Spatio-temporal analysis of ISs development.
A case study of Istanbul, Turkey

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by

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Abstract

In Istanbul and its suburbs informal development has created risky living conditions and led to environmental problems in natural areas. Until now, policies and actions implemented to address this issue were focused mainly on the physical interventions to informal settlements (IS). Even though this approach has proved to be quite effective in the past, it did not prevent further urban expansion. The main reason for this was the lack of sufficient knowledge about informal development. An enhanced understanding of this process is therefore the key for future success in efficient management of ISs and mitigation of related environmental impacts.

This research aimed to improve understanding of the process of ISs development in Istanbul through comprehensive spatio-temporal analyses. First, it investigated spatial and temporal patterns of ISs during 1990-2005 in Sancaktepe district of Istanbul. To assess the scale of urban expansion the rate of changes of ISs development was calculated. This revealed that the area of ISs increased more than 110% between 1990 and 2005.

Second, analyses of the driving forces of informal development and prediction of probable locations of ISs applying logistic regression (LR) modelling were performed. The list of spatial factors determining the ISs development was compiled based on expert knowledge obtained during fieldwork and literature review. The identified predictors were incorporated to build six logistic regression models (LRM) for different time steps between 1990 and 2005. Performance of the models was evaluated and validated to identify models which best explain the ISs development in the study area. As a result, three models built for 1990-1995 and 1995-2000 were selected to generate probability maps of ISs development showing the likelihood for each location to be informally developed. The derived coefficients from LRMs were used to explain how spatial factors influenced informal development between 1990 and 2005. It was found out that population density and slope were the main predictors influencing spatial development of ISs during the analyzed period of time.

Finally, analyses of the spatio-temporal changes in the environmentally sensitive areas (ESAs) due to informal development were performed. The maps of ESAs were produced based on analyses of environmental legislation of Turkey, expert knowledge, and existing maps. Derived maps of ESAs were compared with the maps of ISs and probability maps to identify ESAs which have been already occupied and have potential to be occupied by ISs.

The results of the study can serve as a basis for the evaluation of the process of ISs development in the whole Istanbul. The applied methodology can be further used to study informal development in other cities and countries. At the same time the technique may serve as a decision making tool for urban planners and policy-makers.

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List of acronyms

AIC: Akaike Information Criterion
CA: Cellular Automata
CBD: Central Business District
CI: Confidence Interval
CL: Confidence Level
DEM: Digital Elevation Model
EPASA: Environmental Protection Agency for Special Area
ESA: Environmentally Sensitive Area
IMM: Istanbul Metropolitan Municipality
IMP: Istanbul Metropolitan Municipality Mayor's Office
ITU: Istanbul Technical University
ISKI: Water and Sewage Administration of Istanbul
IS: Informal Settlement
GIS: Geographic Information Systems
LANDSAT TM: Land Satellite Thematic Mapper
LR: Logistic Regression
LRM: Logistic Regression Model
LULC: Land Use/Land Cover
MDA: MacDonald Dettwiler and Associates
MDGs: Millennium Development Goals
PCP: Percentage of Correct Predictions
ROC: Relative Operating Characteristics
RS: Remote Sensing
SE: Standard Error
SIT: Special Environmental Protection
SPOT: Système Pour l'Observation de la Terre
TEM: Trans European Motorway
UN: United Nations
UN HABITAT: United Nations Human Settlements Program
UNCED: United Nations Conference on Environment and Development
UTM: Universal Transverse Mercator coordinate system
VIF: Variance Inflation Factor
WGS 84: World Geodetic System 1984
WSSD: World Summit on Sustainable Development

1. Introduction

The conventional practices used to address the problem of informal settlements (IS) are based on reactive actions on existing informal patterns (Sietchiping, 2005). To be able to forestall proliferation of ISs and, ultimately, mitigate associated environmental and social problems, a new approach oriented on preventative measures is required.

This study aimed to explore possibilities offered by progress in geo-information systems (GIS) and modelling science to address the issue of spatial and temporal changes in ISs. Results of spatio-temporal analyses are considered to be valuable, as they deepen our understanding of the process of informal development. Such knowledge is important to incorporate in new planning policies to overcome disadvantages of conventional methods and to address the problem of ISs on a qualitatively new level.

1.1. Background and significance

The recent high rates of urbanization have resulted in uncontrolled urban growth and significant increase of urban population leading to the change of urban form and structure, exaggerating social and environmental problems. Urban expansion over new areas increases the consumption of natural resources, eventually causing environmental degradation (Angel et al., 2005). If left unchecked, these may threaten sustainable development of the cities in the long term.

In developing countries urban expansion is associated with emergence of informal development patterns in the form of ISs and slums. The empirical evidence provided by the United Nations Human Settlements Program (UN HABITAT) is striking: about one-third of suburban population worldwide lives in slums, while every four out of ten dwellers are informal (UN HABITAT, 2003). The concerns of world community about this issue have been reflected in the Millennium Development Goals (MDGs) Report 2009. The MDG process sets up the goal to "ensure environmental sustainability" and targets to achieve "a significant improvement in the lives of at least 100 million slum dwellers", as well as to "reduce biodiversity loss" by 2020 (UN, 2009, pp. 42, 49).

Today the term "slums" incorporates the vast ISs (UN HABITAT, 2003). Informal refer to those settlements which are built on the land without legal tenure not following established building and planning regulations (Abbott, 2002, UN HABITAT, 2003). The definition of ISs differs from country to country and depends on the factors, which are taken into account while defining "informality" (e.g. invasion of public land, unapproved construction, lack of basic services) (Payne, 1983; Payne, 2001, UN HABITAT, 2003). The quality of buildings in ISs varies, while access to basics services e.g. water, electricity, sewage system, is usually limited (UN HABITAT, 2003).

Location of ISs on the fringes of the cities and edges of central business districts (CBD) usually causes obstacles for the implementation of spatial development plans, while occupation of environmentally sensitive areas (ESAs) by ISs decreases quality of urban environment (Buyuksalih et al., 2008). Overall, this impedes sustainable development of the cities. To address this problem effective planning and management of ISs based on deep understanding of the process itself, driving factors, and development trends is required. Such knowledge can be obtained by applying GIS and modelling techniques, such as logistic regression (LR).

LR coupled with GIS is a powerful tool to explore urban land use change patterns (Cheng and Masser, 2003; Hu and Lo, 2007; Huang et al., 2009; Xie et al., 2009). This method has been recognized to be an effective and robust tool for establishing functional relationships between land use changes and its drivers (Huang et al., 2010; Poelmans and Rompaey, 2009). It allows making predictions of probabilities of further urban expansion based on the trends observed in the past. The application of LR for modelling of ISs development is therefore thought to assist in the gaining of better understanding of ISs development.

The increase of population in Istanbul and its neighbourhoods has resulted in uncontrolled urban development (Eyuboglu, 2004; Yildrim, 2005). According to Istanbul Master Plan studies the portion of irregular and unauthorized settlements[1] in the residential areas of the city is up to 70% (Unsal, 2007). In Istanbul ISs have a tendency to appear in ESAs[2], preservation of which is critical to the normal functioning of the city (Buyuksalih et al., 2008; Green, 2008). For example, much of the water drainage lines served as the green areas are now occupied by ISs (Kucukmehmetoglu and Geymen, 2009). In the areas prone to earthquakes, ISs are usually constructed without considering existing building requirements for ground stability. This creates insecure environments for their inhabitants, as well as for the dwellers of adjacent neighbourhoods (Parker et al., 1995; Unsal, 2007). ISs put obstacles for implementation of spatial plans impeding the development of the city (Buyuksalih et al., 2008).

The problem of informal development in Istanbul and its neighbourhoods is an urgent topic, as the number of ISs is very high and continues to increase (Unsal, 2009). Not surprisingly, it has been recently announced that addressing the issue of ISs is one of the priority tasks for Istanbul Metropolitan Municipality Mayor's

[1] Unauthorized settlements are built on the land parcels registered as an estate of another owner; while irregularity refers to the process of registration of illegally occupied estates as the property of the occupiers through building amnesties (Unsal, 2007).

2 ESA are defined as "wetlands, coastal zones, forest areas, nature reserves, special protection areas, and other areas protected under national legislation of Turkey and international legislation which Turkey has recognized" (adopted from EIA Directive 97/11/EC) (Europa EU, 2010).

Office (IMP). IMP stated that in order to be able to fulfil this task the analytical survey of the existing problems was required (IMP, 2006). Up to date, all studies conducted about ISs have focused on either analyzing political and socioeconomic drivers of the informal development (Eyuboglu, 2004; Unsal, 2007; Unsal, 2009), or monitoring of ISs and their impacts on environment (Buyuksalih et al., 2008; Walker, 1996; Kucukmehmetoglu and Geymen, 2008; Kaya and Curran, 2005; Baykal et al., 1999). However, deeper knowledge is compulsory to identify challenges on dealing with unplanned development, to achieve success in managing existing ISs, and prevent appearance of the new ones. This research therefore aims to enhance understanding of ISs in Istanbul through comprehensive spatio-temporal analyses, to contribute in finding solution for the existing problem.

1.2. Research problem

In Istanbul an uncontrolled urban development has created unsecure living conditions and caused environmental problems. Moreover, it has put obstacles for implementation of master plans slowing down the process of sustainable development of the city. To date, policies and actions implemented to address this issue have focused on reactive measures, such as demolishing or upgrading of existing ISs and land titling through amnesties (Eyuboglu, 2004; Unsal, 2007; Yildrim, 2005; Yonder, 2006). Even though such approach is proved to be quite effective, it did not stop further urban expansion (IMP, 2006; Iossifidis, 2008; Unsal, 2009).

To solve this problem, planning policies should incorporate proactive measures, which are oriented to address informal growth before its appearance (Sietchiping, 2005). Such strategic approach is the key for future success in efficient management of ISs and mitigation of related environmental impacts. Its implementation should be based on enhanced understanding of ISs development which can be achieved by incorporating spatial technologies such, as GIS and modelling, into planning process.

1.3. Research objectives and questions

1.3.1. General objective

To improve understanding of the ISs development in Istanbul.

1.3.2. Specific objectives and questions

In order to achieve the main research objective the following specific objectives and corresponding research questions were set for the study.

1. **To analyze spatial and temporal patterns of the ISs development.**

- Where were the ISs located?
- What are the spatial changes in the informal settlements?
- When was the rate of change in the ISs development the highest?

2. **To model the ISs development based on the causative factors.**
- What are the factors determining ISs development?
- How do the causative factors affect ISs development?
- Where is informal development most likely to occur according to the prediction results of the LR models?

3. **To analyze spatio-temporal changes in the ESAs due to the ISs development.**
- What types of the ESAs are located in the study area?
- Which ESAs are occupied by informal settlements?
- Where are ESAs which have potential to be occupied by informal settlements?

1.4. Research outputs

- Map of identified spatial and temporal changes in the ISs.
- Identified rate of change in the ISs development.
- List of factors of the ISs development.
- Identified relations between the causative factors and ISs development.
- Maps of predicted probabilities of the ISs development based on LR models.
- Map of ESAs in the study area.
- Maps of identified ESAs which are occupied by ISs.
- Maps indicating ESAs which have a potential to be occupied by ISs.
- An enhanced knowledge about ISs and their spatial development in the study area.

1.5. Research design and outline of the thesis context

The main steps in the research process are summarized in Figure *1* starting with the definition of the research based on literature review about ISs in Istanbul, their interrelations with ESAs, and actions used to address these problems. This served as a basis for the design of conceptual framework of the study (Figure 1).

This study includes descriptive elements refer mainly to the nature of ISs development in Istanbul aiming to gain insight into the issue, its socio-economic, political, and planning context, and how this effects natural areas of the city. This contributes in conceptualizing of the problem of ISs in Istanbul serving as the basis for understanding of this process.

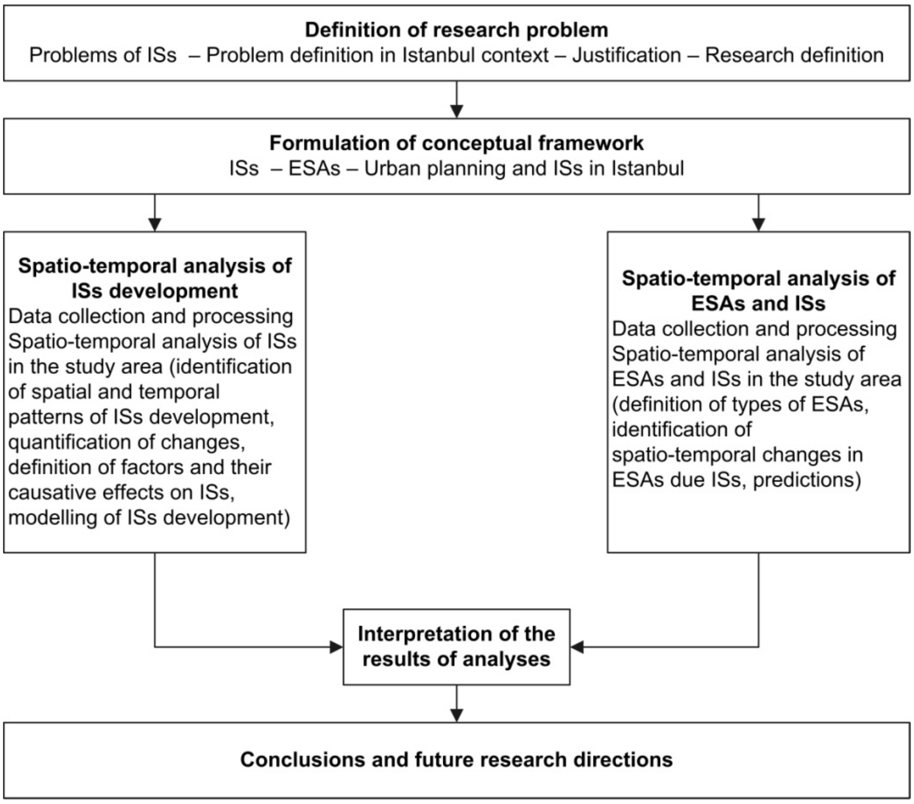

Figure 1: Overview of the research design

The thesis itself consists of 7 chapters. Chapter 1 introduces the research topic providing background information on ISs focusing on the context of the problem in Istanbul. In this chapter the research problem, objectives, and questions are presented. Chapter 2 explores relevant literature on the main themes of the study. Its aim is to describe in details the process of ISs development in Istanbul giving an overview of the existing situation and indicating issues which should be addressed. Chapter 3 introduces the study area and provides information about the conducted fieldwork and the collected data. Chapter 4 focuses on the methods applied to achieve objectives of the study and to answer research questions, while the obtained results are presented in Chapter 5. The following chapter 6 is devoted to the discussion of the results, and their possible implications in urban planning. Finally, in chapter 7 the main concluding remarks of the study are summarized and further research directions are outlined.

2. Informal development and their role in Istanbul

This chapter starts with the definition of informality concentrating on its housing aspect. This is followed by the review of methods which can be applied to analyze informal development with special emphasis on the available modelling techniques. The remaining sections are devoted to ISs of Istanbul, their historical evolution, and the current situation. This information aims to provide background of the problem and to highlight the main reasons of informal development in the city. The chapter concludes with an overview of the studies about ISs which have already been conducted in Istanbul.

2.1. Urban informality

Informality is an important issue to consider for planning of the cities in developing countries. It has been recognized that informal sector contributes significantly to cities urban economies (Roy, 2005). No unity in conceptual definition of the term has been established having strong implication on the policy measures adopted to mitigate this issue (Bromley, 1978). Section 2.1 focuses on the concept of informality and its definition emphasizing on changes occurred towards understanding of this term. It also elaborates more on such aspects of informality, as informal housing and land.

2.1.1. Concept of informality

In the history of the development science the term "informal sector" was first introduced by Keith Hart in a conference "Urban Unemployment in Africa" in 1971(Moser, 1978). By "informal sector" he mainly referred to urban informal employment and production caused by urban poverty (Hart, 1973). Their works have served as a springboard for the fast development and adoption of the concept which has incorporated other aspects of informality, such as informal housing (Bromley, 1978).

Generally, two main different points of view exist on informality: some authors consider it as a part of dichotomy of two sectors of economy– formal and informal (De Soto, 2000; Hall and Pfeiffer, 2000), while the others argue that it should be regarded as a mode of urbanization process (Roy and Alsayyad, 2004; Roy, 2005; Moser, 1978). The first group views informality as an independent sector of economy totally separated from formal one. This idea was initially introduced by Hart (1973) and has been developed by De Soto (2000), Mazumdar (1976), and Tokman (1978). In their works informality is associated with urban poverty. The informal sector is viewed as a phenomenon of local economy which is ultimately integrated to the formal sector through the legalization process (De Soto, 2000; Hall and Pfeiffer, 2000). The second group considers that informality represents a conceptual disagreement towards a division for formal and informal sectors

(Bromley, 1978; Moser, 1978; Payne, 2004; Roy, 2005). Bromley (1978), Moser (1978), Roy (2005), and Roy and Alsayyad (2004) claimed that dualistic classification cannot fully explain the essence of informality, as it assumes that both sectors are substantially independent. In contrast, they argue that formal and informal sectors are continuously interconnected and contribute into each other development (Bromley, 1978). For instance, Roy (2005) defines urban informality as "an organizing logic, a system of norms that governs the process of urban transformation itself" connecting different economies and urban spaces.

2.1.2. ISs as a spatial form of informality

The first studies of informality as a spatial aspect of urbanization were conducted in the mid of 1970s in Latin America (Roy, 2005). Before that, an understanding of informal sector was mainly restricted to the informal work and dual economies (Roy, 2005). The Latin concept has defined informality as "a manifestation of informal process in the urban environment" (Roy and Alsayyad, 2004). It has revealed that political and social issues are strongly embodied in urban informality. This notion spread very fast in the Third World countries serving as a basis for the formulation of the conceptual understanding of spatial forms of informality (Roy and Alsayyad, 2004).

Informal settlements, as a spatial form of informal development, are viewed as a distinguishing market with property and exchange values where affordability increases with the absence of formal planning (Baross, 1990; MacAuslan, 1985; Ward, 1982). This trend poses the questions how legality and illegality are defined by official regulations, as it serves as a basis for the distinction between the forms of informality (Roy, 2005). The examples of variation within informality can be ISs resulted from land invasion and informal subdivisions and residential areas formed through legal land ownership without following land use regulation. The best way to deal with informality is therefore to understand how the authorities of the country define planned and unplanned development and to analyze the ways used to solve this problem (Roy, 2005).

2.2. Dealing with ISs

In many countries upgrading or demolishing of ISs are proved to be effective conventional methods used by official authorities to address this issue (Abbott, 2002, Choguill et al., 1993, Choguill, 1999). There is however no universal guideline to apply physical intervention methods for all situations (Abbott, 2002). Besides, the individual approach for upgrading of ISs has been recognized in order to guarantee the sustainable development of the cities (World Bank, 1991). This requires intervention to the ISs based on understanding of local situations and consequences of such actions (Abbott, 2002).

Though upgrading and demolishing as methods to address a problem of ISs are effective to deal with actual situation (Abbott, 2002, Choguill, 1999; World Bank, 1991), they fall short in prevention of the further ISs development (Abbott, 1996;

Sietchiping, 2005). To address this issue, new planning practices should be implemented based on knowledge of informal development and its main drivers (Roy, 2004; Yildrim, 2005). GIS and modelling techniques are suitable tools for this purpose (Sietchiping, 2005). They permit implementation of inclusive analyses of ISs, identifying their main causative factors, and prediction of future informal patterns (Sietchiping, 2005; Uzun and Cete, 2004). Knowledge of the main forces of ISs development and their causative effects can be employed in urban planning to improve practices of dealing with informal development, while predictions can be involved to elaborate plans and policies for prevention of their growth (Parker et al., 1995; Uzun and Cete, 2004).

2.2.1. Modelling as a new approach to manage ISs

In urban science the conventional approach for the modelling of urban development refers to the application of urban growth and land use change models (De Bruijn, 1991, Huang et al., 2009). Reviews of these models can be found in Brown et al. (2004), De Bruijn (1991), Parker et al. (2003), and Xie et al. (2009). Incorporated techniques for this type of modelling are: cellular automata (CA), LR, artificial neural networks (Batty et al., 1999; Li and Yeh, 2001; Theobald and Hobbs, 1998; Weng, 2002). They have been applied for urban growth studies with different degree of success. Among them, LR has been claimed to be very effective method for land use change analyses due to its explanatory power and spatial explicitness (Cheng and Masser, 2003, Munroe et al., 2004). The examples of its application for modelling urban growth can be found in Cheng and Masser (2003), Fang et al. (2005), Hu and Lo (2007), Huang et al. (2009), and Xie et al. (2009).

