Simulating Sustainable Urban Growth by Using GIS and MCE based CA. The Case of Famagusta, North Cyprus

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ABSTRACT

This thesis utilizes “Geographical Information Systems” (GIS), “Multi Criteria Evaluation” (MCE) with “Cellular Automata” (CA) for simulating Sustainable urban growth scenarios for Famagusta and represents “Do Nothing” and “Sustainable” scenario-based spatial simulations of the City.

Under Do Nothing scenario, Markov Chain probability analysis with CA models is used with temporal land use datasets based on the images from 2002 and 2011. It shows that, Famagusta is diverging from sustainable development. Future expansions of both medium dense and low dense urban zones are generally sited close to the existing built-up urban areas that are connected with road network. A similar model is employed for the application of Sustainable Urban Development policies by Policy Driven Scenario. As a main goal, Sustainable Urban Development includes three main criteria, Compactness, Environmental Protection and Social Equity. Additionally, Brownfield Development, Distance from Center, Soil Characteristics, Soil Productivity, Vegetation, Environmentally Protected Areas, Distance from Local Services, Distance from Open Space are used as criteria with Analytical Hierarchy Process (AHP).

Having such a simulation with the combination of MCE, GIS and CA has several advantages. It presents possible alternative spatial development for the future. Moreover, it makes decision making steps easier for town planners and support spatial planning process. Finally, it creates more realistic results of our choices are related to urban growth.

Keywords: Sustainable Urban Development, Geographical Information Systems, Multi Criteria Evaluation, Cellular Automata

ÖZ

Araştırma Coğrafi Bilgi Sistemleri(CBS), Çok Kriterli Değerlendirme(ÇKD) tekniklerini Hücresel Otomasyon(HO) ile kullanarak Gazimağusa Kenti için sürdürülebilir senaryoların simlasyonunu ortaya koyar. Bu çalışma Gazimağusanın ilk “Mevcut’un Devamı” ve “Sürdürülebilir” senaryo-tabanlı mekansal simülasyonları sunar.

“Mevcut’un Devamı” senaryosu altında, 2002 and 2011 yılı görüntülerden çıkan zamansal arazi kullanım veri setleri kullanılarak Markov Zinciri olasılık analizi ve Hücresel Otomasyon modelleri uygulanmaktadır. Bu senaryo göstermektedir ki Gazimağusa şehri sürdürülebilir gelişme sürecinden uzaklaşmaktadır. Gelecekte büyüyecek düşük ve orta yoğunluklu kentsel alanların yalnızca yol ağına erişime sahip mevcut yapılaşmış alanların yakınında yer seçtiğini ortaya koymaktadır. Benzer model politika tabanlı senaryoları kullanan sürdürülebilir kentsel büyüme modeli için de uygulanmaktadır. Ana hedef olarak, sürdürülebilir kentsel büyüme; kompakt büyüme, çevresel koruma ve sosyal eşitlik olmak üzere 3 temel kriter içermektedir. Bunlara ek olarak çöküntü alanlarının gelişimi, merkeze yakınlık, toprak yapısı, toprak üretkenliği, bitki örtüsü, çevresel koruma alanları, yerel hizmetlere yakınlık ve açık alanlara yakınlık mekansal kriterlerini Analitik Hiyerarşi Prosesi(AHP) yöntemi ile birlikte kullanmaktadır.

ÇKD, CBS ve HO kombinasyonu şeklindeki bir simulasyonunun bazı avantajları bulunmaktadır. Simulasyon gelecekteki alternatif mekansal büyümenin olası sonuçlarını göstermektedir. Dahası karar verme sürecini basitleştirerek mekansal planlama sürecini desteklemektedir. Sonuç olarak kentsel büyüme ile ilgili seçimlerimizin sonuçlarını daha gerçekçi bir şekilde göstermektedir.

Anahtar Kelimeler: Sürdürülebilir Kentsel Gelişme, Coğrafi Bilgi Sistemleri, Çok Kriterli Değerlendirme, Hücresel Otomasyon

To My Family

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AHP: Analytic Hierarchy Process

AI: Artificial Intelligence

CAD: Computer Aided Design

DSS: Decision Support Systems

EMU: Eastern Mediterranean University

GIS: Geographic Information Systems

GUI: Graphical User Interface

GPS: Global Positioning System

PSS: Planning Support Systems

RS: Remote Sensing

SAW: Simple Additive Weights

SIDS: Small Island Developing States

SDSS: Spatial Decision Support Systems

INSPIRE: Infrastructure for Spatial Information in Europe

MCE: Multiple Criteria Evaluation

WLC: Weighted Linear Combination

Chapter 1

INTRODUCTION

It is well known that, after the publication of “Our Common Future” the concept of sustainability has become an important concern in development literature and has been tried to be applied in all fields of economic activities, in many countries (WCED, 1987). As a result of the Agenda 21 and the Barbados Conference in 1994, there has been evidence that various policies, programmes and measures were developed for Small Island Development States (SIDS), and they are trying to improve the integration of development policies with sustainability.

Particularly Agenda 21 strongly emphasizes that SIDS are extremely fragile integrated special systems. Because of their small size, limited resources, and isolation from markets, future development needs to be focused on alternative and integrated planning options, which protects the environment in the long term and creates economical benefits for local communities simultaneously which is called sustainable development. Moreover, land is a limited resource and it should be used for providing sustainable futures. Land use planning is a process which can ensure that by achieving efficiency (UN, 1992).

> “Planning for Sustainable Use of Land resources has as its basic purpose to ensure that each area of land will be used so as to provide maximum socio-economic benefits without degradation of the land resource. Sustainable Land use Development, which ensures the use of land resources in an organized manner so that the needs of the present and future generations can be best addressed” (FAO, 1995).

Therefore, it is necessary to develop integrated land use planning support tools or systems that can deal with land use suitability assessment, land use change analysis in definite period, land use assessment, land use allocation and overall sustainability assessment, which is emphasized by different researchers.

Integrated land use planning process should be combined with European Spatial Development Perspective (ESDP). ESDP promotes spatially balanced and equal distribution of the land use features functions. Therefore, it is necessary to adopt spatial planning policies for achieving planning and management in urban environment. This step requires using spatial planning as main strategy and supports it with land use planning policies.

Geographical Information Systems based planning support tools and urban growth modelling techniques have been widely used in recent years for dealing with the decision making process and planning support. Yong et al. has introduced the “Integrated GIS based Analysis System” (IGAS) model that addresses land use suitability, change, and evaluation and allocation assessment for Lake Areas (Liu, et al., 2007).

Alshuwaikhat and Nassef (1996) developed a Spatial Decision Support System (SDSS) for managing and planning land resources of City Beish, in Saudi Arabia. SDSS includes a model for land use suitability analysis and allocation. It shows an example of implementation of GIS techniques that a wide approach is required for land use management (Alshuwaikhat & Nassef, 1996).

What-if as the combination of Decision Support Systems (DSS) Planning Support Systems (PSS) for Sustainable Development have been suggested by different researchers for supporting decision-making process in planning field and sustainable development (Pettit, 2005;Asgary et al., 2007;Li, 2003).

Beinat and Nijkamp (1997) also proposed several scientific research techniques that help for developing proper methodology to have sustainable land use planning at urban level. For example, CA, Scenario Analysis or geographical information analysis are proposed for this purpose (Beinat & Nijkamp, 1997).

Furthermore, CA has been broadly utilized for modeling of urban growth and urban forms under future scenario alternatives. (Batty & Xie, 1994;Wu, 1998;Yeh & Li, 2001;Zhang et al., 2011;Vaz et al., 2012)

Wu (1998) developed a SimLand prototype that uses GIS and CA with AHP to simulate land conversion in Guangzhou, China. This prototype creates compact growth, highway-promoted growth scenario alternatives and analyzes different future development alternatives (Wu, 1998).

Zhang et al. (2011) use Markov chain analysis within CA to present Shanghai's urban growth. This model simulates landscape changes within three different scenario frameworks such as "baseline", "Service Oriented Center", and "Manufacturing Dominant Center" (Zhang et al., 2011).

Vaz et al. (2012) suggested combining urban development modeling with MCE for the Algarve in order to assist for choosing the optimum development alternative for the case keeping sustainability as input development policy (Vaz et al., 2012).

These methods and GIS based applications show the extensive usage of geo-information technologies in various areas such as regional planning, urban planning, environmental management and etc.

In conclusion, these systems have been fundamental instruments in developing quantitative prediction, modeling and spatial analysis. Therefore, possible future growth simulation and analysis can safely be applied for supporting the sustainable urban development of Famagusta.

1.1 Problem Definitions

Famagusta is one of the SIDS cities and its urbanization process has dramatically accelerated since Eastern Mediterranean University was established in 1986. As a result, unorganized and uncontrolled vast urban development has started to consume land resources by incompatible planning policies and decisions. The city has experienced enormous changes in population, demographic composition, economy and culture by the foundation and growth of the "Eastern Mediterranean University" (EMU) (Oktay & Rüstemli, 2011). By its economic input the city has started to change its fate and experience a rapid development, which continues in acceleration (Aksugür, 2005).

Due to the traditional (conventional) planning approaches, lack of land use planning prints such as master and physical plans, old legal framework and inefficient departments unfortunately it is not possible to control vast development in the city. Moreover, significant physical barriers which include the closed Varosha, the Limni Forest and the military bases have encouraged urban growth towards the University and beyond, which supports urban sprawl and suburbanization. Furthermore, a new university development near Varosha area may increase the rapid urbanization in Famagusta.

In addition to the significant changes mentioned above, particular problems related to land use development in Famagusta city can be highlighted as follows:

-Irregular urban development and site selection of land use functions which generates land degradation and loss of primary agricultural lands

-Piecemeal and fragmented growth particularly in housing environments, which is a continuous sprawl of urban development towards the periphery of the urban area

-Housing Project Investments without determination of demand for housing growth and land suitability options based on different future development strategies

-Spontaneous Social Housing Project Investments without determination of demand for housing growth and land suitability options based on different future development strategies

-Lack of Brownfield or Infill development projects which support compact and rational urban growth

-Lack of methods and information assessing sustainability level for alternative land use development patterns.

Therefore the main problem definition of the study can be given as;

"*Urbanization practices in Famagusta have been diverging from spatially sustainable urban development*". It is obvious that urgent policies and action plans need to be established immediately in order to form an integrated planning approach and model for managing sustainable use of land resources and achieving the spatial sustainable growth in Famagusta.

1.2 Aims and Objectives

Within the framework mentioned above, this research generally aims to suggest a model which predicts and simulates the urban growth of Famagusta using an integrated GIS, MCE and CA model under two different development scenarios. Due to the time limitation and related constraints, this research intends to focus on establishing a model and implementing it to one case study; Famagusta. The model for the case study is expected to be used for further studies in related field. Within the general aim of the study, the aims and objectives are determined as follows:

• To search for the reasons behind the uncontrolled and unorganized land use development process in Famagusta,

• To develop a model based on planning support tools for Integrated Land Use Planning approach,

• To assess land use suitability and land use change for creating future land use development alternatives by using planning support tools,

• To develop and simulate "**Do Nothing**" and "**Sustainability"** oriented future development scenarios by using MCE and CA,

• To develop land-suitability analysis for different land use classes such as Low-dense urban, medium-dense urban, university, industry, and etc. Using MCE

• To increase sustainable urban development level in Famagusta to find clues for better urban management and planning practices in the future.

1.3 Research Hypothesis and Research Questions

In order to achieve the aims defined above, this study searches for a model to predict and simulate alternative futures for sustainable development of Famagusta. Moreover, as it has been discussed before, there is a strong relationship between GIS based planning support tools or systems and sustainable development.

At this point, the initial research hypothesis can be set as:

"GIS based Planning Support Systems is the most reliable way to suggest a sustainable spatial growth for cities"

Figure 1.1: Main Hypothesis Framework

With reference to hypothesis, this research addresses the following four questions:

-What is the relationship between spatial planning and sustainable development?

How can we use/integrate GIS and CA tools as a PSS tool in sustainable urban development?

-Which urban growth modelling tool is the most suitable for sustainable urban development?

-How can we create a model assessing the suitability for urban growth for different scenario alternatives?

Finding answers to these questions will establish the general framework and lead in testing the general hypothesis and answering the main research questions. From this perspective, thesis methodology and structure are constructed by following sections.

1.4 Research Methodology

The research methodology involves both qualitative and quantitative survey methods. These are based on literature survey, documents survey, interviews and case based spatial data analysis. Moreover, GIS and CA based desktop applications will be used for urban growth prediction and simulation. Methodology of the research starts with reviewing sustainable urban development policies and GIS based Planning Support Tools. These are integrated to reach urban level simulation for supporting decision making process. Methodology of the research can be organized under the following stages as given Figure 1.2:

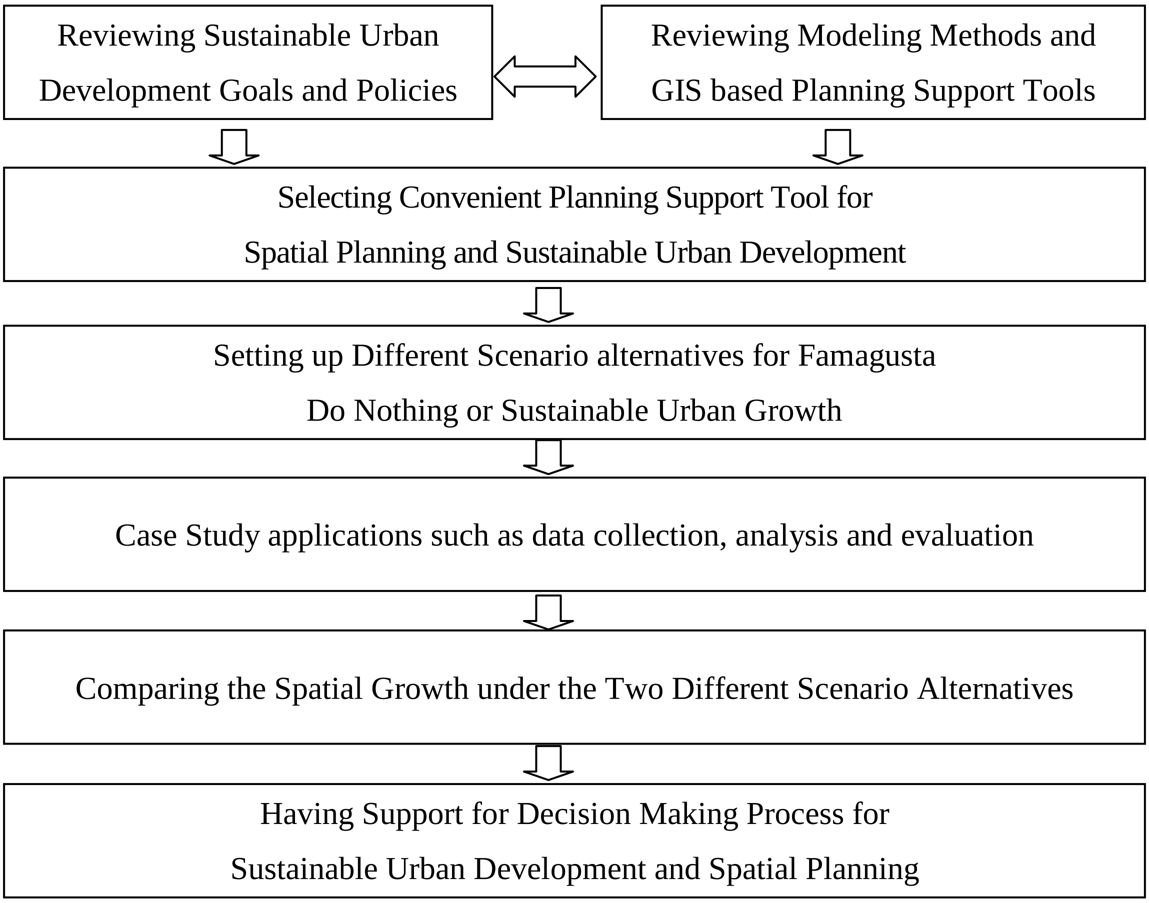


Figure 1.2: Methodology Framework of the Study

As given above, the research starts with the literature review of sustainable urban policies and it continues with the selection of the proper methodologies to represent urban growth policies to reach spatial sustainable futures within the case area. Therefore, GIS based spatial growth methods will be compared within this framework. CA is selected through the comparison process due the it's data availability, linkage with GIS and interpretability which helps decision makers to presents any choice or any spatial urban policy with digital simulation.

Different scenarios perspectives, policies and spatial growth tendencies are analyzed for the case area by having interviews with local experts. Problems are related to existing situation that forms spatial growth are presented by interviews. They also propose and construct understanding Sustainable Urban Growth Policies. Therefore, two different scenario alternatives selected as "Do Nothing Scenario" and "Sustainable Scenario". In order to present different scenario alternatives for the future in CA digital environment, MCE method is used to present GIS based planning choices of the experts related to the case study. AHP is also implemented as a core technique to present experts' choices within this process. Experts mainly will be selected from different departments such as such as Town Planning, Geology and Mining, etc, Gazimağusa (Famagusta) Municipality and EMU. They compare urban growth factors by deciding higher and less importance ones to each other. To employ this process well-know pair-wise comparison method will be realized by conducting interviews (see Appendix 1). These results combined with the factor maps by using Weighted Linear Combination (WLC) and converted to suitability maps based on scenario objectives. Detailed explanation about process will be given in section 3.4.

1.5 Research Structure

Thesis structure is given by Figure 1.3 and organized under five chapters. General policies for Sustainable Development and Sustainable Urban Growth in planning field are stated in Chapter 2. GIS based technologies, GIS based analysis technique and the establishment of hybrid spatial decision support tools such as GIS and CA concepts are introduced in Chapter 3. In Chapter 4, Famagusta case study illustrates the use of GIS and CA with Sustainable Urban Development alternative through a practical example. In the final 5th Chapter, the concluding remarks of GIS and CA model approach and evaluation of case study research findings are underlined.

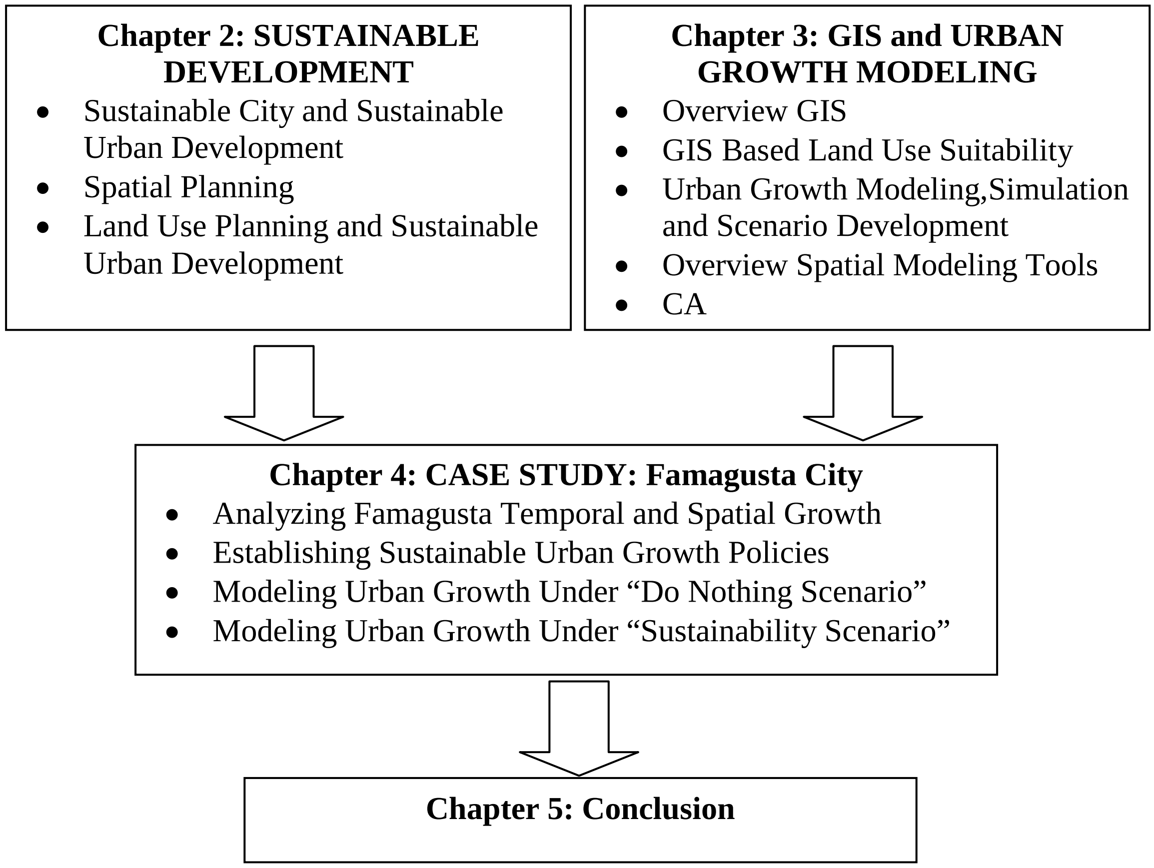


Figure 1.3**:** Thesis Outline

Chapter 2

SUSTAINABLE CIY AND SUSTAINABLE URBAN DEVELOPMENT

The main definitions and principles of sustainable city and sustainable urban development are explained briefly in the beginning of the study according to the study context. Additionally, the importance of land use planning is given within the study framework.

2.1 Sustainable City

Urban areas in Europe face many environmental challenges such as air pollution, traffic congestion, urban sprawl, and generation of waste and waste water. These can cause environmental damage and affect human health which is not fitting with EU's sustainable city concept.

European Commission recognizes that cities have a crucial role in achieving sustainable development. 70% of the European Country's people live in urban areas. Moreover, 70% of the emissions in Europe come from cities. As urban planners, we are responsible to find a way to achieve sustainable development within the urban areas.

European Conference on Sustainable Cities and Towns held in Aalborg, Denmark was organized on 24 to 27 May 1994 and Aalborg Charter was approved in this conference. This charter presents crucial sustainable urban development policies.

Relative planning and urban design targets from this charter are given as follows (EEA, 1995);

- Reusing and regenerating derelict or disadvantaged areas.
- Avoiding urban sprawl by improving appropriate urban densities
- Implementing Brownfield site over Greenfield site development
- Ensuring mixed use of commercial, leisure, administrative and housing use in city centers
- Providing proper protection and restoration of urban cultural heritage.
- Applying requirements for sustainable design and construction

European Union and Council of Europe also handled sustainable urban development as an important concept. European Union declared the sustainability in its main policies and also gave importance to the cities and urban development. The union's interest on environment started in 1970s, but the term 'sustainability' was first seen in the main policies in 1992 in the Treaty of Maastricht. Additionally, it was the first time that a spatial policy in European Union level was seen.

Another step of European Union on this concept was the 5th Environmental Action Program which was called 'Towards Sustainability' in 1993 and the other crucial document of the Union on sustainable development is Aalborg Charter, 1994. Sustainability is seen as a local process in this charter which is 'Charter of European Cities and Towns: Towards Sustainability'. It is related with the management of the city and the urban ecosystem balance. In this management process the decisions are also representing the interests of both current and future generations (EU, 1994)

The next important event in European Union History about sustainability is Cardiff European Council in 1998, which the integration of all policies with environment was underlined. The council stated that “our economies must combine prosperity with protection of the environment. In addition, Göteborg European Council (2001) was the council in which the formation of an international sustainable development pact was decided. The Council agreed with a strategy for sustainable development, which its strategy was renewed in 2006, because of the negative and unsustainable trends in relation to climate change, energy use, public health, poverty, social exclusion, demographic pressure and ageing, management of natural resources, biodiversity loss, land use and transport.

“Leipzig Charter on Sustainable European Cities” (May, 2007) is also an important charter of the European Union. The concern on sustainability of the European Union includes some networks and organizations such as EUROCITIES and METREX, and some tools such as INTERREG III, URBAN II and LEADER+ (Yazar, 2006). Moreover, many documents and policies of the Council of Europe are also related with sustainable urban development. The European Urban Charter and the declaration arose from this charter: the European Urban Rights Declaration, 1992. This charter is complemented and updated in 2008 on “European Urban Charter II Manifesto for a new urbanity” (Yazar, 2006).

In the *URBAN21* Conference was held in Berlin on July 2000, the vision for sustainable urban development was stated as:

> "Improving the quality of life in a city, including ecological, cultural, political, institutional, social and economic components without leaving a burden on the future generations. A burden, which is the result of a reduced natural capital and an excessive local debt. Our aim is that the flow principle, which is based on equilibrium of material and energy and also financial input/output, plays a crucial role in all future decisions upon the development of urban areas." (Keiner, 2003)

As given above, in order to reach sustainable urban development, environmental, social and economic dimensions should be integrated as a whole. According to Nijkamp and Perrels (2009), sustainable city is the concrete spatial reflection of the sustainable urban development (Nijkamp & Perrels, 2009).

> "Sustainable cities ensure continuity in change with a harmony of socioeconomic, environmental and energy concerns" (Street, 1997)

Yazar (2006) also emphasized this harmony and added that the city adopting a development approach which prevents the depletion of natural resources after their usage over their carrying capacities are also defined as sustainable cities (Yazar, 2006). Additionally, sustainable urban development refers to urban development which human needs are met equally and efficiently and also ensures the maintenance of this situation and environment for current and future generations living in the urban boundaries.

Another definition by European Commission (EC) (2003) is that sustainable city boosts the efficiency of land use, conserve valued un-built land, biodiversity and green areas from development and restores contaminated and derelict land (EC, 2003). Within this framework, sustainable city in its simple description is a city succeeding in all aspects of sustainable urban development.

A Sustainable city is one with dense population in mixed types of areas, and with a wide variety of social and commercial activities available within walking distance. Besides, it combines environmental, social and economic dimensions together to meet the needs of current generations without compromising those of future. Moreover, it is also based on the following principles (Godard, 1999);

- A structure that has mixed use functions
- Controlled and minimized mobility
- A city which is adaptive and flexible
- A city which has more compact form

In addition to the characteristics stated above, sustainable city generally promotes better quality of life, natural open spaces, reduced waste, equality, access, lower crime, sense of community, clean air and water quality, and environmental diversity. These are just a few beneficial characteristics of a sustainable city. Moreover, key factors for sustainable development on urban level can be defined as;

> "compact, mixed-use urban form, well-defined higher density, human oriented centers, priority to the development of superior public transport systems and conditions for non-motorized modes, with minimal road capacity increases, and protection of the city's natural areas and food-producing capacity, including environmental technologies, a high-quality public realm, sustainable design principles applied to urban development, and economic growth emphasizing creativity and innovation, and strengthening the environmental, social and cultural amenities of the city" (Kenworthy, 2006).

According to the Roy (2009), ''urban sustainability'' can be stated as;

> "A desirable state, but it is not equivalent to sustainable urban development, which refers to the process for progressing towards the desirable state. In contrast, the concept of sustainable urbanization takes a wider view by recognizing the regional, national and global significance of an urban area while defining and achieving the desirable state".

This perspective realizes the political and institutional sustainability as a view which until recently is generally not being considered within the process. Therefore, to have desirable conditions for an urban area combining sustainability with urbanization is required (Roy, 2009).

2.1.1 Principles for Sustainable Urban Development

It can be stated that cities are the most common research topic in terms of the Sustainable development concept. However, this concept meets the needs of people in the settlements without excluding the environmental dimension. In reality, meeting the needs (of the people) is a part of the corporate, administrative and planning perception of the cities. The reasons why this concept mimics the views of the cities, in order of priority, are:

- The huge importance of the development of the cities at a national, local and economic level that gives it its drive,
- A large amount of the population living in the cities,
- The high importance of the cities' provision of employment, shelter and services,
- A large percentage of damage within the city or surrounding areas that result from the quick growth of the cities,

In general, the concept of sustainable urban development is derived from sustainable development. Table 2.1 shows the relations between development targets and urban strategies (UN-DESA, UN-HABİTAT, 2004).

Table 2.1: Urban Strategies Within Sustainability Dimension

Development Targets	**Urban Strategies**	
	Urban Scale	**National Scale**
Economic Development	Productive Cities	Cities as engines of development
Social Development	Cities covering all aspects	Reducing Urban Poverty
Environmental Sustainability	Eco-cities	Creating Urban-Rural Links

As given above, urban strategies are mainly based on sustainable development concentrated on the productive, ecological and comprehensive characteristics. In terms of urban perspective, sustainable development can be considered as dynamic and a multi-directional process with social, economic and political institutional sustainability, which protects the environment. Thus, sustainable urban development is a connector between human settlements like rural areas, small urban centers and metropolis.

According to Nijkamp and Geenhuizan (1995), sustainability in an urban framework can be considered as a potential, which can be used in a long term process by environmental circumstances in order to reach socio-economic, demographic and technological development. Likewise, unsustainability conditions in urban areas are economic decline, population decrease, environmental degradation, unemployment increase, inefficient energy systems, and changes in socio-economic balance (Nijkamp & Geenhuizen, 1995).

Undoubtedly, the main principles of sustainable development are assumed to incorporate environmental, economic, social and institutional principles. Towards these principles, main targets of sustainable urban development are given as follows (Çubuk, 2000);

- improving quality of life
- alternatives for development
- prevention of poverty
- sufficient employment and nourishment
- meeting the basic health needs
- protection and enhancement of biological diversity
- reconstruction in technology
- controlling population growth
- renewable energy usage and clean water resourcing
- removing risks

European Environment Agency also suggested five important principles for sustainable urban development (EEA, 1995):

- "Environmental capacity": Cities should be planned managed according to the their environmental capacity
- "Reversibility": Planning actions should be designed as reversible as much as possible
- "Resilience": Cities should be resilient that is an ability to recover from external stress
- "Efficiency": Cities should obtain maximum economic benefits from each unit of land resources

- “Equity:” Cities’ inhabitants should have equal accessibility to local resources and services

In order to make cities sustainable, additional goals are required as follows (EEA, 1995):

- Reducing the depletion of spatial and natural resources
- Rationalizing and efficiently managing urban flows
- Conserving the health of the urban population
- Providing equal access to resources and services
- Maintaining cultural and social diversity

It should be emphasized that, sustainable urban development process and principles should be flexible, since all cities are different from each other and they have their own situations, problems and potentials. The problems might be relevant in some cities in some specific situations, so the main principles can be their solutions, but the differences should be considered (Yazar, 2006).

OECD Ecological Cities Workshop recommends that governments at all levels have tasks towards sustainability. These are; (OECD, 1994):

- Define urban regions to encompass distinct bioregions or catchments;
- Establish a methodology, standards and procedures for "time cost" pricing:
- Encourage urban regions to develop strong economically interlinked entities
- Adopt development codes that foster resource conservation, and efficient energy use. enabling
- Mixed use and public transport-orientated urban areas;

- Support advanced transport, technology, communications and production systems;
- Introduce revenue-neutral incentives for purchase of energy conservation technologies; and
- Progress towards ecologically sustainable forms of urban development.

Additionally, the following themes are crucial for sustainable urban development (Wheeler, 2004).

- Land use planning
- Growth Control
- Urban Transportation
- Economic Growth
- Green Architecture
- Energy and material consumption
- Equity and environmental justice
- Natural Protection and restoration
- Population

It is well known that scattered and widespread low density urban growth associates car dependency, air and noise pollution, decrease in quality of life and social inequities. It also contributes to a disjointed and spread urban functions, over-consumption on energy and environmental pollution due to car dependent transportation policies and the loss of natural habitats.

Low-density scattered urban development ignores the main sustainable urban development principles such as sustainable energy usage and the risk of conversion of natural and agricultural areas to urban type. Moreover, spreading low-dense urban development and urban activities offer more air pollution and area loss because the increase in private car circulations and distances in terms of infrastructures. Within this perspective, minimization of urban sprawl is required to achieve sustainability in urban areas. This requires controlling growth in urban periphery and integration of land use distribution with proper transportation systems, properly distributed ecological and recreational activities. Urban growth policies and efficient intervention strategies should be integrated within this perspective. The successful intervention depends on three factors:

- Institutional factors; such as management of urban energy sector or public-private partnership
- Citizens' behaviors; such as Quality of life or environmental awareness
- Urban form and morphological factors; such as population growth, urban form and transportation networks.

As stated above, reshaping of urban space has been one of the important concerns of sustainable urban development. The discussions about the solutions for getting rid of the problems derived from environmental features, improving the quality of life and prevention of environmental degradation, are generally concentrated on urban form, size and population density.

Urban form is related the physical layout or design of the city. It is a spatial pattern of human activities and concerns with the building density type, and also spatial functionality. Urban design generally concerns the density, layout, transportation and employment areas and urban design issues. Additionally, urban sprawl, spatial growth patterns and phasing of developments also heavily influence urban form (http://tr.scribd.com/doc/32002895/8-Urban-Form).

Urban design and planning are generally based on designing of urban form and density. The components related to environmentally sound urban development such as land use development, transportation networks design, efficient energy consumption, minimized infrastructure costs and controlled demographic structure are mainly related to restructuring of urban form.

The restructuring process is highly related with urban ecology and urban ecology targets such as; optimization of land use, minimization of movement within the urban area by reducing the geographical distinction between different uses (residential, commercial, recreational and etc), controlling of private car usage, limiting energy consumption and waste. These can also be referred to as the solutions for sustainable urban form.

