Urban growth monitoring, simulation and management from coastal cities management perspective using Cellular Automata, Remote Sensing and GIS: a case study of Alexandria governorate, Egypt

By

Mustafa Ahmed Mustafa Elmorshdy

A doctorate dissertation submitted to the Faculty of Spatial Planning at TU Dortmund University in partial fulfillment of the requirements for the degree of Doctor of Engineering (Dr.-Ing.)

Dissertation Committee:

Supervisor: Univ.-Prof. Dr. habil. Nguyen Xuan Thinh

Supervisor: Prof. Dr.-Ing. Michael Wegener

Chairman: Univ.-Prof. Dr.-Ing. Stefan Siedentop

Dortmund, Juni 2019

Acknowledgement

First and foremost, I want to praise, and thanks give to Allah, the Lord of everything, who is credited with all of the completion of this work.

This work wouldn’t be completed without the assistance of several persons and organizations, all of whom I grateful acknowledgement. I would like to express my sincerest thanks and appreciation to my supervisors who indeed contributed to the complement of this study. I would like to deeply acknowledge Univ.-Prof. Dr. habil. Nguyen Xuan Thinh and Prof. Dr.-Ing. Michael Wegener for their supervision, support, guidance, helping me overcoming the obstacles, and answering all my questions during the years of my PhD work. I am very grateful to Univ.-Prof. Dr. habil. Nguyen Xuan Thinh, ITMC team and Lido-TU Dortmund team for facilitating me using the HPC server.

Special thanks to Deutscher Akademischer Austauschdienst (DAAD) for the financial support to pursue my studies and related research activities including field research to my study area, conferences, and workshops, to achieve my research objectives.

I would love to thank also Prof. Dr. Mohamed A. Abdrabo the executive director of Alexandria Research Centre for Adaptation to Climate Change (ARCA), Prof. Dr. Mahmoud H Ahmed the chairman of National Authority for Remote Sensing and Space Sciences (NARSS), Dr. Ahmad Farrag (Head of Geological Studies department, Nuclear power plants Authority, and engineer Mohamed Labib from Ministry of Environment for providing me with the required data and in conducting the Multiple Criteria Decision Making for new urban areas suitability analysis.

Special thanks to Dr. Li Cheng and Dr. Yang Mu for their extremely important technical support and consultations. I also wish to express my gratitude to all PhD candidates and colleagues in RIM who were supporting me the entire time with thoughtful encouragement.

Last but not least, with all love and respect I thank my parents, my sister, and my brother for their thoughtful encouragement. Likewise, special thanks and gratitude to my wife for her patience, support, and encouragement all the time. I owe this work to my sweeties (my kids: Soaad, Ahmed, Roqaiya) to let me feel occupied all the time but with love and care.

Abstract

Egyptian coastal cities are astonishing places for people to live, where sunny and awesome beaches attracting tourists all over the world. Due to lack of adequate sustainable management and governance, the coastal cities and its resources suffer from multitude of negative environmental impacts, particularly uncontrolled urban growth. So, historical and precise geospatial data about land features' change is extremely important for any kind of sustainable development program. By the means of Landsat satellite imagery, remote sensing and GIS, Multi-temporal and spatial analysis for the investigation area has been conducted for the last three decades. Using a hybrid classification method of (NDWI), (NDVI), and SVM algorithm features derived from sixteen satellite imageries acquired from 1986 to 2016. Eight LULC types were identified (urban built-up, Lake, Fish Farms, Crop Lands, Desert, Undeveloped (open space), sandy beaches, Reclaimed), Meanwhile, the projects and initiatives implemented for the governance of coastal cities were investigated. Results showed that there are disparities between land-use practices and coastal zone management and spatial planning policies governing the coastal cities. Furthermore, the encroachment of agriculturally productive land and parts of freshwater resources (Lake Mariute) resulting in new urban areas.

There are many driving factors actuate, directly/indirectly, the urban growth process. The urban planners and decision-makers need to identify these factors to propose suitable measures, policies, and strategies dealing with urban growth in a sustainable way. The author and with help of 23 urban decision-makers have proposed driving factors of urban growth for the study area, namely: Distance to residential areas, Proximity to Facilities and Utilities, Distance to Schools, Distance to recreation areas, Proximity to Transportation system, Distance to Industrial Areas, Proximity to Croplands, Proximity to Coastline, Neighborhood Size and radius, Neighborhood type, and stochasticity. Thereafter, urban growth monitoring and prediction were conducted using a standalone CA-based model that was developed by the means of Python programming language.

Monte Carlo method was used to calibration the model, in which, the parameters' calibration process takes place through probability distribution for each used parameter in the calibration process. So, a wide range of random variables was utilized (from 0.0 to 3.0), exponent range (from 0.0 to 1.0), neighborhood size or radius (from 1 to 6), and three types of neighborhoods to conduct 6138 simulations. Figure or Merit and overall agreement as precision indicators resulting accuracy range from 87.6% to 90% goodness-of-fit. That means the developed standalone CA-based model approved to be reliable urban growth prediction. In that regard, five scenarios to predict urban growth for the year 2032 were developed, namely; Baseline, Historical growth trends (Business as Usual), Traffic, maximum environmental protection, and compact cities growth scenarios. Multiple Criteria Decision Making (MCDM) was implemented through the integration of two techniques; Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC), aiming at defining land suitability criteria and weights for the new urban areas. These decision maps (suitability maps) along with the definition of the transition rules were used to develop and predict various future urban development scenarios. The results indicated that maximum environmental protection and compact city growth scenarios are the closest to the strategic urban plan for Alexandria 2032 and also have a low influence on the cultivated lands.

The implemented UA-SA approach was conducted independently from the developed CA-based model by the means of SALib package in Python. The parameters' values were generated using the Saltelli sampler. The neighborhood types and randomness were employed to investigate their effects on the CA-based model simulation results. Nb showed no significant first-order effects, while α denoted significant first-order effects resulting almost zero and about 0.05, respectively. S_T: means α +nb have an impact on the results. Both confidence interval and confidence level go together hand in hand and are used with a 95% level of accuracy

The author proposed management regulations could help in controlling and curbing the unplanned and fast urban expansion at the price of natural resources. That was assumed to be conducted through the integration of strategic environmental assessment and coastal zone management in the urban planning process in Egypt.

Keywords: *Cellular Automata; urban growth simulation; land-use/cover change detection; land suitability analysis; strategic environmental assessment; sustainable development; Coastal Zone Management*

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AHP	Analytic Hierarchy Process
CA	Cellular Automata
CI	Consistency Index
CR	Consistency Ratio
CZM	Coastal Zone Management
DEM	Digital Elevation Model
DOS	Dark Object Subtraction
EA	Environmental Assessment
EEAA	Egyptian Environmental Affairs Agency
EIA	Environmental Impact Assessment
ESP	Environmental Sector Program
FLAASH	Fast Line-of-sight Atmospheric Analysis of Hypercubes
GCP	Ground Control Point
GDP	Gross Domestic Product
GIS	Geographic Information System
GO	Governmental Organization
GOPP	General Organization for Physical Planning
GSA	Global Sensitivity Analysis
ICZM	Integrated Coastal Zone Management
IWRM	Integrated Water Resources Management
LSA	Land Suitability Analysis
LULC	Land Use Land Cover
MADM	Multi-Attribute Decision Making
MCDA	Multiple Criteria Decision Analysis
MCDM	Multiple Criteria Decision Making
MCE	Multi-Criteria Evaluation
MLC	Maximum Likelihood Classifier
MODM	Multi-Objective Decision Making

MSEA	Ministry of State for Environmental Affairs
NGO	Non-Governmental Organization
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
PA	Percentage of Agreement
PCA	Principle Component Analysis
PSS	Planning Support System
RI	Random Index
RMSE	Root Mean Square Error
RS	Remote Sensing
SDSS	Spatial Decision Support System
SEA	Strategic Environmental Assessment
SUPs	Strategic Urban Plans
SUPSCP	Strategic Urban Plans for Small Cities Project
SDUPECP	Strategic and Detailed Urban Plans for the Egyptian Cities Project
SVM	Support Vector Machine
TCT	Tasseled Cap Transformation
UA-SA	Uncertainty Analysis – Sensitivity Analysis
USGS	United States Geologic Survey
UTM	Universal Transverse Mercator coordinate system
V-I-S	Vegetation-Impervious Surface-Soil
WLC	Weighted Linear Combination

1. CHAPTER ONE: INTRODUCTION

Over years, the Mediterranean coastline, particular Egypt, has attracted the population by providing accommodation -living space- which has encouraged the spread and development of economic activities along the coastal zones. The growing human population increases demands on the coastal zone resources and for living space, leisure and recreation, host of accommodation, tourism… etc. Noticeably, coastal urbanization in the Mediterranean basin is severely increasing. The population of the coastal regions of the north rim of the Mediterranean basin is expected to increase by (2.1 million) to be (53.3 million) for the year 2025. Also, for the south and east rim, it is expected to increase by (29.2 million) to be (77.8 million) for the year 2025. Also, for the south and east rim, it is expected to increase by (29.2 million) to be (77.8 million) for the year 2025 (Attané and Courbage, 2001). Uncontrolled and unplanned urban growth is one of the most important factors lead to drastic changes in land use/cover in the world. Accordingly, there are many endeavors to predict potential change by designing models could simulate the future of land-use practices and changes according to the different variables.

Currently, and in the light of the absence of adequate sustainable management approaches, lack of legislation and an effective framework for coastal zone management, the coastal cities of Egypt suffer from severe environmental threats. Although Egypt has signed and rectified the Barcelona Convention[1] ; so far there is no adopted and successful strategic Integrated Coastal Zone Management (ICZM) plan to deal with coastal issues (González-Riancho *et al.*, 2009; Ibrahim and Shaw, 2012).

1.1. Urban Sprawl in the coastal cities of Egypt

Given the outstanding location of the coastal zones, coastal zones have been treated as a destination for urbanization and civilization basis. Because of the abundance of; materials, trade, shipping, fish, tourism, food resources …etc., coastal areas became ideal locations for anthropogenic activities. Which in turn, severely increased urban development practices have risen. All aforementioned activities put these sensitive

[1] Barcelona Convention: In 1975, 16 Mediterranean countries and the European Community adopted the Mediterranean Action Plan (MAP), the first-ever Regional Seas Program under UNEP's umbrella. In 1976 these Parties adopted the Convention for the Protection of the Mediterranean Sea Against Pollution

habitats of these areas under pressure and risk of pollution, along with a multitude of negative consequences on social, economic, and ecological factors. The main human activities take place in the narrow strip of the coastal zone; e.g. industry, agriculture, urbanization, energy production, oil industry, fisheries and aquaculture, tourism and recreation areas. These activities to a high extent are conflicting among each other searching for space and resources from one hand, and with the sensitive environment from the other hand. That needs to formulate and enforce suitable legislation instruments and strategies.

On the northwest coast of Egypt, including the Alexandria governorate, most of the local settlements and economic activities are located within the first 10 km landward of the coastline. By the means of different analysis methods; e.g. mental models, semi-structured interviews based on questionnaires for public experts, stakeholders, and literature review, 18 coastal issues that influence the development were identified as shown in table (1-1) and were categorized under main four items. These issues must come on top of any ICZM or sustainable and strategic urban development plans.