The use of logistic regression model (LRM) for informal development studies yields good results, as it can estimate functional relations between land use change and factors driving this process (Hu and Lo, 2007). This knowledge is considered to be valuable, as it gives deeper insight in the process of informal development and its main driving forces (Sietchiping, 2005). Though LRM lacks description of temporal dynamics of land use changes limiting future scenario generation, it provides an opportunity to analyze future development patterns based on the trend observed in the past (Dendoncker et al., 2007). For LRMs the computation requirements are not so intensive, as for example for CA models and the input data requirements are relatively easy to fulfil (Hu and Lo, 2007).

2.2.2. Factors of urban expansion

In the modelling of land use changes the most important task is to define the main drivers of land use transformation and to explore the relationships between them and land use changes. The number of studies has proved that there is no universal set of factors which can explain the process of urban expansion, as every case is unique (e.g. Xie et al., 2009). It is always necessary to define variables which are relevant for the specific case (Hu and Lo, 2006; Poelmans and Van Rompaey, 2009). This can be done based on empirical studies, literature review, and consultations with local experts (Poelmans and Van Rompaey, 2009).

There are different approaches towards classification of factors used for urban expansion modelling. First approach groups factors based on how they are incorporated in models, such as: site specific, proximity characteristics, and neighbourhood characteristics (Huang et al., 2009). Some authors classify factors according to their nature: spatial (e.g. slope, distance to the major roads) and non spatial factors (race, policies) (Cheng and Masser, 2003); or social, econometric, biophysical variables (Hu and Lo, 2006; Sietchiping, 2005). Verburg et al. (2004) distinguished five types of factors considering both nature of variables and its performance in the model: biophysical, economic, social factors, spatial policies, spatial interactions, and neighbourhood characteristics. The choice of the classification system, as well as causative factors, depends on the authors and the main aims of the study (Poelmans and Van Rompaey, 2009).

2.3. ISs in Istanbul

This section focuses on ISs development in Istanbul. It starts with a definition of ISs and desciption of their types. Then historical overview of the process of informal development in Istanbul is provided. It also includes informtion about legislation related to ISs and planning system in Turkey, as it gives deeper understanding of driving forces of informal development on different stages.

2.3.1. Definition of ISs in the context of Istanbul

Many definitions of ISs are found in the works of Turkish researches (Eyuboglu, 2004; Iossifidis, 2008; Kucukmehmetoglu, and Geymen, 2009; Tiirkoglu, 1997; Unsal 2009; Yonder, 1987; Yonder, 2006). For example, Yonder (1987) defines ISs as “ones that one way or another, do not fit the regulatory framework set up by the government”, while Unsal’s (2009) definition refers to “illegal occupation of estate that belongs to public or another person”. In this study under ISs are referred to the “residential areas where a group of housing units has been constructed on land to which the occupants have no legal claim, or which they occupy illegally” (UN HABITAT, 2003). Using this term all types of ISs are considered including legalized informal settlements. However, it is out of the scope of the research to investigate the semi-legal[3] types of development, as their owners have legal claims on the land. To avoid confusion the terms illegal settlements, irregular settlements, unplanned settlements, informal development, unauthorized settlements are used as a synonyms to informal settlements.

2.3.2. Types of informal development in Istanbul

In Istanbul the types of ISs are distinguished based on the way of land occupation, social status of occupants, and response of official authorities (Eyuboglu, 2004; Tiirkoglu, 1997; Unsal, 2009; Yonder, 2006). From the land occupation point of view ISs emerge through organized land invasions, unauthorized subdivisions of

[3] Under semi-legal[3] types of development we mean unauthorized constructions built on legally owned plots and subdivisions of legally owned plots.

legally owned plots, successive occupation of public land, and customary deals for land occupation (Yonder, 1987). Depending on the social status of informal dwellers, ISs are inhabited by low, middle, and high income groups. Even though, initially informal dwellers were associated with urban poor, in recent years it has been recognized to be an important domain for the middle and upper classes of the society (Roy, 2005; Roy and Alsayyad, 2004). Since 1980s the illegal occupation of land by representatives of the middle and high income groups (examples of informal luxury housing areas in protected water basins in Sancaktepe, Beykos, and Sultangazi) has been observed in Istanbul (Baykal et al., 1999; Kucukmehmetoglu, and Geymen, 2008). From the legal status point of view legalized informal settlements, known as irregular settlements, which have obtained the title deeds through the series of development amnesties and rehabilitation projects are distinguished (Eyuboglu, 2004; Unsal, 2009). More detailed description of the most common types of ISs is provided below.

The gecekondu *"*landed over night" refer to those settlements which are built in a very short period mostly on public land without legal permission (Tiirkoglu, 1997; Yildrim, 2005; Yonder, 1987). In Istanbul the first gecekondu appeared at the end of 1940s. They were mainly located near industrial sites or on periphery of the city. The first official record of the term was found in the Gecekondu Law of 1949, where gecekondu are defined as "illicit constructions, which were built regardless the general regulations and directives determining construction work requirements, regardless the soils on which building is permitted or not, regardless the fact that land do not belong to the builder and that gecekondu are being built without the owner's authorization" (Yonder, 1987, p. 215).

Initially, gecekondu were composed by poor one and two-storied buildings. Lately, they have been transformed into settlements with multi-storied houses constructed from proper materials indicating the change of the social status of squatters (Yildrim, 2005). Traditional gecekondu (built before 1980s) are located around the city centre, while most of the new settlements are situated on the outskirts of the city. Until recently, the basic services and infrastructure were inadequate in those areas (Tiirkoglu, 1997). The situation has changed radically in the last ten years. For example, the districts which are almost completely formed by new ISs (e.g., Sultanbeyli, Sultangazi, and Sancaktepe) were provided with sufficient infrastructure and services due to the populism policies implemented by political parties seeking for more votes (Iossifidis, 2008, Tiirkoglu, 1997; Unsal 2009, Yalcintan and Erbas, 2003).

Hisseli Tapu or unauthorized subdivisions of legally owned land plots emerges as result of partition of big land parcels with title deeds and sale of the smaller plots on the informal market (Yonder, 1987). According to the legislation landowners have the right to sell their land. But division and construction of new buildings are illegal. Informally built houses on subdivided land were usually legalized by local municipalities. At the end of 1970s hisseli tapu subdivisions were common practices providing an opportunity for poor people to get access to the residential areas (Yonder, 1987). This type of ISs also included construction of new buildings without receiving relevant permission on legally owned parcel (Yonder, 2006).

2.4. Historical overview of ISs development in Istanbul

The process of ISs development in Istanbul has passed through several stages (Yonder, 2006):

I stage: formation of the first ISs (1945 – 1960);

II stage: expansion and establishment of ISs (1960 – 1980);

III stage: urban transformation (1980 – current period).

2.4.1. Formation of the first ISs

The second part of 20^{th} century was characterized by fundamental changes in Turkish economy revealed in the fast rates of urbanization, industrialization, and infrastructure development (Yonder, 1987). Unequal development of regions resulted in strong migration from west to east (Unsal, 2009). Located between Asia and Europe, Istanbul became “Asian gates to Europe” (Figure 18 in Appendix A) (Unsal, 2007). The rates of its development were among the highest in the country which made it a preferable destination for the migrants from all over the country. The city experienced high rates of population growth and increasing urban expansion (Kucukmehmetoglu, and Geymen, 2009; Unsal, 2007; Unsal, 2009; Yonder, 1987).

High inflation and cyclical economic development attracted investments on property by all income groups (Kaya and Curran, 2006; Yonder, 1987). This, coupled with rapid urbanization and population growth, resulted in a high demand for land and housing. The legal market was not able to satisfy the growing demand, as the supply was limited by legislative, economical, and technical constraints (Eyuboglu, 2004; Kaya and Curran, 2006; Unsal, 2009; Yonder, 2006). At that time most funding was directed to the industrial development and local government did not have enough funding neither for the development of new housing areas, nor for providing sufficient services and infrastructure in the existed ones (Yonder, 2006). As a result, the first ISs appeared. The governmental responded to the “cancerous growth” of ISs by adopting the Gecekondu Law n 1949 which led to their frequent demolitions (Iossifidis, 2008).

During the first stage the number of gecekondu increased from 5000 to 60000 between 1949 and 1960 (Yonder, 2006). Most of them appeared on public land usually not suitable for conventional construction (i.e. areas with steep slopes, landslides and flood prone areas). They were located near highways, places of employment; and were lacking basic services and infrastructure (Yonder, 2006).

2.4.2. Expansion and establishment of ISs

Economic growth, rapid urbanization, high rate of inflation, population growth, increasing migration, and a failure of government to provide sufficient housing resulted in accelerated growth of ISs (Yonder, 1987). Tolerance of official authorities towards the emerging ISs led to the formation of informal land market in the beginning of 1960s (Yonder, 1987). The way of squatting has changed in the mid of 1960s when the illegal occupation of land became almost impossible. Squatters had to buy the right to occupy even the public land from local dealers on informal market (Yonder, 1987). The illegal subdivisions of agricultural land became one of the main sources of informal development. This created new spatial forms of informality related to the rural-urban conversion on the borders of the middle-class suburban areas and agricultural land and forms created under the strong influence of religious and ethical groups' migration (Roy, 2005).

In 1966 the Law of Unauthorized Buildings was issued aiming to prevent ISs development by creating special prevention zones. Within these areas new construction was not allowed and already existed houses were demolished. As a compensation for expropriated property inhabitants of ISs were provided with small land plots (Unsal, 2009). However, the law was not able to prevent further ISs development. Instead, it fostered urban expansion[4] further supported by politicians who were speculating land to obtain more votes (Unsal, 2009; Eyuboglu, 2004). The land market of Istanbul became a political arena where stakeholders (politicians, local and central governments, municipalities, landlords and land dealers) were following their own interests (Unsal, 2009; Yalcintan and Erbas, 2003; Yonder, 2006).

During the second stage ISs have expanded over the city boundaries occupying agricultural fields around the city, forest areas, water basins, and other open spaces (Figure 2). Preferable locations for new settlements were along roads, near industrial areas, and sites not suitable for formal construction (areas with steep slopes, wetlands, water basins etc) (Yonder, 2006). City expansion had negative impacts on the environment due to occupation of ESAs by new settlements and pollution produced by informal construction (Figure 2) (Parker et al., 1995; Walker, 1996).

2.4.3. Urban transformation

In the 1980s Turkey faced an economical decline resulting in accelerated rates of inflation, decrease of wage levels, and strong migration to the cities. During 1983-1992 the central government issued a number of new laws (e.g. 1983/2805, 1984/2981, 1986/3290, 1987/3366) providing a series of development amnesties aiming to legalize ISs (Unsal, 2007). The Law of Mass Housing was approved in 1984 according to which the institutional arrangements were made and mass housing

[4] In 1970s two third of housing production of Istanbul was formed by informal sector (Yonder, 1987).

fund was created to supply with affordable housing middle and low classes (Eyuboglu, 2004; Unsal, 2009). The new Gecekondu Law was approved in 1984 providing penalties to all sides involved in informal subdivisions. The building densities within ISs were still allowed to increase (Yonder, 2006).

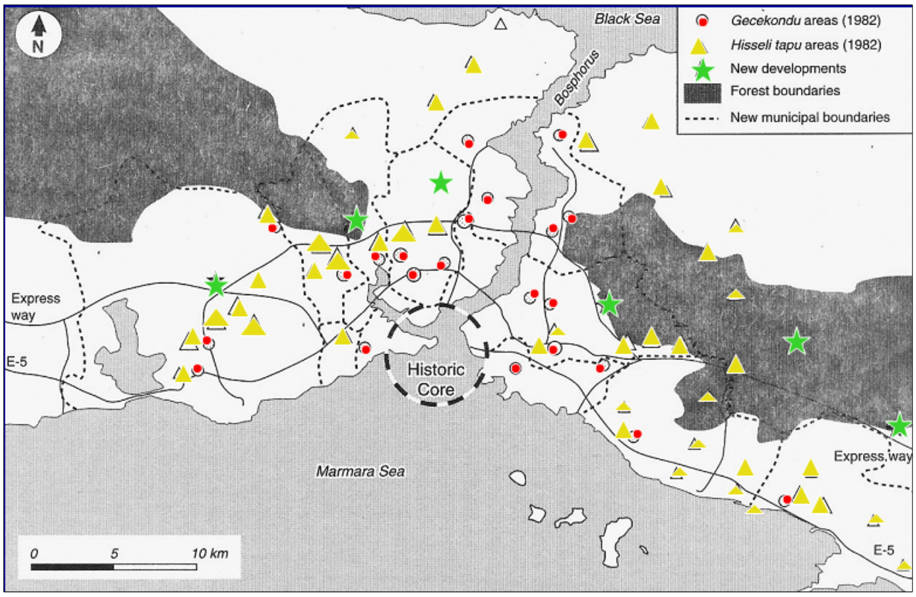

Figure 2: ISs in Istanbul in 1982 (Yonder, 2006)

During this stage the ISs development slowed down, while formal housing production increased. In some cases new housing areas were constructed at the expense of ISs. New settlements were pushed into the protected water basins and forest areas increasing the pressure on environmental resources of the city (Unsal, 2007). After Marmara Earthquake in 1999 the governmental authorities realized the necessity to launch urban transformation to reduce the risk of new disaster and preserve ESAs (Yonder, 2006). In 2005 an environmental plan at scale 1:100000 was prepared for Istanbul aiming to launch sustainable development of the city. But this plan is yet to be approved (Unsal, 2007). In 2005 the Law of Urban Transformation was also issued promoting redevelopment of risky urban areas. However, this law concentrates only on physical aspect of transformation and not provide clear mechanisms for its implementation (Unsal, 2009).

The current stage is characterized by overall decline of ISs development, legalization of existing ISs, infrastructure development, and increasing formal housing production (Yonder, 2006). The decrease in ISs development is explained by the restriction of governmental control, economical restructuring, and strengthen of the formal housing market[5]. Another important reason is the limited amount of land available for the development (Unsal, 2009). Further urban expansion can take place only at the expanse of ESAs on the northern part of Istanbul which has been already observed in some districts (e.g. Beykos, Eyüp) (Buyuksalih et al., 2008; Goksel, 1998).

2.5. Planning system of Turkey

Regulation of spatial development and planning in Turkey started with the approval of the Law of Buildings and Roads in 1933**.** The need for the new planning law emerged with the rapid urban development in 1950s which has been adopted in 1957 (law No 6785) followed by the establishment of the Ministry of Reconstruction and Settlement in 1958 and the State Planning Office in 1963**.** These authorities were responsible for preparation of the first Development Plan in 1967. The current Planning Law No 3194 approved in 1985 was a changing point for the planning system, as it passed the planning rights from the central government to the local ones. Another law which regulates planning and spatial development was the Law of Special Government for Provinces approved in 2005. It delegated planning rights to the local authorities of the provinces. This law caused disputes among special governments of provinces and central planning institutions (Unsal, 2009).

Currently, the two-level planning system is in force in Turkey. For the planning on the first level the State Planning office and the Ministry of Environment are responsible. They prepare regional and environmental plans of 1:100 000 for the whole country. The second level of the planning is implemented by the local governmental authorities who prepare development and implementation plans according to the approved regional and environmental plans (Eyuboglu, 2004). Exceptions are those situations when planning decisions are related to the tourism, protected, illegally developed, and mass housing areas, or major transportation routes. In those cases planning decisions are made by central government (Eyuboglu, 2004). According to the Planning Law local authorities have the right to revise the plans made by the central government to meet planning purposes in the implementation phase by preparing supplementary plans – plan modifications, revision plans, and local development plans (Unsal, 2009). Though the supplementary plans are aimed to improve planning process, they have become the subject of speculations by local authorities (Eyuboglu, 2004; Unsal, 2009). They are used to avoid central government decisions pursuing interests of local ruling party (Unsal, 2009).

The current planning system has shown to be inefficient in the integration and coordination of actions among institutions of different planning levels. What is more, it has led to the fragmentation of the planning authorities through enabling different institutions to participate in the planning processes (Eyuboglu, 2004; Unsal,

[5] In 2008 there were 100000 apartments available for sale. However, there was no demand, as people could not afford to buy apartments for market prices (Key informant 2).

2009). This resulted in frequent disputes related to the decision-making process and overall disorder of planning process in Turkey (Unsal, 2009). The court cases are not rare as a current legislation does not define the hierarchy of the decisions in cases where more than one law is valid (Unsal, 2009).

To summarize, the approved legislation is lacking clear mechanisms for prevention of informal development and launch of urban transformation. There is neither common understanding among politicians and planners about urban transformation, nor consideration of social, economical, and environmental implications of its implementation (Yonder, 2006). Such vagueness introduces uncertainties in successful realization of this process.

2.6. Studies about ISs development in Istanbul

The studies made on the informal development in Istanbul can be divided in two main categories: studies exploring ISs growth over last century (Eyuboglu; 2004; Iossifidis, 2008; Unsal, 2007; Unsal, 2009; Yildrim, 2005; Yonder, 1987; Yonder, 2006) and studies focusing on monitoring of ISs in ESAs (Baykal et al., 1999; Buyuksalih et al., 2008; Kaya and Curran, 2005; Kucukmehmetoglu and Geymen, 2008; Walker, 1996).

Referring to the studies focused on the evolution of ISs development a detailed review was presented in the sections 2.3, 2.4, and 2.5. Most of them are focused on analysis of one group of factors (e.g., institutional and political factors) of informal development (Eyuboglu; 2004; Unsal, 2007; Unsal, 2009; Yonder, 1987). Accelerated growth of ISs as result of mutual effect of different factors was not reflected in these studies. Moreover, there has been no attempt made to explain spatial patterns of ISs development from the point of view of different factors which influence the appearance of ISs.

Only a few authors have reflected other aspects of ISs in their studies. For example, Uzun and Cete (2004) developed a new method for creating alternative design for reconstruction of ISs within frame of upgrading programs. Tiirkoglu (1997) compared satisfaction of dwellers living in informal and formal housing areas. The author came to the conclusion that the difference between levels of satisfaction of these two groups was not significant due to almost similar living conditions in terms of provision of infrastructure and services.

There are a number of recent studies focusing on monitoring of land use/land cover (LULC) change applying RS techniques mainly in water basins of Istanbul (Baykal et al., 1999; Buyuksalih et al., 2008; Coskun et al., 2008; Kaya and Curran, 2005; Kucukmehmetoglu and Geymen, 2008; Kucukmehmetoglu and Geymen, 2009; Walker, 1996). Maktav and Erbek (2005), Rebekah (2008), Sunar (1998) showed that the rapid change of land cover due to urban growth has been detected in Ikitelli and Beykoz districts at the expanse of agricultural land and forest areas. Studying land cover change in Beykoz Musaoglu et al. (2005) came to the conclusion that urban expansion over the last 20 years has caused degradation of

ESAs in the district. The author indicated that the fast land cover changes were caused by the construction of new transport network. The same conclusion was given by Goksel (1998) who pointed out that the fast urban invasion to the Elmali water basin can be explained by the construction of the second Bosporus Bridge and Trans European Motorway (TEM). Most of the reviewed studies indicated that the main reason of rapid ISs growth in ESAs of Istanbul is due to the rapid development of infrastructure, especially transport networks. These studies did not set up the aim to analyze factors of urban expansion but concentrated more on LULC change detection and techniques applied for this procedure. Such knowledge is not enough for the formulation of the policies and plans sufficient for preventing further urban expansion and environmental degradation (Kucukmehmetoglu and Geymen, 2009).

Up to date, the research on informal development in Istanbul has focused on either historical evolution of ISs, or LULC changes in water basins due to urban expansion. These studies fall short of explaining different factors of informal development in combination with detailed survey of changes in growth of ISs and related impacts on ESAs. This knowledge is important to gain better understanding of ISs development which is necessary for the formulation of effective policies and planning decisions capable to prevent further urban expansion.

3. Study area and data collection

This chapter provides background information of the study area and the data collection. It explains the rationales behind the selection of Sancaktepe as the study case for this research. The overview of the collected data and data sources are also included. The chapter concludes with the explanation of the quality of the collected data and its implications on the current study.

3.1. Selection of the study area

The choice of suitable case study depends on the research problem (Yin, 2003). Thus, to choose the study area several selection criteria were defined considering research objectives of the thesis. The identified criteria were: dynamic development of ISs and presence of ESAs. The final choice of the case study was made during the fieldwork.