Sustainable urban form should include the following characteristics:

- intense housing design,
- higher density housing areas,
- direct and improved accessibility on urban centers,
- average settlement size,

The city with sustainable urban form which has the characteristics as given above has the following fundamentals in Figure 2.1

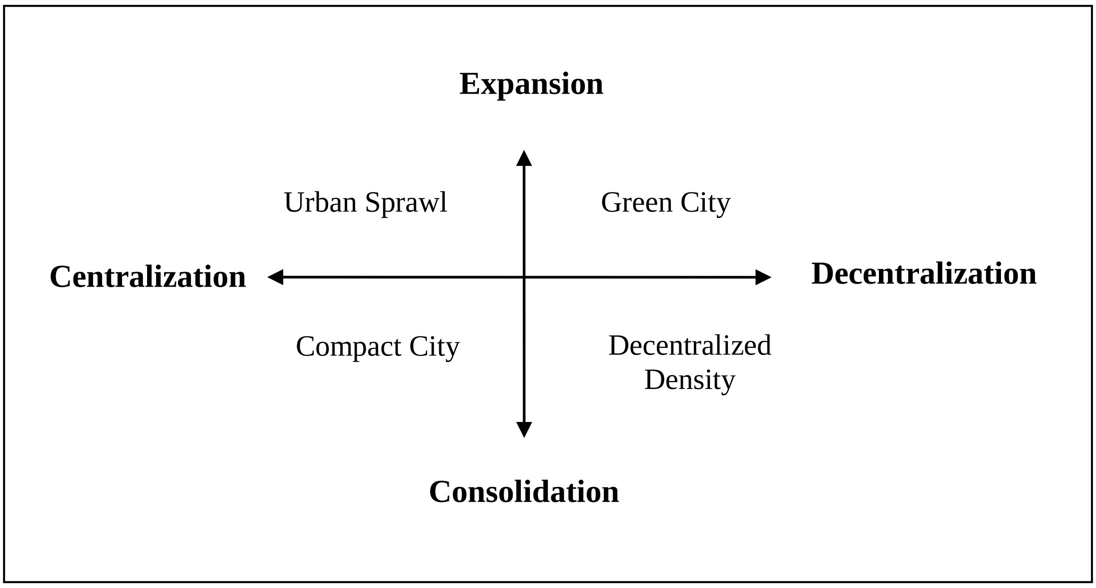


Figure 2.1**:** Sustainable Urban Form (Holden, 2004)

As can be seen in Figure 2.1, centralization and expansion represents sprawl while decentralization and expansion shows green city concept. On the other hand, decentralization and consolidation brings decentralized densities where consolidation and centralization brings compact urban form. Compact city policies are generally on urban renewal, regeneration of urban centers, limitation of development in rural areas, higher densities, mixed land use schemes, incentives on public transportation systems and lower travelling periods between different functions. Compact city form has a vision against car dependent urban sprawl which exists in many modern cities. Compact form process is generally defined as “consolidation” and “intensification”.

Accordingly, it can be stated that, the compact urban form is vital for sustainable urban development. Consideration would convey to a better understanding of its importance for sustainable urban development. Thus, the advantages and disadvantages of compact urban form with reference to economic, social, environmental and physical dimensions are presented in Table 2.2.

Table 2.2: Advantages and Disadvantages of Compact Urban Form (Yazar, 2006).

	Advantages	**Disadvantages**
Economic Dimension	• Reducing cost and energy usage in travelling • Reducing cost in infrastructure and efficient management • Decrease in travelling time from home to work • Improving economic structure by regeneration of urban centers and slum areas • Minimization of energy used in buildings	• Possible housing congestion • High land prices due to high-density development
Social Dimension	• Accessibility to standard houses from low-income groups • Limitation on social accessibility and spatial division • Increase in social integration and sense of place • Increase in public place usage	• Neurological sickness risk • Possibility in increase in crime rates • Inequity in land ownership
Environmental Dimension	• Reducing poisoning gas emissions • Decrease in environmental degradation by protection of open and rural areas • Protection of natural habitats and biological areas within Urban periphery	• Sun delivery and air ventilation problems due to multi-storey building structures • Increase noise pollution
Physical Dimension	• Easy access to urban (public) services • Promotion of Public Transportation and alternative transportation (pedestrian-bicycle) systems • Improvement in accessibility for urban services • Reduced car-dependency	• Risk of decrease in green spaces in urban area • Crowded urban life

It is a clear fact that, there is a powerful relation between sustainable urban development and urban form, which has not been achieved by most of the cities. Scattered and expanded urban areas have many conflicts with sustainability policies. Therefore, the easiest way of achieving sustainability can be defined as compact urban form. Structuring compact urban form requires spatial and land use planning policies with successful urban management processes. Within this perspective land use planning and sustainable urban development policies are explained in the following sections.

2.2 Spatial Planning and Sustainable Urban Development

Spatial planning can be used as a tool to implement socioeconomic development by preventing environmental problems and simultaneously protecting the natural environment and the cultural environment. The challenge for planning is to ensure the efficient use of limited land resources and to contribute to balanced regional business development and balanced use of resources, including natural and landscape resources, soil, water and air. Since spatial planning has a long-term perspective, it can also include important principles of sustainability. Based on this, using spatial planning to promote sustainable development involves striving to view the concepts of *development* and *protection* as being complementary rather than contradictory.

Spatial planning can coordinate various aspects of socioeconomic development across the sectors of society: urban development, development in rural districts, urban-rural relationships, the development of infrastructure and environmentally sound use of land and natural resources. Planning procedures are based on and should be developed further to ensure the involvement of the public in a democratic decision-making process so that various societal interests can be weighed and balanced in decisions on development.

In 1999, the European Union approved the European Spatial Development Perspective (ESDP). The ESDP describes a concept for balanced and sustainable development of the territory of the European Union. It emphasizes that sustainable development means not only environmentally sound economic development but also balanced spatial development. This means that social and economic objectives for developing a geographical territory must consider environmental and cultural functions to achieve sustainable development. The policy guidelines of ESDP are as follows (EC, 1999):

- A balanced and polycentric urban system and a new urban-rural relationship,
- Securing parity of access to infrastructure and knowledge (by promoting integrated transport and communication systems that support polycentric development),
- Sustainable development, prudent management and protection of nature and cultural heritage.

The ESDP has there by emphasized the potential of spatial planning in contributing to a sustainable future. The development policies to achieve these objectives are very dependent on local conditions. The five following aspects are of particular importance to the sustainable development of towns and cities (EC, 1999)

- control of the physical expansion of towns and cities (compact urban form);

- mixture of functions and social groups (which particularly applies to large cities in which increasingly large sections of the population are threatened by exclusion from urban society);
- wise and resource-saving management of the urban ecosystem (particularly water, energy and waste);
- better accessibility by different types of transport which are not only effective but also environmentally friendly
- the conservation and development of the natural and cultural heritage.

Compact Development; As specified above, Spatial planning is one of the contributors in achieving a balance between undeveloped land and reusing old urban sites in urban development. It also helps to promote compact urban development. Uncontrolled urban sprawl into the open landscape must be prevented for a sustainable urban development. Urban sprawl will lead to problems in increased use of undeveloped land, increased transportation and dependence on car transport with excessively high infrastructure costs and an increased usage of energy. Compact development reduces usage of new land for urban development. Using Spatial planning, old industrial and harbor sites as well as districts can be revitalized, for example, by converting them to take on new urban functions.

The reuse of old urban districts will allow the integration of different urban functions only if it does not cause excessive adverse effects on the environment of the community. The new service and commercial can be absorbed into other urban functions because they do not create as many adverse effects on the environment as the traditional industry does. Mixed use will lower the volume of commuting transport and promote using more environmentally friendly modes of transport, especially the public transport.

Better Accessibility; The accessibility of cities has a very important impact on the quality of life, environment and economic performance. It should be bolstered by a Spatial policy for the location that is congruent with land use and transport planning. The aim should be to abate the expansion of the towns and cities and to embrace an integrated approach to transport planning. Hence, dependence on using private cars would be reduced and other means of mobility, like public transport and cycling, would be promoted.

Protection of the Environment; The number of protected areas within the European Union has expanded in the past ten years. "Natura 2000", which is an objective of a community-wide network of protected areas, is incorporated into the Habitat Directive (as well as other directives) and is a very encouraging approach. However, it must be harmonized at an early stage with the regional development policy. This policy requires the preparation of integrated spatial development strategies of protected and environmentally sensitive areas as well as areas of high biodiversity like coastal and mountainous areas and wetlands. Thus, balancing protection and development on the basis of territorial and environmental impact assessments and ensuring the involvement of all the concerned partners.

These policies emphasized by European Commission guiding principles for sustainable spatial development for Europe(EC, 2000);

- Encouraging development generated by urban functions and improving the relationship between town and countryside
- Promoting more balanced accessibility
- Developing access to information and knowledge
- Reducing environmental damage
- Enhancing and protecting natural resource and the natural heritage
- Encouraging high quality of sustainable tourism

Finally, implementing planning policies of polycentric development of European settlement structure and achieving sustainable development in towns and cities (EC, 2000);

- Controlling the expansion of urban areas (urban sprawl): limiting trends towards suburbanization by increasing the supply of building land in towns and cities.
- Regenerating deprived neighborhoods and producing a mix of activities and social groups within the urban structure
- Managing the urban ecosystem particularly with regard to open and green spaces, water, energy, waste and noise
- Conservation and enhancement of the cultural heritage
- Development of networks of towns

2.2.1 Land Use Planning

As a part of spatial planning; land use planning deals with an active planning process of land to be used in the specific future by people and meet their needs. These needs are diverse food products to places, to live, industrial production sites to places, to relax and to enjoy beautiful landscapes; from human uses to places where natural plants and animals can live and survive.

Land use planning determines required components to achieve the selection of a type of land use, which is sustainable. It sets in motion social processes of decision making and consensus building concerning the use and protection of private, communal or public areas. Two situations should be fulfilled for making planning successful:

- The demand for changes in land use, or action to prevent some desired change. Must be accepted by the people involved;
- A political willingness and ability to implement the plan effectively.

Land use planning is a decision-making process which enables the allocation of land to the uses for improving sustainable benefits. This process should be depended on the social, economic and environmental conditions and also possible growth of the population on natural land unit (FAO, 1996).

Land use planning normally targets to get the best use of limited resources by the following principles (FAO, 1996):

- Evaluating present and future needs and systematically evaluating the land's ability to supply them
- Determining and solving conflicts between competing uses
- Searching sustainable options and selecting the best meet identified needs
- Developing plans for bringing desired changes
- Mastering from experience.

2.2.2 Land Use Planning Principles for Sustainable Urban Development

Land use planning is a crucial tool for reaching sustainable urban development. Sustainability and planning have common features. Moreover, they are complementary to each other in a way that sustainability has the potential of providing much, if not all, of the conceptual context (theories, goals, objectives, etc.) for the activity of planning.

> "Sustainability and the field of planning are inextricably linked and mutuall relevant" (Jepson, 2001).

Urban planning, which is a significant tool for achieving, promoting and moving towards sustainability, is one of the important arenas in which conceptions of sustainable development are contested. Spatial planning promotes sustainability with plans, policies and programs and the sustainability of land use planning process is a step towards sustainability of communities.

In summary sustainable urban plan includes; dense and mixed-used land use, human scale designing, emphasizing the public spaces for common(public) good, human oriented transportation systems, participatory process, protection of green space structure, obtaining technical infrastructure and coordination of social improvement.

Naess also emphasizes five basic principles of sustainable land use within the overall urban planning approach (Naess, 2001).

- Decreasing the emission and energy use per capita
- Minimization the conversion of natural resources, eco-systems and soil for good production

- Limiting harmful productions that may damage the environment
- Developing re-cycling systems
- Decreasing air and noise pollution by increasing green spaces

Accordingly, the following tasks have been identified for sustainable land use in cities (Brebbia et al., 2002);

- Attainment of the housing, employment and service functions of the cities that creates a mixed and dense land usage, with a view to minimize private, trade and work travel.
- Renewal of the city urban regions and also to prioritize the traffic in the main streets according to work, housing and other usage. Renewal of the worn out infrastructure in these regions and the provision of modern services and other opportunities required in life.
- Support the regeneration of housing property by removing barriers to small-scale urban renewal projects and making the city self-sufficient.
- Creation of sustainable plans and programs to support the improvement of the participation of the community. Within this concept, community identity is needed to be created with meeting places, public places, pedestrian networks, protection of historic sites and attractive streets.
- Provision of cultural and recreational opportunities that help in the active use of the natural areas.
- Provision of the water and infrastructure needs of the local community; this approach would also satisfy any healthy politically-motivated environmental targets.

- Expansion and improvement of the transportation systems in order to maintain healthy competition

American Planning Association also emphasizes similar land use planning policies for sustainable urban development (APA, 2002), which;

A. Reducing usage of upon fossil fuels by promoting

- Compact development
- A mix of land use functions within walking distance
- Pedestrian friendly human scaled development that is
- Public transit oriented development
- Home office based occupations and working options

B. Reducing of activities on environment by:

- Promoting growth on the actual developed areas and limiting development in outlying
- Redeveloping of brownfield sites
- Encouraging local designs that concern local ecology
- Promoting regulatory incentives for infill development

Land resources are used for purposes which interact and may compete with one another. Therefore, planning and managing all uses has to be combined. This combination should be implemented on two levels. On the one hand, all environmental, social and economic factors and; on the other hand, all environmental and resource components together should be united. In order to achieve this, the following activities are required (UN, 1992);

- Supporting policies and policy instruments that select optimum land use option
- Strengthening planning and management systems
- Encouraging the usage of convenient tools for planning and management
- Increasing awareness
- Supporting public participation
- Strengthening information systems

2.3 Summary

Sustainable urbanization needs cooperative activities on various disciplines. It is a process, which covers many successive and overlaying activities with the local expert's participation on different stages. In this perspective, the main task aims to discover a equality between economic, environmental and social dimensions. In order to achieve this, there is a need for a system of policy formulation involving the combination of individual thought, which is obtained by the participation of citizens and with scientific understandings, which is provided by experts. The development and testing of alternative scenarios is also a necessity, in order to ascertain that the option is economically, environmentally and socially sustainable.

The execution of such a comprehensive course in practice necessitates an assortment of planning dimensions that include land use, transportation, local economic development, environmental justice and urban design combined within a strategic framework. Spatial and Land use planning are crucial tools of achieving spatial urban sustainability. To increase the level of sustainability, main principles introduced by spatial and land use planning include decisions on compact form, protection of special sites, improvement of accessibility technical and social services, redevelopment and regeneration, and, etc. In this study, these principles are used as guide for preparing the sustainable urban development policies for the spatial planning process.

Chapter 3

GEOGRAPHICAL INFORMATION SYSTEMS AND URBAN GROWTH MODELING

In this section, GIS and urban growth modeling tools are briefly explained. GIS based planning support technologies, which have been used for land use planning and examples for sustainable urban growth development are discussed. Additionally, urban growth modeling tools for prediction and simulation are also presented.

3.1 Geographical Information Systems (GIS)

There are many descriptions of GIS, but essentially a GIS is a computer-based tool for visualizing, mapping and analyzing events that happen on earth. GIS is regarded as;

> "A set of tools for the input, storage and retrieval, manipulation and analysis, and output of both spatial and attribute data and it is unique in its capacity for integration and spatial analysis of various datasets such as land use, population transportation, infrastructure, network, topography, hydrology, climate, vegetation, etc" (Malczewski, 2004).

Additionally, GIS provides a production that helps to see the generated information in the form of 2D thematic maps, 3D visualization scenes, tables, diagrams, graphics, etc. The history of GIS depends on the history of using computers to handle and analyze mapped data. Availability of powerful, low-cost and easy to use GIS tools (both hardware and software) and more extensive spatially referenced data make GIS an essential tool for planning tasks (Malczewski, 2004).

It also reflects the dramatically increased quantity and quality of spatially referenced information that is becoming available with the maturation of municipal and regional GIS databases, the incredible growth of the internet and the emergence of new tools and techniques (Klosterman, 1999).

> "GIS is an integrated technology. It allows for combining different geographical technologies and also with reasoning, modeling and decision making techniques" (Malczewski, 2004).

These technologies or techniques could be separated by the role of the item in enhancing GIS capabilities. However, in some reviews of PSS and GIS literature, all these related techniques (and also GIS) are accepted within PSS framework (Malczewski, 2004).

Among GIS related technologies (Table 3.1), remote sensing is defined as the acquisition of information about an object without being in physical contact with it. The advent of satellites is allowing the acquisition of global and synoptic detailed information about the earth and environment (Elachi & Zyl, 2006).

Table 3.1**:** GIS Based Technologies (Malczewski, 2004)

Technology	**Role of the Technology in Enhancing GIS**
Database Management Systems (DBMS)	Storing attributes for display in GIS; Data querying, sorting, joining, appending, updating, restructuring, relating tables and fields.
Computer Aided Design (CAD)	Delivering effective use of computer technology in geometric modeling, 3D modeling and animation; enabling appropriate rendering.
Land Information System (LIS)	Extending GIS capabilities to land surveys and land records for legal, administrative and aid records for legal, administrative and aid for planning and development.
Automated Mapping / Facilities Mapping (AM/ FM)	Enhancing GIS functions by automated mapping and map maintenance for public utilities such as waterworks, drainage, gas and electricity.
Global Positioning System (GPS)	Enhancing location accuracy of objects and verifying accuracy of attributes in GIS; Enabling navigation and tracking.
Remote Sensing and Photogrammetry (RS-RSP)	Integrating image processing and analysis; Source of raster data.
Spatial Decision Support Systems (SDSS)	Extending GIS functions for spatial decision making
Planning Support Systems (PSS)	Extending GIS functions by modeling and visualization to support planning
Multimedia Systems (MS)	Enhancing visualization of geographic information by use of sound, videos, images hypertext and hot links
Internet-based Systems (IS)	Enhancing communication, participation, data sharing, joint task operation and online GIS service delivery
Groupware Systems (GW)	Enabling multiple users in different locations to commit tasks related to planning and decision making

Remote sensing refers to collecting information about an object without coming into contact with that object. The field of remote sensing encompasses many activities, including sensor design and function, data processing and storage and image classification.

Satellite Imagery is typically analyzed to produce land cover maps and statistics. Planners use these data to study many conditions such as urban sprawl, open space, forestry areas, etc. This image classification is the process of assigning the pixels of image to a specific class or category to identify to ground features.

The option of one meter resolution in satellite imagery and aerial photography will make the information useful for geographic and urban analysis. Also these opportunities allow the user for generation of digital terrain models (DTM) and for accurate geo-referencing, street mapping, identifying and locating features and infrastructure by using global positioning systems (GPS).

Typical samples for GIS related and web based systems can be given as Geoportal and Google Earth. Geoportals are web gateways that organize content and services such as directories, search tools, community information, support resources, data and applications (Maguire & Longley, 2004). The main aim of these portals is to construct a web based gate for accessing to maps, data and other related services. to institute a collaborative process to develop data content standards ensuring consistency among data sets and allowing government and private sector to share data and integrate multiple sources of information (Maguire & Longley, 2004).

Groupware, OpenGIS, WebGIS, GOS (GeoSpatial One Stop), INSPIRE (Infrastructure for Spatial Information in the European Community), Google Earth and many other web based geo-spatial applications/consortiums have made major contributions to the interoperability and collaborative efforts in city planning and geographical studies (Geospatial One Stop, 2005; Google Maps, 2009; INSPIRE, 2008). Also, an increasing amount of information can be downloaded from the internet.

On the 15th of May 2007, the INSPIRE directive came into force. Full implementation of this directive is required by 2019, but it will be implemented in various stages leading to this end date. Its aim is to create a European Union spatial data infrastructure. This will allow the exchange of environmental spatial information between the public sector organizations and simplify public access to the spatial information across Europe (ESRI, 2008). Policy-making across EU boundaries will be supported by a European Spatial Data Infrastructure. Hence, the spatial information deliberated under the directive is considerable and incorporates a large variety of topical and technical themes.

Table 3.2**:** Planning and Information Technology (Klosterman, 2001)

Decade	**Views of Planning**	**Concerns of Information Technology (IT)**
1960s	Planning as Applied Science/System Optimization: Information technology is viewed as providing the information needed for a value-neutral and politically-neutral process of 'rational planning'.	Data: 'Observations which have been cleaned coded, and stored in machine-readable form' Electronic data processing (EDP)
1970s	Planning as Politics/ Politics: Information technology is seen as inherently political, reinforcing existing structures of influence, hiding fundamental political choices, and transforming the policy-making process.	Information: 'Data which has been organized, analyzed, and summarized into a meaningful form' Management information systems (MIS)
1980s	Planning as Communications/ Discourse: Information technology and the content of planners' technical analyses are seen as often less important than the ways in which planners transmit this information to others.	Knowledge: 'Understanding based on information, experience, and study' Decision support systems (DSS)
1990s	Planning as Reasoning Together/ Collective Design: Information technology is seen as providing the information infrastructure that facilitates social interaction, interpersonal communication and debate that attempts to achieve collective goals and deal with common concerns.	Intelligence: 'Ability to deal with novel situations and new problems, to apply knowledge acquired from experience, and to use the power of reasoning effectively as a guide to behavior' Planning support systems (PSS)

3.2 GIS Based Land Use Suitability Analysis

Land use suitability analysis can be defined as the one of the most powerful GIS applications for planning and management. In general, land use suitability analysis aims to identify the most convenient spatial form for future growth according to specific requirements or preferences of some activity. It's the process of determining the convenience of a given space of land for a defined use. In order to determine the most desirable direction for the future development, the suitability for various uses should be studied with the aim of directing growth to the most appropriate sites (Baniya, 2008).

GIS based land use suitability analysis has been applied in a many fields such as agricultural suitability, regional planning, geological planning, Strategic Environmental Assessment, (Marull et al., 2007), Natural Source Management (Steiner et al., 2000), Forestry Planning in (Temiz &Tecim, 2009), Urban Growth Prediction in South Korea (Park et al., 2011), Windfarm Site Selection in western part of Turkey (Aydin et al, 2009), Locating Sustainable Suburban Centers in Palestine (Abusaba & Thawaba, 2011) and Urban Growth Simulation in Guanghzou in China (Wu, 1998).

Literature survey reveals that, for land suitability analysis, various methods have been suggested. According to Malczewski (1999) there are different methods for land use suitability analysis, which are:

- **Computer Aided Overlay Mapping**
- **Multi-Criteria Decision Making (MCDM) Methods**

In the following section these methods will be summarized.

3.2.1 Computer Aided Overlay Mapping

Rather than manual overlay, computer assisted Overlay Mapping helps to store the suitability values in numerical form as matrices in the computer(Fig 3.1).

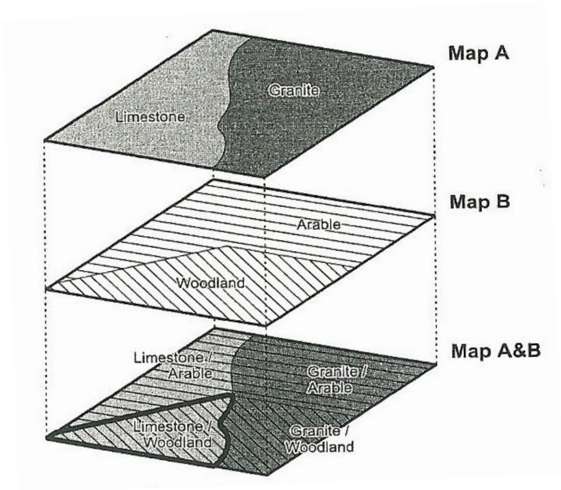


Figure 3.1**:** Map Overlay (O'Sullivan & Unwin, 2002)

Computer aided map overlay method has been widely used to develop land use suitability in the form of "Boolean Approach" and "Weighted Linear combination" (WLC). In Boolean Approach, all criteria and factors (constraints and factors) are standardized to Boolean Values (0-1) and the method of aggregation is the intersection of criteria layers. In WLC; "the decision maker directly assigns weights of relative importance to each attribute. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute" (Eastman, 2001). Since these methods are easy to implement within a GIS environment with map algebra operations, they have increasingly become popular through the time.

3.2.2 Multiple Criteria Decision Making (MCDM)

> "MCDM is a decision-aid and a mathematical tool allowing the comparison of different alternatives or scenarios according to many criteria, often contradictory, in order to guide the decision maker(s) towards a judicious choice" (Roy, 1996).

In MCDM the decision maker pick up one option among many options. The set of alternatives is the collection of all alternatives. Selecting an alternative among this set depends on many characteristics, often contradictory, called criteria. Accordingly, the decision maker generally has to be contented with a compromising solution (Chakar, 2001)

MCDM aims to solve problems that have multiple attributes, objectives and goals. The Multi-criteria problems are commonly categorized as continuous or discrete, depending on the domain of alternatives that classify them as multiple attribute decision-making and multiple objective decision-making. AHP and Ordered Weighted Averages (OWA) are the main examples of multiple attribute decision making methods. Within the research framework, only AHP method will be explained by the following section. Additionally, pairwise comparison technique will be also given in detail.

3.2.2.1 Analytical Hierarchy Process (AHP)

AHP has been widely used as in land use suitability studies in recent years as one of the MCDM techniques AHP is created by Saaty (1980) for assisting the decision maker or experts to give best decision while dealing with multiple conflicting goals or objectives. In AHP, the complicated problem is separated into several simple problems within the hierarchical structure (Kara & Doratlı, 2012).

The decision problem includes three levels. The first one presents the main goal, the second one presents the main criteria and the last one shows sub-criteria for different aspects of main criteria (Moeinaddini et al., 2008) (Figure 3.2). After the identification of criteria for a particular goal, weights for criteria were computed with a pairwise comparison methodology (Kara & Doratlı, 2012). This is explained in the following sections

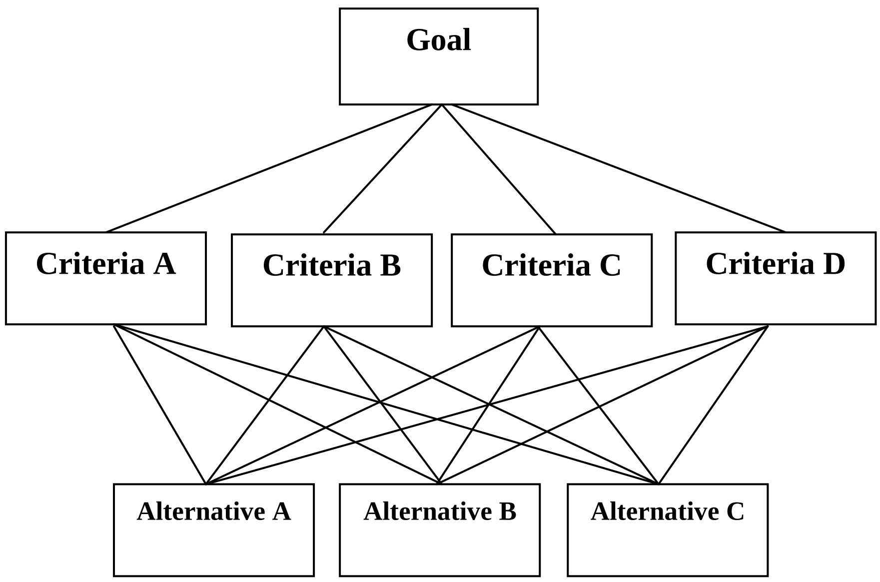


Figure 3.2**:** AHP Hierarchy, Constructing Complex Process (Wang, 2010)

3.2.2.2 Pairwise Comparison

Analytic Hierarchy Process, like other decision making methods, needs to quantify qualitative data, and it uses pairwise comparison matrix for that purpose. AHP takes pairwise comparisons as inputs and converts them into relative weights as outputs. As it has been proposed by Saaty, Pairwise comparisons are quantified by using a scale, with values from 1 to 9 to rate the relative preferences (Table 3.3) (Saaty, 1994).

Table 3.3: Pairwise Comparison Values (Saaty, 1994)

Intensity of Importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance

Pairwise comparison method is the process of comparing the relevance importance, preference or likelihood of two elements with respect of another element. This pairwise comparison assist decision makers to assess the contribution of each factor to the objective independently, hence simplify the decision-making process. The relative importance of the row variable to its corresponding column variable is considered while filling the matrix cells (Kara & Doratlı, 2012) (Sharifi et al., 2009). These values were acquired according to the rating system which is determined by Saaty (1980).

After constitution of the pairwise comparison matrixes for criteria and alternatives in terms of each criterion, decision maker has to extract the relative importance of criteria and scores of the alternatives from those judgment matrixes. The next step is to estimate the right principal eigenvector of the judgment matrix. Corresponding maximum left eigenvector is approximated by using the squaring matrix. That is, the matrix is to square and then the elements in each row are added, finally each added number is normalized by dividing the row sum by the row totals (Table 3.4 & 3.5).

Table 3.4: Pairwise Comparison Example

Criteria	A	B	C	Weights
A	**1**	1/3	1/3	0.14
B	3	**1**	1	0.43
C	3	1	**1**	0.43

Table 3.5: Calculation of Priority Vector

1.000	0.333	0.333
3.000	1.000	1.000
3.000	1.000	1.000
7.00	2.33	2.33

Normalizing Column Sums ⇨

0.14285714	0.142735	0.142735
0.42857143	0.428633	0.428633
0.42857143	0.428633	0.428633
1	1	1

Getting Row Averages ⇨

0.142775
0.428612
0.428612
1

This process must be iterated until the eigenvector solution does not change from the previous iteration. Unfortunately it is a clear fact that achieving perfect consistency in pairwise comparison for real life situations is unusual. If the decision maker evaluates that element *A* is much more important than element *B*, *B* slightly more important than element *C*, and *C* slightly more important than *A*, then judgments are inconsistent and decisions are made by the decision maker are distrustfully. The next stage is to calculate a Consistency Index and Consistency Ratio (CR) to measure how consistent the judgments have been relative to large samples of purely random judgments (Equation 3.1).

$$CI = \frac{\lambda \max - n}{n-1}$$

λ max= the greatest Eigen value of preference matrix

n=the order of matrix

The final step is to calculate the Consistency Ratio, CR by using the table below, derived from Saaty's book (Saaty, 1980).

Table 3.6: Random Consistency Index

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

The upper row is the order of the random matrix, and the lower row is the corresponding index of consistency for random judgments. Consistency of comparison in a judgment matrix can be controlled by consistency ratio (*CR*) and comparison is considered to be sufficiently consistent if corresponding *CR* is less than %10. *CR* is calculated by dividing the consistency index (*CI*) by random consistency index (*RCI*) (Saaty, 1980). In order to explain this process in detail, an example is given in Appendix I.

3.3 Urban Growth Modeling and Simulation Tools

In urban growth process there are three main components that should be concerned in modeling or simulation activities. These can be stated as developed urban, undeveloped and planned. They have very complicated and non-linear form which is affected by several factors (Cheng, 2003).

Rapid physical development in an urban area may be a suitable case to evaluate the impacts under each possible scenario or recognized driven factors. The entry data for the modeling urban growth add spatial layers generated from satellite images for two different years. This time based or temporal layers are the basis components of the simulating platform in GIS environment (Soltani, 2011)

Urban growth developments are connected with elements that represent various dimensions of artificial and natural environment. Due to several growth strategies, the urban zones have a chance to see environmental degradation which is not desired. According to sustainable city debates, recognizing effective factors could be a useful idea in terms of accessing the urban policies (Soltani, 2011)

Realized studies and surveys to understand and manage complicated systems of the town and cities has been a long tradition in planning. Accordingly, many urban growth modeling tools have emerged which are reliable for urban planners and experts in different fields. These models mainly focus on supporting decision making process towards a sustainable development of urban regions.

3.3.1 Urban Growth Modeling Methods

In the following sections, urban growth modeling methods are briefly explained to present before selection of proper one for the simulation of Famagusta alternative scenarios.

3.3.1.1 Spatial Statistics

Traditional statistical tools such as Markov chain analysis, multiple regression analysis, principal component analysis, factor analysis and logistic regression, have been very successful in interpreting socio-economic activities.

Luo & Wei (2009) constructed a model that uses explanatory spatial and social variables for Nanjing between 1988 and 2000. The study defines spatial variables for presenting the reasons of non-urban to urban conversion (Table 3.7).

Table 3.7: Explanatory Variables for Nanjing Growth Probability(1988-2000) (Luo & Wei, 2009)

Explanatory variables	*B*	S.E.	*t* value	Exp(*B*)
Constant	5.453	0.472	11.552**	233.564
Dis2Hwy	−0.269	0.021	−12.744**	0.764
Dis2Lard	−1.369	0.100	−13.698**	0.254
Dis2Rail	0.034	0.016	2.091*	1.035
Dis2YRiver	−0.100	0.020	−4.942**	0.905
Dis2YBrid	0.115	0.024	4.703**	1.122
Dis2MCen	−0.192	0.022	−8.573**	0.825
Dis2MNCen	−0.073	0.018	−4.039**	0.930
Dis2Induc	0.087	0.024	3.653**	1.091
AgriDen	−2.125	0.404	−5.262**	0.119
BuiltDen	4.039	0.653	6.181**	56.745
WaterDen	−4.812	0.803	−5.994**	0.008
ForeDen	−5.360	0.517	−10.369**	0.005
Sample size	2682			
−2 Log likelihood	1873.536			
PCP[a]	70.1			

This study statistically shows the main reasons of the Nanjing and it develops a probabilistic surface of urban growth (Figure 3.3).