Table 1-1: Key issues in the coastal areas in the Egyptian context
Source: Author based on (EEAA, 1999; EEAA/ESP, 2008; MSEA, 2009)

Item	Key-issues	Item	Key-issues
Urban development	Uncontrolled urban expansion	Natural risk	Coastal erosion
	Shoreline exploitation		
	Razing agricultural land		
	Transportation network		Climate change and Sea Level Rise
	Informal settlements		
	Water bodies shrinkage		
Economic development	Agriculture	Governance & environmental management	Salt pans and wetlands
	Fisheries and aquaculture		Administrative coordination
	Industry		Capacity building
	Salt pans		Stakeholders involvement
	International tourism		Wastewater management

Economically, coastal zones are perceived as highly valuable areas as they greatly contribute to the Gross Domestic Production (GDP) and the national income of the country due to the activities carried in these areas. Therefore, it was urgent to confirm and promote ICZM policies to ensure sustainable development of the Egyptian coastal areas responding to the aforementioned challenges, on one hand, caused by internal pressures, and on the other hand by the external pressure represented by the World Bank and other international donors (Ibrahim and Shaw, 2012). ICZM has been defined as "*a dynamic process for the sustainable management and use of coastal zones, considering at the same time the fragility of coastal ecosystems and landscapes, the diversity of activities and uses, their interactions, the maritime orientation of certain activities and uses and their impact on both the marine and land parts*" (UNEP, MAP, PAP, 2001). It worthy mention, on the international scale, ICZM is highly promoted to be utilized as a tool for sustainable development for the coastal areas, along with spatial planning (Osthorst and Lange, 2007; González-Riancho *et al.*, 2007). The planning process for the coastal areas in Egypt used to be in ministerial and governorate levels with the absence of local communities, civil societies, and public participation, resulting in unsustainable urban development

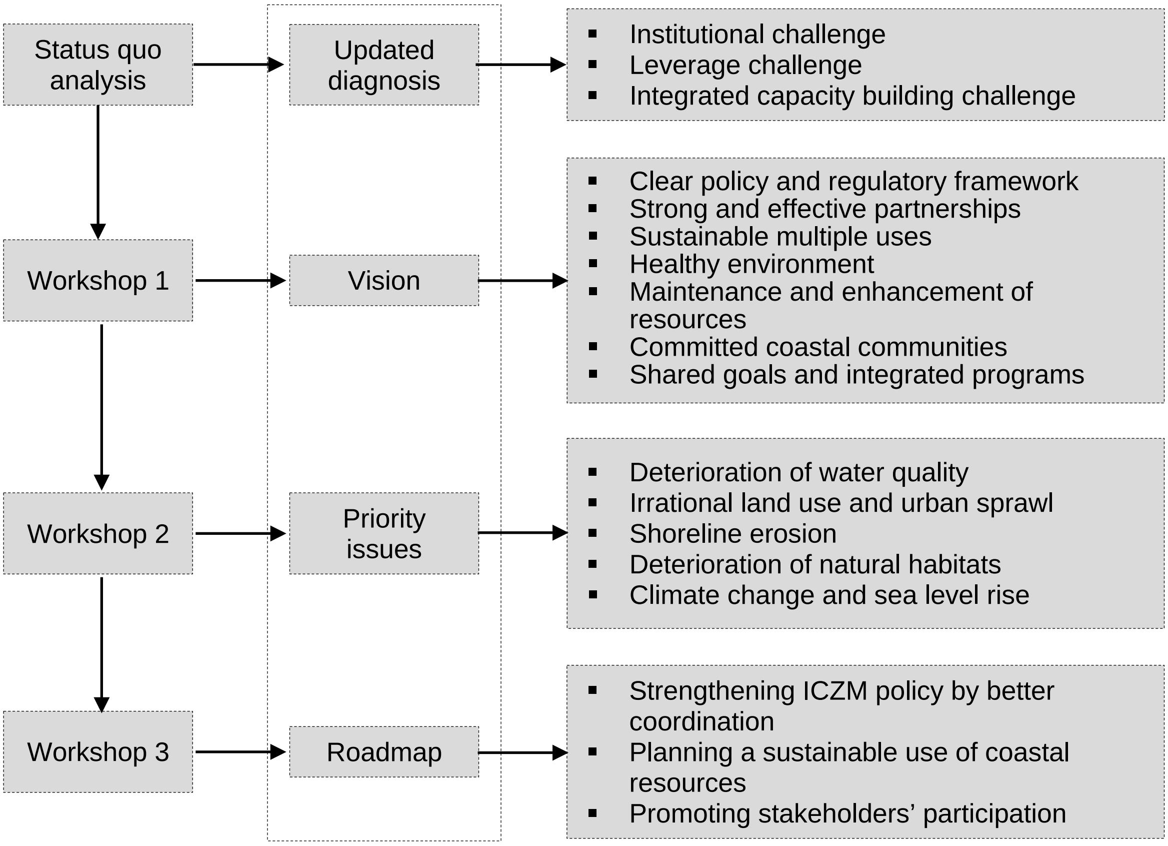


Figure 1-1: Steps of building an ICZM strategy for Egypt
Source: (EEAA/ESP 2008)

(PAP/RAC - EEAA, 2009; EEAA/MAP, 2005; EEAA/ESP, 2008).

To build a consensus regarding coastal issues, three workshops on a national scale have been organized (Attané and Courbage, 2001). The main outcomes of these three workshops were indicated in the figure (1-1). In the third workshop, the National Committee for Integrated Coastal Zone Management (NCICZM) set three main items as a roadmap: Strengthening the ICZM policy by better policy coordination, planning a sustainable use of coastal resources, and Promoting the awareness of stakeholders (EEAA/ESP, 2008). Strengthening ICZM policy by better policy coordination: by the commitment and integrated decision making of coastal policies in the planning stages, should be highlighted. That could be achieved by horizontal coordination between considered stakeholders; GO and especially that involved in the decision making process, NGO, different sectors and civil society. Planning a sustainable use of coastal resources: to ensuring sustainable use of natural resources, it is important to coordinate and enact ICZM plans applied on national, regional, and local scales and based on concrete statistics. Promoting stakeholders' awareness: by raising awareness among the whole players of the coastal areas, it will derive them to understand the value of the coastal areas and its irreversible resources. So that they can proactively react and effectively involved in long/short-term goals related to coastal zones development. Hence, all stakeholders will be aware of any further coastal development, involved effective coordination and data sharing and dissemination of the guidelines of the coastal management practices and lessons learned and highly capacity building among the individuals at all levels (Attané and Courbage, 2001; MSEA, 2009).

Table 1-2: ICZM initiatives, activities, and projects in Egypt on national and local scales
Source: Author based on (Ibrahim and Shaw, 2012; Ibrahim, 2013)

Phases	Level	Projects & Initiatives	Date
First phase (1995-2005)	National Level	Setting up the National Committee for ICZM (NCICZM)	Setup in 1995 Stop working in 2001
		Preparing a national ICZM framework	Prepared in 1996
	Local Level	FUKA-Matrouh Coastal Area Management Programme (CAMP).	Started in 1993 Completed in 1999
		Red Sea Coastal and Marine Resource Management programme (RSCMRMP).	Started in 1994 Completed 2002
Second phase (2005 – present)	National Level	Re-establishing the NCICZM.	Re-established in 2007
		The new environmental regulations (Law 9/2009).	Enacted in 2009
		Preparing the National ICZM Strategy for Egypt.	Started in 2008 Not yet completed
	Local Level	Alexandria Lake Mariute Integrated Management (ALAMIM).	Started in 2006 Completed in 2009
		Plan of action for an ICZM in the area of Port Said.	Started in 2006 Completed in 2009
		ICZM between Matrouh and El Sallum (MSICZMP).	Started in 2006 stopped end of 2007 Not yet completed, (2009-2012)

As indicated in the table (1-2), starting from the middle of the 1990s, there were a series of attempts to promote ICZM policies aiming at the adoption of a national ICZM strategy for Egypt. ICZM initiatives have been started on local and national scales. The main objectives of the ICZM projects and initiatives were to establish a National Committee for integrated Coastal Zone Management (NCICZM) and a framework for ICZM. As a result, two projects have been implemented: Fuka-Matrouh Coastal Area Management Program (CAMP) and the Red Sea Coastal and Marine Resource Management program (RSCMRMP).

The coastline of the Red Sea is rich in a diverse range of ecosystems, mangroves, dunes, estuaries, and coastal forests. Lack of strong protection mechanism for the coast originates from unplanned urban development, intensive pressure from industries, coastal erosion and flooding, urban and tourist development, conflicts over resource uses and uncontrolled use of the natural resources in absence of the environmental laws enforcements (EEAA/MAP, 2005). Therefore, the contracting agencies for RSCMRMP implementation agreed to set back the zone which limits the development to 200 meters landwards, according to decree in 1984, through the Shoreline Protection Authority and the Red Sea Governorate provide any construction and development license. Also, the Tourism Development Agency and local Red Sea governorate were given the responsibility to issue licenses for developments independently. In 2006, Shore Protection High Committee was created. This agency consists of representatives from the three central government agencies and local governorates and is empowered to grant or refuse licenses in the setback zone. However, overlapping legal responsibilities, without effective mechanisms for coordinated action within the setback zone, led to unsatisfying results (Ibrahim and Shaw 2012; Abu-Zeid et al. 2011; EEAA/ESP 2008).

The termination of the Fuka-Matrouh pilot project in 1996 revealed that implementing ICZM in Egypt is still confronted with overarching governance challenges (Ibrahim and Shaw, 2012). Yet, the outcomes of pilot projects like Fuka-Matrouh, combined with the government’s recognition and support of the concept of ICZM, as evidenced by the 2009 amendments to Law 4, have created an environment favorable to the pursuit of ICZM programs.

In 2007 the NCICZM was officially established. It consists of 13 ministerial bodies and the Egyptian Environmental Affairs Agency (EEAA) was given the responsibility to lead the committee and initiate the ICZM projects. On a later stage, in 2009, EEAA amended the environmental law NO. 4 for the year 1994, giving the EEAA the power to approve or refuse projects in the coastal zone based on the results of Environmental Impact Assessment (EIA) studies. Then three projects on the local scale have been implemented: Alexandria Lake Mariute Integrated Management (ALAMIM), the action plan for an ICZM in the area of Port Said, and ICZM between Matrouh and El Sallum (MSICZMP) (Ibrahim and Shaw, 2012; MSEA, 2009).

In Port Said ICZM project, there was no integration of all concerned agencies on a national scale. The EEAA, the main stakeholder in ICZM in Egypt, and the regional office of the Shoreline Protection Agency, for example, didn’t participate in this project. Also, the focus of the project didn’t cover the main issues and threats faced in that area like urban sprawl, construction of new infrastructure (new highway) and overuse of the productive lands. The project considered only irrigation and agricultural run-off issues. However, Port Said offers considerable opportunities and capacity for tourism development in terms of its physical, environmental, natural, historical and cultural resources; the ICZM project also ignored these potentialities and issues. Even the strategic plan set by the General Organization for Physical Planning wasn’t involved in the project (Abdelwahab 2009; El-Kady et al. 2008). Regarding the project MSICZMP, it was implemented on a local level but without real participation from and coordination with the local stakeholders (Ibrahim and Shaw, 2012; EEAA 2009). The same applies to Alexandria and Port Said projects.

ALAMIM project is one of the eight Regional Projects financed by the European Commission’s Short- and Medium-Term Environmental Action Program SMAP III [2] around the Mediterranean in the light of the rapid deterioration of this sensitive area (AICZMP 2009). The reason for the geographic scope for the formulation of ICZM plans on the Mediterranean is due to the urgency of short-term impacts that are likely to result in the flooding of 16 km^2 of three of the coastal lagoons in the Nile Delta by 2020/2025 (Ibrahim and Shaw, 2012). The Draft of National ICZM Strategy, which already identified a set of priorities for coastal management, importantly dedicated to evaluating the impacts of the urban growth on the coastal zone.

[2] SMAP III promotes sustainable development and supports high priority environmental related activities, through technical and financial assistance for Algeria, Egypt, Jordan, Lebanon, Morocco, Occupied Palestinian Territory, Syria, Tunisia, Turkey, Timeframe: 2005-2008 with Budget of €15 million (MEDA)

In the last three centuries, around 1.2 million km^2 of woodland and forest, and around 5.6 million km^2 of pastures and grasslands have been converted to other land uses (Agarwal *et al.*, 2002). So, increasing urban population and urban expansion have direct effects on the changes in the land-use patterns and land cover. Therefore, there were many endeavors to predict the changes in land use through designing simulation land-use models aiming at predicting the future land use/cover transformation under various scenarios and variables (Agarwal *et al.*, 2002). However, monitoring urban growth is challenging in developing countries. In developing countries, access to the data is extremely difficult even if it is only for research purposes (Masek et al., 2000). Even if the data are available, in most cases, it is not accurate enough to be used in concise studies (Barreira-González *et al.*, 2015). In that context, arises the usefulness and importance of the urban simulation tools which indeed helps in understanding the driving forces and process of urban growth. These urban growth simulation models can reproduce past land-use dynamics and future evolution of urban growth in the future (Batisani and Yarnal, 2009a; Barreira-González *et al.*, 2015), not only that but also assess the impacts of these land use and urban changes on the landscape and environment (Cheng and Masser, 2016; Brown, 2006; Al-Gaadi *et al.*, 2011).

To cope with the aforementioned challenges, it is of a great importance to have Information provision and spatial data integration; whether qualitative or quantitative dataset need to be created in every sector and organization of planning to be used in different planning contexts, to avoid the silo mentality through linkage and share with other exiting public or private data sets. In the developing countries, data sharing, and availability still exists whether on the macro or micro scales due to security and confidentiality issues (Bowen and Riley, 2003). So, proliferation of spatial datasets and sources relevant for urban planning is very beneficial, however, fragmentation of datasets, lack of harmonization, gaps in availability, and duplication of the information make it very difficult to access and use the data (El-Asmar *et al.*, 2015; Pickaver *et al.*, 2004). One of the successful examples to handle these problems was ‘Infrastructure for Spatial Information in Europe _ INSPIRE’ initiative which aimed to stimulate the creation of the European spatial information infrastructure from the local to the global level in an interoperable way for a variety of uses and users including citizens, planners and designers, academics, managers, and policymakers who are required to understand the cities and also to get detailed information regarding socioeconomic data which are required in the development plans preparation (Sanò *et al.*, 2010; Taussik, 2007; Sanò *et al.*, 2007).