To identify districts of Istanbul corresponding to the first selection criterion the proportion of changes in built-up areas[6] in 1990-2005 were calculated (Eq. 3 in section 4.2.2). According to the results three districts: Esenyurt, Beylikduzu, and Sancaktepe had the highest values of proportion of changes (22.05%, 18.97%, and 14.55% correspondingly). As there are almost no natural areas left within Esenyurt and Beylikduzu districts, it was decided to select Sancaktepe, as almost 37% of its area is ESAs[7]. This decision was approved after discussion with urban planners from Istanbul Metropolitan Municipality Mayor's Office (IMP) (key informants 1, 16).

3.2. Study area

Sancaktepe is situated in Anatolian part of Istanbul (Figure 3). The area of the district is ≈ 62 km^2. Population is 230 thousand people. The district consists of 22 wards (Sancaktepe municipality, 2009a). The northern and southern parts of Sancaktepe are covered with forest, while its north-eastern part is situated within the water basin of Omerli lake (Figure 19 in Appendix A). The natural boundary of the city passes through Sancaktepe (key informant 11). All districts which are situated upper on the north are within protected forest and water basins areas, where only special development projects can be implemented; while the rest of the neighboring districts are well developed (Figure 19 in Appendix A).

[6] It was decided to concentrate on changes in built-up areas, as there were no maps of ISs available during fieldwork when the choice of study was made.
[7] Obtained from the analysis of land cover maps of Istanbul.

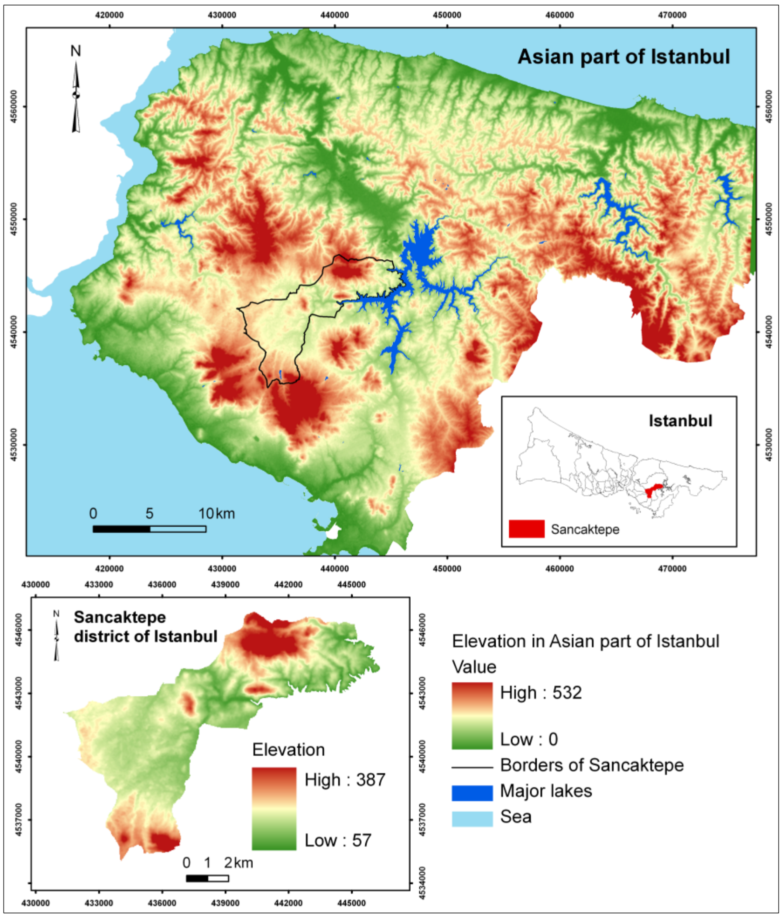

Figure 3: Study area – Sancaktepe district of Istanbul

Sancaktepe as an administrative unit was created on 22nd of March, 2008 by merging Samandıra, Sarıgazi, and Yenidoğan neighbourhoods. From 2004 to 2008 these areas belonged partly to Umraniye, Maltepe, and Pendik districts (Sancaktepe municipality, 2009a). Before 2004 this territory was not managed by authorities of Istanbul, as they were out of the city boundary. This has resulted in appearance of unplanned development patterns, mainly ISs (key informants 16, 19). Currently, the local authorities of Sancaktepe have initiated dynamic development of the district with special focus on the infrastructure and rehabilitation of ISs (key informants 17, 25). The problem of informal development still remains an urgent issue for the district due to the high proportion of ISs and availability of the undeveloped land (Emir, 2009)[8].

3.3. Fieldwork

Fieldwork was conducted in September of 2009 in Istanbul on the base of MP. The main tasks during this stage referred to the collection of the sufficient datasets for the research, conducting interviews with key informants, and gathering relevant information and materials.

3.3.1. Primary data collection

Interviews were chosen as a method to collect primary data during the fieldwork. This choice was guided by the necessity to obtain additional qualitative information which cannot be derived from the secondary data and gain expert opinions on the relevance of the proposed analyses for control and management of ISs development. Topic focused interviews were held with 26 key informants (Table 17 in Appendix B) to collect information specifically related to the field of expertise of the respondents. The interviews were held with the specialists from IMP, academic staff from Istanbul Technical University (ITU) and Mimar Sinan Fine Arts University, and urban planners from municipalities of Sancaktepe and Kucukcekmece districts (Figure 4). Before going to the field the provisional list of topics and questions was prepared (Appendix C). The questions were mainly related to three subjects: ISs development in Istanbul and its impacts on ESAs, localization factors of ISs, and measures/tools for the management of informal development. All interviews were recorded and the records were processed by summarizing information and eliminating ambiguous responses as suggested by Groenendijk and Dopheide (2003).

Apart from expert interviews, several informal discussions were conducted with urban planners and academic staff to gain deeper understanding of the informal development in Istanbul and Sancaktepe district. The outcomes of the interviews and discussions were one of the main sources of information for the study due to the limited amount of literature available on the topic.

3.3.2. Secondary data collection

The provisional list of required data was compiled during pre-fieldwork stage. The initial requirements were to collect datasets which included ISs maps, land use maps, ESAs maps, topographic maps, transport network, and population data for three time steps. The choice of time periods was dependant on the data availability. The compiled list was based on the review of conducted similar studies (Huang et al., 2009; Sliuzas, 2004; Xie et al., 2009). Most of the datasets were collected from IMP

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[8] In Istanbul only a few districts left which have undeveloped land. Mostly, they are located on the fringes of eastern and western part of Istanbul, while other districts are characterized by high density of urban land (key informant 2, 5, 7, 10, 12)

during fieldwork time, though available secondary data does not fully correspond to the provisional list and data requirements (section 3.3.3).

On the photo from left to right: Olena Dubovyk (ITC student), Ismail Erdem (Mayor of Sancaktepe district), Pedzisai Kowe (ITC student), Bugra Otken (Interpreter).[9]

On the photo from left to right: Pedzisai Kowe, Gyanendra Raj Devkoty (ITC students), Selahattin Taspinar (IMP staff), Ibrahim Baz (Head of IMP), Emmanuel Kofi Gavu (ITC student), Ulas Akin (IMP staff), Nancy Blakelock, Olena Dubovyk, James Gachanja (ITC students).

Figure 4: Meetings with key informants during fieldwork in Istanbul in September, 2009.

3.3.3. Data collected from IMP

Land cover maps for years 1990, 1995, 2000, and 2005 derived from LANDSAT TM imagery were used as a basis for the study. There were no ISs maps for these years. Instead the ISs map for 2006 consisting of two layers: current ISs and legalized ISs was obtained from Housing Department of IMP. Shape files of population data on neighbourhood level for 2000 and 2005 were provided by the same department. Transport data collected from Transport Planning Department was available for 1996 and 2006. Transport network of 1996 included only highways. Topographic and environmental data were collected from Natural Resource department. Almost all GIS data had scale 1:25000 (environmental, topographic, and transport data). GIS and RS Department of IMP have provided a DEM with resolution of 20 m derived from SPOT images, LANDSAT TM images of 1990, 1995, 2000 and 2005, and IKONOS of 2008. RS data was used as reference information for the study. Additional materials obtained from IMP included housing, environmental, transport reports, and power point presentations.

All collected GIS data were in two coordinate systems: ED 1950 UTM Zone 35N and UTM3 Istanbul based on the same Transverse Mercator projection. The data in UTM3 Istanbul coordinate system was converted to ED 1950 UTM Zone 35N.

[9] Sancaktepe municipality (2009b)

As the data quality is critical for any type of analysis, attention was paid to get this information. The consultations with the key informants 24, 21 were held to obtain more information about the maps preparation procedure. The key informant 21 explained that all maps produced in IMP are verified based on ground truth data and approved by National Cartographic Agency. The information about map accuracy assessment of the series of land cover maps was also provided.

3.4. Data inconsistency issues

This study makes extensive use of secondary data from a variety of sources and time periods. Establishing the presence of inconsistencies is requirement for further processing and analysis.

Land cover maps of 1990 and 2000 produced by MDA Federal Inc. are derived from LANDSAT TM images with the ground resolution of 30 m. The images were processed in ERDAS IMAGINE software package applying semi-automated approach (MDA Federal Inc. 2009a). These maps were prepared in UTM projection on WGS84 spheroid using standard 13-class land cover legend (in the area of Istanbul only 9 land cover classes are identified) (MDA Federal Inc. 2009b). The accuracy assessment of the maps is a compulsory procedure. It is based on the use of different sources of verification data i.e. ground control points, existing maps for accuracy assessment. The average kappa index per class for LANDSAT GeoCover-LC products is more than 0.7 which is a case for 96% of maps (MDA Federal Inc. 2009a).

The land cover maps of 1995 and 2005 were produced by IMP using LANDSAT TM mosaicked images. The classification of the images was performed according to the LANDSAT GeoCover classification system to guarantee consistency between these maps (key informant 21). The accuracy assessment was performed based on ground control points. The Kappa index values of 0.80 (1995) and 0.76 indicate that the assessed maps were 80% and 76% above random agreement.

Even though land cover maps of 1990, 1995, 2000, 2005 were derived based on similar classification methods and systems, there were some inconsistencies between datasets in the form of the “salt-and pepper” effect in the land cover map of 1995 which is due to pixel based classification (key informant 21). Such problem is not new for land cover maps derived from RS images classification and have been reported in a number of papers (Alesheikh and Fard, 2000; Walter and Fritsch, 1998). The common way to deal with this problem is to apply the majority filter to the classified data (Guerschman, 2003). As this procedure was not done for the data from year 1995 (key informant 24), it was decided to eliminate polygons less than 3 pixels in GIS. The results of elimination were assessed qualitatively by visual examination of LANDSAT TM images as suggested by Hussin and Atmopawiro (2004). The applied procedure was sufficient to reduce inconsistencies between land cover maps. Considering the absence of alternative dataset, it was assumed that the land cover maps of 1990, 1995, 200, and 2005 are consistent to each other and sufficient for further analyses.

4. Methodology

This chapter focuses on the research methodology adopted to reach objectives of the study. After giving a general overview of applied methods, details on the main stages of the research progress are provided.

4.1. Method overview

An overview of the research workflow is shown in Figure 5. The whole research process is divided into three main steps:

- analysis of spatial and temporal patterns of ISs development;
- spatial modelling of ISs development using LR;
- analysis of spatial and temporal changes in ESAs due to ISs.

The first step was to analyze spatial and temporal patterns of ISs development in the study area during 15-years period from 1990 to 2005. The maps of ISs were obtained by combining built-up areas from land cover maps of 1990, 1995, 2000, and 2005 and the map of ISs of 2006 obtained from IMP. Rate of change of informal development was calculated to quantify changes happened in this period.

The second step was concentrated on LR modelling of informal development based on predefined factors. The list of factors determining ISs development was compiled considering opinions of key informants and literature review (Table 11 in Appendix A). Based on the identified factors and available datasets an input data for LRM was prepared. During the modelling stage two sets of models based on all available factors and factors recommended by experts were built for three time steps. Derived parameters were used to identify the main driving forces of ISs development and explain their influence on this process. Produced probability maps were used to analyze likelihood of future expansion of ISs and define areas which are more vulnerable to appearance of informal development.

On the final stage analysis of spatial and temporal changes in ESAs due to ISs development was carried out. The ESAs were identified for the study area based on the expert knowledge and literature review. The compiled maps of ESAs was compared with the maps of ISs and probability maps to identify ESAs which are currently occupied by informal development and are more likely to be occupied in the future.

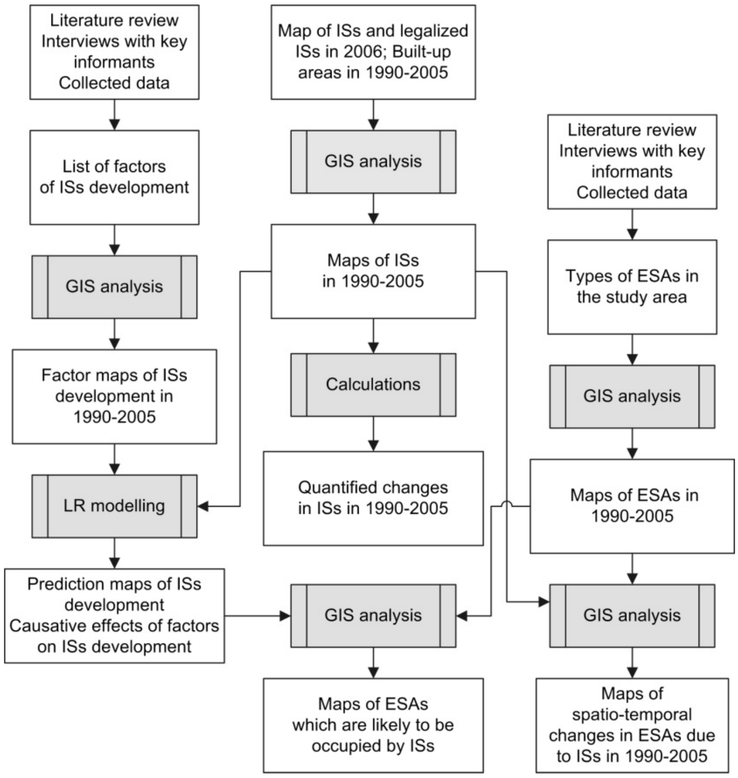

Figure 5: Overview of workflow

4.2. Spatial and temporal patterns of ISs development

In order to define the appropriate methodology for the analysis of spatial and temporal patterns of informal development, understanding of how these patterns can be defined in time and space is required. Blok (2005) suggested that basic cognitive pattern-related tasks refer to identification and comparison of spatial patterns. In this case it relates to the identification of locations of ISs and comparison of obtained results. To incorporate temporal dynamics the analyses based on where-when-what questions were implemented as suggested by Peuquet (1994).

4.2.1. Locations of ISs in the study area in 1990-2005

ISs in Sancaktepe in 1990-2005 were identified assuming that ISs of 2006 have not changed their locations since 1990 within existed built-up areas. This assumption was data-driven due to the availability of ISs and legalized ISs maps only for year 2006 (section 3.2). Analyses of spatial and temporal patterns of ISs development were implemented applying GIS operations. The layers of built-up areas extracted from land cover maps of 1990, 1995, 2000, and 2005 were overlaid with the layer of ISs in 2006 to identify locations of ISs in these years. Produced maps were combined to discover spatial changes in ISs between 1990 and 2005.The locations of legalized ISs were identified by overlaying map of ISs of 2005 and the layer of legalized ISs of 2006. [10].

4.2.2. Quantification of changes in ISs development

Changes in ISs were assessed by calculating the rate of change, average annual growth rate, and proportion of changes.

The rate of change (%) and average annual growth rate (% per year) in informal development were estimated for three time steps within 1990-2005 and the whole period of time. The *rate of change* (%) was calculated applying the following formula (Eq. 1) (McDaniel, 2009):

$$\frac{V_2 - V_2}{V_1} \times 100 \qquad (1)$$

where V_2 is an area of ISs at the end of the period and V_1 is an area of ISs at the beginning of the period.

The *average annual growth rate* (% per year) was calculated using the following formula:

$$\left(\frac{V_2 - V_2}{V_1} \times 100 \right) / N \qquad (2)$$

where V_2 is an area of ISs at the end of the period, V_1 is an area of ISs at the beginning of the period, and N is a number of years between V_2 and V_1.

Proportion of change (%) shows the proportion of the area which has been informally developed relative to the total district's area in the analyzed period of time (Eq. 3).

$$\left(\frac{V_2 - V_2}{V_1} \times 100 \right) / S \qquad (3)$$

where V_2 is an area of ISs at the end of the period, V_1 is an area of ISs at the beginning of period, and S is an area of Sancaktepe.

4.3. Spatial modelling of ISs development using LR

The choice of LR for modelling of ISs development was driven by its explanatory power. Applying LR the functional relationship between the probability of informal development and identified factors causing such development were established. The

[10] In analyses both types of ISs (ISs and legalized ISs) were considered. This was done to capture all changes in ISs irrespectively to the status assigned to ISs after their appearance.

relative importance of each factor was assessed based on the derived parameters of LR models. The probability maps indicating relative likelihood of the area to be informally developed were finally created and analyzed.

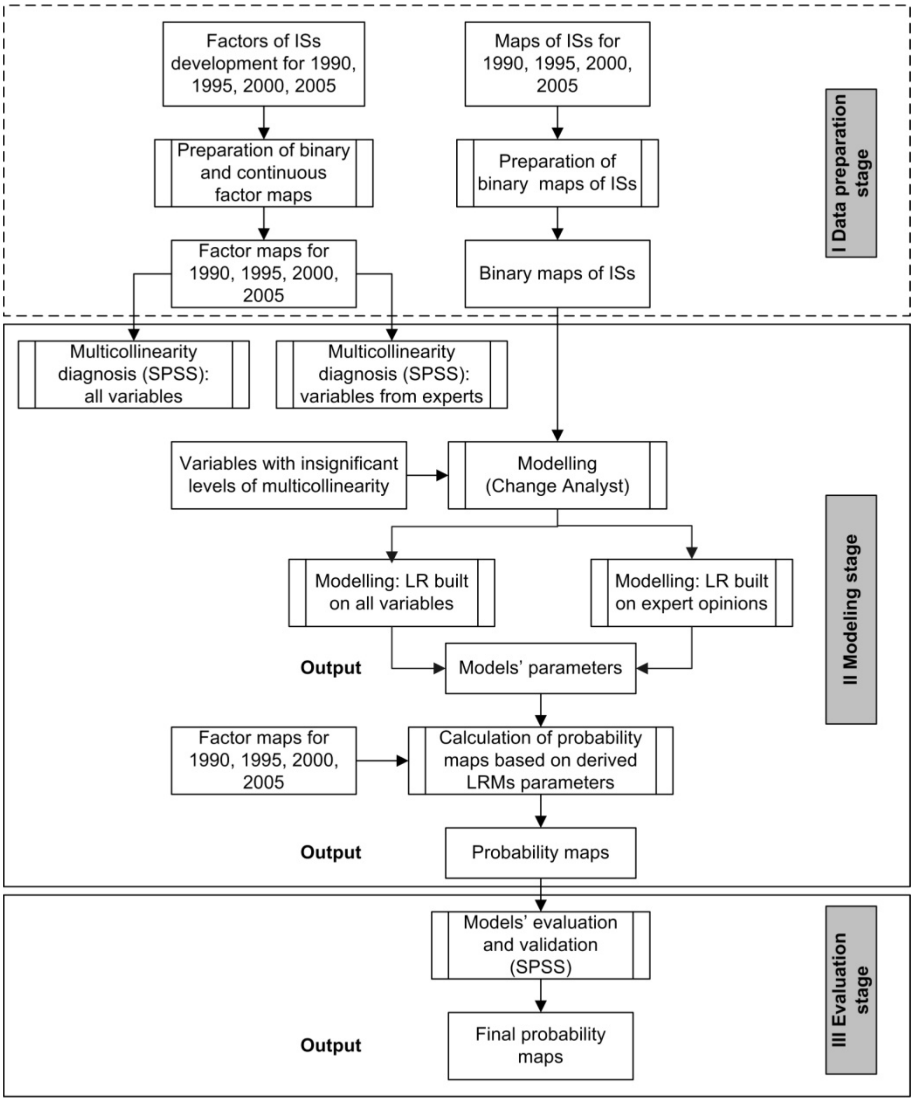

Figure 6: Steps of LR modelling

The process of LR modelling was accomplished in the following stages: data preparation, modelling, and evaluation (Figure 6). First, the list of factors which influence spatial development of ISs was compiled based on which input data for LRMs was prepared (section I in Figure 6). During the modelling stage to avoid multicollinearity among model predictors variance inflation factors (VIF) were calculated and correlated predictors were eliminated one by one. In this way only those factors without significant levels of multicollinearity were selected and used.

