

Monitoring Mediterranean Sprawl: A Longitudinal Study in the Case of Famagusta

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ABSTRACT

Monitoring urban sprawl is a controversial topic among scholars. Many studies have tried to employ various methods for monitoring urban sprawl in North American and Northern and Western European cities. Although numerous methods have been applied with great success in various countries, they are mostly inapplicable to Mediterranean and developing regions, lacking reliable census data.

The complexity of the methods also makes them difficult to perform in underfunded situations. This study, therefore, aims to develop a new multidimensional method that researchers and planners can apply readily in Euro-Mediterranean cities and developing regions. The new method was tested in the city Famagusta, North Cyprus, including its coastline, which has experienced unplanned growth for the past half-century.

In support of this proposal, a detailed review of the existing literature that emphasizes urban sprawl characteristics is presented. Five characteristics were chosen to monitor urban sprawl's development in the Famagusta Eastern Shore. The method was structured based on a time-series (2001, 2006, 2011, and 2016) dataset that used remote sensing data and geographical information systems to monitor the urban sprawl.

Based on the findings, I can say that Famagusta experienced rapid growth during the last 15 years. The lack of a master plan resulted in the uncontrolled expansion of the city in the exurban areas. The development configuration was polycentric and linear in form with single-use composition. Together, the expansion and configuration

manifested as more built-up area, scattered development, and increased automobile dependency.

Keywords: Urban Sprawl, Famagusta, Euro-Mediterranean, Monitoring Sprawl, Remote Sensing

ÖZ

Kentsel yayılmanın izlenmesi bilim adamları arasında tartışmalı bir konudur. Birçok çalışma, Kuzey Amerika ve Kuzey ve Batı Avrupa şehirlerinde kentsel yayılmayı izlemek için çeşitli yöntemler kullanmaya çalışmıştır. Çeşitli ülkelerde çok sayıda yöntem büyük bir başarı ile uygulanmış olsa da, güvenilir nüfus sayımı verileri olmayan Akdeniz şehirleri için çoğunlukla pratik değildir.

Ayrıca, yöntemlerin karmaşıklığı, yetersiz fonlu durumlarda uygulanmalarını zorlaştırdı. Bu nedenle bu çalışma, araştırmacıların ve planlamacıların Akdeniz ve gelişmekte olan bölgeler kolaylıkla uygulayabilecekleri çok boyutlu yeni bir yöntem geliştirmeyi amaçlamaktadır. Yeni yöntem, geçtiğimiz yarım yüzyılda plansız bir büyüme yaşayan Kıbrıs'ın Gazimağusa'da test edildi.

Bu öneriyi desteklemek için, kentsel yayılma özelliklerini vurgulayan mevcut literatürün ayrıntılı bir incelemesi sunulmaktadır. Gazimağusa vey akin çevresi kentsel yayılmanın gelişimini izlemek için beş kategori seçilmiştir. Yöntem, kentsel yayılmayı izlemek için uzaktan algılama verilerini ve coğrafi bilgi sistemlerini kullanan bir zaman serisi (2001, 2006, 2011 ve 2016) veri setine dayalı olarak yapılandırılmıştır.

Elde edilen bulgulara göre, Mağusa son 15 yılda hızlı bir büyüme yaşadı. Bir master planın olmaması, şehrin dış mahallelerde kontrolsüz bir şekilde genişlemesine neden oldu. Geliştirme konfigürasyonu, tek kullanımlık kompozisyon ile çok merkezli ve doğrusaldı. Genişleme ve konfigürasyon birlikte daha fazla yerleşim alanı, dağınık gelişme ve artan otomobil bağımlılığı olarak kendini gösterdi.

Anahtar Kelimeler: Kentsel Yayılma, Gazimağusa, Avrupa-Akdeniz, Yayılma
İzleme, Uzaktan Algılama

DEDICATION

*I would like to dedicate this study to my
beloved family
and everyone who
supported me in this way.*

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I would like to thank my supervisor Assoc. Prof. Dr. Mge Riza and co-supervisor Prof. Dr. Mustafa İlkan for their trust, efforts and excellent guidance during my research. Without their incredible patience this study would not have been possible at all. I would also like to thank my examining committee, Prof. Dr. Burak Beyhan, Prof. Dr. Naciye Doratli, Prof. Dr. José Manuel Pagés Madrigal and Asst. Prof. Dr. Alper Doğanalp for their support and suggestions during this study, which helped me to progress and finalize it successfully. I would also like to emphasize my gratitude to Prof. Dr. Haşim Altan, Assoc. Prof. Dr. Mehmet Adil, Asst. Prof. Dr. Hassina Nafa, and Asst. Prof. Dr. Mustafa Riza for their kindness in difficult days.

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
EM	Electro Magnetic
EMU	Eastern Mediterranean University
FCM	Fuzzy C-means
GIS	Geographical Information System
GSci	Geographic Information Science
IFOV	Instantaneous Field of View
LULC	Land-use Land-cover
MISC	Miscellaneous
RMSE	Root Mean Square Error
RMSLE	Root Mean Squared Logarithmic Error
RS	Remote Sensing
TRNC	Turkish Republic of Northern Cyprus
UCE	Urban Civil Engineering
UHI	Urban Heat Island
UN	United Nations
UTM	Universal Transverse Mercator
VMT	Vehicle Miles Traveled
WGS	World Geodetic System

Chapter 1

INTRODUCTION

“... Looking at cities can give a special pleasure, however, commonplace the sight may be. Like a piece of architecture, the city is a construction in space, but one of vast scale, a thing perceived only in the course of long spans of time...”(Lynch, 1960).

The United Nations estimates that by 2050 roughly two-thirds of the world population will live in urban areas, leading to future rapid urbanization. Urbanization is characterized by the movement of the rural population to urban areas resulting in a population increase in the urban environment. Urbanization is a multi-dimensional socio-economic process that expands the built environment towards the natural environment (Liang & Wang, 2020, p. 833). A well-managed urbanization process may result in a planned growth of the city that minimizes environmental degradation. On the other hand, unmanaged urban expansion and consumption patterns result in urban sprawl and environmental degradation (United Nations, 2015, 2019).

In most cases, unplanned expansion results in low-density development creeping beyond the city boundary while jobs still stay in the core of the urban area. Although the spread of cities is a sign of a prosperous economy, following this sequence will result in irreparable losses to the earth and destabilize the environment (T. Liu & Yang, 2015). The urban development process of cities is also closely linked with the development process of the country or region in terms of economic transformations and governmental institutions. Changes in the built environment and land uses, the

expansion of the cities and the addition of new socio-economic activities are reflecting the relationship between economy and governmental policy (Constantinides, 2001). Hence, this is important in relation to the urban development in especially developing regions, as the public policy is highly dependent on economic capital and investment rather than on the public needs and sustainable urban growth. Unplanned and uncontrolled urban growth is a common problem in developing regions. As stated before and by Constantinides (2001), the common feature of Mediterranean countries lies in the dominating role of the business sector due to their economic importance which prevents planned growth and restrictive planning. Montanari (2021) mentioned, that especially mass tourism in coastal areas have a large impact on the natural environment. The problem of urban and coastal over tourism is mainly visible in the northern parts of the Mediterranean region. In addition to its destructive effects, this fast and uncontrolled growth negatively affects the existing urban areas. Thus unplanned urban growth will appear in the form of a 'disperse or sprawled pattern' (Shahraki et al., 2011).

Urban sprawl is a debated topic among scholars. Galster et al. (2001) have stated that sprawl "...is one name for many conditions...". The characterizations of sprawl cannot be generalized throughout the world (Hamidi & Ewing, 2014). Early literature on urban sprawl was mainly based on the experiences of the North American continent. North American sprawl differs from Europe and the Euro-Mediterranean cities (Salvati & Morelli, 2014). Nonetheless, there is a common agreement that sprawl is a particular form of suburbanization (Behan, Maoh, & Kanaroglou, 2008; Burchell et al., 1998, p. 6; Downs, 1999; Galster et al., 2001). Additionally, most scholars consider sprawl to be a multi-dimensional phenomenon (Frenkel & Ashkenazi, 2008; Fuladlu, 2019,

2020; Fuladlu, Riza, & İlkan, 2018b; Galster et al., 2001; Hamidi, Ewing, Preuss, & Dodds, 2015; Oueslati, Alvanides, & Garrod, 2015; Torrens, 2008).

Sprawl is therefore a challenging topic partly due to its multidimensionality. That being said, it is essential to determine to what extent a city sprawls and how development occurs. In this situation, monitoring sprawl becomes necessary, and its findings could provide a baseline from which to avoid, through regional planning, future undesirable development. There are many different methods and/or techniques for monitoring sprawl. The majority of available monitoring techniques mainly quantify urban sprawl through Land-use Land-cover (LULC) studies. Fundamentally, LULC studies can use either raster data or vector data in a time-series manner as both allow the quantification of the urban sprawl (Bhatta, Saraswati, & Bandyopadhyay, 2010; T. Liu & Yang, 2015; Shahraki et al., 2011). Nevertheless, monitoring urban sprawl is of limited value unless the following questions and problems are appropriately addressed.

1.1 The Problem Statement and Questions of the Study

The definition and monitoring of sprawl term remains a complex issue. Urban sprawl is associated with diverse issues, including the economy, environment, social capital, conservation challenges, transportation and even water pollution. As claimed by Couch, Leontidou, and Petschel-Held (2007, pp. 3-4),

“Many of the definitions found in the literature tend to emphasize the idea of urban sprawl being a type of urban form or a pattern of urbanisation, rather than a process of urban change ... since it is the process of sprawling that leads to undesirable side effects and it is in the process of sprawling that policy must intervene.”

Likewise, the literature on monitoring relies on two types of spatial and non-spatial monitoring using Remote Sensing (RS), Geographical Information System (GIS), and

census tracts on different scales (Kew & Lee, 2013). Many studies have put forward innovative research on monitoring sprawl (See Barnes, Morgan III, Roberge, & Lowe, 2001; Bhatta et al., 2010; Reid, H. Ewing, Pendall, & Chen, 2003; Galster et al., 2001; Hamidi et al., 2015; Torrens, 2008). Undoubtedly, most of the studies are pioneering, and are essential studies for understanding sprawl monitoring. However, the following problems remain critical:

- a) Most studies have presented a set of chosen dimensions of sprawl according to their location. Using the same dimensions for other regions is not necessarily suitable, as each region has its own peculiarities and so sprawl dimensions should vary based on the specific location in which it occurs.
- b) Most of the available methods present several dimensions of sprawl. However, these dimensions have many overlaps.
- c) Sprawl studies mainly developed using North American and Western European methods. Those methods are not appropriate for other regions such as developing countries and the Mediterranean due to a lack of census data, high-resolution statistical datasets and census tracts.
- d) Likewise, dependency on the census, high-resolution statistical dataset and census tract stand for using a complex mathematical method with various metrics at different scales. These types of methods make sprawl monitoring more complex.
- e) Apart from sprawl monitoring methods, sprawl's causes vary from region to region. For instance, Euro-Mediterranean sprawl could result from an increase in 'second home' or tourist residence development, while Northern American sprawl mainly occurred as a result of affordable housing units.

As stated earlier, sprawl is a multidimensional phenomenon; it is not unreasonable that each study should point to a specific dimension of sprawl. For instance, sprawling in the case of American cities occurred as the result of an effort to find affordable houses, while this scenario is only partially valid in the case of Mediterranean cities. Likewise, the increasing automobile dependency revealed in the American literature is not valid in the case of all Mediterranean due to a lack of public transportation. Therefore, the monitoring dimensions could vary from one case to another. Fundamentally, the North American studies, based on high-resolution census data, statistics and census tracts, can quantify sprawl using different metrics, principal components, and confusion matrices at different scales. However, in most countries, high-resolution datasets either do not exist or, if they exist, are neither as comprehensive nor reliable as the North American dataset. American studies also combined the main dimension and developed other dimensions. For instance, Galster et al. (2001) had eight dimensions, and Torrens (2008) had forty-two, which should be minimized in terms of overlapping. As a result, the North American method seems not applicable to Mediterranean cities and developing regions.

Therefore, a successful method for monitoring sprawl must be comprehensive yet straightforward, which means that the method must be easy both to perform and understand. It must cover both developed and developing countries, and distinguish urban sprawl from any other pattern of urban expansion. Deriving from this background, the main question the current study will ask and seek to answer is **‘What is a merited and reliable model for monitoring sprawl in the case of Mediterranean cities?’** In addition to the main question, this study raises the following sub-questions:

- a) What is sprawl, and why should sprawl be monitored?

- b) What are the differences between urban, rural and coastal sprawl?
- c) Why is North American and Northern-Western European sprawl literature not wholly valid for Euro-Mediterranean cities?
- d) What are the sprawl differences between North American and Northern-Western European and Euro-Mediterranean cities?
- e) What are the main dimensions of sprawl?
- f) What are the possible overlaps between the sprawl dimensions?
- g) What sort of sprawl modeling is practical for Euro-Mediterranean cities?
- h) Why is a high-resolution dataset that includes census data, statistical data and census tracts essential for sprawl monitoring?

1.2 The Aim and Objectives of the Study

The current study aims to develop a practical model for monitoring sprawl in the case study area which can be considered a developing Mediterranean coastal city. Since the thesis is trying to investigate a method that is applicable for developing regions, the hypothesis of the thesis can be formulated as following: Monitoring sprawl is possible without consideration of available census and statistical data and a set of five dimensions. To achieve this aim, this study will use Famagusta city and its boundaries as the case area. The study area is located in the Eastern Mediterranean considered as a part of the Euro Mediterranean region. Therefore, the current study proposes a model to monitor Euro-Mediterranean Sprawl as seen in Famagusta. Additionally, the following objectives are components of the study's primary aim:

- a) To provide a comprehensive review of the literature on sprawling with a focus on monitoring sprawl.
- b) To give an overview of the characteristics of Mediterranean sprawl apart from North American and North Western European sprawl.

- c) To provide a set of dimensions for monitoring sprawl in the case of Euro-Mediterranean cities including Eastern Mediterranean.
- d) To develop a model based on the sprawl dimension but with a minimum overlap of the dimensions, which could be applicable for the Mediterranean as well as developing cities.
- e) To develop a model with minimal dependency on the high-resolution census data, statistical datasets and census tracts applicable to less developed regions.

The current study's methodology will be developed to meet the main aim and objectives of the study. Likewise, the study's methodology will be discussed in sections '1.4 The Methodology of the Study' and 'Chapter 4'.

1.3 The Limitation of the Study

As sprawl is a very broad and complex topic with numerous aspects to assess, such as sprawl dimensions, causes and consequences, the current study will be conducted with certain limitations. Furthermore, since the main aim of the current study is to monitor Mediterranean sprawl, the causes and consequences of sprawl will not be thoroughly or generally justified. As stated early, this study will be performed on the Famagusta region in Cyprus, which is considered an Eastern Euro-Mediterranean city. The study is limited to a set of five dimensions for monitoring sprawl which were selected as most appropriate for the case study area, after a thorough literature review on dimensions and monitoring approaches.

The study is excluding the neighborhood Varosha. The total area of Famagusta, according to the shape-file, is 896.72 km², and the total area under investigation in this study is 84.06 km². The uninhabited neighborhood of Varosha (6.30 km²) will be

excluded from the Famagusta study area (Figure 10). The detailed information on Famagusta will be presented in the ‘5.1 Study Area’ section. The study will focus on the city of Famagusta, including its coastal development. The area gained popularity due to the potential for investment in a ‘second home’ (i.e., summer houses for vacation time) and the advent of the edu-tourism, which is partly responsible for the rapid development of the residential units in Famagusta and its surrounding area. In addition, the area is favored for leisure and sports activities along the coast, which increased new development of holiday accommodation, restaurants, cafes etc.

The main challenge with Famagusta is the lack of census data, statistical dataset, or census tract. Therefore, Famagusta will be considered a currently developing region. Although there are some available governmental censuses and statistical datasets, they are limited to specific periods of time (State Planning Organization, 1999, 2007, 2013), with low to moderate resolution. Therefore, these three points become a base for the projection and estimation of the future sequence. The method for projection and estimation will be described in specific detail in the relevant sections. In this study, due to social and ethnic considerations and political constraints, the names of centers, including cities, villages and regions, are mainly in Turkish. Hence, the ‘List of Exonyms’ has been added as an appendix for the convenience of international readers.

1.4 The Methodology of the Study

The methodology used in this research adopts a mixed-methods approach, including qualitative and quantitative methods to address the study problem and research questions.

The mixed-methods approach emerged after the 1980s as an alternative to the quantitative and qualitative research approaches. According to Gray et al., mixed methods are helpful because together they overcome the weaknesses of the other methods. Gray, Williamson, Karp, and Dalphin (2007) argue that the study could be performed using the quantitative method, which used numbers to describe existence or objective reality. The main advantage of the quantitative method is that it uses data of a type that can be counted, stored, manipulated and analyzed by a computer. It mainly deals with the positivist paradigm (Teddlie & Tashakkori, 2009).

Gray et al. (2007) believed that numbers often do not replace explicit descriptions. In such circumstances the qualitative method becomes a solution for a study, as it relies on narrative and words, particularly nouns and adjectives, that support reality. The qualitative method mainly deals with the pragmatist paradigm. The main advantage of the qualitative method is its expression of the subtleties of meaning and interpretation that numbers do not convey (Teddlie & Tashakkori, 2009).

The study's methodology begins with a comprehensive literature review of urban sprawl, defining urban sprawl and assessing its causes and consequences. In addition, various types of sprawl such as urban, rural, and coastline sprawl will be examined. For this purpose, literature on North American and European sprawl will be compared and discussed, with a particular focus on Euro-Mediterranean sprawl. Afterwards, different dimensions of urban sprawl will be discussed, focusing on monitoring urban sprawl in the case of Euro-Mediterranean cities. Eventually, a set of sprawl dimensions will be chosen for monitoring purposes, with much effort devoted to choosing dimensions with minimum overlapping.

The monitoring model will be developed based on the literature and dimensions explored. To enhance the monitoring model and improve its performance for Euro-Mediterranean cities, the model must be less dependent on the census, statistical dataset and census tract. Therefore, the monitoring model will combine the use of RS and GIS techniques.

During the 1960s, the use of satellites as an operational system for collecting information about the earth became a discussion topic. By the 1970s, RS had matured with the instruments flown on Skylab and Landsat, which were explicitly dedicated to monitoring land and ocean surfaces. Today, the RS and GIS techniques are used as an ideal method for monitoring the LULC pattern. In the same way, the current study combines RS and GIS to develop a monitoring model for urban sprawl. Finally, the current study chooses Famagusta city and its suburbs/boundaries as a case study to perform urban sprawl monitoring for Euro-Mediterranean regions. The table below outlines the aims, objectives, research questions and methodology of the current study (Table 1).

Table 1: Aims, objectives, questions, and methods

Aim	Objectives	Questions	Method
Monitoring Euro-Mediterranean Sprawl	To provide a comprehensive review of the relevant literature with a focus on monitoring sprawl.	a. What is sprawl, and why should sprawl be monitored? b. What are the differences between urban, rural and coastal sprawl?	Comprehensive literature review on sprawl that defines sprawl and considers causes and consequences. Comparing different types of sprawl such as urban, rural and coastline sprawl.
	To give an overview of the characteristics of Mediterranean sprawl apart from North American and North Western European sprawl	c. Why is North American and Northern-Western European sprawl literature not wholly valid for Euro-Mediterranean cities? d. What are the sprawl differences between North American and Northern-Western European and Euro-Mediterranean cities?	Literature review on North American, European, and Euro-Mediterranean sprawl.
	To provide a set of dimensions for monitoring sprawl in the case of Euro-Mediterranean cities including Eastern Mediterranean	e. What are the main dimensions of sprawl?	Defining sprawl dimensions for the study.
	To develop a model based on the sprawl dimensions, but with a minimum overlap of the dimensions	f. What are the possible overlaps between the sprawl dimensions? g. What sort of sprawl modeling is more applicable for Euro-Mediterranean cities?	Using RS and GIS to develop a model applicable to Euro-Mediterranean sprawl and developing cities.
	To develop a model with minimal dependency on the high-resolution census data, statistical datasets and census tracts applicable to less developed regions	h. Why is a high-resolution dataset that includes census data, statistical data and census tract valuable for sprawl monitoring?	Using RS and GIS to enhance monitoring model with the minimum dependency on the census, statistical dataset, and census tract.

1.5 The Importance of the Study

The proposed method is an appropriate method for responding to sprawl as a planning problem. This study was conducted based on the belief that monitoring sprawl is a preliminary step towards minimizing its negative impacts. This study, first of all, looks at sprawl through the lens of Euro-Mediterranean sprawl, integrating urban, rural and coastal sprawl patterns. Moreover, the proposed model will contribute to monitoring sprawl wherever census and statistical data are inadequate.

1.6 The Structure of the Study

This study consists of six chapters. The first chapter provides a general overview of the study, including the problem statement, its aims and objectives, its limitations, and the methodology it adopts in order to address the problem.

Chapter two is a review of the literature on sprawl that includes a definition of urban, rural, and coastal sprawl, and considers the main characteristics of Euro-Mediterranean sprawl. Additionally, a set of characteristics with minimal overlapping will be provided for monitoring the sprawl. Similarly, different monitoring techniques will be covered by considering their advantages and disadvantages.

The third chapter explains the measurement techniques applied in the case study. Accordingly, GIS and RS techniques will be described in detail, including the processes by which they are applied.

The fourth chapter proposes a monitoring model based on previous chapters. The monitoring model will apply to Euro-Mediterranean sprawl, and it will be tested in the next chapter as a case study.

The fifth chapter presents the case study. In this chapter, Famagusta city and its eastern shore is chosen as a test case for the proposed model (which will uses GIS and RS) because it is a representative city in the Euro-Mediterranean region.

Chapter six, the conclusion, presents the findings of the study and the measurement process, and offers concluding remarks.

The structure of the study is charted in Figure 1.

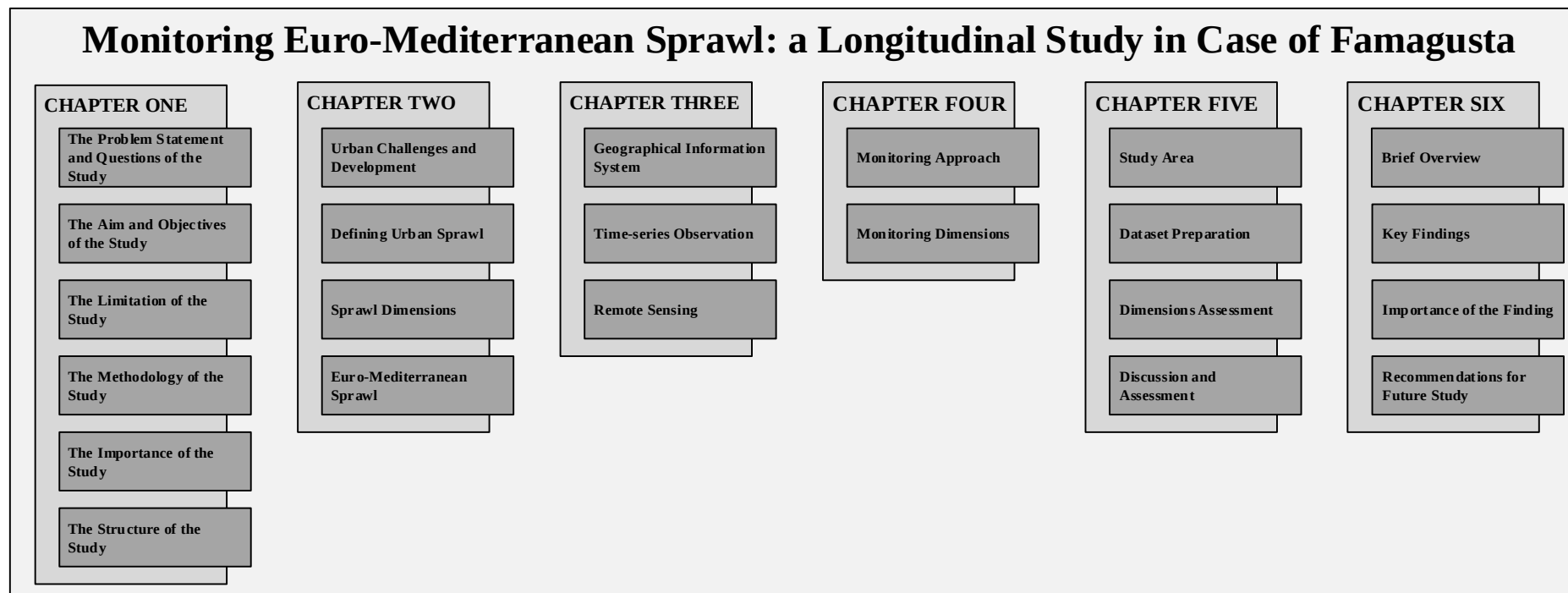


Figure 1: The structure of the study

Chapter 2

SPRAWL: A MONITORING CHALLENGE

“... Development has become something to be opposed instead of welcomed; people move out to the suburbs to make their lives, only to find they are playing leapfrog with bulldozers. ... Many communities have no sidewalks -- and nowhere to walk to, which is bad for public safety as well as for our nation's physical health. ... A gallon of gas can be used up just driving to get a gallon of milk. ... This kind of sprawl is harder on families than just the long drive to work and back; it means working families must sink thousands of dollars into extra commuting costs ...”(Gore, 1999).

The city is like the heart in a body: a control mechanism that pumps the blood of energy, people and trade to all parts of the region. (Friedmann, 1956). Cities are places where the population is progressively concentrated, and the land is a valuable resource because it is vital to the future development of cities. Therefore, maximum land utilization is the main goal of any development and spatial planning.

It is not easy to define a city. Scholars such as Lewis Mumford and Louis Wirth mainly emphasize cities' cultural dimensions. For instance, Wirth (1938), in his article 'Urbanism as a Way of Life', stated that;

“The city has thus historically been the melting-pot of races, peoples, and cultures, and a most favorable breeding-ground of new biological and cultural hybrids. It has not only tolerated but rewarded individual differences. It has brought together people from the ends of the earth because they are different and thus useful to one another, rather than because they are homogeneous and like-minded.”