1.2. Problem Statement

In light of this increased population and rapid industrial, agricultural, and touristic development, the conflict over coastal resources and land among different users is also increasing. The coastal area is in turn suffering from an uncontrolled urban expansion and informal settlement, shoreline exploitation, destruction of agricultural land, shrinkage of freshwater bodies, fisheries and aquaculture, increased pollution, touristic development, industrial pollution, the rise of the sea level and coastal erosion. These negative impacts are not only affecting the environment, but also the national and local economy and human beings. Loss and destruction of the croplands and natural resources; e.g. water bodies is a matter of global concern and threatening food security in Egypt (Abou-Korin, 2014b; Linard *et al.*, 2013; Mohammadi *et al.*, 2013). Encroachment of urban growth on the cultivated land and water bodies can cause degradation of the land productivity in the Nile Delta area causing food security problems and natural resources deterioration, due to the inefficient national development policies (Khalifa, 2011). Besides, demographic growth can pose pressure on the inhabited areas to decrease the per capita area from 0.12 ha in the year 1950 to 0.06 ha in the year 1990 (Khalifa, 2012). The surface area of Egypt is about one million Km^2, 95% of its area is desert and uninhabited lands. The entire population of about 95 million are mainly living and concentrated around the Nile River and Delta, which is a really unbalanced distribution (Khalifa, 2015; Khalifa and Connelly, 2009; Mohamed *et al.*, 2017; Nassar and Elsayed, 2018). Figure (1-2) shows the interplay of urban development and the associated environmental problems.

Random and unplanned urban development cause increasing the informal settlement mass in Egypt. The focus of the government or the planning authorities only was on the development of satellite cities in the desert and with no attention paid to dealing with the informal settlements in the cities and rural areas in the Nile Delta and valley. The direct implication lies in the burdens of the poor urban quality environment. Air pollution wastewater and drinking water quality deterioration are the major problems in urban cities all over Egypt. In that essence since the 1980s, and to decrease the pressure on the croplands, the government has initiated urban development plans aiming at redistributing the population in the vast space of desert and fringes of the Nile Delta through action plans enhancing the urban expansion.

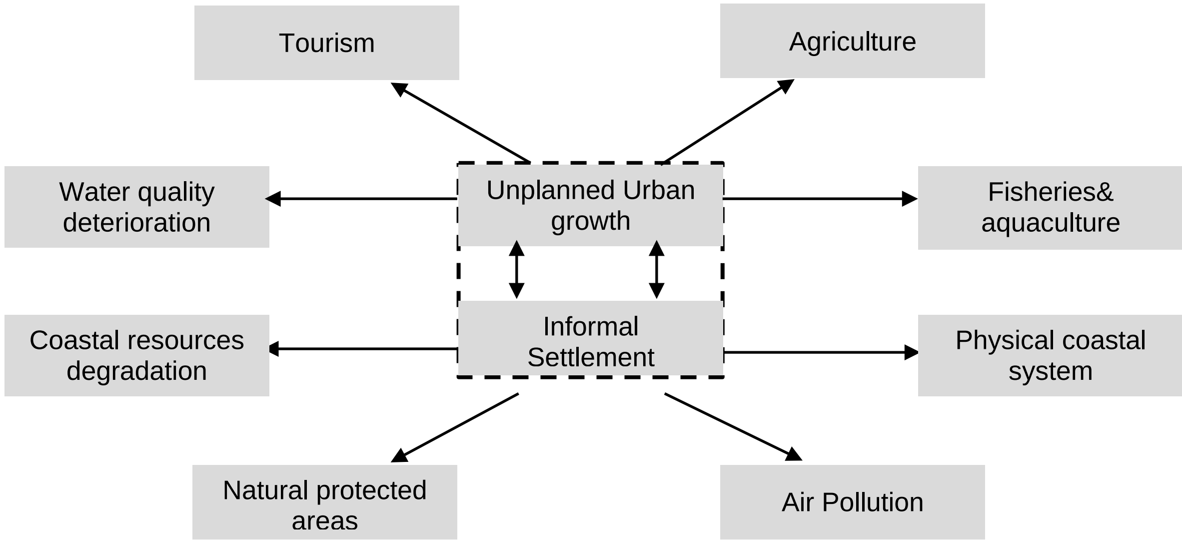


Figure 1-2: Interplay of the urban development activities
Source: Author

46.5% of the population is still living in unplanned high-density areas, with poor streets and road conditions and lack of community services and utilities; e.g. unpaved streets, inadequate access to healthcare, education and community facilities. As an attempt to solve the problematic issue of what counts slums, the Informal Settlement Development Facility (ISDF), since its establishment by a presidential Decree # 305/2008, has made a substantial change in the Egyptian vocabulary by replacing the term "Slums" or "Informal Settlements" or "Ashwa'iyyat" by two distinctive terms; "Unsafe Areas" and "Unplanned areas". Unsafe areas are characterized by being subject to life threat, or having inappropriate housing, or exposed to health threat or tenure risks, while unplanned areas are principally characterized by its noncompliance to planning and building laws and regulations (Khalifa, 2011; Hegazy, 2015a; Hassan, 2012; Khalifa and Connelly, 2009; AFD, 2015). Accordingly, information and determination of the trends and rates of land cover changes are necessary for the planners and decision-makers enabling them to develop rational urban development and land-use policies. Remote sensing and GIS can play a vital rule in that process by the means of multi-temporal Landsat satellite imageries (Mukhtar *et al.*, 2013; Abd El-Kawy *et al.*, 2011; Al-Ahmadi and Hames, 2009; Alesheikh *et al.*, 2007; Andrews *et al.*, 2002).

1.3. Research Objectives

The main objective of the current PhD research is to develop a Cellular Automata-based model to be used in urban growth modeling and simulation for various growth scenarios under different variables aiming at introducing a tool to decision-makers and planners used in the preparation of regional development plans for the governorate of Alexandria. Besides, develop a planning process that is justifiable and sound across other Mediterranean coastal cities in Egypt within the environmentally appropriate planning framework. In the following section, the main objectives and sub-objectives are discussed, based on which each step methodology for the research was developed:

Sub-objective 1- is to conduct Land Use/Cover (LULC) Change Detection:

Is to use GIS and remote sensing technologies through the utilization of satellite imageries for the last three decades to investigate the change in land cover from one hand. Then highlighting whether there are disparities between land-use practices and the laws and policies used for governing the coastal cities of Egypt or not need to be conducted. The projects, initiatives, policies, and legislations implemented so far were investigated for the governance of the coastal zones.

Sub-objective 2- is to conduct Land Suitability Analysis:

The main objective of this part of methodology is to investigate the optimal/suitable locations new residential development in Alexandria governorate using Multiple Criteria Decision Making (MCDM) method throughout integration of two techniques; Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC) in the environment of the ArcGIS, to improve the process of planning and decision making.

Sub-objective 3- is to conduct urban growth simulation and prediction:

The main objective of this part of the research is to develop, calibrate and validate the CA-based model to simulate the urban sprawl in the Alexandria governorate. Furthermore, to predict urban growth for the year 2032 under five different scenarios and figure out which of the simulated scenarios correspond best to the objectives of ICZM and sustainable development in the light of the “Participatory strategic urban planning for Alexandria city till 2032”. Also, to identify the areas which would be mostly influenced by urbanization and investigate the current and simulate future trends of urban growth of the city.

Sub-objective 4- is to propose a Participatory planning approach:

- The fundamental objective of this part is to propose a SEA and ICZM tool assisting in the planning support system/decision-making process to be integrated into the urban planning system to achieve sustainable urban development in the coastal cities in Egypt.
- To formulate policy aims at controlling and managing urban development
- Developing a generic decision-making model for designing SEA/ICZM that could guide in the Egyptian context

1.4. Research Questions

Concerning the research objectives, the author has prepared questions which was answered at the end of the current study:

- What are the barriers to implementing ICZM and sustained urban development for the Mediterranean coastal cities of Egypt?
- How the experts' knowledge, decision-makers' preferences, and consider socio-economic and environmental factors are integrated into the PSS framework?
- How coupled GIS, Remote Sensing, and urban models participate in better conducting ICZM and urban development planning?
- How geospatial models and MCDM can tell suitable and optimal land uses for future urban development?
- How the SEA/ICZM system can be integrated into the Egyptian planning policies?

1.5. Thesis Structure

In the essence of the aforementioned issues, it could be concluded that the interface between socioeconomic activities, urban development management, environmental change and degradation as fundamental issues of ICZM, are remarked neither in the Egyptian action plans nor understood by the decision-makers. Accordingly, it is urgent to create a geospatial database for the coastal areas and cities, formulate urban development management and control strategies, identify environmentally suitable locations for further development, and finally formulate a participative approach able to effectively manage coastal cities and spatial planning in an ongoing basis. Figure (1-3) shows the general flow of the proposed methodology.

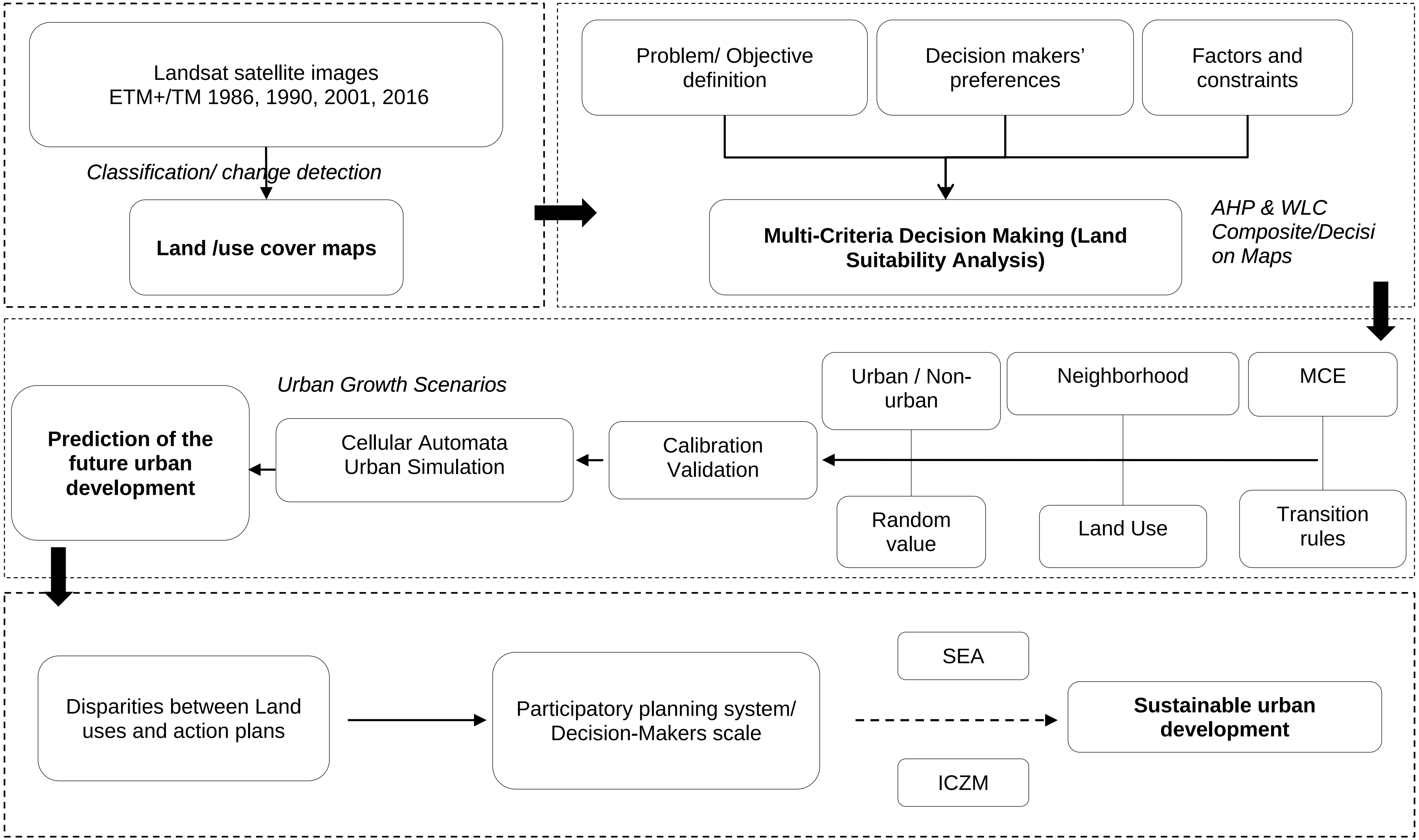


Figure 1-3: General flow of the PhD research methodology and context
Source: Author

2. CHAPTER TWO: THEORETICAL PRINCIPLES

2.1. Background

Land is considered as a finite and irreversible resource and sustainable management and spatial planning of land resources is of great importance in the light of uncontrolled rapid urban growth and conflict among different land users. Therefore, land-use planning must consider the various social interests and preferences to justify the measures in such complex multi-dimensional land uses (AbdeL-Latif *et al.*, 2012; Abd-Alah, 1999). There is a historical and on-going conflicting relationship between environmental protection and economic activities and development. These two topics were put on the top of the planning agenda on all scales. In that essence, the term “sustainable development” was introduced in the Brundtland Commission in the year 1987, formally known as the World Commission on Environment and Development (WCED) (Vojnovic, 2014). Also, sustainable land resources management gained the world’s attention since 1992 in the United Nations Conference on Environment and Development. So, land resources, land uses, and land planning are considered important substantial components for sustainability analysis and evaluation (Drexhage and Murphy, 2010).