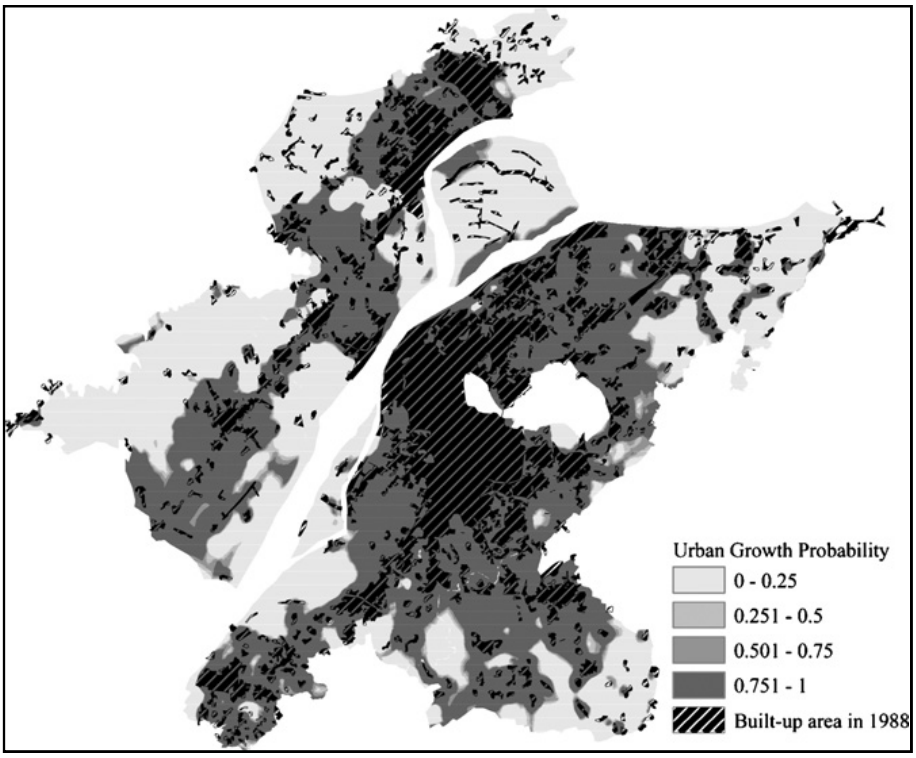


Figure 3.3: Probability surface of urban growth in Nanjing, 1988–2000 (Luo & Wei, 2009)

Wu and Yeh (1997) used logistic regression for modeling land development patterns for the two periods 1978-1987 and 1987-1992, based on a series of aerial photographs. Major determinants of land development have changed significantly during the two periods. It shows that various factors are changing their roles in the process of land development. Also, logistic regression has a stronger capacity for interpreting urban development based on the probability of land conservation (Wu & Yeh, 1997).

Lopez et al. (2001) used a model for predicting land cover and land use change in Morelia city, Mexico. Allen and Lu (2003) applied a GIS-based combined approach to model and prediction of urban development to analyze land use changes. This approach is based on a binomial logistic framework, coupled with a rule-based suitability module and focus group involvement, and is designed to predict land transition probabilities and simulate urban growth under different scenarios.

Traditional statistics are criticized as being ineffective in modeling spatial and temporal data. A major reason is that spatial and temporal data often violate basic assumptions such as normal distribution, appropriate error structure of the variables, independence of variables, and model linearity.

3.3.1.2 SLEUTH (Slope, land Use, Excluded area, Urban Area, Transportation and Hillshade)

SLEUTH is developed by Prof. Dr. Keith C. Clarke and it is based on influencing factors which are "slope, land use, excluded area, urban area, transportation map and hill shade area" (Silva & Clarke, 2002). It stimulates and predicts urban dynamics through according to four growth rules. These are "spontaneous growth", "new spreading center growth", "edge growth" and "road-influenced growth". These are controlled by five factors as given in Figure 3.4.

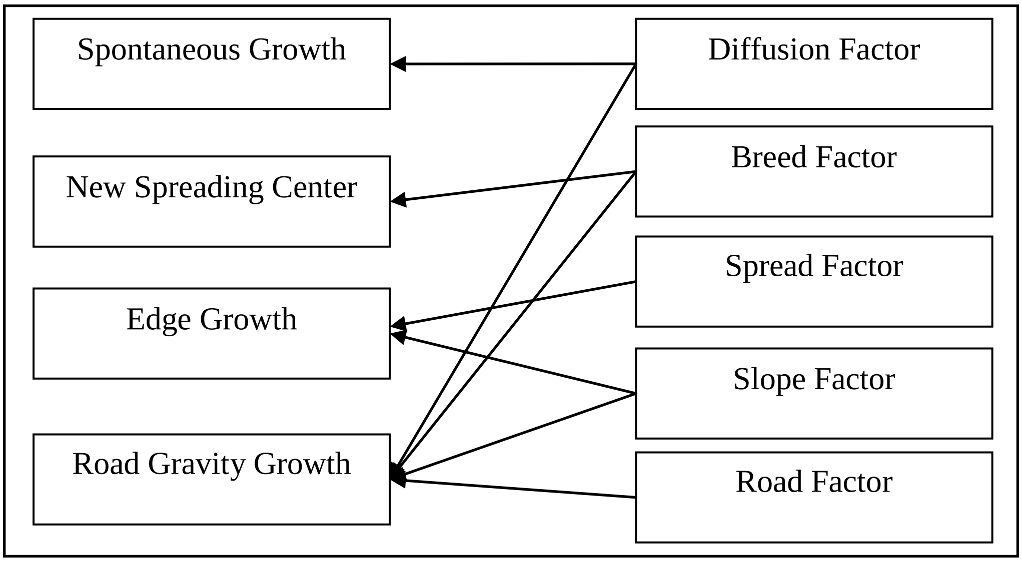


Figure 3.4**:** Linkage between growth rules and parameters (Ding & Zhang, 2007)

The SLEUTH model not only simulates and predicts the actual growth, but it also provides a useful tool for scenario – a tool for imaging, testing and choosing the possible futures (Silva & Clarke 2002). Feng & Liu (2009) uses SLEUTH in Dongguan City, China for analyzing Urban growth prediction and tests different scenario alternatives such as Future Urban Growth Scenario that would allow urban growth in a manner similar to the past, Forest Protection Scenario that protect forest area in the steep areas and Growth Scenario that restrict urban sprawl along the transportation networks (Feng & Liu, 2012).

Additionally, Rafiee et al. (2009) applied SLEUTH in Mashad, Iran with three different scenarios. The first one is called historical urban growth. It allows the continuation of urban area expansion, like existing conditions without any limitation. The second one is called environmentally-oriented and urban growth has limitations. The third scenario one represents the urban sprawl growth is free to continue. It has existing conditions with a limitation was applied to construction on steeper slopes (Rafiee et al., 2009).

3.3.1.3 Artificial Neural Networks (ANN)

An artificial neural network (ANN) is “a system composed of many simple processing elements operating in parallel, whose function is determined by network structure, connection strengths, and the processing performed at computing elements or nodes. The development of a neural network model requires the specification of a network topology, a learning paradigm and a learning algorithm.

Unlike the well-known analytical methods, the ANN is not dependent on particular linkages between functions, which makes no assumptions regarding the distributional properties of the data, and doesn’t need to understand factors relationship between each other. This independence feature gives a powerful ability to ANN for modeling or discovering nonlinear complicated issues (Olden & Jackson, 2001).

Pijanowski et al., (2009) created an Urban Expansion Model (UEM) to simulate urban growth which utilizes GIS, ANN and RS. In this model, Tehran Metropolitan Area is shown for the demonstration of this growth. In this study, UEM discovers how spatial factors like such as roads, building areas, service centers, green space, elevations, aspects and slopes can affect urban growth (Figure 3.5 and Figure 3.6).

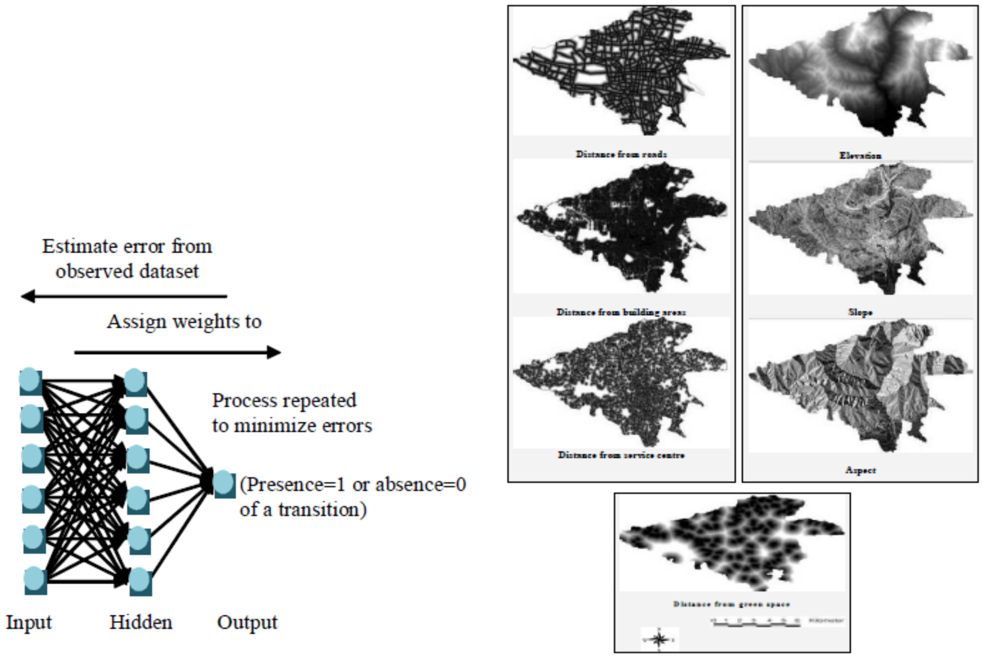


Figure 3.5: Artificial Neural Networks Model Framework (Pijanowski et al., 2009)

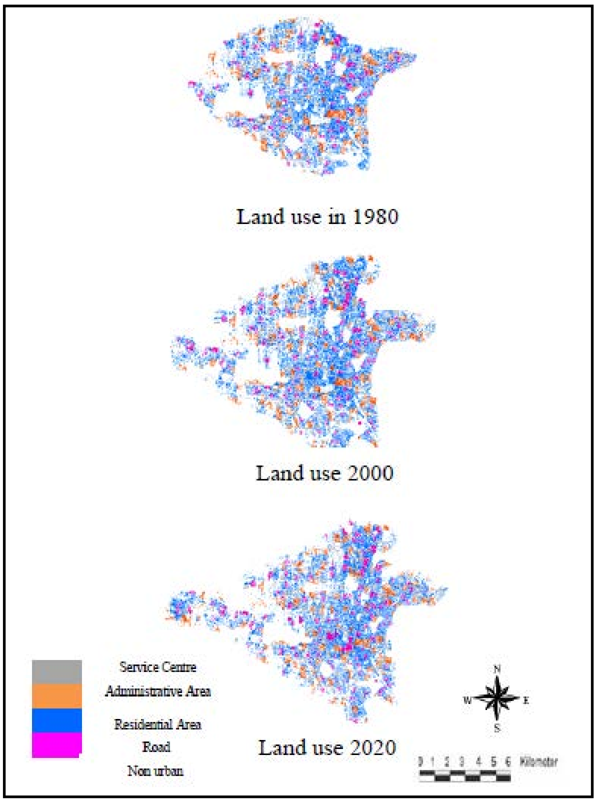


Figure 3.6: Tehran from 1980 -2020 Simulated by Artificial Neural Networks (Pijanowski et al., 2009)

ANN is a proper tool which can help experts to understand non-linear spatial development characteristic in a short-term period, on which a short-term prediction may be based. However, the main critique about ANN can be stated as its black-box and static nature. This creates limitation on understanding modeling process (Cheng, 2003).

3.3.1.4 Fractal-based modeling

Fractals were originally used for natural objects such as coastlines, plants and clouds or ill-defined mathematical or computer graphics. They are defined as spatial objects whose forms are irregular, scale-independent and self similar. Batty and Longley (1994) mentioned that designed spatial objects such as urban structures can also be treated as fractals.

Diffusion Limited Aggregation (DLA), a physical model used to describe aggregation phenomena, has been implemented to present urban growth. These models are also cellular in nature, but only two cell states -vacant and occupied- are possible. Moreover, only vacant cells that are in contact with an occupied cell can be changed to an occupied cell (Batty & Longley, 1994).

DLA creates complicated patterns with simple activities. They can be suggested to present real urban areas and their changes. These changes simulated by DLA, can cover a representation of a fractal structure which is similar to existing urban areas.

3.3.1.5 Cellular Automata (CA)

Cellular Automata (CA) are “dynamic models that can be used to simulate the evolution of natural and human systems”. They were first developed in the 1940s and 1950s by Ulam and Von Neumann in the study of behavior of complex systems. CA shows a powerful simulation environment represented by a grid space of raster, in which a set of transition rules determine the attribute of each given cell taking into account the attributes of cells within its vicinities.

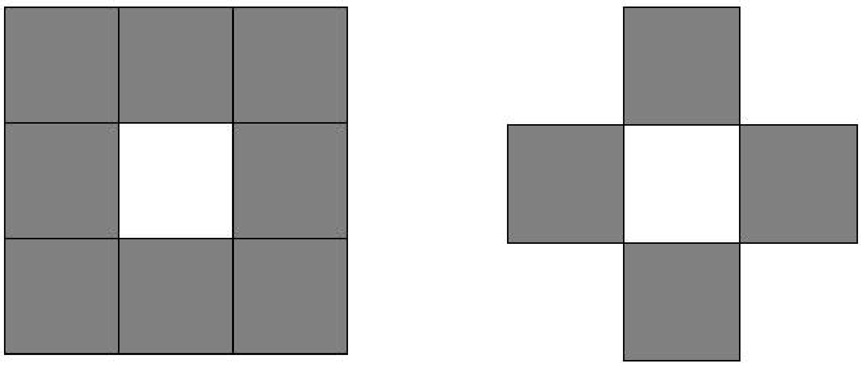
A large and increasing volume of work shows that CA is a proper tool for modeling spatial dynamics (Wu, 1998). CA has been attractive for urban planners due to their spatial nature. Moreover, CA can develop complicated patterns with straight codes.

Wu (1998) presented A Prototype is called SimLand for simulating land development and change by combining GIS based CA with MCE based transition codes in Guangzho, China. The Simulation of land changes includes a complex decision-making process and distinctive spatial patterns could be revealed. SimLand helps the stakeholders, planners and experts to simulating land changes derived from different growth policies (Wu, 1998)

Barredo et al. (2003) developed an application of an urban CA in the city of Dublin. A simulation for 30 years has been produced using a CA. In this study, land use allocation factors were also studied in order to propose a bottom-up approach which integrates the land use factors with the dynamic approach of the CA for modeling future urban land use scenarios. Generally, CA consists of four elements they are given as follows (White & Engelen, 2000) (Equation 3.2)

CA= X, S, N, R,

Where "X is cell space or lattice, S is set of all possible states which a cell can attain, N is neighborhood of a cell and T is a set of transition rules" (Ozah et al., 2010). "Cell Space" includes of individual cells. Although these cells may be in any geometric shape most CA adopts regular grids to represent such space, which makes CA very similar to cellular statements of raster GIS (Singh, 2003). "Cell states" can be determined the states of each cell that represents spatial factors like different land use types. Each cell can get only one condition or state at any time from a set of states (Ozah et al., 2010). "Transition Rules" lead and check the dynamic evolution of CA. In classical CA these rules are deterministic and unchanged during the modeling process (Ozah et al., 2010). However, they are changed into stochastic and fuzzy logic controlled methods in recent studies (Singh, 2003) (Wu, 1998). "Neighborhood" is defined by the local neighbors of a cell. In a two dimensional cellular automata model there are two common types of neighborhood. These are the Von Neumann with four neighboring cells and the Moore neighborhood with 8 neighbors (Liu, 2009).



(a) Moore neighborhood (b) Von Neumann neighborhood

Figure 3.7: Von Neumann and the Moore neighborhood (Liu, 2009).

The following transition function or algorithm is used to update cell's future development state or condition.

$$_{t+1}S_{i,j} = f\left(\left({}_{t}S_{i,j}\right),\left({}_{t}N_{i,j}\right),\left({}_{t}R_{i,j}\right)\right)$$

where $_{t+1}S_{i,j}$ = new (next) state of a cell, $C_{i,j}$ at time t+1;

$_{t}S_{i,j}$ = initial state of a cell, $C_{i,j}$ at time t;

$_{t}N_{i,j}$ = neighborhood of a cell, $C_{i,j}$ at time t;

$_{t}R_{i,j}$ = transition rule applied to cell, $C_{i,j}$ at time t.

The following steps are required for applying CA;

-Identifying a grid or a cellular space.

-Identifying a neighborhood type.

-Determining a set of transition rules between spatial objects or land use types

-Adjusting CA for giving results according to historical data.

-Implementing the rules in a sequence of iterations of the spatial pattern.

-Predicting or simulating possible future scenarios

Two basic examples are given in Appendix 2 in detail to show transition functions.

3.3.2 Selection of Modeling Method

It is important to ask which urban growth methodology is better in simulating urban growth. Within this framework, Cheng (2003) presents three crucial criteria. "data requirement", "linkage with GIS" and "interpretability". Table 3.4 presents a comparison of different modeling approaches based on the given criteria.

Table 3.8**:** Modeling Tools Comparison Table (Cheng, 2003;Liu, 2009)

Modeling Tools	**Data Requirements**	**Linkage with GIS**	**Interpretability**
Statistical (Logistic Regression)	• Remote sensing data can be used • Feature data should be converted as raster format	• It is possible to get Loose coupling relationship is required with ArcGIS, Quantum GIS with R, Mathlab, etc • Geographically Weighted Regression Module can be used within ArcGIS Toolbox	• It has great capacity for explaining the relationship between spatial variables. • It doesn't modeling future development alternatives. It only shows statistical relationship between spatial variables.
SLEUTH	• Remote sensing data can be used • Feature data should be converted as raster format	• It is possible to get Loose coupling relationship with GRID values with SLEUTH algorithms.	• SLEUTH have determined spatial factors and they cannot be changed for modeling process. It's not possible to use different spatial factors such as
ANN	• Remote sensing data can be used • Feature data should be converted as raster format	• ANN Extension module for ArcGIS can be used directly inside of GIS environment • Another solution is developing GIS and ANN module in Mathlab as Loose coupling	• ANN "black box" provides little explanatory about independent variables in the prediction process.
Fractal Based Modeling	• Remote sensing data can be used • Feature data should be converted as raster format		
CA	• Remote sensing data can be used • Feature data should be converted as raster format	• CA ArcGIS Extension • URBAN SIM as open source package for advance GIS users • IDRISI CA module has strong capacity for simple GIS users.(Loose coupling)	• Markov chain analysis can explain the probability values of spatial factors • Transition rules can be designed according to the suitability of any spatial factors.

Selection of Appropriate Model for modeling urban development of Famagusta requires reviewing and comparison of possible modeling approaches. As explained in and was discussed in introduction, this research aims to simulate spatial development alternatives under the possible scenario and policy frameworks. In other words, spatial policies should be adopted for the modeling process as land use suitability within urban form. Therefore, adding these policies as spatial variables is required. Interpretability is a key feature for choosing the convenient model. The evaluation of the modeling Tools Comparison table reveals that "Interpretability" seems to be the key feature for the selection of the most appropriate model. Based on evaluation of interpretability of different models, it can easily be suggested that CA has many advantages over the others. These are;

- CA has a great capability as defining transition probabilities policies under possible scenario alternatives
- MCE based suitability maps for different policy alternatives can be integrated with CA module as transition which makes CA flexible
- Existing IDRISI CA Module is very easy to use than other tools under the well known GIS software
- It also present urban growth scheme which very useful for urban planners

After the selection of the most appropriate planning support tool for simulation it is necessary to set up the model which will be applied to the case. This process is briefly explained in the following section.

3.4 Construction of the Model Framework for the Case Study

In order to apply spatial planning policies into simulation through Famagusta, different scenario perspectives should be constructed such as “Do Nothing Scenario” and “Sustainable Scenario”. Since this study seeks the sustainable urban development alternatives based on the spatial planning, these policies should be adopted into simulation process too. Therefore, literature review about sustainable urban development and spatial planning policies is required as the first step of the application model (Figure 3.8). Selection of proper model that supports spatial planning policies to reach sustainable urban development simulation through the case follows this step.

After selection of the proper simulation tool (CA), the defined scenarios perspectives, policies and spatial growth tendencies should be analyzed for the case area by having interviews with local experts and analyzing existing spatial temporal growth. Under “Do Nothing Scenario” local experts interviews were used for understanding spatial factors that defining existing urban growth for 2002 and 2011 years. Additionally, Markov chain tool was applied for having transition probabilities between different land use classes. Finally, 2020 development alternative was modeled by using transition probabilities and spatial criteria weights for Famagusta.

Sustainable Development Scenario simulation was mainly constructed by spatial planning policies. These policies adopted from literature review. Then they are converted into spatial criteria set and inputted into MCE based cellular automata for Sustainable Urban Growth Modeling for 2020.

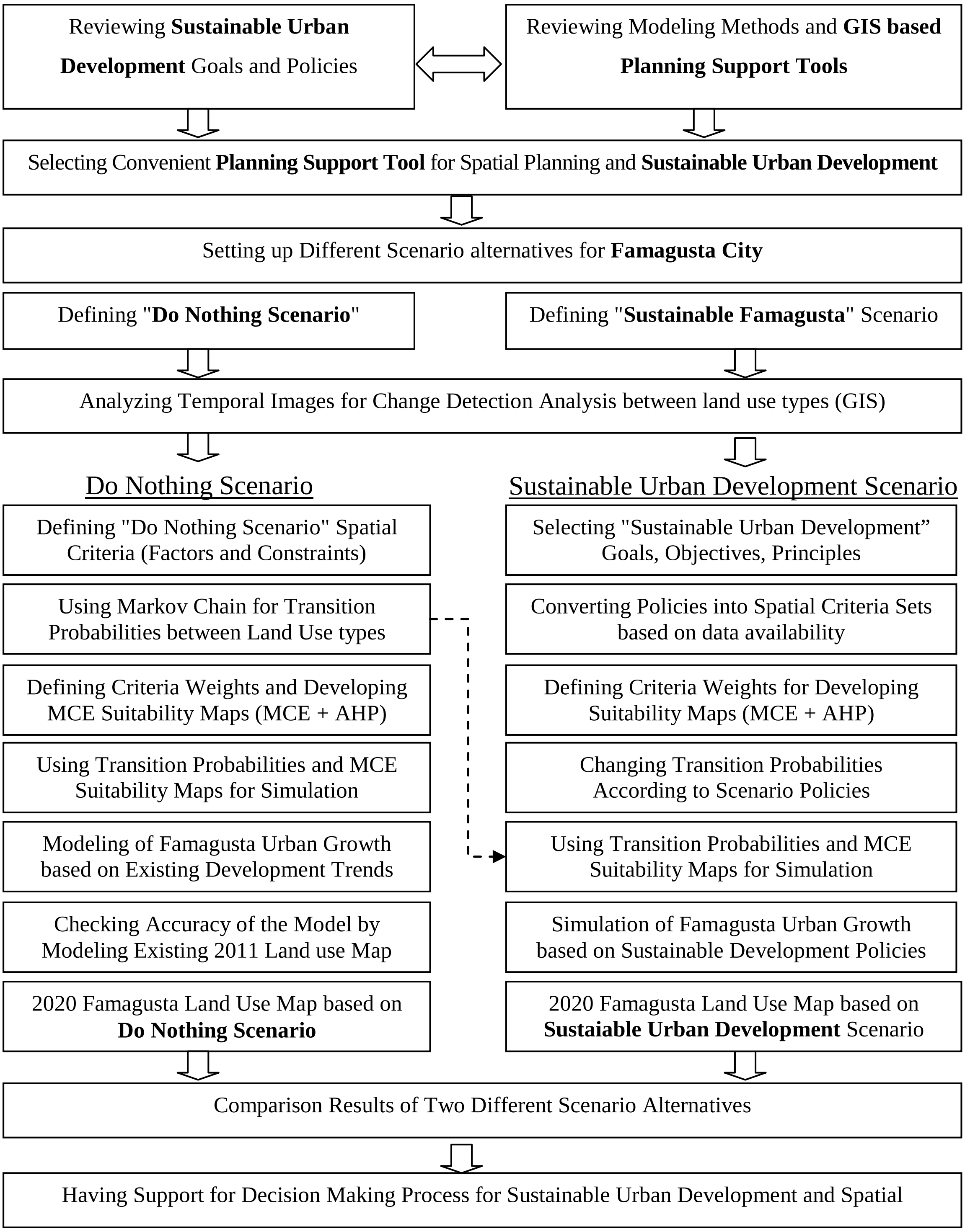


Figure 3.8**:** Model Framework for the Case Area

3.5 Summary

There are many different GIS based planning support tools and it is important to ask which method would be better in simulating urban growth or can be used in spatial planning decision-making process. Within this framework, GIS based tools and urban growth methods are presented in this chapter. According to Cheng (2003) three major criteria are important for selection process. These are data requirement, linkage with GIS and interpretability. CA has a great potential for urban spatial growth simulations.

CA models are convenient for discovering many principal theoretical issues in dynamics and evaluation. A GIS based CA system should be developed to simulate the changes of urban structure for Famagusta in that manner. Operating a GIS environment, makes experts' works more easer while monitoring, evaluating, analyzing and detecting the spatial and temporal changes. The output of such integrated CA and GIS systems would be a land use and cover map with defined land use classes, such as urban, open land, forestry area, water resource and etc that are possible to change within alternative scenarios. This output can assists experts or managers to simulate future growth and evaluate strategies or policies in the decision making process.

From this point, it is important to set up an application to construct sustainable urban growth policies for different land use types by using GIS and MCE. Moreover, these policies should be adopted into CA urban growth model to predict and simulate future development alternatives of Famagusta. These steps are explained in the following chapter.

Chapter 4

CASE STUDY

In this chapter, a pilot study is presented for comprehending the methodology of the thesis. In order to achieve the goals of the study and to verify the hypothesis, the proposed model is tested on a pilot project by integrating GIS and CA. The major aim of developing this pilot project is to utilize the former city planning experiences (land use pattern, geographic analyses, regulations and plans) of Famagusta and to develop alternative development scenarios by using GIS and CA. Before applying the model brief information about Famagusta and the historical development process is given by in the following sections.

4.1 Famagusta

Famagusta (Gazimağusa) is located on the eastern coast of the island of Cyprus in the Eastern Mediterranean Sea. It has an area of 120 km^2 and has a population of 40,920 (SPO, 2013). Similar to other cities, Famagusta is also faced with several economic, social and environmental problems from a Sustainable Urban Growth perspective. For example, fragmented and incoherent growth continued sprawling urban development towards the urban periphery, heavy traffic circulations and congestion on main arteries due to the linear commercial growth etc. These problems are explained in the section 4.1.2. However, before explaining these problems, the urban growth process, in other words, the evaluation of the city will briefly be highlighted.

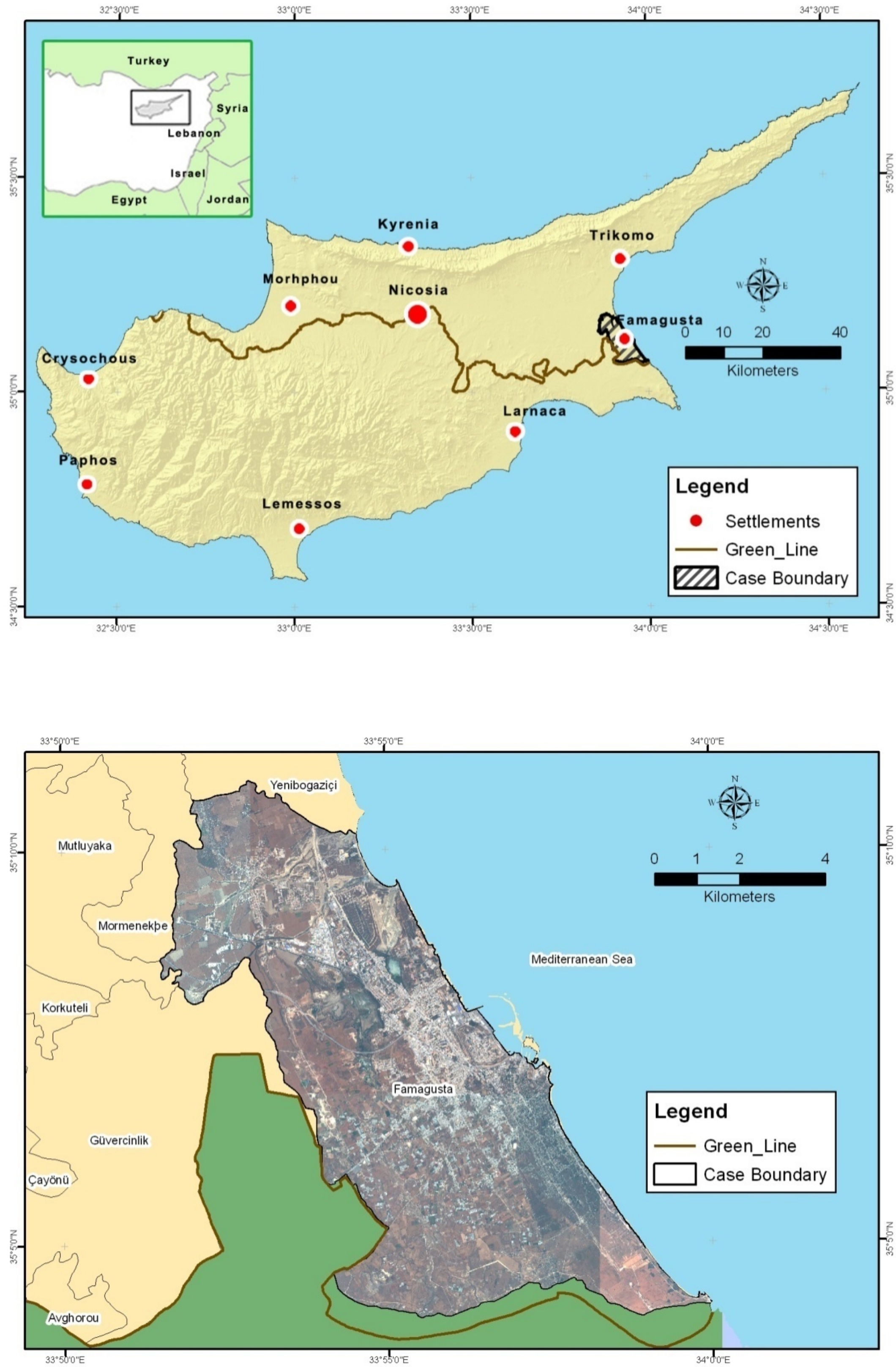


Figure 4.1: Location Map of Famagusta

4.1.1 Brief Information about the Evolution of Famagusta

According to Doratlı et al., (2001) the evolution of the urban patterns of Famagusta can be studied in seven historical periods:

The early periods (648-1192 AD – the foundation of the city)

Lusignan period (1192-1489)

Genoese Period (1372-1464)

Venetian period (1489-1571)

Ottoman period (1571-1878)

First and second British periods (1878-1960)

Republic of Cyprus period (1960-1974)

1974-1986

1986-

Famagusta, originally established as a small fishing village, came to prominence after the destruction of "neighbouring Salamis/Constantia by Arab raiders (Saracens) in 648 AD. It later became an important commercial port town.

The Lusignan era of Famagusta was signified by the crusades resulting a significant increase in religious architectural structures in the city (Doratlı et. al., 2001). Moreover, initiation of a larger fortified city is dated within this period.

Impressive fortification of the city of Famagusta was vastly taken place during the Venetian Period. This fifteenth century fortification "is a superb example of a fortified Medieval city with its bastions, citadel (Castella), moat (cut out of solid rock), [and] Sea Gate (Porte del Mare)"

The importance of Ottoman Period in historical transformation of Famagusta was the relocation of non-Muslim population out of the inner city following the Ottoman interventions in Cyprus. This resulted in segregation among population forcing Greek Cypriots to live mainly in the Varosha (Maras) and Kato Varosha (Asagi Maras) areas south of the walled city.

In the British Period, Turkish population was located in the inner town while Greek population continued to live mainly in Varosha region which became the center of urban growth during the period. Two significant developments of the period were the increase in port's importance and the increase in population living outside of the walled city. Varosha which was located on the south of Famagusta continued its development throughout the period towards becoming a commercial centre and tourist resort by the end of the British Period. An administrative base was also established by the British between Turkish and Greek regions which were in contrast with the traditional implementation of creating a center in the inner town.

During the British Period, especially in the late 1960s, Famagusta attracted the attention of the world as an entertainment and tourist centre with its unique structural characteristics displaying both British colonial prints and modern architecture mostly present in Varosha. Once being a small port in the seventieth century, Famagusta became a representative of universal trends in contemporary architectural movement in the 1970s (http://en.wikipedia.org/wiki/Famagusta)(Figure 4.2).