Similarly, Mumford (1938), in his book 'The Culture of Cities', mentioned that

“The city, as one finds it in history, is the point of maximum concentration for the power and culture of a community. It is the place where the diffused rays of many separate beams of life fall into focus, with gains in both social effectiveness and significance. The city is the form and symbol of an integrated social relationship: it is the seat of the temple, the market, the hall of justice, the academy of learning.”

Correspondingly, Friedmann (1956), in his article ‘The Concept of a Planning Region’, argued that;

“City regions are the nerve centers of economic life in an area. They are the seats of economic power where most of the population is concentrated, where most of the vital decisions affecting larger areas are made, and where the financial means are present for carrying these decisions into action.”

Friedmann (1956) believed that each city depends on three main resources: transportation, space and community organization. Transportation allows access to the center and fast circulation among the different parts of the city. Space is mostly in limited supply, determined as it is by its location, physical attributes, and the extent of man-made improvements on the land. The community organization of a city lies in its different neighborhoods, and how those neighborhoods interact with each other. During time, the broader economic role of urban centers and their governments moved away from their geographically limited administrative role, decision-making about urban futures re-scaled and re-introduced ideas of multi-level and participatory governance (Brenner, 1999; Watson, 2009). Furthermore, a city region forms a community that is composed of a number of interrelated parts such as the urban core, industrial satellites, suburban and rural areas, and areas reserved for recreation and agricultural use.

According to Beyhan (2019), the growth of metropolitan areas is directly related to the ‘delimitation’ of planning regions in regional planning. Moreover, Beyhan (2019)

argues in referring to Wirth (1942) and Friedmann (1956), that regional planning considers the 'geographical extent' when there is a strong connection between relevant cities in form of commuting etc. (Beyhan, 2019). Wirth (1942), in 'The Metropolitan Region as a Planning Unit' (a report based on commuter flows), proposes that the metropolis should be considered not only as an administrative unit but also necessarily as a planning unit. Additionally, Wirth believed that an appropriate delimitation of the planning regions is crucial for the prospect success of the regional plans. After Wirth's proposal, it became clearer that functional regions could be considered as a suitable basis for delimiting both planning regions and administrative regions for emerging and growing urban areas. There is no doubt that Wirth (1942) proposal "... may in itself become an important factor in the shaping of the cities, the regions, and the nation of the future".

Another concept, which is expressed by Geddes (1915) in his book 'Cities in Evaluation', is 'Conurbations', which may serve as the essential word for defining cities. Conurbations express a new form of population grouping, which may initially form subconsciously and subsequently through definite governmental and administrative action. The growth-process of 'conurbation' even appears with industrial towns and cities uniting into vast city-regions. It seems that for the immense coalfield city-groups, 'conurbation' is process of indefinite growth. Surely it is appropriate to recognize the present-day growth of our cities, their spreading and their pressure into new and vaster groupings or conurbations, and to assess this properly requires in-depth study.

By the early 80s, Cedric Price (1982) had described morphologies of the city with a three-part diagram (Figure 2). The traditional ancient cities with a dense core were

represented as ‘boiled egg’ cities, which were static within the concentric rings of development in its shell or walls. Industrial cities looked like ‘fried eggs’, where railways expanded the city with faster linear space-time corridors into the landscape. Finally, modern cities resembled ‘scrambled eggs’, evenly spread in small grains in a continuous network across the landscape.

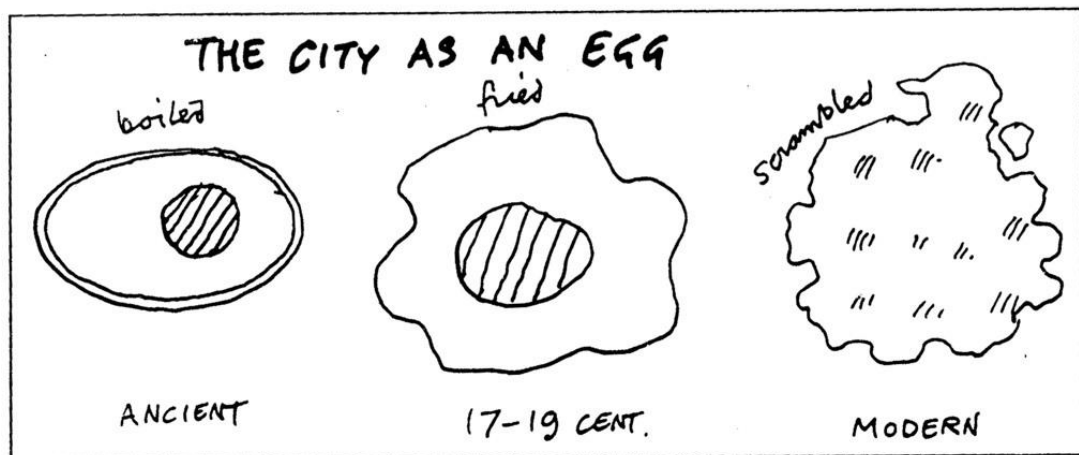


Figure 2: The city as an egg by Cedric Price (1982)

However, the Cedric Price (1982) egg diagram does not work for today's cities due to the excessive land utilization that works against sustainable development. Today's cities are also vibrant than before. Currently, 3% of the earth's land area is urbanized and hosts more than half of the world's population. This amount of urbanization is responsible for more than 78% of carbon emissions, 60% of residential water use and 76% of wood used for industrial purposes (Wu, 2010b; Wu, Jenerette, Buyantuyev, & Redman, 2011). According to the United Nations (2015, 2019), by 2050 we will see two-thirds of the world's population living in cities.

2.1 Urban Challenges and Development

The expansion of cities for future housing is one of the most important features of urbanization. Therefore, a key tenet of future development is promoting equitable

urbanization and land development to mitigate land-use conflicts (Wei, 2017). These intentions have recently been seen and followed in many cities' urbanization processes. Unfortunately, rapid urban development for housing is now becoming a challenge given the pre-determined goal of spatial planning. In addition to maximizing land utilization, each city strives to provide clean water, electricity, telecommunications, sanitation, and generate low per capita refuse. Correspondingly, cities aim to achieve better access to education, health, social services and occupations (Cohen, 2006), which justify various urban management programs.

In addition to creating problems in urban management, rapid urban development also has negative environmental, economic and social consequences for the future of the world. For example, rapid urban development combined with the energy imbalance in urban areas has significant consequences for local and regional climate, a phenomenon well documented as the formation of Urban Heat Islands (UHIs). A UHI is a condition of the ground-air temperature of the cities, which has increased in comparison to the suburban area (Arnfield, 2003; Fuladlu, Riza, & İlkan, 2018a; Oke, 1982).

Similarly, cities are the main producers of greenhouse gases and air pollutants, both of which have caused serious health problems for humans and negative effects on the environment (Burchell et al., 1998; Duh, Shandas, Chang, & George, 2008; Fenger, 1999; Mayer, 1999). Noise is another hazard in the urbanized areas of developed and developing countries (Moore, Gould, & Keary, 2003). Sources of noise pollution in the urbanized area include vehicle traffic, neighborhood, electrical appliances, televisions and music systems, religious functions, public address systems, rail and air traffic, and manufacturing complexes (Singh & Davar, 2004).

Rapid urban development negatively affects water resources by increasing the per-capita use of fresh water. Additionally, urban wastewater and waste result in the contamination of water resources (Duh et al., 2008; Moore et al., 2003). Rapid development and transformation of natural surfaces to impervious surfaces may adversely affect surface water flow paths and hydrological cycles in the urban landscape (Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005). Rapid urban development intensively and extensively affects biodiversity and ecosystem services due to the conversion of the land-cover. It results in the destruction and fragmentation of natural habitats as well as the creation of exotic species (Hope et al., 2008; Wu, 2010a).

Finally, rapid urban development due to rapid population growth leads to ‘uncoordinated and unbalanced growth’ in cities (Batty, Besussi, & Chin, 2003). Simultaneously, the uncoordinated and unbalanced growth of cities causes urban sprawl (Bhatta, 2010, p. 20; Downs, 1999). The main reason for rapid population growth is that overpopulation is mainly accommodated in urban areas. However, urban areas remain unready for this population level. Undoubtedly, many other factors effects sprawl in the urban area , but the mistaken decisions on growth management carry more weight (Torrens, 2008).

Caruso, Rounsevell, and Cojocaru (2005) studied urban expansion by considering the creation of exurban morphology, in which residents and agricultural activities are mixed. They found that the economy of housing choice can be expressed by the following aggregation-dispersion forces:

- a) At the regional level, the primary forces correlated with the monocentric housing model, where households trade the cost of additional transportation for space and facilities.
- b) At the local level, the secondary forces mainly correspond to those who are looking for low-density space within the exurban environment. In other words, residents are assumed to know close to local facilities and their proximity in mixed-use development, but they also care about open landscapes, low-density spaces, greenery and proximity to rural land-use.

Until now, this study has discussed the urban area and current global urban development pattern. It has looked at the consequences of rapid urban development and urban expansion as emphasized in the city and the surrounding environment. Accordingly, different terms such as urban, suburban, exurban, rural, and edge city have been used. Therefore, before addressing urban sprawl, it is worth taking a moment to discuss urban ontology and explain relevant terms.

Ban and Ahlqvist (2007) believed that Urban Civil Engineering (UCE) studies generated ontological classifications, and could be used to analyze the role of ontology as a tool to strengthen better communication between stakeholders by constructing UCE multilingual explanatory dictionaries. Based on ontology, rural–urban dynamics could be presented as shown in Figure 3.

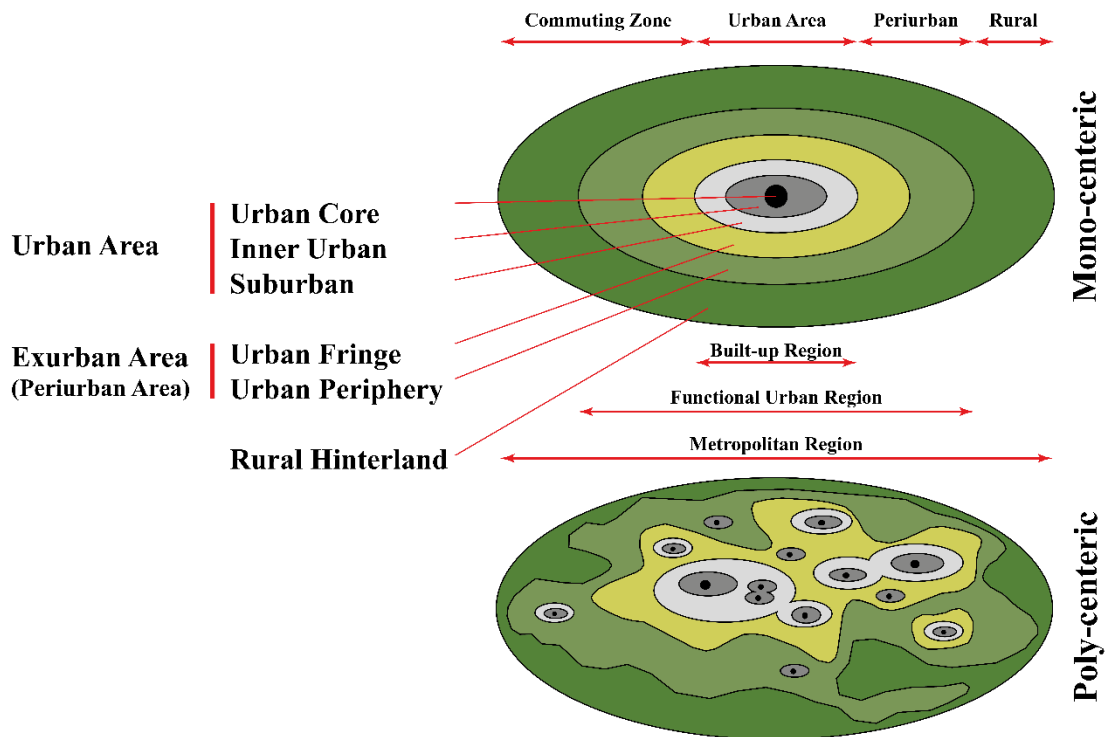


Figure 3: The urban-rural dynamics, after Ravetz, Fertner, and Nielsen (2013)

The urban ontologies concept based on Ban and Ahlqvist (2007) and Ravetz et al. (2013) can be defined and categorized as follows:

- An urban area is a zone with a population of at least 50,000 and a population density of at least 2,560 per Km². Such zones are located in an urbanized area or an urban cluster, and urban areas consist of the urban core and inner urban.
- An urban cluster is an area that has census block groups that are neighboring and have a dense distribution. These cluster populations are of at least 2,500 people and do not exceed 50,000 people.
- An urban core consists of the central business district and is the location for other public and cultural functions, although some of these functions could be associated with the mentioned spaces too.
- Inner urban areas cover fundamentally more densely built developments that have residential, commercial and even industrial uses. Inner urban areas also have some public open and green spaces.

- e) A suburban area is a non-central city that is part of a metropolitan region. Suburban areas are less densely built up in adjacent areas, which are connected to inner-city areas, and houses are usually no more than 200 meters away, with local shops, services, parks and gardens. The regions outside the suburban rings are considered exurban.
- f) An exurban area is located between suburban and rural areas. Defining the exact location of exurban areas is not easy. It could be stated that exurban areas are closer to the rural area. Exurban in French literature is called 'periurban', while European and American literature use terms such as 'sprawl', 'deconcentration', 'decentralization' or 'extended suburbanization'.
- g) The urban fringe is a zone along the edges of the built-up area that includes a scattered pattern of low-density settlement areas. Urban fringe is mainly seen around transportation hubs, along with large green open spaces like forest lands, agricultural lands and nature reserves.
- h) Urban periphery is a zone surrounding the main built-up areas, and it has a lower population density. The urban periphery can be considered a part of the functional urban region, which includes smaller settlements, industrial areas, and other urban land-uses within the matrix of functional agriculture.
- i) The rural hinterland zone includes all areas outside the boundary of a functional urban region. Rural zones are areas surrounding the exurban area but within the metropolitan region and accessible in a practical commuting zone. The administration of these areas is difficult since some part belongs to urban areas and others belong to the rural area. The rural character is influenced by residents with urban incomes and lifestyles.

- j) The edge city concept refers to a new environmental cluster that has brought together a wide range of urban activities. The edge city density is between low-density suburban and high-density urban core. Edge cities are not physically or socially central cities, and, with a few exceptions, are geographically distinct from them (Beauregard, 1995). An edge city is also known as an ‘exopolis’ (Soja (1992) or they may be called ‘outer cities’, ‘growth corridors’, ‘suburban downtowns’, ‘technopolises’, and ‘techno-cities’.

2.2 Defining Urban Sprawl

Sprawl is one of the most considered topics in the field of urban planning and urban studies. The research topics informing urban policies include the factors that cause urban sprawl, the consequences of urban sprawl, and monitoring methods for urban sprawl. According to Galster et al. (2001),

“Urban sprawl is one name for many conditions. It has been attached to patterns of residential and nonresidential land use, to the process of extending the reach of urbanized areas ... Sprawl has been denounced on aesthetic, efficiency, equity, and environmental grounds and defended on choice, equality, and economic grounds. Sprawl has become the metaphor of choice for the shortcomings of the suburbs and the frustrations of central cities.”

Galster et al. (2001) believed that “all sprawl does not have the same characteristics or dimensions”. The characteristics of sprawl are not similar across the world (Hamidi & Ewing, 2014).

Many scholars believe urban sprawl is a particular form of suburban development (Behan et al., 2008; Burchell et al., 1998, p. 6; Downs, 1999; Galster et al., 2001), and urban sprawl is known as a multi-dimensional phenomenon (Frenkel & Ashkenazi, 2008; Fuladlu, 2019; Fuladlu et al., 2018b; Galster et al., 2001; Hamidi et al., 2015; Oueslati et al., 2015; Torrens, 2008). Therefore, it is difficult to provide a

comprehensive definition of urban sprawl. The majority of the reviewed literature agrees that sprawl can be identified according to un-planned land consumption; that it is low-density, single-use, auto-dependency and non-contiguous; and that it contains leapfrog development (Behan et al., 2008; Bhatta, 2010, p. 9; Bhatta et al., 2010; Burchell et al., 1998, pp. 6-8; Downs, 1999; Reid. H. Ewing, 1997, 2008; Frumkin, 2002; Fuladlu, 2019; Fuladlu et al., 2018b; Gillham, 2007, p. 292; Hamidi et al., 2015; Harvey & Clark, 1965; Pendall, 1999; Sierra Club, 1998; Soule, 2006, p. 3; Torrens, 2008). According to Meredith (2003);

“First, sprawl has a low relative density. Second, it consists of unlimited and noncontiguous or ‘leapfrog’ development. In residential areas, this type of development primarily includes single-family tract housing. Third, under sprawled conditions, different types of land uses tend to be segregated. In these areas, municipal zoning ordinances only permit one use in each district. Fourth, sprawl consumes large quantities of exurban agricultural and other fragile lands. Fifth, in sprawled areas, people must rely on automobiles to access individual land uses. Finally, some commentators include the lack of integrated land-use planning as a component of urban sprawl. ...sprawl occurs in areas in which the land-use framework has been fragmented among numerous municipalities and developers.”

A conceptual definition for the urban sprawl could be found by examining its LULC situation in comparison to the adjacent pattern at a particular time (Barnes et al., 2001; Galster et al., 2001). LULC stands for land-use and land-cover: land-use denotes the human utilization of the land (a primary concern of social scientists), while land-cover refers to the physical and biological condition of the land, and is principally a concern of the natural sciences (Liang, Li, & Wang, 2012; Meyer & Turner II, 1992, 1994). These two terms are closely related in most of the LULC studies, since any land-cover changes will be connected to land-use change which in turn will be associated with demographic and economic change (Green, Kempka, & Lackey, 1994).

2.2.1 Urban Sprawl Causes

Cugny-Seguin (2017) believed that European cities underwent three major changes before the twentieth century. Firstly, the urban population was grew at a rate unmatched in previous periods in history, and cities become denser and covered a greater area. Secondly, during the industrial period, urban landscapes were rapidly transformed due to the need for sites of mass production, accessibility to raw materials and energy, transportation infrastructure, and workers' settlements in the proximity of the factories. Finally, the advent of transportation through trains, electric subways, metros and cars changed the structure of European cities. These factors resulted in sprawl, overcrowding and the expansion of the cities over larger spaces.

There are many causes associated with urban sprawl: it is usually a challenge to differentiate among them. Urban sprawl and urban growth are highly interlinked and there are some common intersectional causes. In summary, it can be stated that if development occurred in a coordinated and planned way it is not considered urban sprawl. For instance, population growth mainly results in urban growth, but uncoordinated development may cause urban sprawl (Bhatta, 2010, p. 17). Of course, the cause of urban sprawl and urban growth cannot be limited to coordinated development, and many other causes are involved (Burchfield, Overman, Puga, & Turner, 2006; Harvey & Clark, 1965, p. 6; Squires, 2002). According to Bhatta (Table 2), twenty-five causes are associated with urban sprawl, whereas six causes may result in urban growth (see Bhatta, 2010, pp. 17-27).

Table 2: Causes of urban growth vs urban sprawl adopted by Bhatta (2010)

	Causes	Urban Growth	Urban Sprawl
1	Population growth	•	•
2	Independence of decision		•
3	Economic growth	•	•
4	Industrialization	•	•
5	Speculation		•
6	Expectations of land appreciation		•
7	Land hunger attitude		•
8	Legal disputes		•
9	Physical geography		•
10	Development and property tax		•
11	Living and property cost		•
12	Lack of affordable housing		•
13	The demand for more living space	•	•
14	Public regulation		•
15	Transportation	•	•
16	Road width		•
17	Single-family home		•
18	Nucleus family	•	•
19	Credit and capital market		•
20	Government developmental policies		•
21	Lack of proper planning policies		•
22	Failure to enforce planning policies		•
23	Country-living desire		•
24	Housing investment		•
25	Large lot size		•

2.2.2 Urban Sprawl Consequences

Similar to the variations in the definition of sprawl, there is also no clear agreement on the consequences of sprawl. Burchell et al. (1998, pp. 41-43) have not only considered the environmental consequences but also the social aspects of sprawl. Accordingly, they categorized urban sprawl consequences, including positive and negative consequences, under the following five categories:

- a) Public/private capital and operating costs,
- b) Transportation and travel costs,
- c) Land/natural habitat preservation,
- d) Quality of life, and
- e) Social issues.

Likewise, Table 3 tries to gather both positive and negative consequences of sprawl according to the above-mentioned categories.

Table 3: Possible consequences of sprawl adopted by Burchell et al. (1998)

Consequences	Positives	Negative
Public/private capital and operating costs	Lower public operating costs Less expensive private residential and non-residential development costs Fosters efficient development of “leapfrogged” areas	Higher infrastructure costs Higher public operating costs More expensive private residential and non-residential development costs More adverse public fiscal impacts Higher aggregate land costs
Transportation and travel costs	Possible decrease in commuting times Less congestion Lower governmental costs for transportation Automobiles most efficient mode of transportation	More Vehicle Miles Traveled (VMT) Longer travel times More automobile trips Higher household transportation spending Less cost-efficient and effective transit Higher social costs of travel
Land/natural habitat preservation	Enhanced personal and public open spaces	Loss of agricultural land Reduced farmland productivity Reduced farmland viability (water constraints) Loss of land containing fragile environments Reduced regional open space
Quality of life	Preference for low-density living Lower crime rates (in certain cases) Enhanced value or reduced costs of public and private goods Fosters greater economic well-being	Aesthetically displeasing Weakened sense of community Greater stress Higher energy consumption More air pollution Lessened historic preservation

Consequences	Positives	Negative
Social issues	Fosters localized land-use decisions Enhances municipal diversity and choice	Fosters suburban exclusion Fosters spatial mismatch Fosters residential segregation Worsens city fiscal stress Worsens inner-city deterioration

However, Frumkin (2002) has focused more on the negative consequences of sprawl, particularly:

- a) Direct effects of automobiles reliance,
- b) Effects of land-use decisions,
- c) Social aspects of sprawl, and
- d) Environmental justice considerations.

Urban sprawl also has positive consequences, such as decreased risk of heatwaves (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017). Likewise, sprawl provides more personal and public open space to individual households. Sprawl offers ownership of a detached and single-family home. Sprawl has low crime rates compared to compact development (Burchell et al., 1998, pp. 80, 93 & 95). Although sprawl has both negative and positive consequences, since it is considered an uncontrolled development, the negative consequences outweigh the positive ones (Bhatta, 2010, p. 28). Euro-Mediterranean literature does not focus on the negative impacts as heavily as North American literature; instead, it considers the role of actors and processes as being more important to sprawl study (Chorianopoulos, Pagonis, Koukoulas, & Drymoniti, 2010). In a study on sprawl in a suburban area of Famagusta, Fuladlu et al. (2018b) observed that general negative impacts such as car dependency or social isolation are not valid in the case of Tuzla, Famagusta. Since there is an already existing lack of public transportation availability in Famagusta, people are less effected by car dependency. The observed negative impacts are to a lesser extent related with the individual well-being, but strongly related to loss of natural and agricultural land, uncontrolled development of high-rise constructions and insufficient provision of governmental obligations such as paved roads, maintained green areas etc (Fuladlu et al., 2018b).

Rural sprawl is very similar to urban sprawl; this similarity is even seen in its overall definition, causes, and consequences. However, urban sprawl may be distinct from rural sprawl as follows. First, the location of sprawl is mainly seen at the proximity of villages and/or along the main arteries leading into and out of villages. Second, conflicts may arise between farmers and new neighbors because newcomers frequently have little understanding of the agricultural and forestry trades. The conflict could involve newcomers' complaints about odors, noise, dust, crop spraying and slow-moving farm machinery on local roads. Similarly, farmers complain about crop theft, vandalism, littering and the harassment of livestock by dogs and children. In short, the industries of agriculture and forestry should be kept as separate as possible from rural residential development (Daniels, 1999).

2.3 Sprawl Dimensions

As stated earlier, determining an absolute definition of sprawl that includes its characteristics is a challenging task. Consequently, the quantification of sprawl is difficult too (Bhatta et al., 2010). Fundamentally, the lack of a clear understanding of sprawl results in the confusion of relevant authorities when addressing and monitoring sprawl. Therefore, the effective next step is to determine to what extent a city is 'sprawling'. Monitoring sprawl development is necessary to avoid future undesirable development. Accordingly, studies about monitoring urban sprawl characteristics have proliferated recently (Terzi & Kaya, 2011).

The reason for this may be that without monitoring sprawl, no proposal could be made to curb it. It should be noted that sprawl development, in most cases, is measured through LULC changes. This method proceeds in a time-series manner that enables the study to quantify results (Bhatta et al., 2010; T. Liu & Yang, 2015; Shahraki et al.,

2011). According to Pendall (1999), "... the measurement of sprawl is not straightforward, partly because of the variation in how sprawl is defined. Conceptual difficulties aside, calculation of urban density ..." is another crucial problem. Additionally, there is a lack of clarity surrounding the monitoring type itself. As mentioned by Bhatta et al. (2010), sprawl can be monitored absolutely or relatively. The absolute monitor can sharply specify sprawl from the compact development, whereas the relative monitor can depict several quantitative attributes of sprawl. This latter type of monitoring can be applied to different cities, zones, and even during different times.

A combination of different methods and characteristics should be considered, rather than using a single technique or characteristic. Therefore, researchers try to determine a method that combines adequate characteristics for monitoring urban sprawl (Soule, 2006, p. 273). Most of the early attempts to monitor urban sprawl were not successful since researchers and scholars were primarily limited to density analysis. Although density has been identified as the most visible characteristic of urban sprawl, sprawl is a multi-dimensional phenomenon, and looking at it through the density lens alone will be inefficient (Hamidi et al., 2015).