Various land uses in the coastal cities were systematically classified into seaports, shipping (carriers, routes, navigation aids), sea pipelines and cables, natural biological resources, renewable energy, recreation, waste disposals, research, archaeology, environmental preservation, and protected areas, urban, agriculture, wetlands, lagoons, river mouths, fisheries, salt pans and salt marshes…etc (Comber, 2008). The aforementioned uses were further sub-classified into around 250 uses; all are competing for space, available land, resources and absorption capacity of the resulted waste ignoring the environmental aspects. These uses have a spatial aspect which makes the process of coastal cities management a spatial problem and a spatial management problem. Hence, an appropriate spatial planning tool is, in turn, required to resolve the conflict among these various uses, minimize the likelihood of the conflicting interests, and keep the spatial compactness and contiguity of the urban development planning in the coastal cities and the land resources. It is now believed that land use planning is a process of decision-making in which it is important to ensure the best use of land resources and allocation (Hersperger *et al.*, 2018; Weiland, 2010; Tulu, 2014).

2.2. Analysis of land-use changes by using GIS and remote sensing

As indicated in the figure (2-1), a wide range of human driving forces, including; social, economic, political, and cultural variables can determine the patterns of land use and hence on land cover (Bürgi *et al.*, 2005). Any changes in land use/cover can have strong impacts on local, regional, and global environments, which can cause climate change, changes in atmospheric chemistry, hydrology, water quality and even quantity, soil condition, and ecological complexity…etc. these environmental changes, in turn, may have feedback effects on land use/cover, and also human driving forces and activities (Hassan *et al.*, 2016). Continual, historical, and precise geospatial data about LULC changes of the Earth's surface is extremely important for any kind of sustainable development program, in which LULC serves as one of the most important and major input criteria (Stephenne *et al.*, 2016). Water and land resources are the basic need and livelihoods source of human beings. Given unplanned urban development existing in developing countries, overexploitation of the environmental resources, and misuse of the land resources, they are under severe pressure, declining and degradation. Therefore, monitoring the natural resources changes, fast intervention for environmental and natural resources rehabilitation and sustainable decision-making process are very urgent actions at the time being for any further sustainable management and planning activities (Abd El-Kawy *et al.*, 2011; Rodríguez *et al.*, 2009; Van Zuidam *et al.*, 1998).

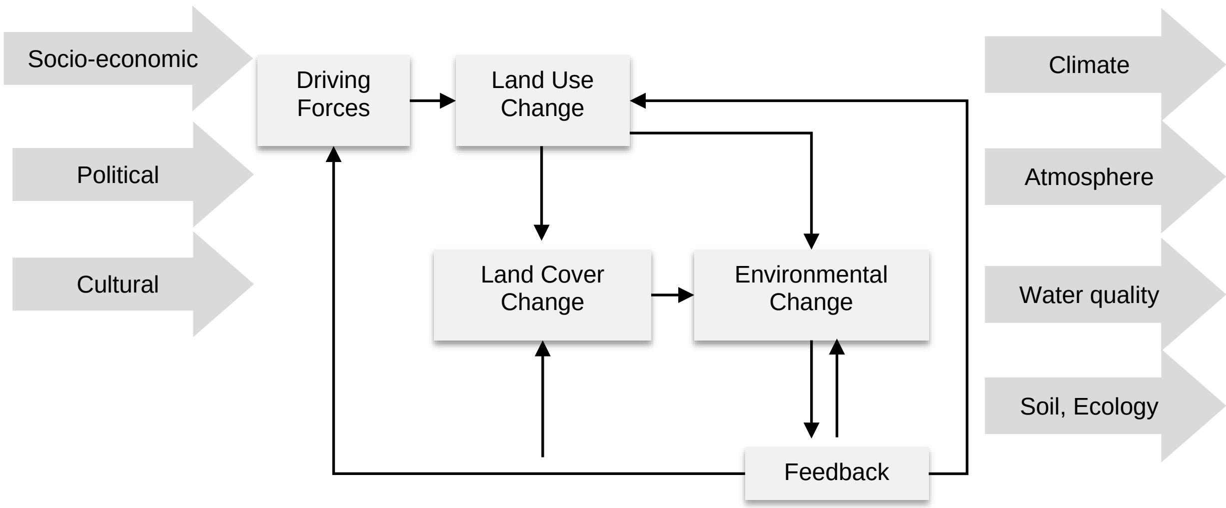


Figure 2-1: Interaction between driving forces, land-use changes, and environment

GIS and remote sensing are one of the most advanced technologies utilized efficiently to track land cover change (Al-Ahmadi and Hames, 2009; Rawat and Kumar, 2015; Al-Gaadi *et al.*, 2011; Kamusoko *et al.*, 2014; Masria *et al.*, 2015; Mukhtar *et al.*, 2013; Rawat and Kumar, 2015; Kira Gee *et al.*, 2004). This technology is characterized by its ability to provide abundant information on the Earth and play an important role in the continuous monitoring of the Earth and its various natural resources (El-Asmar *et al.*, 2014; Motevalli *et al.*, 2012; Charlier and Bologa, 2000). Satellite imageries in that essence are vitally important (Yuan *et al.*, 2005; El-Asmar *et al.*, 2014). These images can help to produce both the paper and digital types and also utilized in the analysis and monitoring of the spatial distribution of terrestrial phenomena on a large scale. These are also used to study the rapidly changing phenomena, urban growth for instance, temporally and spatially (Iqbal and Khan, 2014; Motevalli *et al.*, 2012).

In the literature, various methods and techniques were efficiently used for land features extractions; e.g. pixel-based (supervised and unsupervised) as in (Abd El-Kawy *et al.*, 2011; Al-Ahmadi and Hames, 2009; Alesheikh *et al.*, 2007; Masria *et al.*, 2015) and sub-pixel-based methods (gives information about different classes within a pixel - Multiple End-member Spectral Mixture Analysis - MESMA) as in (Eckmann *et al.*, 2008; Salih *et al.*, 2017; Singh and Singh, 2018). It is worthy to mention that GIS and remote sensing were used in the process of coastal zone management (Fabbri, 1998; Gangai and Ramachandran, 2010; Areizaga et al., 2012; Bell et al., 2013; Billé and Rochette, 2015; Masria et al., 2014; Sanò et al., 2010) with a strongly integration of the spatial dimension (Tabet and Fanning, 2012; Taussik, 2007). GIS and remote sensing also can be used to develop spatial models used in the prediction of the urban and spatial changes in the coastal cities; e.g. shoreline erosion/accretion, evolution, coastal dune evolution…etc. (Rodríguez *et al.*, 2009; Andrews *et al.*, 2002).

2.3. Planning Support System

As (Geertman and Stillwell, 2009) declared in their book, the computer-based support systems developed by researchers were adopted and widely used, however, still need to be more involved and implemented within the planning practices and policy-making (Geneletti, 2008; Ghavami *et al.*, 2016; Gigović *et al.*, 2016). Since the mid of the 90s, the concept of Planning Support System (PSS) came to the scene as a geotechnical instrument capable of improving and supporting the performance of specific planning tasks (Hopkins, 1999). PSS was regarded as a different tool not related to GIS, which is a tool only for capturing, manipulating, storing, analyzing, and visualizing the referenced spatial data, unlike PSS which focuses only on the supporting specific planning tasks (Van Niekerk *et al.*, 2016; Dragan *et al.*, 2003;

Ferretti and Pomarico, 2013). There is no fixed definition for PSS (Geertman, 2003), while, Stan Geertman and John Stillwell (2009) regarded PSS as "*a combination of planning-related information, theory, data, methods, knowledge, and instruments which are regarded as integrated framework with a shared graphical user interface*" which in turn enabling the planner to handle the complex planning process (Schetke *et al.*, 2012). It was agreed that a single PSS consists of three main sets: a) data assembly and information, b) models and methods, c) results' visualization (Russo *et al.*, 2018). GIS or/and computer-based models can be integrated with PSS and utilized as an effective instrument providing predictions to certain points in the future and produce some estimations of the impacts which resulting from sorts of urban development (Jankowski *et al.*, 2014; Geneletti, 2008). According to the state-of-the-art, PSS was not widely used and implemented due to some obstacles '*bottlenecks*' which are hindering usage and implementing PSS (Klosterman, 1995, 1997; Geertman and Stillwell, 2009). These obstacles were categorized under three approaches named: instrumental approach, user approach, and transfer approach, as summarized in figure (2-2) (Pettit *et al.*, 2018; Vonk *et al.*, 2016).

The instrumental approach deals with the appropriateness of the instrumental quality used. The quality here means how well the instruments capable of carrying out the planning tasks (Pettit *et al.*, 2018). (Vonk, 2006; Geertman and Stillwell, 2009) indicated that there is a fundamental dichotomy between the PSS demanded by the potential users and PSS supplied by the system developers based on their different perceptions. The planning practices require simple and straightforward PSS for explanatory tasks, which is acceptable instrumental quality. Nevertheless, the majority of the PSS developed focuses on analytical tasks including complicated modeling and predictions, which are considered a poor match (Vonk, 2006). Figure (2-2) also shows the bottlenecks hinder matching the appropriate instrumental quality for the planning practices and tasks.

The user approach elaborates on to what extent the users can accept PSS (Guido A. Vonk, 2006). This approach focuses on the users' characteristics which indicate the acceptance of PSS. (Bach *et al.*, 2016; Dulcic *et al.*, 2012; Wang and Liu, 2005) have used a model called 'Technology Acceptance Model _ TAM' to evaluate the success of the PSS. Figure (2-2) shows too the various obstacles 'bottlenecks' hindering the widespread acceptance of PSS (Geertman and Stillwell, 2009; Zhou, 2011).

The transfer approach clarifies the flow of PSS information from the system developers and among the user's community (Zhou, 2011; Vonk, 2006; Geertman and Stillwell, 2009). In the planning organizations, the flow direction of the PSS is more likely to be bottom-up than top-bottom; that is because the geo-information specialists consider themselves responsible for PSS development and adoption through their working environment (Pettit *et al.*, 2018). Lack of opportunity among geo-specialists to innovate, put them at the bottom resulting in hindering the technology transfer from the external environment to the attention of the top management and planners in the organizations. Figure (2-2) shows the bottlenecks

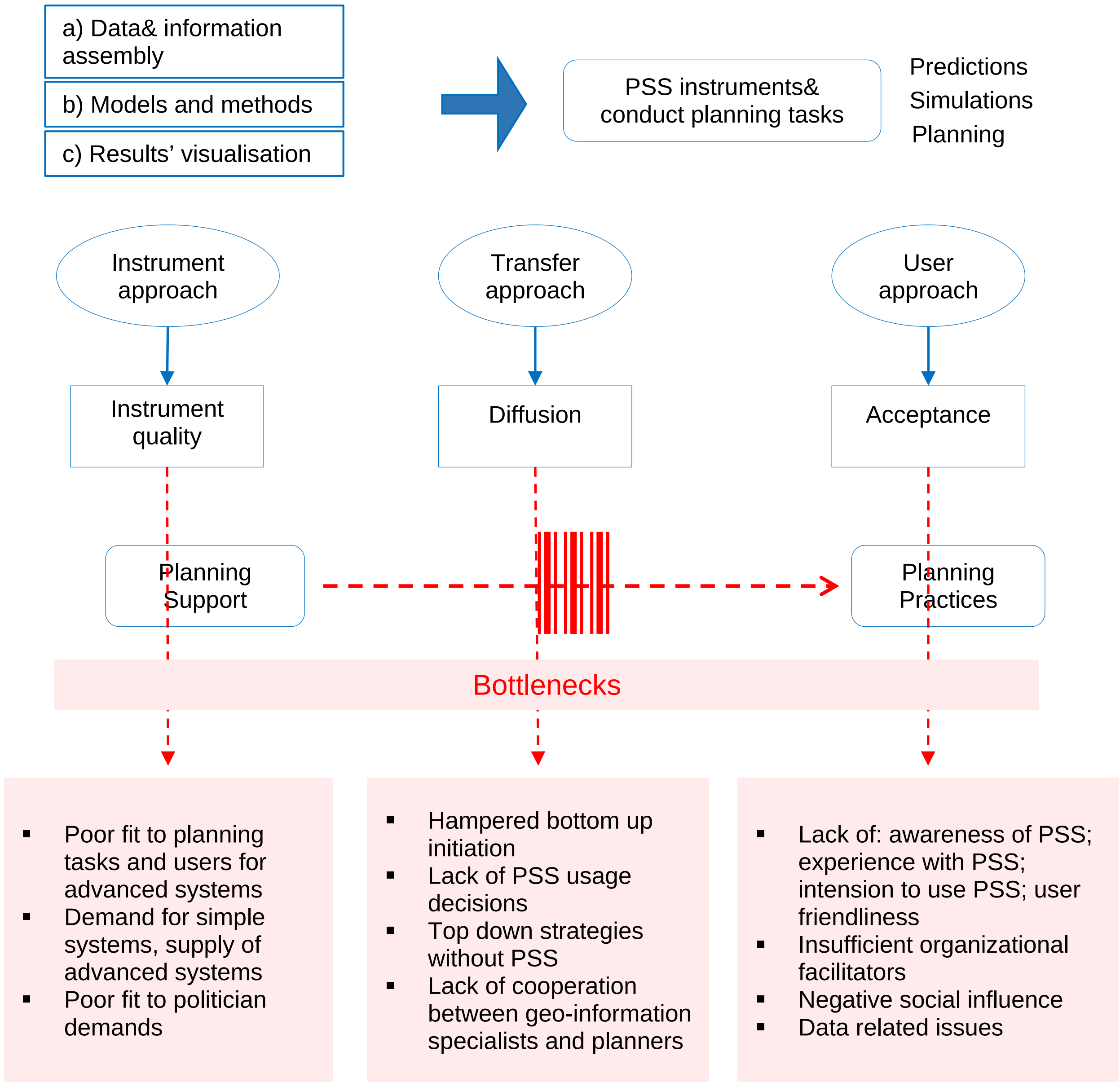


Figure 2-2: Conceptual framework explaining under-use of PSS explains its components, approaches and implementation's bottlenecks
Source: Author based on (Vonk, 2006; Geertman and Stillwell, 2009)

encountering the discrepancy between planners' questions and the geo-specialists offers (Vonk *et al.*, 2016).