For each time step two LRMs were created based on the compiled list of factors ("all-inclusive models") and factors identified by key informants ("expert models"). This was done to compare the performance of the LRMs built on all available factors and main factors suggested by experts. During modelling stage statistically not significant predictors were removed using backward stepwise procedure. Based on the remaining variables the final LRMs were generated. The main outputs on this stage were estimated models' parameters which indicate possible causal relations between allocation of ISs and defined factors (section II in Figure 6). The following step was to evaluate models' performance and validate modelling results. The results of these procedures were employed to select models to create final probability maps of ISs development (section III in Figure 6).

Preparation of input data for LR and calculation of probability maps was done in ArcGIS 9.3; parameters of LRMs were estimated using Change Analyst tool (Huang et al. 2009); while statistical analyses were performed in SPSS 16.00.

4.3.1. Compilation of the list of factors for modelling of ISs development

The general list of factors which influence spatial development of ISs was compiled based on literature review and interviews with key informants (Table 11 in Appendix B). Factors were classified according to the first approach for factors grouping, as it is used in the similar studies of LULC modelling based on LRM (section 2.2.2) (Hu and Lo, 2006; Huang et al., 2009).

This list served as a basis for the factors selection to include in LR modelling (Table 11 in Appendix B). Two sets of factors were chosen: factors identified by key informants (Table 12 in Appendix B) and factors suggested by both literature and expert knowledge (Table 13 in Appendix B).

4.3.2. Preparation of input data for LR modelling

The input data for spatial LR modelling are factor maps representing independent variables (x_i) which determine spatial development of ISs (dependent variable (z)). They were prepared for years 1990, 1995, 2000, and 2005 according to the final list of factors (Table 12 and Table 13 in Appendix B). All input variables had the same spatial extent, projection (Tranverse Mercator), coordinate system (ED 1950 UTM Zone 35N), and cell size (30×30 m). Factors of 2005 were applied for predictions of probabilities of ISs development. The nature of factor maps was both binary (presence of factor is represented by 1, absence - 0) and continuous. The mask for Sancaktepe district was created to avoid inconsistencies in the input data and to exclude military zone from the analysis. In the following paragraphs the more detailed description of the preparation of the specific factor maps is provided.

Site specific characteristics

The site specific characteristics were represented by the following factors: population density, forest, ESAs, and slope. Population density is considered to be one of the most important causes of urban development (Huang et al., 2009). To incorporate this factor in the analysis population densities for 2000 and 2005 were rasterized. To estimate population density in 1995 it was assumed that population in Sancaktepe changed according to the general trend in Istanbul, i.e. it increased on 21.04% and 28.18% in 2000 compared to 1995 and 1990 respectively (Yonder, 2006). It was also assumed that population increased equally within the district. Based on these assumptions population densities in 1995 and 1990 were calculated and corresponding factor maps were created.

The factor maps of forest areas and ESAs were derived from land cover maps and maps of ESAs, while slope map was created from the DEM.

Proximity characteristics

The proximity characteristics were represented by the distance to roads, distance to industrial sites, and distance to central business district (CBD). Corresponding factor maps were derived based on measurement of minimum Euclidean distances to the selected factors as suggested by Xie et al. (2009).

The variable distance to roads showed distances to the main roads in 1990, 1995, 2000, and 2005. As shape files of the road network were available only for years 1996 and 2006. The roads for year 1990 were derived comparing road network of 1996 with LANDSAT image of 1990 and choosing only those roads that existed in year 1990. For 1995 the road network of 1996 was used assuming that there were no significant changes within 1 year. For years 2000 and 2005 the roads of 2006 were used, as according to the key informants (key informant 19) there were no road construction between 2000 and 2006. This information was verified by visual comparison of LANDSAT images of 2000, 2005 and the road network of 2006.

To create predictor distance to the industrial sites industrial areas in 2005 were clipped to built-up areas in 1990, 1995, and 2000 assuming that industrial land use observed in 2005 was the same within existed developed areas.

To create factor map distance to the CBD the location of central business district was digitized from the master plan of 1:100000 scale (2005) and the distance from the CBD was calculated.

Neighbourhood characteristics

To incorporate spatial interaction effect between developed and undeveloped areas the following factor maps were prepared: proportion of urban/agricultural/undeveloped land and ISs in the surrounding area. These maps showed for the each cell the number of cells of specified land use in the 14-cells circular neighbourhood[11]. The selection of neighbourhood's size was made after testing different alternatives (e.g. 7-cells circular neighbourhood, 5*5, 7*7, and 14*14 rectangle neighbourhoods) suggested by other urban modelling studies (Hu and Lo, 2007, Verburg et al., 2004; Xie et al., 2009).

4.3.3. Multicollinearity diagnoses

The presence of high degree of multicollinearity[12] between spatial factors results in disproportionately big values of standard deviations of regression coefficients in LRM (Owen, 1988). This can lead to the wrong acceptance of null hypothesis (H_o)[13] of LRM or biased estimation of model parameters (Owen, 1988). It is therefore essential to eliminate those factors which cause strong correlation among each other. Variance Inflation Factor (VIF) is a common measure which is applied to test multicollinearity (Eq. 4) (Kutner et al., 2004).

$$VIF = \frac{1}{1-R_i^2} \tag{4}$$

where R_i^2 is a square of standard deviation of the explanatory variables.

The value of VIF more than 10 indicates the presence of strong multicollinearity (Kutner et al., 2004). Multicollinearity diagnoses were performed for factors of 1990, 1995, and 2000. Those variables for which corresponding values of VIF exceeded 10 were removed starting with the one with the highest VIF value. After elimination of one variable, VIFs for the remaining ones were recalculated. The procedure was repeated until multicollinearity was not significant (VIF<10)

4.3.4. Sampling

Data incorporated in the LRM has a tendency to be dependent or spatially autocorrelated (Cheng and Masser, 2003). Spatial dependency can lead to inaccurate results of conventional statistical methods applied for LR modelling, unreliable results of hypothesis test and parameters estimation (Cheng and Masser, 2003; Irwin and Geoghegan, 2001). The possible sources of spatial dependence are the existing errors in data, omitted variables from LR, and spatial interactions among observations (Irwin and Geoghegan, 2001). The common approach to deal with spatial autocorrelation in LRMs is to design a sampling scheme which increases distance between samples (Cheng and Masser, 2003). The most frequently adopted sampling schemes reported in the literature are either stratified random sampling (Dhakal et al., 2000; Gobin et al., 2001) or systematic sampling (Cheng and Masser, 2003; Sikder, 2000). Stratified random sampling is effective for representation of the

[11] The processing cell is located in the centre of the circle with radius of 420 m. (ArcGIS Desktop Online Help, 2009a).

[12] Multicollinearity refers to "undesirable situation when one independent variable is a linear function of other independent variables" (Kutner et al., 2004).

[13] H_o of LR states that all regression coefficients equal zero.

whole population, but it does not decrease spatial dependency to sufficient extent (Cheng and Masser, 2003). On the contrary, systematic sampling is a good approach to decrease spatial autocorrelation, while it can lead to the loss of some important information (Cheng and Masser, 2003; Huang et al., 2009). To incorporate effect of spatial autocorrelation systematic sampling scheme was applied in this study. In similar studies sample resulted from sampling window of 9×9 cells is suggested to be more effective to reduce spatial autocorrelation (Huang et al., 2009; Xie et al., 2009). In this study resulted sample from mentioned sampling window was not sufficient to fit LR to the data, as the results of chi-square test suggested acceptance of null hypothesis of LR (section 4.3.5). Such result was obtained due to the small changes in ISs between 1995 and 2005 which required bigger sample size to incorporate them in the model. Huang et al. (2009) suggested that in such cases systematic sampling should be applied selecting optimal sampling window size to include even small areas with urban changes. After testing different samples resulted from various sampling windows (e.g. 9×9, 8×8…3×3 cells), systematic unbalanced sampling was performed applying 3*3 cells window size in Change Analyst software (Huang et al., 2009).

To test LR for the presence of spatial autocorrelation Moran's I index was calculated on the map of the models' residuals. Moran's I measures spatial autocorrelation using data from pairs of observations (Eq. 5) (ArcGIS Desktop Online Help, 2009b*)*. It evaluates whether the analyzed pattern is spatially dependent. Calculated z-statistics and corresponding p-value indicates whether the null hypothesis can be rejected[14]. For confidence level (CL) of 95% critical z-score values are +/-1.96. If calculated z-value falls within this interval, the null hypothesis cannot be rejected which means that there is no spatial autocorrelation between observed features. In case of acceptance of null hypothesis the positive values of Moran's I index indicates the tendency of clustering, while negative values are the sign of tendency towards dispersion (ArcGIS Desktop Online Help, 2009b).

$$I(d) = \frac{(\frac{1}{W})\sum_{h=1}^{n}\sum_{i=1}^{n} w_{hi}(Y_h - \bar{Y})}{\left(\frac{1}{n}\right)\sum_{i=1}^{n}(Y_i - \bar{Y})^2}, h \neq i \tag{5}$$

where I(d) is Moran's I, Y_h and Y_i are the values of the observed variable at sites h and i, w_{ij} are weights.

4.3.5. Logistic regression model

LR is suitable for explanation of relationships between independent variables and response of dependent variable. It estimates empirical relationships between explanatory variables and observed phenomena, and predicts probabilities of event occurrence by fitting data to the logistic curve (Lee and Wong, 2000; Lie, 2009). Probability (P) of positive response of dependent variable, i.e. occurrence of ISs

[14] Null hypothesis of Moran's I states that feature values are randomly distributed across analyzed area (ArcGIS Desktop Online Help, 2009).

development, is described as a function of independent variables, i.e. the factors determining ISs development. The dependent variable depicts total contribution of independent variables (Eq. 6) (Moore and McCabe, 1998):

$$f(z) = \beta_0 + \sum_{i=1}^{n} \beta_i \, x_i \tag{6}$$

where z is dependent variable, x_i are independent variables, β_0 is intercept of the model, β_i are coefficients to be estimated or parameters of the model, n is number of variables, and i = (1; +∞).

LRM is based on *logistic function* (Eq. 7) (Moore and McCabe, 1998):

$$f(z)=\frac{1}{1 + \mathrm{e}^{-\mathrm{z}}} \tag{7}$$

where z varies from -∞ to +∞, e is the base of natural log, and $f(z) = 1 \; or \; 0$. From the Eq. 6 and 7 function of logistic regression model is estimated (Moore and McCabe, 1998):

$$\mathrm{P(S{=}1}|x_1 \, , x_2 \, ,... \, x_n) = \frac{1}{1+e^{-(\beta_0+\sum_{i=1}^{n} \beta_i x_i)}} \tag{8}$$

where $\mathrm{P(S{=}1}|x_1 \, , \; x_2 \, ,... \, x_n)$ is a probability of occurrence of a new unit considering the presence of independent variables (x_i).

LRM can also be expressed through logit function and logarithm of odds[15] (Eq. 9) (Moore and McCabe, 1998):

$$\mathrm{Logit(Px)} = \; \mathrm{log(odds)} = \log\left(\frac{P_x}{1-P_x}\right) = \beta_0 + \sum_{i=1}^{n} \beta_i \, x_i \tag{9}$$

where $log(\frac{P_x}{1-P_x})$ are odds of the occurrence of a new unit considering the presence of independent variables (x_i).

The expression $\frac{P_x}{1-P_x}$ refers to the odds of the model's successful performance. When value of the odds ratio is more than 1, it means that the chance that a new unit will occur (e.g. transition of a cell from undeveloped to develop) is higher than when odds ratio is less than 1 (Christensen, 1997).

Parameters of the models (β_i) are coefficients of independent variables. They are estimated from LRM by applying maximum likelihood algorithm which finds the best fit of the independent variables to explain known status of dependent variable (Dendoncker, 2007). Huang et al. (2009) and Verburg et al. (2004)

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[15] Logit function, logarithm of odds, and probability refers to different mathematical ways to express LRM (Moore and McCabe, 1998).

suggested that the sign of the coefficient (+ /-) indicates positive or negative correlation to the response of the dependent variable. Odds ratios (O.R.) are also used for interpretation of model's coefficients. From Eq. 9 it can be estimated that if x_i increases by 1, then odds will increase by factor $e^{\beta_n x_n}$. This factor refers to odds ratio for the corresponding x_i indicating relative amount by which odds ratio will increase (O.R.>1) or decrease (O.R.<1), if the value of independent variable increases by 1 unit (Moore and McCabe, 1998).

Evaluation of goodness of fit of LRM is based on *chi-square statistics* (Eq. 10) (Christensen, 1997; Huang et al., 2009; Moore and McCabe, 1998)

$$X^2 = \sum \frac{(observed\ count - \text{exp}ected\ count)^2}{\text{exp}ected\ count} \tag{10}$$

where X^2 is chi-square, observed count are observed values of the cell, expected count are predicted values of the same cell.

Large value of chi-square indicates that independent variables have significant influence on the outcome of the model. To obtain statistical evidence to reject null hypothesis (H_0)[16] corresponding p-value is estimated and compared with significance level[17] (α). If p-value is smaller than α H_0 is rejected which means that at least one independent variable has an influence on the model outcome (Moore and McCabe, 1998)[18].

T-Wald statistics is usually applied to evaluate significance of the coefficients of explanatory variables in LRM (Hu and Lo, 2007; Lee, 2005; Kyngas, and Rissanen, 2001). In principle, the idea behind Wald statistics is the same as for t-statistic used for parameters of linear regression (Lee, 2005). A null hypothesis tests whether associated coefficient of independent variable is significantly different from zero. When the result is significant, it indicates that an independent variable makes contribution to the results of the model (Cheng and Masser, 2003). T-Wald statistics is estimated by squaring z statistics (Eq.11) (Moore and McCabe, 1998):

$$z = \frac{\hat{\beta}}{SE} \tag{11}$$

where z is z statistics, β is a coefficient of model's variable, SE is a standard error.

A backward stepwise procedure was applied to obtain LRMs with significant variables (Moore and McCabe, 1998). Based on Wald statistics the significance of

[16] Null hypothesis of chi-square claims that all coefficients of explanatory variables equal zero (Moore and McCabe, 1998).
[17] In this study significance level $\alpha = 0.05$, while confidence level (CL) is 95% as suggested by Huang et al. (2009) and Xie at al. (2009).
[18] For more details on chi-square statistics see chapter 9 in Moore and McCabe (1998).

each independent variable was estimated. If significance was more than assigned CL, the variable with the largest significance was removed, and new parameters for the model were estimated. This procedure was repeated until the significance of all of the model's parameters were less than CL.

4.3.6. Model evaluation

The model evaluation was performed based on threshold-dependent (Kappa statistics, Percentage of Correct Predictions) and threshold-independent (Relative Operating Characteristics) statistics. The choice of the threshold depends on the probability values and management applications of the study (Liu et al., 2005). In case of low occurrence of modelling event, it is recommended to use as a threshold either the proportion of event occurrence compared to all the sites, or the mean value of the predicted probabilities (Liu et al., 2005). After empirically testing two methods it was decided to assign threshold based on proportion of the observed changes in ISs development, as it maximized performance of models' evaluation statistics.

Percentage of Correct Predictions (PCP) is a measure which indicates the percentage of total number of correct predictions (Eq. 12) (Christensen, 1997). It is usually computed based on contingency table which is a cross tabulation between observed and predicted counts of response variable. PCP is a measure which gives a quick indication of the model performance. However, it is advisable to use additional measures to evaluate LRM (Overmars et al., 2003). PCP is calculated with the following equation (Christensen, 1997):

$$PCP = \frac{(a+d)}{n} \times 100 \tag{12}$$

where PCP is a rate of correct predictions, a is a number of correctly predicted occurrences, d is a number of correctly predicted absences, n is a total number of observations.

Cohen's Kappa is a measure of inter-rater agreement between observations and predictions incorporating chance effects (Kraemer, 1982). It is considered to be robust and effective statistics for evaluation of LRM (Eq. 13) (Manel et al., 2001). Kappa value varies from -1 to 1, where 1 indicates the perfect agreement between observations and predictions, 0 – random agreement, while -1 means that the agreement is worse than chance (Kraemer, 1982).

$$K = \frac{Pr_a - Pr_e}{1 - Pr_e} \tag{13}$$

where K is Cohen's Kappa, Pr_a stands for relative observed agreement among raters, while Pr_e is hypothetical probability of chance agreement where the observed data is used to calculate the probabilities of each observer randomly assigning each category.

Relative Operating Characteristics (ROC) compare the actual map with the produced probability map through a series of two-by-two contingency tables. Calculated ratios of true-positives[19] and false-positives[20] are plotted at a series of thresholds for a positive outcome in the graph, known as "ROC curve" (MedCalc, 2009). ROC can be interpreted "as the percentage of all possible pairs of cases in which the model assigns a higher probability to a correct case than to an incorrect case" (Pontius and Schneider, 2001, p. 244).

The area under ROC curve (AUC) indicates how well probabilities where assigned to the locations. The value of the area varies from 0.5 (absolutely random assignment of probabilities) to 1 (perfect assignment of probabilities) (Pontius and Schneider, 2001). The ROC method is reported to be an effective measure for evaluation of LRM (Cheng and Masser, 2003; Christensen, 1997; Poelmans and Rompaey, 2009).

Before evaluating LRMs Moran's I was calculated on the residuals of predicted probability maps for each LRM. In case of detection of spatial autocorrelation such models were not considered in further analysis. Presence of spatial autocorrelation indicates that model cannot capture all spatial dependency in the land use (Overmars et al., 2003) leading to unreliable estimation of model's parameters and incorrect conclusions regarding hypothesis tests (Cheng and Masser, 2003; Irwin and Geoghegan, 2001).

Having selected LRMs with not significant spatial autocorrelation the models' performance was evaluated with the actual situation and validated with the future time steps. Validation was implemented by applying estimated model parameters to the factors of the following periods. For example, if the model was built based on period of 1990-1995 incorporating factors of year 1990, its evaluation was performed by comparing calculated probability map with actual situation in 1995. For validation of the same model its parameters were used to calculate probability map for year 2000 based on the factors of 1995. The resulting map was compared with the map of locations of ISs in 2000 (Hu and Lo, 2007; Huang et al., 2009). In this case validation procedure is based on the assumption that the observed trend in ISs development in the past still continue in the following periods.

Comparison of the models' performance was done by estimating the *Akaike Information Criterion* (AIC) (Eq. 14). AIC is a measure which allows selecting among different models. It adjusts the residuals deviance for the number of independent variables (Rossiter and Loza, 2009). The model which has the lowest value of AIC is considered to be a better one (Koehler and Murphree, 1998).

[19] True-positive rate or sensitivity is a proportion of observed developed cells correctly predicted (MedCalc, 2009).
[20] False-positive rate or specificity is a proportion of observed undeveloped cells incorrectly predicted (MedCalc, 2009).

$$AIC = log\left(\frac{SSE}{n}\right) + \frac{2K}{n} = \frac{-2l}{n} + \frac{2K}{n} \quad (14)$$

where K is a number of estimated coefficients, n is a number of observations, SSE stands for error sum of squares, and l is a log-likelihood of the model.

4.3.7. Probability maps

Probability maps were produced by fitting parameters of the LRMs to the Eq. 7 containing significant predictors of 1990, 1995, and 2000. These maps were used for models' evaluation, validation, and calculation of residuals maps (section 4.3.6). By applying estimated parameters of the final models and factors of 2005 to the same equation probability of informal development was predicted (Hu and Lo, 2007). Such predictions are based on the assumption that future development will occur according to the trends observed in the past.

4.4. Spatial and temporal changes in ESAs due to ISs development

Analyses of spatio-temporal changes in ESAs due to ISs development were performed in the following steps: identification of ESAs located in the study area and production of the corresponding map; comparison of the maps of ESAs with the maps of ISs to identify those ESAs which were occupied by ISs; comparison of the maps of ESAs with the predicted probabilities of ISs to identify areas which are more likely to be informally occupied in the future. Related analyses were conducted in ArcGIS 9.3.

Information about ESAs in the study area was obtained during fieldwork from the interviews with experts (key informants 1, 11, 15, 17, 18, 19) and investigation of the available maps provided by Natural Resources Department of IMP. Relevant literature was not available, as the district has been recently created and limited number of studies has been conducted within current borders of Sancaktepe (section 3.2, key informants 17, 18).