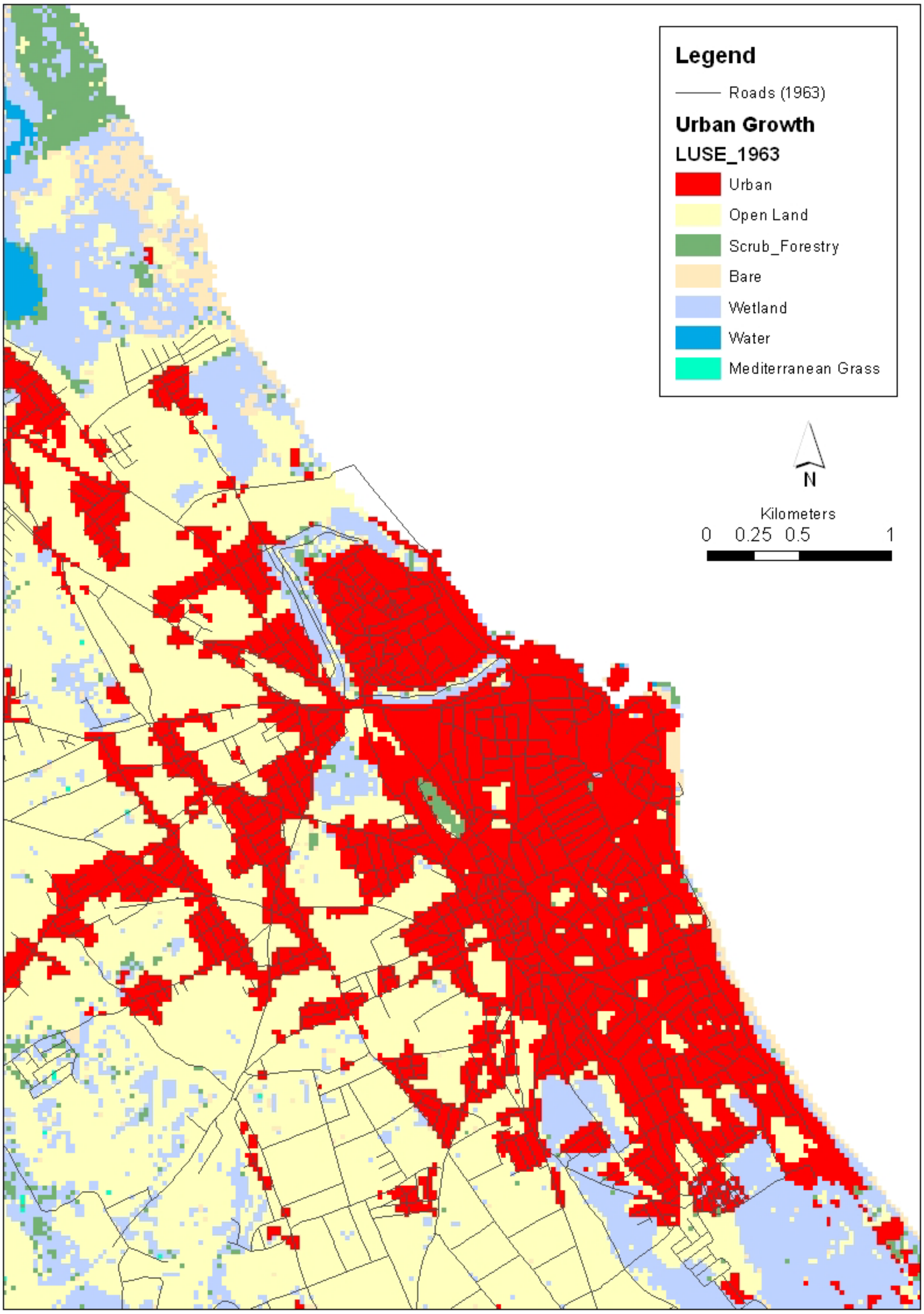


Figure 4.2: Famagusta Land Cover and Urban Growth 1963

In 1974, Famagusta's political, social, economic and physical dynamics have changed drastically with the Turkish army's interference in the island aiming to protect Turkish population. This milestone pointed the final step in the segregation of Turkish and Greek communities in the island. Political and economic embargos following the intervention put a giant obstacle in front of the city's tourism sector. Moreover, Varosha's closure to both populations deepened the severity of the situation and directed the city's linear growth towards the north (Doratlı et. al. 2001;Oktay, 2005). In contrast with the significant changes in demographics of the island, the spatial configuration was preserved after the war.

4.1.1.1 1974 and 1986

Turkish Army's intervention separated the Island into two regions gathering Turkish in the north and Greek in the south. This had a major negative impact on Famagusta minimizing its importance in the island. Especially, Varosha which was the most developed region of the Famagusta became deserted due to UN decisions of leaving the region uninhabited. Moreover, Varosha which was the main tourist attraction of the island lost its significance and Famagusta's commerce activities came to a hold down turning its growth and development trends.

In contrast with Varosha, walled city continued to show progress(Figure 4.3). The main reason behind this growth and development was resettlement of refugees from south and settlers from Turkish Anatolia mainly into evacuated properties. Resettlement was directed towards Kato Varosha region in order to preserve existing agricultural areas (Dağlı & Bayındır, 1997). Abandoned buildings by Greek Cypriots created a large pool of housing which was more than enough for the Turkish inhabitants of the city.

Based on the Town Planning Department's factsheet (1981), Famagusta's population increased to 20,000 due to Turkish migration from Anatolia and population exchanges between Turkish and Greek Cypriots after the war.

While Kato Varosha (Aşağı Maraş) was the main spot for the Turkish settlers, Baykal, Çanakkale, Dumlupınar, Namık Kemal, Sakarya, Tuzla, Canbulat and Lala Mustafa Paşa districts were populated by Turkish Cypriot refugees. Around 70% of the local refugees resettled in Famagusta's abandoned properties and only 30-35% of the pre-1974 Famagusta locals stayed in the city. This resettlement and migration process increased the demographic heterogeneity of Famagusta drastically.

Additionally, the termination of the flagship tourism sector degraded the position of the city to a regional center providing commercial, administrative and educational services for its newly defined hinterland. Although being restricted to a certain extent due to the new circumstances, the harbor still kept its important position in trade activities of the northern part of the Island.

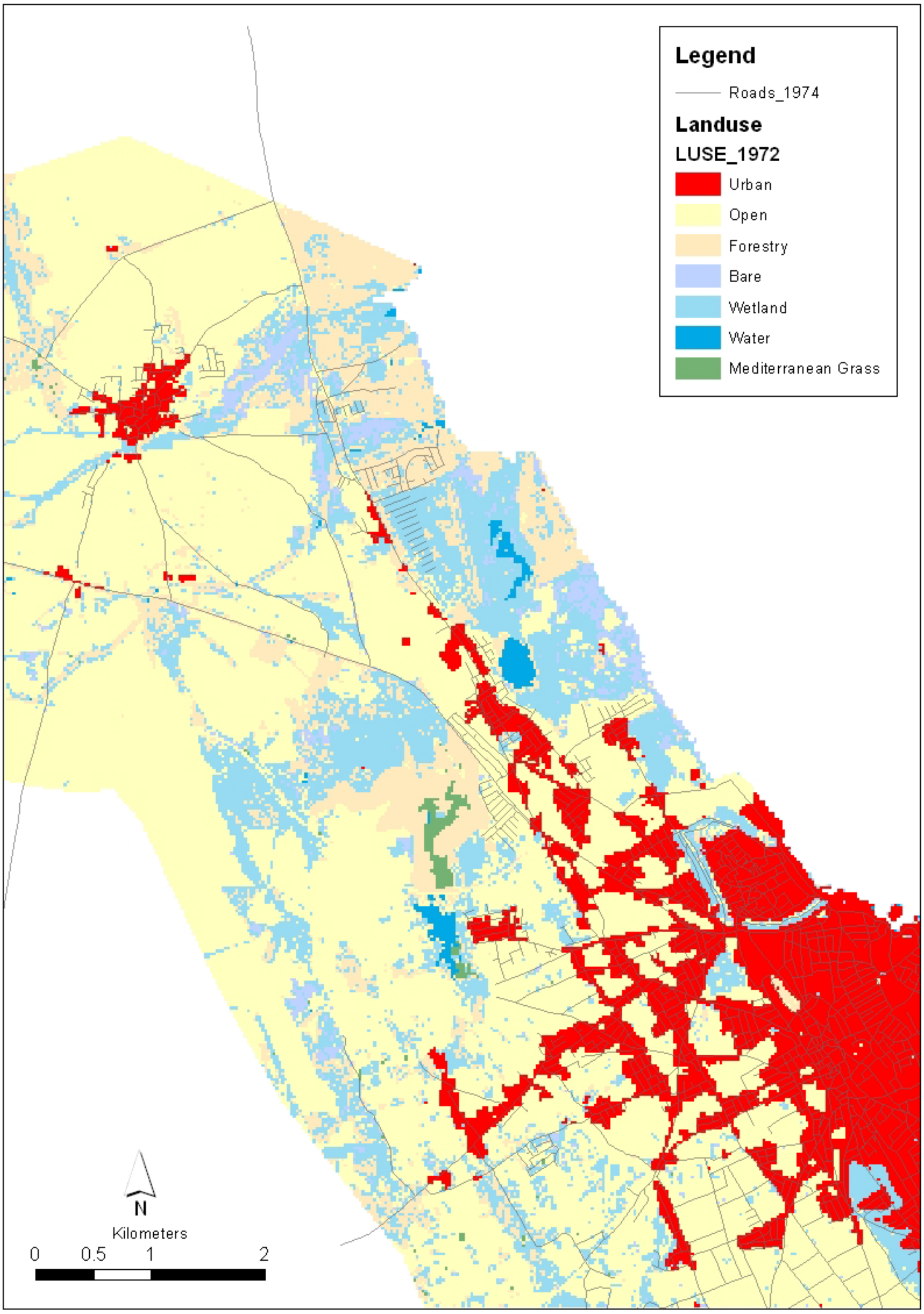


Figure 4.3: Famagusta Land Cover and Urban Growth 1974

Accordingly, the studies show that, until 1981, the rate of development remained at a very limited level. Reorganized and regenerated economic activities, unadjusted land and property ownership issues influenced the urban growth and development pattern of the overall city and exposed a completely different image and identity to the city than that before 1974. This can be considered as a natural result of the uncertainties in political circumstances. Following a very stagnant period, the Walled City, and the newly developing residential quarters (Karakol and Baykal districts), where land and property ownership patterns did not create a constraint against development, showed some growth and development tendencies.

The establishment of a High Institute of Technology in 1979 and development of social housing projects by the central authorities (initiated in 1982) also played and important role in shaping these tendencies in this period.

4.1.1.2 After 1986

With a domestic population of 105 students in its High Institute of Technology in the first academic year of 1079-80, the university attracted a huge number of international students, a rise of almost a 100% in a six year period (reaching a total number of 1,008 students). This number increased by ten folds in the forthcoming ten year period between 1986 and 1997. Its population in 2005 stood at 14,063, representing one third of the total population of Famagusta and its environs which is a total 46,000-31,285 (local residents) plus 15,000 (university students and staff).

Famagusta is one of the SIDS cities and its urbanization process has dramatically grown up since Eastern Mediterranean University was established in 1986. As a result, unorganized and uncontrolled vast urban development has started to consume land resources by incompatible policies and decisions. Traditional (conventional) planning approaches, lack of master and physical plans, old (out of date) legal frameworks and inefficient institutional departments unfortunately do not meet the needs of the vast development in the city. Moreover, significant physical barriers, which include the closed Varosha, the Limni Forest and the Gulseren military base, encouraged linear city growth towards the University and beyond, which supports urban sprawl and suburbanization. Consequently, this kind of developmental process has brought many problems to the city.

4.1.2 Overview of the Existing Problems

There is no doubt that rapid urban growth brought many problems to the built environment. In addition to literature survey, interviews were held with different experts, academician and stakeholders from different Universities, Governmental Offices, NGOs, etc in order to understand the problems. Experts from the Famagusta Municipality, the Chamber of Environmental Engineers, the Chamber of Town Planners, the Town Planning Department, the Geology and Mining Department, the Waterworks Department, the Antiquities Department, the Eastern Mediterranean University and the Near East University were selected for the case interviews. These are presented in Table 4.1.

Table 4.1**:** Selected Departments and Experts for Interviews

Departments	Town Planning Department	Town Planner
	-Environmental Protection	Environmental Engineer
	-Agriculture	
	-Geology and Mining	Geologist
	-Waterworks	Water
	-Forestry	Forest Engineer
	-State Planning Organization	Town Planner
	-Famagusta Municipality	Architect
		Manager
		Landscape Architect
		Civil Engineer
University	-EMU – Faculty of Architecture	Architect
	-EMU – Faculty of Economy	Economist
	-EMU – Faculty of Social Sciences	Economist
Chambers	-Chamber of Town Planners	Town Planner
	-Chamber of Architects	Architect
	-Chamber of Civil Engineers	Civil Engineer
	-Chamber of Environmental Engineers	Environmental Engineer
	-Biologist Association	Biologist
	-KADEM	Sociologist

According to the different stakeholders and experts, Famagusta has many different problems. These are given as follows;

Environmental Problems;

- Traffic problem is too high because of the linear urban development based on two major arteries (Salamis Road, Mustafa Kemal Boulevard)
- Lack of appropriate car parking areas on major roads
- There isn’t any surface water protection on the small lake area in Gulseren
- Solid waste problem; crude storage is still taking place. Modern solid waste management is not practiced.
- Biodiversity lost the disappearance of the wetlands in Tuzla – the simplest example is what the municipality did to the Gulseren pond. It is being filled with rubble. Also the same thing is being done to other wetlands and lakes/ponds. The building permissions which are given next to these areas are also building up pressure.
- Irregular structuring; the absence of master planning is a reason for irregular structuring. Settlements are being developed on water courses, lakes or places such as Tuzla that have terrain problems. In other words unsuitable site selection for Housing areas, which ignores the high water level, creates structural problems in the Tuzla region
- Piecemeal and fragmented growth particularly in housing environments, which is a continuous sprawl of urban development towards the periphery of the urban area
- Abandoned (Unused) areas; Free Zone and Harbor surroundings areas should be subject to renewal
- The absence of efficient water management; Güzelyurt is still providing water for Famagusta. This problem has been around for years even though a sea water treatment plant has been made established recently.

Economic Problems;

- Economic embargos; Famagusta is faced with economic embargoes and restrictions on trade (inefficient utilization of the port)
- Limited economic activities; Lack of industrial development in the city with other sectors such as manufacturing
- Dependence on the student population as a service sector brings the question of sustainability of economy in the future
- Lack of alternative sectors for economic growth
- Too limited tourism activities even Famagusta has many potential areas tourism such as the historical town (walled city) and ancient ruins in Salamis

Social Problems;

- Inequity on investments; from the 1974 Varosha region (Aşağı Maraş) haven't been invested from governmental organizations
- Increased drug use
- Lack of cultural activities and community services.

Institutional Problems

- Lack of Planning: There isn't any planning activity related to master planning or land use planning process. Lack of planning document can be called one of the main environmental problems in Famagusta. Moreover, There isn't any vision for transportation nor a public planning policy
- Uncertainty on Varosha, Political issues create a problem for urban growth. Areas are located on the southern part of the city. These haven't developed

for many years. Municipality or other Governmental Organizations and also residents of the city don’t invest in these regions for many years.

- Military areas; there are big military areas that are located within in the city and that are preventing the connection of the city with coastal areas. This creates significant disadvantages in terms of compact growth.

As can be seen from above, there are many problems against sustainable urban development in Famagusta. In order to overcome these problems, stakeholders and experts were asked what their main goals and objectives would be and how they would make them sustainable. In order to create Sustainable Urban Growth for Famagusta the main objectives have been set for Sustainable Development scenario (Figure 4.4).

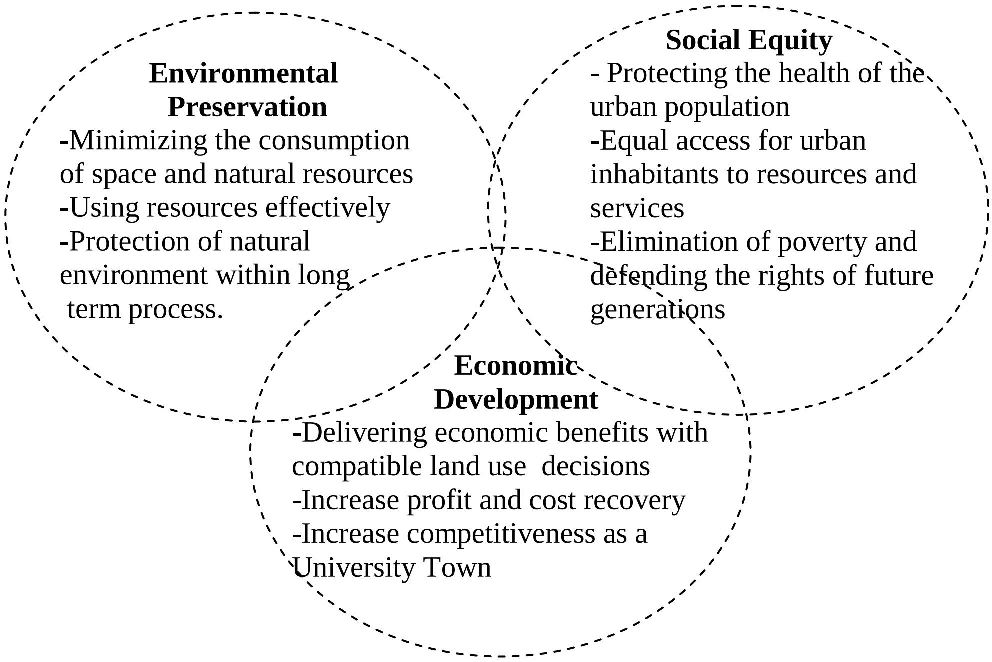


Figure 4.4: Sustainable Urban Development Scenario Objectives

As can be seen above, the Sustainable Urban Development in Famagusta can be achieved by following the policies indicated in the following Table 4.2

Table 4.2**:** Sustainable Famagusta: Sustainable Urban Development Policies

Physical/Environmental	**Economic**	**Social/Institutional**
• *Promote compact urban form* • *Increase amount of mixed use land* • *Increase density of built up areas* • *Re-use (re-develop) of existing vacant urban area (infill and brownfield)* • *Redevelopment of urban centers for area use optimization* • *Protection of Natural Resources* • *Discourage growth in natural areas like wetlands, steep slopes, flood plains, and stream corridors (such as Limni Forest, Tuzla wetland areas and so on* • *Relocation of industrial areas from natural areas.* • *Selecting suitable areas for urban development* • *Protection of water resources* • *Preserve historic resources and archeological sites by proper land use functions* • *Capitalize on, but do not harm natural amenities by proper recreational uses (like rivers, forested or wooded areas, wetlands, etc)* • Consider sustainability of future water supplies and impacts of solid and liquid waste treatment and disposal • Increased recycling improved solid waste management and waste water treatment • Encourage public transport • *Promote effective and environmentally sound transportation systems such as bicycle or pedestrian* • *Reduce average travel time, reduce emission and green house gases*	• *Providing competitive education services and increasing student numbers for economic viability* • *Encouraging environmentally sensitive tourism and recreational activities* • *Strengthen small and micro enterprises in tourism and manufacturing sector by new investments* • Encourage public-private sector partnership and stimulate productive employment opportunities • Increase economic profit by encouraging local ownership of business • *Promote and support organic agriculture activities*	• Provide equal opportunities for a safe and healthy life • *Minimization of traffic derived noise* • Improving equal traffic safety through city (Victims of traffic accidents) • *Ensuring equal accessibility of basic services* • *Ensuring equal accessibility to open spaces* • *Ensuring equal accessibility to municipality services* • Ensuring equal safety and security • *Adaptation of strategic approach to planning* • *Preparation of Land Use Plans* • *Relocation of military areas*

**Policies related to land use planning are presented in italic.

4.2 Application of the Model

In the following sections, the urban growth of Famagusta city is tried to be predicted for the current conditions and development trends, which is called the Do Nothing Scenario. Then, a similar model is employed by applying Sustainable Urban Growth policies by Policy Driven Scenario (Spatially Integrated Urban Growth).Therefore, the model application starts with the prediction of urban growth and it's explained to present an unsustainable future of Famagusta. In other words, it tries to present that Famagusta is diverging from sustainable practices.

4.2.1 Prediction of Urban Growth under the Do Nothing Scenario

Application of model for urban growth includes a basis for understanding of how cities are built. In other words, it is required to understand which factors are the reasons for urban change. In this manner, the factors that are related to urban change should be defined by monitoring temporal Land use images. This step is the beginning of CA model application for the case study (Figure 4.5). It is stated that under this scenario it is assumed that; there will be no master plan and developments will take place to Famagusta.

Monitoring land use changes by time series images requires development of these images within a GIS environment. Since growth of Famagusta has been changing from 1974, different land use images have been constructed by using 25000 and 5000 scaled maps for years 1986 and 2002, 2008 Land cover map, 2011 Satellite Images (Quickbird, 3-Band, Transverse Mercator, 50*50 Resolution), etc are used for the development of time series land use images. This process is detailed in the Data Development Process section.

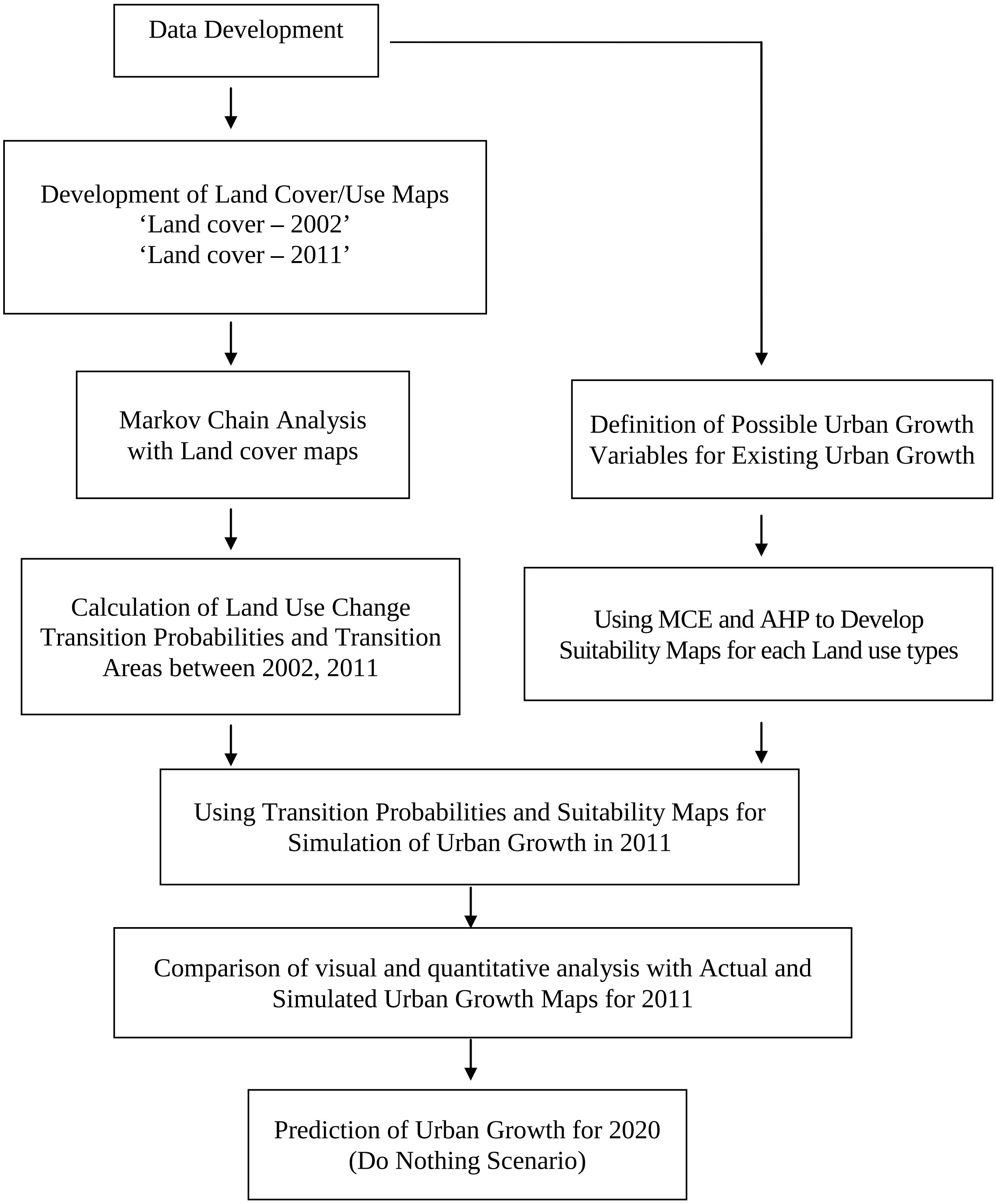


Figure 4.5**:** Do Nothing Scenario Cellular Automata Application Steps (Liu, 2009)

4.2.1.1 Data Development Process

The required spatial layers and their attributes were developed by creating digital layers or updating existing ones. These digital thematic maps were developed by employing the following commonly used procedures (Sumathi et al., 2008)

- Scan of the related paper maps
- Using geo-referencing technique for scanned maps to give coordinate
- Using digitization for developing features derived from referenced maps
- Obtaining the GPS coordinates and marking important points from satellite image
- Conversion of the latitude and longitude data into the point data using the software
- Modification of existing layers

In order to perform spatial analysis given above, widely used GIS software ArcInfo 9X was used for creating GIS layers and geo databases attributes (Kara & Doratli, 2012) (Table 4.3).

Table 4.3: Spatial Criteria Source and Attributes of Spatial Data Used In the Case

No	Name	Map(Data Formats)	Source
1	Road Network	-Road Layer (Shapefile) -2012 Satellite Images(Geo-referenced Image)	Famagusta Municipality
2	Urban Areas (Residential, Industrial, Tourism, etc)	-1963-1972-1974 Urban Maps(Scanned Papers) -1986-1997 5000 Scaled Maps (Scanned Papers) -Land Cover Map (2008) (Geo-referenced Image) -2012 Satellite Images (Geo-referenced Image) -Land Use Survey (Field Survey)	Town Planning
3	Surface Water Resources (Dams, Rivers, etc)	-1/25000 Hydrology Maps (Scanned Papers) -Land Cover Map (2008) (Geo-referenced Image)	Waterworks
4	Ground Water Resources (Aquifers)	-1/25000 Geology Maps (Scanned Papers) -Land Cover Map (2008) (Geo-referenced Image)	Geology-Mining
5	Environmentally Sensitive Areas	-NATURA 2000 Sites Map (Shapefile)	Environmental Protection
6	Cultural Heritage Sites	-Excel Sheets with Latitude, Longitude Values	Antiquities
7	Soil Classification (Primary Soil, Secondary Soil, etc)	-Soil Classes Map (Shapefile)	Agriculture
8	Vegetation (Forestry, Sandy Dunes, etc)	-Land Cover Map(2008) (Geo-referenced Image) -2012 Satellite Images (Geo-referenced Image)	Town Planning
9	Slope and Aspect	-Digital Elevation Model	Mapping

4.2.1.2 Development of Grid as Core Geo-Database

All required geographical information from Land use/Use maps by 2002 and 2011 were transferred into a Grid Lattice by using ArcGIS editing and spatial modeling tools. 25x25 grid lattice first developed as an ESRI shapefile format then table attributes columns for each different year were defined for 2002 and 2011. These columns were populated according to the land use classes (Figure 4.6).

Figure 4.6**:** 25x25 Meter Grid Lattice

4.2.1.3 Analyzing Land Use Changes with Temporal Images

Following Grid development for the case area, cell attributes were updated accordingly for different land use types. 13 different land use and cover types; Low dense urban, medium dense urban, university, industry, small industry, open land, forest/grass, bar ground, Mediterranean Grass, water, wetland, open-Varosha, urban-Varosha were updated for 2002 and 2011 years (Figure 4.7 and Figure 4.8). Then changes for each land use class were detected (Figure 4.9). Computer aided overlapping technique was used for analyzing changes and inputting table attribute values.

As can be seen from Figure 4.8, between 2002 and 2011, there were so many changes for Low dense urban class in the Tuzla region, University, Industry and Medium dense urban areas in the regions of Karakol, Sakarya and Çanakkale. On the other hand, urban-Varosha class has limited growth or change. Due to the political deadlock on the Cyprus problem and also property issues, the Varosha region hasn't been invested in by governmental organizations since 1974. In other words, urban-Varosha land use class has very limited growth. Therefore, existing trend, which is not open for growth, is applied for urban-Varosha land use class in the Do Nothing Scenario.

In addition to land use changes, land cover changes were also analyzed. From 2002 to 2011, open areas have been subject to transform into low-dense, medium-dense, university, industry and low industry classes. Forest/grass and Mediterranean grass areas also transform to low dense, industry and university (Figure 4.9). After development of land use change maps for 2002 and 2011, all of them converted into

IDRISI environment (see Appendix 3) and the Markov Chain tool is used for calculating transition probability between land use types.

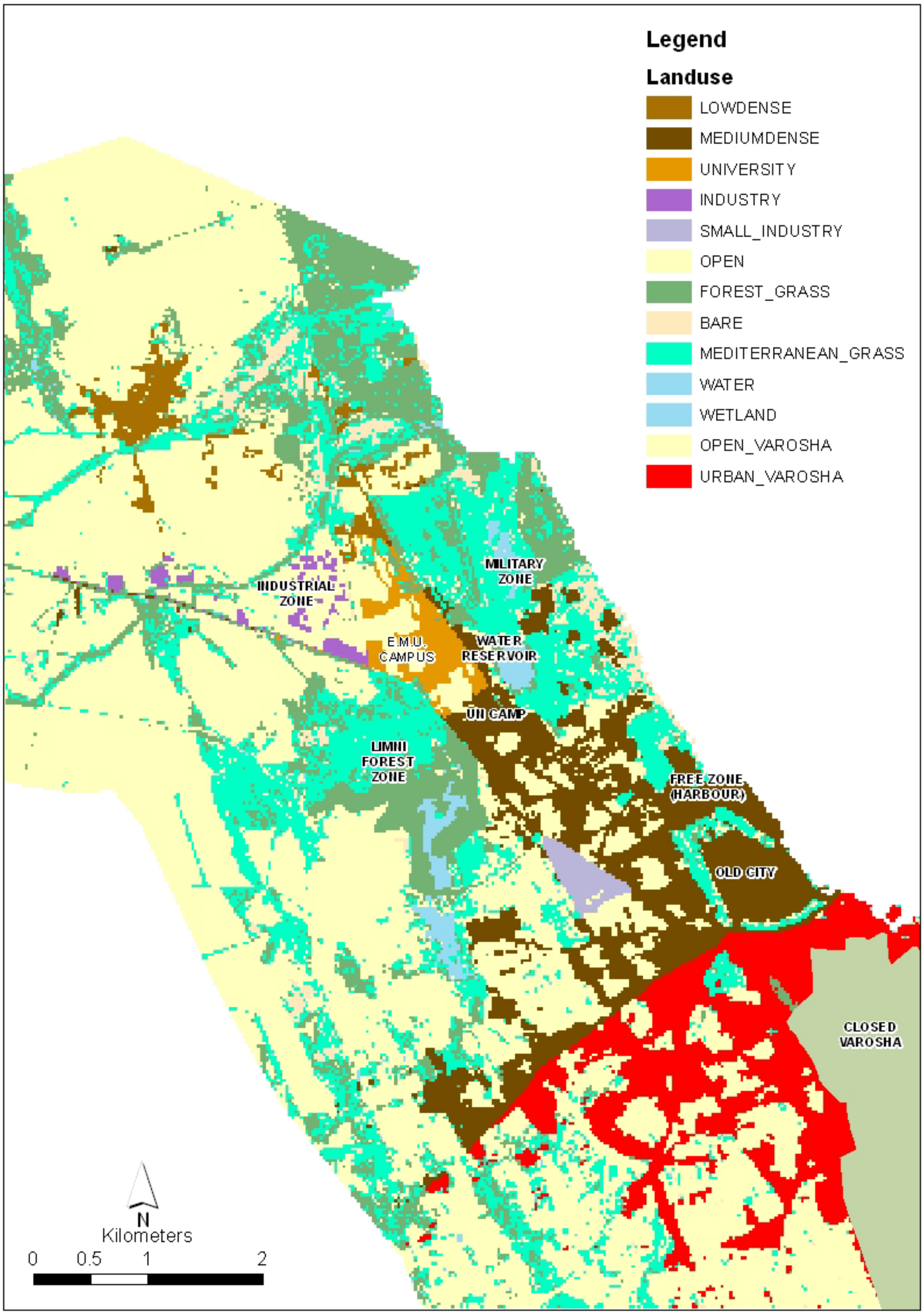


Figure 4.7: Land Use Map 2002

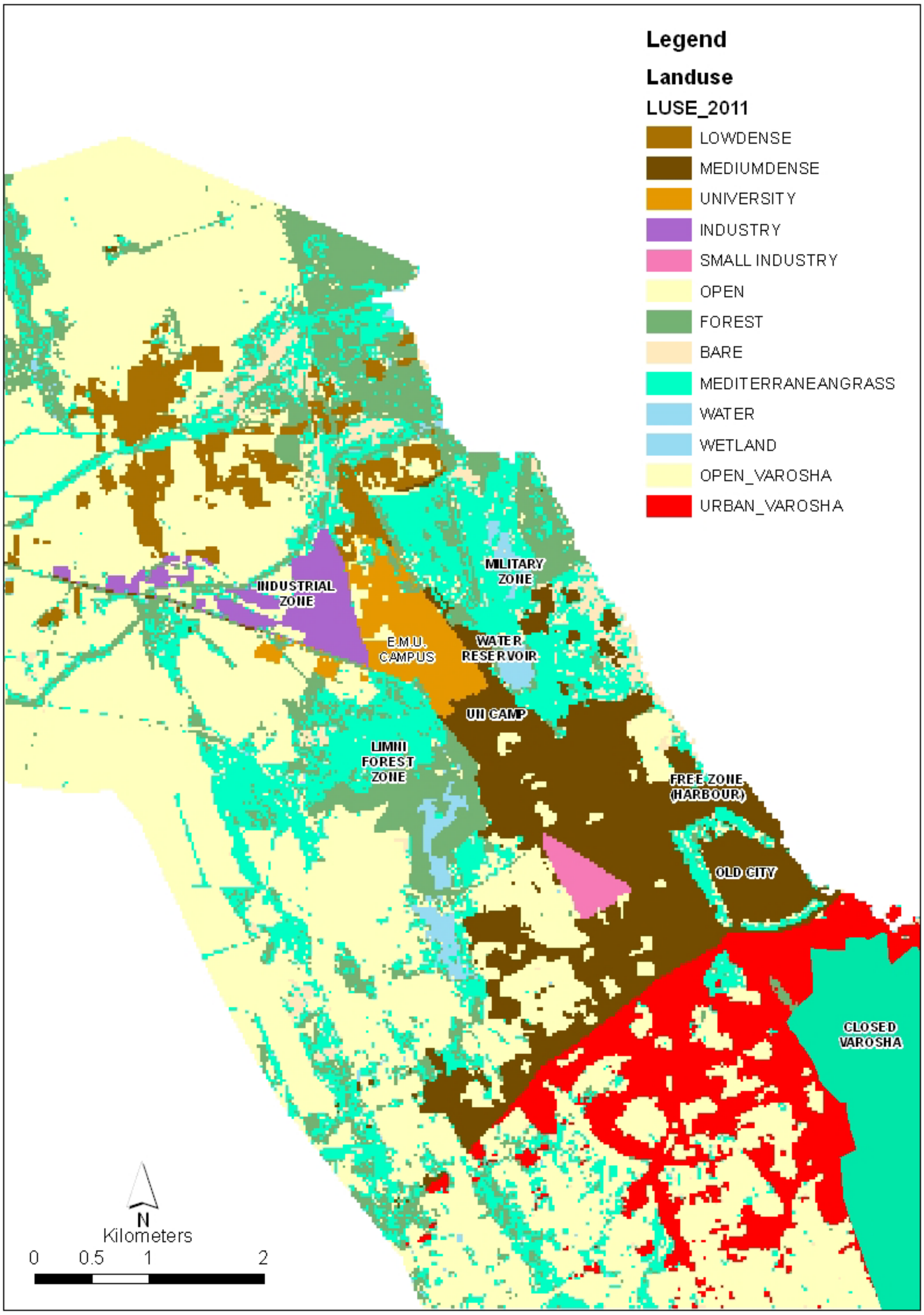


Figure 4.8**:** Land use Map 2011

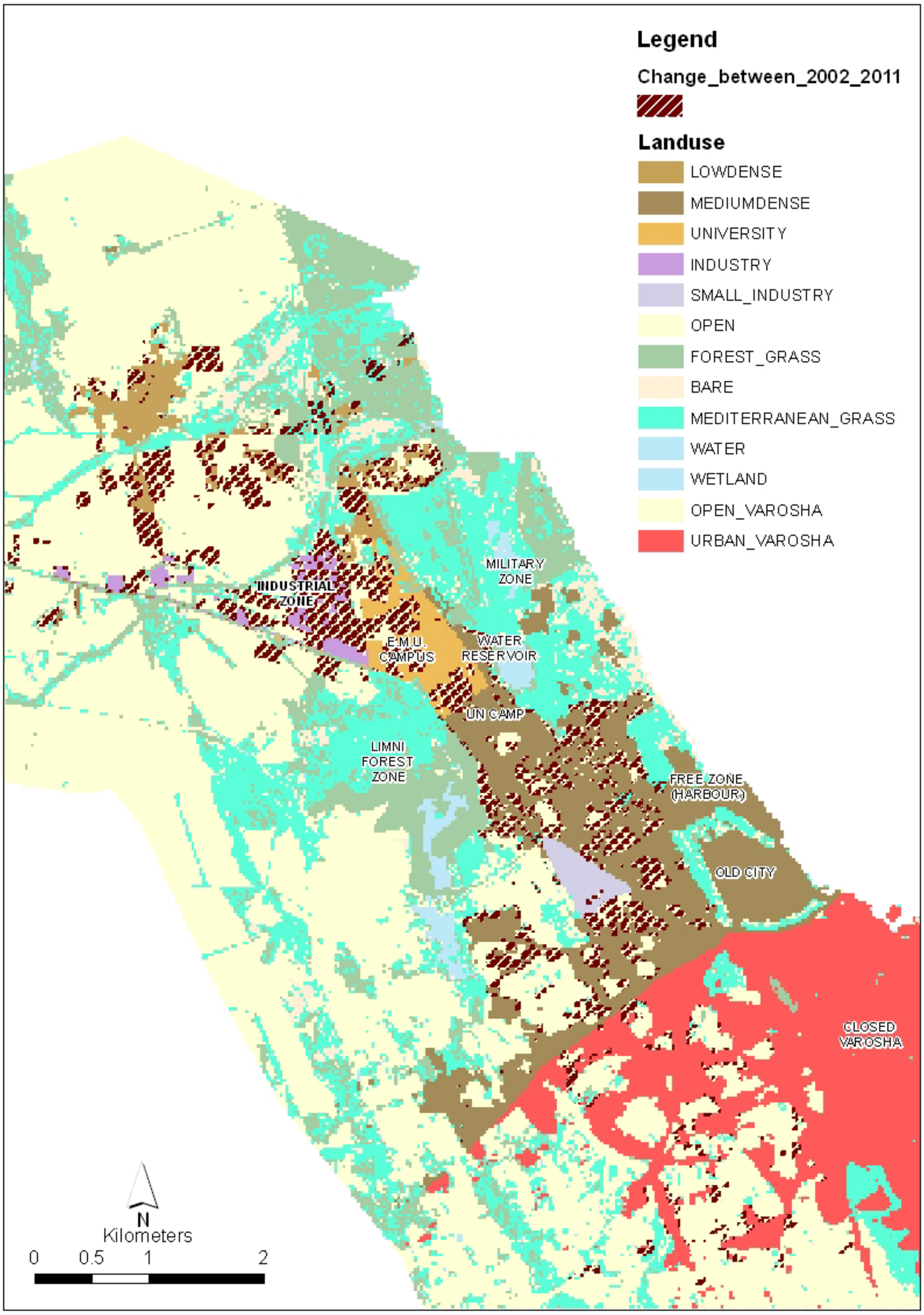


Figure 4.9**:** Change Analysis between 2002 and 2011

4.2.1.4 Markov Chain Analysis with Land Use Maps

In general, the Markov chain can be defined as;