To ensure more efficient policies, actions, and strategic planning tools, more interest was paid to involve the public, local communities and stakeholders in the PSS. That is an important ingredient in healthy and democratic planning and development (Horelli, 2013). Hence, in the last decade, new terms were raised; e.g. Participatory Geographic Information System (P-GIS), Public Participation Geographic Information System (PP-GIS), Participatory Planning Support System (P-PSS), or Public Participation Planning Support System (PP-PSS) tools to be used explicitly in the planning contexts and tasks where there is a spatial dimension (Geertman and Stillwell, 2003; Zhou, 2011; Horelli, 2013). These tools are also available online in North America and Europe, but with some shortcomings, for instance, the participants must be very skilled in terms of technology used to deal with it and accept it. Also, problems of representing the people's opinions, believes, perceptions, and value judgements in a PSS and using them in GIS with quantitative spatial data, were raised (Kingston *et al.*, 2003; Geertman and Stillwell, 2009).

The grid computing is considered a good potential for PSS, for example, simulation of mega-events like earthquakes, tsunami, urban growth, modeling of weather events like hurricanes, air pollution monitoring and modeling. It's possible to carry out dozens of thousands of simulations of in record time; e.g. High Performance Computing (HPC) (Pijanowski *et al.*, 2014; Pettit, 2016). In the current study, simulation and prediction of future urban growth scenarios using variance CA-based model for different growth scenarios (Abedini and Azizi, 2016; Jantz *et al.*, 2016a; Serasinghe *et al.*, 2018; Barredo and Demicheli, 2003; Miller, 2003; Barredo and Demicheli, 2003; Osman *et al.*, 2015) and Multi-Criteria Decision Making based on Analytic Hierarchy Process and Weighted Linear Combination in GIS environment for many spatial applications (Abudeif *et al.*, 2015; Comber *et al.*, 2010; Comino *et al.*, 2016; Dragićević *et al.*, 2015; Erener *et al.*, 2016; Geneletti, 2008; Karmakar *et al.*, 2007; Liu *et al.*, 2014; Thinh *et al.*, 2004; Zolekar and Bhagat, 2015) have been employed to study the urban growth simulation and prediction for the area of investigation, as will be explained in more details in the following sections and chapters.

2.4. Multiple Criteria Decision Making - MCDM and GIS

Spatial data is the core of the decision-making process, as it introduces the logic intelligence and the basis for resolving the conflict among various users (Boroushaki and Malczewski, 2010; Abudeif *et al.*, 2015). GIS capabilities can enrich decision-makers with tools for analysis, manipulation, retrieving, and management of the spatially related data. However, it is lacking the ability to incorporate the experts' and decision-makers' preferences (Geertman, 2003; Geertman and Stillwell, 2009; Geneletti, 2008). Therefore, GIS can be regarded as a static tool and can't stand alone for decision support systems (Moeinaddini *et al.*, 2010; Mokarram and Hojati, 2017; Montgomery *et al.*, 2016). For instance, in the site selection analysis, GIS can conduct analyses and state the best site for a certain use, but without any guarantee, that decision-makers will select the same site or not. Subsequently, integration of GIS and Multiple Criteria Decision Making (MCDM) techniques together is considered as an efficient way for rational PSS (Sabaei *et al.*, 2015; MacDonald, 1996; Sharifi and Rodriguez, 2002). MCDM can be classified into two groups, Multi-Attribute Decision Making (MADM) deals with a choice from a small set of discrete and feasible actions, and Multi-Objective Decision Making (MODM) utilized in finding the optimal solution in a set of feasible solutions bounded by a set of constraints (Mateo, 2012). Both MADM and MODM can be utilized in solving probabilistic, deterministic, and fuzzy decision-making processes (Thinh *et al.*, 2004; Mateo, 2012). MCDM could be further categorized into two approaches; compensatory and non-compensatory (Sabaei *et al.*, 2015). The compensatory approach requires cognition and well-informed decision-makers on the priorities and weights of each criterion. Also, this approach assumes that the high performance of one alternative for a set of criteria can compensate for the performance of the same alternative for other criteria (Ferretti and Pomarico, 2013). Contrariwise, the non-compensatory approach assumes that the high score of any criterion doesn't offset the low score of the other criterion for an alternative; i.e. only the alternatives can be compared along set of criteria without exchanging the criteria (Majumder, 2015; Banihabib *et al.*, 2017; Comino *et al.*, 2016).

MCDM can be translated mathematically as follows (Banihabib *et al.*, 2017): assuming that we have a set of alternatives X, these alternatives can be defined as decision variables $X = \{x^k | k = 1,2,3 \dots k\}$. In the GIS environment, these alternatives can be represented by set of pixels or cells in the raster database or points/lines in vector database (Glanville *et al.*, 2014; Mosadeghi *et al.*, 2015). The attributes associated with each pixel for all thematic layers in the database indicate the criteria used for the evaluation process. The set of all pixels in the entire thematic layers for a raster database X, with total pixels x, can be represented mathematically as follows: $X = \{x^1, x^2, x^3 \ldots\ldots x^k\}$, $K = 1,2,3 \ldots K$; pixels represent set of criteria or decision variables I, the pixel k[th] gets value X for criterion I. Likewise, all possible values in whole thematic layers can be represented as follows: $X^k = \{X_1^k, X_2^k \ldots X_i^k\}$; $i = 1,2 \ldots. |$; $\forall X_i^k \in X$; where, X_i^k designates the score of an attribute/thematic map layer, i could be attained by alternative k, subsequently, it can be stated that, X^k is a vector of k number assigned to each cell/pixel/alternative and gather all available information for that alternative (Arabinda, 2003).

There are different methods used in MCDM; e.g. Analytic Hierarchy Process (AHP), Fuzzy-AHP, Weighted Linear Combination (WLC), Compromise Programming (CP) (Geneletti, 2008; Gorsevski *et al.*, 2012; Hajehforooshnia *et al.*, 2011; Hariz *et al.*, 2017; Irfan *et al.*, 2017). CP is mathematical programming dealing with multi-criteria decision problems. CP has been applied widely in the regional planning, water resources development, and generally in the natural resources utilities (Thinh *et al.*, 2004). The basic idea of CP is to identify feasible solutions; these solutions are ordered according to mathematical procedures. Because the ideal solution for any problem is not always feasible, CP is used to conclude one optimal solution satisfies the decision-makers' preferences. Equation (2-1) is used to solve the inherent conflict among the multiple objectives concerning the proposed criteria and ideal solution. Solving the equation represents the closest distance between the objective and its ideal solution.

$$d_j = \frac{|Z_j^* - Z_j|}{|Z_j^* - Z_{*j}|} \qquad \text{Equation (2-1)}$$

Where; d_j is the distance between the objective j and its ideal solution, Z_j^* is the ideal value for the j objective, and Z_{*j} is the lowest value for objective j (Thinh *et al.*, 2004).

Analytic Hierarchy Process (AHP) is one of the widely used MCDM methods which was proposed by Saaty in the year 1980 (Pilehforooshha *et al.*, 2014; Bozdağ *et al.*, 2016; Javadian *et al.*, 2011; Saaty, 1987). AHP is a subjective activity process based on the preferences of decision-makers and experts. The hierarchy structure should be built based on the importance (weights) of criteria to decision-makers (Romano *et al.*, 2015; Sindhu *et al.*, 2017; Rekha *et al.*, 2015; Pontius and Si, 2015; Motlagh and Sayadi, 2015; Mousavi *et al.*, 2015; Musakwa *et al.*, 2017).

Fuzzy AHP method is the extension of Saaty's theory and was widely used by many researchers (Boroushaki and Malczewski, 2008; Mardani *et al.*, 2015; Laarhoven and Pedrycz, 1983; Klosterman, 1997; Yager, 1995; Chang, 1996; Grošelj and Stirn, 2018) and approved sufficient description in the decision-making process (Jiang and Eastman, 2000; Rahman *et al.*, 2013). Fuzzy AHP overcomes the inaccurate judgements or lack of adequate knowledge among decision-makers or experts coming from the uncertainty inherent with using the crisp values (9 points weighting scales of Saaty used in AHP) (Singpurwalla and Booker, 2004; Zoghi *et al.*, 2017; Xu and Zhai, 1992). Fuzzy AHP method computes eigenvectors until the composite final vector is obtained, which means the weights representing the importance of each alternative towards the proposed main goal (Wang *et al.*, 2008; Zhang *et al.*, 2015).

The weighted linear combination (WLC) method or also called additive weighting method and is based mainly on the concept of the weighted average (Pilehforooshha *et al.*, 2014; Jeong and Ramírez-Gómez, 2017; Zoghi *et al.*, 2017; Qiu *et al.*, 2017; Rahman *et al.*, 2012; Abudeif *et al.*, 2015; Chen and Paydar, 2012; Rikalovic *et al.*, 2014). In the WLC, continuous criteria must be standardized to a common range (numeric) and then combined utilizing a weighted average in GIS environment (Saeidi *et al.*, 2017; Sakieh *et al.*, 2015; Soltani *et al.*, 2015; Vettorazzi and Valente, 2016; Tsangaratos *et al.*, 2017). Decision-makers and experts assign the weights (preferences) directly to each attribute map layer. GIS and Idrisi can be used efficiently in the overlay process of the weighted factors to generate the composite/decision/suitability map (Stevens *et al.*, 2013; Hajehforooshnia *et al.*, 2011). This method was implemented in the current study to produce the land suitability maps which were used as an important input in the developed Standalone CA-based model, as explained in detail in the next sections and chapters. Formula (2-2) shows how WLC method works (Zoghi *et al.*, 2017; Rahman *et al.*, 2013; Rahman *et al.*, 2012; Qiu *et al.*, 2017; Abudeif *et al.*, 2015):

$$Suitability\ map = \sum w_i \times x_i \times constraints \qquad \text{Equation (2-2)}$$

Where; w_i are the standardized raster layers and factors, x_i are the weights of the corresponding factors, and $constraints$ are the restricted features.

2.5. Urban Growth Simulation using Cellular Automata model

Sustainable land use and transportation planning require a holistic view of reciprocal interaction between land use and transportation. Transportation networks and the spatial patterns of land-use jointly influence each other over time. Changes to transportation networks, such as the expansion or construction of a new link can influence the location of investment in a location, which in turn influences the demand for travel to and from a location (Iacono et al., 2008; Hunt et al., 2005). Changes in urban land use, transportation, and the environment are usually resulting from actions of different actors; e.g. individuals, households, landlords or firms. This relationship is sometimes referred to as the so-called land-use transportation cycle (Iacono et al., 2008). That's in turn, should be considered in any simulation or prediction of urban growth processes to ensure the planning efficacy and rational decision making.

Changes in the location of activities and the demand for travel is the accessibility to other activities; e.g. work, shopping, domestic, etc. changes in relative accessibility; which is measured by the influence of new infrastructure; e.g. highway or transit station on land markets. As long as the accessibility is usually approximated by some measures; e.g. travel time or distance, then the degree of land market impact is related to the impact of the new transportation link and reduction in travel time. In the models where land and space markets are considered explicitly, these accessibility factors can be important determinants of price. Land use- transportation models and measures of accessibility are incorporated in determining the activities or new locations. Accessibility is calculated via the regional transportation network and any changes to the travel network will have an impact on the location accessibility (Iacono et al., 2008).

Numeric and CA-based models are very vital analysis tools for planners working in the fields of transportation and land use simulation and prediction. By the means of urban land-use–transport interaction, it is possible to predict changes to transportation and land use systems as the result of policy measures and under various frameworks. This is exactly the strength of microscopic models such as ILUMASS. Other models such as ITLUP, MEPLAN, TRANUS, MUSSA, NYMTC-LUM, and UrbanSim are capable of their representations of physical systems and decision-making processes including the following most important components: population, firms, residential mobility, residential buildings, non-residential buildings, and transport (Iacono et al., 2008; Hunt et al., 2005; Wagner and Wegener, 2007). Unfortunately, it was not possible in the current thesis to simulate the land-use change along with transportation. However, Transportation as a land suitability criteria were used with various weights and scores in different urban growth prediction scenarios as an important input for the urban growth simulation and prediction.