4.5. Assumptions and source of errors

The main assumption of the research refers to the identification of locations of ISs in different time steps (section 4.2.1). Other data related assumptions were made to overcome the lack of the temporal data for LR (section 4.3.2). On the modelling stage it was assumed that the identified causative factors are the only ones which explain informal development in the study area. The influences of external factors were neglected i.e. interactions with adjacent districts. The main source of errors in the study is introduced by data inconsistency issues described in more details in section 3.4. Another source refers to the error accumulation due to performed GIS operations. The lack of the recent data to validate predictions of probabilities of ISs development should be also considered.

4.6. Employed software

The following software was used in this research: ArcGIS 9.3 software packages, SPSS 16.0 under the ITC authorized licences; general office software packages on Windows XP, and Change Analyst software (Huang et al., 2009)

5. Results

In this chapter the main research findings are presented in three sections: spatial and temporal patterns of ISs development, spatial modelling of ISs development using LR, spatial and temporal changes in ESAs due to ISs development.

5.1. Spatial and temporal patterns of ISs development

The results obtained from the analysis of spatial and temporal patterns of ISs development refer to the identified locations of ISs between 1990 and 2005 in the study area. Spatial changes in ISs were also analyzed and quantified.

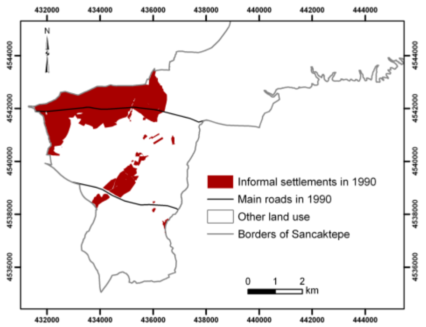

Figure 7: Location of ISs in 1990

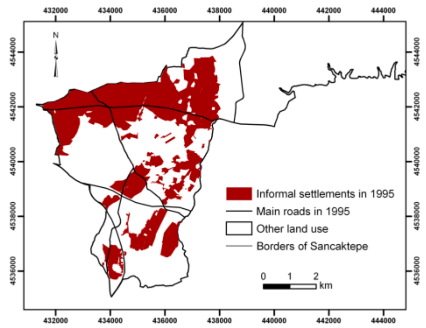

Figure 8: Location of ISs in 1995

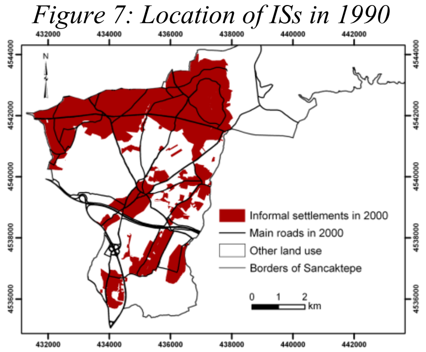

Figure 9: Location of ISs in 2000

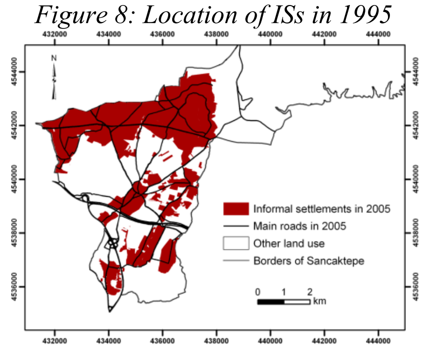

Figure 10: Location of ISs in 2005

5.1.1. Locations of ISs in Sancaktepe in 1990-2005

The ISs were mainly located in the upper central part of Sancaktepe in 1990 (Figure *7*). Between 1990 and 1995 the ISs spread to the north and south of the district occupying agricultural fields, barren land, and grasslands (Figure 8). The growth of ISs towards north was caused by construction of a new highway which was passing through agricultural fields in that part of the district (Figure 8 and Figure 11). In 1995-2000 several new settlements appeared near central upper border of the district (Figure *9*). In 2000-2005 new informal development was observed mainly in the central part of Sancaktepe near existed built-up areas (Figure 10 and Figure *11*).

Main spatial changes in ISs development occurred between 1990 and 1995, when ISs expanded to the north-east and south of the district (Figure *11*). Minor changes in ISs were observed between 1995 and 2005. The development which took place at that time had infill character occupying spaces within existed built-up areas (Figure *11*).

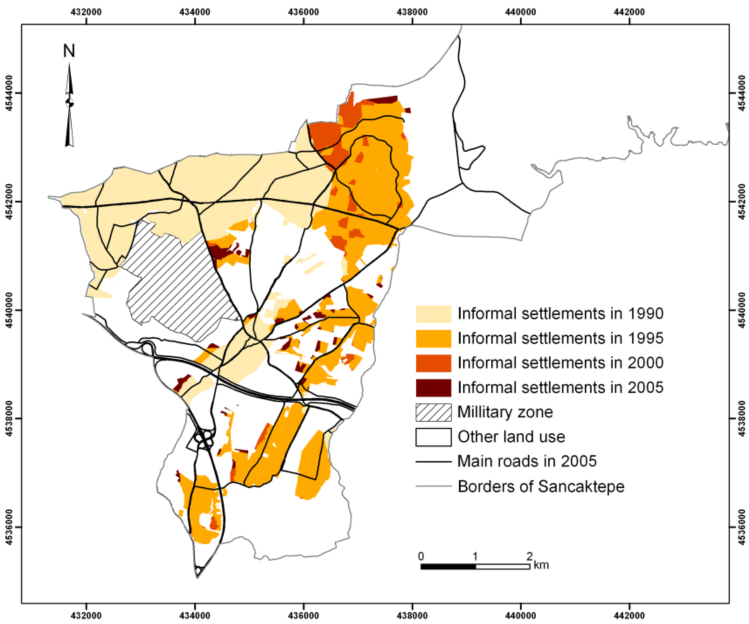

Figure 11: Spatial changes in ISs development in Sancaktepe in 1990-2005

Most of the legalized ISs were found in the upper central part of the district (Figure 20 in Appendix A). The area of these settlements was 7.87 km^2, which was almost a half of the total area of the ISs. The exact time of the legalization process is not known. According to the key informant 19 the duration of the legalization process observed in the district coincided with the main amnesties which took place in Istanbul between 1980 and 1992. However, this process has not finished yet, as some parts of ISs are still legalized according to the decision of the local authorities of Sancaktepe (key informant 19).

5.1.2. Quantifying changes in ISs development

The overall rate of change in ISs development between 1990 and 2005 was 112.06% indicating an increase in the area of ISs more than twice from 7.84 km^2 in 1990 to 16.10 km^2 in 2005. The highest rate of change of 92.91% was observed in 1990-1995 following by very sharp decline in 1995-2000 and 2000-2005 (7.92% and 1.85% respectively). The average annual growth of ISs during 15 years was 7.47% per year. The annual growth of ISs differs between time steps, i.e. 18.58% per year in 1990-1995, 1.58% per year in 1995-2000, and 0.37% per year in 2000-2005. The proportion of ISs compared to the built-up areas was ≈12% (1990), 24% (1995), 26% (2000), 27% (2005) showing that the area of ISs in respect of the total area of the district increased on 12%, 2%, and 1% between 1990 and 1995, 1995 and 2000, 2000 and 2005 respectively.

5.2. Spatial modelling of ISs development using LR

This section presents the main findings of LR modelling applied to explain spatial development of ISs in the study area in 1990–2005.

Table 1: List of variables included in LRMs

Type of Factor	Variable in LRM	Description	Nature of Variable
Dependent	Z	1 - ISs development; 0 - no ISs development	dichotomous
Independent	X	-	-
Site specific characteristics	X_1	Population density (person/ha)	continuous
	X_2	1 - Forest; 0 - not forest	dichotomous
	X_3	1 - ESAs; 0 - not ESAs	dichotomous
	X_4	Slope (%)	continuous
Neighbourhood characteristics	X_5	Proportion of urban land in the surrounding area (a circular neighbourhood with a 420 m radius)	continuous
	X_6	Proportion of undeveloped land in the surrounding area (a circular neighbourhood with a 420 m radius)	continuous
	X_7	Proportion of agricultural land in the surrounding area (a circular neighbourhood with a 420 m radius)	continuous
	X_8	Proportion of ISs in the surrounding area (a circular neighbourhood with a 420 m radius)	continuous
Proximity characteristics	X_9	Distance to roads (m)	continuous
	X_{10}	Distance to industrial sites (m)	continuous
	X_{11}	Distance to CBD (m)	continuous

5.2.1. Independent variables for ISs development

LR modelling was performed based on the factors proposed by both literature and experts and only experts (section 4.3.1 and 4.3.2). According to the key informants development of ISs occurred near the roads and industrial sites on unoccupied public land, e.g. undeveloped city's neighbourhoods and districts' outskirts. The experts also mentioned importance of social factors, such as: population density, migration rate, presence of social communities, and spatial policies. Overall, 11 independent variables were used in this study (Table 1 and Table 13 in Appendix B). Five out of these variables were suggested by key informants (Table 12 in Appendix B). As modelling of ISs development was performed for 1990-1995, 1995-2000, and 2000-2005, for each time step the set of factor maps were prepared according to the certain requirements (section 4.3.2). The example of factor maps for 1990 is shown in Figure 12.

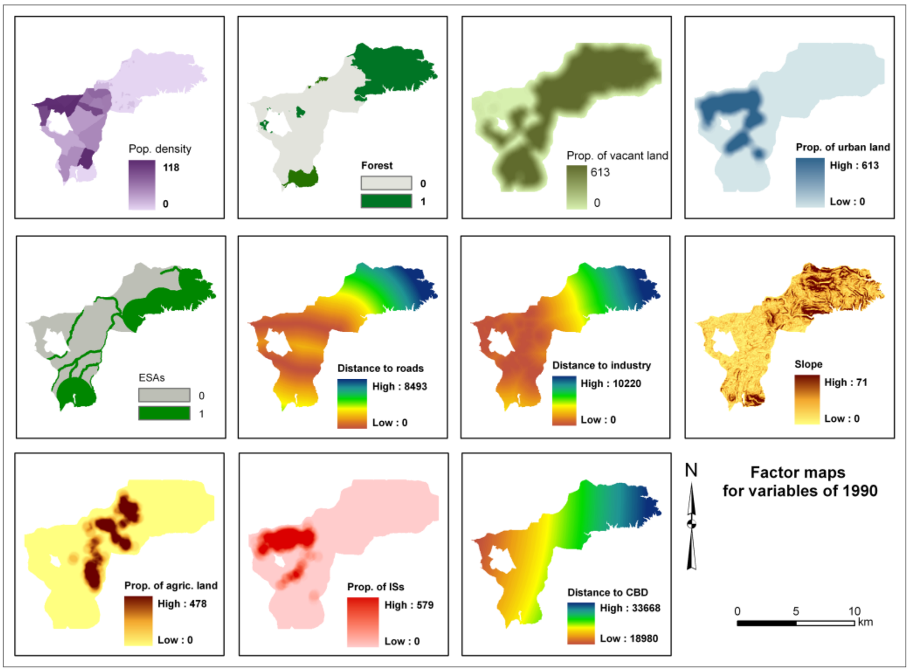

Figure 12: Raster layers of independent variables of 1990

5.2.2. Multicollinearity diagnoses

Multicollinearity diagnoses were performed for factors of 1990, 1995, and 2000 (section 4.3.3). For each year two sets of factors were tested, i.e. factors included in all-inclusive models and factors included in expert models.

5.2.2.1. Multicollinearity diagnoses: factors included in all-inclusive models

For independent variables of year 1990 multicollinearity was significant for factors x_9, $x_{10,}$ and x_{11} with corresponding VIF values of 23.09, 46.14, and 14.17. As variable distance to industrial sites (x_{10}) had the highest value of VIF, it was eliminated first. The result of repeated test showed that there was no significant multicollinearity among remaining variables, as values of VIF did not exceed the value of 10 (Table 2).

For variables of year 1995 the significant multicollinearity was found for x_9, x_{10} with corresponding VIF values of 12.47 and 25.15. After elimination of x_{10} the result of the test showed that multicollinearity was not significant for the remaining variables (Table 2).

Table 2: Results of multicollinearity diagnoses for all independent variables

No	Variable in LRM	Description	VIF 1990	VIF 1995	VIF 2000
1	X_1	Population density (person/ha)	2.426	1.715	3.195
2	X_2	1 - Forest; 0 - not forest	3.873	8.83	4.369
3	X_3	1 - ESAs; 0 - not ESAs	1.157	2.247	1.359
4	X_4	Slope	1.219	1.288	1.42
5	X_5	Proportion of urban land in the surrounding area	4.735	6.155	eliminated
6	X_6	Proportion of undeveloped land in the surrounding area	1.139	5.019	4.719
7	X_7	Proportion of agricultural land in the surrounding area	1.491	5.108	1.568
8	X_8	Proportion of ISs in the surrounding area	4.248	1.439	3.181
9	X_9	Distance to roads (m)	7.804	3.421	3.231
10	X_{10}	Distance to industrial sites (m)	eliminated	eliminated	eliminated
11	X_{11}	Distance to CBD (m)	7.773	3.267	1.202

Multicollinearity diagnoses of the independent variables of year 2000 showed that VIFs for x_9, x_{10}, x_5 exceeded threshold value of 10 (corresponding VIF values are 11.25, 20.02, and 12. 97). After removal of x_{10}, the multicollinearity was still significant for the variable x_5 (VIF = 10.48). This variable was also eliminated and test repeated. The results showed that there was no significant multicollinearity among the remaining variables (Table 2).

*Table 3**:** Results of multicollinearity diagnoses for independent variables from key informants*

No	Variable in LRM	Description	VIF 1990	VIF 1995	VIF 2000
1	X_1	Population density (person/ha)	2.1	1.776	2.786
2	X_5	Proportion of urban land in the surrounding area	1.713	3.535	7.703
3	X_6	Proportion of undeveloped land in the surrounding area	1.075	1.891	7.433
4	X_9	Distance to roads (m)	1.653	1.675	1.499
5	X_{10}	Distance to industrial sites (m)	eliminated	eliminated	eliminated

5.2.2.2. Multicollinearity diagnoses: factors included in expert models

Multicollinearity diagnoses performed for the set of variables from key informants also showed that x_{10} was highly correlated with other variables (VIF=17.79 (1990), 19.41 (1995), and 11.77 (2000)) (Table 3). It was eliminated from the analysis. The repeated test did not detect significant multicollinearity among the remaining variables.

After multicollinearity diagnoses the final set of factors for all-inclusive and expert models was reduced by one variable, i.e. distance to the industrial sites (x_{10}) for all analyzed years. Exception was the year 2000 for all-inclusive models, for which the variable proportion of urban land in the surrounding area (x_5) was also eliminated.

5.2.3. LR modelling of ISs development

LRMs for different time steps were built on the independent variables selected after multicollinearity diagnoses. The final models were created using backward stepwise procedure which was applied to select those spatial factors which had significant influence on the predictive power of the models. The estimated parameters of the model were tested using t-Wald statistics (section 4.3.5). The residuals of the estimated models were tested on the presence of spatial autocorrelation. Models exhibiting spatial autocorrelation were discarded from the further analysis. The performance of the remaining models was evaluated by calculation of PCP, Kappa and ROC statistics. The models were compared using as an indicator the value of AIC.

All-inclusive LRM for 1990-1995

The final all-inclusive model for 1990-1995 was obtained on the second backward step after elimination of the predictor x_2 ($p=0.97$, $\alpha=0.05$) and x_{11} ($p=0.16$, $\alpha=0.05$). The model was significant with the value of chi-square of 20052.17 and corresponding p-value of 0.0000 ($\alpha=0.05$). The estimated value of Moran's I showed that no significant spatial autocorrelation was detected (Table 7). The value of AUC was 0.87 (Table 8 and Figure 21 in Appendix A). The overall accuracy (PCP) was 84, 90%, while the value of Cohen's Kappa was 0.54 (threshold=0.14) showing average agreement. Summary of the results of all-inclusive LRM for 1990-1995 is presented in Table 4.

Table 4: Parameters of all-inclusive LRM for 1990-1995

No	Variable in LRM	β_i	SE (β_i)	z-value	T-Wald test (p-value)	O.R.
	Constant	-6.5163	-	-	-	-
1	X_1	0.0649	0.0010	66.16	0.0000	1.07
2	X_3	-0.1415	0.0379	-3.73	0.0002	0.87
3	X_4	0.0238	0.0023	10.54	0.0000	1.02
4	X_5	-0.0064	0.0005	-14.32	0.0000	0.99
5	X_6	0.0075	0.0003	26.45	0.0000	1.01
6	X_7	0.0022	0.0001	15.06	0.0000	1.00
7	X_8	0.0180	0.0009	19.99	0.0000	1.02
8	X_9	-0.0006	0.0000	-32.99	0.0000	1.00

Expert LRM for 1990-1995

The expert model for 1990-1995 was significant with chi-square of 19227.21 and corresponding p-value of 0.0000 (α=0.05).). The calculated value of Moran's I and corresponding z-score indicated that no significant spatial autocorrelation was detected among model's residuals (Table 5). The AUC was 0.90 (Table 8 and Figure 22 in Appendix A). The PCP was 84, 72%, while the value of Cohen's Kappa was 0.61 (threshold=0.14) indicating that agreement was higher than average. Summary of the results of expert LRM for 1990-1995 is presented in Table 5.

Table 5: Parameters of expert LRM for 1990-1995

No	Variable in LRM	βi	SE (βi)	z-value	T-Wald test (p-value)	O.R.
	Constant	-6.4135	-	-	-	-
1	X_1	0.0650	0.0010	65.92	0.0000	1.07
2	X_5	-0.0020	0.0004	-5.74	0.0000	1.00
3	X_6	0.0079	0.0003	29.31	0.0000	1.01
4	X_9	-0.0006	0.0000	-34.20	0.0000	1.00

The estimated models' parameters showed consistency in explanation of causative effects of the analyzed factors. Both models indicated that population density and availability of undeveloped land were positively related to the informal development, while presence of roads and developed areas had a negative relation. The relative significance of the causative factors was evaluated by analyzing corresponding odds ratio (section 4.3.5). Most of the variables in both models had odds ratios≥1 (except x_3 and x_5 in the all-inclusive LRM for 1990-1995) indicating that probability of ISs development was higher when these factors were present (Table 4 and Table 5).

Table 6: Parameters of all-inclusive LRM for 1995-2000

No	Variable in LRM	β_i	SE (β_i)	z-value	T-Wald test (p-value)	O.R.
	Constant	3.3345	-	-	-	-
1	X_1	0.0409	0.0020	20.85	0.0000	1.04
2	X_3	-1.9015	0.1335	-14.24	0.0000	0.15
3	X_4	0.0658	0.0057	11.56	0.0000	1.07
4	X_6	0.0012	0.0004	-3.35	0.0008	1.00
5	X_7	0.0092	0.0004	21.57	0.0000	1.01
6	X_8	0.0110	0.0005	20.96	0.0000	1.01
7	X_9	0.0017	0.0001	34.32	0.0000	1.00
8	X_{11}	-0.0005	0.0000	-20.67	0.0000	1.00

All-inclusive LRM for 1995-2000

The final all-inclusive model for 1995-2000 was obtained on the second backward step after elimination of the predictor x_2 (p=0.9585, α=0.05) and x_5 (p=0.16, α=0.05). The model was significant with chi-square of 4290.72 and corresponding p-value of 0.0000 (α=0.05). The estimated value of Moran's I and corresponding z-score showed that no significant spatial autocorrelation was detected among model's residuals (Table 7). The AUC was 0.93 (Table 8 and Figure 23 in Appendix A). The overall accuracy (PCP) was 82.97%, while the value of Cohen's Kappa was 0.59 (threshold=0.02) indicating that agreement was higher than average. Summary of the model results is presented in Table 6.

The estimated parameters of the expert LRM for 1995-2000 indicated that population density was the main driving force of ISs development between 1995 and 2000. Distance to the roads was also positively related to the appearance of the new ISs. As presence of developed areas was not a significant parameter, it was eliminated. Odds ratios were more or equal to1 for all variables of the model, except for the variable x_3 (Table 6).

All-inclusive LRM for 1995-2000, all-inclusive and expert LRMs for 2000-2005

As for the expert model for 1995-2000, all-inclusive and expert models for 2000-2005 the corresponding z-score for values of Moran's I at α=0.05 were significant, H_0 of Moran's I was denied. This indicated the presence of spatial autocorrelation, therefore, these models were not considered in the further analyses (sections 4.3.4 and 4.3.6). The details on the derived parameters of these models are presented in Table 14, Table 15, and Table 16 in Appendix B.