The literature review indicates that the first multi-dimensional and wide-ranging measurement of urban sprawl was conducted by Galster et al. (2001), who measured urban sprawl based on eight dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed uses and proximity. However, this multi-dimensional measurement is dependent on a high-resolution dataset. Another difficulty with the method was that it required partitioning census data into cells by calculating total areas within a square mile, even though there are many common characteristics between

these eight dimensions. This method is not useful and made the monitoring process even more complicated.

Reid. H. Ewing et al. (2003) introduced a method that combines several variables into four groups: residential density, neighborhood mix-use, the strength of activity centers, and accessibility of streets. This is a useful method for monitoring urban sprawl. The main problem of this method for Euro-Mediterranean areas, especially developing cities, is the lack of census data. Later, Torrens (2008) put together a toolkit for sprawl monitoring. He believed that;

“Measurements should translate descriptive characteristics to quantitative form. The methodology should be broad enough to accommodate all of the characteristics of the phenomenon that can be measured. Analysis should focus at micro-, meso-, and macro-scales and should operate over net and gross land. The analysis should examine sprawl at city-scale and at intra-urban levels.”

Torrens identified forty-two characteristics of sprawl and start monitoring for ten years. This monitoring method is reputable, but the use of different scales and metrics makes it complicated to perform (Bhatta et al., 2010). A more recently published method, by Hamidi et al. (2015), uses a “... principal component analysis to derive four separate compactness factors, one for development density, another for land-use mix, a third for activity centering, and a fourth for street connectivity ...”. This study is an update of the work done by Reid. H. Ewing et al. (2003). As stated earlier, both methods are based on the powerful United States census, which provides data unavailable in most developing countries. Both also focus on transportation and develop methods based on confusing metrics.

A similar study of European cities was conducted by Oueslati et al. (2015). They tried to determine urban sprawl in European cities by using different metrics. However, this

study was also developed based on the ‘European spatial planning observation network’ database which is useful only for the European research program.

In summary, there are many different studies all around the world. Therefore, Table 4 tries to gather most impactful approaches for monitoring urban sprawl in the past twenty years and summarizes them in chronological order. Each of the following studies considered a set of dimensions and they were applied in various ways. Their advantages and disadvantages are covered in the following table.

Table 4: Dimensions/approaches for monitoring sprawl

Author/s	Dimension/s	Region	Approach/es	Advantages	Disadvantages
Mills (1981)	Density Land-use Continuity Accessibility Aesthetic	USA	Longitudinal, Statistical, Census tract Observation	The longitudinal aspect of the study depicts the amount of sprawl. Covers most of the sprawl dimensions.	Dependency on high-resolution census data. Confusing due to overuse of metrics.
Peiser (1989)	Density	USA	Longitudinal, Statistical, Census tract	The longitudinal aspect of the study depicts the amount of sprawl.	Monodimensional, in contrast with multidimensional sprawl. Dependency on high-resolution census data.
Gordon and Richardson (1997)	Land-use Density Growth efficiency Accessibility Aesthetic	USA	Longitudinal, Literature Review, Census, Statistical, Observation	Covers most of the sprawl dimensions. Could be adopted in many areas. The longitudinal aspect of the study depicts the amount of sprawl.	Mainly based on literature reviews. Lack of practical method for monitoring. Dependency on high-resolution census data.
Torrens and Alberti (2000)	Density Geometry Fractal Aesthetic Accessibility	USA	Landscape metric	Covers most of the sprawl dimensions.	Dependency on high-resolution census data. There are some common dimensions. The growth rate dimension of the sprawl was missing. The study is not longitudinal.

Author/s	Dimension/s	Region	Approach/es	Advantages	Disadvantages
Galster et al. (2001)	Density Continuity Concentration Clustering Centrality Nuclearity Mixed uses Proximity	USA	Census, Statistical, Census tract	Covers most of the sprawl dimensions.	The aesthetic dimension of the sprawl was missing. Dependency on high-resolution census data. Partitioning the census data in the square grids-net. There are some common dimensions. The study is not longitudinal.
Reid. H. Ewing et al. (2003)	Residential Density Land-use Mix Degree of Centering Street Accessibility	USA	Census, Statistical, Census tract	Covers most of the sprawl dimensions.	Dependency on high-resolution census data. The growth rate dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. There are some common dimensions. The study is not longitudinal.
Y. Song and Knaap (2004)	Density Land-use Mix Accessibility Pedestrian Access	USA	Census, Statistical, Census tract	Covers most of the sprawl dimensions.	Dependency on high-resolution census data. The growth rate dimension of the sprawl was missing. The spatial and geometric dimensions of the sprawl were missing. The aesthetic dimension of the sprawl was missing. There are some common dimensions. The study is not longitudinal.

Author/s	Dimension/s	Region	Approach/es	Advantages	Disadvantages
Jiang, Liu, Yuan, and Zhang (2007)	Spatial configuration Growth efficiency External impacts	China	Landscape metric, Longitudinal, Statistical, Census tract	Covers most of the sprawl dimensions. The longitudinal aspect of the study depicts the amount of sprawl.	Dependency on high-resolution census data. Confusing due to overuse of metrics. The aesthetic dimension of the sprawl was missing. There are many common dimensions. Study dimensions are not valid for other cases. There are some common dimensions.
Torrens (2008)	Growth Rate Build-density Accessibility Social Activity-space Fragmentation Decentralization	USA	Longitudinal, Census, Statistical, Census tract	Covers most of the sprawl dimensions. The longitudinal aspect of the study depicts the amount of sprawl.	Dependency on high-resolution census data. Confusing due to overuse of metrics. The growth rate dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. There are many common dimensions.
Frenkel and Ashkenazi (2008)	Growth rates Density Spatial geometry Accessibility Aesthetic	Israel	Census, Statistical, Census tract, Observation	Could be adopted in many areas. Covers most of the sprawl dimensions. Dependency on medium-low resolution census data.	The study is not longitudinal.

Author/s	Dimension/s	Region	Approach/es	Advantages	Disadvantages
Terzi and Bolen (2009)	Density Proximity to the urban center Neighborhood mix Strength of centers	Turkey	Longitudinal, Census, Statistical, Census tract	Could be adopted in many areas. The longitudinal aspect of the study depicts the amount of sprawl.	The growth rate dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. The accessibility dimension of the sprawl was missing. There are some common dimensions.
Bhatta et al. (2010)	Build-density	India	Longitudinal, Satellite	Could be adopted in many areas. The longitudinal aspect of the study depicts the amount of sprawl.	Monodimensional, in contrast with multidimensional sprawl. The growth rate dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. The accessibility dimension of the sprawl was missing.
Shahraki et al. (2011)	Population growth Land-use transformations	Iran	Longitudinal, Satellite, Census	Could be adopted in many areas. Dependency on medium-low resolution census data. The longitudinal aspect of the study depicts the amount of sprawl.	The density dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. The accessibility dimension of the sprawl was missing.

Author/s	Dimension/s	Region	Approach/es	Advantages	Disadvantages
Oueslati et al. (2015)	Income, Population, Agricultural land value, Transportation costs, Other socio-economic, Climatic & Geographic variables	European Cities	Longitudinal, Census, Statistical, Census tract	Covers most of the sprawl dimensions. The longitudinal aspect of the study depicts the amount of sprawl.	Dependency on high-resolution census data. The growth rate dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. There are some common dimensions.
Hamidi et al. (2015)	Development Density Land-use Mix Activity Centering Street Connectivity	USA	Census, Statistical, Census tract, Principal Component	Covers most of the sprawl dimensions.	Dependency on high-resolution census data. Mainly based on principal component analysis. The aesthetic dimension of the sprawl was missing. There are some common dimensions. The study is not longitudinal.
Zhou, Jiao, Yu, and Wang (2019)	Land Consumption per-capita Density Clustering	China	Longitudinal, Satellite, Census	Could be adopted in many areas. Dependency on medium-low resolution census data. The longitudinal aspect of the study depicts the amount of sprawl.	The growth rate dimension of the sprawl was missing. The aesthetic dimension of the sprawl was missing. The accessibility dimension of the sprawl was missing. There are some common dimensions.

Author/s	Dimension/s	Region	Approach/es	Advantages	Disadvantages
Fuladlu (2020)	Annual VMT, Growth Rate, Build-density	Cyprus	Longitudinal, Satellite, Census, Statistical	Covers most of the sprawl dimensions. Dependency on low-resolution census data. The longitudinal aspect of the study depicts the amount of sprawl.	The aesthetic dimension of the sprawl was missing. Could be adapted for small development areas.
Fuladlu, Riza, and İlkan (2021b)	Growth Rate, Built Density, Spatial Geometry, Accessibility	Cyprus	Longitudinal, Satellite, Census, Statistical	Covers most of the sprawl dimensions. Dependency on low-resolution census data. The longitudinal aspect of the study depicts the amount of sprawl.	The aesthetic dimension of the sprawl was missing.

According to Table 4, the longitudinal (time-series) approach is common to most of the studies, and it is discussed in detail under the ‘3.2 Time-series Observation’ section. Besides longitudinal approaches, census, statistical, census tract, observation, and satellite approaches are common to most of the studies in the table. Most of the studies in the table were performed in the USA, and many had common dimensions.

Table 4 tries to summarize different continents’ significant studies on urban sprawl in chronological order. The table provided a brief summary of the advantages and disadvantages of each study. It shows that each study used a mixture of dimensions and sub-dimensions to monitor urban sprawl. Therefore, Table 5 was developed to classify the dimensions and sub-dimensions of sprawl identified in Table 4 to identify more precise dimensions for future monitoring of urban sprawl.

Table 5: Sprawl dimensions, sub-dimensions matrix

Dimensions	Sub-dimensions	Mills (1981)	Peiser (1989)	Gordon and Richardson (1997)	Torrens and Alberti (2000)	Galster et al. (2001)	Reid, H. Ewing et al. (2003)	Y. Song and Knaap (2004)	Jiang et al. (2007)	Torrens (2008)	Frenkel and Ashkenazi (2008)	Terzi and Bolen (2009)	Bhatta et al. (2010)	Shahraki et al. (2011)	Oueslati et al. (2015)	Hamidi et al. (2015)	Zhou et al. (2019)	Fuladlu (2020)	Fuladlu, Riza, and İlkan (2021a)
Aesthetic	Development / Form	•		•	•						•								
Build-density	Build-density									•			•					•	•
	Density	•	•	•	•	•		•			•	•					•		
	Development density															•			
	Residential density						•												
Growth Rate	Growth efficiency			•					•										
	Growth rate									•	•							•	
	Population growth													•					
	Population														•				
LULC Pattern	Mix-use	•		•		•	•	•				•				•			
	Land-use transformations													•					
	Activity centering															•			
	Activity-space									•									
	Agricultural land value														•				
	Land consumption																•		•
	Centrality					•	•					•							

Dimensions	Sub-dimensions
	Mills (1981)
	Peiser (1989)
	Gordon and Richardson (1997)
	Torrens and Alberti (2000)
	Galster et al. (2001)
	Reid. H. Ewing et al. (2003)
	Y. Song and Knaap (2004)
	Jiang et al. (2007)
	Torrens (2008)
	Frenkel and Ashkenazi (2008)
	Terzi and Bolen (2009)
	Bhatta et al. (2010)
	Shahraki et al. (2011)
	Oueslati et al. (2015)
	Hamidi et al. (2015)
	Zhou et al. (2019)
	Fuladlu (2020)
	Fuladlu, Riza, and İlkan (2021a)
	Physical characteristics
	External impacts

Table 5, summarizing Table 4, reveals that most of the reviewed studies from different areas agree on six main dimensions (aesthetic, built-density, growth rate, LULC pattern, spatial geometry and transportation) and some other sub-dimensions. The aesthetic dimension was mainly not used as a practical monitoring dimension (it will be discussed in detail in the ‘5.3.5 Aesthetic’ section). The five other dimensions were confidently used for sprawl monitoring by different studies in different areas. This study will use these dimensions to develop its monitoring method. To support this idea, a comprehensive discussion will be provided in the ‘4.2 Monitoring Dimensions’ section.

2.4 Euro-Mediterranean Sprawl

Within the last half-century, Mediterranean cities have faced rapid urbanization and urban sprawl has become a concern (Munoz, 2003). Many Mediterranean cities have undergone a transition from a traditional compact structure to a sprawled and polycentric form. The main reasons could be the lack of statutory planning, but the recent increase of foreign real-estate ownership also contributes to urban sprawl (Chorianopoulos et al., 2010; Salvati & Morelli, 2014; Salvati, Sateriano, & Bajocco, 2013). The term Euro-Mediterranean was established in the 1990’s as result of the Barcelona declaration in 1995 aiming to improve social, cultural, and economic ties in the Mediterranean area. The Euro-Mediterranean area consists of EU and non-EU countries which are facing the Mediterranean sea, south and north shores (Montanari, 2021). Hence, the region is defined by regional similarities due to the Mediterranean location such as culture, climate, vegetation and not its geographical borders.

The Mediterranean region is a relatively small, enclosed sea with limited exchange with the ocean. The largest islands are Sicily, Sardinia, Corsica, Cyprus, and Crete,

and the major island groups includes the Balearics off the coast of Spain and the Ionian, Cyclades, and Dodecanese islands off Greece. Region today had coastlines with following twenty-one countries: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia, and Turkey. As a result of intricate political history involving many different ethnic groups, Mediterranean region has led to a complex and patchy political map (Mediterranean Action Plan, 2017).

Historically, Euro-Mediterranean cities have been recognized for their high density, and they have a complex urban form with social diversity. At the same time, the recent growth of Euro-Mediterranean cities reflects the expansion of territories that manifest other morphological criteria (Leontidou, Afouxenidis, Kourliouros, & Marmaras, 2007). From the cultural perspective, it can be stated that contemporary Euro-Mediterranean growth was based on the ‘thematization’ of the North American sprawl. In other words, the appearance of sprawl in the Mediterranean in terms of building typology, urban landscape etc. is rooted in an archetypical image of the American ‘dreamscape’ of suburbia (Muñoz, 2003).

2.4.1 History of Sprawl in the Euro-Mediterranean Region

Literature review on Mediterranean sprawl indicates, that a large number of the available studies focus on the southern European cities, mainly Athens as a case study for Mediterranean European cities. The emergence of urban sprawl can be seen as a manifestation of the belief that urban life is a protector against rural insecurity and poverty. The outcome was urban sprawl and informal settlements springing up around all South European cities. Sprawl was initially created by workers during the inter-war

period rather than middle classes or wealthy families, as workers sought affordable housing near industry and urban infrastructure (Leontidou et al., 2007).

During the 1920s, the North American lifestyle resulted in urban sprawl. Accordingly, the powerful and wealthy families moved beyond city boundaries because their lifestyle required proximity to the countryside. The North American lifestyle was later seen in Northern Europe as a mass movement. For instance, in London, tens of thousands of affluent families who were able to move out from congested central neighborhoods of terraced houses moved into single-family detached houses in the countryside (Bruegmann, 2005, p. 33).

Urban sprawl in the Euro-Mediterranean region occurs toward the popular suburbs, and in general Euro-Mediterranean residents were not looking for a countryside lifestyle, but affordable housing. As stated earlier, the urban sprawl in Greece, Italy, and Spain was different and mainly arose from populations dreaming of urban life as protection (Leontidou et al., 2007). In Southern European cities specifically, postmodern urbanism occurred, as can be seen in its mixed-use tendencies, informal construction procedures and spaces fragmentation. These evidence political economy and real-estate activity with extensive informal structures. Euro-Mediterranean urban development, in comparison to Anglo-American, was extensively influenced by tradition and historical memory. Correspondingly, Ancient and Medieval monuments remained a significant construction attribute of South European cities (Craglia, Leontidou, Nuvolati, & Schweikart, 2004).

In Eastern Mediterranean countries such as Lebanon, Jordan, Greece, and Cyprus rapid changes are taking place under the force of urban sprawl, abandonment of villages and

the adoption of different agricultural techniques, intensification of tourism and shift of displaced populations between the Mediterranean coasts (Trovato & Ali, 2019). In a study by Hepcan, Hepcan, Kilicaslan, Ozkan, and Kocan (2012) the evolution of landscape change and sprawl in İzmir from the 1963 to 2005 was explored. According to the findings, the initial compact urban form of İzmir in 1963 was transformed towards sprawl development by 2005 mainly at the coastline towards İzmir Bay and the main transportation arteries. According to Hepcan et al. (2012), sprawl development in İzmir is similar to those in southern European cities from the 1950's expanding transportation systems by referring to the report of European Environment Agency (2006). The report stated that historically compact and dense southern European cities developed rapid growth and sprawl, while unrestricted zoning and expansion of transportation systems were the main drivers.

H. Alphan (2003) studied the LULC changes between the years 1984 and 2000 in Adana, Turkey. According to his findings, the built-up area increased as a result of the high amount of rural immigration and urban development strategies. The main LULC change was visible in semi-natural (-33.99%) and agricultural land (-22.99%). Similarly, a study by Beyhan et al. (2012) analyzed the spatial growth of Mersin between 1987-2009 by using RS with the integration of social sciences. The study looked at spatial growth and built up density in large and small scale, revealing that urbanized areas nearly doubled.

Taubenböck, Wegmann, Roth, Mehl, and Dech (2009) analyzed sprawl development in the mega city of Cairo by using multisensoral remote sensing data, landscape metrics and gradient analysis in order to understand spatiotemporal perspectives of urban sprawl. The findings reveal that between 1972 until 2000 the city has undergone

an extensive spatial increase, especially in form of leapfrog developing satellite development observing its transformation from an initial monocentric compact city towards a discontinuous and polycentric development. Another study from Cairo by Effat and Shobaky (2015) identified and quantified the spatial pattern of urban sprawl in Cairo between the years 1984-2011, highlighting that the negative impacts of sprawl in developing areas can be considered as more severe than in developed regions. Their findings shows that the urban area in Cairo is expanding towards all direction, while there is visible tendency towards the east and north-east axe. The reason can be seen in the availability of vacant land, the highway as well as the direction of the main airport. Similar to the findings of Taubenböck et al. (2009), Cairos built-up area has changed from a compact and homogeneous distribution in 1984 towards a sprawling and scattered development in 2011 (Effat & Shobaky, 2015).

The study of Effat and Shobaky (2015) also highlights the differences of sprawl problems between developing and developed regions. According to them, the urban dynamics and urban changes in developing countries are more dependent on unpredictable and rapid population growth, informal development and similar factors and differ in geographic, economic, social and cultural circumstances. Similarly Osman, Divigalpitiya, and Arima (2016) observed that sprawl in Giza, Greater Cairo Metropolitan Region are dependent mainly to ‘geographical characteristics, availability of life facilities, economic incentives, land demand and supply, population increases, administrative functions, and development plans’. However, the main influence for sprawl is seen in the population growth while development plans are rather unimportant. Since the region has a rise in young population due to employment opportunities, people prefer to live nearby the cities in sprawl rather in new development areas provided by the government.

Therefore, sprawling development are different among these group of countries. For instance, a longitudinal LULC study by Marraccini et al. (2015) on Western Mediterranean region includes urban areas of Montpellier and Avignon (France), Pisa (Italy), Madrid (Spain), Meknes (Morocco), and Constantine (Algeria). Marraccini et al. (2015) results show, that there are not significant differences in LULC change between the north-south and Western Mediterranean urban areas. In fact, the main difference could be seen between small to medium cities and large metropolitan areas in type of urban development. Urban development is more sprawled in small to medium cities while development is more compact in large metropolitan areas.

2.4.2 Coastal Sprawl in the Euro-Mediterranean Region

The emerge of residential tourism shaped contemporary urban sprawl in the Euro-Mediterranean region by the end of the 1970s. Northern-Western European populations started to purchase real estate along Mediterranean coasts and on islands in which they preferred to stay for at least six months a year and sometimes longer. This lifestyle was later called ‘Mediterraneanisation’ and it can be considered a sort of long-distance sprawl. Along with coastal areas, much agricultural land was devoted to the sprawl developments. The majority of tourists seeking residences preferred nearby islands and coastlines. This phenomenon was seen, after Greece, occurring in waves in Alicante and Benidorm, Spain (Cuadrado-Ciuraneta, Durà-Guimerà, & Salvati, 2017; Leontidou et al., 2007; Salvati, 2013).

The residential tourist's values in Euro-Mediterranean were combined with a rural second home for leisure days. Accordingly, the rural second home rate increased for residents of Euro-Mediterranean cities, and a seasonal family lifestyle emerged that separated the time between work and leisure. Seasonal rural second homes became drivers for increasing sprawl and creating a commuting pattern within the year due to

the requirement to travel between first and second homes. This commuting pattern results in traffic jams during weekends and holidays when everyone leaves the city and returns home at the same time; this pattern seems to be similar in many Euro-Mediterranean cities such as Athens, Rome, and Barcelona (Leontidou et al., 2007). Similarly, Balta and Attik explored sprawl development in the case of Antalya, concluding that growth and urban sprawl in Antalya are mainly resulting in the deterioration of the traditional land use patterns and decrease of farming activities (Balta & Atik, 2022).

As mentioned earlier, the Mediterranean region is defined by regional similarities due to the Mediterranean location such as culture, climate, vegetation and the Mediterranean lifestyle due to the location at the sea. Many residents from city centers and also tourists start to invest in a ‘second home’ to have a summer house for their vacation time. Accordingly, the coastal suburbs become highly attractive for investment. As also mentioned by Hof and Blázquez-Salom (2013), these kind of development ‘are the opposite of the classical dense Mediterranean urban form and are the outcome of population, economic and housing shifts’.

Furthermore, as mentioned by Salvati (2013), a small, upper-class phenomenon within tourism is becoming a massive industry. This type of tourism is less interested in sun-seeking beach lounging, culture, or alpine tourism. Instead, this phenomenon is eco-tourism, which calls for the rapid development of residential units. Residential units serving as ‘second homes’ are mainly developed in large residential complexes, either in the form of separate villas on a large plot developed by private real-estate companies, or high-rise developments with specific amenities. These types of developments are evident in many Mediterranean cities in Turkey, France, Greece,

Italy, Spain or on Islands such as Cyprus. In addition, the coastline is also preferred for tourism and recreational purposes. Tourist resorts, local commercial and industrial infrastructure, dense road networks, and residential buildings detached from agricultural land are the most apparent signs of transition from rural to suburban areas (Salvati, 2013). As mentioned by Yılmaz and Terzi (2021) coastal areas can be seen as ‘topographic threshold’ and an appealing natural element which on the other side triggers urban growth. Hence, the attractiveness of coasts leads to population growth and increased development and consequently changes in LULC. The expansion of settlements and built-up environment into natural and agricultural is one of the visible outcomes of coastal sprawl.

The coastal development of Mersin, Erdemli in Turkey can be seen as a representative example for coastal sprawl for the developing eastern Mediterranean regions. According to Hakan Alphan (2020), the intensive growth of the built-up are started in the 1980’s with development of apartment blocks along the coastline serving domestic tourism and recreation. As a result of the increase in construction, ‘the coastline was completely occupied by buildings’ in 2007. This also resulted in fragmentation of natural landscape as well as degrading agricultural and natural vegetation. Hence, monitoring sprawl development, analyzing changes and projection of future development are crucial of managing coastal development. As argues Hakan Alphan (2020), a wholistic and multilevel approach is needed to assist governmental decisions and plan for sustainable growth.

The literature review has shown that research in sprawl literature was fundamentally enriched by Mediterranean sprawl studies in recent years. Nonetheless, the characteristics and dimensions of sprawl are generally known and applicable and will

be discussed in the next section. Yet Euro-Mediterranean cities, in addition to sharing general sprawl characteristics, are distinct in their:

- a) Variation of urban forms,
- b) Weak or absent regional planning, and
- c) Mismatch between population and urbanity (Salvati & Morelli, 2014).

Another fundamental difference is that North American literature on sprawl strongly concentrates on the negative impacts of urban sprawl, whereas Euro-Mediterranean literature foregrounds the role of actors and processes (Chorianopoulos et al., 2010). The majority of Euro-Mediterranean urban sprawl, whether legal or illegal, could be classified into the following categories:

- a) Sprawl attached to existing villages but far from the main urban area,
- b) New sprawl developments mainly by cooperatives or real estate agencies on vacant land,
- c) Sprawl along the coastline, around activity hubs and main arteries mainly for a second home or middle-class resort housing,
- d) Sprawl related to ‘action planning’ legislation or technological parks, although this type has rarely been successful (Leontidou et al., 2007),
- e) Sprawl due to the fact that Euro-Mediterranean urban development rates are much faster than population growth rates (Catalán, Saurí, & Serra, 2008),
- f) Sprawl near large cities due to job opportunities, and
- g) Sprawl development for recreation purposes along coastline.

The studies above has shown that Mediterranean sprawl, specifically in coastal areas are a threat for the coasts not only for loss of agricultural and natural environment, but also it seems unpredictable and in need of management and control which could be

through a rigorous monitoring and governance. Especially in developing regions, as seen in the cases of Cairo, the population growth has a significant impact on the random and uncontrollable development of sprawl. As mentioned beforehand, urban dynamics and changes in developing regions are more dependent on unpredictable and rapid population growth, informal development, socio cultural as well as economic, conditions than in developed regions.

Table 6 gathers the most comprehensive Euro-Mediterranean studies on urban sprawl in chronological order and summarizes the author/s, region, keywords and method/s, and interprets each study's outcomes. Its main aim is to present the main features of each study, including their dimensions, methods, and principal findings. Table 6 also plays an important role in enabling readers to understand the differences of sprawl dimensions in Euro-Mediterranean cities as compared with other regions. This study previously identified different dimensions of sprawl in the '2.3 Sprawl Dimensions' section. Later, Table 6 was used to define the monitoring dimensions for this study area. Extensive further information will be provided in the '4.2 Monitoring Dimensions' section. Finally, Table 6 paves the road to compare the sprawling features of Euro-Mediterranean studies with the case of Famagusta. This will be discussed in detail in section '5.5 Famagusta Sprawl in Relation to Euro-Mediterranean Sprawl'.