> "A discrete random process with the Markov property whereby the probability distribution for the system at the next step and all future steps depends only on the current state of the system and not additionally on the state of the system at previous steps" (Zhang et al., 2011).

Markov chain is a proper method for understanding transition rules between different uses when changes are difficult to describe. A homogenous Markov chain can be represented mathematically as follows (Zhang et al., 2011) (Equations 4.1 and 4.2).

$$Q_{t+1} = Q_t^T P^n \qquad \text{(Eq: 4.1)}$$

$$\begin{pmatrix} q_1 \\ q_2 \\ \cdots \\ q_m \end{pmatrix}_{t+1} = \begin{pmatrix} q_1 \\ q_2 \\ \cdots \\ q_m \end{pmatrix}_t^T \begin{pmatrix} p_{11} & p_{11} & \cdots & p_{11} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ p_{m1} & p_{m2} & & p_{mm} \end{pmatrix}^n \qquad \text{(Eq: 4.2)}$$

Where n = number of time steps;

m = number of states;

Q_t = vector of initial states at an initial time, t;

Q_{t+1} = vector of states at the next time, t+1;

P = transition probabilities matrix.

In this study considering different land use types such as low dense urban, university, industry, small industry, etc. transition probabilities about land use change were calculated by the Markov chain method. The IDRISI Markov Chain tool was used to produce the transition probabilities for modeling. Table 4.4 presents transition probabilities during 2002 and 2011

Table 4.4: Markov Chain Analysis with Land use Maps, Transition Probabilities

	LOW	MEDIUM	UNIVERSITY	INDUDSTRY	SMALL IND.	OPEN	FOREST	BARE	MEDI GRASS	WATER	WETLAND	OPEN VAROSHA	URBAN VAROSHA
LOW	1	0	0	0	0	0	0	0	0	0	0	0	0
MED.	0	1	0	0	0	0	0	0	0	0	0	0	0
UN.	0	0	1	0	0	0	0	0	0	0	0	0	0
IND.	0	0	0	1	0	0	0	0	0	0	0	0	0
SMALL IND.	0	0	0	0	1	0	0	0	0	0	0	0	0
OPEN	0.027	0.0425	0.0148	0.0173	0.0007	0.8977	0	0	0	0	0	0	0
FOREST	0.0049	0.004	0.0013	0.0022	0	0	0.9876	0	0	0	0	0	0
BARE	0	0.0052	0.0016	0.0052	0	0	0	0.988	0	0	0	0	0
MEDI GRASS	0.0127	0.0046	0.0001	0.0006	0	0	0	0	0.982	0	0	0	0
WATER	0	0	0	0	0	0	0	0	0	1	0	0	0
WET.	0	0.0032	0	0	0	0	0	0	0	0	0.9968	0	0
OPEN VAR.	0	0	0	0	0	0	0	0	0	0	0	0.9373	0.0627
URBAN VAR.	0	0	0	0	0	0	0	0	0	0	0	0	1

According to the transition probabilities, open land class has many possibilities to convert to low dense, medium dense, university, industry and small industry. It has the highest probability values to convert, low dense, medium dense, university and industry land use types. This shows that open areas are the most suitable areas for future growth. Additionally, Mediterranean grass has a higher probability to transform into low-dense urban class than Forest/Grass or Bare ground.

4.2.1.5 Using MCE and AHP to Develop Suitability Maps

It is crucial to generating adequate transition rules for CA model. In this study, the transition rules are represented by group of suitability maps. These maps take into consideration both the total suitability of each land use type and the neighborhood effect (Zhang et al., 2011). The MCE and AHP (Saaty, 1980) methods were utilized for developing the set of suitability maps in case area.

MCE is mainly based on the integration of several spatial criteria to form a decision. Criteria should be separated as factors and constraints such as unsuitable (value 0) or suitable (value 1) (Kara & Doratlı, 2012). However, for these factors, WLC is a widely-used method and was utilized in this study (Eastman, 2001) (Eq: 4.3)

Suitability $S = \sum_{j=1}^{n} WjXij$

Wj= Relative importance weight of criteria j

Xji=the standardizing value of area i under criterion j

n=is the number of criteria

In order to define factors and constraints for Famagusta, it is required to monitor spatial parameters via temporal images over time and decide which spatial land use interactions are more important or how they operate over distance in practical situations. For example, Free Zone and Harbor are closed for development for housing environments. Military Zones in Sakarya, Karakol and Varosha are closed for any kind of land use development. Moreover, designated university area is only open for university class. Surface water resources such as Dams, Rivers, and Wetlands have not developed between 2002 and 2011. Areas like Limni Forest which has wetland characteristics have also been protected up to now. Therefore, these are selected as constraint criteria within the Do Nothing Scenario.

According to the land use maps 2002 and 2011, land use categories in Famagusta show tendency for preference to allocate themselves where a road development exists. In other words, they select an area which is close to existing road network. Additionally, they also tend to get closer to similar land use categories. Therefore, distance to road and distance to existing classes have been added as determining factors within the Do Nothing Scenario (Table 4.5)

Table 4.5**:** Factors and Exclusionary Zones (Constraints) for the Do Nothing Scenario

	Low Dense	**Medium Dense**	**University**	**Industry**	**Small Industry**
Constraints					
Free Zone & Harbour	*	*	*	*	*
Military Zones	*	*	*	*	*
The campus of EMU	*	*		*	*
Surface Waters	*	*	*	*	*
Cultural Heritage Zones	*	*	*	*	*
Factors					
Distance to roads	*	*	*	*	*
Distance to similar class	*	*	*	*	*

After the decision of factors and constraints to each land use type, general constraint maps were developed and converted into byte format in order to use it in modeling process (Figure 4.10 and Figure 4.11).

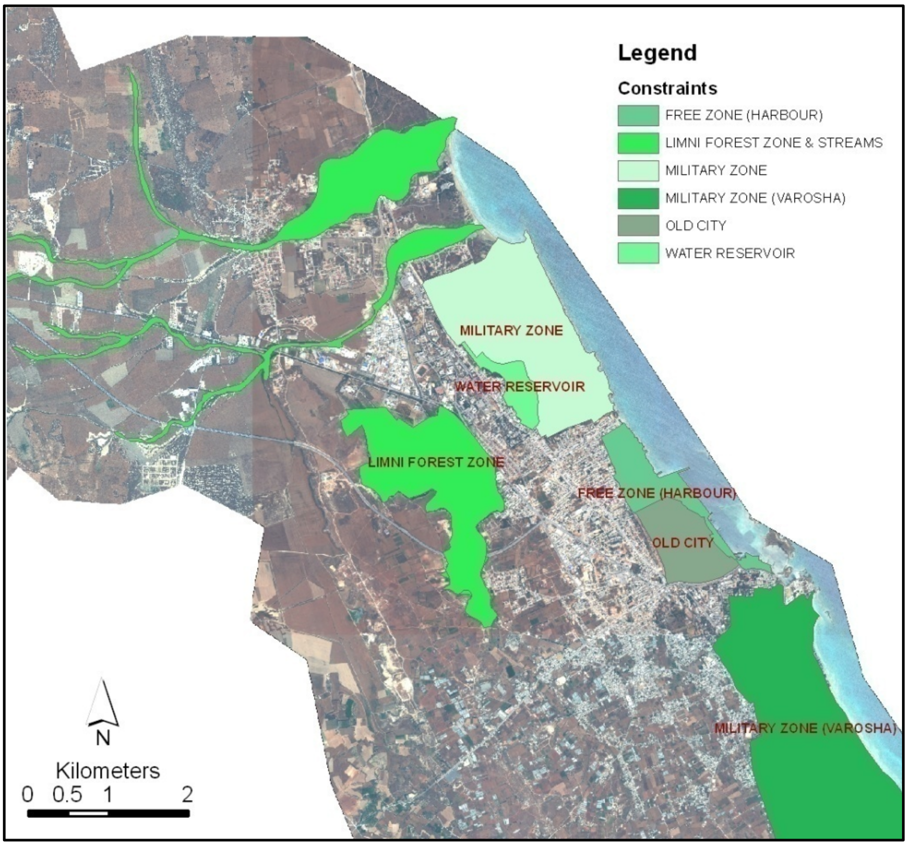


Figure 4.10: General Constraints for growth

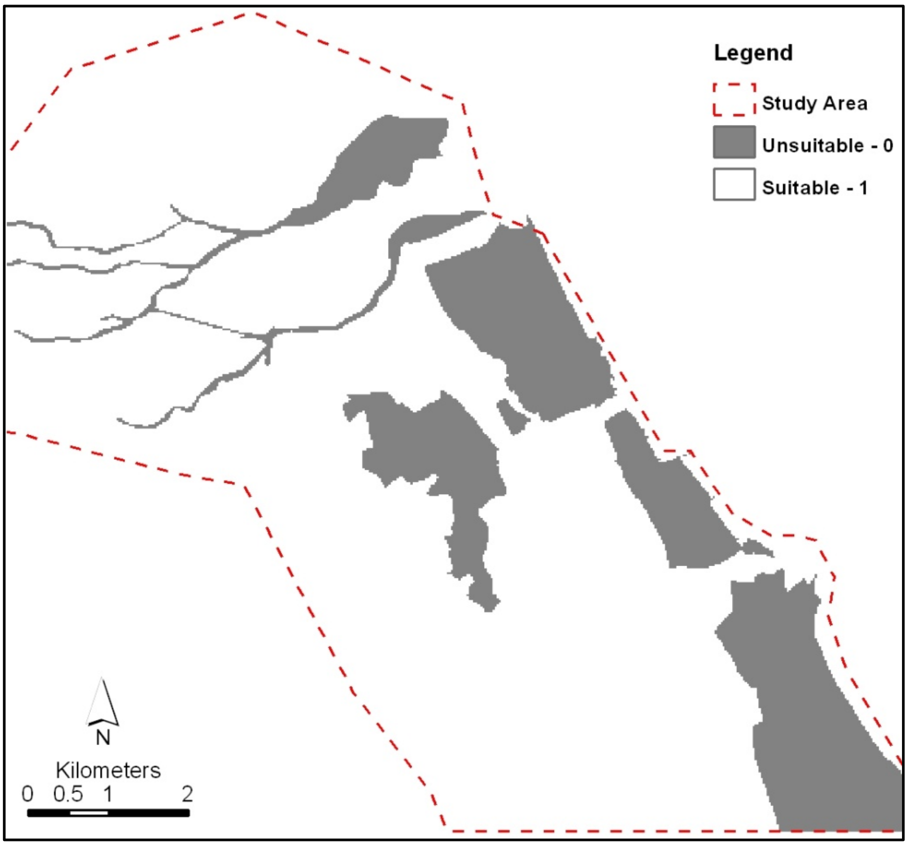


Figure 4.11: Constraint Map Development

AHP is one of the most commonly used approaches for establishing factor weights is of MCE.As it has been presented before, AHP was developed by Saaty (1980) and is based on the principle that decisions can be effectively made from a descending hierarchy from general criteria to sub-criteria, and at each particular level comparisons are made (Zhang et al., 2011).

In this study, distance to road factor is only used as factor criteria for suitability map development under the Do Nothing Scenario (see Figure 4.12). Fuzzy transformation method is used for conversion distance values into 0-255 integer type raster map for cellular automata modeling (see Figure 4.13).

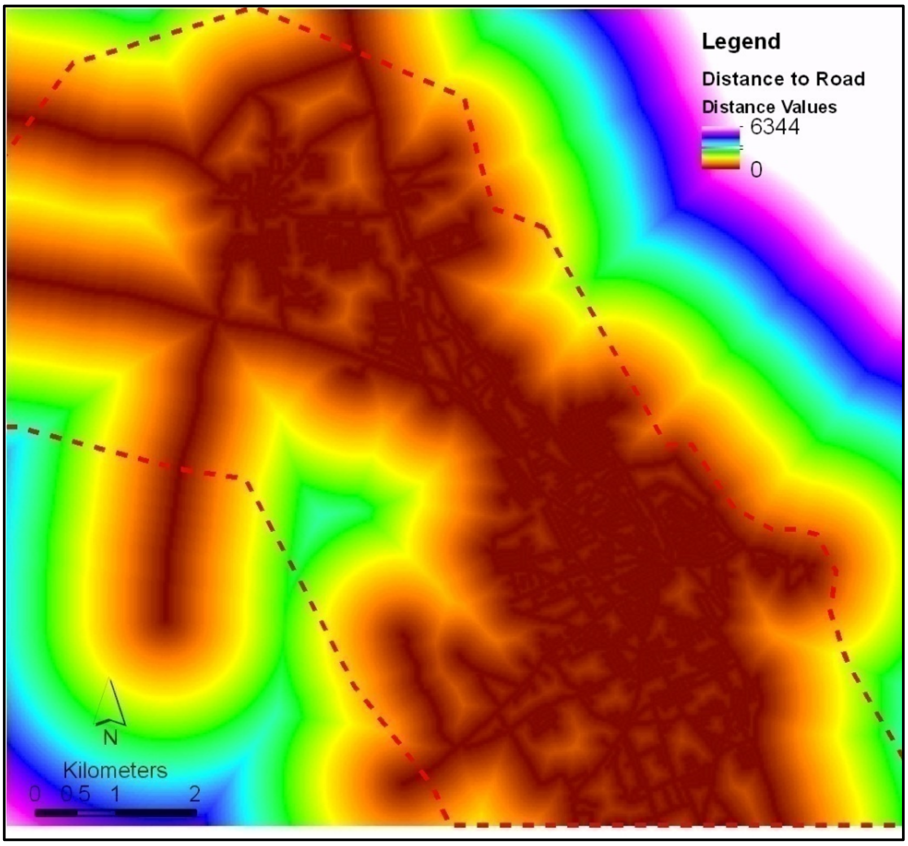


Figure 4.12: Distance to Road Map

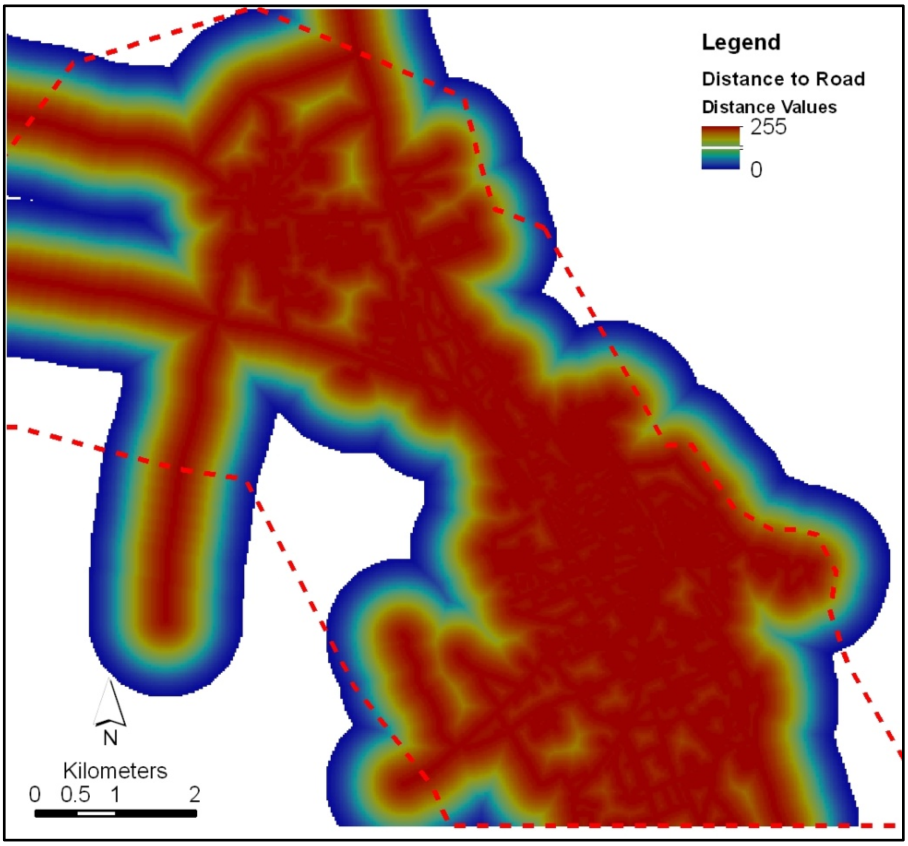


Figure 4.13**:** Distance to Road Fuzzy Transformed Map

"Simple Additive Weighting" method (SAW) was utilized to construct a suitability maps for land use types. This method is the most often used technique for spatial Multi-criteria decision making. The technique is also referred to as WLC or scoring method (Kara & Doratlı, 2012).

In this method, the decision expert assigns weights of importance to each attribute or criteria. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the criteria over all attributes (Kara & Doratlı, 2012). With a SAW, criteria sets are combined by applying a weight to each followed by a summation of the results in the suitability map (Kara & Doratlı, 2012).

Since there are many constraints within the case area, constraint mapping was produced for removing improper sites for each land use classless and to reduce the amount of the area for further analysis. Then constraint and factor criteria maps are combined for MCE suitability maps in IDRISI with Decision Support Tool (Figure 4.14).

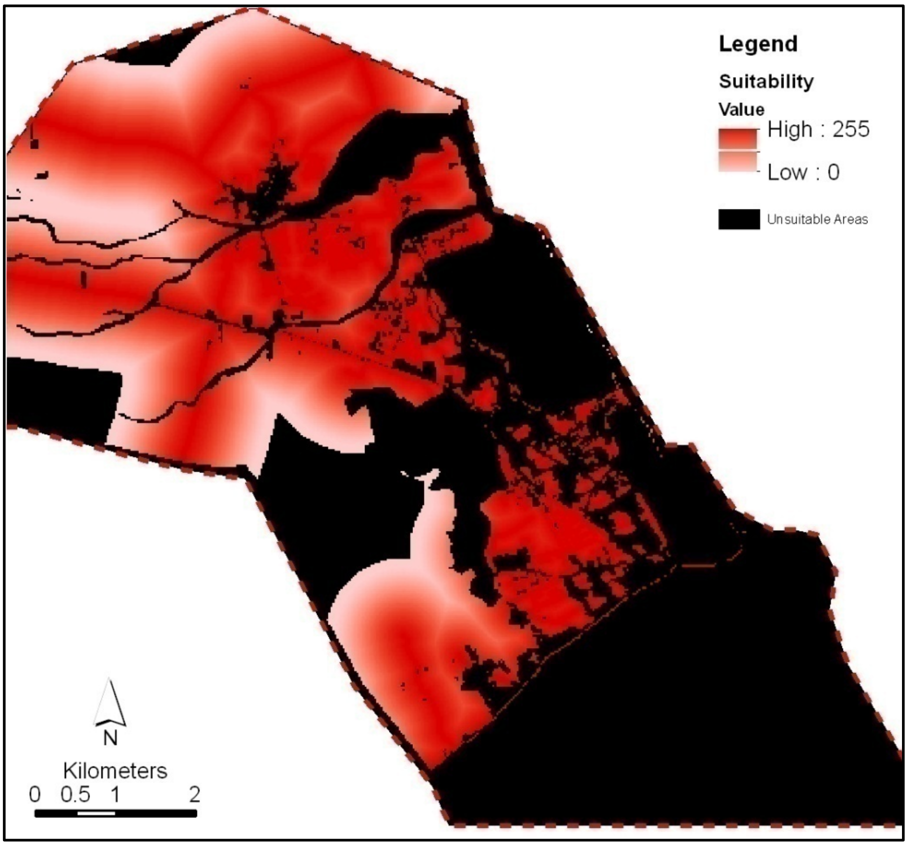
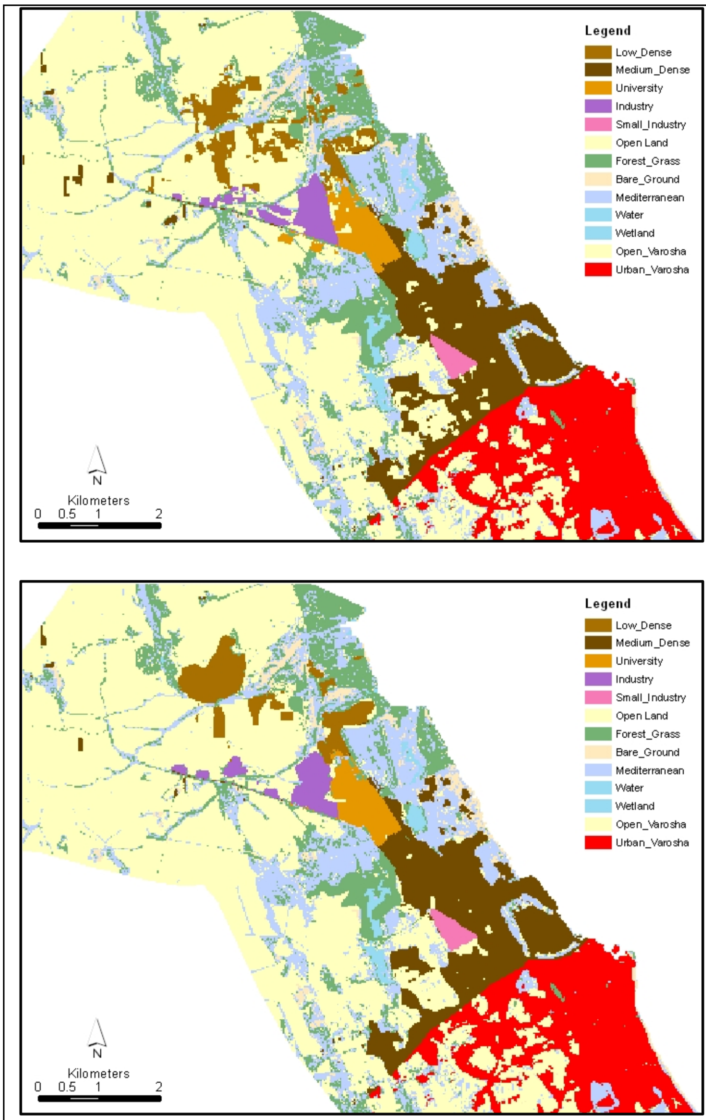


Figure 4.14**:** Combination of Constraints and Factors for Suitability Map

These constraint suitability maps are then imported into CA for defining suitability matrices for each land use type. Additionally, these maps are combined with transition probabilities for cellular automata modeling in IDRISI environment. Finally, modeling urban growth for 2011 with these MCE maps and comparing them with actual 2011 land use map is needed for checking accuracy and reliability of the model. The following section explains the accuracy results.

4.2.1.6 Comparison for Accuracy

Checking the accuracy of the model is another important step for urban growth modeling. Visual comparison and Computer aided Overlay is used for Simulated Land Use Map and Actual land use map differences in an IDRISI environment. Visual comparison presents whether the modeled urban form fits with the actual urban form or not. Figure 4.15 presents that existing linear form with land use class locations formed accordingly for the case area.



Actual Land use 2011

Simulated Land use 2011

Figure 4.15**:** Visual Comparison of Actual and Simulated Land use for 2011

It also gives a visual idea about the different land use types whether they fit with each other in terms of form and shape. As can be seen from Figure 4.15, the EMU campus and Industry zones almost look like the actual zones in the 2011 land use map. This can be seen in medium dense urban areas too. Moreover, the small industry zone has very similar shape with the actual land use in 2011. This shows that simulated 2011 land use for Famagusta has significant similarities with actual land use in 2011 (Figure 4.16 and Figure 4.17).

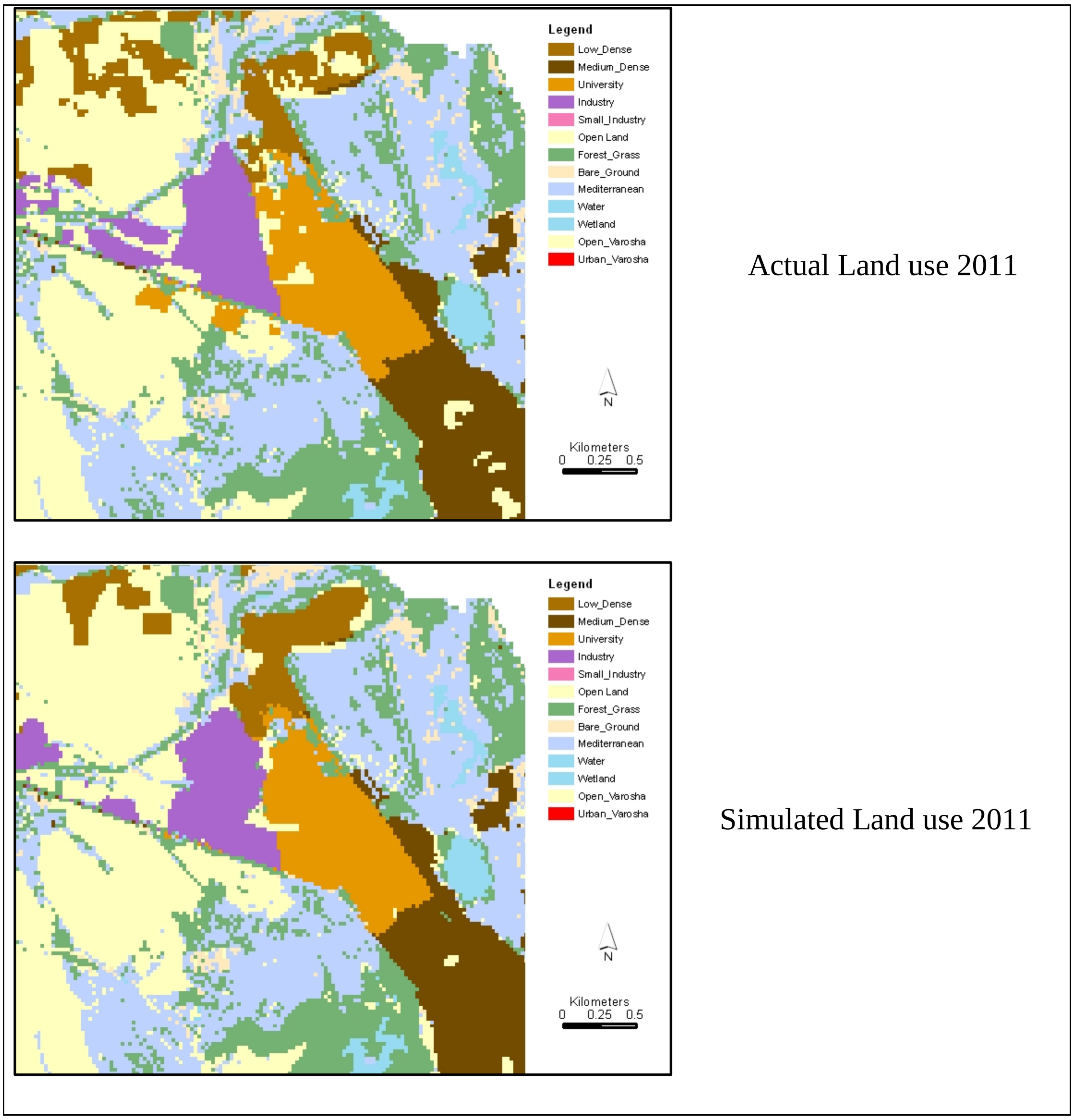


Figure 4.16**:** Visual Comparison of Actual and Simulated Land use for 2011

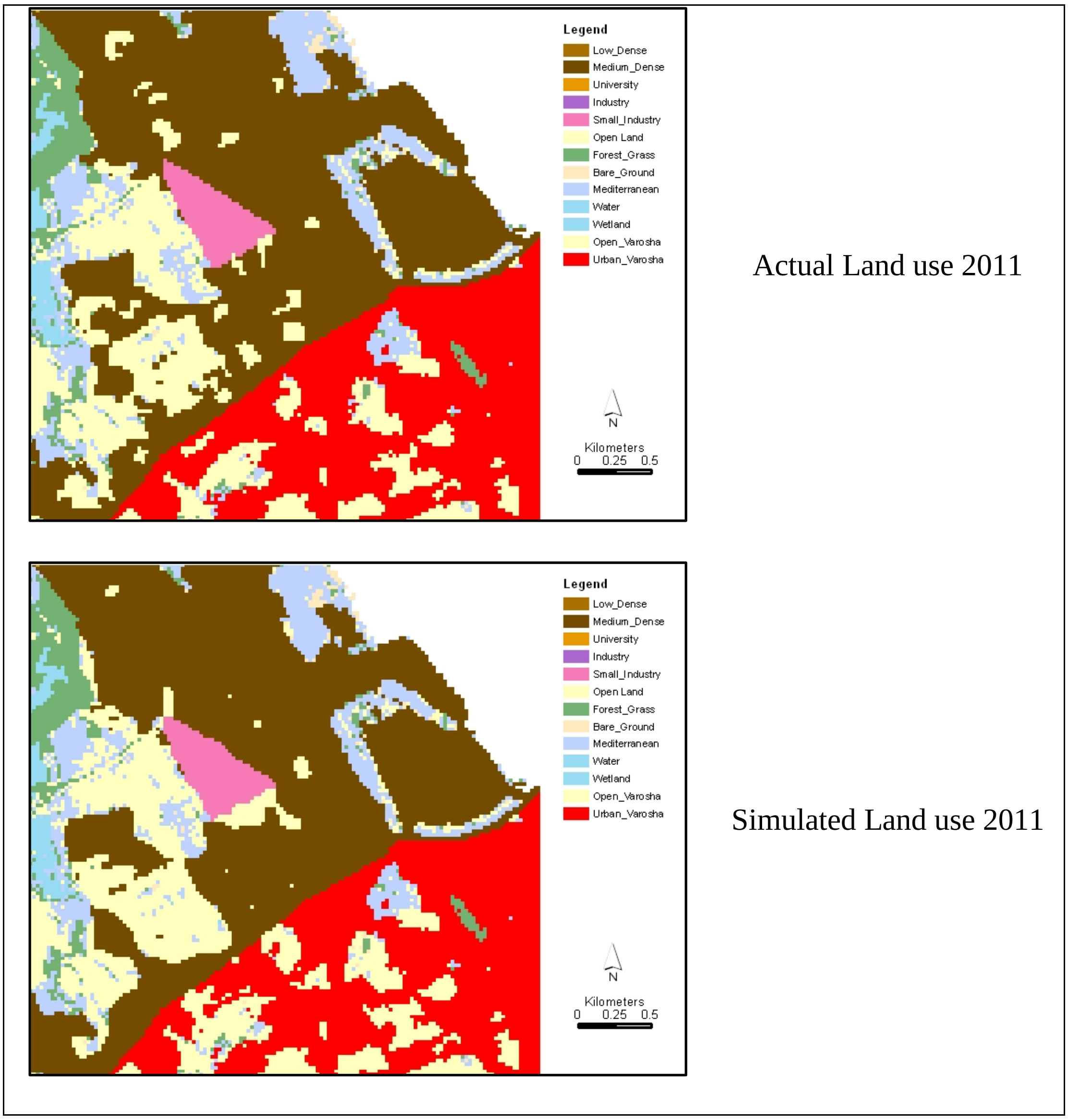


Figure 4.17**:** Visual Comparisons of Actual and Simulated Land covers for 2011

In addition to visual comparisons, geographical accuracy method is used for checking how much area or pixel for each class is matched between modeled and actual land use maps. The IDRISI macro modeler tool is used for each land use class with multiplying simulated land use type with actual land use types (Figure 4.18). Overlayed cells for each class compared with actual land use cells and accuracy ratios are given in Table 4.6.