The final expert model for 1995-2000 was obtained on the first backward step after elimination of the predictor X_5 (p=0.34, α=0.05). The model was significant with chi-square of 2257.28 and corresponding p-value of 0.0000 (α=0.05). Summary of the model's results is presented in Table 14 in Appendix B.

The final all-inclusive model for 2000-2005 was obtained on the third backward step after elimination of the predictor X_2 (p=0.98, α=0.05), X_4, (p=0.47, α=0.05), and X_7 (p = 0.23, α=0.05). The model was significant with chi-square of 1243.40 and corresponding p-value of 0.0000 (α=0.05). Summary of the results of LRM of is presented in Table 15 in Appendix B.

Table 7: Values of Moran's I

Type of Model	Time step	Moran's I	Z-score (α=0.05, critical values +/-1.96)
All-inclusive model	1990-1995	0.15	1.6
Expert model		0.14	0.77
All-inclusive model	1995-2000	0.19	1.43
Expert model		0.33	3.31
All-inclusive model	2000-2005	0.66	4.41
Expert model		0.62	4.19

The final expert model for 2000-2005 was obtained on the second backward step after elimination of the predictors X_5 (p=0.54, α=0.05), X_6, (p=0.11, α=0.05).The model was significant with chi-square of 911.73 and corresponding p-value of 0.0000 (α=0.05). Summary of the model's results is shown in Table 16 in Appendix B.

5.2.4. Evaluation of models' performance

The performance of LRMs was first evaluated with actual situation and then validated with the following time steps (section 4.3.6). The models for 1990-1995 were evaluated by comparing probability maps with the map of the ISs in 1995, while model for 1995-2000 was evaluated using the map of ISs in 2000. Results of models' evaluation described in section 5.2.3 are summarized in Table 8.

Table 8: Evaluation results of LRMs

LRM	Evaluation year	PCP	Kappa	Roc (AUC)[21]	Thres-hold
All-inclusive LRM for 1990-1995	**1995**	84.90	0.54	0.87	0.12
Experts LRM for 1990-1995	**1995**	84.72	0.61	0.90	
All-inclusive LRM for 1995-2000	**2000**	82.97	0.59	0.93	0.02

All models were validated based on the same time period (2000-2005) assuming that the causative relations of the factors observed in 1990-1995 and 1995-2000 remain the same in 2000-2005 (section 4.3.6). Thresholds used to calculate Kappa index and PCP were based on the proportion of change in ISs between analyzed time steps (sections 4.3.6 and 5.1.2). The LRMs were compared based on AIC (section 4.3.6). The validation results for all models are shown in Table 9. The AUC values and corresponding ROC curves are shown in Figure 24, Figure 25, Figure 26 , in Appendix A.

Table 9: Validation results of LRMs

LRM	Validation year	PCP	Kappa	Roc (AUC)	Threshold
All-inclusive LRM for 1990-1995	**2005**	78.57	0.50	0.81	0.12
Experts LRM for 1990-1995	**2005**	73.54	0.49	0.82	
All-inclusive LRM for 1995-2000	**2005**	87.54	0.65	0.94	0.02

The obtained evaluation and validation results indicated that both models for 1990-1995 had similar performance. This was also confirmed by the values of AIC, i.e. 0.45 (all-inclusive model) and 0.47 (expert model). This indicated that the model

[21] Standard error of AUC for all variables is 0.000 (α=0.05).

built on expert opinion had similar prediction and explanatory power, as the all-inclusive model (Table 9).

According to the validation results of all-inclusive model for 1995-2000 AUC value of 0.94 showed almost perfect assignments of probabilities, PCP was 87.56% and Kappa values indicated higher than average agreement (Table 9 and Figure 26). Computed value of AIC was 0.13 indicating better model's performance compared with both LRMs for 1990-1995 (section 4.3.6)

5.2.5. Models' interpretation

The final all-inclusive models for both time steps were built incorporating 8 out of 11 factors, while expert model for 1990-1995 was based on 4 out of 5 factors (Table 12 and Table 13 in Appendix B). The only predictor eliminated from LR due to the high value of VIF for years 1990, 1995, 2000 was distance to industrial sites (x_{10}). The explanation of high multicollinearity of x_{10} can refer to the assumption made to incorporate this variable to the analysis (section 4.3.2). During LR modelling variable forest (x_2) was also eliminated from both all-inclusive models due to its insignificance. This refers to the location of the forest areas in the far northern part of the district where no ISs were observed (section 5.3.3). The variable distance to CBD (x_{11}) was eliminated from the all-inclusive model for 1990-1995, while the variable proportion of urban land in the surrounding area (x_5) was eliminated from the all-inclusive models for 1990-1995.

According to the estimated models' parameters population density and slope had the highest influence among other predictors on appearance of new informal settlements. It indicated that informal development had a tendency to occur near highly-populated sites on the undeveloped land with the low slope. New ISs appeared close to the other ISs. This corresponded to the experts' opinion that ISs had a tendency to cluster around existing settlements (key informants 18, 19). Spatial development of ISs was driven by land availability indicated by the positive coefficients of the factors x_6 and x_7 in 1990-2000. The negative relation of the factor proximity to roads (x_9) in 1990-1995 pointed that ISs had a tendency to develop further away from the roads in the unoccupied suburban areas. By 1990 ISs had been already located along two main roads (Figure *11*). Between 1990 and1995 ISs spread away from the roads occupying undeveloped land. In 1995 new roads including connectors for E-5 and TEM highways were built (key informant 18). This increased accessibility of the central and southern parts of the district encouraging ISs development near the roads. This situation explained by the positive coefficient of the predictor x_9 in the all-inclusive model for 1995-2000. Thus, the new roads encouraged the growth of ISs indicating that ISs development was dependant on both access to the developable land and actual land availability. This corresponded to the expert opinion that construction of the roads stimulated urban expansion of Istanbul (key informants 1, 5, 7, 11, 12). ESAs had the highest negative relation to the ISs development confirmed by values of the factor's coefficients and odd ratios suggesting that ISs tended to develop further from ESAs (Table 4 and Table 6). Although this contradicts, to an extent, the observed ISs within protected rivers' basins in the central part of Sancaktepe, the influence of the biggest ESAs located in the northern part of the district within the water basin of Omerli lake, where no ISs were located, outweighs the presence of these riverside settlements. Proportion of developed land in the neighbourhood had either negative (1990-1995) or insignificant influence (1995-2000) on allocation of the ISs indicating that in 1990-1995 ISs were developing out of built-up areas, while in the following years this factor did not have any influence on their allocation. Though coefficient estimated for the predictor distance to CBD (x_{11}) showed negative relation to ISs development, its value was the smallest among estimated parameters indicating weak influence on informal development. The reason behind this was the location of the CBD of Istanbul far from Sancaktepe.

Overall, estimated models' parameters were consistent in defining causative effects of analyzed factors of ISs development. This indicates that the trend and driving forces of ISs development remained almost the same in 1990-2000. This is important for identification of the areas which are likely to be occupied by ISs in the future, as the predictions are made based on the observed trend in the past.

5.2.6. Predictions of ISs development

Parameters of the LRMs were employed to calculate probability maps based on factors of 2005 to predict areas which are more likely to be informally developed in the future. From derived probability maps built-up areas were masked out and the remaining probabilities were classified to provide better visual interpretation of the results. The choice of the method for visualization of probability maps depends on the specific case and objectives of the work (Aylew and Bulut, 2005). Having tested four classifications system (standard deviations, natural breaks, equal intervals, and quantile) natural breaks classification was selected for visualization purposes. This method maximized differences between various classes providing better visualisation of probability map.

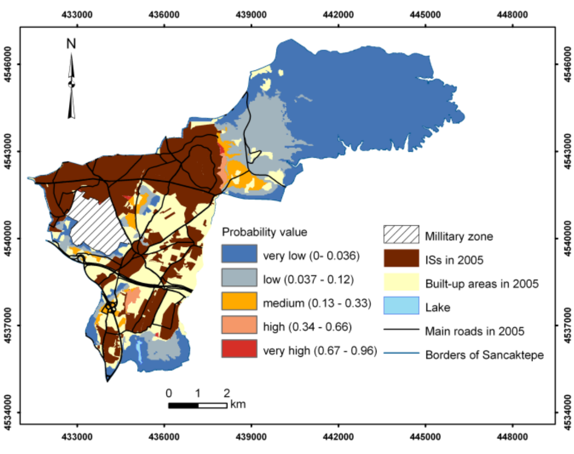

Figure 13: Predicted probabilities of ISs development based on all-inclusive model for 1990-1995

Predicted probabilities based on all-inclusive and expert models for 1990-1995 have very similar pattern showing gradual spread of informal development further on north of the district occupying first areas around existing settlements (Figure 13 and Figure 14). The highest probabilities of appearance of new ISs were assigned to the locations adjacent to the existing ISs and in between built-up areas in the central part of the district. The lower probability values were assigned to the areas located further from developed land suggesting successive growth of ISs from the highway further on north.

The probability map derived from all-inclusive model for 1995-2000 had less variation in distribution of probability values. The prediction results showed that ISs would occur in unoccupied patches of land adjacent to the existing built-up areas and ISs. The predicted very low values of probability suggested low likelihood of further spread of the informal development over still undeveloped land in the north and south of Sancaktepe.

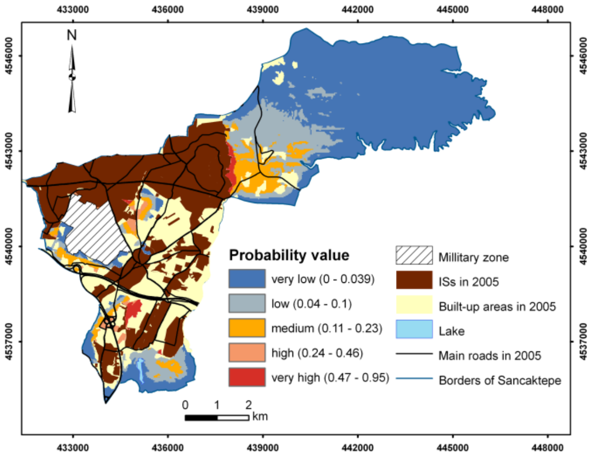

Figure 14: Predicted probabilities of ISs development based on expert model for 1990-1995

The difference in prediction results of the all-inclusive model for 1995-2000 and both models for 1990-1995 referred mainly to the assignment of very low values to the undeveloped areas in the north and south of the district, while both models for 1990-1995 indicated higher probability of IS growth for these areas. This reflect the trend-based nature of predictions of LR, as between 1990 and 1995 ISs expanded over new areas, while in 1995-2000 informal development was characterized mainly by in-fill character (section 5.1.1). The observed edge effect in the probability map based on the results of the all-inclusive model for 1995-2000 referred to the mutual effects of high negative coefficient of the variable x_3 (ESAs), in the combination with the rest of variables, e.g. lower slopes along the northern border of the district and banks of Omerli lake.

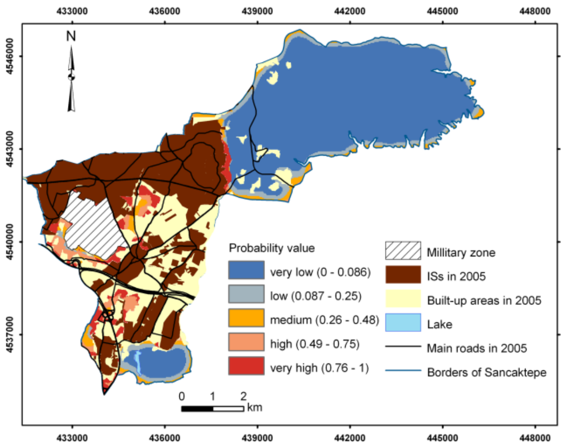

Figure 15: Predicted probabilities of ISs development based on all-inclusive model for 1995-2000

By calculating areas assigned to each probability class it was found out that comparing to the other models' results the biggest area with the high and very high probability values showed the prediction result of the model for 1995-2000, while results of both models for 1990-1995 indicated smaller area of high and very high probability of ISs growth (Table 10). The all-inclusive model for 1990-1995 predicted the smallest area with high and very high probability of ISs development.

Table 10: Area corresponded to the assigned probability classes of further ISs development

No	Probability class	Area per probability class, km^2		
		All-inclusive model for 1990-1995	**Expert model for 1990-1995**	**All-inclusive model for 1995-2000**
1	Very low	22.91	22.52	25.01
2	Low	7.47	6.26	3.09
3	Medium	1.80	2.94	1.55
4	High	0.45	0.51	1.31
5	Very high	0.10	0.52	1.78
Total	Class 1+2	30.38	28.77	28.01
Total	Class 4+5	0.56	1.04	3.09
Total	Class 3+4+5	2.36	3.97	4.64

5.3. Spatial and temporal changes in ESAs due to ISs development

This section presents the main findings of analysis of spatial and temporal changes in ESAs due to ISs development in Sancaktepe.

5.3.1. Types of ESAs in Sancaktepe

According to the expert knowledge and investigation of available maps the following types of ESAs were identified: forest areas, water basins of rivers and lakes, and special environmental protection areas (SIT areas) (Figure *16*). These ESAs are protected by Turkish legislation, such as: the Forest law No 6831 from 31/8/1956 (Ministry of forestry, 2009), ISKI regulations No 2560 from 20/11/1981 (ISKI, 2009), and Environmental law No 18132 from 09/08/1983 (EPASA, 2009a).

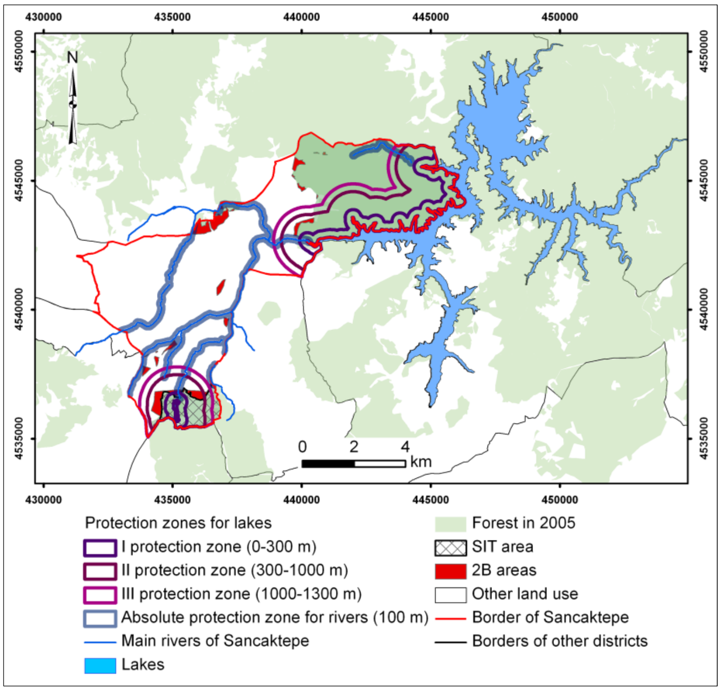

Figure 16: Types of ESAs in Sancaktepe

Most of the forest areas were located in the northern and southern part of the district (Figure 16). The area of the forest within Sancaktepe decreased from 21.20 km^2 in 1990 to 19.60 km^2 mostly due to the encroachment of forest patches as 2B areas[22]. There are two main lakes in the district, i.e. Omerli lake in the north-east and Siniri lake in the south (Figure 16).Omerli lake belongs to the water drinking reservoirs of Istanbul preservation of which is essential for the normal functioning of the city (key informants 1, 15). The water from Siniri lake is used for local water supply (key informant 18). The main rivers of Sancaktepe are the Koy Dere, Palanut Dere, Ozan Dere, Cyrcyr Dere, Kum, and Cos in the centre and Alemdaoy in the north of Sancaktepe (ISKI, 2009). The responsible authority for protection of the water basins is Water and Sewage Administration of Istanbul (ISKI). The current ISKI regulation No 2560 approved in August 2009 establishes protection zones

[22] The item 2B of the Forest law states ”publicly owned forest areas which have lost the characteristics of being a forest and which contain a large number of dwellings, can be taken out of the forest zone” (Unsal, 2009, p.10).

around water basins to regulate activities in these zones. The following protection zones are distinguished for lakes (ISKI, 2009):

I. absolute protection zone – 0 - 300 m buffer zone;
II. short distance protection zone – 300 - 1000 m buffer zone;
III. medium distance protection zone - 1000 - 2000 m buffer zone;
IV. long distance protection zone – from 2000 m till the border of water basin.

The absolute protection zone is a strictly protected zone where any kind of activities is prohibited. In the short distance protection zone some recreational activities are allowed e.g. tourist paths, with the special permission of ISKI. In the medium distance protection zone industrial buildings cannot be located. However, in these areas people can settle without exceeding the certain threshold of population density. In Sancaktepe the maximum population density in the medium distance protection zone should not exceed 40 persons per ha. In the long distance protection zone industrial and residential areas can be located (ISKI, 2009). For the rivers only the absolute protection zone of 100 meters buffer for each side of the river is defined (ISKI, 2009). The protected zone refers to the main stream of the river, if other is not specified.

ISKI regulations have been changed twice for the last twenty years. In 1990-2005 there were three zones (I (0-300) meters, II (300 – 1000 meters), and III (1000 – 1300 meters)). The first and the second protection zones were defined as the absolute protection zones (any type of development was prohibited); while in the third zone some type of development was allowed with the special permission of ISKI. From 2005 till August 2009 there were only two absolute protection zones (0-300 meters and 300 – 1000 meters), while further areas did not have any restrictions for the development (key informant 1). According to the key informants 1 and 15 one of the reasons of changing ISKI regulation was to legalize ISs located within boundaries of the water basins.

Special Environmental Protection Areas (SIT areas) are defined as “areas which are characterized by the integrity of historical, natural and cultural values and ecological importance in both countrywide and worldwide scales” (EPASA, 2009b). SIT areas were identified in order to guarantee a balance between usage and preservation of natural resources, to preserve ESAs, and to achieve sustainable development of the city (EPASA, 2009b). SIT areas are under control of the local municipalities of the Istanbul’s districts. The management authority of the SIT areas is responsible for preservation and management of natural and cultural resources of these sites. According to the Construction and Development law No 3194 from 03/05/1985 SIT areas are included in plans of 1:1000000, 1:25000, 1:5000, and 1:1000 scale plans of Istanbul city (EPASA, 2009c). In Sancaktepe there is one SIT area in the south of the district (Figure 16).

5.3.2. ESAs and ISs

By overlaying the map of ESAs[23] with the maps of ISs in 1990-2005 it was identified that ISs were located within protected water basins of the rivers and Siniri lake. Main expansion of ISs over protected water basins occurred between 1990 and 1995 resulting in invasion to the absolute protection zone of the rivers in the lower central part of the district and II and III protection zones of Siniri lake (Figure 27 and Figure 28 in Appendix A). ISs in the south expanded to the border of SIT area and I protection zone of the lake. This situation remained the same for the following 10 years (Figure 29 and Figure 30 in Appendix A).

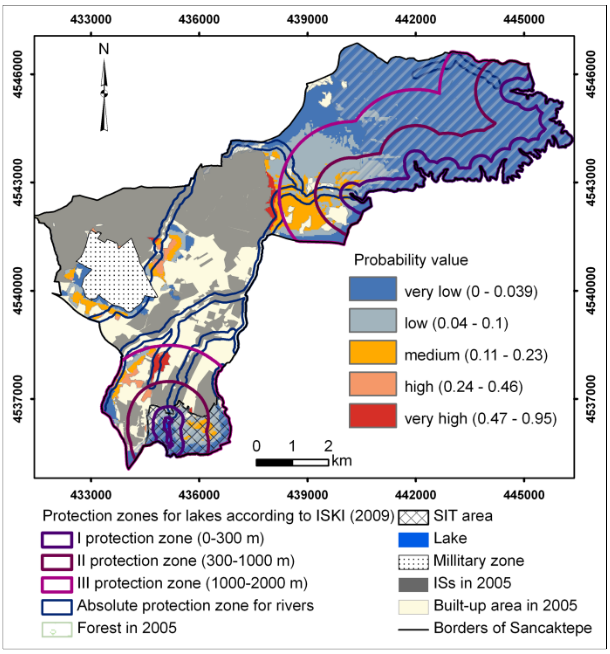

Figure 17: ESAs which are likely to be occupied by ISs according to the prediction results of expert model for 1990-1995

5.3.3. ESAs and predicted ISs development

The map of ESAs in 2005 was overlaid with the maps of predicted probabilities of ISs development. As both models for 1990-1995 were quite consistent in predictions of future patterns of informal development, the similar location of the ESAs were predicted to be occupied by the ISs. The difference referred only to the degree of probability assigned to these locations (Figure 17, Figure 31 in Appendix A). It is

[23] In the map of ESAs protection zones for rivers and lakes are identified according to ISKI regulation which was in force at that time (section 5.3.1). Forest areas for every time step were derived from available land cover maps.

more likely that informal development will appear within absolute protection zone of rivers in the upper central part of the district spreading further towards III and II protection zones of Omerli lake (Figure 17 and Figure 31 in Appendix A). According to the prediction results of the expert model for 1990-1995, the higher probability values were assigned to the area in the south of the district indicating invasion of ISs to the SIT area and I and II protection zones of Siniri lake (Figure 17). Results of all LRMs indicated that the absolute protection zone of the rivers located in the central and south-western part of the district had higher probability to be occupied by ISs (Figure 17 and Figure 31, Figure 32 in Appendix A). Models' results for 1990-1995 showed that, if unregulated, development is likely to reach eventually forest areas in the north of Sancaktepe.