Table 6: Summary of examined Euro-Mediterranean sprawl research

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Muñoz (2003)	Madrid (Spain) Barcelona (Spain) Valencia (Spain) Milan (Italy) Turin (Italy)	Peripheral development Security Commodification Housing design	Literature Reviews	This study reviews the literature to summarize Euro-Mediterranean sprawl characteristics. The study provides comprehensive analysis of Euro-Mediterranean sprawl, classified under the following headings: metropolitan dynamics in the ‘multiplied city’, landscaping urban sprawl in Mediterranean cities, ‘thematization’, and commodification of residential space.
H. Alphan (2003)	Adana (Turkey)	Urbanization Land-use/land-cover change Adana Turkey Remote sensing	Satellite imagery and GIS	This study analyzed LULC changes in case of Adana by using satellite data of 1984 and 2000. According to the study findings, the built-up area increased which could be attributed to the immigration and urban development strategies. As a result Adana is witnessing loss of agricultural and semi natural lands.
Catalán et al. (2008)	Barcelona (Spain)	Urban form Compact city Dispersed city Europe Barcelona	Census tract, Cartography, and GIS	This study analyzed how the LULC of the Barcelona metropolitan region stabilized the sprawl development, particularly in the exurban area. It found extensive land occupation, damage to agricultural and forest lands, declining urban density, and large amounts of bare urban land awaiting further development. These could be the main signs of current urban transformation and strong indicators of a new direction for urbanization. Therefore, the promotion of a polycentric system not only prevents the proliferation of urban development that fragments the natural space but also causes relatively compact growth and controls sprawl.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Chorianopoulos et al. (2010)	Messoghia Plain (Greece)	Sprawl Competitive city Planning Athens Olympics	Satellite imagery and GIS	This study found that the promotion of competitiveness activity is related to the spatial policies, an internationally oriented, and place focuses. Accordingly, Athens focused on the geographically specific and economically promising part of the metropolis. Supra-local space interventions in Messoghia tried to address the lack of urban infrastructure and the stimulation of economic development. These reflect a reorientation of planning priorities toward competitive goals. However, formal, comprehensive planning structures were not involved in this effort. The statement of competitiveness concepts never became a coherent spatial policy on the sustainable development of metropolises. Therefore, the dynamics of spatial reformation interventions in Messoghia resulted in sprawl.
Salvati and Sabbi (2011)	Rome (Italy)	Urban growth Urban sprawl Land-cover change Land-cover relationships Rome	Cartography and GIS	This study analyzed the LULC of large Mediterranean cities. The outputs provided a comparison between the effect of urban growth and urban sprawl. Accordingly, the compact growth phase was rapid and mainly affected agricultural areas on the urban fringe. During the growth phase, the city expansion affected other agricultural lands. The sprawl phase could affect the entire Mediterranean landscape.
Beyhan et al. (2012)	Mersin (Turkey)	Urban sprawl Informal settlement Social housing Elite segregation Tertiarisation Remote sensing	Census tract, Cartography, and GIS	This study analyzed urban growth and sprawl in case of Mersin with use of earth observation together with socio-economic data. Study concluded, spread of the built-up areas at the neighborhood level. Study summarized, reformation in specific part of Mersin is in relation to the corresponding contingent factors such as movement and resettlement from rural to urban, planned social housing, generation of holiday district, segregation in the context and emergence of gated communities, and tertiarization of a district by the appearance of a shopping and mall.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Lagarias (2012)	Thessaloniki (Greece)	Urban sprawl Simulation Cellular automata Micro-dynamics Urban land cover Thessaloniki	Satellite imagery and GIS	This study used a Cellular Automata model try to simulate urban patterns and urban expansion processes realistically. The model investigated a link between macro-scale processes and micro-dynamics, considering it a two-scale process allocating a wide range of demographic, accessibility, socioeconomic, environmental and urban planning data and a set of local characteristics of land units and neighborhood interactions. The study expected to see a continuing accentuation of low-density sprawl development around Thessaloniki until 2030. This study believed severe land-use regulations and defining zones were required to protect natural and agricultural areas.
Salvati, Munafo, Morelli, and Sabbi (2012)	Rome (Italy)	Urban sprawl Building density Land-cover Changes Rome Southern Europe	Cartography and GIS	This study contributes to analyzing the spatial evolution of low-density settlements in large Mediterranean Urban Regions. During the studied period, sprawl not only increased on low-quality fringe areas, but even transformed the land of high environmental quality.
Salvati et al. (2013)	Attica (Greece)	Compact growth Exurban development Land-cover changes Land-cover relationships Mediterranean region	Cartography and GIS	This study, by observing the LULC of the urban fringe and rural areas, demonstrated that compact growth phases urbanized the agricultural and forest lands. Sprawl-phase forests converted to agricultural land due to the proximity of low-density urbanized areas. Additionally, in rural areas cropland was mainly urbanized, and forest land was transformed into cropland and pasture lands at a significant rate. The study area was differently impacted by factors such as distance from the urban core and land availability.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Salvati (2013)	Attica (Greece) Kyklades (Greece) Mykonos (Greece)	Tourism-driven sprawl Residential settlements Land fragmentation Mykonos Kyklades Greece	Census tract and Statistics	This study showed that socio-economic changes caused by tourism development and housing speculation led to recent urban development in Mykonos. Accordingly, most of the agricultural and pasture lands of the suburb urbanized in the 80s and 90s. A low-diversity landscape with relatively high land availability encouraged development along the coastline. The increase in the resident population and in ‘second home’ settlements affects the fragile and fragmented landscape and possibly stimulates soil and land degradation.
Chorianopoulos, Tsilimigkas, Koukoulas, and Balatsos (2014)	Messoghia Plain (Greece)	Urban sprawl Mediterranean city Athens Start-up businesses Kernel intensity	Geocoding and GIS	This study found that prioritizing rapid economic growth over long-term sustainable development leads to sprawl associated with inefficiencies and expenses, resulting in ‘attractiveness’ traits. Similarly, urban growth factors show a clear preference for locating in areas that are compatible with their activities and demonstrate the benefits of a regular urban environment.
Colantoni, Grigoriadis, Sateriano, Venanzoni, and Salvati (2016)	Athens (Greece)	Urban containment Land-use changes Sprawl Mediterranean region	Satellite imagery and GIS	This study concluded that regional economic developments and the emergence of new urban forms, including sprawl, social fragmentation and economic polarization, indicate that urban dynamics of land-use lead to dramatic change. In this sense, exurban areas are an example of land-cover changes and landscape rearrangements along the urban-rural dynamics due to the dynamic human pressure they experience. Therefore, the protection of natural areas mixed with cultivated land on the urban fringes contributes to the developing green infrastructure, preserving important ecosystem services, and securing rural traditions and local food systems.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Cuadrado-Ciuraneta et al. (2017)	Catalonia (Spain)	Urban growth Metropolization Land consumption Barcelona Mediterranean Europe	Census tract, Cartography, and GIS	This study found that urban growth continued in the next phase and stabilized the development of tourism. Urban plans and practices could not be developed without a formal comprehensive regional plan for settlements and infrastructure. The early 90s was a turning point in Alt Empordà development. The housing sector suffered a recession, which impacted the construction sector. The traditional tourism pattern shows signs of saturation. Some symptoms are observed in the local population such as rapid growth along the coastline and population decline from the urban core. This phase was a response to these socio-economic dynamics, which result in housing demands, different types of mobility, and the latent changes in the tourism pattern. This phase was marked by new, low-density settlement development, which reflects the failure of traditional offshore compact patterns. New urban configuration in the 60s and 70s result in the breakdown of traditional villages and urban centers related to tourism and the development of the 'second home'.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Lagarias and Prastacos (2018)	Madrid (Spain) Barcelona (Spain) Valencia (Spain) Seville (Spain) Bilbao (Spain) Athens (Greece) Thessaloniki (Greece) Rome (Italy) Milan (Italy) Naples (Italy) Turin (Italy) Lisbon (Portugal) Porto (Portugal) Marseille (France)	Fractal dimension Urban form Soil sealing Built-up density South European cities	Fractal dimensions, Grayscale maps of built-up densities	This study integrated traditional and other methods to estimate the fractal dimension using grayscale maps of built-up densities. The result suggested that the fractal dimension can reflect different urban forms. For instance, Spanish cities are classified as fragmented and clustered development, which contrast with patterns of urbanization that depict lower fractal dimensions. In contrast, most Italian and Portuguese cities had a more homogeneous urban form. Additionally, Bilbao, Seville and Thessaloniki are more compact with concentrated development in exurban areas: these settlements are built around a dense central core and this urban form reduces fractal dimensions. This study concluded that the fractal dimension is higher where urban areas are relatively homogeneous, distribution of developed areas, and the built-up density level. The fractal dimension is less where the built-up areas in exurban are discontinuous, the development pattern is relatively linear/elongated, or urban concentrations are clustered and polycentric.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Cecchini et al. (2019)	Attica (Greece)	Landscape Olive Athens Metropolitan area Sustainable land management Recession	Census tract and Statistics	This study concerned land diversity, topographic complexity, urban development and land fragmentation, which were important challenges for politicians, policymakers and land managers. Today's olive groves, a crop compatible with weak soils and dry Mediterranean climates, were increasingly grown on marginal and fragmented land on the exurban parts of metropolitan areas, replacing economically viable crops. Such a transformation results in a heterogeneous, diverse landscape often blending with natural elements with low-density and discontinuous settlements. By growing olives, water demand increases and land degradation occurs in the suburbs due to increasing conflicts over soil and water resources. These regional transformations have advantages and disadvantages in terms of socio-economic systems. Therefore, environmental impacts should be monitored extensively from a socio-ecological perspective. Accordingly, landscape transformations must be effectively governed by multilevel and multi-disciplinary policies incorporating short-term and long-term targets.
Salem, Tsurusaki, and Divigalpitiya (2020)	Cairo (Egypt)	Land Use/Land Cover Change Urban sprawl Agricultural land loss Driving forces Peri-urban area Egyptian revolution of 2011	Satellite imagery and GIS	This study uses Landsat 5 and Landsat 8 images as a point to identify the spatial trends of LULC changes and visualize the transformation in LULC. Based on the findings, LULC change processes, especially urban sprawl, have directly affected natural resources and particularly agricultural land. This study believed that rapid population growth and land value were the main driving forces of LULC changes during study period. The results of this study were similar to the results of previous research in Mediterranean cities. Since most of the urban sprawl was scattered and occurred in the outer boundary of the villages or cities.

Author/s	Region	Keywords	Method/s	Interpretations and Findings
Balta and Atik (2022)	Antalya (Turkey)	Antalya Rural planning guideline Urban sprawl patterns Village design statement	Satellite imagery and GIS	This study by used of 1984, 2000, and 2020 Google Earth satellite images as a three points to detected temporal and spatial changes found that, growth and urban sprawl in Antalya result in deterioration of the traditional land use patterns and decrease of farming activities. The study area due to scattered settlement texture, developed on the plain and on the hillsides. The study area has an organic pattern with a geographical location where local houses with gardens and fields, natural reserves consisting of forests and bushes are indigenous and unique to the village. The rural and cultural landscape characteristics of the region are potentially considered as an ideal example to guide rural planning in order to preserve traditional rural characteristics. Unfortunately, these characteristics are becoming vulnerable due to the effects of irreversible urban sprawl.

Chapter 3

SPRAWL MONITORING WITH USE OF RS AND GIS

In the past half-century, society's interaction with its environment has been complex. Rapid development and exploration of highly complicated geographical phenomena have made analyzing the process more difficult than before. Accordingly, the need to observe, analyze and synthesize such phenomena remains vital, with the primary aim of managing and predicting negative consequences to reduce and control them. Based on Koshkarirov, Tikunov, and Trofimov (1989) article, a fundamental contradiction exists between the complexity of geographical phenomena and the relatively limited human capability to analyze and make decisions. Therefore, demand for computer systems to present and interpret geographical phenomena has increased. Geographical Information System (GIS) development has been a significant product of these factors.

3.1 The Geographical Information System

Geographic Information Science (GSci) was almost considered a new discipline when it first appeared at the end of the 1960s. GSci represents the science of 'spatial data processing' and emerged from the quantitative revolution, the evolution of digital cartography, and rapid expansions in computer technology. GSci is used to solve conceptual problems and includes the capture, storage, retrieval and analysis of spatial data. Until the mid-1990s, the GIS term was mainly used to emphasize the software. Recently, the GSci term was coined to define the theoretical underpinnings of the technology, including database theory, analysis methods and visualization techniques. Today, the GIS term remains in use, although often inappropriately by individuals

emphasizing the hardware and software modules. Using it just to highlight the system itself demonstrates a lack of awareness of the rapid evolution of the science.

GIS, thanks to its involvement in the development of digital mapping technology, is now considered a billion-dollar industry in the USA. Many private sector companies such as engineering firms and environmental consultants employ GIS; even the public sector, at the different levels of local, state and national governments, use GIS. Likewise, the academic sector extensively lectures on GIS in minor and major fields. GIS is becoming a common tool for analyzing and displaying spatial data and, broadly speaking, it is used for the following purposes:

- a) Urban planning and LULC mapping,
- b) Geodemographic and demographic analysis,
- c) Transportation mapping and accessibility analysis,
- d) Public utilities and infrastructure mapping, and
- e) The evaluation of natural resources (McMaster & Craig, 2002; Peuquet & Marble, 1990; Steinberg & Steinberg, 2015).

A GIS is a specialized computer database program designed for the collection, storage, manipulation, retrieval and analysis of spatial data (Parker, 1988; Peuquet & Marble, 1990). Although maps are the regular GIS output, its abilities are not limited to their creations. GIS is a powerful tool for collecting, organizing, exploring and analyzing data and it can aid the researcher in various ways. Perhaps most valuable is its ability to confer understanding of, and visibility on, the relationship between factors or variables when viewed through the spatial lens (Steinberg & Steinberg, 2015). Topology as a mathematical model plays a significant role in defining places and relationships between geographical phenomena and may establish the connection of

one entity to another. Topological relationships are independent of distance or direction (L. Liu & Özsu, 2018, p. 4173).

GIS performance generally depends on the following two basic features:

- a) The locational feature and spatial data are mainly represented in vector format as a point, a line (polyline) and an area (polygon). However, spatial data as a raster can also be represented in form of topological data such as grid and network.
- b) The actual characteristic is usually known as the non-locational attribute. Attribute data are responsible for describing the location feature.

Attribute features include quantitative data such as numbers and values. Likewise, attribute features can capture qualitative data like class, name. However, time is the third feature specifically related to GIS (Parker, 1988; Peuquet & Marble, 1990). Both qualitative and quantitative features may change during a longitudinal sequence of time. Therefore, any geographical data must be studied using the time-series method (Figure 4).

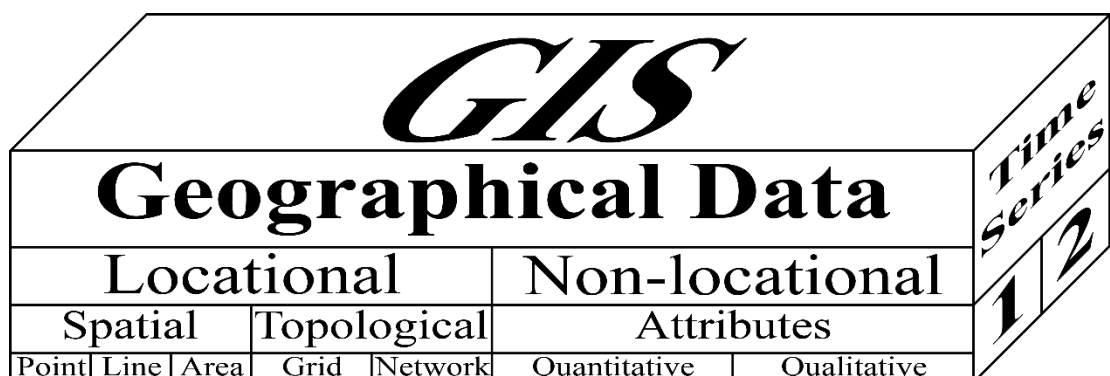


Figure 4: Three conceptual features of a GIS, after Peuquet and Marble (1990)

3.2 Time-series Observation

Time-series measurements (longitudinally) are a record of observations prepared in a particular place and related to the evolution over time of certain variables. The time-series method is used for a wide range of phenomena, from economics to the physical sciences, and general techniques may be applied without the need for prior knowledge of the fundamental causal links between dependent and independent variables. However, this causal link was missed by presents an inherent uncertainty in the appropriate, and particularly in the predicting estimation. Observed behavior cannot be simulated with repeated experiments (a single occurrence happens at any point in time) and the observations are usually time-dependent (Salcedo, Alvim-Ferraz, Alves, & Martins, 1999).

Air quality monitoring is an excellent example of an environmental time-series study. The method commonly used to estimate environmental parameters is based on classical descriptive statistics. However, this value is relatively limited due to the high variability associated with air quality data and the low signal-to-tonnage ratio of existing measurements. Accordingly, time-series studies may be an appropriate way to avoid these difficulties by identifying hidden deterministic behavior and thus contributing to an understanding of origin and consequence associations in environmental and urban problems (See Schwartz & Marcus, 1990).

Time-series studies may offer statistical methods that can be used for non-repeatable experiments and structural models (Salcedo et al., 1999). Likewise, time-series monitoring is a useful method to analyze how geographical data change over time. The primary purpose of any time-series geographical data is to record or display changes

over time. Change is usually described as an event or set of events. For instance, changes in dominant species within a forest, forest fires, land ownership changes, or the construction of a road (See Longley, Goodchild, Maguire, & Rhind, 2005, pp. 91-104). In this context, Soule (2006, p. 276) has stated that time-series data is a primary method of detecting change in LULC. Of course, time-series should be applied in a specific area over discreet periods, enabling the numerical quantification of change data.

3.3 Remote Sensing

More than a thousand satellites with different tasks are currently orbiting the Earth. These satellites provide a suitable platform for performing different studies. Satellite imagery data has become popular due to online access through various platforms. Satellite Remote Sensing (RS) -based studies and their integration into a GIS platform provide a base for diverse types of urban development studies.

RS is a science and technology that allows the identification or measurement of objects' properties without direct contact (Munafò & Congedo, 2017). The RS discipline covers the analysis and interpretation of Electromagnetic (EM) radiation measurements. EM radiation energy consists of a wide range of wavelengths (λ) that comprise the EM spectrum. The EM radiation is reflected by or emitted from a target, and it is observed by an instrument that does not touch the target. The observation process records the target from a vantage point above the earth. The EM radiation is reflected from any part of the earth's surface such as bare land, forests, oceans, lakes, snow or icy surfaces, and even the atmosphere. The EM radiation is recorded by installed sensors on aircraft, Unmanned Aerial Vehicles (UAVs) and satellites. The RS measures the Earth's surfaces within the atmosphere to discover the relations

between the nature and distribution of phenomena on the Earth's surface (Mather & Koch, 2011; Tso & Mather, 2001, p. 4).

As stated earlier, the EM spectrum comprises an extensive wavelength range that can be measured in meters (1×10^0 m), micrometers (1×10^{-6} m = 1 μ m) and nanometers (1×10^{-9} m = 1 nm) units. Increasing the wavelength has an inverse relationship with frequency (ν). Discrete sets of continuous wavelengths called wavebands, such as the x-ray band, the infrared band, the ultraviolet band, the microwave band and the visible band (Figure 5), only represent part of the total EM spectrum. The visible band is a waveband of 400 nm to 700 nm that can be seen by unenhanced human eyes. However, the visible band represents only a minor proportion of the EM spectrum (Tso & Mather, 2001, p. 4).

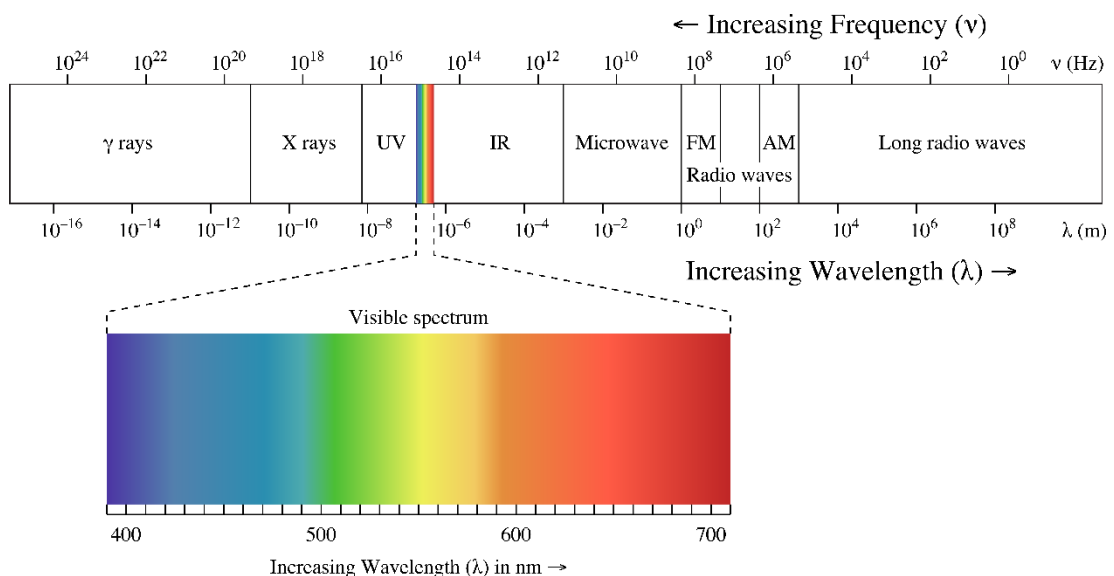


Figure 5: The EM spectrum consists of a wide range of wavelengths

The measurement of EM radiation is affected by the Earth's atmosphere. The main consequences could be on a) the radiation wavelength used and b) the atmospheric characteristics of the study area. Absorption and scattering are also factors. Scattering,

also known as ‘Rayleigh scattering’, is mainly seen at shorter wavelengths and can result in haze on RS imagery. There is a strong correlation between wavelength and scattering effects ($\sim\lambda^{-4}$), which means that shorter (blue) wavelengths are scattered more than longer (red) wavelengths. This results in the indirect blue light coming from all regions of the sky. Rayleigh scattering of sunlight in Earth’s atmosphere causes diffuse sky radiation, which is the reason for the blue color of the daytime sky and the yellowish-reddish hue of the low Sun (Tso & Mather, 2001, pp. 5-6).

The atmosphere has multiple levels of absorption, and this level changes according to wavelengths. The atmosphere’s energy absorption is nearly complete in some wavebands and these wavelengths are impossible to use in RS. However, there are so-called ‘atmospheric windows’ that permit the transmission of certain parts of the spectrum and have potential for RS mission candidates. The characteristics of the surface are also considered in the waveband selection for RS. The energy that strikes a target can be divided into three parts: transmitted energy, absorbed energy and reflected energy. The reflective properties of surface materials can be measured using spectral reflection. The process for measuring the percentage of energy reflected is simply achieved by dividing the reflected energy by the observed energy at the given waveband (Tso & Mather, 2001, pp. 5-6).

3.3.1 Radiometric and Atmospheric Correction

EM energy consists of the combination of energy reflected from the Earth's surface and scattered energy in the atmosphere detected by the RS instrument. The amount of EM energy in the near-infrared and visible region of the spectrum can be detected by a sensor above the atmosphere. However, the extent of detection depends on the amount of incoming solar energy (irradiance). Of course, this amount is reduced by

the process of atmospheric absorption and the reflection properties of the earth's surface.

Fundamentally, the energy recorded at the sensor is considered a function of irradiance. This measurement records target reflectance, atmospherically scattered energy and atmospheric absorption. Thus, the optical region of the spectrum in RS can be analyzed and interpreted by assuming that the values are related to image pixels. Indeed, the accurate representation of the spatial distribution of the earth's surface reflectance is attributed to magnitude reflectance and associated with the chemical, physical, and biological characters of the earth's surface (Tso & Mather, 2001, p. 11).

3.3.2 Geometric Correction

The RS device resolution is defined based on the resolution of radiometric and spatial data. An instrument with a higher spatial resolution will be able to capture smaller terrestrial objects. The spatial resolution is associated with the Instantaneous Field of View (IFOV) sensor, which indicates the dimensions of the area from which the sensor receives energy at a specified time (Figure 6). The path of energy transfer to the sensor resembles a cone form. Accordingly, the resolution on the earth is approximately equal to the diameter of the circle created from this cone's intersection with the earth's surface (Richards & Jia, 1999, pp. 39-40).