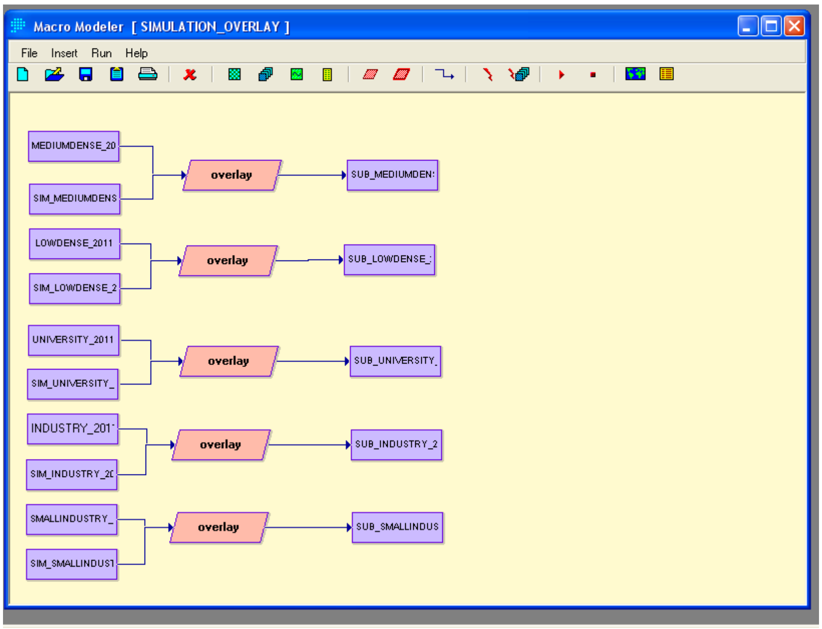


Figure 4.18**:** Comparison of Simulated and Actual Land Uses

Table 4.6**:** Simulation Accuracy for Do Nothing Scenario

		Existing 2011	Simulated 2011	Modeling Accuracy
		CELLS	OVERLAYED CELLS	PERCENT
LAND USE TYPES	LOW DENSE	2513	1605	0.63867887
	MEDIUM HOUSING	8636	7943	0.919754516
	UNIVERSITY	1436	1260	0.877437326
	INDUSTRY	1205	941	0.780912863
	SMALL_INDUSTRY	402	388	0.965174129
TOTAL		**14192**	**12137**	**0.855200113**
LAND COVER TYPES	OPEN	40668	40668	1
	FOREST	9186	9186	1
	BARE	1895	1895	1
	MEDI GRASS	13882	13882	1
	WATER	500	500	1
	WETLAND	315	315	1
	OPEN_VAROSHA	7555	7555	1
	URBAN_UVAROSHA	11031	11031	1

After checking the accuracy ratios for the Do Nothing Scenario, possible land use development for 2020 was simulated in an IDRISI environment in order to obtain information about future development alternatives in Famagusta.

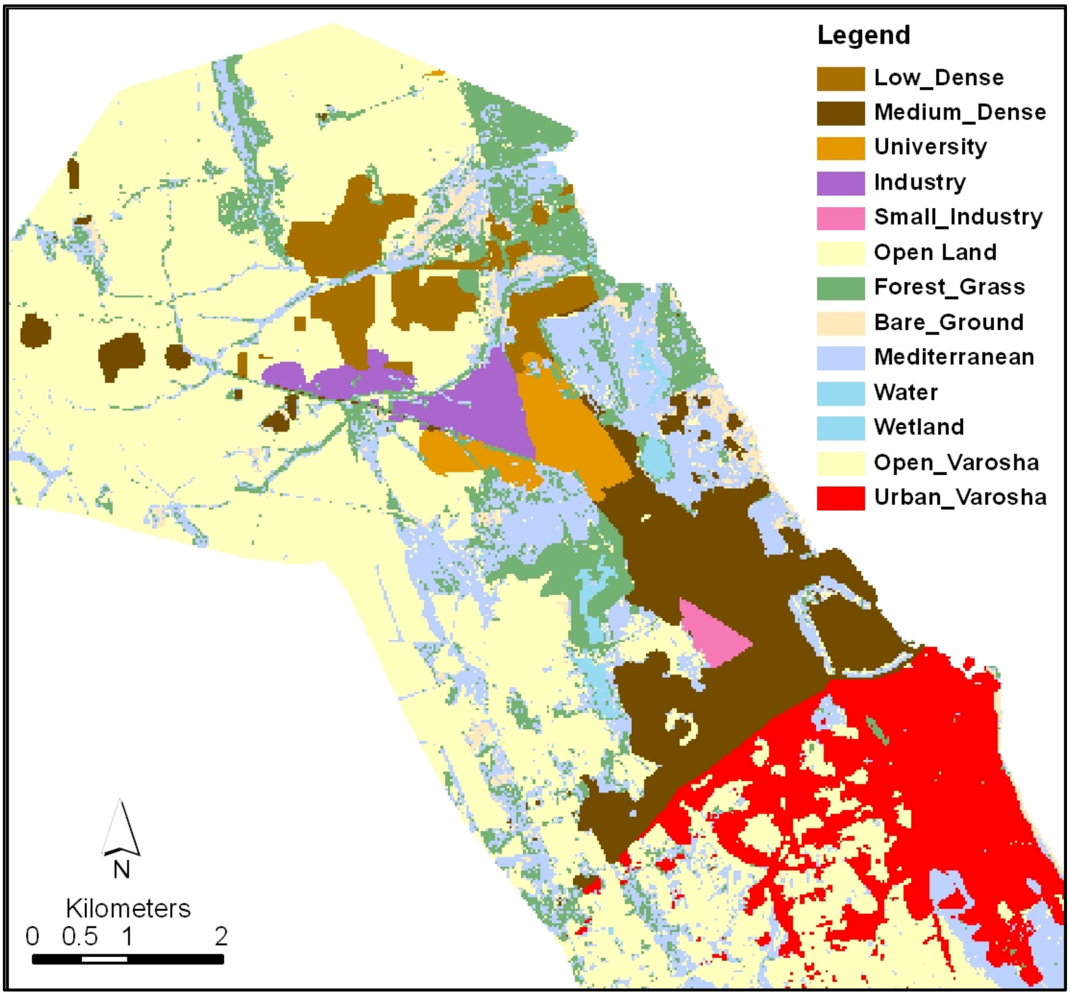


Figure 4.19**:** Simulated Land use 2020 under the Do Nothing Scenario

The figure given above clearly shows that urban growth in Famagusta is diverging away from sustainability. It appears that the development in low dense areas is expanding away from local services along linear transportation routes in the Tuzla region. Industry areas are intensifying next to the Industrial Zone along the Nicosia-Famagusta main road and also divides Tuzla housing areas from university and medium dense areas. This situation doesn’t support future accessibility to local services or open public spaces. Additionally, there are still unused spaces within the

Free zone region which is in opposition to the perspective of infill or brownfield development theories for sustainable urban growth. The Do Nothing Scenario simulation results are presenting similar problems which are explained by local experts in the previous section.

4.2.2 Simulating Sustainable Urban Growth for Famagusta

In order to simulate Sustainable Urban Growth of Famagusta, literature review for sustainable urban growth policies and then defining these policies with local experts is entitled. Moreover, these policies are converted into spatial criteria set and inputted into MCE based cellular automata for Sustainable Urban Growth Modeling (Figure 4.20)

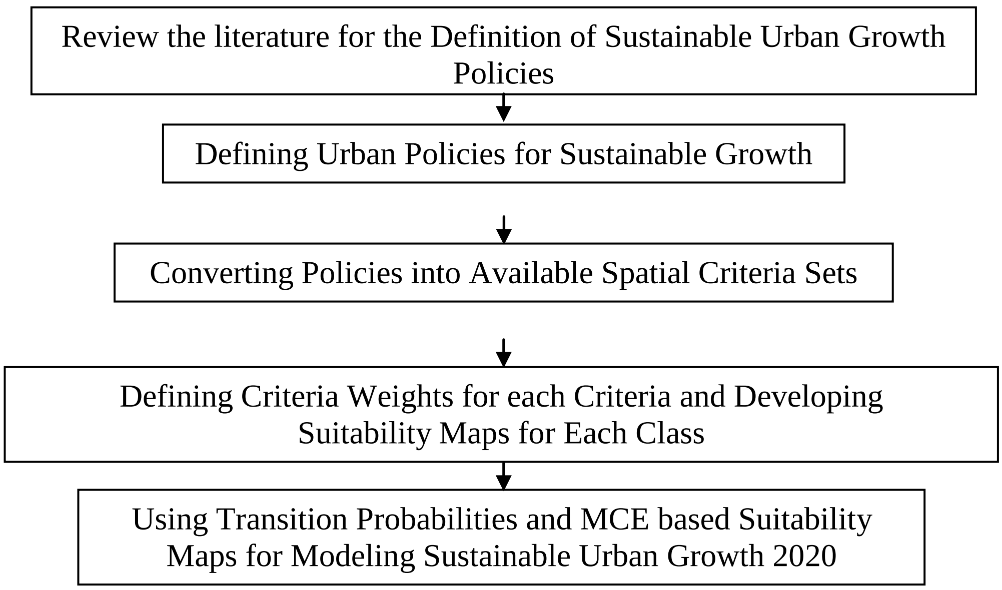


Figure 4.20**:** Sustainable Urban Growth Modeling Process

Sustainable urban growth policies were constructed from not only literature but also local experts' interview as that is explained in the previous section (Table 4.2.). These are grouped into three main policy and sub policies that can be converted into spatial criteria for a multi-criteria evaluation process (Figure 4.21). Each policy is transferred to spatial parameters for improving the land use suitability degree within

MCE based Urban Growth Modeling under Sustainability Scenario. In other words, they are defined as site selection criteria for different land use classes. Selected policies from literature review and local expert interviews are given in summary Table 4.7.

Table 4.7: Summary of Policy and Criteria Selection from Literature Review

GOAL	POLICY	SUB-POLICY	SPATIAL CRITERIA
Sustainable Urban Development	**Physical Compactness (Compact Urban Form)** (EEA, 1995;APA, 2002;EC, 1999)	Re-use (re-develop) existing urban area (Local Experts; EU, 1994)	Brownfield Areas
		Increasing density of areas close to city center	Distance from city center
	Environmental Protection (EC, 1999)	Selecting suitable soil for urban development (FAO,1996)	Soil Characteristics
		Protection of Soil Productivity (EC, 1999)	Soil Productivity
		Discourage growth in natural areas FAO, 1996)	Vegetation
		Protection of Natural 2000 Sites (EC, 1999)	Protection of Natural Areas
	Social Equity (EC, 2001; EC, 1999;)	Ensuring equal accessibility of basic services (EC, 2001; EC, 1999;)	Distance from local services
		Ensuring equal accessibility to open spaces (EC, 2001; EC, 1999)	Distance from open spaces

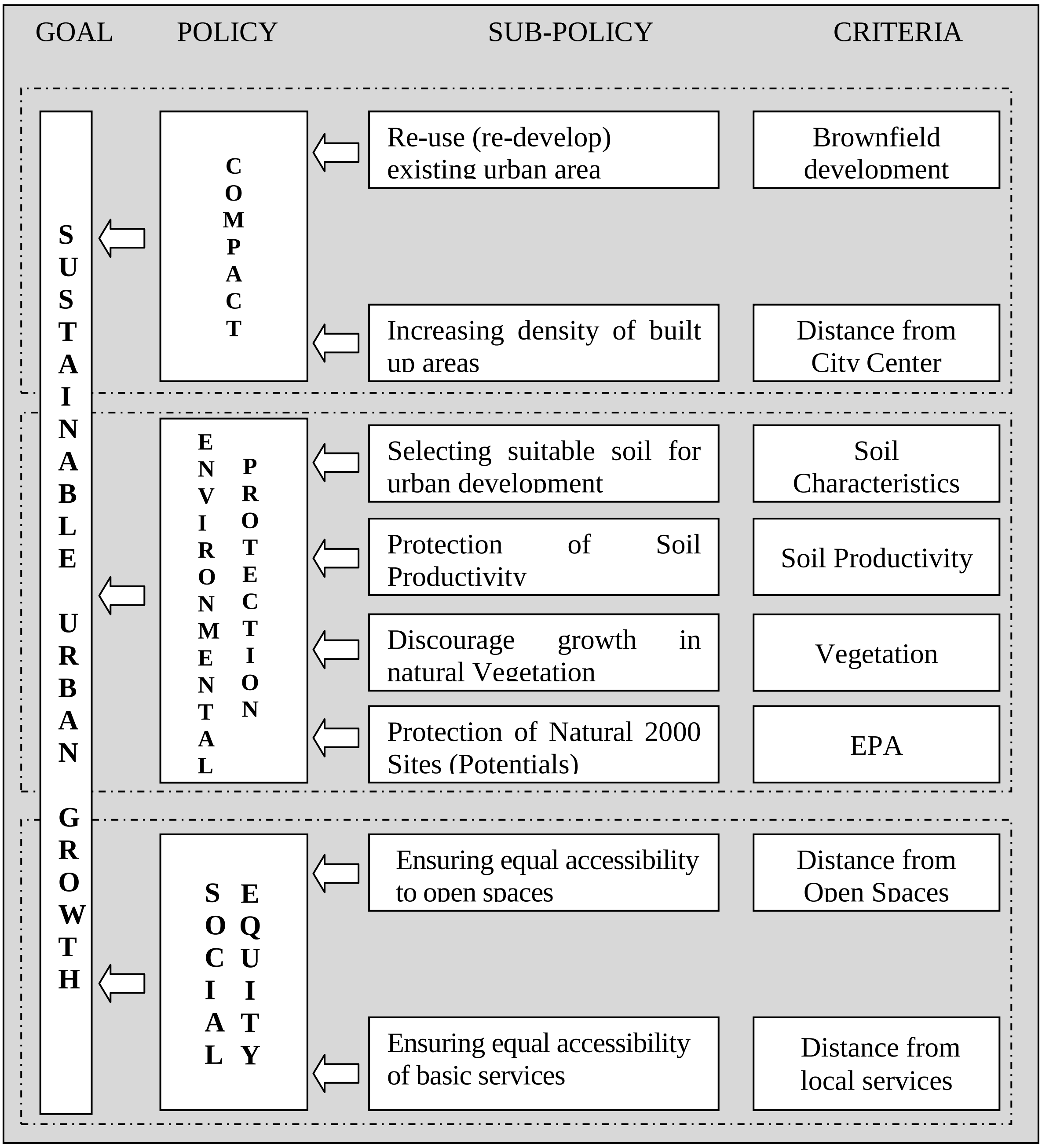


Figure 4.21**:** MCE Model for assessing Sustainable Urban Growth for Famagusta

4.2.2.1 Criteria Description

In the following section, criteria (physical, environmental or social) that are used for Sustainable Urban Growth scenario are explained.

Brownfield Areas: Brownfield development is necessary for regenerating urban space and reaching physical compactness within the urban environment. Therefore, possible areas for Brownfield development were scanned and detected within Famagusta. Free Zone, Small Industry Zone and some factories were detected that are suitable for regeneration projects and ranked according to their importance (Figure 4.22). Due to the availability of empty spaces in the Free Zone, this area has higher weights.

Distance from CBD (City Center): Distance from city center is another criterion for reaching compact urban growth. For Famagusta, there isn't any central business district. Therefore, the crossing point of the main commercial axes is assumed as the city center point. From that point, distance from city center calculated and transformed into 0-255 byte map (Figure 4.23).

Soil Characteristics: It's well known that soil characteristic is another critical factor for construction costs and it is suggested to select proper and suitable soil types for sustainable urban growth. Unsuitable site selection for housing function particularly in the Tuzla region is one of the main urban growth problems in Famagusta. From this point, different geological formations within the case area were researched and ranked accordingly. There are many different soil formations and these are given as follows (Table 4.8);

Table 4.8**:** Soil Characteristics in Famagusta

Q6ba	Quaternary
Q2a	young quaternary
Qmg	early Pleistocene
Q4b	young quaternary
Q6ak	Quaternary
Tmç	young Pliocene
Q4akk	young quaternary
Q5ab	young quaternary

Q6ba, Q6ak, Q5ab and Q4akk formations are not suitable for dense construction. They should be improved with different materials. On the other hand, Q2a and Qmg have stable ground characteristics. Q4b format has this feature if it is improved with cement. Additionally, it doesn't have stable ground if hillsides or slopes are included. However, it has consolidated characteristics since it constitutes the main body of the region. Therefore, it doesn't have any disadvantage for building construction. From that point, the rank order for soil characteristics are given as Qmg, Q2a, Q4b, Tmç and the others (Figure 4.24).

Soil Productivity: Agricultural land classification should be understood for suitability analysis for different land use types. In general, land is classified into eight groups according to soil, slope and other properties. 1st and 2nd classes are reserved for agricultural activities with the 3rd, 4th 5th 6th and 7th are suitable for dry agriculture and forestry. Therefore, areas within the 1st and 2nd classes were classified as exclusionary areas for any land use classes. According to the agricultural department, there isn't a complete soil productivity map for Famagusta. Therefore, some parts of the case area are missing (Figure 4.25).

Vegetation: From the natural protection perspective, it's important to protect the ecological uniqueness of the regional vegetation. Several vegetation classes have agricultural activities and different forests types must be selected as constraints and should be subtracted from assessment process. Forest Needle, and Forest Eucalyptus were determined as exclusionary areas for evaluation. Grass, Bare ground, Irrigated Agriculture, Dry Pasture and grassland were selected in different zones for evaluation (Figure 4.26).

Environmental Protection Areas: There are internationally recognized environmental areas in Famagusta. Limni Forest Wetland and Gulseren Lagoon areas are listed as NATURA 2000 areas which are called as wetlands. Therefore, these areas added as constraints for evaluation. Areas within 0-250m, 250-500m and 500m+ zones were determined for the evaluation (Figure 4.27).

Distance to Public Open Areas: Access to public open areas is essential in a sustainable community for the quality of life. Having these areas close to residents or housing environments reduces the need to travel. Public parks and open sport facilities are grouped under this criterion (EC, 2003). Areas within 0-300m and 300-1000m and 1000m+ zones were determined for the evaluation (Figure 4.28).

Distance to Local Services: Like public open spaces, access to basic services is also essential in a sustainable community for the quality of life and the viability of the local economy. Having basic services close to residents also reduces the need to travel. Areas within 0-300m and 300-1000m and 1000m+ zones were determined for the evaluation (Figure 4.29).

