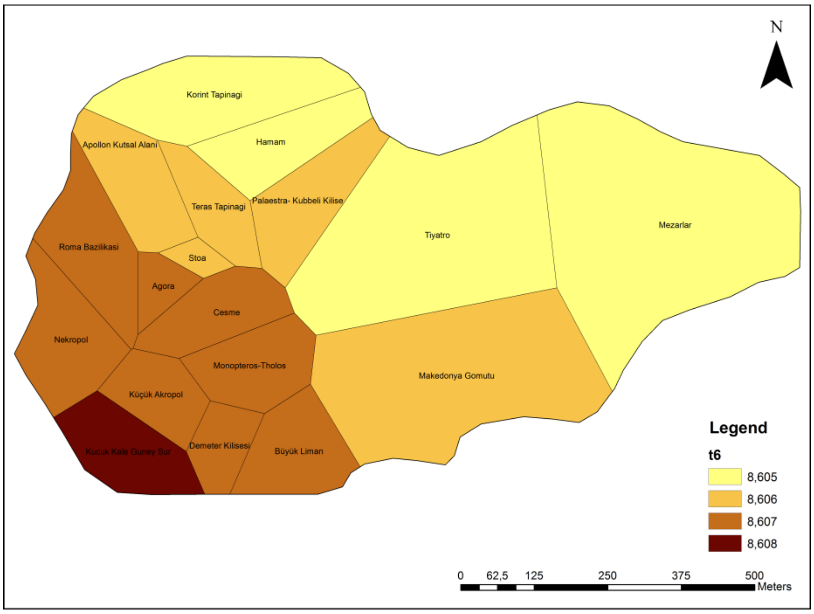
E10: t values of Temple Terrace – Model 2



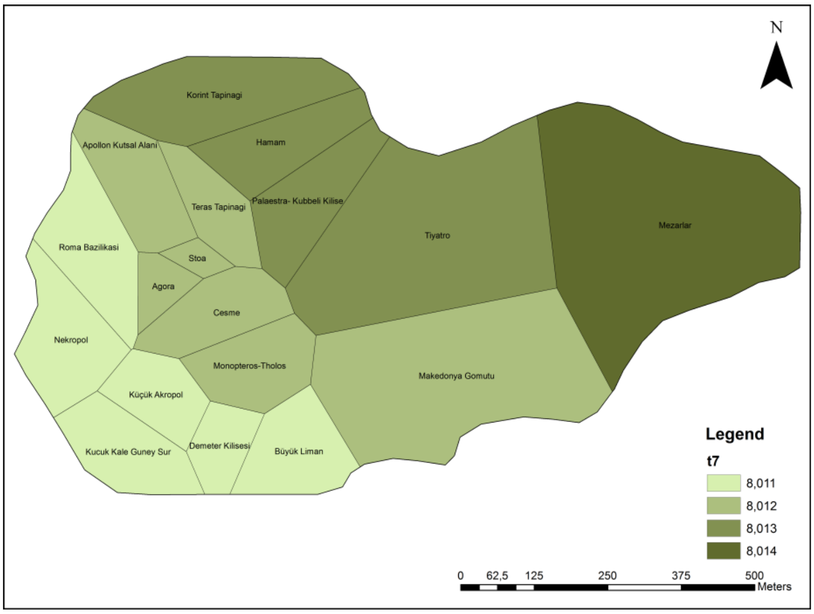
E11: t values of Palaestra – Model 2



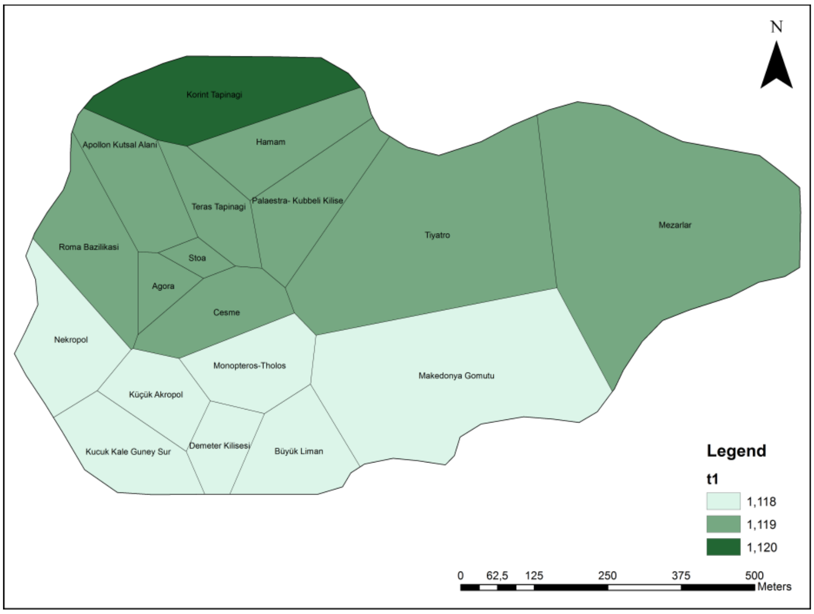
E12: t values of Demeter Temple – Model 2