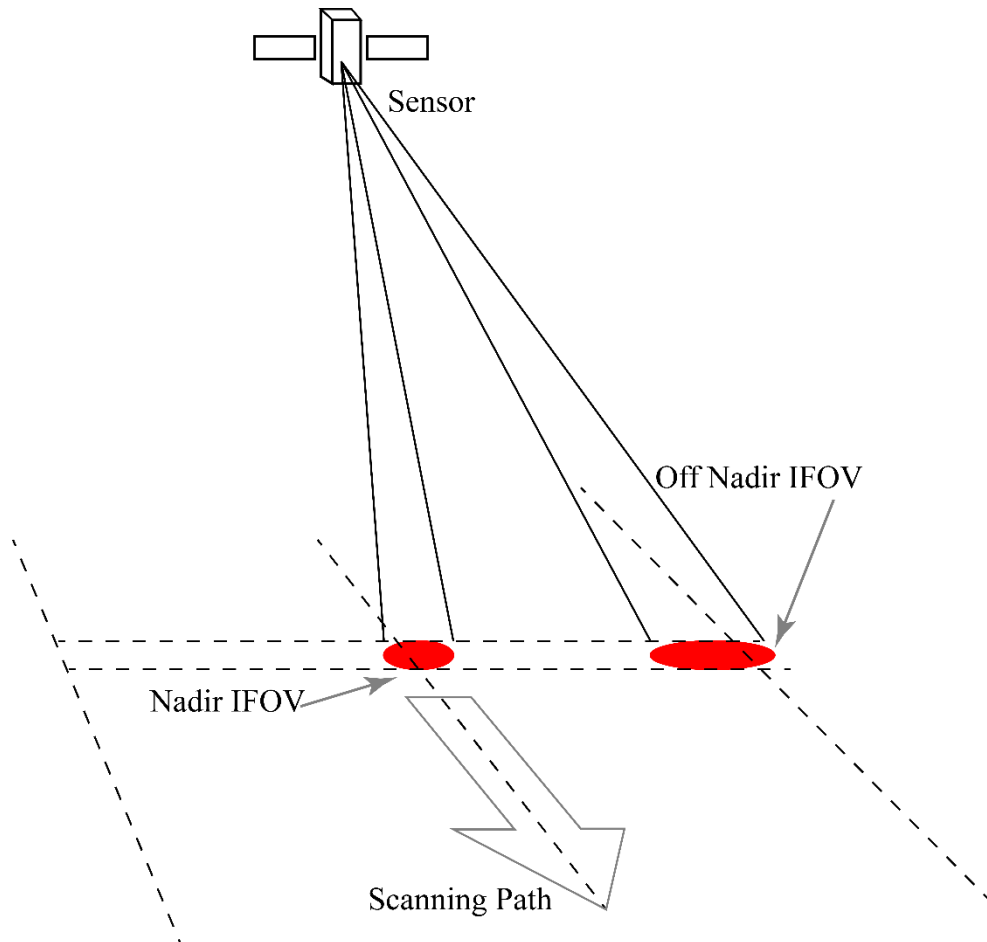


Figure 6: The IFOV of a sensor across a scan line

If the sensor scan area is distant then the nadir IFOV will be larger, distorting the image because the spatial scale is minimized from both edges at the left and the right to the image center. The geometric correction process is used to correct the effect of scale distortion. Scanning process effects can be extended to include other factors such as platform orbital characteristics and eastward rotation of the earth. This correction is usually made by constructing a transformer so that the ground map coordinates correspond to the satellite image coordinates (Jensen, 1996, p. 16; Richards & Jia, 1999, pp. 39-40). There are two methods to construct a transformer: the experimental method based on the least-squares method, and the analytical method developed by using orbital information (Tso & Mather, 2001, pp. 8-9).

3.3.3 Pattern Recognition Principles

The pattern represents the vector and the vector feature describes an object. The measurement pattern is built using feature sets. The feature sometimes refers to the ‘k-dimensional’ axis in space; it may be known as a space feature. Pattern recognition aims to establish a connection between the label (tag) of the class and the pattern. This connection could be one-to-one, which is called a ‘hard’ (or ‘crisp’) classification; it may also be one-to-many which is called a ‘fuzzy’ classification. As stated earlier, the vector feature describes an object. This vector feature could be a spectral reflection (radar backscatter values), infrared imagery (optical), secondary image measurement, or geographical features (terrain elevation and slope). Likewise, ‘object’ refers to the single pixel, and sometimes the group of surrounding pixels, that represent the geographical entity (i.e., the built-up area, forest, agricultural field, barren land, etc.). Finally, the class label is a list of all object categories in a particular study, as defined by the user. The class label is sometimes unknown to other users (Tso & Mather, 2001, pp. 41-42).

Fundamentally, there are two approaches to pattern recognition labelling: ‘supervised’ and ‘unsupervised’, although some methods use both. The supervised approach expects users to gather samples to ‘train’ or adapt the classifier function. This function determines logical decision boundaries according to the feature space. These decision boundaries are influenced by the attributes and sizes of the samples employed to train the classifier function. The label (tag) set is chosen experimentally for supervised classification to recognize class information. The researcher must be aware of the type and number of information classes offered in the study area in order to gather training samples of pixels from the image representing the information classes.

In contrast, the unsupervised pattern recognition approach is less reliant on user interaction. Usually, unsupervised classifiers ‘train’ the properties of each class and perhaps even the number of classes straight from the input data. The unsupervised approach appears more subtle and automatic than the supervised approach. However, the accuracy of the unsupervised approach is less than the accuracy of a supervised approach (Tso & Mather, 2001, pp. 41-42).

3.3.3.1 Unsupervised Classifiers

As mentioned before, the main variation between supervised and unsupervised approaches is that the unsupervised approach does not depend on the user choosing a set of training data to describe the goals or training of the classifier function. Instead, the user only defines the number of required clusters. This approach automatically classifies the clusters by reducing some pre-defined error functions. Sometimes, the required clusters can be automatically identified by the classifier. Theoretically, the function of the classifier works automatically, without the user's interaction. In practice, the output may be rejected or accepted depending on the user's expectations (Tso & Mather, 2001, p. 54).

3.3.3.1.1 The ‘k-means’ Algorithm

The ‘k-means’ algorithm is the most common unsupervised algorithm. It has been used extensively for years to segment images in RS automatically. This algorithm is realized through recursive migration from the set of cluster means (centers) using a ‘closest distance to mean’ approach. It does so until the locations of the cluster means are unchanged, or until the change from one iteration to the next is less than some predefined threshold. The change may also be defined by the number of pixels transferred from one cluster to another between iterations, or by the value of the cluster compression measurement. For instance, the sum of the square of each pixel's

deviation from the cluster's mean is summed for all classes (Tso & Mather, 2001, p. 54).

Using the 'k-means' algorithm, the initial number of clusters should estimate, such as N , present in the data. This algorithm first defines the position N cluster mean in the feature space by creating random feature vectors (i.e., randomly selecting N pixels from existing data and sometimes using a predefined set of feature vectors). Each pixel is then related to the closest cluster center. Next, the nearest distance is determined by measuring the 'Euclidean' distance ('Mahalanobis' distance). After that, the mean location of each cluster is recomputed according to the set of pixels assigned to the cluster mean. This operation is repeated unless the difference between iterations will be fewer than the determined threshold by the user (Tso & Mather, 2001, p. 54).

3.3.3.1.2 Fuzzy Clustering

Fuzzy clustering with the use of the 'k-means' is an alternative method for unsupervised classification. The fuzzy clustering algorithm, unlike the 'k-means' algorithm, results in fuzzy clustering instead of 'hard' ('crisp') clustering. Each pixel could simultaneously fit into more than one cluster, so it obtains a 'membership value' for each cluster. Accordingly, the fuzzy clustering method's performance is considerable due to responding to the hard clustering and mainly not preferred to fall into a local minimum. The Fuzzy C-Means (FCM) algorithm is considered a base for most fuzzy clustering methods. The FCM algorithm and its derivatives have been successfully employed in many applications such as pattern classification and image segmentation, especially in cases where the ultimate goal is making a crisp decision. Based on possible restrictions, the FCM algorithm must set the probability of joining a data point through classes as a whole (Tso & Mather, 2001, p. 56).

3.3.3.2 Supervised Classifiers

The supervised approach is a process for labeling the pixel and function performed based on the user demands. The user for each predefined class trains data, although the process of data training is boring for most of the users. In fact, the classifier's function performance is extremely dependent on the user's experience as they decide the distribution of the target class. Accordingly, the experienced user will find the place providing the most homogeneous example for the training of the known cover type. Supervised statistical classification can be done in the following phases:

- a) Determining the number and required info for the classes,
- b) Gathering adequate data training for every class,
- c) Evaluating the essential statistical criteria based on the trained data, and
- d) Using suitable decision rules.

Most researchers prefer the supervised approach due to the class definition's accuracy as compared to the unsupervised methods. The supervised classifiers are statistically categorized as the 'Parallelepiped Method', 'Minimum Distance Classifier', and 'Maximum Likelihood Classifier' (Tso & Mather, 2001, p. 57).

3.3.3.2.1 Parallelepiped Method

The parallelepiped method is performed by defining a parallelepiped boundary such as the sub-space (hyper-rectangle) for each class. Parallelepiped boundaries for each feature can be defined by the minimum and maximum pixel values in a given class. An alternative could be using a confident amount of standard deviation at both sides of the mean training data for an assumed class. The decision rule is used to prove that that point, as an indicator of the pixel in the feature-space proper, is located in one of the parallelepipeds.

The parallelepiped approach is fast and simple to perform, but if a pixel falls in more than one parallelepiped or a pixel is located outside all parallelepiped it results in errors. These are the two possible error conditions that could occur, mainly due to the complex distribution of pattern vectors in the feature space. Therefore, a robust classification is not easily achieved through a simple method like the parallelepiped approach (Tso & Mather, 2001, p. 57).

3.3.3.2.2 Minimum Distance Classifier

This classifier is similar to the ‘k-means’ algorithm. The pixel label is regulated by a decision rule adopted by the minimum distance classifier. Accordingly, the minimum distance between the pixel and the class centers is the base for this classifier. The measurement is done using either by the ‘Euclidean’ distance or the generalized ‘Mahalanobis’ distance. Both of these distance measures (i.e., ‘k-means’ algorithm and Minimum Distance Classifier) can be defined as dissimilar coefficients. This means that by increasing the similarity between two objects of i and j , distance will decrease. The mean spectral vector (class centroid) for each class is determined from the training data set. An unclassified pixel is labeled by calculating the distance between the unknown pixel value and each class centroid in turn. The label closest to the centroid is assigned to the pixel.

The minimum distance classifier is computationally efficient and mathematically simple, but theoretically might not be as strong as the Maximum Likelihood Classifier (which will be described in the ‘3.3.3.2.3 Maximum Likelihood Classifier’ section). A comparison study found that the output of the minimum distance classification with the ‘Mahalanobis’ distance measure is better than classification with the ‘Euclidean’ distance measure, but the accuracy is still significantly less than the Maximum Likelihood Algorithm (Tso & Mather, 2001, pp. 57-58).

3.3.3.2.3 Maximum Likelihood Classifier

The Maximum Likelihood Classifier is a supervised and statistical approach for pattern recognition. It runs by using sufficient training data for each class. The size of the training data is significant, as it should be enough to minimize unclassified pixels. The function of this classifier works according to the probability threshold and available training data. The highest probability is the criterion to assign each pixel: if the probability is less than the given threshold, the pixel remains unclassified. That being said, the use of the statistical approach is preferred to the other classifier. However, the performance of the statistical maximum likelihood classifier is limited by frequency distribution assumptions. Moreover, in past decades, the potential use of ‘Artificial Neural Networks’ as sophisticated classifiers have drawn researcher attention (Jensen, 1996, pp. 374-376; Richards & Jia, 1999, pp. 194-195; Tso & Mather, 2001, pp. 58-61).

3.3.4 Artificial Neural Network

By observing the pattern recognition efficiency of the eye/brain combination in human beings, researchers in the RS field started to develop a simplified computer-based eye/brain model that could operate more effectively than standard statistical classification methods. This resulted in the Artificial Neural Network (ANN), which over the last few decades has increasingly been used for RS image classification. The main advantage of ANN is its high computation rate, made possible by massive parallelism. A compact organization of interconnections (weights) and simple processors (neurons) also facilitate real-time processing of enormous datasets.

ANN is mainly described as non-parametric, as it is a neural network that is independent of any expectations concerning the statistical distribution of the data. Its performance significantly depends on the degree of good training. Likewise, the ANN

within the training phase ‘learns’ and requires regulations from the training data. These regulations result in the construction of future rules that extend to unknown data. Throughout the process, the user is responsible for defining the network architecture and determining different parameters, including the learning rate, which influence performance, training time, and rates of neural network convergence. Of course, no clear rules are available for the network architecture except the thumb (heuristics) rule, which helps the user to choose network parameters (Tso & Mather, 2001, p. 77).

In this study, the ANN method was chosen for classification. This method was founded on a three-layer perceptron that includes input, hidden and output. The classification process was based mainly on the back-propagation algorithm. To execute the algorithm, the required parameters were collected from the user-defined training data. The value of the training data was gathered from the input layer. The received input layers had to be multi-spectral and possess a value for each pixel (Figure 7).

By starting the classification process, all the pixels were delivered to the neurons in the input layer. In the following stage, each pixel was evaluated using a back-propagation algorithm and based on the pixel weights stored on the hidden layer. The hidden layer was used to generate a predicted value for each neuron on the output layer (Jensen, 1996, pp. 421-423; Mather & Koch, 2011, pp. 250-252; Richards & Jia, 1999, pp. 232-235; Tso & Mather, 2001, pp. 77-79).

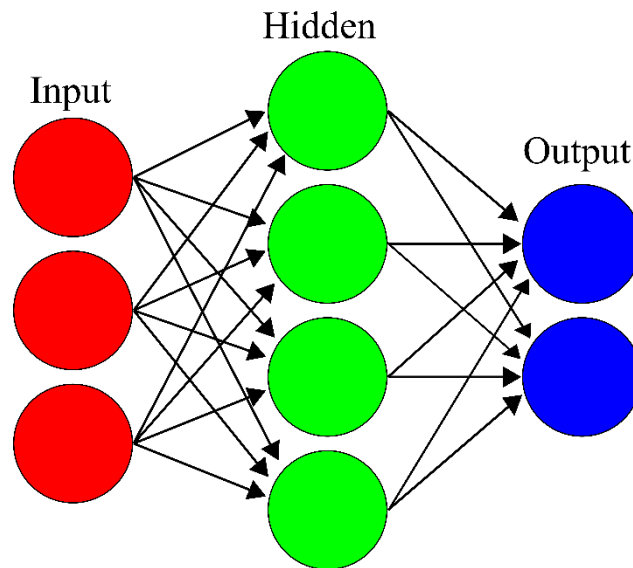


Figure 7: A typical three-layer multilayer perceptron neural network

3.3.5 Classification Assessment

There is currently no common agreement on the assessment of accuracy in classification; however, a confusion (error) matrix for accuracy assessment has been used in many studies (e.g., Congalton, 1991; Congalton & Plourde, 2002, p. 352; Foody, 2002; Lu & Weng, 2007). The confusion matrix uses a simple descriptive and analytical statistical technique. The classification accuracy was computed by dividing the number of correct pixels in each class by the total number of pixels in either the corresponding row or column. Accordingly, rows and columns as two novice raters will be selected to read the excerpts and themes to determine inter-rater reliability.

As well as assessment methods, sampling design is a critical issue that directly affects the results of such studies (Congalton & Plourde, 2002, pp. 356-357; Foody, 2002; Lu & Weng, 2007). According to Foody (2002), a large, simple random sample is sufficient, if it can adequately represent all the classes. Congalton and Plourde (2002, p. 357) recommended 50 to 100 samples for each class.

The confusion matrix measured the user's accuracy by dividing the total number of correct pixels in a class by the total number of pixels that were classified in that class. The producer's accuracy was measured by dividing the total number of correct pixels in a class by the total number of pixels derived from the sampling references (Congalton, 1991; Congalton & Plourde, 2002, pp. 352-355). The Kappa coefficient is another discrete multivariate statistical technique for assessing the accuracy of inter-rater reliability. The Kappa coefficient (Equation 1) is used to evaluate qualitative documents and determine the agreement between two raters (Hudson, 1987; Landis & Koch, 1977; Monserud & Leemans, 1992).

$$\hat{K} = \frac{N \sum_{i=1}^r x_{ii} - \sum_{i=1}^r (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^r (x_{i+} \times x_{+i})} \quad (1)$$

where $\hat{K}$ is the Kappa coefficient, r is the number of rows in the matrix, x_{ii} is the number of observations in row i and column i , x_{i+} and x_{+i} are the marginal totals of row i and column i , and N is the total number of observations.

According to Landis and Koch (1977), the strength of the Kappa coefficients is interpreted as shown in Table 7.

Table 7: Strength of agreement for Kappa coefficients

Kappa coefficients	Strength of Agreement
< 0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost Perfect

Chapter 4

PROPOSED MONITORING MODEL

“... ‘No big deal,’ ... Our place isn't hard to find. But here's a map. He gave me a sheet of paper with all kinds of lines indicating major and minor roads, lanes and such, with arrows pointing to the four poles of the compass. A large X marked the location of his house ...” (Carver, 1983).

This chapter presents the proposed modeling approach based on the given contents. The reviewed literature provided the basis to identify the difference between sprawl and other growth forms. Different types of sprawl, such as urban, rural and coastline sprawl, were explored; the sprawl dimensions for Euro-Mediterranean sprawl were discussed in section ‘2.3 Sprawl Dimensions’. Table 4 gathered most of the well-known monitoring approaches and discussed the advantages and disadvantages of each approach. Therefore, this chapter tries first to emphasize on the monitoring approaches, such as quantitative and qualitative methods. Later, the main dimensions of sprawl will be explained and discussed in detail. Finally, this chapter proposes a monitoring approach for Euro-Mediterranean regions with limited available data sets.

4.1 Monitoring Approach

There are different approaches for sprawl monitoring, such as spatial or non-spatial, static or dynamic, inductive or deductive, and agent-based or pattern-based (see Mas, Kolb, Paegelow, Olmedo, & Houet, 2014). Each of those approaches has advantages and disadvantages. Sometimes several approaches should be integrated to monitor different sprawl dimensions. Besides the above-mentioned approaches for sprawl monitoring, sprawl can also be monitored by comparing the LULC transformation

pattern over specific periods of time (Barnes et al., 2001; Galster et al., 2001), as I explained in section ‘2.3 Sprawl Dimensions’. Therefore, a study on the LULC change over time using the time-series method is one of the ways to monitor sprawl. The time-series method will later be described in detail in section ‘3.2 Time-series Observation’.

The time-series method itself incorporates different approaches to monitoring sprawl, such as census data, statistical datasets, census tracts and observation. RS and the ability to integrate big data with GIS provide a new approach to monitoring the sprawl, as was described in sections ‘3.1 The Geographical Information System’ and ‘3.3 Remote Sensing’. Land-cover monitoring can be based on two main approaches:

- a) A field survey, which is especially useful because the result is a spatial product that could be used as input for future spatial modeling and evaluation of ecosystem services, and
- b) Sampling, which is statistically more reliable, delivers more flexibility in its use and has data that can be easily updated. This approach is essential to monitor land cover based on an integration of field survey and sampling approaches (Munafò & Congedo, 2017).

The integration of RS and GIS delivers a powerful and outstanding tool for monitoring the spatial distribution and alteration of LULC patterns (Weng, 2001, 2002). The flexibility of RS and GIS make this method distinct from other methods (T. Liu & Yang, 2015; Mas et al., 2014; Ridd, 1995; Weng, 2001, 2002). Coupling RS and GIS creates a non-competing technique, especially for developing countries dealing with a lack of census data, statistical datasets and census tracts.

GIS power is not limited to the RS. GIS provides a particularly suitable platform for spatial analyses, and also offers a base for managing the landscape indices (McGarigal & Marks, 1995). The majority of the last two decades' studies focusing on LULC use RS and GIS to monitor urban development (Barnes et al., 2001; Batisani & Yarnal, 2009; Bhatta et al., 2010; Farooq & Ahmad, 2008; Kabisch, Selsam, Kirsten, Lausch, & Bumberger, 2019; Shahraki et al., 2011).

4.2 Monitoring Dimensions

In addition to the monitoring approach, choosing the appropriate set of dimensions for sprawl monitoring was an important issue. As stated earlier, in section “1.2 The Aim and Objectives of the Study”, the proposed monitoring model must address the following objectives of this study:

- a) To provide a set of dimensions for monitoring the sprawl of Euro-Mediterranean cities,
- b) To develop a model based on the sprawl dimensions, but with a minimum overlap of those dimensions,
- c) To deliver a model that is comprehensive and applicable not only to Euro-Mediterranean cities but which has the potential to perform with developing cities, and
- d) To develop a model with minimal dependency on high-resolution census data, statistical datasets or census tracts.

Table 4 and Table 5 show that Frenkel and Ashkenazi (2008), with an unusual combination of sprawl indices, tried to monitor four Israeli metropolises (Jerusalem, Tel-Aviv, Haifa, and Beersheba). Their results are not comprehensive because their study depended on recent literature using multidimensionality and a strong correlation

between high sprawl rate, high population and high growth rate. Moreover, Israel has urban planning problems similar to developing Euro-Mediterranean cities. However, Frenkel and Ashkenazi (2008) reviewed five characteristics of sprawl, which have minimal overlap: growth rate, density, spatial geometry, accessibility, and aesthetic measures.

Despite this, their methodology did not slavishly follow those dimensions. In fact, Frenkel and Ashkenazi (2008) try to limit their study to three dimensions: density measures, scatter measures, and land-use composition. These three dimensions relate to the configuration and composition characteristics of sprawl. Their method continues to depend on significant quantities of census, statistical dataset and census tract data; using factor analysis, they defined thirteen indices, which rely on density, scatter and land-use composition dimensions. Because of their dependence on high resolution data that this study lacks, their method is of limited utility here; however, the dimensions they adopted are extremely useful and will be used, after adaptation, in this study as a basis for monitoring sprawl in the Euro-Mediterranean region of Famagusta.

The dimensions' utility may be applicable more generally to Euro-Mediterranean cities, and could be integrated with different monitoring approaches. Similarly, the suggested dimensions can monitor sprawl either qualitatively or quantitatively. These five dimensions have minimum overlap with each other, which means that each dimension could monitor specific aspects of sprawl. In section '2.3 Sprawl Dimensions', different dimensions were identified for sprawl monitoring purposes in different countries. The approaches of each study were then specified, and advantages and disadvantages were discussed in detail in Table 4. At this point, all the dimensions identified in Table 4 will be compared with Frenkel and Ashkenazi (2008) to

synthesize Table 8. Table 8 has been developed to determine possible methods for monitoring each sprawl dimension.

Table 8: Different dimensions/approaches for monitoring sprawl

	Census	Statistical	Census tract	Observation	Longitudinal	Satellite
Build-density	1, 3, 2, 4, 5, 6, 7, 9, 10, 11, 14, 15, 16, 17, 18	1, 3, 2, 4, 5, 6, 7, 9, 10, 11, 12, 14, 15, 16, 17, 18	1, 4, 5, 6, 7, 9, 10, 11, 14, 15		1, 2, 9, 11, 12, 14, 16, 17, 18	12, 16, 17, 18
Growth Rate	3, 8, 9, 10, 13, 17, 18	3, 8, 9, 10, 13, 17, 18	8, 9, 10		8, 9, 13, 18	13, 17, 18
Spatial Geometry	1, 4, 5, 8, 9, 10, 16	1, 4, 5, 8, 9, 10, 16	1, 4, 5, 8, 9, 10	18	1, 8, 9, 18	16, 18
Transportation	1, 4, 6, 7, 9, 10, 14, 15, 17, 18	1, 4, 6, 7, 9, 10, 14, 15, 17, 18	1, 4, 6, 7, 9, 10, 14, 15		1, 9, 14, 17, 18	
Aesthetic				1, 3, 4, 10		
1 Mills (1981)		6 Reid. H. Ewing et al. (2003)	11 Terzi and Bolen (2009)		16 Zhou et al. (2019)	
2 Peiser (1989)		7 Y. Song and Knaap (2004)	12 Bhatta et al. (2010)		17 Fuladlu (2020)	
3 Gordon and Richardson (1997)		8 Jiang et al. (2007)	13 Shahraki et al. (2011)		18 Fuladlu et al. (2021a)	
4 Torrens and Alberti (2000)		9 Torrens (2008)	14 Oueslati et al. (2015)			
5 Galster et al. (2001)		10 Frenkel and Ashkenazi (2008)	15 Hamidi et al. (2015)			

As stated earlier, one of the current study objectives is to develop a model with minimal dependency on the census, statistical dataset and census tract. However, based on Table 8, most studies on sprawl dimensions use these resources, as well as longitudinal methods. Therefore, this study will propose a monitoring model based on satellites to meet the above-mentioned objectives. The satellite will be used for monitoring build-density, growth rate and spatial geometry, which will be discussed in detail in later sections.

The main limitation of satellites is their inability to see accessibility patterns (Hamidi et al., 2015). Instead, transportation research could help to determine accessibility. Therefore, the transportation dimension will be discussed in detail in section ‘4.2.4 Transportation’.

4.2.1 Build-density

The build-density of a development is the most crucial factor for measuring sprawl (Downs, 1999; Reid. H. Ewing, 1997; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Gillham, 2007, pp. 290-291; Torrens, 2008). As Hamidi et al. (2015) announced, “low residential density is on everyone’s list of sprawl indicators”. Build-density can be described as the average number of units for residential use per square mile of developable land in an urban area (Shahraki et al., 2011). However, build-density, in terms of sprawl development, is a condition in which density in a fixed period is low and even decreases (Frenkel & Ashkenazi, 2008). Most of the time, new development occurs around specific points, an effect called density concentration (Galster et al., 2001).

4.2.2 Growth Rate

The growth rate of a population indicates the amount of the population or the number of individuals in a particular place in a particular period. It is calculated based on the

initial population, and refers to population change over a given time. However, the growth rate, in terms of sprawl, can be defined as the state in which the growth rate in the suburban area is higher than the population growth in the inner central cities during the same period (Downs, 1999; Frenkel & Ashkenazi, 2008; Jackson, 1985; Oueslati et al., 2015).

Rapid population growth can itself cause uncontrolled development and result in sprawl (Bhatta, 2010, p. 20; Downs, 1999). Because populations must be accommodated somewhere, a wrong decision results in sprawl development (Torrens, 2008). Therefore, the ‘uncoordinated growth’ of the population without concern for its consequences results in incremental urban growth (Batty et al., 2003).

4.2.3 Spatial Geometry

Spatial Geometry deals with geometric monitors and is adopted based on ecological research or fractal geometry (Frenkel & Ashkenazi, 2008). Both ecological and geometric measures of the urban landscape commonly apply to the two characteristics of configuration and composition. The configuration is related to the geometry of the built-up area (Barnes et al. (2001)] and Galster et al. (2001)] call it *continuity*), while composition is related to the degrees of heterogeneity (Barnes et al. (2001)] call it *diversity* and Galster et al. (2001)] call it *Mixed uses*). In this sense, the geometric configuration of sprawling refers to any irregular configurations, such as scattered or fragmented development (Galster et al., 2001), and the composition of the sprawl is the LULC composition. The percentage of different LULC can represent the level of landscape heterogeneity (Frenkel & Ashkenazi, 2008).