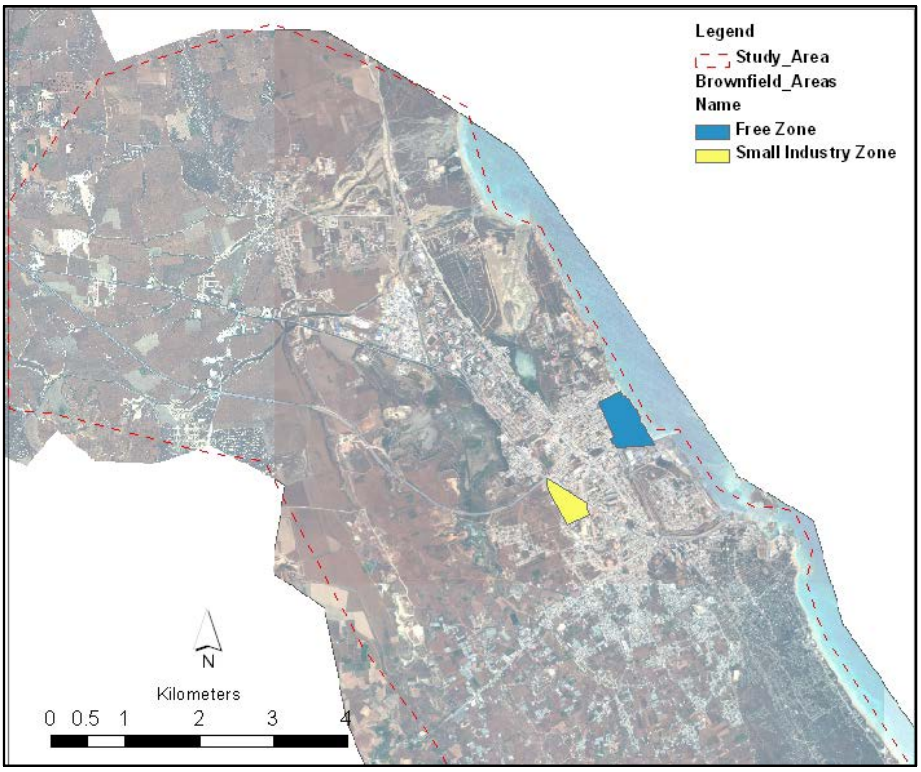


Figure 4.22: Brownfield Areas

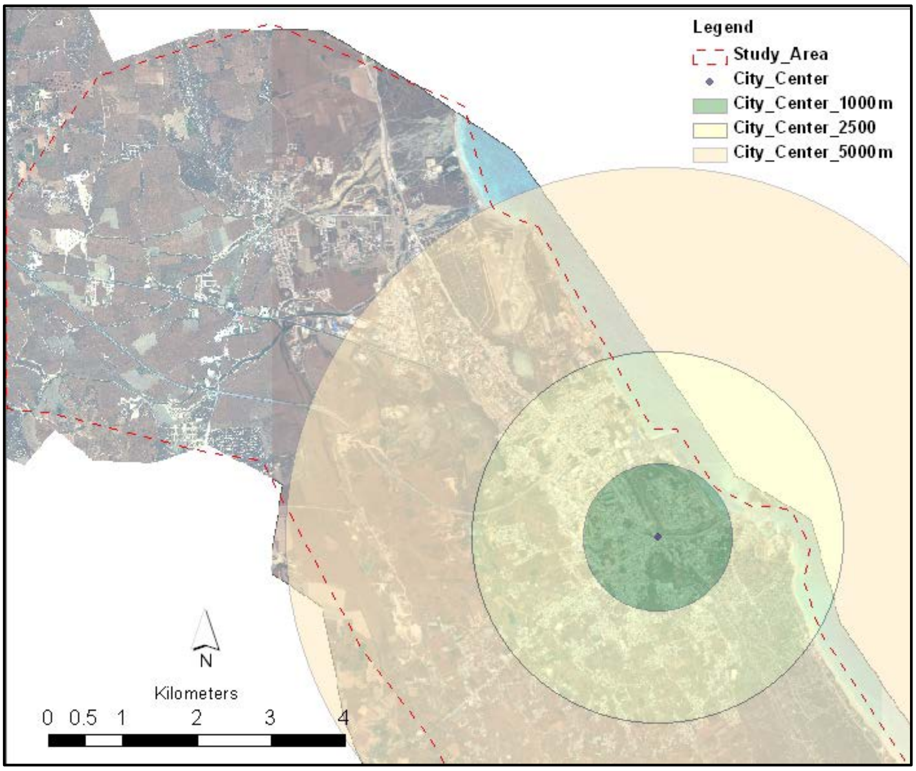


Figure 4.23**:** Distance to City Center

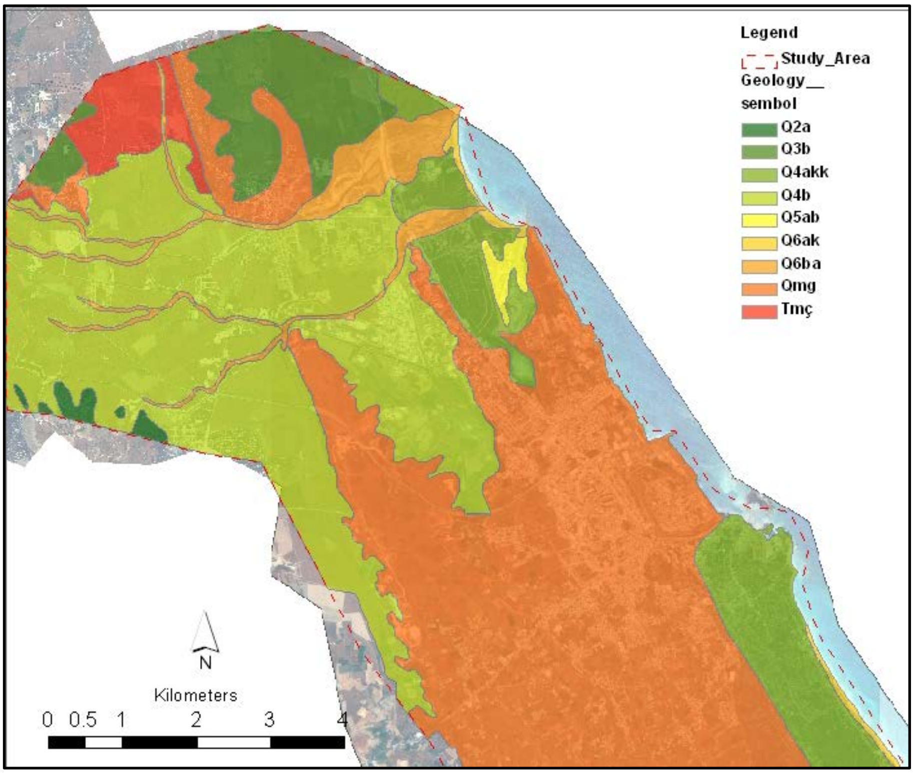


Figure 4.24**:** Soil Characteristics

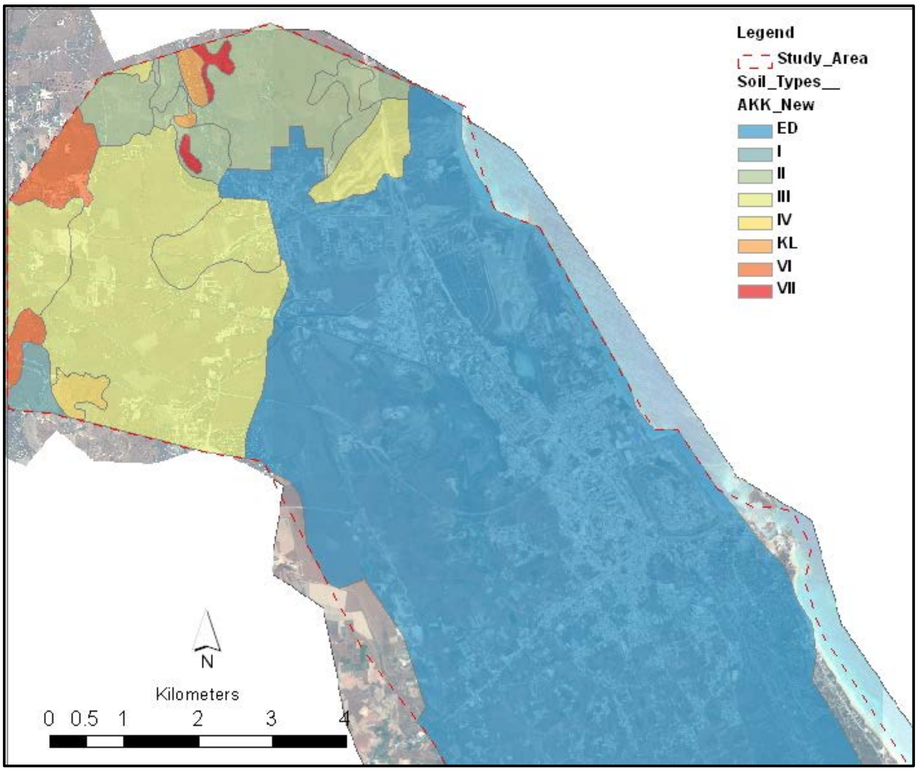


Figure 4.25: Soil Productivity

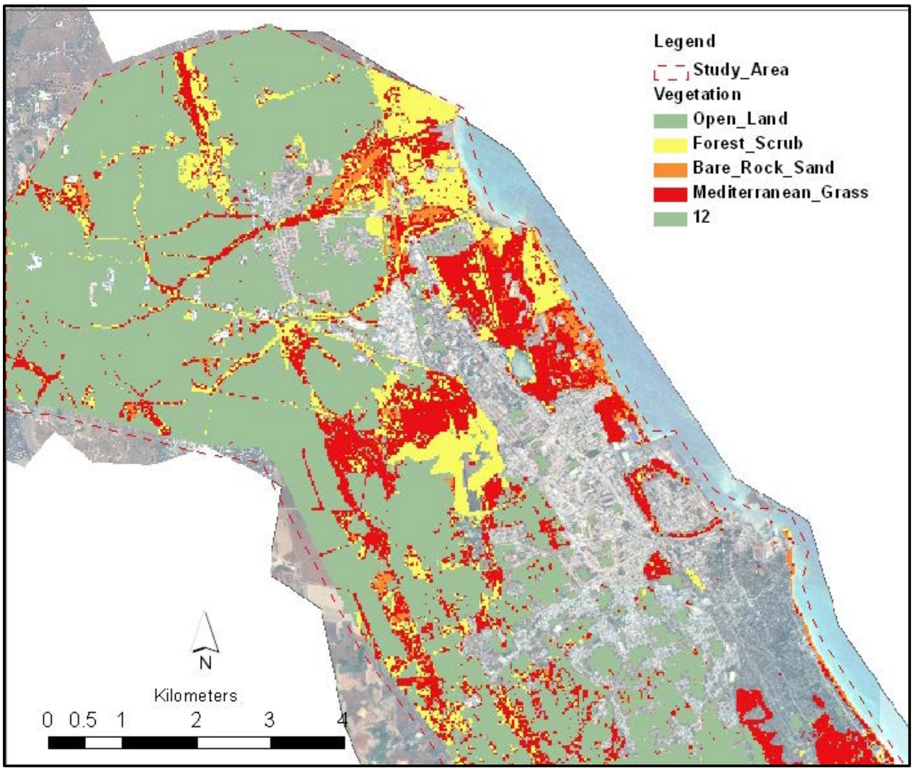


Figure 4.26: Vegetation

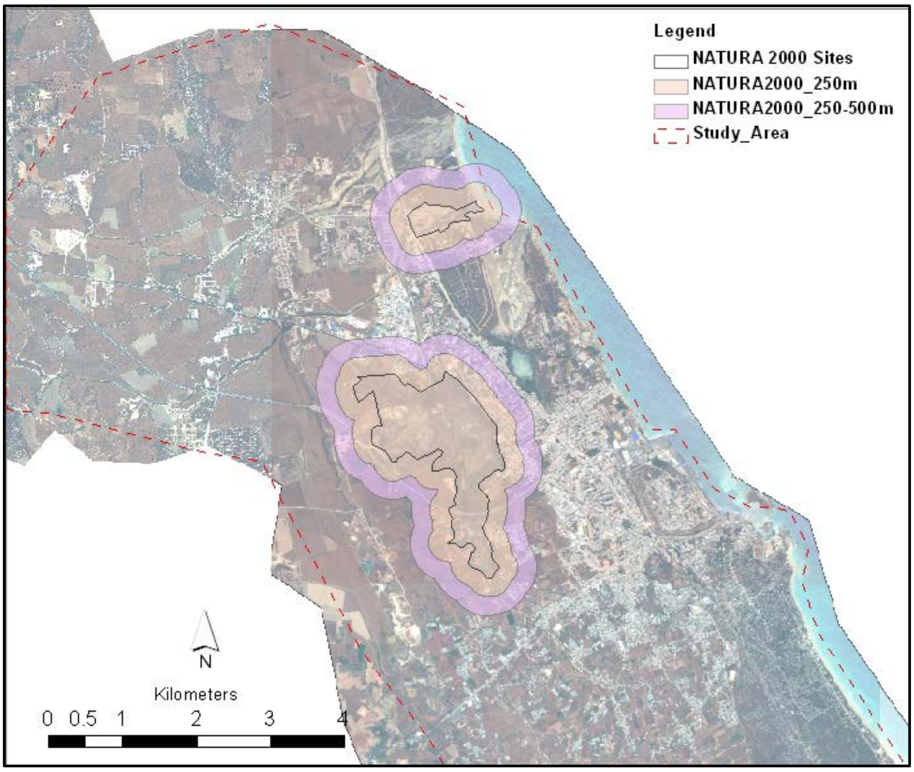


Figure 4.27**:** Distance from Natura 2000 Areas

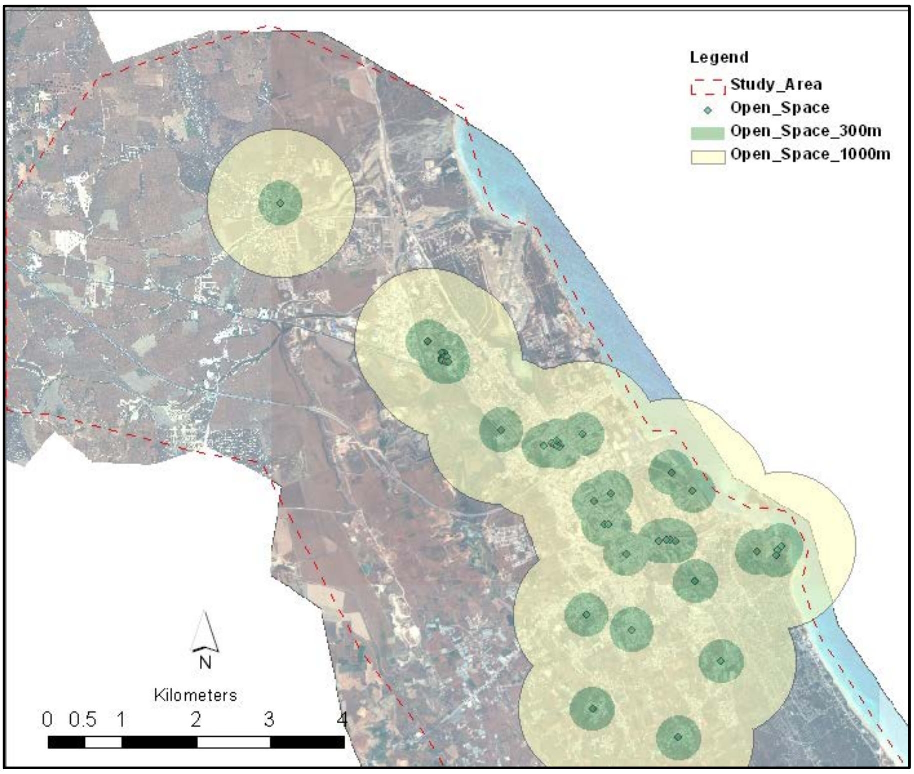


Figure 4.28**:** Distance to Open Space

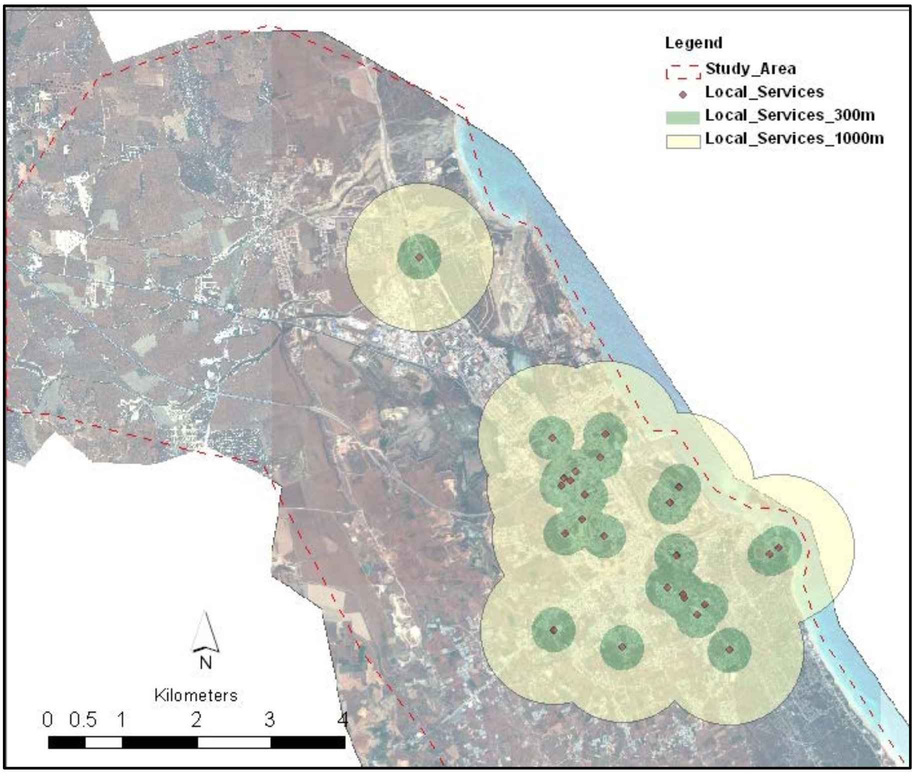


Figure 4.29**:** Distance to Local Services

4.2.2.2 Pairwise Comparison

Pairwise comparison matrices were formed by the interviews with various experts and stakeholders from different institutions. Decision-makers such as Town Planner, architects, Geology Engineer, Civil Engineer, Environmental Engineer, etc. ranked each criteria weights by comparing and filling the matrices (see Appendix 4). After that, CR values for each comparison table were checked to confirm the reliability of these experts' choice.

According to the (Saaty, 1980) CR should have a value of less than 10 percent. In this study, CR values have lower values than the 10 percent which indicate the consistency of the pairwise comparison (Kara & Doratlı, 2012) (Table 4.9 - 4.21).

Table 4.9**:** Main Criteria Pairwise Comparison Matrix

Criteria	Physical Compactness	Environmental Protection	Social Equity	Weights
Physical Compactness	**1**	1/3	1/3	0.14
Environmental Protection	3	**1**	1	0.43
Social Equity	3	1	**1**	0.43

Consistency Ratio: 0.00

Table 4.10**:** Physical Compactness Criteria Pairwise Comparison Matrix

Criteria	Brownfield Development	Distance to City Center	Weights
Brownfield Development	**1**	2	0.33
Distance to City Center	1	**1**	0.67

Consistency Ratio: 0.00

Table 4.11**:** Environmental Protection Criteria Pairwise Comparison Matrix

Criteria	Soil Permeability	Soil Productivity	Vegetation	EPA	Weights
Soil Permeability	**1**	3	2	1	0.36
Soil Productivity	1/3	**1**	1/2	1/2	0.12
Vegetation	1/2	2	**1**		0.23
EPA (Natura2000)	1	2	1	**1**	0.29

Consistency Ratio: 0.018

Table 4.12**:** Social Equity Criteria Pairwise Comparison Matrix

Criteria	Distance from Local Services	Distance from Open Spaces	Weights
Distance from Local Services	**1**	1	0.50
Distance from Open Spaces	1	**1**	0.50

Consistency Ratio: 0.00

Table 4.13**:** Brownfield Sub-Criteria Pairwise Comparison Matrix

Criteria	Free Zone	Small Industry Zone	Weights
Free Zone	**1**	3	0.75
Small Industry Zone	1/3	**1**	0.25

Consistency Ratio: 0.00

Table 4.14**:** Distance to City Center Pairwise Comparison Matrix

Criteria	0-1000	1000-2500m	2500-5000m+	5000m+	Weights
0-1000	**1**	2	5	8	0.55
1000-2500m	1/2	**1**	3	5	0.28
2500-5000m	1/5	1/3	**1**	2	0.11
5000m+	1/8	1/5	1/2	**1**	0.06

Consistency Ratio: 0.06

Table 4.15**:** Soil Characteristics Pairwise Comparison Matrix

Criteria	Qmg	Q2a	Q4b	Tmç	Q3b	Q4ak	Weights
Qmg	**1**	3	5	7	8	9	0.52
Q2a	1/3	**1**	2	4	5	6	0.20
Q4b	1/5	1/2	**1**	2	3	4	0.11
Tmç	1/7	1/4	1/2	**1**	2	3	0.07
Q3b	1/8	1/5	1/3	1/2	**1**	2	0.05
Q4ak	1/9	1/6	1/4	1/3		**1**	0.05

Consistency Ratio: 0.029

Table 4.16**:** Soil Productivity Pairwise Comparison Matrix

Criteria	3rd and 4th Classes	5th, 6th, 7th Classes	Weights
3rd and 4th Classes	**1**	1/4	0.20
5th, 6th, 7th Classes	4	**1**	0.80

Consistency Ratio: 0.0

Table 4.17**:** Vegetation Pairwise Comparison Matrix

Criteria	Open/Dry Pasture	Bare/Sand/Rock	Grassland	Forest Scrub	Weights
Open/Dry Pasture	**1**	3	5	7	0.60
Bare/Sand/Rock	1/3	**1**	2	4	0.21
Grassland	1/5	1/2	**1**	2	0.12
Forest Scrub	1/7	1/4	1/2	**1**	0.07

Consistency Ratio: 0.017

Table 4.18**:** Distance to Natura2000 Sites Pairwise Comparison Matrix

Criteria	0-250m	250-500m	500m+	Weights
0-250m	**1**	1/3	1/6	0.10
250-500m	3	**1**	1/2	0.30
500m+	6	2	1	0.60

Consistency Ratio: 0.0

Table 4.19**:** Distance to Open Spaces Pairwise Comparison Matrix

Criteria	0-300	300-1000m	1000m+	Weights
0-300m	**1**	3	7	0.67
300-1000m	1/3	**1**	4	0.24
1000m+	1/7	1/4	1	0.09

Consistency Ratio: 0.0

Table 4.20**:** Distance to Local Services Pairwise Comparison Matrix

Criteria	0-300	300-1000m	1000m+	Weights
0-300m	**1**	3	7	0.67
300-1000m	1/3	**1**	4	0.24
1000m+	1/7	1/4	1	0.09

Consistency Ratio: 0.0

After the development of the criteria sets with criteria weights and converted them criteria maps (Figure 4.30), it is required to develop constraint map for urban growth simulation under the Sustainable Scenario. Therefore, General Constraints for growth the Sustainable Scenario (Figure 4.31) were used and converted into byte format before modeling process (Figure 4.32). This process is explained in Appendix 5.

Table 4.21: Summary of the Criteria Sets

Main Criteria	Weight	CR	Criteria	Weight	CR	Sub-Criteria	Weight	CR
(A) Compactness	0.14	0.00	Brownfield Development	0.33	0.00	Free Zone	0.75	0.00
						Small Ind. Zone	0.25	
			Distance from Center	0.67		0 -1000m	0.55	0.06
						1000- 2500m	0.28	
						2500-5000m	0.11	
						5000m+	0.06	
(B) Environmental Protection	0.43	0.018	Soil Characteristics	0.36	0.018	Qmg	0.52	0.029
						Q2a	0.20	
						Q4b	0.11	
						Tmç	0.07	
						Q3b	0.05	
						Q4ak	0.05	
			Soil Productivity	0.12		3rd and 4th Classes	0.20	0.00
						5th, 6th, 7th Classes	0.80	
			Vegetation	0.23		Open/Dry Pasture	0.60	0.017
						Bare/Sand/Rock	0.21	
						Grassland	0.12	
						Forest Scrub	0.07	
			EPA	0.29		0-250m	0.10	0.00
						250-500m	0.30	
						500m+	0.60	
(C) Social Equity	0.43	0.00	Distance from Local Services	0.50	0.00	0 -300m	0.67	0.00
						300- 1500m	0.24	
						1500m+	0.09	
			Distance from Open Space	0.50		0 -300m	0.67	0.00
						300- 1500m	0.24	
						1500m+	0.09	

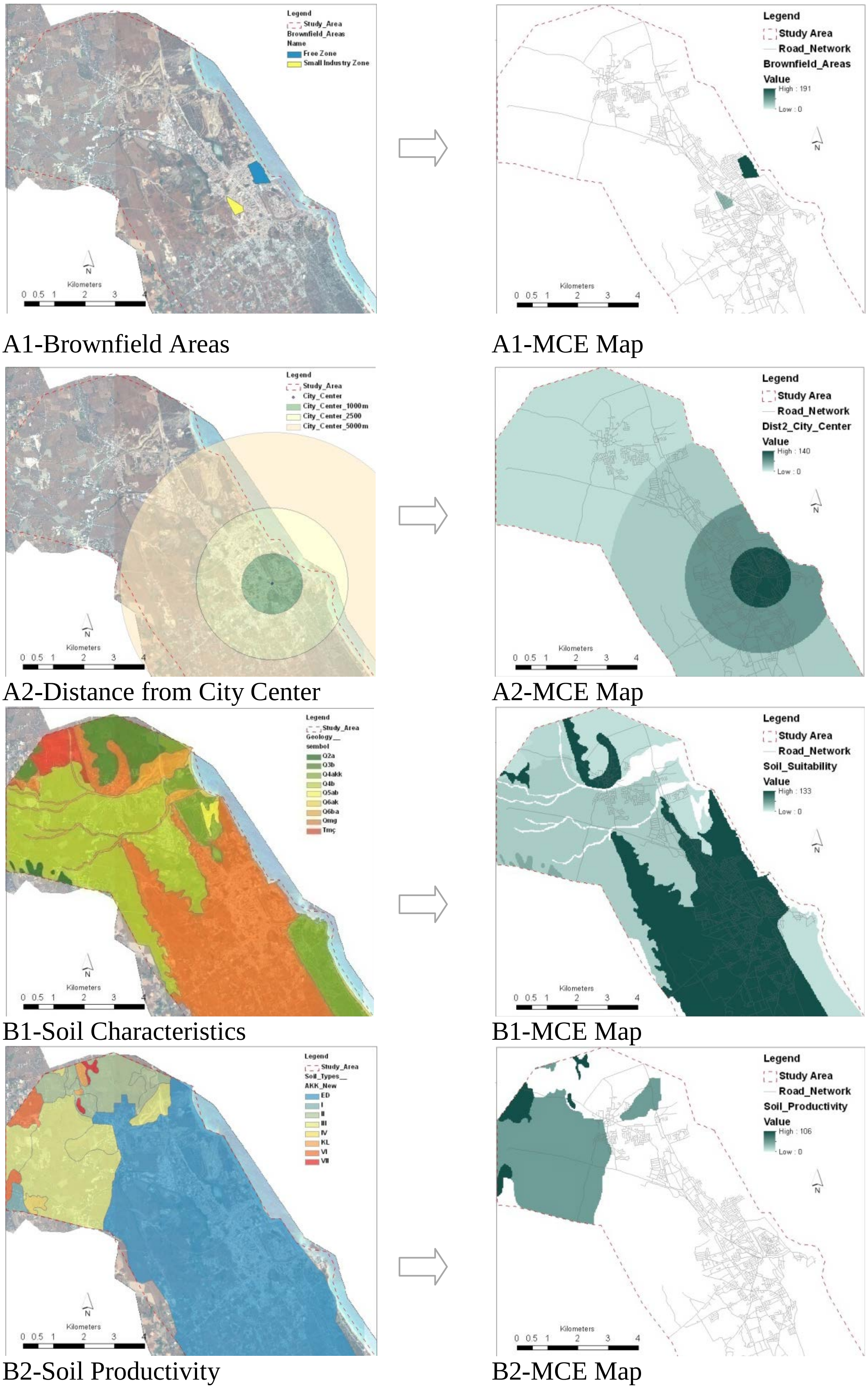
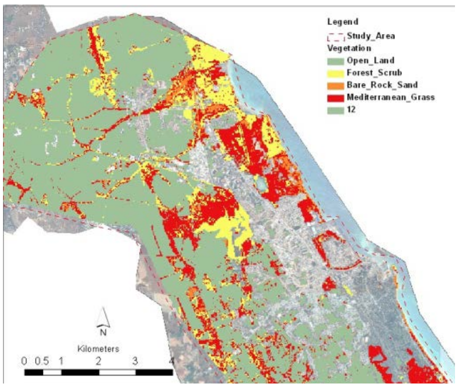
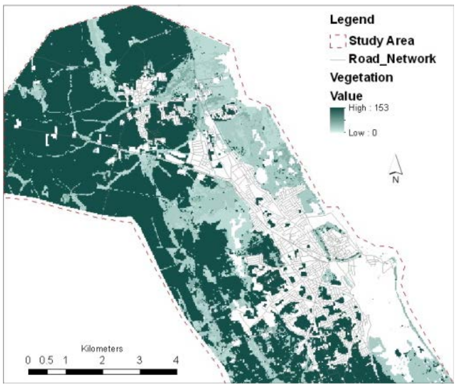


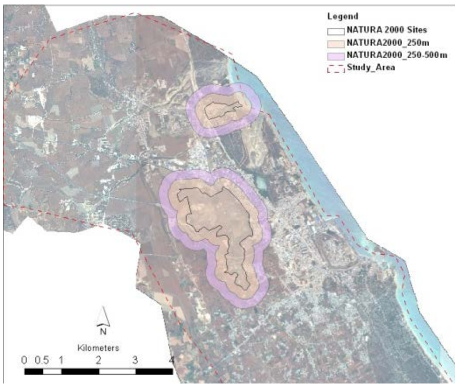
Figure 4.30: Criteria Suitability Maps

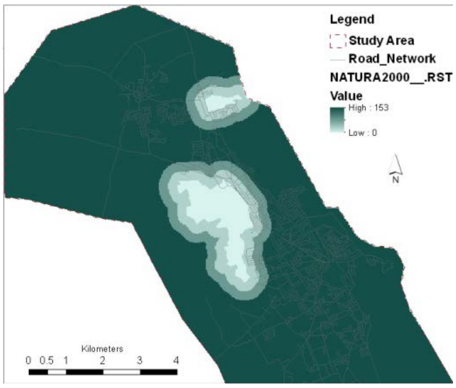




B3-Vegetation

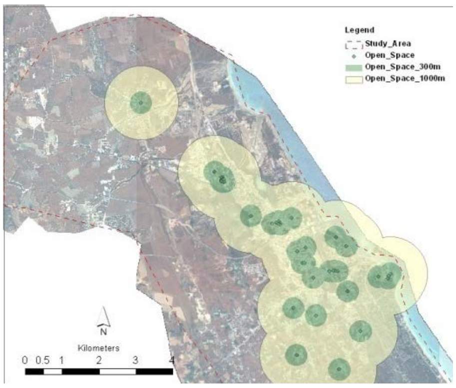
B3-MCE Map

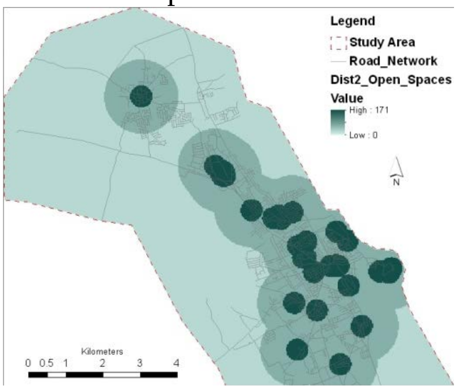




B4-Distance from Natura 2000 Areas

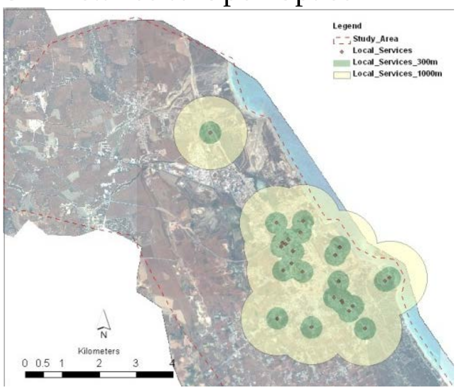
B4-MCE Map

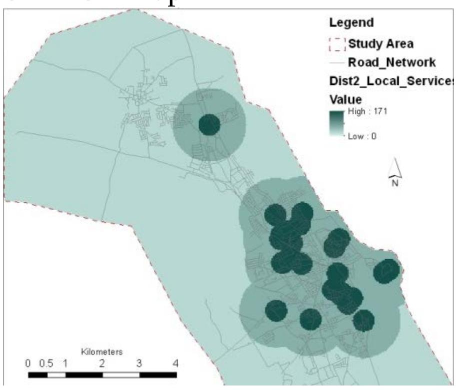




C1-Distance to Open Space

C1-MCE Map





C2-Distance to Local Services

C2-MCE Map

Figure 4.30: Criteria Suitability Maps (Continued)

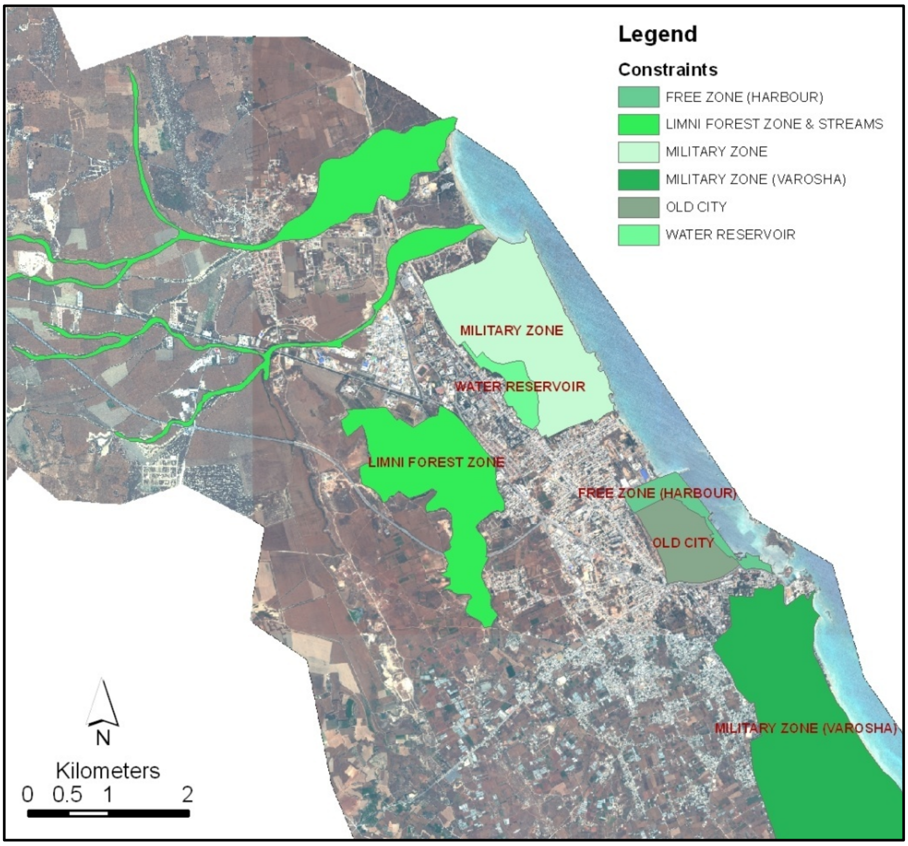


Figure 4.31**:** General Constraints for Sustainable Scenario

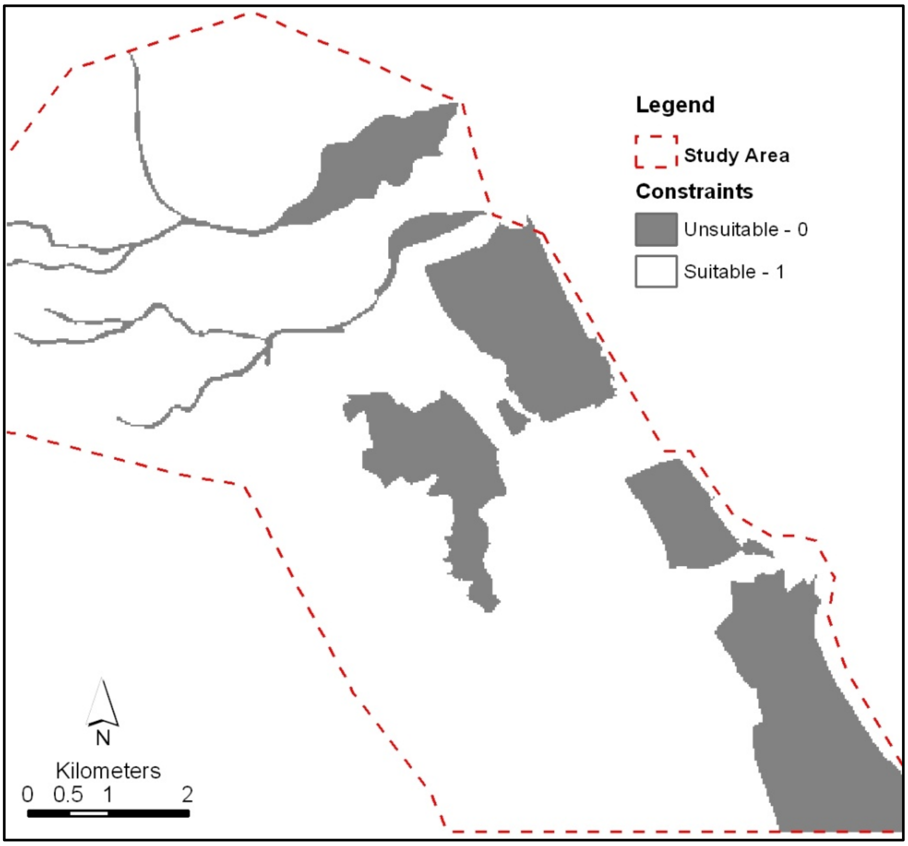


Figure 4.32: General Constraint Map Development for Sustainable Scenario

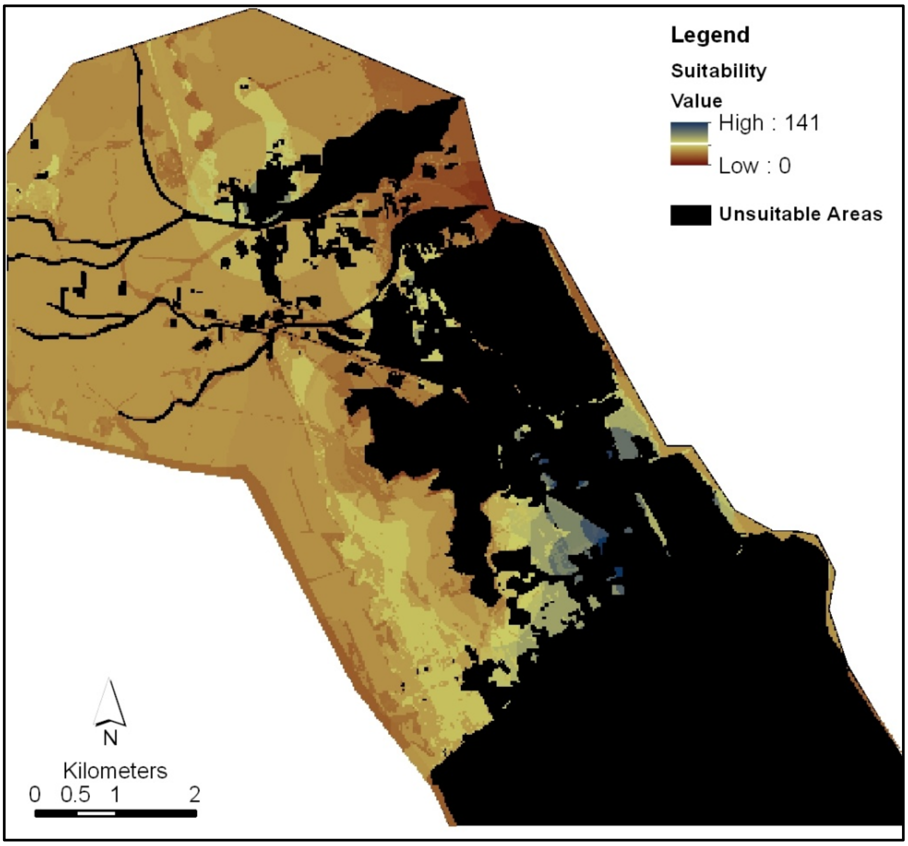


Figure 4.33: Multi Criteria Evaluation Results for the Sustainable Scenario

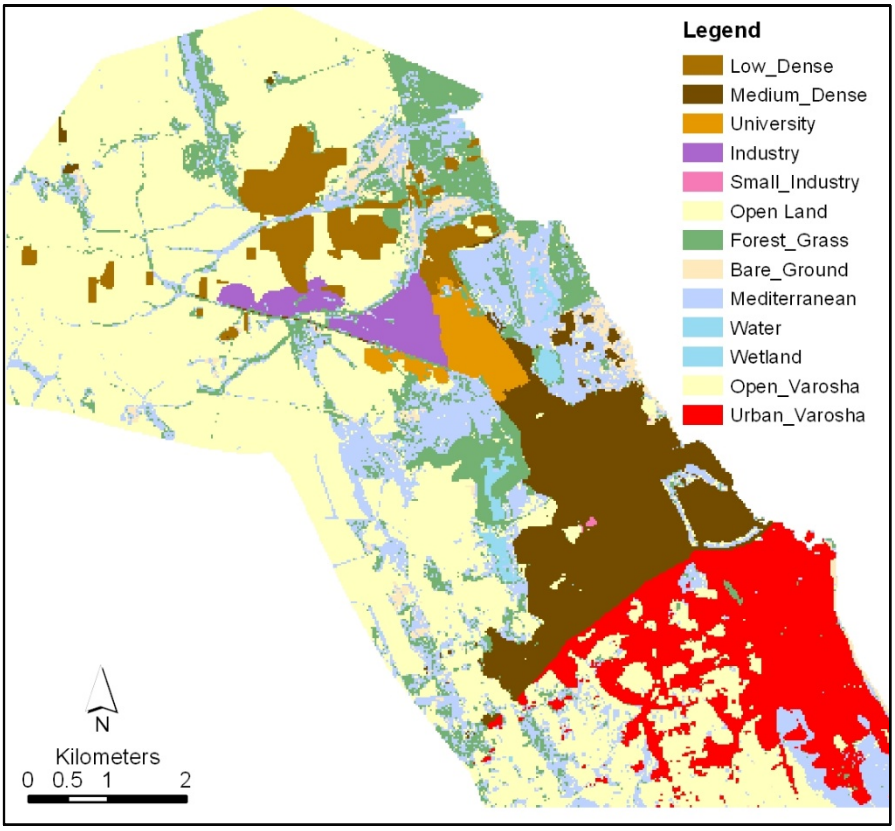


Figure 4.34: Simulation of Sustainable Scenario

The figure given above clearly shows that urban growth in Famagusta is moving towards spatially more compact and dense within the center region which supports sustainable urban development policies. Unlike the Do Nothing scenario results, free zone area and small industry zone developed with medium dense urban class according to the spatial criteria weights and transition area tables. This requires Brownfield development activities for the selected areas. This also increases the accessibility of medium dense areas too to existing open spaces and local services. This will help to achieve social equity of sustainable urban development in Famagusta.

In low dense urban areas, there is still problem for having accessibility to city center, local services and open spaces. Simulation presents that it’s not very easy to change this tendency of urban sprawl and limit the low dense housing areas. In order to increasing accessibility of these areas, Tuzla open spaces and local services should be planned and it’s required to get land use suitability analysis for defining a new sub-center in long term period.

University and Industry zones were developed very similar to Do Nothing scenario results. Since these areas have been pre-defined by central government they were accepted as input from the planning perspective. Moreover, sustainability policies were mainly defined medium dense and low dense urban areas. Therefore, they showed similar spatial pattern for two different scenarios.

Chapter 5

CONCLUSION

Land use suitability assessment which is a crucial application in urban planning and land use management, provides fundamental base for planning through decision making process. Many researchers and planners have created detailed applications for many case studies and explore different perspectives about land suitability assessment. In general, this study concentrates on using GIS and MCE to produce suitability maps as spatial factors of urban growth. Accordingly, it aims to construct sustainable urban development goals and perspectives and converting them as spatial criteria choices. In this manner, land suitability assessment of Famagusta was utilized to reach sustainable urban development schemes by presenting within two different scenario based future development alternatives, Do Nothing and Sustainable Urban Growth Scenarios

Under Do Nothing scenario, Markov Chain Probability analysis with CA models is used with temporal land use datasets based on the images from 2002 and 2011. Additionally, general development trends converted into development factors and constraints to employ suitability map for future development growth with MCE. Finally, the suitability map and Markov Chain probabilities combined with CA to have spatial growth simulation. The result shows that, Famagusta is moving away from sustainable development.

A similar model is employed by applying Sustainable Urban Development policies by Policy Driven Scenario. As a main goal, Sustainable Urban Development policies were separated into three main criteria, Compactness, Environmental Protection and Social Equity. Additionally, brownfield development, distance from center, soil characteristics, soil productivity, vegetation, environmentally protected areas, distance from local services, distance from open space were used as sub-criteria. Then two different future development alternatives were obtained.

Comparison of the two different scenario and their land use layouts presents that Famagusta is moving away from sustainable spatial growth. Comparison of the two scenario based spatial layout presents that;

-compactness of the medium dense urban areas can be increased by using spatial sustainable growth policies

-optimum usage of the available land can be achieved with sustainable spatial growth policy driven suitability analysis

-small industry area should be renovated as medium-dense urban class to increase compactness

-Unused areas like free zone empty areas also should be used as to increase compactness

It is required to emphasize the advantages of the compact city which is been given in the Chapter 2. Since the compact city is the fundamental of the spatial sustainable growth, sustainable scenario shows convenient future development layout within this manner. This shows an important spatial process can be achieved by the selection of the factors which are derived from the sustainable city concept and it's key elements.

GIS and MCE based CA model could be used as a spatial planning support tool for urban planners and decision makers in Famagusta. Such tool helps to assist for testing administrative planning strategies or spatial goals, which influences decision making process in the planning process. This may help to understand spatial factors that affect development and consequently give a chance for assessing alternatives through sustainable urban development.