Small and isolated settlements centers are fast-growing by time and become big metropolis due to urban sprawl (Mohammadi *et al.*, 2013) whether by demographic explosion or increasing demand on more space, or both (Miller, 2003). If that urban sprawl was unplanned, the collapse of public services and negative environmental and socio-economic implications will be induced (Barredo and Demicheli, 2003; Guan and Rowe, 2016; Lagarias, 2012). So, shifting the urban planners' point of view to the cities from an architectural phenomenon to a rational interactive activity throughout urban growth simulations and predictions is necessary (Mohammadi *et al.*, 2013) to understand the urban growth process (Yeh and Li, 2006b; Stevens *et al.*, 2007).

As it was denoted in the section (2.3.), PSS usually exists in the form of a computer model or collection of interlinked computer models, including land-use change models (Geertman and Stillwell, 2009). Although various techniques are available to simulate land-use dynamics, two types are particularly suitable for PSS. These are cellular automata (CA) based models and Agent-based models (ABM) (Geertman and Stillwell, 2009). CA has shown a high efficacy as shown in many previous studies conducted by (Ramachandra *et al.*, 2016; Kamusoko and Gamba, 2015; Lin and Li, 2015; Jat *et al.*, 2017b; Klosterman and Pettit, 2016; Stephan, 2008; White and Engelen, 1993; Barreira González *et al.*, 2015; Clarke, 2014; Yeh and Li, 2006a; Clarke, 2008). The process of urban growth simulation and prediction consists of three major phases, as shown in figure (2-3). After model development, calibration must be conducted to adjust the model's parameters. By the means of historical land use/cover data (at T0 and T1), calibration is conducted and reproducing the dynamic change (simulated) then compared with the real (observed) data at T1. The produced simulated data T1, after validation and agreement with observed ones, enable projection of the future trends of the urban growth T2, T3.

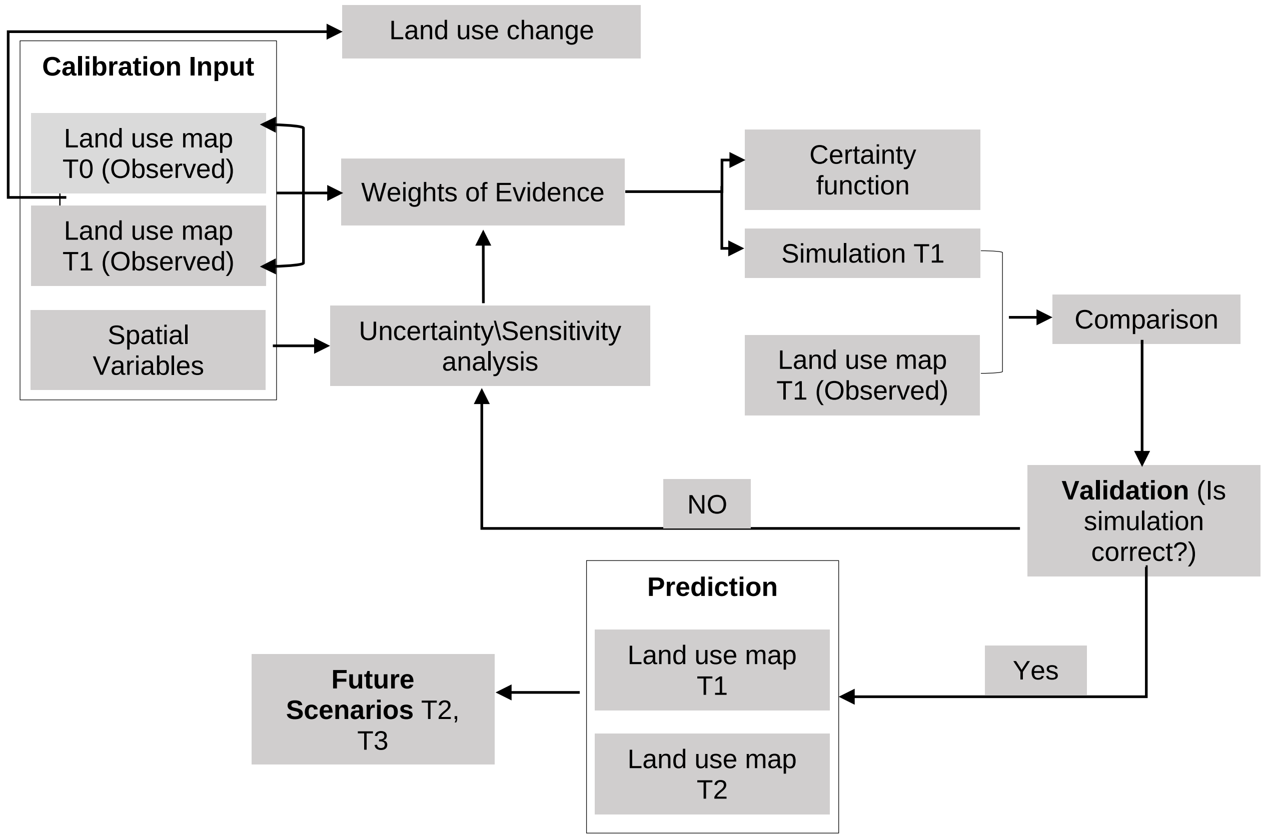


Figure 2-3: General steps of the CA based models for urban growth simulation, calibration and validation
Source: Author based on (Kamusoko and Gamba, 2015)

Since the 1960s, there were different types of land-use models, table (2-1) introduces an overview of some used land-use change models. SLEUTH CA-based model (formerly called Clarke Cellular Automaton Urban Growth Model) is considered the most popular and most used in Washington, DC, and San Francisco to simulate the urban expansion (Aburas *et al.*, 2016; Silva and Clarke, 2002; Jantz *et al.*, 2010; Guan and Rowe, 2016; Jantz *et al.*, 2016a). In Mashad city, Iran, (Rafiee *et al.*, 2009) has used SLEUTH model in simulating urban growth and understanding the growth dynamics, forecast urban sprawl for various future scenarios and to provide a basis for urban management. Also, (Jantz *et al.*, 2010) have utilized (SLEUTH-3r) CA-based model in the regional land cover modeling system in the Chesapeake Bay drainage basin in the eastern United States. SLEUTH-3r is a newly developed version of SLEUTH model which introduces new functionalities and metrics that substantially increase the performance and applicability of the model to be able to incorporate economic, cultural and policy information and variables.

Table 2-1: Overview of the used models in land-use changes and urban growth simulation
Source: Author, based on (Agarwal *et al.*, 2002; Aburas *et al.*, 2016) and references in the table.

Model and Author	Model type	Description
General Ecosystem Model (Fitz *et al.*, 1996)	Dynamic system model	▪ It is a spatially dependent model, captures feedback among abiotic and biotic components of the ecosystem and that model requires about 103 input parameters; e.g. hydrology macrophytes algae nutrients fire dead organic matter. ▪ Lacking human decision-making
CLUE (Conversion of Land Use and Its Effects) Model (Fresco and Veldkamp, 1996)	Discrete finite state model	▪ It consists of three modules: regional biophysical, regional land-use objectives, and local land-use allocation modules ▪ Predicts land cover in the future and considers Land suitability analysis for crops, effects of historical land use mainly on crops, human Drivers (including Population size and density and political structure) ▪ Limited consideration of institutional and economic variables
Area base model (Hardie and Parks, 1997)	use a modified multinomial logit model	▪ The model predicts land-use proportions at the county level and depends on (land features classification, crop and land pricing, land crop suitability, population density, per capita income, land owners, irrigation) as input variables ▪ The model requires lots of extended datasets over long periods
Univariate spatial model (Mertens and Lambin, 1997)	Univariate spatial models	▪ The model composed of multiple univariate models based on deforestation patterns; e.g. 1) total study area, 2) corridor pattern, 3) island pattern, 4) diffuse pattern, each model runs with the aforementioned four independent variables separately ▪ All four models run with all four independent variables: 1) road proximity, 2) town proximity, 3) forest-cover fragmentation, 4) proximity to a forest/non-forest edge ▪ Interaction between factors is not modeled
Spatial dynamic model (Gilruth *et al.*, 1995)	Spatial dynamic model	▪ The model predicts sites used for shifting cultivation in terms of topography and proximity to population centers ▪ Mimics expansion of cultivation over time ▪ Input data don’t include the impact of land quality and socioeconomic variables
CUF (California Urban Futures) (Landis and Zhang, 1998; Landis *et al.*, 1998; Landis, 1995)	Spatial simulation model	▪ The model explains land use in a metropolitan setting, in terms of land demand (population growth) and supply of land. And composed of (Population growth, spatial database, spatial allocation) sub-models. Besides, it relies on the following variables: Housing prices, Zoning, Slope, Wetlands, Distance to city center, Distance to the freeway, Distance to sphere-of-influence boundaries ▪ Characterized by a great strength represented in the underlying theory of parcel allocation by population growth projections and incorporation of incentives for intermediaries’ developers.

		▪ No feedback on mismatch between demand and supply on price of developable land/housing stock, impact of interest rates, and economic growth rates
LUCAS (Land Use Change Analysis System) (Berry *et al.*, 1996)	Spatial stochastic model	▪ Composed of socioeconomic, landscape change, and Impacts modules ▪ It explains the transition probability matrix (TMP) of land cover change relying on the following variables: Land cover type (vegetation), Slope, Aspect, Elevation, Land ownership, population density, Distance to the nearest road, Distance to the nearest economic market center ▪ It uses low-cost open-source GIS software (GRASS)
Simple log weights (Wear *et al.*, 1998)	Simple log weights	▪ It predicts an area of timberland adjusted for population density ▪ Limited consideration of human decision-making
Logit model (Wear *et al.*, 1999)	Logit model	▪ Predicts the probability of land being classified as potential timberland, depending on (Population per square mile, Site index, Slope, and accessibility) as variables ▪ Includes only basic human choice variables, e.g., population density
Dynamic model (Swallow *et al.*, 1997)	Dynamic model	▪ Simulates an optimal harvest sequence based on three components (timber model, forage production function, nontimber benefit function) ▪ the optimal management pattern on any individual stand requires specific analysis rather than rules of thumb
FASOM (Forest and Agriculture Sector Optimization Model) (Darius *et al.*, 1996)	Dynamic, nonlinear, price endogenous, mathematical programming model	▪ It performs allocation of land in the forest and agricultural sectors based on three sub-models ▪ The model is dynamic, thus changes in one-decade influence land-use change in the next decade ▪ Suitable for long-term policy impacts
CURBA (California Urban and Biodiversity Analysis Model) (Landis *et al.*, 1998)	Overlay of GIS layers with statistical urban growth projections	▪ The model explains the interaction among the probabilities of urbanization, its interaction with habitat type and extent, and the impacts of policy changes, by the means of various input variables (Slope and elevation, Location and types of roads, Hydrographic features, Jurisdictional boundaries, Wetlands and flood zones, Jurisdictional spheres of influence, Various socioeconomic data, Local growth policies, Job growth, Habitat type, and extent maps) ▪ Allows projection of future urban growth patterns, and the impact of projected urban growth on habitat integrity and quality
Cellular automata model (Clarke *et al.*, 1995; Kirtland *et al.*, 1994)	Cellular automata model	▪ Simulation module consists of complex transition rules Allows each cell to act independently according to rules to simulate the change in urban areas over time ▪ Consider digital dataset of biophysical and human factors including Extent of urban areas, Elevation, Slope, Roads

CA-based models are dynamic, flexible, intuitiveness, bottom-up approach, and capable to be combined with other models (Mohammadi *et al.*, 2013; Aburas *et al.*, 2016; Agarwal *et al.*, 2002; Aljoufie *et al.*, 2013). CA-based models can provide the decision-makers with realistic urban dynamics, determine the various parameters' values in the urban growth process, and consider the external factors affecting the urban growth process (Deep and Saklani, 2014; García *et al.*, 2012; Mitsova *et al.*, 2011; Itami, 1994; Santé *et al.*, 2010; Tian *et al.*, 2016). CA-based models are powerful spatial dynamic modeling techniques that represent major development over previous conventional models are: a) spatiality, b) linking macro (in which various land uses were distributed based on socio-economic factors,) to micro (the cells assigned to the different land-use types) approaches, c) integration between GIS and RS techniques, d) dynamics, e) simplicity and visualization (Aburas *et al.*, 2016; Mohammadi *et al.*, 2013; Lagarias, 2012).