4.2.4 Transportation

Transportation systems can be assessed in different ways that reflect the type of performance indicators used and the different perspectives of users, such as modes,

land-use, transportation problem-solutions and transportation measurements. Consequently, the following concepts of accessibility, mobility, traffic and connectivity are the main points of discussion in transportation studies (Litman, 2003):

- a) Accessibility is the opportunity to reach desired goods, services, activities and destinations. Accessibility concerns are travel time, travel expenses, travel options, convenience and risk while meeting the needs of people in the community (Lessa, Lobo, & Cardoso, 2019). The potential of each locality is mainly determined by its accessibility to other parts of the region (Friedmann, 1956). Its main aim is to provide access to various land-uses through access-management techniques. Accessibility is the ultimate goal of most transportation, except for a small part of the journey where the movement is purposeless and without a destination. Mobility is considered one of the ways to achieve accessibility (Litman, 2003).
- b) Mobility is the ability and ease-level of movement for goods and services. Mobility supposes that ‘travel’ stands for person- or ton-miles and ‘trip’ means a person or freight vehicle trip (Lessa et al., 2019). Congestion management systems are trying to improve the budget deficit and land constraints to continue expanding the transportation system. These systems manage travel demand through innovative ideas to increase volume and capacity such as bus rapid transit systems and designated truck lanes.
- c) Traffic refers to the movement of humans, animals and vehicles. Traffic on roads involves road users including pedestrians, animals or herds, vehicles, streetcars, buses, and other conveyances, either individually or in combination using the public way for purposes of travel. Traffic is supposed to increase

vehicle mileage and speed for social benefits, to which congestion or inadequate roads are the main obstacles.

- d) Connectivity is the relative location of an object to destination centers. There are different levels of hierarchy for connectivity. The destination may not be very far, but the travel time is long. For instance, traditional downtown areas have poor connectivity with many cul-de-sacs, requiring long travel times to escape the subdivisions, while the main road is located nearby.

Accessibility and mobility are two terms that are particularly important to the transport planning discipline. Accessibility and mobility are considered the ‘yin and yang’ of transportation. Road transport planners consider accessibility and mobility to contradictory. This is because increasing on-road accessibility reduces speeds, and therefore decreases mobility. Accessibility and mobility can be summarized as shown in Figure 8.

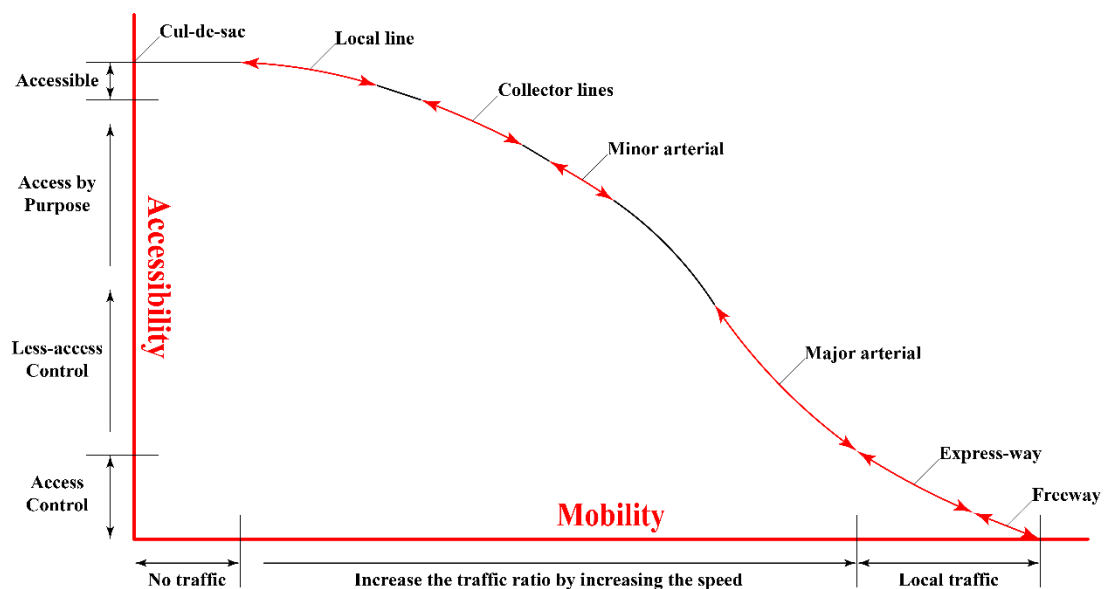


Figure 8: Accessibility and mobility after AASHTO (2004)

Lessa et al. (2019) believed that;

“High mobility can result from strong access restrictions for low-income people ... Conversely, low mobility may be a choice, especially for affluent populations who are able to live in the denser central areas in urban facilities ... Therefore, mobility is not a sufficient condition to amplify accessibility ... Similarly, greater accessibility, especially to the public transport system, does not directly translate into gains in mobility, neither in the volume of flows, nor in efficiency and quality.”

Accessibility is an important factor in monitoring sprawl. Sprawl generally means poor access development, which results in increasing auto-dependency (Fuladlu, 2020). The accessibility of sprawl development from the inner cities can be measured based on household travel time, the number of lanes, road length, etc. (Reid. H. Ewing, 1997, 2008; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Gillham, 2007, pp. 291-292; Torrens, 2008). Schimek (1996) concluded that low-density development results in increasing car ownership. The absence of other land-uses made sprawl residents auto-dependent and increased their mobility. However, the development of transportation networks leads to urban sprawl and the creation of low-density suburban areas, which contribute to a decline in accessibility (Lessa et al., 2019).

According to Figure 8, less accessibility signifies low-density development, an absence of mix-used development and an increase in mobility. However, high accessibility means dense development, mix-used development and decreased mobility. Build density is directly proportional to accessibility, while build density is inversely proportional to mobility. Fuladlu (2020) concluded that increasing the built density may result in the decline of VMT. Therefore, car ownership will increase when development is less dense and single-use (i.e., sprawl). The fleet miles driven measurement is influenced by the number of driver licenses and license plates (Choo, Mokhtarian, & Salomon, 2005). Increasing the VMT represents increasing fuel consumption (Salon, Boarnet, Handy, Spears, & Tal, 2012) as well as greater numbers

or likelihood of automobile crashes, which are associated with traffic injuries and fatalities (Reid H. Ewing, Hamidi, Gallivan, Nelson, & Grace, 2014; Salon et al., 2012; Yeo, Park, & Jang, 2014).

Sprawl is a single-use development since the residents have to spend considerable time traveling between where they live, work and play. Moreover, the majority of this travel is done by single-occupant vehicles, which increase traffic congestion in the urban area (Burchell et al., 1998, p. 62; Duany, Plater-Zyberk, & Speck, 2000, p. 7; Morris, 2005, p. 17; Samariüütel, Selvig, & Holt-Jensen, 2010). Therefore, sprawl significantly increases VMT (Behan et al., 2008; Fuladlu, 2020). The VMT is an essential factor for monitoring the total miles traveled by all vehicles on the network and provides an essential base for monitoring vehicular dependency. There are two possible methods for estimating VMT:

- a) Traffic basis using odometer readings and traffic counts, and
- b) Non-traffic basis using of household surveys and fuel consumption (Kumapley & Fricker, 1996; Leduc, 2008, p. 13).

This study monitored the transportation dimension of sprawl using the non-traffic method to estimate the VMT pattern. The annual VMT (Equation 2) will be estimated using the fuel sales approach. Although this is one of the earliest methods for doing so, it is still useful (Fricker & Kumapley, 2002). The advantages of this method include, firstly, that VMT can be estimated annually, and secondly, that there is no need for the researcher to travel on the roads (Azevedo & Cardoso, 2009).

$$A_{VMT} = T_{Gallon} \times T_{fleet} \quad (2)$$

where A_{VMT} is the annual VMT, T_{Gallon} is the total gallons of fuel sold (gasoline and diesel) and T_{fleet} is the total fleet mile drive per gallon.

4.2.5 Aesthetics

Isis (2012) through studies on aesthetics, emphasized that investigating aesthetics means exploring, examining and interrogating emotional experiences. These include ugliness, beauty and even the way in which humans give value to the place. The discipline of aesthetics has for centuries been associated with the philosophy of art. When humans experience art such as a symphony, a play or a painting, it is important to consider the human response to its aesthetic. In general, sprawl development is mainly seen as a monotonous, homogeneous and boring form of development. Lessinger (1962) at the beginning of his entitled paper “The Case For Scatteration” stated that:

“Urban sprawl, roller-painted across the countryside, is often without form, grace, or a sense of community. Planning philosophies aimed to strike down this amorphous creature should only gladden our hearts.”

Literature review indicates that aesthetics as a measurement dimension is applied and interpreted in diverse aspects by scholars. The interpretation varies from development form, building typology, urban landscape, and design. From an architectural point of view, the exterior façades of the buildings became an important feature. As stated by Nasar (1994):

“Urban designers formulate policies to shape the physical and spatial character of development. This includes a variety of kinds of development, such as large-scale private sector development, public conservation of the environmental quality of communities, and low-cost neighborhood improvement by citizens. The development may occur in a variety of urban and nonurban settings, including central business districts, small town commercial strips, neighborhoods, industrial parks, and mixed-use developments. In each case,

urban design attempts to shape the character of the exterior of ... buildings outward.”

McGlynn, Smith, Alcock, Murrain, and Bentley (1985, p. 42) argue that the character of the exterior façade, physical form and activity pattern mean that each building creates and has an aesthetic meaning that can be read; the building is, in a certain sense, ‘legible’. Sprawl development minimizes legibility due to its monotonousness and lack of activity pattern. Nasar (1994) believed that aesthetic judgments depend on the human experience of, and are mediated by, the exterior façade’s character. These judgments directly reflect each individual's feelings concerning each building. There are two main forms of judgments: those that use denotative interpretations and those using connotative interpretations. For instance, when an observer classifies a building according to its uses (e.g., residential, business, recreational, etc.) and style (e.g., contemporary, classical, traditional, etc.), these represent denotative meanings. However, observer inferences about the quality of the external façade and the building’s presentation (such as monotonous, ugly, boring or friendly) represent the connotative meanings.

Monotonous architecture combined with the lack of public space, pedestrian pathways and landmarks makes sprawl boring and lowers the quality of life (Barnes et al., 2001; Burchell et al., 1998, p. 84). The cultural aspects (including heritage and aesthetic values) of landscapes are threatened and can be irreversibly destroyed by uncontrolled urbanization and the development of transportation networks. Life quality in urban areas relates to the quality of public spaces (including green open space) which can be considered the ‘living room’ of the city. Likewise, grand central plazas and squares, their streets, and sidewalks to neighborhood parks are also important for offering

healthiness and well-being benefits to urban inhabitants; they may become an important part of the urban landscape. Therefore, architecture is the main component for enhancing the quality of the urban setting and the transformation of the urban landscape (Cugny-Seguin, 2017).

Sprawl demonstrates how new urban development in very different forms becomes more homogeneous and eventually follows the process of ‘metropolitanization’. Additionally, low-density development sprawl shows the proliferation of territories establishing the same morphological principles in different areas. In other words, a new suburb in Mediterranean cities appears similar to the archetypal images of the American suburban ‘dreamscape’. The new ‘semi-detached’ landscape is designed and structured as a disjointed sequence of physical elements including semi-detached houses, roundabouts as local traffic collectors, and sometimes medium-large shopping malls (Muñoz, 2003).

Although the aesthetic dimension of sprawl has not been studied as much as other dimensions, existing studies have often paid attention to the architectural form of the sprawl. Cecchini et al. (2019) tried to look at the aesthetic dimension of sprawl through the lens of the Athenian ‘olive’ landscape. According to Cecchini et al. (2019), olive trees are the most extensive agriculture around cities, especially in long-inhabited exurban environments surrounding metropolitan areas in Euro-Mediterranean cities. Additionally, the olive tree is a constitutive element in cropping systems, representing a typical crop for mixed urban-rural settlements. Olive cultivations are responsible for delivering environmental services, biodiversity protection, and aesthetic quality to suburban landscapes and offering indirect support for rural economies and tourism development. The authors believed that sprawl development into the landscape and the

spread of single-family houses with gardens would result in excessive soil consumption, negative environmental impacts on transforming rural areas and detrimental aesthetic outcomes. However, active and small-scale olive trees can play a special role in buffering sprawl. Olive groves represent an indirect response to sprawled settlements and infrastructures (Cecchini et al., 2019).

Hence, the scholar has attempted to generalize sprawl definitions on the basis of land use, i.e., residential sprawl, single-use development, and strip malls (Frenkel & Ashkenazi, 2008). Mills (1981) criticizes sprawl by calling it aesthetically unattractive. Similarly, Gordon and Richardson (1997) have stated that the term sprawl implies “...an unaesthetic, lazy and undisciplined form of body expression”. Galster et al. (2001) and Soule (2006, p. 5) both consider sprawl to be ugly. Yu (2013) believed:

“Urban sprawl is a pejorative term while its definition is illusive. For many observers, urban sprawl is an aesthetic judgment about an urban development pattern which is associated with many transportation, environmental, and socioeconomic problems.”

Hess et al. (2001) defined seven measures that are directly related to spatial characteristics and dimensions of sprawl. According to their study, architecture and aesthetic measurement of sprawl is considering the lack of sidewalks, wide roads, the large setbacks of the buildings from the street as well as the rotational placement in the lot. Their study mentioned architecture and aesthetics as a measurement dimension but did not include them in the quantitative analysis.

Torrens and Alberti (2000) proposed approaches for quantifying the aesthetic dimension using architectural and photogrammetric techniques. They refer to the automated analyses of built environments and the mathematical analysis. According

to them, in the architectural technique, the digital images of cities (each pixel) can be analyzed using image processing techniques by relating images to ‘known primitives’. Whereas the photogrammetric analysis associates an image's spectral signature with typologies and characteristics of urban land covers or uses. The latter can help identify the repetition and sameness of the built form in sprawl development. However, the proposed approaches were not applied in their study.

It is essential to mention that most examined scholars have thematized appearance and aesthetic aspects. Most interpreted sprawl as unattractive but did not use the dimension as part of their quantitative measurement. On the other hand, spatial aspects of sprawl are discussed under the dimension of spatial geometry, measuring scattering and fragmentation of the development. Hence, the form of the development can also be interpreted from an aesthetical point of view. The urban form refers to physical character of cities, including ‘the size, shape, and configuration of an urban area or its parts’ and its transformation. It is also considering housing type, street type, and their spatial arrangement or layout (Živković, 2019).

The aesthetic dimension is an essential feature of sprawl and even adds ‘flavor’ to sprawl measurements (Torrens, 2008). However, the aesthetic dimension is difficult to quantify as it is subject to its nature. As stated by Torrens and Alberti (2000):

“The aesthetic qualities of sprawl certainly provoke a level of eloquence in commentary, but the subjective nature of aesthetic sensitivities leave us with little room for quantification.”

This study tries to integrate the aesthetic dimension of sprawl into the measuring model since it is believed that the interpretation of architecture and form of the development is a necessary value to interpret sprawl development. The aesthetic dimension of

sprawl will consider the form and typology of sprawl development. Accordingly, the monitoring model for sprawl in Euro-Mediterranean cities is summarized in Figure 9.

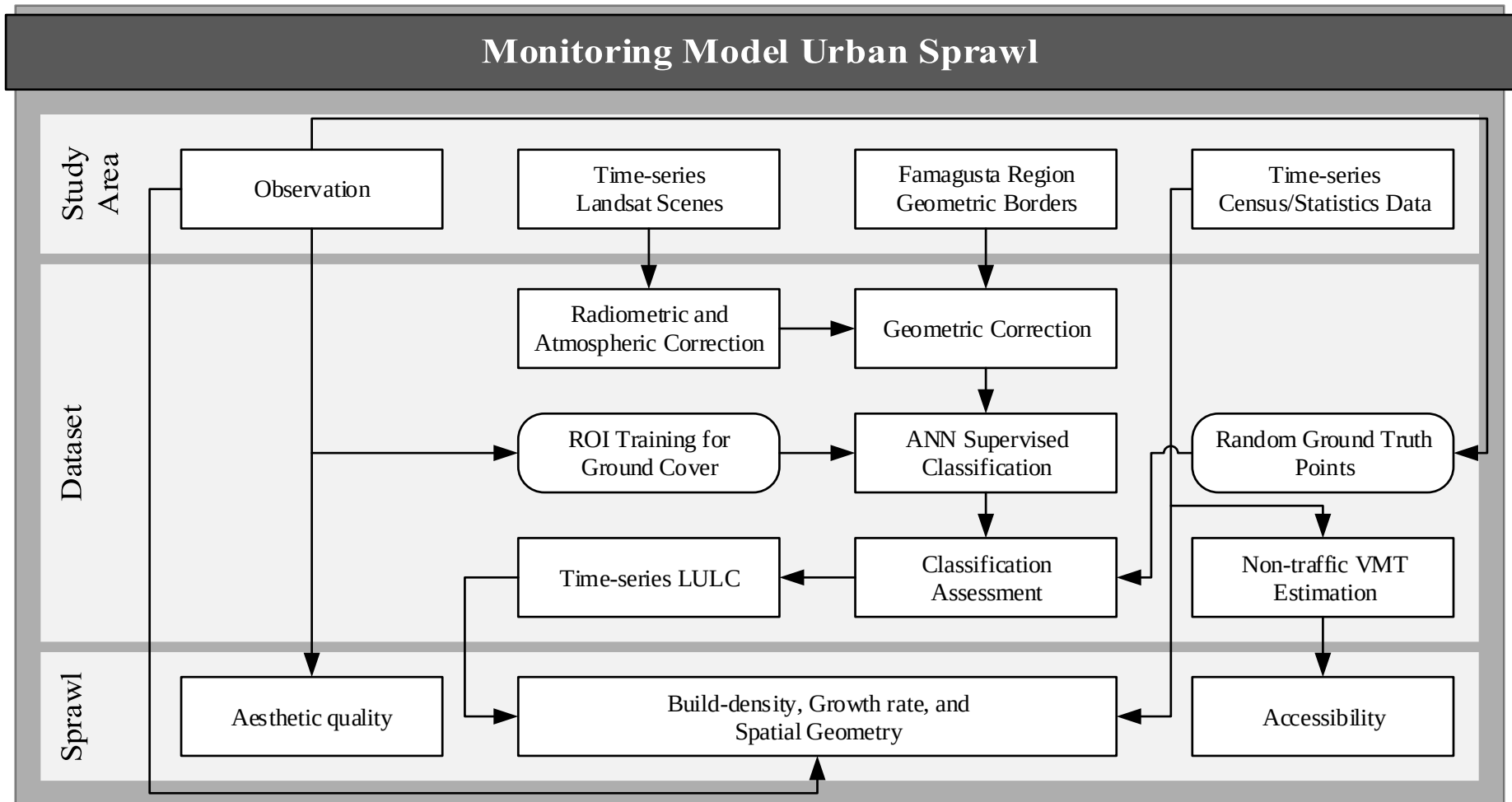


Figure 9: Proposed monitoring model for sprawl

Chapter 5

CASE STUDY

In this study, Famagusta city in Cyprus serves as a case study for exploring a new combined method of monitoring sprawl. The core of the applied method is time-series data (2001, 2006, 2011, and 2016) integrated with RS and GIS technologies to monitor the transformation of the designated sprawl characteristics. The following characteristics of sprawl were considered: build-density, growth rates, spatial geometry, transportation, and aesthetics. The required data was gathered from satellites, available census and statistical data, and personal observations. The monitoring model (Figure 9) was used for monitoring the sprawl; the whole monitoring process could be summarized as follows:

- a) Famagusta's current situation, including its economy and geopolitics, will be explained;
- b) Famagusta's geometric boundary will be defined and the time-series satellite scenes will be classified; and
- c) the predefined monitoring model, including five dimensions of sprawl, will be applied.

5.1 Study Area

Famagusta city is located at 35°07'30"N 33°56'30"E on the eastern coast of Cyprus (Figure 10). The population of the Famagusta region of the Turkish Republic of Northern Cyprus (TRNC) was 69,741 (de-jure) in 2011 (State Planning Organization, 2013). The entire Famagusta region is governed by three sub-regions: Famagusta,

Akdoğan, and Geçitkale. According to the definitions offered by Ravetz et al. (2013), each of the sub-regions mentioned above include urban, exurban and rural areas. Famagusta city and its region have had an eventful history; after the Cyprus conflict of 1974, the most dynamic neighborhood, Varosha, was vacated due to decisions made by the UN. In 1986, the existing Higher Technological Institute in the city of Famagusta became the Eastern Mediterranean University (EMU) (Önal, Dağlı, & Doratlı, 1999). EMU directly increased the population and housing demand in Famagusta (Oktay, 2005; Oktay & Marans, 2010). By 2004, the enactment of the United Nations (UN) peace plan (Annan, 2004) had significantly boosted construction in Northern Cyprus, which was driven by domestic and foreign demand (Fuladlı, 2020; Yorucu & Keleş, 2007). According to Yorucu and Keleş (2007),

“The Plan assigns environmental policy primarily to the federal government, but there is significant state role in such areas as land zoning, building permits and land registration. The federal and constituent states are expected to cooperate, coordinate and harmonise their policies and legislation, through cooperation agreements, common standards and regular consultations.”

Following these events and despite the Annan plan’s stipulations, the lack of a regional master plan and weak construction regulations resulted in sprawling development (Fuladlı, 2020; Hoşkara, Çavuşoğlu, & Öngül, 2009; Önal et al., 1999). Sprawl is observed primarily along the main arteries leading from Famagusta city toward Nicosia and on the main road to Yeni Boğaziçi and Yeni İşkele along the coastline.

Legend

-  Landsat Path / Row
-  Cyprus
-  Buffer Lines
-  Famagusta
-  Famagusta Eastern Shore
-  Varosha Neighborhood
-  Eastern Mediterranean University

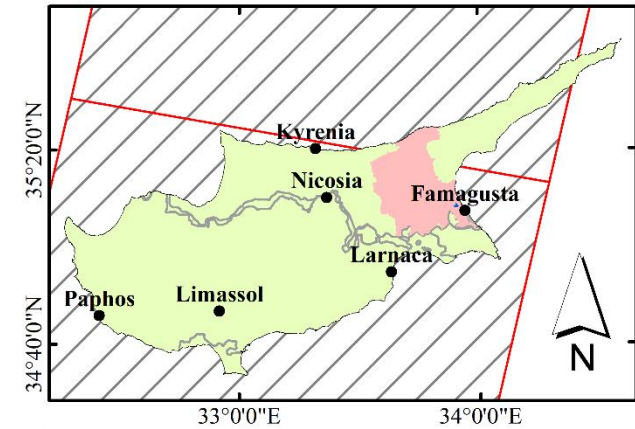
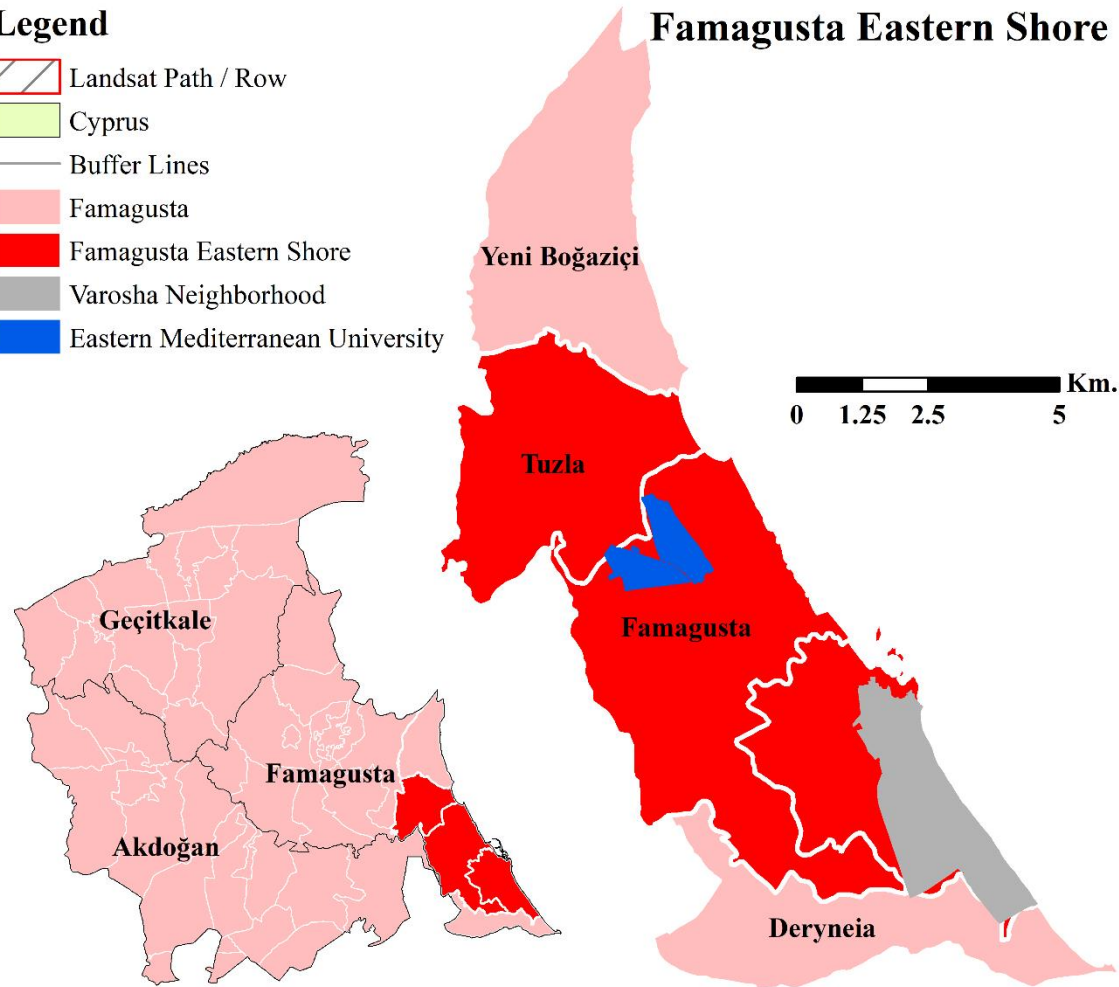


Figure 10: Famagusta Region and City

Famagusta is a university city and hosts more than seventeen thousand students and academic staff from various countries. The lack of a master plan remained a condition of Famagusta at the time this study was conducted; therefore, landowners and construction companies essentially controlled construction development. As a result, construction activities in Famagusta largely reflect the student population and its potential growth.