Additionally, local experts and stakeholders can be benefited within this simulation environment by testing different spatial factors to improve sustainable spatial growth. Therefore, it should be noted that, spatial criteria may be changed according to the policy perspective or research concept. GIS, MCE and CA based simulation study is the first application for Famagusta and these policies can be increased or decreased according to the data availability and participatory conditions for further studies.

Finally, this study is a key to construct common spatial factor set to reach sustainable spatial growth simulation which may not be found in the literature frequently. Moreover, this pilot study uses factors derived from different disciplinary and shows unique suitability analysis for Famagusta. In this manner, it can be used for further researches by planners, managers, etc.

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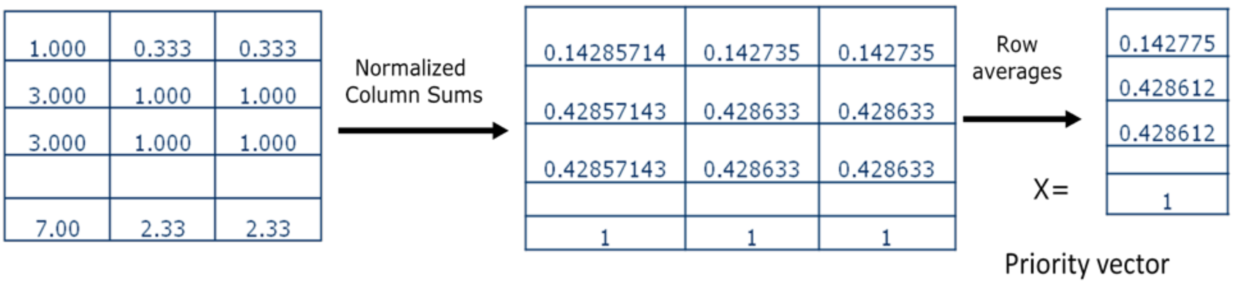
APPENDICES

APPENDIX 1: PAIR-WISE COMPARISON EXAMPLE

Step One

- To find the weights of criteria, namely the Eigen Vector X:
- Normalize the column entries by dividing each entry by the sum of the column.
- Take the overall row averages.

Criteria	Physical Compactness	Environmental Protection	Social Equity	Weights
Physical Compactness	**1**	1/3	1/3	0.14
Environmental Protection	3	**1**	1	0.43
Social Equity	3	1	**1**	0.43



- The next stage is to calculate a Consistency Ratio (CR) to measure how consistent the judgments have been relative to large samples of purely random judgments.
- AHP evaluations are based on the assumption that the decision maker is rational, i.e., if A is preferred to B and B is preferred to C, then A is preferred to C.

- If the CR is greater than 0.1 the judgments are untrustworthy because they are too close for comfort to randomness and the exercise is valueless or must be repeated.

Step Two

- The next stage is to calculate λ_{max} so as to lead to the Consistency Index and the Consistency Ratio.
- Consider [Ax = λ_{max} x] where x is the Eigenvector.

1.000	0.333	0.333
3.000	1.000	1.000
3.000	1.000	1.000
7.00	2.33	2.33

0.142775
0.428612
0.428612
1

=

0.142775
1.285837
1.285837

λmax=average(0.142775 / 0.142775 , 1.285837/0.428612, 1.285837/0.428612)/3

= 2.33 is lower than 3 so

$$CI = \frac{(\lambda \max - n)}{n-1}$$

CI is found by CI= (3-3)/(3-1)= 0.00

Step Three

The final step is to calculate the Consistency Ratio, CR by using the table below, derived from Saaty's book. The upper row is the order of the random matrix, and the lower row is the corresponding index of consistency for random judgments.

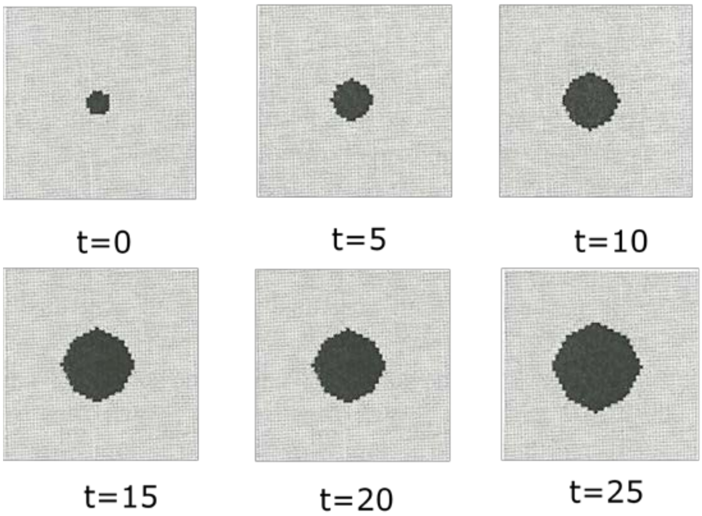
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

$$CR = \frac{CI}{RC}$$

CR=(CI/RC)= (0/0.58)=0.00

APPENDIX 2: URBAN CA EXAMPLES

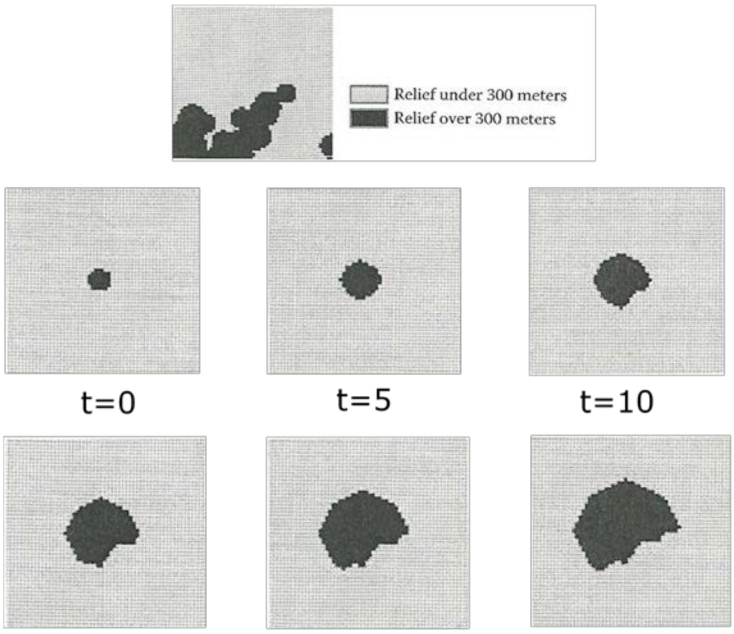
- **Example One – Simple Urban Growth**



RULE 1

- **IF**
  there are three or more developed cells in the Moore Neighbourhood of a non-urban cell in question
- **THEN**
  the non-urban land cell will be developed into an urban state

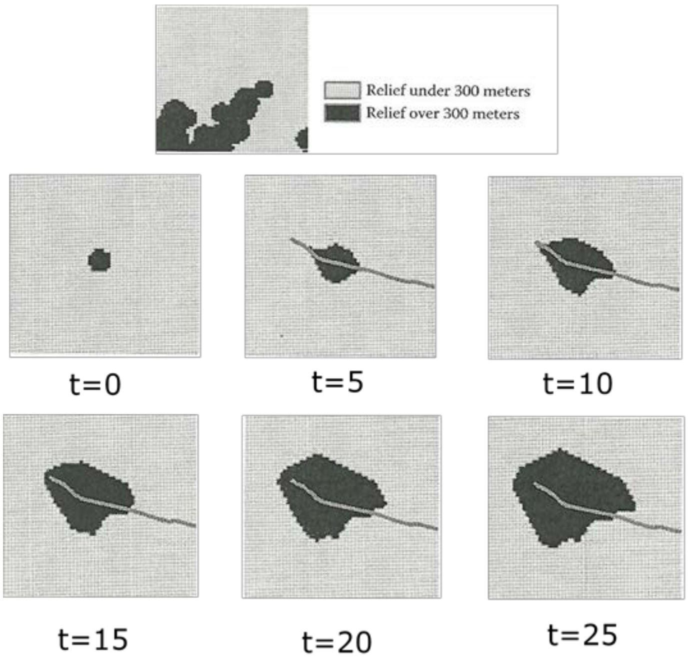
- **Example Two - Urban Growth with Relief Constraint**



RULE 2

- **IF**
  the relief of the landscape is more than 300m
- **THEN**
  the land cell will remain undeveloped or stays as non-urban cell

- **Example Three – Urban Growth with Relief Constraint and Road Factor**



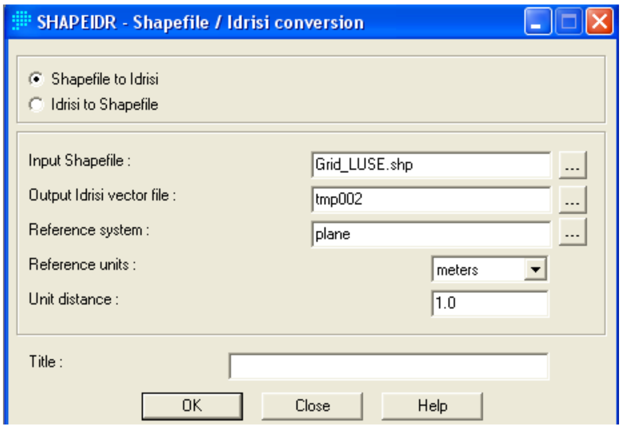
RULE 3

- **IF**
  there are one or two developed cells in the Moore Neighbourhood of a non-urban cell and there is a road running through that cell

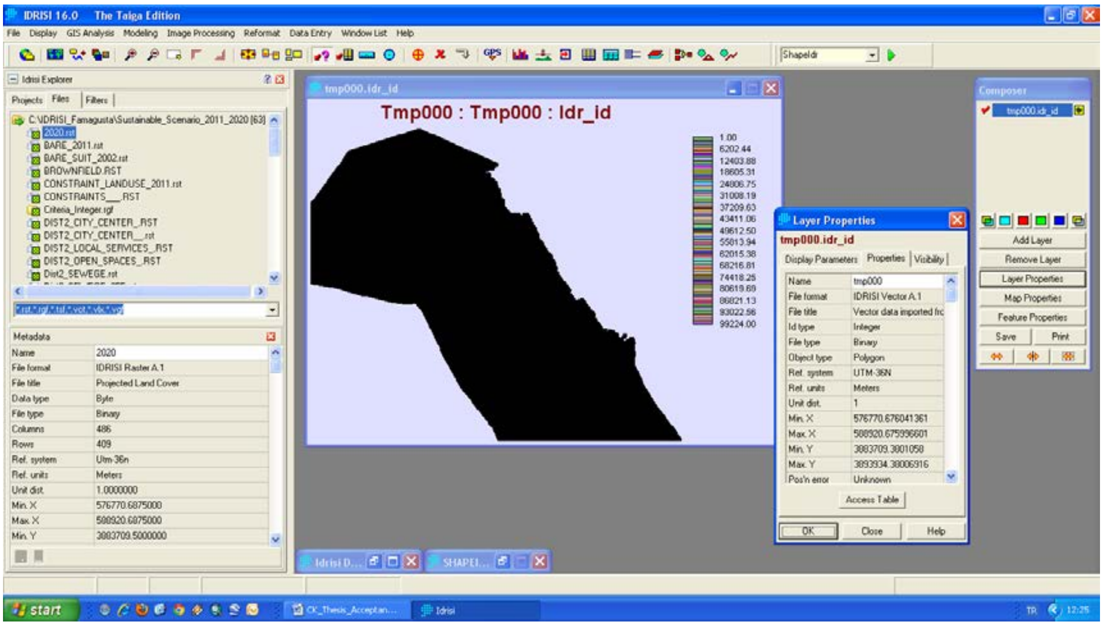
- **THEN**
  the non-urban land cell will be developed into an urban state

APPENDIX 3: ARCGIS TO IDRISI EXAMPLE

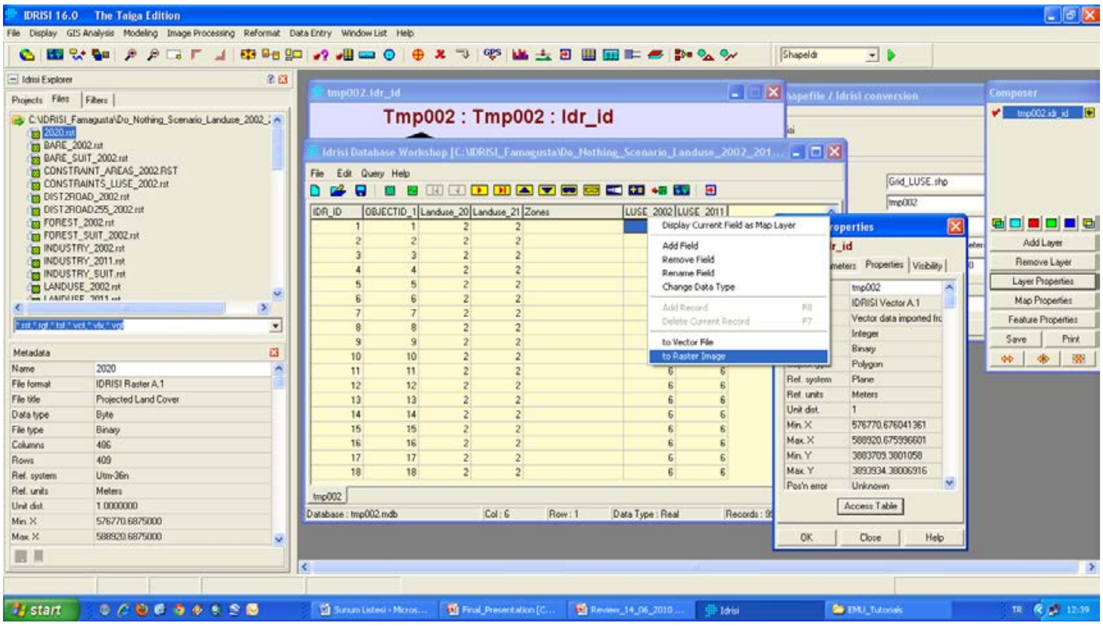
Step One: Opening Idrisi Shape to Idrisi Module an define the layer to be converted



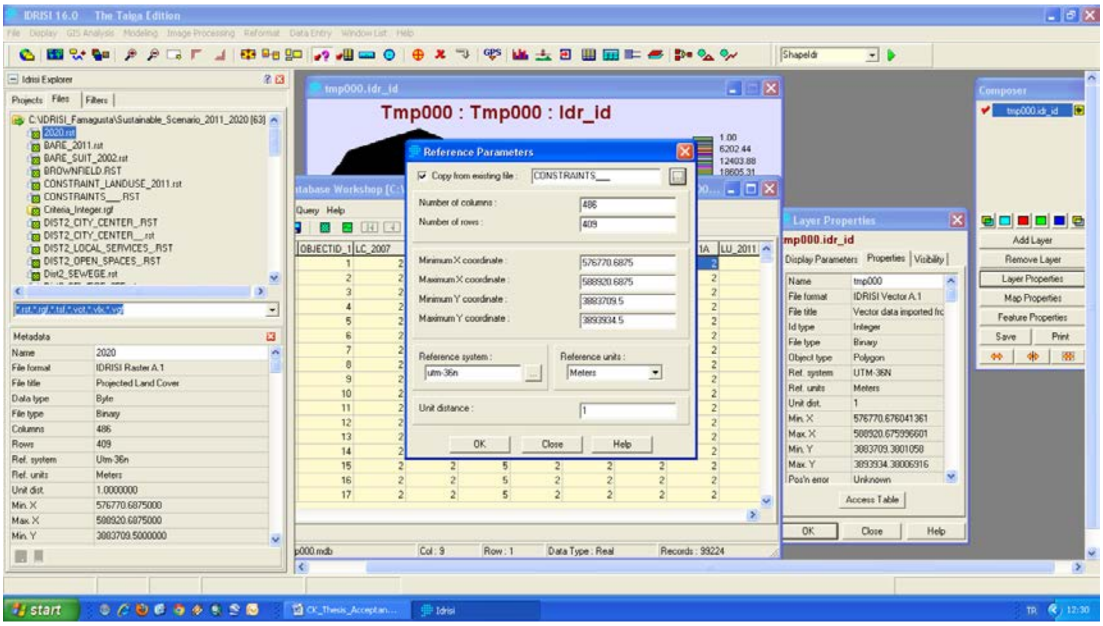
Step Two: Select the layer properties tab and click the properties tab to access table for values to be converted.



Step Three: Select the column to be converted to raster format (srt)

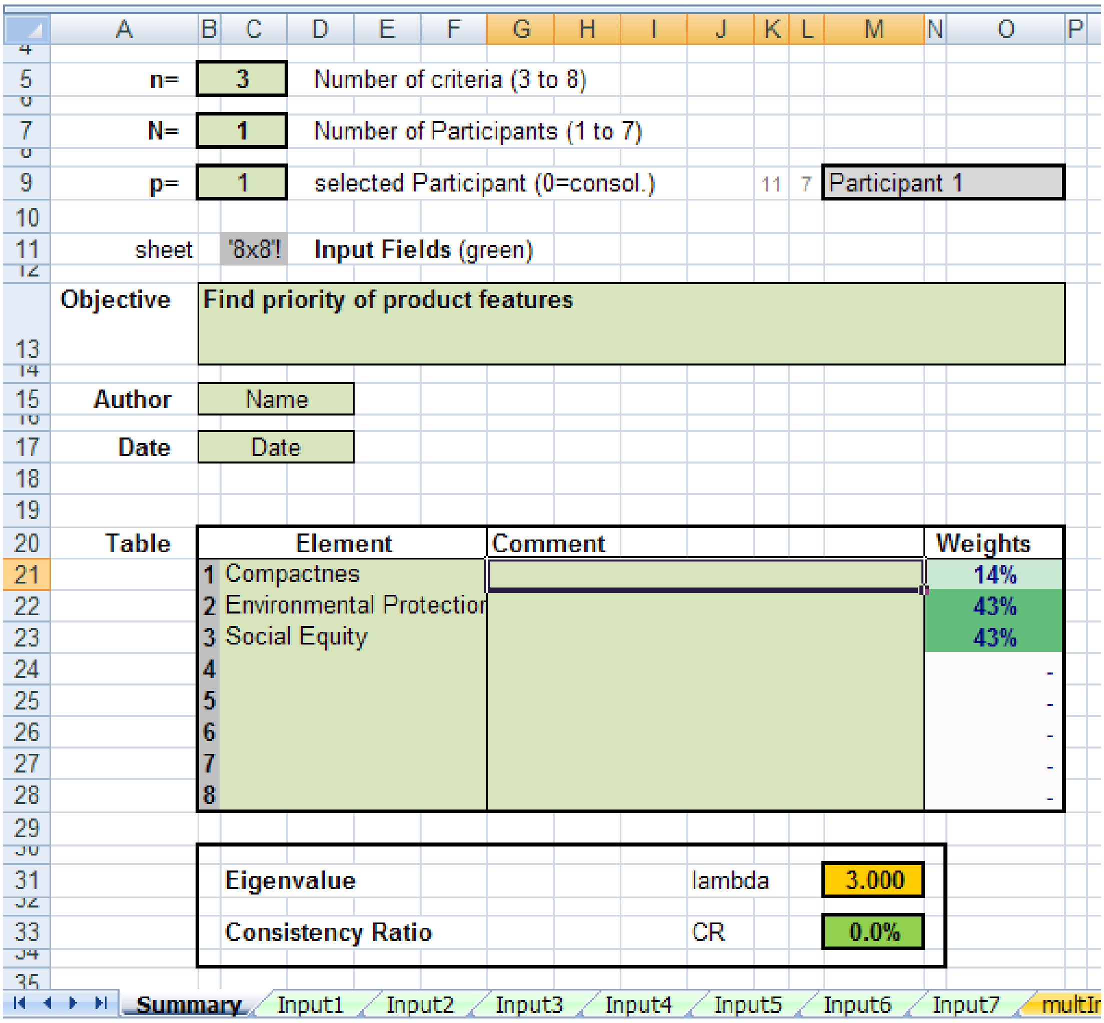


Step Four: Define the name and the parameters for the raster layer to be created. It is important to define grid size and reference grid accordingly.

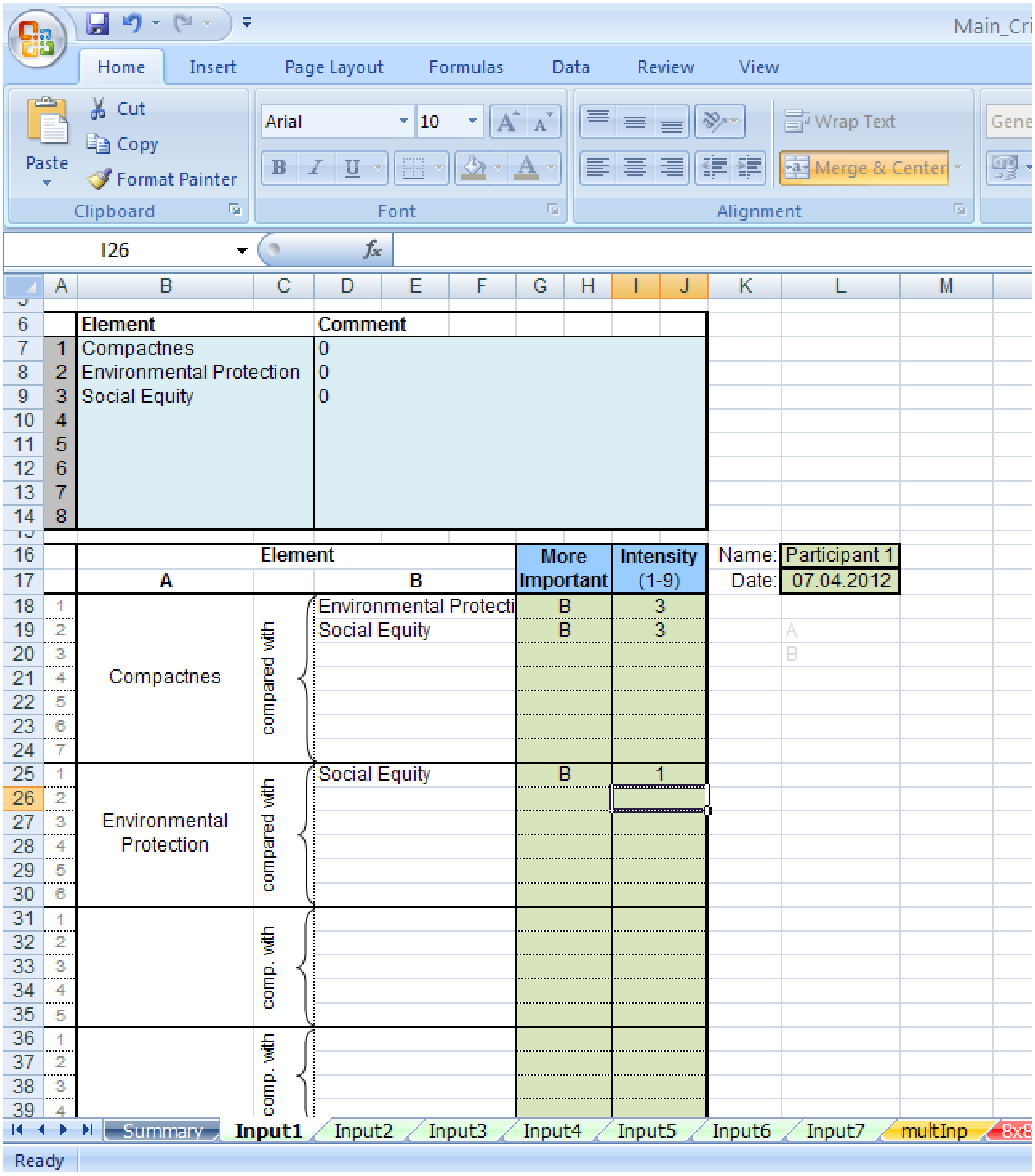


APPENDIX 4: AHP EXCEL SHEET FOR EXPERTS

Screenshot of Main Criteria Comparison Matrix



Screenshot of Comparison Input

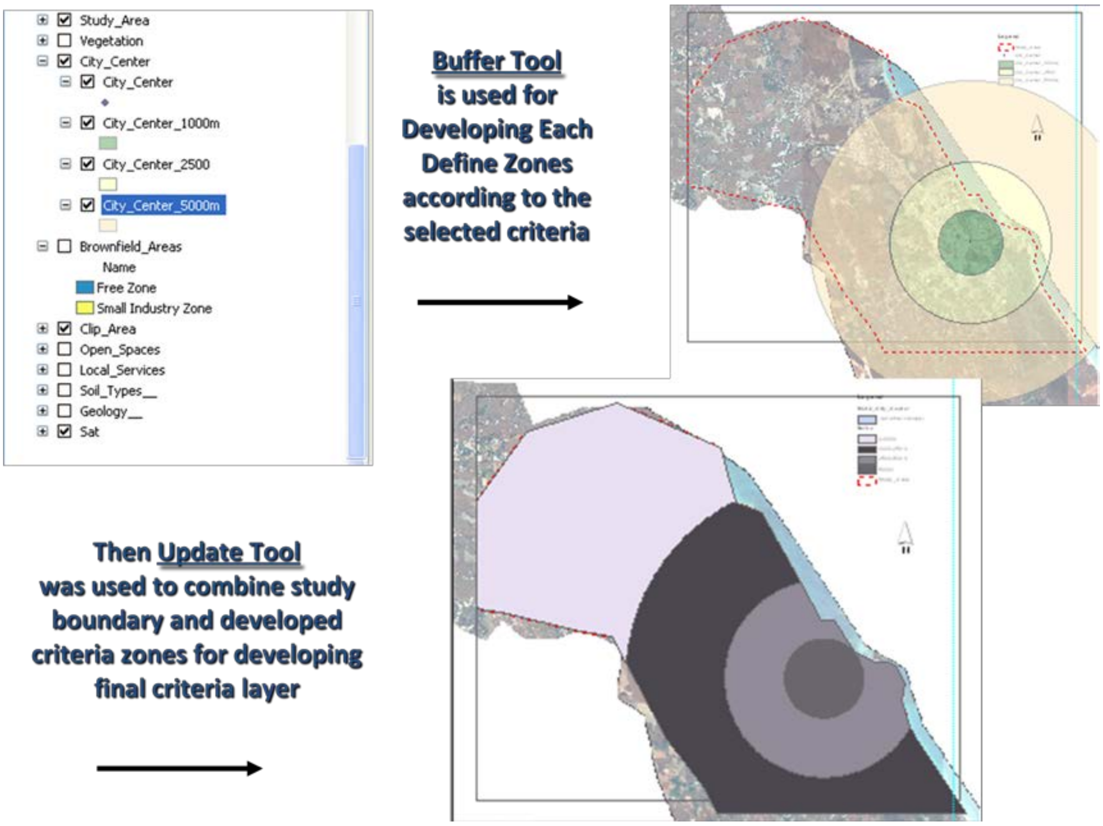


Screenshot of Final Main Criteria Comparison Table

Matrix	Compactnes	Environmental Protection	Social Equity						normalized principal Eigenvector
Compactnes	1	1/3	1/3	1	1	1	1	1	14.3%
Environmental Protection	3	1	1	1	1	1	1	1	42.9%
Social Equity	3	1	1	1	1	1	1	1	42.9%
	1	1	1	1	1	1	1	1	
	1	1	1	1	1	1	1	1	
	1	1	1	1	1	1	1	1	
	1	1	1	1	1	1	1	1	
	1	1	1	1	1	1	1	1	

APPENDIX 5: GENERATING SUITABILITY INDEX AND MCA MAPS

Step One: Defining Suitability Layers and Criteria Zones in ArcGIS



Step Two: Updating Attributes of Criteria Layers and Normalize Them for 0-255

Attribute weights were normalized in the ArcGIS Environment

Table

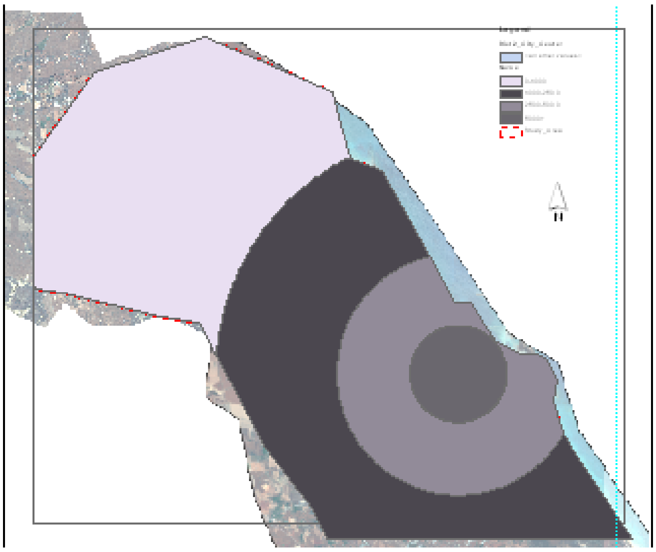
Dist2_City_Center

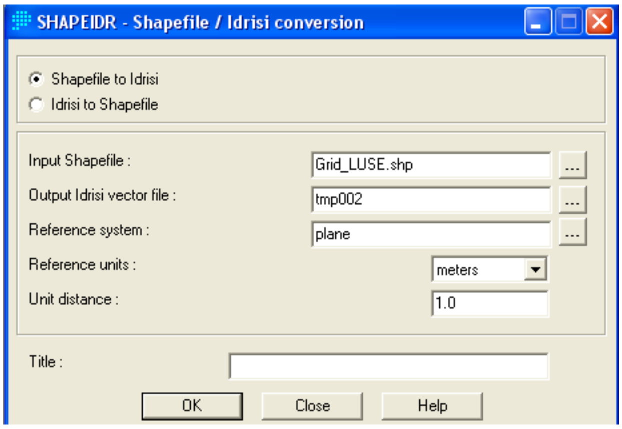
FID	Shape *	OBJECTID	Name	Shape_Leng	Shape_Area	Weigth	Byte100	Byte255
0	Polygon	1	0-1000	20956.237123	26528188.6155	0.55	55	140
1	Polygon	2	1000-2500	31110.634368	23645202.5212	0.28	28	71
2	Polygon	3	2500-5000	21324.113617	12253345.5399	0.11	11	28
3	Polygon	4	5000+	6283.185307	3141592.65359	0.06	6	15

(0 out of 4 Selected)

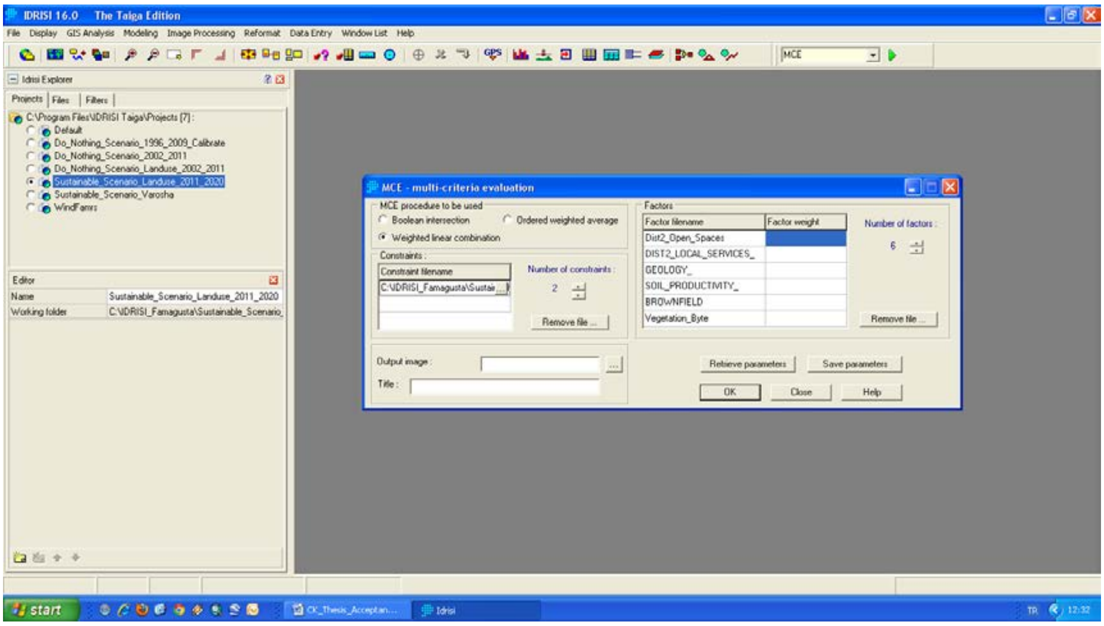
Dist2_City_Center

Step Three: Converting Shapefile to IDRISI Raster Format by "ShapetoIdr" tool

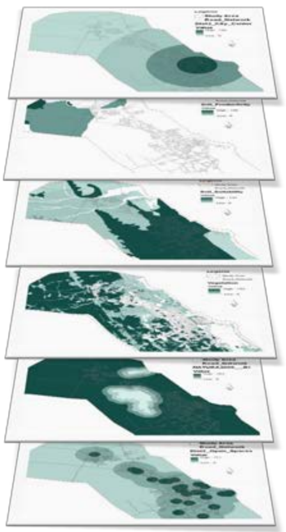




Step Four: Using IDRISI MCA Module to Develop Suitability Map by Combining MCA Maps with Suitability Index equation $SI = \sum_{j=1}^{n} (w_j x_{ij})$



Main Criteria * Sub Criteria * Criterion=Cell value



A1	0.14 * 0.33= 0.0462
A2	0.14 * 0.67= 0.0938
B1	0.43 * 0.36= 0.1548
B2	0.43 * 0.12= 0.0516
B3	0.43 * 0.23= 0.0989
B4	0.43 * 0.29=0.1247
C1	0.43 * 0.50= 0.215
C2	0.43 * 0.50= 0.215