6. Discussion

This chapter focuses on the discussion of the obtained results, methods employed, and their possible practical applications for urban planning.

6.1.1. Spatial and temporal patterns of ISs development

The identified spatial and temporal patterns of ISs development in the study area are consistent with the general trend in informal development observed in Istanbul and described in the studies of Eyuboglu (2004), Unsal (2007), Unsal (2009), Yonder (1987), and Yonder (2006) (section 2.4). The obtained results are still the subject to the following consideration: scale of analysis, data availability and data quality. First, identified spatio-temporal changes do not reflect dynamics within the existing settlements (e.g. densification of ISs) due to the scale of data incorporated in the analysis. The use of the maps with the larger scale could therefore be beneficial, as more detailed information about dynamics in development of ISs, like density changes, is important for understanding of this process, its control and management. There was not enough information to identify ISs which were legalized in every time step during 1990-2005. Information about legalization process of ISs would contribute for better understanding of the spatio-temporal changes in ISs. Considering reported problems with data consistency (section 3.4) it is preferable to validate produced maps of ISs. Due to the absence of the relevant data this issue is left for investigation in the further research.

6.1.2. Spatial modelling of ISs development based on LR

LR modelling was applied in this study to analyze influence of the factors of ISs development and to predict future informal growth in the study area. In the reviewed similar studies (Hu and Lo, 2007; Huang et al., 2009; Sietchiping, 2005; Xie et al., 2009) it is suggested that the causative power of the factors depends on the specific situation. In most studies population density, distance to the roads, proportion of urban and undeveloped land in the neighbourhood are reported as the factors which have the highest influence on urban expansion (Cheng and Masser, 2003; Fang et al., 2005; Hu and Lo, 2007; Huang et al., 2010; Xie et al., 2009). However, the effect of these variables differs from case to case. This is confirmed with the statement of Xie et al. (2009) made in their study of the urban-rural conversion in Newcastle county, the UK, who claimed that LRM built for one time step might not be appropriate for the same region for another time period. This indicates that, though the list of factors which drive informal development is similar in different cases (Sietchiping, 2005), the causative effects of the variables depends on the specific case and varies over the time. Nevertheless, the explanatory power of LR is valuable, as it may allow a better understanding of the forces driving ISs growth (Hu and Lo, 2007; Huang et al., 2009; Verburg et al., 2004).

The predicted patterns of future ISs development are very similar for all-inclusive and expert models for 1990-1995. This indicates that models built on variables which are the main predictors for the specific area can yield similar results to the models incorporated more variables. The same result was obtained by Huang et al. (2009) who applied LR for modelling urban expansion in the UK based on only 6 variables (population density, zoning status, distance to roads/commercial sites/residential areas, proportion urban land use in neighbourhood) which yielded good results. However, crucial for such models is to identify factors which have the strongest causative effect on informal development, as models based on "additional" factors can produce less accurate results (Sietchiping, 2005). In this case it also shows that the local planning experts have a good understanding of the drivers of IS development; perhaps creating an opportunity for them to gain more influence in policy debates on ISs issues. The application of models based on fewer variables can also have practical application, as they are less data consuming. In case when the quick overview of the situation is required, the models incorporated the main factors can be built to get required information.

The evaluation and validation results of LRMs indicated that the models were valid which was confirmed by comparison of the obtained results with the conducted similar studies. For example, Fang et al. (2005) and Hu and Lo (2007) reported ROC values of 0.72 and 0.85 respectively; while in the study of Huang et al. (2009) the values of PCP for different LRMs varied between 68.52% and 75.62%. The obtained results affirmed the spatial explicitly of LR which is considered as one of its biggest advantageous compared to the other models (Dendoncker et al., 2007; Hu and Lo, 2007; Huang et al., 2009). The data constraints had implication on evaluation of future predictions based on LRMs. This procedure would be possible to implement by comparison with the results of similar studies or recent maps of ISs, if relevant data are available.

One of the disadvantages of LR is the lack of temporal dynamics in the predictions that are unable to incorporate what-if scenarios. Another aspect is that probability maps indicate locations of informal development but not the time when it takes place. In case the time aspect is important for practical purposes, it can be incorporated by coupling LR with other models which can handle temporal dynamics (Poelmans and Rompaey, 2009; Sietchiping, 2005). Despite this, trend-based predictions are still valuable, as they provide insights in further ISs development. By comparison of predictions based on different time periods with observed various trends in informal development the knowledge of relative importance of different factors and their implications on ISs growth can be obtained, as was demonstrated by the results of models for 1990-1995 and 1995-2000.

Another disadvantage of LR refers to the type of the factors which are incorporated in the model. While LR can be built based on biophysical, economic, social and other factors, it cannot include such predictors as people's preferences for household locations and political drivers. These factors might be still very important to consider. For example, in case of Istanbul political factors are among the main drivers of ISs growth (key informants 16, 19).

During LR analysis several issues were identified which should be considered with caution while applying this method. First, care should be taken about spatial dependence. In this study a systematic sampling scheme was applied to account for its effect (Sikder, 2000). This method was effective only for models for 1990-1995 and all-inclusive model for 1995-2000 (section 5.2.3). Therefore, other methods, e.g. autoregressive models, not considered in this study should be tested to address this issue (Overmars et al., 2003). Another point which has to be investigated refers to the degree to which spatial autocorrelation can be eliminated and its implications on the results of LR. Cheng and Masser (2003) and Hu (2010) stated that spatial autocorrelation could be decreased by applying different techniques; however, it could not be fully eliminated in all cases.

Second, LR is sensitive for the scale of the analysis. In this study the resolution of LRM was 30×30 m. Modelling conducted on a larger scale is still desirable, as it may disclose causative effects of the factors which are neglected at the smaller scale. Nevertheless, there are factors which are important at all scales, while others can be revealed only in the small scale of modelling (e.g. regional planning policies) (Hu and Lo, 2007). Thus, multi-scale comparison of LRMs could yield interesting results.

Third, predictions of LR are conditioned to the factors incorporated to the models. Data shortage is a common problem in LULC modelling studies and reported in works of Huang et al. (2009) and Xie at al. (2009). The LR models built in this study are also the subject to the data constraint which unable to include all identified factors in the analysis. This can lead to over- or underestimation of causative effects of incorporated variables and approximation of models' results. The extent of modelling also matters. In this study the effects of the factors located in adjacent areas were neglected, though they also influence ISs development, especially in the areas near the borders of the districts

Despite mentioned limitations, it was shown that LR can be used to explain ISs development and to predict probabilities of its further growth. The created list of factors can be applied for LR modelling of ISs. However, derived LR models are valid only for the case study within their spatial and temporal resolution (Huang et al., 2009; Xie et al., 2009).

6.1.3. Spatial and temporal changes in ESAs due to ISs development

The ISs observed within protection zones of the rivers and Siniri lake in Sancaktepe corresponds to the general pattern in allocation of ISs within ESAs in Istanbul (Yonder, 2006). The main growth of ISs within ESAs occurred in 1990-1995. Though in the following 10 years development of ISs within ESAs was minor, their locations within natural areas did not change. This has caused not only negative environmental impacts, but also created risky living conditions to the dwellers of such settlements confirmed by the serious consequences of the recent flash floods in Istanbul (BBC World News, 2009). The absence of identified ISs within protected zones of Omerli lake reported in the other studies (Kucukmehmetoglu and Geymen, 2008; Kucukmehmetoglu and Geymen, 2009) and confirmed by the key informant 15, as well as minor variations observed in 1995-2005 might be due to the scale and extent of the maps used in the analysis. The use of larger scale maps with bigger spatial extent may reveal more details in allocation and development of ISs in ESAs, as well as provide more specific information about further spread of ISs within natural areas. Such information is important for planning activities aimed to protect ESAs and prevent further ISs growth within such areas.

6.1.4. Practical application of the results

The outputs of LRMs combined with information about spatio-temporal changes in ISs and types of ESAs where employed to predict likelihood of emergence of new ISs and identify ESAs which are more likely to be occupied in the future. Regardless of some limitations, obtained models' results showed good consistency with actual situation in informal development. Such knowledge can be employed in urban planning to support policy development and spatial decision making, which are able to address future informal growth before its appearance (Sietchiping, 2005). The importance of this information was confirmed during interviews with urban planners in Istanbul (key informants 1, 12, 19) who have mentioned that knowledge about areas more likely to be occupied by ISs can facilitate planning process and help to avoid wrong decisions encouraging informal development.

However, to be able to utilize this type of analyses in urban planning practises the further improvements of the techniques are required. For example, to simplify computation costs of predicted probabilities of ISs growth a tool with a user-friendly interface should be created. Such a tool has to incorporate different sampling schemes, statistical analyses which should be conducted on different stages of LR modelling, and models' evaluation tests. The similar software was developed by Huang et al. (2009). However, it currently lacks the necessary statistical and evaluation tests which should be computed out of its environment.

Another practical application of obtained results refers to the generation of informal growth maps based on produced probability maps (Hu and Lo, 2007). Such growth maps combine planning information and predicted probabilities of ISs development to answer the question where ISs will be located, if the amount of informal growth is known or assumed (Hu and Lo, 2007). The growth maps will provide effective visual interpretation of LR predictions and will be able to define exact locations of possible ISs. Combination of such maps with information about ESAs will assist planning policies directed to protect natural areas of Istanbul.

LR can be effectively employed in urban studies which incorporate other modelling techniques, i.e. simulation models for urban growth, to take an advantage of its spatial explicitness and explanatory power (Poelmans and Rompaey, 2009; Sietchiping, 2005).

7. Conclusions

To achieve the general objective of the research, i.e. to improve understanding of the ISs development in Istanbul, three specific objectives were set up for this study. The first objective was focused on analysis of spatial and temporal patterns of ISs development in the study area. It was found out that the main growth of ISs was in 1990-1995 following by its decline in 1995-2005. The highest rate of change of 92.91% was observed between 1990-1995, while the total rate of change was 112.06% between 1990 and 2005, indicating that the area of ISs has increased more than twice in analyzed period of time. The results were consistent with the general trend in ISs development in Istanbul reported in literature.

The second objective aimed to predict informal development based on causative factors of informal growth. The list of such factors was complied based on literature review and experts' opinion. This was followed by modelling of ISs development using LR. The results showed that the main factors which drive informal growth in the study area are population density and slope. The factors proportion of ISs/undeveloped/agricultural land in the neighbourhood are positively related to spatial allocation of ISs, while distance to CBD and ESAs are negatively related to ISs development in the study area. The results of predictions of further ISs growth of all-inclusive and expert model for 1990-1995 were similar showing the gradual spread of ISs over still undeveloped areas, while all-inclusive model for 1995-2000 predicted high probability of informal growth on undeveloped patches within built-up areas. The results of all models showed that informal growth is more likely to happen in the undeveloped land adjacent to the existing ISs. The computed evaluation and validation statistics indicated that the models were valid in prediction of ISs in the study area. The value of AIC was the smallest for the all-inclusive LRM for 1995-2000 indicating its better performance compared to the all-inclusive and expert model for 1990-1995. The prediction results of the same model indicated the biggest area with the high probability of further ISs development among evaluated results of LRMs.

The third objective focused on spatio-temporal analysis of ESAs and related changes in such areas caused by informal development. The following ESAs were defined in Sancaktepe: forest areas, protected water basins of rivers and lakes, and special environmental protection area. During 1990-2005 the main spatial changes in ESAs due to ISs occurred within protected water basin of Siniri lake in the south and riparian zones of rivers located mainly in the central part of the district. According to the prediction results of all LRMs ESAs with the highest probability to be further occupied by ISs are riparian zones of the rivers located in the south-western and central part of Sancaktepe. Results of all-inclusive and experts models for 1990-1995 suggest that, if no preventive measures are taken, it is likely that ISs will develop within ESAs in the northern part of the district.

7.1. Specific conclusions

This research has brought up the following specific conclusions:

- Spatio-temporal analysis is a suitable approach to improve understanding of ISs development. This knowledge can contribute to the decision-making process and support urban planners in the debates with stakeholders on ISs issues.

- Data availability and quality are crucial factors for successful application of spatio-temporal analysis of ISs development.

- LR modelling is a statistical-based approach. In order to obtain accurate and reliable results required statistical procedures should be carried out.

- LRMs of informal growth are only valid within spatial extent, temporal and spatial resolution for which they were designed. Thus, derived models are not applicable for the other districts of Istanbul. The identified causative factors of informal development can be still incorporated to build LRMs in other areas.

- Analysis of LR for different time steps allows identifying trends of informal development, as well as its main factors and their causative effects for each time period. This knowledge is important for evaluation of possible consequences of planning decisions on informal growth and ESAs.

7.2. Further research directions

- To repeat spatio-temporal analysis of ISs development for the same study area on the larger scale. The additional datasets of good quality for different time steps are required.

- To repeat LR modelling increasing the spatial extent of the study area by including adjacent areas into analysis and incorporating more factors identified in Table 11 in Appendix B.

- To repeat LR modelling at multi-scale levels to investigate the influence of the spatial resolution on the parameters estimation and prediction results of LRMs.

- To investigate interactions of mutual effects of factors on ISs development.

- To test other methods to deal with spatial autocorrelation.

- To produce growth maps of ISs to investigate whether such maps can better visualize probability of informal development and, thus, can have more practical value for urban planning.

- To test adopted methods to another study area in Istanbul. Performance of expert models versus all-inclusive models should be also investigated. If it is confirmed that LRMs built on the main drivers of informal development has similar explanatory and prediction power as the model which include more variables, it will have practical application for urban planning, as models based on few variables are less data-dependant.