Table 9: Population and annual-growth rate within the Famagusta city boundary

Time Series	Famagusta**		Tuzla		Yeni Boğaziçi	
	Population (#)	Annual-growth rate (%)	Population (#)	Annual-growth rate (%)	Population (#)	Annual-growth rate (%)
1996	*24,743		*335		1,684	
2001	*29,129	3.26	*1,107	23.89	*2,256	5.85
2006	33,504	2.80	1,877	10.56	2,802	4.34
2011	37,868	2.45	2,645	6.86	3,347	3.55
2016	*42,221	2.18	*3,411	5.09	*3,891	3.01

* The population is estimated due to the lack of a census. Details of the estimation are provided in the '5.3.2 Growth Rate' section

The population of Famagusta is summarized in the following stack bar-chart (Figure 11).

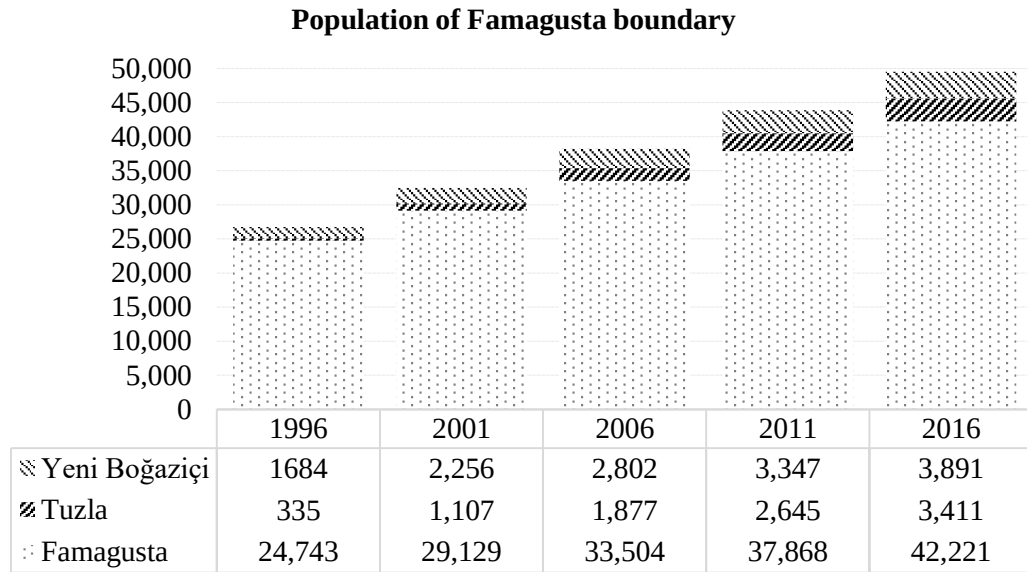


Figure 11: The population and built-up density in Famagusta

5.2 Dataset Preparation

The Famagusta geometric boundary was obtained from the Famagusta municipality as a GIS-ready shape-file. This shape-file includes the boundaries of the urban and exurban areas. The total area of Famagusta, according to the shape-file, is 896.72 km², and the total area of the study area is 84.06 km². According to the study framework, the Landsat level-1 product with medium spatial resolution data can respond to the methodology (Lu, Mausel, Brondízio, & Moran, 2004; Lu & Weng, 2007). The time-series data scenes (Table 10) were chosen from the summer months because summer scenes have minimal cloud coverage, maximum stability of meteorological conditions, and improved distinction between the forested, agricultural and urban areas (Carlson & Arthur, 2000). Another selection criterion for the data scenes is related to the availability of the government census and statistics data.

Table 10: Landsat metadata

Path / Row	ID	Collection	Acquired Date	Cloud Cover	Spectral Set of Bands	Cell Size	RMSE
176/36	LE71760362001222MTI00	L7 ETM+ SLC-on	2001/08/10	0%	1 2 3 4 5 7	30 m	0.278656 (72 Points)
176/35	LE71760352001222MTI00	L7 ETM+ SLC-on	2001/08/10	0%	1 2 3 4 5 7	30 m	
176/36	LE71760362006156ASN00	L7 ETM GLS2005	2006/06/05	0%	1 2 3 4 5 7	30 m	0.108580 (82 Points)
176/35	LE71760352006156ASN00	L7 ETM GLS2005	2006/06/05	0%	1 2 3 4 5 7	30 m	
176/36	LT51760362011210MOR01	L4-5 TM	2011/07/29	0%	1 2 3 4 5 7	30 m	0.019239 (78 Points)
176/35	LT51760352011210MOR01	L4-5 TM	2011/07/29	0%	1 2 3 4 5 7	30 m	
176/36	LC81760362016224LGN00	L8 OLI/TIRS	2016/08/11	1%	2 3 4 5 6 7	30 m	Reference Mosaic
176/35	LC81760352016224LGN00	L8 OLI/TIRS	2016/08/11	4%	2 3 4 5 6 7	30 m	

5.2.1 Pre-processing

The Landsat scenes path 176 and rows 35 and 36 (each 183 km by 170 km) are sufficient to cover Famagusta (Figure 10). The scenes were converted to a unique scene using seamless mosaic tools. In order to avoid image distortion, all datasets were projected to WGS1984 UTM Zone 36 North. The multi-source data integration made geometric correction mandatory (Lu et al., 2004; Lu & Weng, 2007; Toutin, 2004). This process used image-to-image registration (Richards & Jia, 1999, p. 57), and mosaics were resampled according to the 2016 mosaic. The amount of Root Mean Square Error (RMSE) for pixel distortion should be less than 0.5 pixels for all pairs of scenes 30 m in size. The amount of RMSE was acceptable according to the Mas (1999) study (Table 10).

5.2.2 Radiometric and Atmospheric Correction

Many scholars believe that atmospheric correction is not necessary for single-scene classification because the image is being classified on a relative scale (Lin, Wu, Tsogt, Ouyang, & Chang, 2015; C. Song, Woodcock, Seto, Lenney, & Macomber, 2001; Tso & Mather, 2001, p. 11). However, atmospheric correction was mandatory for this study as multiple scenes were used for classification (Lu et al., 2004; Lu & Weng, 2007; Tso & Mather, 2001, p. 11). The image-based, dark-object subtraction model was used for atmospheric correction (Chavez, 1996; C. Song et al., 2001). The required constant for the radiometric calibration and the atmospheric coefficients were extracted from Chander, Markham, and Helder (2009).

5.2.3 Geometric Correction

Multi-source data integration made geometric correction mandatory (Lu et al., 2004; Lu & Weng, 2007; Toutin, 2004). This process used image-to-image registration (Richards & Jia, 1999, p. 57), and mosaics were resampled according to the last

sequence mosaic. The amount of RMSE for pixel distortion should be less than 0.5 pixels for all pairs of scenes 30 m in size. The amount of RMSE was acceptable according to the Mas (1999) study.

5.2.4 Method of Classification

As stated in section ‘3.3.3 Pattern Recognition Principles’, there are different principles for pattern recognition, such as ‘unsupervised’ and ‘supervised’. However, the current study used the ANN principle for classification purposes.

5.2.4.1 Data Training

In line with the aims of this study, instead of a detailed LULC classification, the classes were chosen according to Anderson, Hardy, Roach, and Witmer (1976). The classes are:

- a) urbanized land – includes any structure such as buildings, communication, and transportation utilities and infrastructure,
- b) vegetated land – includes any green cover such as forests, pasture, plants or gardens, and
- c) open land – includes any remaining ground cover such as rangeland, wetland, and barren land.

Accordingly, the required parameters for the classifications were collected for the predefined classes. Meanwhile, the process experimentally trained data for the classes mentioned above. The data training used the high-resolution raster and the field survey.

5.2.4.2 Classification Assessment

As stated earlier, the confusion matrix will be used for classification assessment and will incorporate user accuracy, producer accuracy and kappa coefficients. Because the study area was not big enough to incorporate a large number of samples, regular sample points distributed at 520 m distances were used; these respected the shape-file

boundary defined in GIS. An attribute table was prepared for all the samples, showing their exported coordinates and relevant characteristics gathered from the high-resolution mono-band raster, Google Earth™ and a field survey.

The designed random samples were subsequently compared with each classification raster by using the confusion matrix in GIS (Table 11). Likewise, the output results were compared to Table 7, which shows the strength of agreement for the Kappa coefficients. Accordingly, except for the 2011-year classification raster which is almost perfect, the rest of the classifications raster's Kappa coefficient is substantial.

Table 11: Confusion matrix for the accuracy assessment

Time series	Classes	Random Sample Points				Classification Accuracy (%)		
		Vegetated land	Open land	Built land	Total	Producers	User	Kappa Coefficient ($\hat{K}$)
2001	Unclassified	1	0	0	1	-		
	Vegetated land	48	8	0	56	90.57	85.71	
	Open land	4	400	29	433	97.56	92.38	
	Built land	0	2	28	30	49.12	93.33	
	Total	53	410	57	520	91.5385		0.7406
2006	Unclassified	1	0	0	1	-	-	
	Vegetated land	50	14	1	65	94.34	76.92	
	Open land	2	391	19	412	95.37	94.90	
	Built land	0	5	37	42	64.91	88.10	
	Total	53	410	57	520	91.9231		0.77164
2011	Unclassified	1	0	0	1	-	-	
	Vegetated land	51	14	1	66	96.23	77.27	

Time series	Classes	Random Sample Points				Classification Accuracy (%)		
		Vegetated land	Open land	Built land	Total	Producers	User	Kappa Coefficient ($\hat{K}$)
2016	Open land	1	392	13	406	95.61	96.55	0.8192
	Built land	0	4	43	47	75.44	91.49	
	Total	53	410	57	520	93.4615		
	Unclassified	1	0	0	1	-	-	0.7981
	Vegetated land	48	13	3	64	90.57	75.00	
	Open land	4	395	14	413	96.34	95.64	
	Built land	0	2	40	42	70.18	95.24	
	Total	53	410	57	520	92.8846		

5.2.4.3 Raster Overlay and Clipping Process

The classified rasters with the use of the Famagusta Eastern Shore boundary (Figure 10) will be clipped. There are several methods for matching or extracting pixel values from the classified rasters, and each method has advantages and disadvantages. For instance, in some studies, raster registration and re-sampling with the latest raster are preferred (Richards & Jia, 1999, p. 57). Other studies preferred to reduce the edge effects and dissimilar cell size, and to achieve a better fit for curved surfaces using the honeycomb (hexagonal) tessellation (Fuladlu & Altan, 2021).

Since the current study benefits from identical classified rasters, a fishnet (square grid) vector dataset will be generated for the cell size (Table 10). The fishnet vector provides a platform to observe each cell, which aids future comparisons (Figure 14). Accordingly, all the classified rasters were placed over the fishnet, and the result is presented in Figure 12.

2001

2006

2011

2016



Legend

 Open land  Vegetated land  Built land  Varosha Neighborhood

0 2.5 5 10
Km.

Figure 12: The ANN time-series classification

5.3 Dimensions Assessment

Although the required time-series classification was developed by RS and GIS, the classification only partially helped to monitor the sprawl characteristics. Therefore, the limited statistical and census data for the Famagusta region was used to fill the gaps.

5.3.1 Build Density

Build density is a crucial indicator of sprawl. Build density was calculated based on the ratio between the built-up area and the total area of the specific zone. The main criteria for build-density measurements are the residential units and the number of buildings in the built-up areas (Downs, 1999; Reid. H. Ewing, 1997; Frenkel & Ashkenazi, 2008; Galster et al., 2001; Gillham, 2007, pp. 290-291; Torrens, 2008). The built-up area was retrieved from the classification section and its density was calculated using the built-up land ratio (Table 9 and Table 12). The results are shared in Figure 21.

Table 12: Built-up area and annual-growth rate within Famagusta's boundaries

Time Series	Famagusta		Tuzla		Yeni Boğaziçi	
	Built-up area (m ²)	Annual-growth rate (%)	Built-up area (m ²)	Annual-growth rate (%)	Built-up area (m ²)	Annual-growth rate (%)
2001	4,767,300		407,700		209,700	
2006	6,725,700	6.88	877,500	15.33	554,400	19.44
2011	8,085,600	3.68	1,628,100	12.36	1,106,100	13.81
2016	7,926,300	(0.40)	2,592,900	9.31	1,337,400	3.80

The built-up area of Famagusta is summarized in the following stack bar-chart (Figure 13).

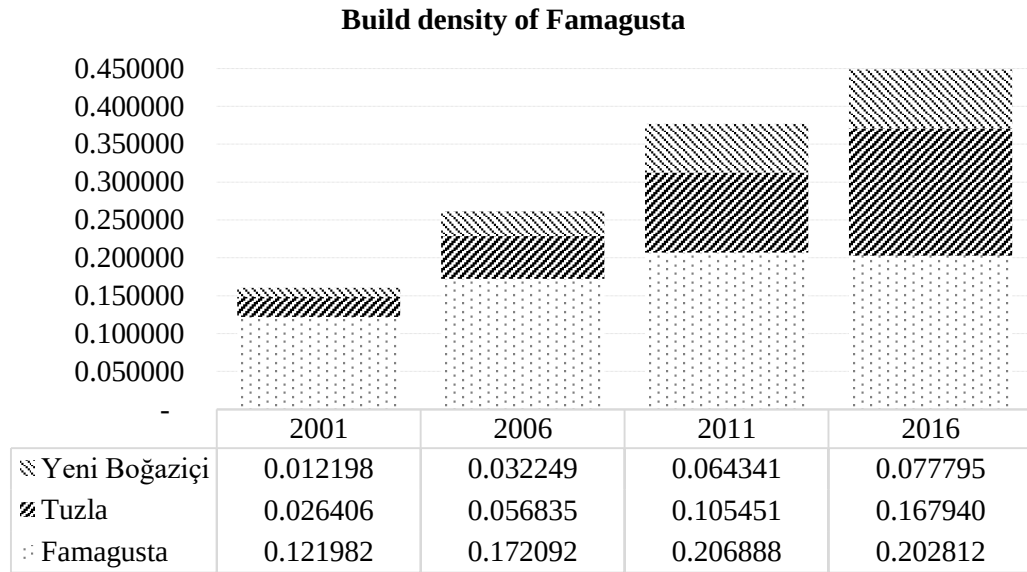


Figure 13: The built-up density in Famagusta

5.3.2 Growth Rate

A lack of development regulations and master plans catalyze sprawl, especially in the study area, while Famagusta's growth rate is an important characteristic for sprawl monitoring. The growth rate can be calculated for any specified place using its initial and current population. For Northern Cyprus, there are only three years (1996, 2006, and 2011) of reliable census data available after the Cyprus conflict (State Planning Organization, 1999, 2007, 2013). This population data partially matched the classification data; therefore, population census data became a basis for projecting the missing years (2001 and 2016). Regression curve estimation was used to estimate the population for 2001 and 2016. Based on the outcomes, the logarithmic model (Equation 2) concerning R-square and significance exhibited maximum conformity (Table 13).

$$f(x_t) = (a \times \ln(x_t)) + d \quad (3)$$

where x_t is the variable of time, a is the estimated parameter, and d is the estimated constant.

Because the modern authority that governs the Famagusta region has never been recognized by any country except Turkey, there are no other international resources, such as administrative records or reports of international organizations, to compare with the estimated population. For this reason, the Root Mean Squared Logarithmic Error (RMSLE) was used (Equation 4) to identify the potential difference between the values predicted by the estimation model and the actual values. The RMSLE was employed to prevent underestimates and overestimates (Table 13).

$$RMSLE = \sqrt{\frac{1}{n} \sum_{i=1}^n (\log(p_i + 1) - \log(a_i + 1))^2} \quad (4)$$

where n is the number of observations, p is the estimated value, and a is the actual value.

Table 13: Logarithmic projection model and parameter/constant estimates

Logarithmic Equation	Model Summary				Parameter Estimates		
	R-Square	df1	df2	Sig.	Constant	A	RMSLE
Famagusta population	1.000	1	0	.000	-13296265.208	1753017.895	
Tuzla population	1.000	1	0	.000	-2343966.894	308505.441	
Yeni Boğaziçi population	1.000	1	0	.000	-1661891.909	218926.387	
Northern Cyprus Motor Vehicle (2016)	.972	1	16	.000	-163190596.200	21487859.358	0.01825

Based on the estimated parameters, the missing population figures were projected and the annual rate of population growth (Equation 5) was calculated as follows:

$$r = \frac{\log \frac{P_{t+n}}{P_t}}{n \times \log(e)} \times 100 \quad (5)$$

where r is the annual rate of population growth, P_t is the population in the current census, n is the number of years between censuses, and e is the base of natural log (with a value of approximately 2.71828...).

5.3.3 Spatial Geometry

The spatial geometry of Famagusta was interpreted based on configuration and composition. At the local scale, with the use of classification (Figure 14) and observations, the composition of the new development was found to be mainly residential in the absence of other land-uses or evident landmarks. Configuration at the local scale could be classified into the following major types:

- a) Linear development, which developed around the main arteries and coastline,
- b) Polycentric development around activity hubs and village settlements, mainly occurring in the form of leapfrogging and discontinuities, and
- c) Infill development, mainly seen at the urban core and inner urban areas.

All types of development gradually lose their density based on their distance from the focal element. From Figure 14, four different patches of geometry on Famagusta's Eastern Shore were taken, observed and described in Table 14. The location of the patches was defined using Figure 3, which was adopted after Ravetz et al. (2013). The configuration of the patches will be defined according to the above-mentioned classes (linear, polycentric, and infill development). Eventually, the composition of the patches will be classified at the city block level based on the 'hierarchic urban land use class system' (Hvidberg, 2001).

Table 14: Analyzing the four geometric patches in Famagusta

Geometry Patches	Location	Configuration	Composition
(a) Blue	Urban Core Inner Urban	Infill development	11, 12, 13, 10, 21, 22, 23, 24, 25, 26, 27, 28, 20, 31, 32, 30, 42, 43, 44, 40, 50, 60
(b) Green	Inner Urban Suburban	Infill development	11, 12, 13, 10, 21, 22, 23, 24, 25, 25, 28, 20, 31, 32, 30, 42, 43, 44, 40, 50, 60
(c) Red	Suburban Urban Fringe	Linear development Polycentric development	11, 12, 13, 10, 21, 22, 23, 26, 28, 20, 31, 32, 30, 41, 42, 44, 50, 60
(d) Orange	Urban Fringe Urban Periphery	Linear development Polycentric development	11, 12, 13, 10, 21, 23, 20, 31, 30, 41, 42, 44, 50, 60

1.Residential	2.Business	3.Mixed residential & business	4.Recreation	5.Underdeveloped	6.Misc.
11.Detached houses 12.Semidetached houses 13.Blocks of flats 10.Misc. Residential	21.Farming 22.Industry 23.Sales & administration 24.Hotels & restaurants 25.Education 26.Health & social work 27.Culture 28.Infrastructure 20.misc. Business	31.Mixed residential & service 32.Mixed residential & industry 30.Misc. Mixed Residential & Business	41.Summer houses 42.Allotment gardens 43.Sport 44.Park & playground 40.Misc. Recreation	50.Underdeveloped	60.Misc.

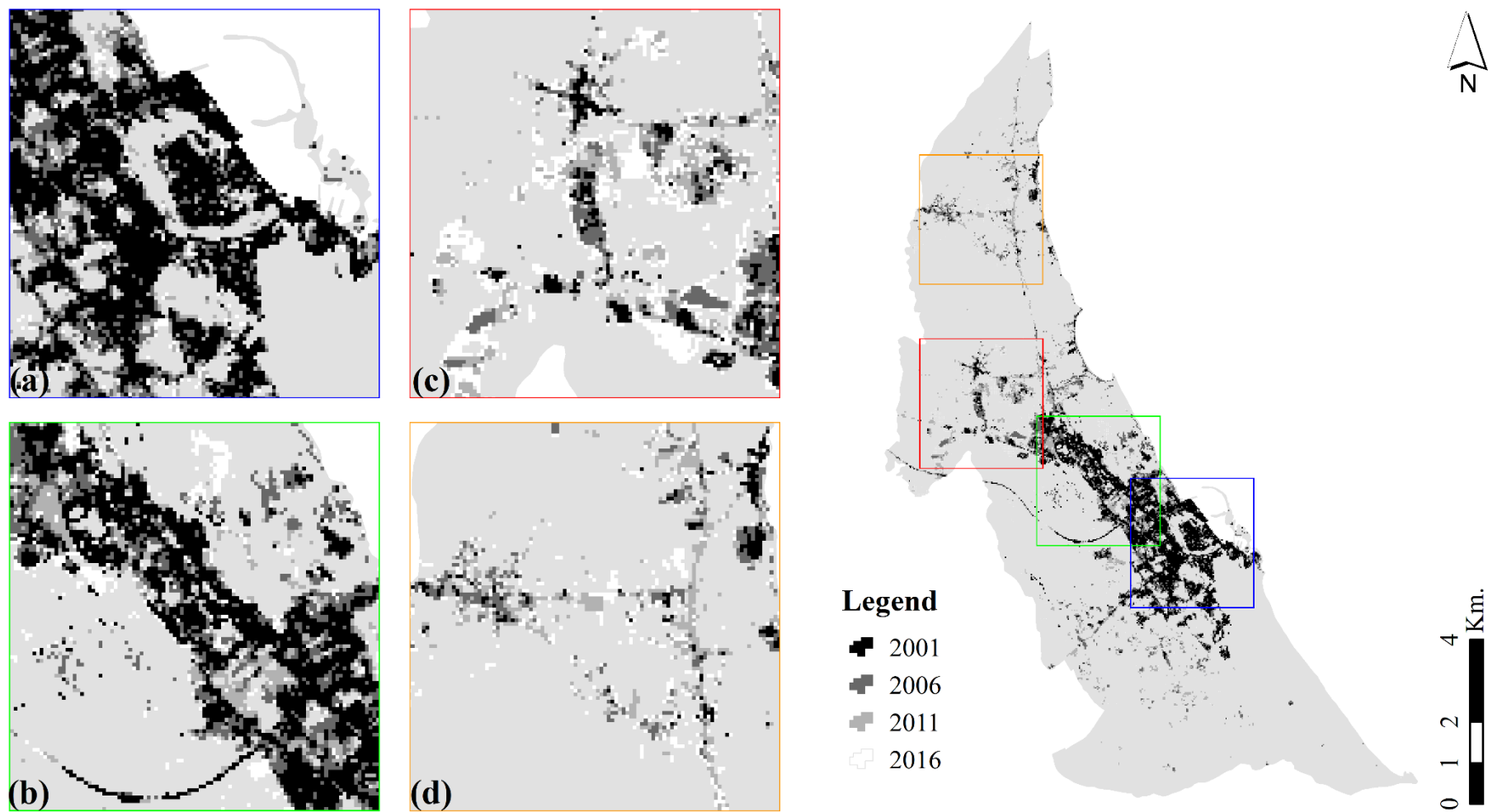


Figure 14: Four different geometric patches in Famagusta

5.3.4 Transportation

The number of registered motor vehicles was used as a parameter for monitoring transportation. The number of registered motor vehicles in the TRNC was retrieved from the published statistical yearbook (State Planning Organization, 2005, 2011, 2016, 2019). Since the registered motor vehicles were not classified by region, the number of motor vehicles registered for the Famagusta region was estimated according to that region's population. According to a 2012 government decision to remove unregistered motor vehicles from government statistics, the number of motor vehicles was projected for 2016 using the logarithmic model (Equation 3). The required parameters and constants from Table 13 were applied and the results are shown in Table 15.

Table 15: TRNC statistics and projected data for transportation

Time-series	Population	License Plate	Gallon Sales		Traffic Accident	Injuries and Fatalities
			Diesel	Gasoline		
2001	222,085*	135,640	12,740,757	15,228,844	2,131	1,250
2006	256,644	207,787	18,102,135	44,490,744	3,403	1,390
2011	286,257	260,084	24,050,926	37,452,724	4,461	1,262
2016	320,047*	307,746**	28,514,105	36,065,597	3,878	644

* The estimated population is due to a lack of census data.

** Estimation of license plates is due to the removal of unregistered motor vehicles from government statistics.

5.3.5 Aesthetic

The aesthetic dimension of sprawl, as mentioned by Frenkel and Ashkenazi (2008) is subjective by definition and therefore complicated to measure and quantify. Nonetheless, sprawl is widely considered as a monotonous and therefore boring kind of development form (Gordon & Richardson, 1997). This can be related to the

buildings' typology and the form of the development itself. As stated by Hess et al. (2001), architecture and aesthetic measurement of sprawl is considering the lack of sidewalks, wide roads, the large setbacks of the buildings from the street as well as the rotational placement in the lot. Moreover, as mentioned by Frenkel and Ashkenazi (2008) and Torrens and Alberti (2000), studies have attempted to define an archetypes of urban development in form of sprawl, considering residential sprawl and strip-mall sprawl development, and trying to compare landscapes with those archetypes.

Since it is clear that the aesthetic assessment of sprawl is a qualitative and subjective process, it was aimed to evaluate aesthetic dimensions related to the discussion in section '4.2.5 Aesthetics', even though it is limited to the author's perspective. The characteristics of sprawl development of the Famagusta suburban area could be used for aesthetic interpretation similar to the arguments gathered under sections '4.2.5 Aesthetics', since the formation of sprawl itself is regarded as an unaesthetical development form. As seen in the below selected pictures of the sprawl area, the new urban development in Famagusta region is mainly in form of grids, occurring surrounding the villages, contrasting the traditional and organic formation of the existing built environment.