2.5.1. Driving factors of urban growth

There are many driving factors actuate, directly or indirectly, the urban growth process. The urban planners and decision-makers need to identify these factors to propose suitable measures, policies and strategies dealing with urban growth in a sustainable way (Nassar and Elsayed, 2018). in the state of the art, various factors affecting the urban growth process have been articulated; e.g. physical factors, social factors, environmental or natural factors, political factors, and socio-economic factors (Hongrun *et al.*, 2016). Environmental factors refer to the land nature; e.g. suitability of the land for agricultural activities or new urban development; topography ...etc. Regarding socio-economic factors, urban economists have admitted that "the population growth, distance to socioeconomic centers (GDP and households' income), and accessibility improvement" are three important factors that can underlie the urban expansion in any area (Li Cheng, 2014). Regardless of the socio-economic variable, accessibility strongly actuates the urban growth process (Hegazy and Moustafa, 2013). While, political factors can be represented by the urban planning and land-use policies as they have a great impact on the land cover changes and the future patterns of land uses and urban growth (Hongrun *et al.*, 2016). Wegener (2012) stated that "*Sustainable spatial development requires democratic decision making at the lowest possible level of government at which not particular interests but the common welfare are pursued*". The policies are not always for urban development scenarios, but also can be empowered for curbing the growth process in the sensitive environmental areas.

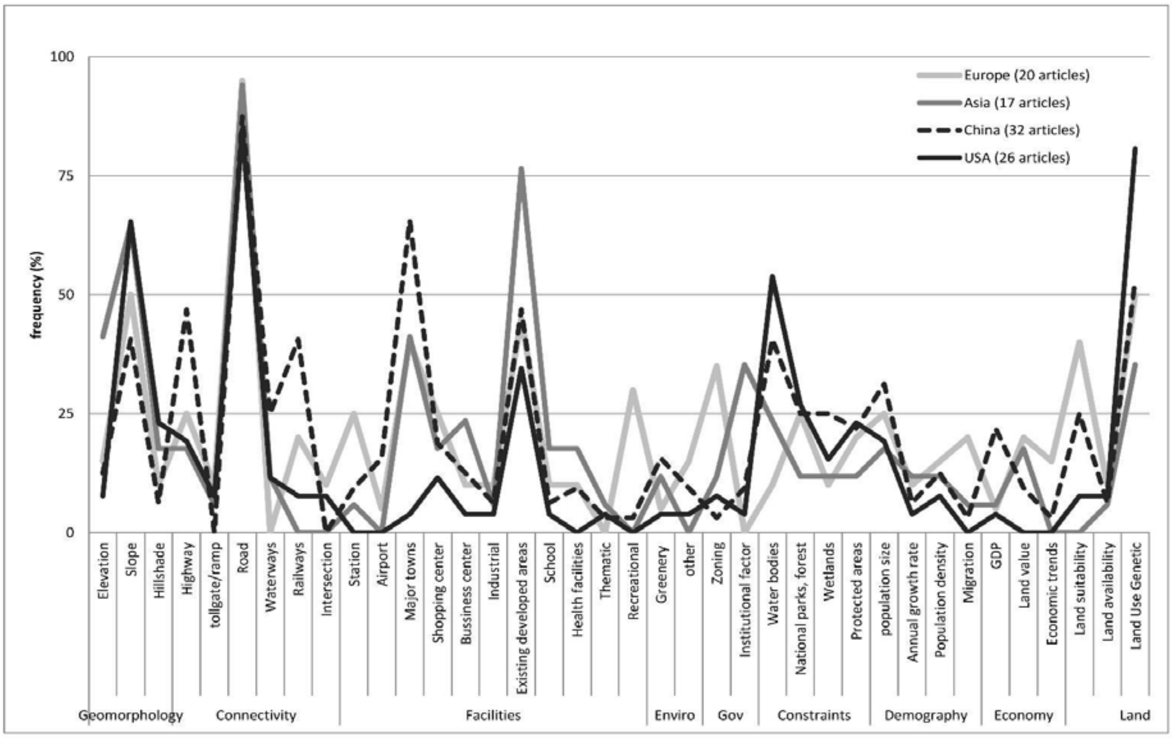


Figure 2-4: Summary of factors used in CA urban growth models in different regions
Source: (Wahyudi and Liu, 2016)

There are variations of the used factors over regions and time. Figure (2-4) shows the frequency of modeled factors in different regions. Transportation is a common factor used in all regions with a high peak. In the USA, the dominant factors were slope, road, and water bodies (as constraints) that was because of the use of the CA model (SLEUTH) which has been adopted as one of the standard models for urban growth in the USA (Wahyudi and Liu, 2016). In Europe, land suitability and zoning along with other factors were the most frequently used, due to the limited land available for development (Wahyudi and Liu, 2016). So, there are strict regulations were imposed by authorities to keep balanced land distribution. While in China, CA-based models consider more factors; e.g. highways, railways, major towns, population size and GDP factors which indicate the rule of investments in shaping the urban growth patterns. Table (2-2) denotes the most used factors affecting urban growth. According to the problem statement (section 1.2.), urban growth in the investigation area is due to the informal settlement. For this reason, political and institutional factors such as tax incentives don't have a remarkable effect on the urban growth process rather than the socio-economic and physical factors (Hongrun *et al.*, 2016).

Table 2-2: List of the influential driving factors on the urban sprawl based on many previously conducted studies and projects
Source: Author based (Li Cheng, 2014) and references stated in the table

	Influential factors used in previous research projects																		
	Zoning	Distance to industrial areas	Conservation areas	Elevation	Population density	Suitability	Distances to urban	Distance from water networks	Social services	Distance to Transport.	Distance to open water	Distance to City Center	Distance to airport	Strategic/ Master plan	Hazard land	GDP, Income	Housing rent	Soil type	Neighbourhood effect
(Abou-Korin, 2014b)		×			×	×		×	×	×					×				
(Soliman, 2012)		×						×	×										
(Al - kheder *et al.*, 2008)		×					×			×									×
(Aspinall, 2004)				×						×	×								
(Barredo *et al.*, 2003)	×				×	×			×	×	×								×
(Batisani and Yarnal, 2009b)	×			×	×			×		×		×						×	
(Braimoh and Onishi, 2007)			×	×			×			×	×		×			×			×
(Cheng and Masser, 2003)					×		×			×	×			×					×
(Connelly, 2009)														×					
(Dendoncker *et al.*, 2007)				×			×					×						×	×
(Dewan and Yamaguchi, 2009)				×	×											×			
(Dubovyk *et al.*, 2011)				×	×		×			×									×

(Farhoodi et al., 2009)														×					
(Hu and Lo, 2007)				×	×					×		×				×	×		×
(Barredo et al., 2004)										×				×					×
(Hongrun et al., 2016)				×	×					×	×					×			
(Li and Yeh, 2000)	×		×			×				×		×							
(Linard et al., 2013)				×			×												×
(Luo and Wei, 2009)							×			×	×								×
(Deadman et al., 1993)						×								×					×
(Poelmans and Rompaey, 2009)			×				×			×									×
(White and Engelen, 2000)	×					×				×			×					×	×
(Verburg et al., 2016)			×	×						×	×	×	×					×	×
(Zhang et al., 2011)										×	×								×
(Pérez-Molina et al., 2017)				×	×							×							
(Feng et al., 2016)							×			×		×							
(Tian et al., 2016)				×	×					×	×		×						

In any natural system where the environment and humans are interacting arrange of driving forces or variables are there affecting the prediction and trends of the land uses (Reynolds and Smith, 2002). In the current study, land suitability, vegetation, water resources, undeveloped areas, and main roads are considered as explanatory variables of new urban land uses. That was also confirmed in many other studies worldwide figured out that much of the land converted to urban areas (urbanization and settlement) was primarily agricultural lands close from coastal zones and fertile river valleys (Levia, 1998; Nelson, 1992; Platt, 2010; Rudel, 2005; Wood and Porro, 2002) as also was clarified and approved in the LULC (section 5.1.), simulated and predicted urban growth (5.3.) maps of the investigation area, Alexandria governorate.

2.5.2. Introduction to CA-based models

CA was first introduced in 1948 by Von Neumann and Ulam then applied intensively and widely in physics and mathematical science (White and Engelen, 1993). Tobler (1979) was the first who proposed the application of cellular space models to geographic modeling. Numerous CA-based models have been developed to investigate the urban growth and flood events modeling, for instance, on different scales all over the world (Jokar *et al.*, 2013; Clarke *et al.*, 1997; He *et al.*, 2008; Li and Yeh, 2002; Wu and Webster, 1998; Xie, 1996). CA-based models have several characteristics made them unique in terms of application in urban and environmental systems; as stated in (Batty *et al.*, 1999; White and Engelen, 1993; Li and Yeh, 2002):

- It can be efficiently integrated with GIS
- Results generated are in the form of maps and tables
- It can represent the complex and dynamic urban systems and applications related to the decision-making process by using transition rules

The future cell state or the conversion from one cell state to another is mainly based on four main elements: lattice figure (2-5-a), cell state figure (2-5-b), neighborhood type figure (2-5-c), and transition rules (Barredo et al., 2003; White and Engelen, 1993, 1994, 1997; Barreira González *et al.*, 2015).

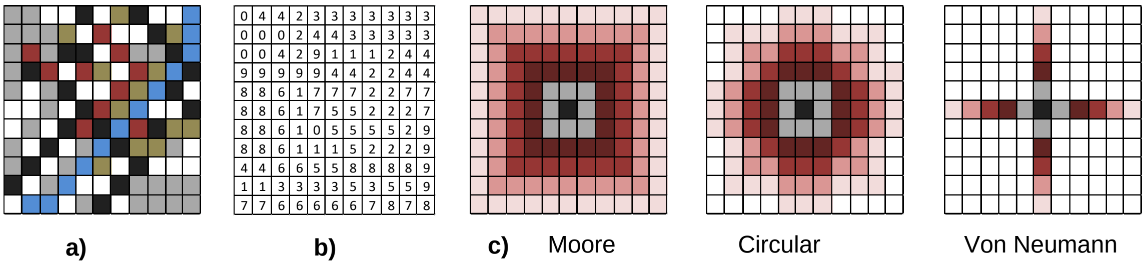


Figure 2-5: Main elements of the Cellular Automata modelling a) grid cells, b) land use features, c) different neighborhoods.

a) *Cell (Lattice or grid cell or pixel):*

It is the smallest spatial unit used in CA modeling and analysis (Li and Yeh, 2000). Each cell represents a land feature in a certain area. CA-based models are sensitive to cell size (Ménard and Marceau, 2016). The resolution is various in the applications of urban growth simulations, it could be resampled to 25*25 m, 50*50 m, 100*100 m, 200*200 m, 300*300 m, 500*500 m, 800*800 m (Pan *et al.*, 2010; Malczewski, 2004). 300*300 m cell size has been implemented in modeling urban growth in San Francisco Bay (Clarke *et al.*, 1997). Also, 210*210 m, 420*420 m, 840*840 m and 1680*1680 m have been adopted too in their case study in Washington/Baltimore region (Kirtland *et al.*, 1994; Clarke *et al.*, 1995; Clarke *et al.*, 1997).

b) *Cell states:*

Cell states could be binary values; e.g. urban or non-urban land use or qualitative values representing different land use/cover types (Su *et al.*, 2012; Fuglsang *et al.*, 2013) or quantitative values representing urban land use development (Lau and Kam, 2016). The cell states can be represented in attribute numbers, each cell carries one state at a time and during the simulation process it can be updated according to the transition rules settings.

c) *Neighborhood:*

The term 'neighborhood' refers to "*a set of cells located in a specific distance and have a relationship to other particular cells*" (Verburg *et al.*, 2004). The neighborhood configuration determines the distribution and number of neighborhood cells that will affect the evolution of each central cell (Ménard and Marceau, 2016; Barredo *et al.*, 2004). The optimal neighborhood size can be determined based on a calibrated procedure and it was concluded that the most applicable neighborhood radius ranged from 1 to 8 (Caruso *et al.*, 2005; Ménard and Marceau, 2016). As the distance between the neighboring cells and the central cell increases, the effect of neighborhood cell decreases. Each cell in the neighborhood is assigned a weight according to its state and the distance to the central cell. Three neighborhood types were presented in the state of the art: Moore, Circular, and Von Neumann neighborhood types (Batty *et al.*, 1999; Clarke *et al.*, 1997; Ménard and Marceau, 2016; Omidipoor and Samani, 2017). Moore neighborhood is defined as a 2D square lattice and is composed of a central cell and the eight cells which surround it (Batty *et al.*, 1999; Caruso *et al.*, 2005; Ménard and Marceau, 2016). Von Neumann neighborhood; is classically defined on a two-dimensional square lattice and is composed of a central cell and its four adjacent cells. The red cells are the von Neumann neighborhood for the brown cell. The extended neighborhood includes the pink cells as well (Clarke *et al.*, 1997; Ménard and Marceau, 2016).

d) Transition Rules:

The transition rules' setting is the most important part of CA-based models and represents the logic of the spatial process being modeled (Mohammadi *et al.*, 2013; White and Engelen, 2000; Jokar *et al.*, 2013). The transition rules can be categorized under various groups according to the definition method used (Li Cheng, 2014). The first type is the t*ransition rules based on the transition potential type*: in which the key driver of urban growth is the transition potential. The transition potential is calculated as a function of the current state of the cell, its neighborhood, suitability (Multi-Criteria Evaluation), randomness (Stochasticity), and other factors which influence the urban growth can be considered (Wu and Webster, 1998; Thinh and Vogel, 2005a,b). Also, logistic regression was utilized to calculate the transition potential as in (Wu, 2002), Principle Component Analysis (PCA) to identify the factors used in transition rules as in (Li and Yeh, 2002). The second type is the t*ransition rules based on urban shape and form*: that method was introduced in the SLEUTH model as in (Clarke et al., 1997; Jantz et al., 2010). SLEUTH is a pattern-based model capable of urban growth dynamics simulation through applying four growth types: spontaneous, new spreading center, edge, and road-influenced growth (Osman *et al.*, 2015; Li Cheng, 2014). Each type is determined by diffusion, breed, spread, road growth coefficients which reflect the relative contribution of a particular growth type to urban dynamics (Osman *et al.*, 2015). The third type is the t*ransition rules based on fuzzy logic*: in this method, the uncertainty of human behavior is considered (Al‐kheder *et al.*, 2008). Nevertheless, the definition of the fuzzy logic transition rules has difficulties represented in the choice of fuzzy functions (Santé *et al.*, 2010). The fourth type is the t*ransition rules based on artificial intelligence methods*: a variety of CA-based models were based on neural networks as in (Li and Yeh, 2002) and Support Vector Machine (SVM) as in (Yang *et al.*, 2008; Triantakonstantis *et al.*, 2011) generated more plausible results. While the fifth type is the *Strictly orthodox transition rules method*: in that method the probability of a cell change from state to another based on neighborhood effect and cell state only without considering any other factors influencing urban growth dynamics (Jenerette and Wu, 2001; Yüzer, 2004).