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9. Appendices

9.1. Appendix A – Figures

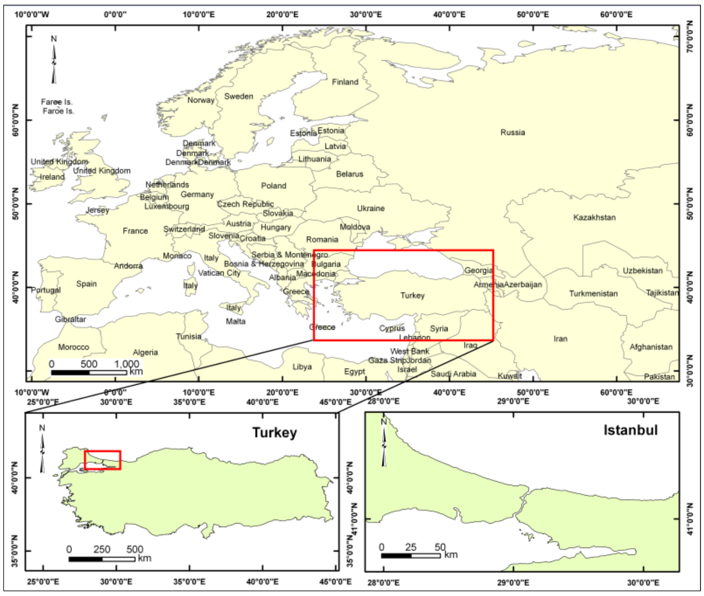

Figure 18 Geographical location of Turkey and Istanbul

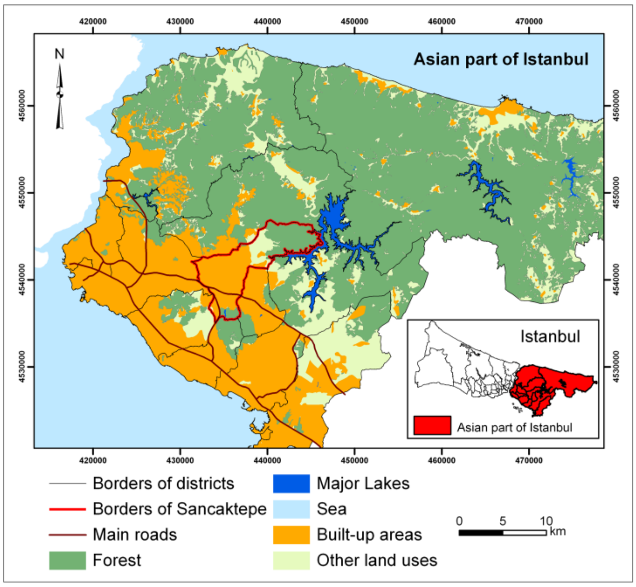

Figure 19 Location of Sancaktepe district in Istanbul

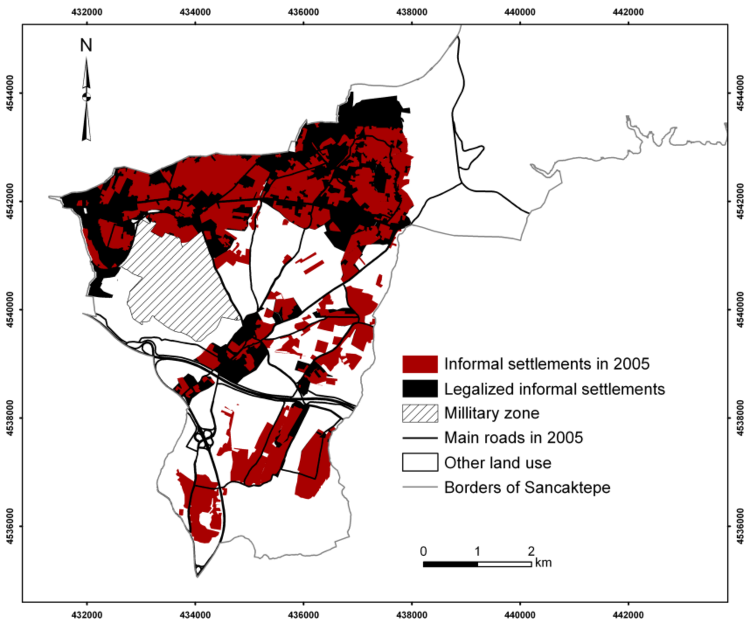

Figure 20: Locations of legalized ISs in Sancaktepe

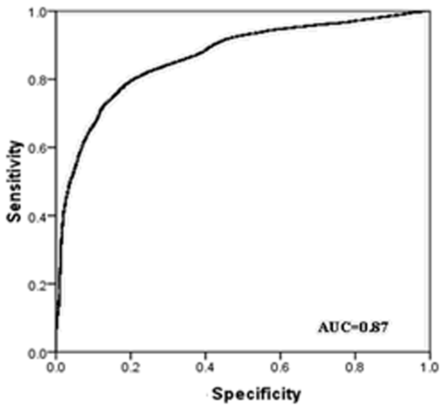

Figure 21: ROC statistics for evaluation of all-inclusive model for 1990-1995

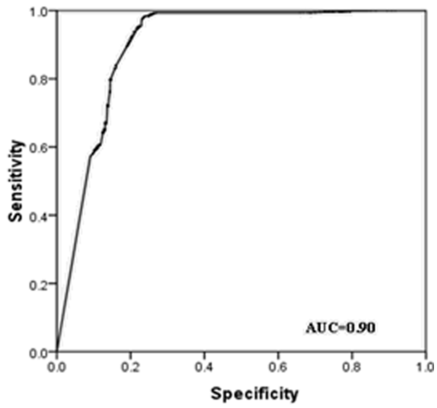

Figure 22: ROC statistics for evaluation of expert model for 1990-1995

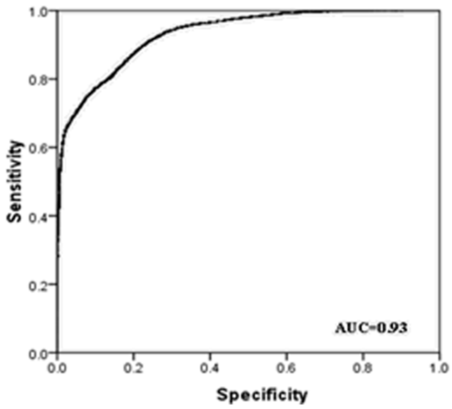

Figure 23: ROC statistics for evaluation of all-inclusive model for 1995-2000

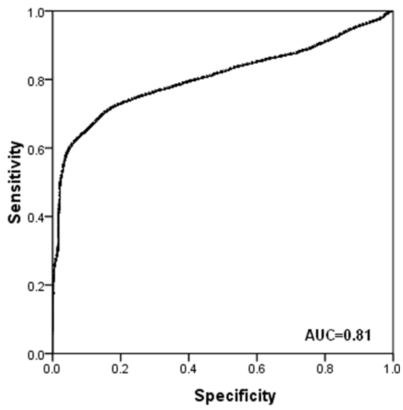

Figure 24: ROC statistics for validation of all-inclusive model for 1990-1995

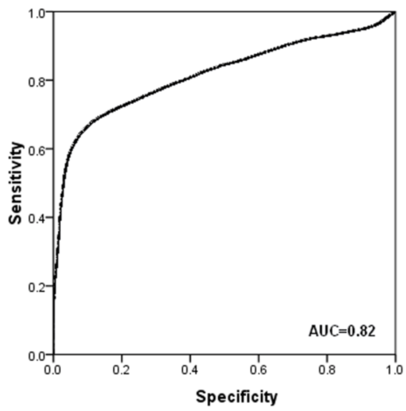

Figure 25: ROC statistics for validation of expert model for 1990-1995

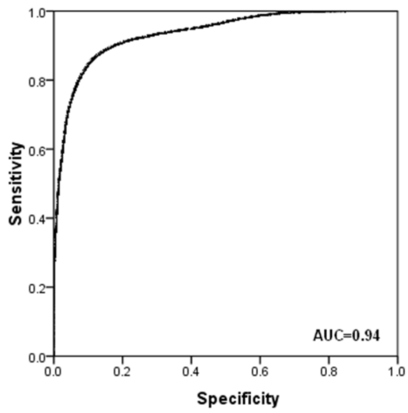

Figure 26: ROC statistics for validation of all-inclusive model for 1995-2000

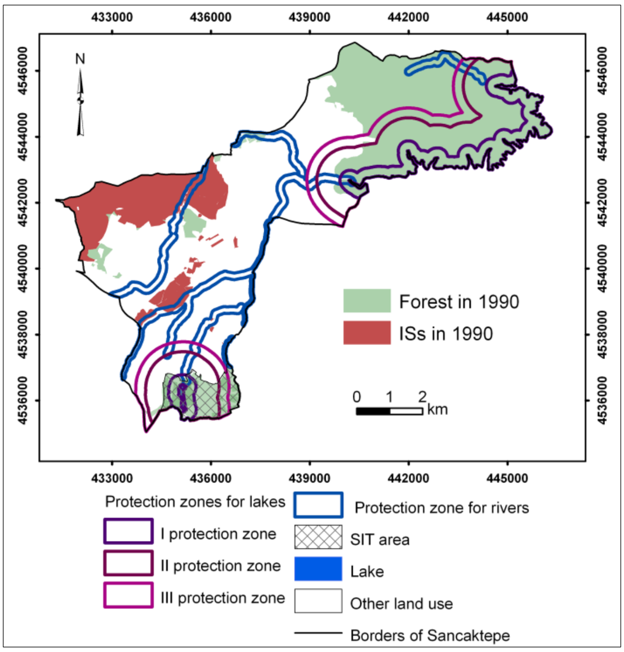

Figure 27: ESAs and ISs in 1990 in Sancaktepe

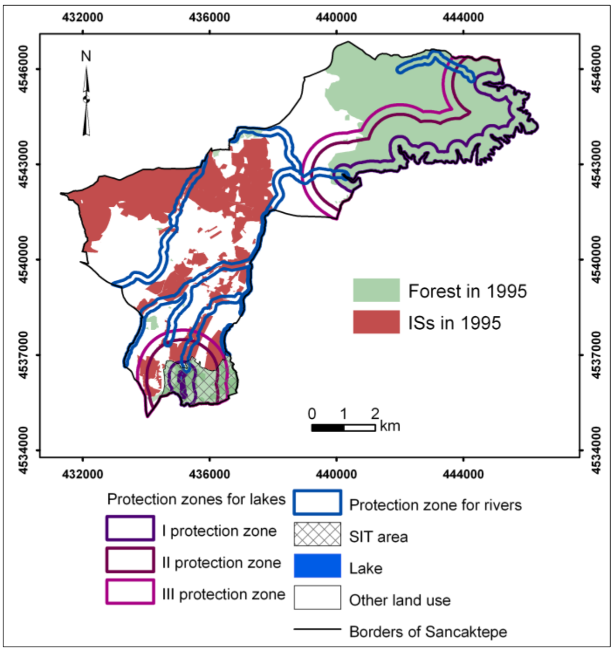

Figure 28: ESAs and ISs in 1995 in Sancaktepe

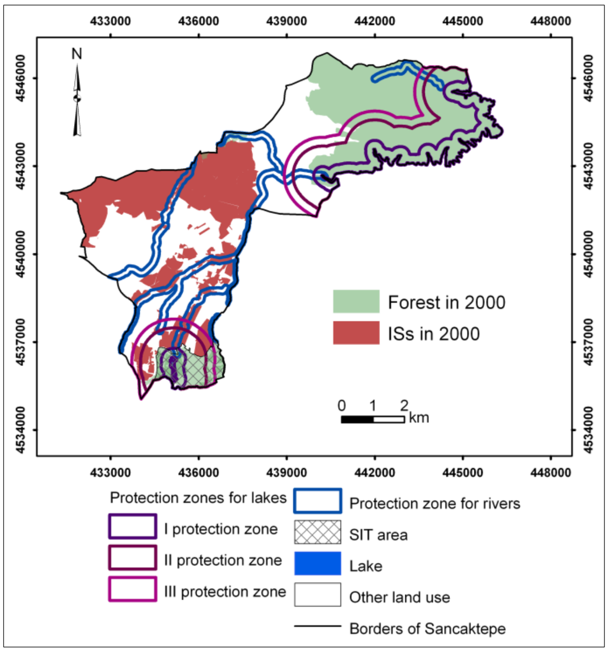

Figure 29: ESAs and ISs in 2000 in Sancaktepe

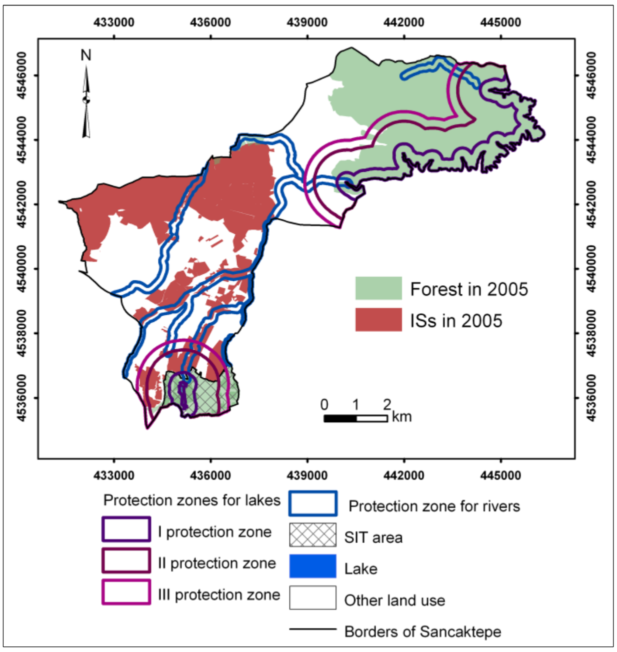

Figure 30: ESAs and ISs in 2005 in Sancaktepe

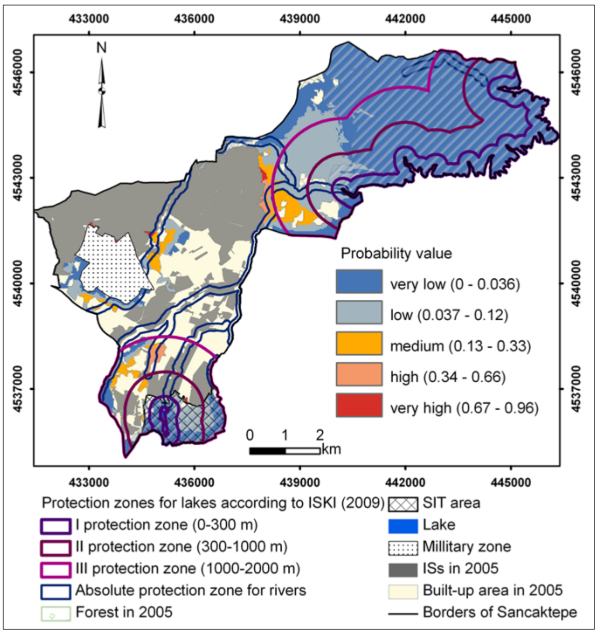

Figure 31: ESAs which are likely to be occupied by ISs according to the prediction results of all-inclusive model for 1990-1995

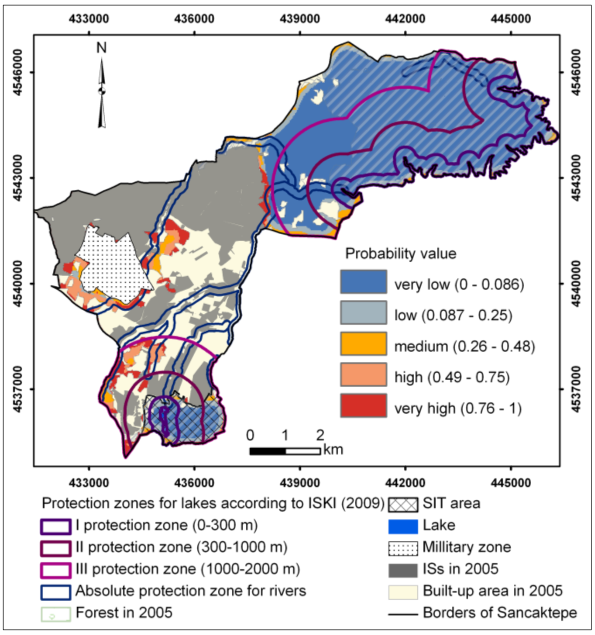

Figure 32: ESAs which are likely to be occupied by ISs according to the prediction results of all-inclusive model for 1995-2000

9.2. Appendix B – Tables

Table 11: Summary of factors which determine spatial development of ISs

Type of factors	Factors
Proximity characteristics	Distance to the industrial sites (Key informants; Cheng and Masser, 2003; Hu and Lo, 2006; Poelmans and Van Rompaey, 2009; Sliuzas, 2004; Xie et al., 2009) Distance to the roads (Key informants; Cheng and Masser, 2003; Hu and Lo, 2006; Huang et al., 2009; Poelmans and Van Rompaey, 2009; Sietchiping, 2005; Sliuzas, 2004; Xie et al., 2009) Distance to the commercial site (Cheng and Masser, 2003; Hu and Lo, 2006; Huang et al., 2009; Poelmans and Van Rompaey, 2009; Sliuzas, 2004; Xie et al., 2009) Distance to the residential areas (Huang et al., 2009; Xie et al., 2009) Distance to the CBD and other city's centres (Hu and Lo, 2006; Poelmans and Van Rompaey, 2009)
Site specific characteristics	Population density (Key informants; Huang et al., 2009; Hu and Lo, 2006; Sliuzas, 2004; Xie et al., 2009) Income per capita (Hu and Lo, 2006; Sliuzas, 2004) Poverty rate (Hu and Lo, 2006) Employment rate (Hu and Lo, 2006; Poelmans and Van Rompaey, 2009) Locations available for change and locations where no change could occur because of constraints (e.g. ESAs, protected areas, water bodies) (Cheng and Masser, 2003; Hu and Lo, 2006; Landis and Zhang, 2000) Migration rate (Key informants; UN HABITAT 2003; Sietchiping, 2005) Environmental hazards (areas prone to floods, earthquakes, landslides etc.) (Sliuzas, 2004) Zoning status of the land (Huang et al., 2009; Poelmans and Van Rompaey, 2009) Landownership (Sliuzas, 2004) Slope (Clarke et al., 1997; Hu and Lo, 2006; Huang et al., 2009; Poelmans and Van Rompaey, 2009; Sietchiping, 2005; Sliuzas, 2004) Level of infrastructure development (Sietchiping, 2005; Sliuzas, 2004)
Neighborhood characteristics	Proportion of urban land in the surrounding area (Key informants; Hu and Lo, 2006; Verburg et al., 2004; Xie et al., 2009) Proportion of undeveloped land in the surrounding area (Key informants; Hu and Lo, 2006; Verburg et al., 2004; Xie et al., 2009) Proportion of ISs in the surrounding area (Sietchiping, 2005) Social communities (Key informants; Sietchiping, 2005) Spatial policies (Key informants; Poelmans and Van Rompaey, 2009)

Table 12: List of variables from experts incorporated in LR modelling

No	Type of factor	Variable	Description
1	Site specific characteristics	X_1	Population density (person/ha)
2	Neighborhood characteristics	X_5	Proportion of urban land in the surrounding area (a circular neighborhood with a 420 m radius)
3		X_6	Proportion of undeveloped land in the surrounding area (a circular neighborhood with a 420 m radius)
4	Proximity characteristics	X_9	Distance to roads (m)
5		X_{10}	Distance to industrial sites (m)

Table 13: List of all variables incorporated in LR modelling

No	Type of factor	Variable	Description
1	Site specific characteristics	X_1	Population density (person/ha)
2		X_2	1 - Forest; 0 - not forest
3		X_3	1 - ESAs; 0 - not ESAs
4		X_4	Slope
5	Neighborhood characteristics	X_5	Proportion of urban land in the surrounding area (a circular neighborhood with a 420 m radius)
6		X_6	Proportion of undeveloped land in the surrounding area (a circular neighborhood with a 420 m radius)
7		X_7	Proportion of agricultural land in the surrounding area (a circular neighborhood with a 420 m radius)
8		X_8	Proportion of ISs in the surrounding area (a circular neighborhood with a 420m radius)
9	Proximity characteristics	X_9	Distance to roads (m)
10		X_{10}	Distance to industrial sites (m)
11		X_{11}	Distance to CBD (m)

Table 14: Parameters of expert LRM for 1995-2000

No	Variable in LRM	Description	βi	SE (βi)	z-value	T-Wald test (p-value)	O.R.
	Constant	-	2.9208	-	-	-	-
1	X_1	Population density (person/ha)	0.0363	0.0015	24.24	0.0000	1.04
2	X_6	Proportion of undeveloped land in the surrounding area	0.0032	0.0002	-12.93	0.0000	1.00
3	X_9	Distance to roads (m)	0.0003	0.0000	14.09	0.0000	1.00

Table 15: Parameters of all-inclusive LRM for 2000-2005

No	Variable in LRM	Description	βi	SE (βi)	z-value	T-Wald test (p-value)	O.R.
	Constant	-	3.3812	-	-	-	-
1	X_1	Population density (person/ha)	0.0103	0.0018	5.68	0.0000	1.01
2	X_3	1 - ESAs; 0 - not ESAs	-0.8325	0.1284	-9.57	0.0000	0.29
3	X_6	Proportion of undeveloped land in the surrounding area	0.0023	0.0004	5.18	0.0000	1.00
4	X_8	Proportion of ISs in the surrounding area	0.0083	0.0006	13.27	0.0000	1.01
5	X_9	Distance to roads (m)	-0.0013	0.0003	-4.79	0.0000	1.00
6	X_{11}	Distance to CBD (m)	-0.0004	0.0000	-10.72	0.0000	1.00

Table 16: Parameters of expert LRM for 2000-2005

No	Variable in LRM	Description	βi	SE (βi)	z-value	T-Wald test (p-value)	O.R.
	Constant	-	-3.9918	-	-	-	-
1	X_1	Population density (person/ha)	0.0199	0.0035	5.69	0.0000	1.02
2	X_9	Distance to roads (m)	-0.0025	0.0007	-3.35	0.0008	1.00

Table 17: List of key informants

No	Key informant	Position	Institution	Name of department
1	Alypaj Adam	City planner	IMP	Natural Resources Department
2	Aykut Karaman (Prof. Dr.)	Head of Department	Mimar Sinan Fine Arts University	Faculty of Architecture, Department of City and Regional Planning
3	Birgul Aksoy	Head of Department	Municipality of Kucukcekmece district	Project and Planning Department
4	Cigdem Goksel (Dr.)	Academic stuff	ITU	Faculty of Civil Engineering, Department of Geodesy and Photogrammetry
5	Dr. Engin Eyuboglu (Dr.)	Academic stuff	ITU	Faculty of Architecture, Urban and Regional Planning Department
6	Elif Kısar Koramaz	Head of Department	IMP	City and Regional Planning Department
7	Erbatur Çavuşoğlu (Dr.)	Academic stuff	Mimar Sinan Fine Arts University	Faculty of Architecture, Department of City and Regional Planning
8	Erdi Sahip	Urban planner	Municipality of Sancaktepe district	Planning Department
9	Eylem Gulcemal	Urban regeneration specialist	NGO "Y.Şehir Plancısı"	Department of Strategic Planning
10	Fatih Terzi (Ph.D.)	Academic stuff	ITU	Faculty of Architecture, Urban and Regional Planning Department
11	Fatma Unsal (Dr.)	Academic stuff	Mimar Sinan Fine Arts University	Faculty of Architecture, Department of City and Regional Planning
12	Gulay Gevik	City planner	IMP	City and Regional Planning Department
13	Gurcan Buyuksalih (Prof., Dr.)	Personal advisor to head of IMP-Bimstas	IMP	Personal advisor to the head of Bimtas company
14	Guvan Audial	Head of Department	Municipality of Kucukcekmece district	Development and Reconstruction of Public Facilities and City Planning Department

No	Key informant	Position	Institution	Name of department
15	Halil Ibrahim	Water engineer	ISKI regional directorate	Drinking Water Treatment department
16	Ibrahim Orjinalp	City planner	IMP	Strategic Planning Department
17	Ismail Erdem	Mayor	Municipality of Sancaktepe district	
18	Maskut Karamustafaoyt	Urban planner	IMP	City and Regional Planning Department
19	Nursen Ozer	Head of Department	Municipality of Sancaktepe district	Planning Department
20	Omer Yazici	Head of Department	Municipality of Sancaktepe district	Department of Development Works
21	Oosguz Oral	Assistant to coordinator of IMP, Cadastral specialist	IMP	
22	Seher Başlık (Dr.)	Academic stuff	Mimar Sinan Fine Arts University	Faculty of Architecture, Department of City and Regional Planning
23	Selahattin Taspinar	Head of Department	IMP	GIS and RS Department
24	Serdar Bayburt	GIS and RS analyst	IMP	GIS and RS Department
25	Tarik Yusuf Ucar	Deputy Mayor	Municipality of Sancaktepe district	
26	Ulas Akin	City planner	IMP	City and Regional Planning Department

9.3. Appendix C – Template of interview sheet

INTERVIEW

Name:
Date:
Location:
Educational Background:

Current employment:

Employment	Institution (optional)
☐ Academic staff	
☐ Governmental planning agency's staff	
☐ Planning NGOs' staff	
☐ Other	

Experience in planning:

☐ <5 years

☐ 5 – 10 years

☐ >10 years

Informality in Istanbul

1. What is the definition of ISs be in Istanbul context?
2. What are the main stages in the history of ISs development of Istanbul?
3. What are the main drivers of ISs development on every stage?
4. What were the measures (if any) taken to prevent ISs development in Istanbul on every stage?
5. How can you describe the current situation with ISs development in Istanbul?
6. What are the main problems with ISs development in Istanbul?
7. What is the role of ISs development in environmental degradation of Istanbul?
8. What are on your opinion the main allocation factors of informal settlements?

Localization of informal development

9. What are the factors which determine the localization of ISs(e.g. proximity to urban areas, roads, landownership (public/private land etc)?
10. How do you think the identified factors determine the allocation choice for new ISs e.g., new ISs usually appear near the roads/industrial areas, but not in the private areas? Please, explain your answer.

Measures to manage informal development

11. Which tools are usually used to monitor ISs in Istanbul?
12. Which tools/measures are usually used to manage ISs in Istanbul?
13. Are these tools/measures effective enough to prevent further informal development and to manage existing one?
14. What measures should be taken/tools applied to manage ISs development?
15. Do you think that the application of models to predict informal development can be beneficial for management and prevention of informal development?
16. What are the requirements (accuracy/scale) for such models to make them useful to apply for the problem of informal development?
17. What are the shortcomings of such models?