Figure 15: Vanora Park at Yeni Boğaziçi by ‘Uzun Group of Companies’

Sprawl development of Famagusta are visible in wide roads and absent of sidewalks, the large setbacks of the buildings from the street together with the rotational placement in the land parcels. Most of the Famagusta sprawl development could be classified as detached, semi-detached, and villa buildings, while the newer development pattern is showing an increase in high rise apartment blocks. From an architectural point of view, there are varies development forms and exterior façades, which are mainly dependent on the personal choice of the building owner or the real - estate companies. The monotonous form of Famagusta sprawl development makes it boring with loss of identity. The development identity can be used to identified real-estate companies as building producer. Additionally, the Famagusta sprawl development shows absent of public open spaces, landmarks, other land uses, and urban design elements.



Figure 16: Ikon Premium Villas at Tuzal by ‘Uzun Group of Companies’



Figure 17: Tuzla village core and sprawl development by Google Earth™



Figure 18: Stilos Villas II at Tuzal by ‘Uzun Group of Companies’



Figure 19: Zodiac City-Virgo Villa at Trikomo by ‘Uzun Group of Companies’

In the Famagusta region, the aesthetic characteristics of sprawl can be summarized as:

- a) The development can be identified as the product of identifiable real-estate companies because each company uses its own architectural language in plan and façade design,

- b) The development can be classified into detached, semi-detached, and villa buildings,
- c) The ‘thematization’ of American sprawl can be observed in the quality of life indicators like vegetation in gardens, decorative elements, swimming pools, barbecues, play areas, garages, open-plan kitchens, front doors and chimneys (Muñoz, 2003),
- d) The development lacks public open space, landmarks and quality pedestrian ways,
- e) The archetype is a residential development with few other land uses, and
- f) The development in wide roads and absent of sidewalks, the large setbacks of the buildings from the street together with the rotational placement in the land parcels.

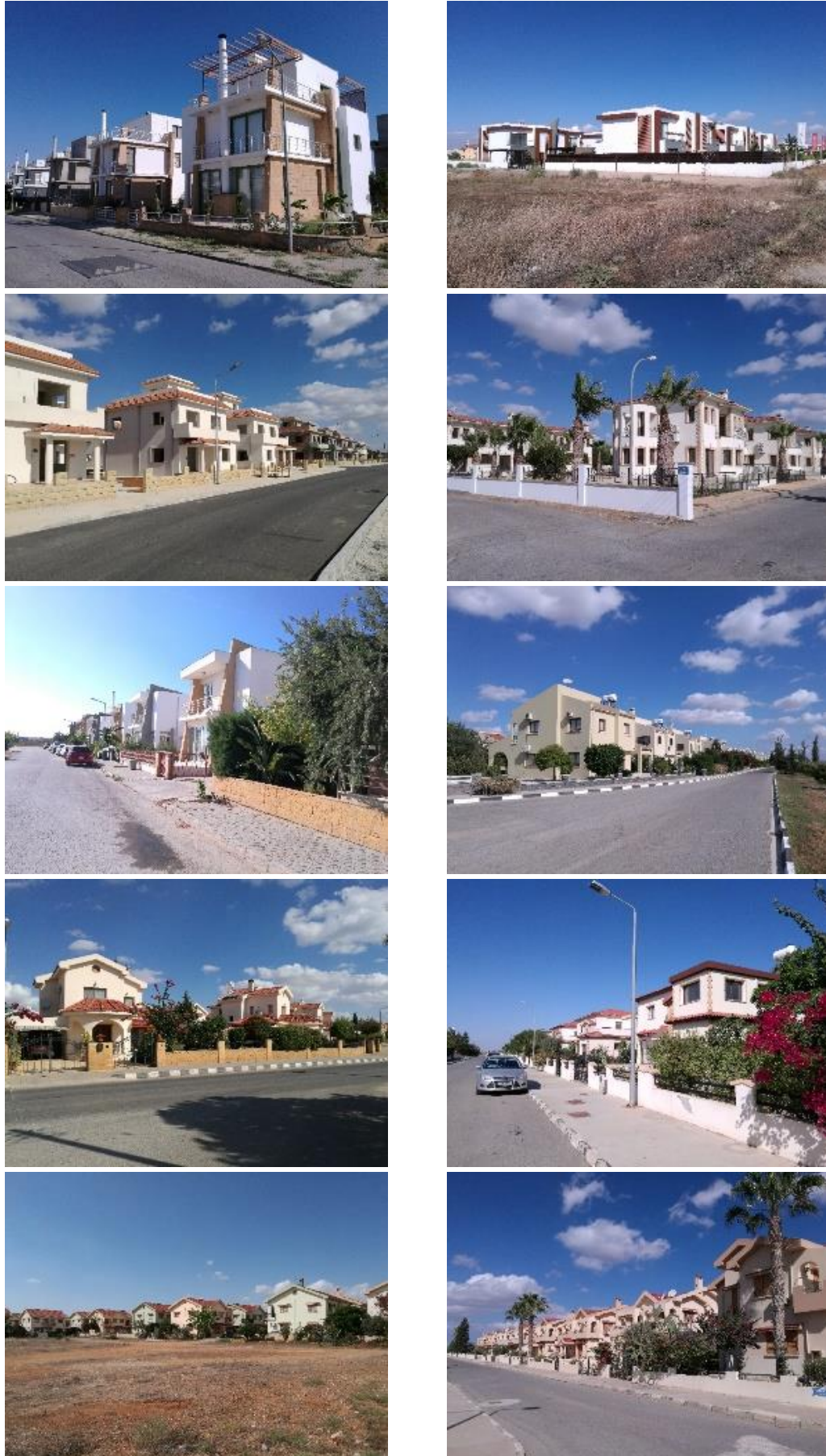


Figure 20: Stereotypical development in Famagusta suburbs

5.4 Discussion and Assessment

The Famagusta population increased with a 2.18% mean annual growth and a total change of 38.68% over the last 15 years (Table 9 and Figure 21). In raw numbers, the population increased from 55,763 (43,756 urban and 12,007 suburban) in 2001 to 77,336 (63,675 urban and 13,661 suburban) in 2016. The rapid population growth significantly affected the growth of the built-up area (Table 12), with the built-up area increasing with a 9.67% mean annual growth rate and a total change of 326.69% for the same period. Therefore, built development increased from 7,176,600 m² (5,856,300 m² urban and 1,320,300 m² suburban) in 2001 to 30,621,600 m² (18,354,600 m² urban and 12,267,000 m² suburban) in 2016. A closer look at the urban and suburban alterations reveals that suburban development growth was four times greater (829.11%) than urban development growth (213.42%), while suburban population growth (13.77%) was three times lower than urban population growth (45.52%).

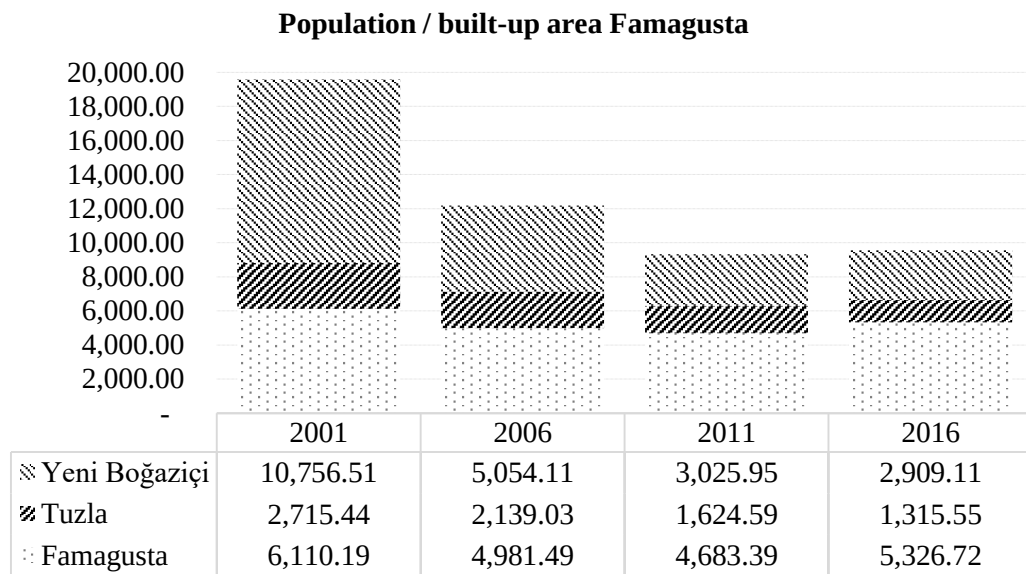


Figure 21: The population/built-up area ratio in Famagusta

Rapid population growth is an instigator of sprawl because the growing population must reside somewhere. Lack of planning regulations in the Famagusta region led to increased suburban development growth. Moreover, suburban development takes advantage of more affordable land prices compared to land in the urban area. The new development has sprawled to the suburban areas of the Famagusta region. The inconsistency between population and development growth significantly affects population density. The overall population density of the Famagusta region (-72.33%) decreased over the past 15 years, with the urban area having -53.57% and the suburban area having -87.75%. Accordingly, the population density decreased from 16,566 per km² total (7,472 per km² urban and 9,094 per km² suburban) in 2001 to 4,583 per km² total (3,469 per km² urban and 1,114 per km² suburban) in 2016 (Figure 21).

The spatial geometry of development was also affected by the absence of regulation. Although development sprawled toward suburbia, the configuration was shaped by factors such as land prices and proximity to the main arteries, the coastline and the hubs. The spatial geometry of development for the Famagusta is linear, polycentric and infill (Figure 14). Development along the Mediterranean coastline towards Yeni Boğaziçi and Yeni İskele is linear, as is development along both sides of the main arteries towards Nicosia. Development around hubs, such as village cores, the university and other well-known real-estate sites, is polycentric. Infill development is mainly seen in Famagusta's inner urban core.

Due to the absence of other land-uses in the composition of new development and the decline of the built area to population ratio, automobile dependency increased in the Famagusta region. Based on Table 15, the number of registered motor vehicles (represented by license plates) increased by 118.35% over the last 15 years (Figure

22). Similarly, the automobile to population ratio for each year is shown increasing below: for 2001, 0.61; 2006, 0.81; 2011, 0.91; and 2016, 0.96.

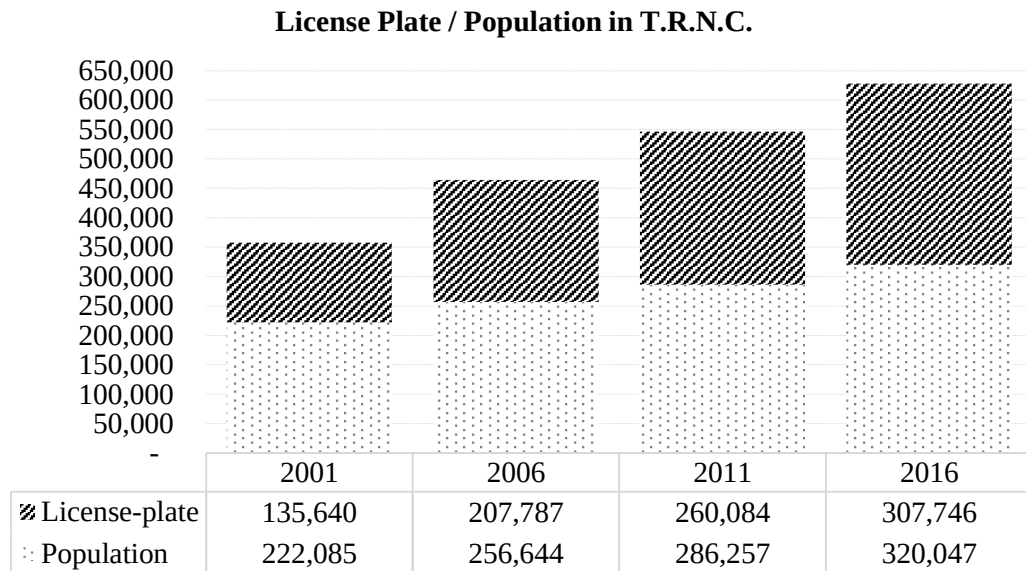


Figure 22: The license plate to population ratio in T.R.N.C

This fact is proved in Table 15 by checking the fuel consumption, which has increased 8.73 percentage in 15 years (Figure 23).

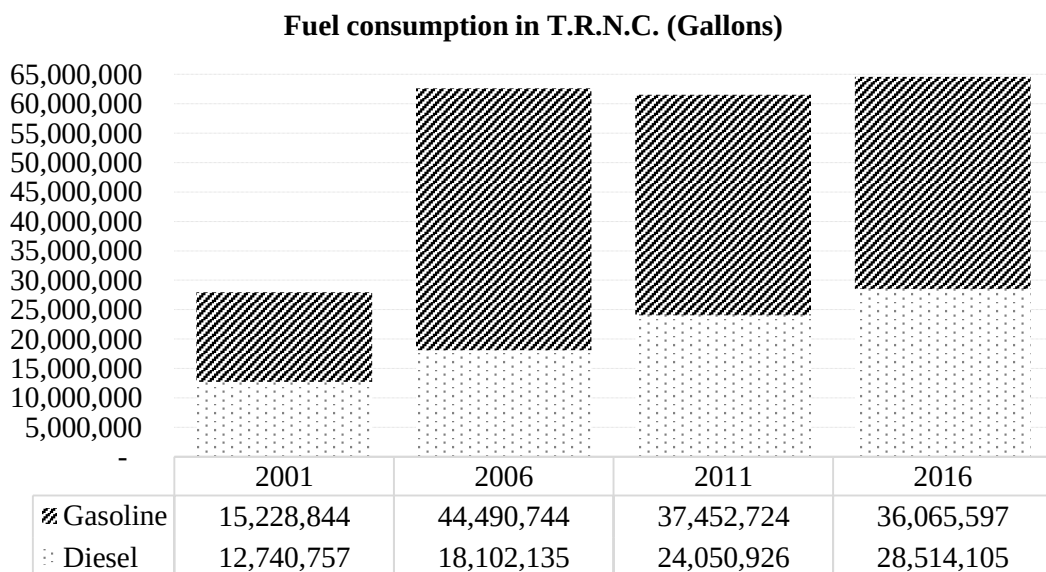


Figure 23: The fuel consumption in T.R.N.C. (Gallons)

Relatedly, the Famagusta region suffers a lack of public transportation, which likely adds to automobile dependency. The declining build area to population ratio and lack of mixed land-uses also have an effect (Schimek, 1996), because low-density and single-use development also increase automobile dependency (Fuladlu, 2020).

5.5 Famagusta Sprawl in Relation to Euro-Mediterranean Sprawl

This section interprets the sprawl features for Famagusta with the recent Euro-Mediterranean studies, which were presented earlier in Table 6. Many commonalities were found. They are itemized below:

- a) According to Muñoz (2003), Euro-Mediterranean sprawl is the ‘thematization’ and commodification of residential space. The development future provides ‘semi-detached’ landscapes that are safer, more protected, and watched-commodified. Based on my observations and Figure 20, these features are visible in the case of Famagusta as well, whose development is mainly detached and semi-detached, with proliferation and commodification of residential space.
- b) Catalán et al. (2008) argue that in the case of Barcelona, large amounts of bare urban land are still available for further development. Extensive land occupation causes damage to agricultural and forest lands, and declining urban density. These could be the main signs of current urban transformation and strong indicators of a new direction for urbanization. However, this study is limited in its monitoring of agricultural and forest land-cover. Nevertheless, according to Figure 12, a considerable amount of open land is devoted to the creation of built land. The built-up density in the study area increased, but the population to built-up area ratio (Figure 21) significantly decrease.

- c) A study on Messoghia Plain concluded that Messoghia tried to address the lack of urban infrastructure delays and the stimulation of economic development. However, formal comprehensive planning structures were not involved in this effort. Therefore, the dynamics of spatial reformation interventions in Messoghia resulted in sprawl. In the case of Famagusta, a lack of planning, together with the enactment of the UN peace plan (Annan, 2004), have resulted in sprawl development.
- d) Salvati and Sabbi (2011), Salvati et al. (2012), and Salvati et al. (2013) analyzed the LULC transformation of the Rome and Attica. They found that sprawl negatively affects the agricultural and cropland of the urban fringe. Likewise, forest land transforms into cropland and pasture lands. As stated earlier, the current study is limited in its monitoring of LULC. Nonetheless, according to the Figure 12, a considerable amount of open land and vegetated land were devoted to the creation of built land.
- e) Lagarias (2012) used the Cellular automata model to study Thessaloniki, for which Greece expected low-density sprawl development until 2030. Thessaloniki needs strict land-use regulations to protect natural and agricultural areas. This is also true of Famagusta, as Figure 12 shows the loss of open and vegetated land between 2001-2016. Planning regulation is required to preserve Famagusta's natural and agricultural areas.
- f) Salvati (2013), examining Greece, highlighted that socio-economic changes caused by tourism development and house speculation led to recent urban development. Furthermore, a low-diversity landscape with relatively high land availability encourages development along the coastline. An increase in the residential population and number of 'second home' settlements affects the

fragile and fragmented landscape and possibly stimulates soil and land degradation. Similarly, in the case of Famagusta, extensive investment in education and policies for attracting capital by granting residence permits to foreigners result in increasing the residential population and the number of 'second home' settlements. Therefore, sprawl development appears along the main arteries towards Nicosia and along the coastline towards Yeni Boğaziçi and Yeni İskele.

- g) Chorianopoulos et al. (2014), investigating Messoghia Plain, emphasized that prioritizing rapid economic growth over sustainable development eventually results in sprawl. In the case of Famagusta, Kara and Doratlı (2021) realized by evaluating LULC for 2002 and 2011 that Famagusta's development is not sustainable. This may be attributable to the lack of development planning or a master plan for Famagusta.
- h) Colantoni et al. (2016), who studied Athens, concluded that regional economic developments and the emergence of new urban forms, including sprawl, social fragmentation and economic polarization, indicate that urban land-use dynamics lead to dramatic change. Therefore, exurban areas are examples of land-cover changes and landscape rearrangements along the urban-rural dynamics due to the dynamic human pressure they experience. It is certain that sprawl development in Famagusta's exurban area significantly affects the rural area. This can be seen in other types of activity, such as the opening of new supermarkets and grocery stores in the rural area.
- i) Cuadrado-Ciuraneta et al. (2017) looked at Catalonia and emphasized a turning point for response to these socio-economic dynamics, which result in housing demands, different types of mobility, and latent changes in the tourism pattern.

This phase was marked by new, low-density settlement development, reflecting the failure of traditional offshore compact patterns. Eventually, the new development configuration results in the breakdown of traditional villages and the creation of urban centers related to tourism and ‘second home’ developments. In the case of Famagusta, auto-dependency, land prices for the exurban area and policies for attracting capital through granting residence permits to foreigners result in increasing the resident population and ‘second home’ settlements.

- j) Lagarias and Prastacos (2018), by comparing the urban form of southern European cities using fractal dimensions, found that fractal dimensions are higher when sprawl is relatively continuous and homogeneous than they are in areas with elongated sprawl forms or in exurban areas exhibiting discontinuous sprawl. According to Figure 14, in Famagusta, both types of geometry (continuous and discontinuous) are visible. Therefore, it is likely that both high and low fractal dimensions occur in exurban areas.
- k) Cecchini et al. (2019) considered olive cultivation, water demand increases and land degradation in Attic suburbs due to increasing conflicts over soil and water resources. Taking a socio-ecological perspective demands that environmental impacts should be monitored extensively. The current study is limited to considering horticulture and agriculture production and their impacts on soil and water resources.
- l) Salem et al. (2020) used Landsat 5 and Landsat 8 images to identify the spatial trends of LULC changes and visualize the transformation in LULC. Based on the findings, LULC change processes, especially urban sprawl, have directly affected natural resources and particularly agricultural land. The results of this

study were similar to the results of previous research in Mediterranean cities. Since most of the urban sprawl was scattered and occurred in the outer boundary of the villages or cities. In the case of Famagusta, sprawl development by transferring the natural resources and agricultural lands impact to the natural environment. Moreover, Famagusta sprawl development like other Mediterranean cities occurred in the outer boundary of the villages or cities.

m) Balta and Atik (2022) by observed of Google Earth satellite images in case of Turkey found that, urban sprawl result in deterioration of the traditional land use patterns and decrease of farming activities. This study believed that, unique rural and cultural landscape characteristics of the region will be becoming vulnerable due to the effects of irreversible urban sprawl. There is no doubt that, Antalya scenario could be valid for case of this study (Figure 12 and Figure 13) if sprawling continue.

As a summery, there are many similarities between other Mediterranean cities and case of Famagusta. For sure new development of Famagusta are mainly detached and semi-detached, with proliferation and commodification of residential space. Additionally, Famagusta, auto-dependency, land prices for the exurban area and policies for attracting capital through granting residence permits to foreigners result in increasing the resident population and ‘second home’ settlements. Furthermore, lack of planning and regulation bootstring sprawl development, which has negatively impacts on agricultural land and natural resources.

5.6 Postface to Sprawl Monitoring

The current study takes significant steps for monitoring sprawl in the Euro-Mediterranean city of Famagusta. Sprawl monitoring is a crucial process in city planning and especially LULC management, which provides a fundamental basis for planning by guiding the decision-making process. Therefore, many studies and planners have developed detailed models for monitoring sprawl. Monitoring sprawl explores different aspects of the further development and expansion of the city. There is no doubt that monitoring the city growth and sprawl should be considered on different scales from local to regional due to the socio-economic impact.

This study, by monitoring sprawl for the period of 2001 to 2016, provides a long-term base for future planning drafts. It depicts Famagusta's sprawl on a local scale by using the dimensions of build-density, growth rate, spatial geometry, transportation, and aesthetics. In light of the technology monitoring process of the sprawl becomes moderate.

The role of technology in moderating the monitoring process is significant, and this study found the technological tools available to be helpful. It helps counter the limitations experienced by this study, alleviating its dependence on high-resolution datasets, including census, statistical data and census tracts. These benefits also apply to developing countries that lack high-resolution datasets including census, statistical data and census tracts.

Chapter 6

CONCLUSION

6.1 Brief Overview

Rapid population growth and a lack of regulation result in sprawling development in suburban areas. Sprawl is a multi-dimensional phenomenon that negatively affects the sustainability of urban development. There remains no standard definition for sprawl or its dimensions, impacts and drivers. Sprawl's definitions vary from place to place, to the extent that North American sprawl characteristics do not match those of Northern-Western Europe or the Euro-Mediterranean cities. Monitoring urban sprawl is a controversial topic among scholars. Ways of monitoring sprawl have been extensively discussed by researchers, and various studies and methods have been developed and applied in North American and Northern and Western European cities. Some sprawl-monitoring methods are based on principle components, relevant metrics, or particular tools like RS and GIS. Although numerous methods have been applied with great success in various countries, they are mostly inapplicable to Mediterranean and developing regions, lacking reliable census data. For the most part, these were developed by considering the conditions of developed countries where census and high-resolution statistical datasets are available. Moreover, the majority of available methods are structured in complex ways that make them difficult to apply to developing countries. The complexity of the methods also makes them difficult to perform in underfunded situations. This study, therefore, aims to develop a new multidimensional method that researchers and planners can apply readily in Euro-

Mediterranean cities and developing regions. The method was structured based on a time-series (2001, 2006, 2011, and 2016) dataset that used remote sensing data and geographical information systems to monitor the urban sprawl.

An extensive literature reviews on sprawl dimensions depict that, regardless of the sprawl location, the dimensions of sprawl are often very similar. In short, dimension of sprawl which are used at American and European cities could be used in case of Mediterranean cities. This study used a time-series approach to consider the five characteristics of sprawl in the Famagusta region. According to the study results, rapid population growth led to a construction boom over the 15 years between 2001-2016. The absence of a master plan fostered an uncontrolled development pattern that eventually resulted in sprawl. The configuration of the sprawl in Famagusta is polycentric and linear with single-use composition. The polycentric development formed around the rural villages and activity hubs, whereas the linear development occurred along the main transportation arteries and the Mediterranean coastline. The population growth was predominant in the urban areas, while the construction boom responded to cheap land prices in suburbia and the urban periphery. Relatedly, the population density in suburbia significantly decreased compared to that of the urban area because of the abundant construction. Although build density increased, single-use composition in Famagusta and its outskirts facilitated automobile dependency, which further enabled sprawl once most of the population had cars. Additionally, the lack of public transportation served as a catalyst, exacerbating automobile dependency.

The study's methods are applicable to responding to sprawl as an urban planning problem. This study was conducted based on the belief that monitoring sprawl is a preliminary step toward minimizing its negative impacts. This study affirms that

sprawl monitoring can be conducted in developing countries despite insufficient census and statistical data as it is possible to perform other types of sprawl analysis. Moreover, Auto dependency is not an issue as Famagusta city does not provide sufficient public transportation for the inner city as well. it means that, commuting to sprawl regions or city center has same cost for the Famagusta resident.

6.2 Recommendations for Future Study

This study attempted to take the first step in monitoring sprawl in cities lacking census data. As such, it is the first study of its kind. Future studies will be required to consider the environmental and socio-cultural aspects related to sprawl's highly scattered development patterns in Famagusta and other developing and developed places. Beside, since this study was limited to considering the sprawl consequences, this could be important to considering the consequences of sprawl by futures studies.

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APPENDIX

List of Exonyms

Agios Sergios	Yeni Boğaziçi	Άγιος Σέργιος
Cyprus	Kıbrıs	Κύπρος
Deryneia	Derinya	Δερύνεια
Enkomi	Tuzla	Έγκωμη
Famagusta	Gazimağusa	Αμμόχωστος
İskele	İskele	Ισκέλε
Larnaca	Larnaka	Λάρνακα
Lefkoniko	Geçitkale	Λευκόνοικο
Limassol	Limasol (Leymosun)	Λεμεσός
Lysi	Akdoğan	Λύση
Mediterranean	Akdeniz	Μεσόγειος
Nicosia	Lefkoşa	Λευκωσία
Paphos	Baf	Πάφος
Trikomo	Yeni İskele	Τρίκωμο
Varosha	Maraş	Βαρώσια