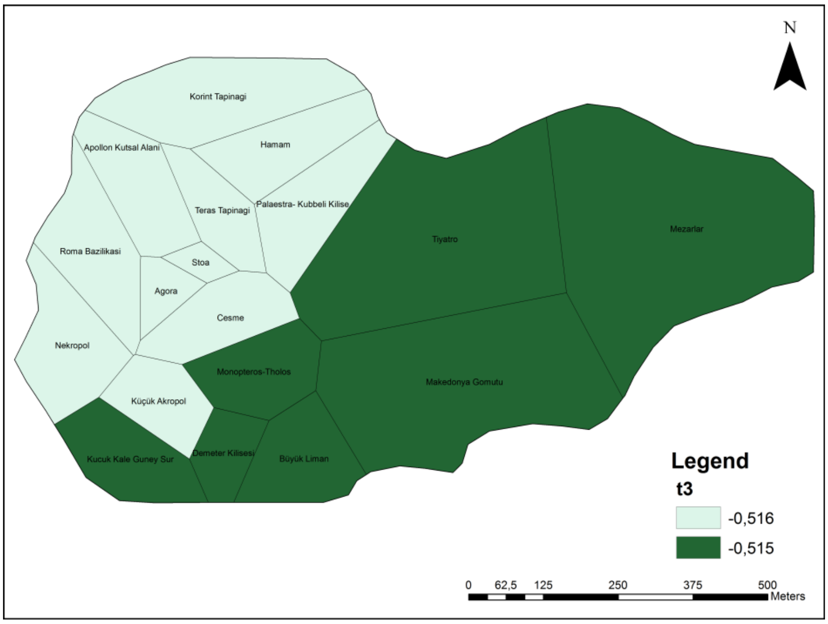
E12: t values of Graveyard – Model 2



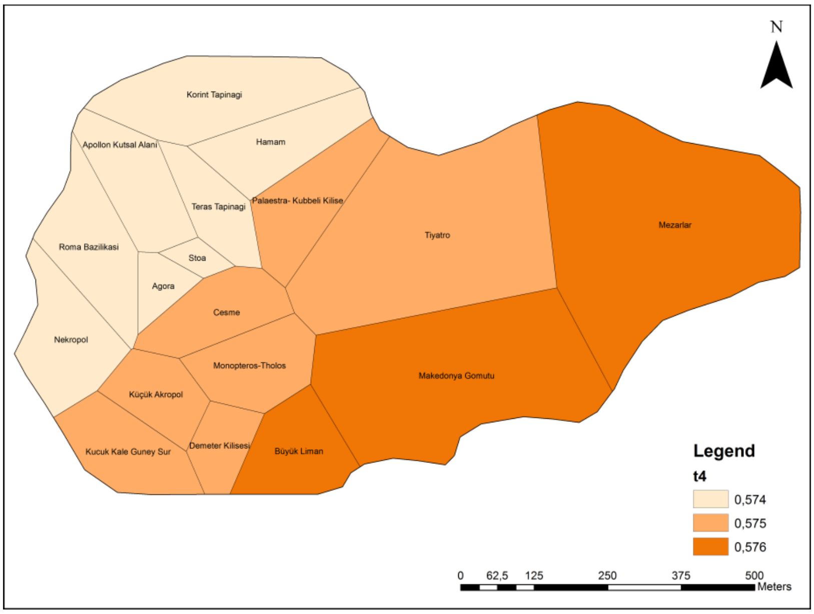
E13: t values of time of usage – Model 2



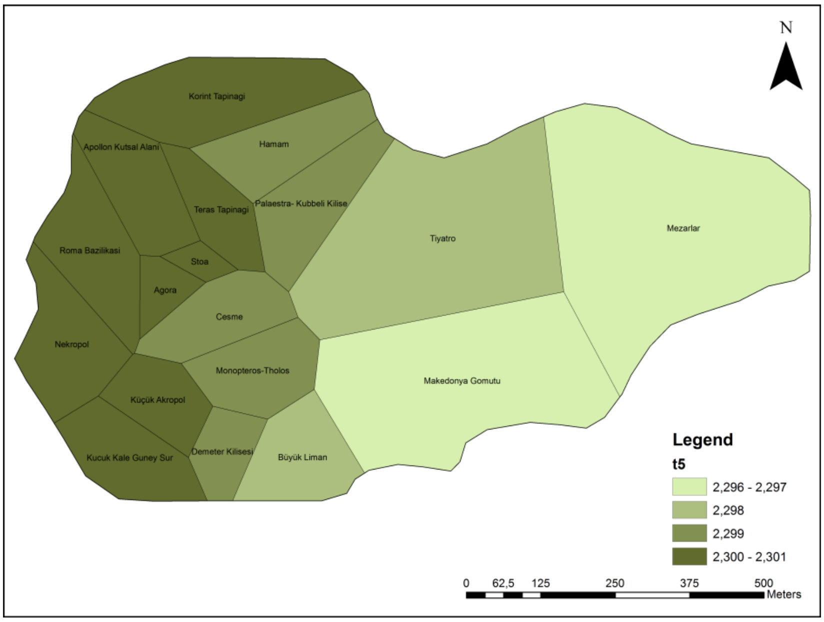
E14: t values of holy places – Model 3



E15: t values of graveyards – Model 3



E16: t values of glass ratio – Model 3



E16: t values of time of usage – Model 3