In general, CA-based urban growth models, the state of a cell in time S_{t+1} is determined by its state and its neighbors in the time S_t as well as corresponding transition rule (Li and Yeh, 2000), as represented in formula (2-3):

$$S_{t+1} = f(S_t, N, T) \qquad \text{Equation (2-3)}$$

Where; S_{t+1} is the state of a cell at a time $(t+1)$, S_t is the state of a cell at time t, and T is a set of transition rules followed by cells (Li and Yeh, 2000).

2.5.3. CA models Calibration and validation

The calibration process was defined as "*estimation and adjustment of model parameters and constants to improve the agreement between model output and a data set*" regardless of the interacting variables involved (Wu, 2002; Li and Yeh, 2002; Pan *et al.*, 2010). In the state of the art, there are various calibration methods for CA-based models' calibration (Li Cheng, 2014). "Trial and error" method is usually conducted by running the model to carry out several simulations, in each simulation different parameters combination is assigned, thereafter, identifying the most suitable parameters' values (Santé *et al.*, 2010; Li and Yeh, 2002). While the statistical-based method is possible in case of a wide range of parameters and efficient computational tools. For instance, logistic regression, as was applied in (Wu and Webster, 1998) through developing a statistical relationship between the historical land cover change and the variables (Jokar *et al.*, 2013; Ward *et al.*, 2000). Despite the difficulty of interpreting the values of parameters in the case of Artificial Neural Network (ANN), it was applied in CA-based models' calibration, as in (Li and Yeh, 2002; Wu, 2002). SVM and Kernel-based methods approved high efficiency in the calibration process (Yang *et al.*, 2008). Furthermore, an automated method through using a Generic Algorithm was used as in (Al-Ahmadi *et al.*, 2009) to the parameters of the transition rules because of its capability in dealing with complex optimization processes

(Abedini and Azizi, 2016; Malczewski, 2004; Miller, 2003; Malczewski, 2004; Pontius and Neeti, 2010; Malczewski, 2004).

Validation of the simulated results is aiming at assessing the performance of CA models with different combinations of parameters. It is conducted by comparing the simulated with observed maps through visual comparison as in (Yang *et al.*, 2008; Al-Ahmadi *et al.*, 2009) and various indicators; e.g. locational and pattern indicators (Jenerette and Wu, 2001). Overall accuracy, Kappa Index and Figure of Merit for locational indicators are widely used for to measure the agreement based on a cell by cell comparison (Pontius *et al.*, 2007; Santé *et al.*, 2010; Meentemeyer *et al.*, 2013), as applied in the current PhD study.

2.5.4. Uncertainty and Sensitivity Analysis for CA models

Uncertainty can arise from various types of factors; e.g. aleatory and epistemic (Saltelli *et al.*, 2008; Saltelli *et al.*, 2004; Xu and Zhang, 2013). Aleatory uncertainty refers to the physical inherent variability in the natural world and arises from the randomness and erraticism in the system which is cannot be reduced or avoided (Saltelli *et al.*, 2004); e.g. changing in the rainfall over time and space, spatial variability of roughness, slope, and elevation. Epistemic (knowledge) uncertainty refers to an insufficient understanding of the natural process and incomplete data or analysis in the physical world/system. Epistemic type can be reduced through more understanding and realistic assumptions close to the real world (Mu Yang, 2017).

Sensitivity Analysis was categorized under two main groups: Local Sensitivity Analysis and Global Sensitivity Analysis (Moreau *et al.*, 2013; Rajabi *et al.*, 2015). The local sensitivity analysis method was used in many applications: e.g. climate change, flood and urban simulation (Hu *et al.*, 2015; Sudret, 2008). However, this method is based on the linearity, normality assumptions, and local variations; which limit the comprehensiveness of the sensitivity analysis' parameters. OAT approach, which represents the local sensitivity analysis, is computationally efficient and doesn't need a large number of model executions. It investigates individual variations and applied in case no higher-order interactions are expected (Marzban, 2013). While, global sensitivity analysis approach can overcome the limitations of the local sensitivity analysis by considering the whole variation range of the inputs (Sudret, 2008). Global UA-SA was conducted using various methods; (Şalap-Ayça *et al.*, 2017) used Variance-based sensitivity analysis methods; e.g. a meta-modeling technique called Polynomial Chaos Expansion (PCE) on a SLEUTH model developed by (Clarke *et al.*, 1997). Variance-based sensitivity analysis often referred to as the Sobol method/ indices used for calculation of the global sensitivity analysis (Sobol', 2001; Chen and Jin, 2004; Tarantola *et al.*, 2000; Gómez‐Delgado and Tarantola, 2006; Crosetto and Tarantola, 2010; Barreira González *et al.*, 2015). Sobol index is generated through enhancing the relative weight of each uncertain parameter in the various calculated output parameters and combinations.

2.5.5. Urban growth scenarios' development

Urban growth scenario development is a tool for predicting future alternatives. Planners and decision-makers should participate in designing these scenarios and propose suitable land-use plans, policies, and regulations (Aguilera *et al.*, 2011; Fuglsang *et al.*, 2013; Song *et al.*, 2006; Xiang and Clarke, 2016a). In literature, many scenarios have been investigated; e.g. Baseline, Service-Oriented Center, and Manufacturing Dominant Center scenarios using Markov chain analysis and CA, as in (Zhang *et al.*, 2011). Also, Baseline and Planning Strengthened scenarios have been designed to investigate the effect of planning on urban expansion using a logistic regression-based CA model, as in (Long *et al.*, 2012). Three growth scenarios have been investigated by making use of CA-model in the SLEUTH modeling, namely; Historical growth trends Scenario, Compact growth Scenario, Growth as planned officially, to future urban growth in Great Cairo, Egypt (Osman *et al.*, 2015). Furthermore, three scenarios, namely; spontaneous, environment-protecting, and resources-saving were defined to optimize spatial patterns of future urban growth in Kathmandu, Nepal (Thapa and Murayama, 2012). Also, the growth of the Copenhagen metropolitan area under three scenarios: business as usual, growth within limits, and new welfare scenarios were simulated as in (Fuglsang *et al.*, 2013).

2.6. Coastal Areas Management in the Egyptian context

From the economic perspective, coastal cities are considered valuable areas that have a high share of the GDP and national income of any country, due to its strategic location and the activities carried out over there. So, it is of great importance to sustainably develop these irreversible land and coastal resources. Therefore, ICZM was widely and internationally promoted to deal with the coastal issues and threats (Ibrahim and Hegazy, 2013; MSEA, 2009; Sanò *et al.*, 2010; Sanò and Medina, 2012; Sanò *et al.*, 2014; El-Raey, 1997). The international community committed to develop ICZM action plans for the contracting countries, to successfully apply coastal governance in the Mediterranean basin. 16 Mediterranean countries and the European Community adopted the Mediterranean Action Plan (MAP) in the year 1975. One year later, the contracted parties adopted the Barcelona Convention aiming at the protection of the Mediterranean Sea against pollution. In the year 1995, Barcelona Convention renamed Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. At the time being, the contracting countries became 22 countries, and all attempting to achieve sustainable development and adopt a national ICZM strategy (MSEA, 2009).

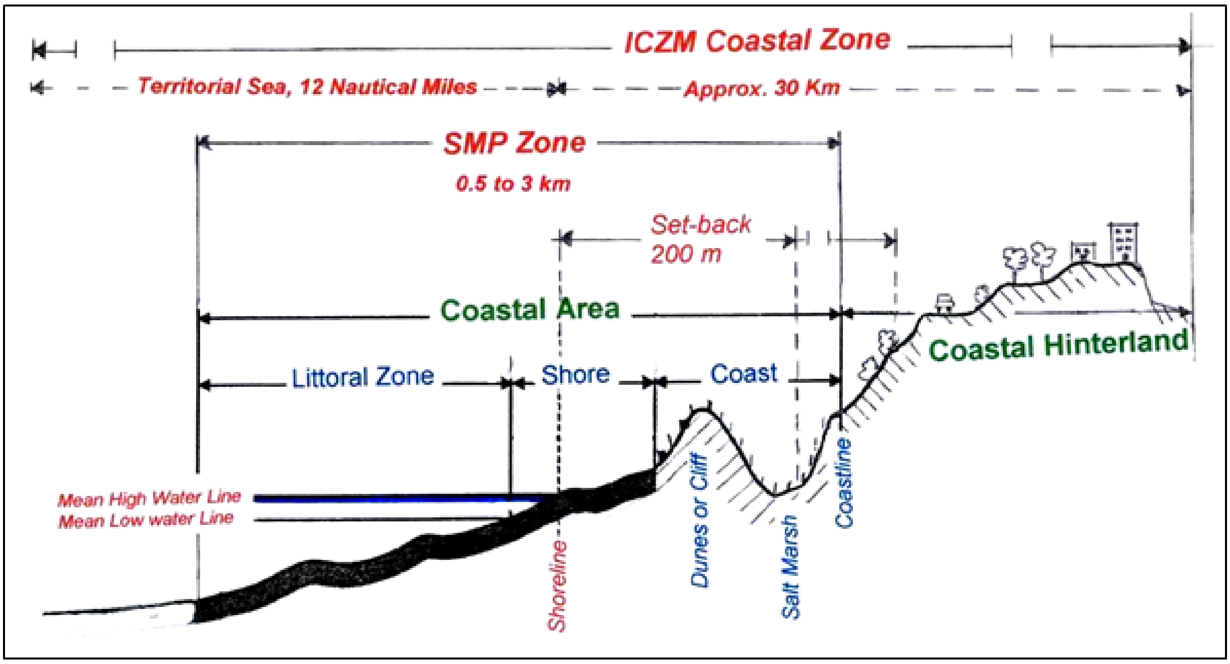


Figure 2-6: Geographic extension of ICZM coastal zone
Source: (EEAA/ESP, 2008)

After a defined, 200 m strip landward (regulated according to Article 73 in the Law 4/1994 and Article 98 and 99 in the Water Resource Law No. 12/1984), the Shore Protection Authority (SPA) has the responsibility to issue and give license for any development projects especially urban or tourism projects within this 200 m zone. In the year 2006, the Prime Minister issued Decree No. 1599 aiming at the establishment of a Coastal High Committee to approve coastal development projects and set the characterization of these potential developments for the investors (EEAA/ESP, 2008). Moreover, new policies for the conservation of new national parks, especially the marine ones including the precious and irreversible landscapes, were proposed by the Cabinet. In the year 2009, amendments of the Egyptian Environmental law NO.4 for the year 1994 have been approved. So, the ICZM protocol legislation could be included in the Egyptian environmental law including the definition of the coastal zone, figure (2-6), coastal ecosystem, and coastal plans and programs. There are five articles from the ICZM protocol have been included in the Egyptian environmental legislation, as following (EEAA/ESP, 2008): Article 5 Objectives of ICZM, Article 6 General principles on ICZM, Article 7 Coordination, Article 15 Mediterranean Strategy for ICZM, Article 16 National coastal strategies, plans and programs (PAP/RAC - EEAA, 2009).

All coastal zone management projects conducted for governing coastal zones of Egypt, table (1-2) chapter 1, section 1.1., have the following main objectives: coordinate and solve the conflict management between urban expansion and nature protection including water, wetlands, and land; prepare measures and policies for regional development in wider coastal areas; coordinate between the involved stakeholders and promote for participatory approach (Borhan *et al.*, 2003; EEAA, 1999; EEAA/MAP, 2005). Table (2-3) shows some indicators assessing the progress of ICZM projects conducted in Alexandria governorate using twelve strategic objectives and twelve progress indicators (more details about the strategic and operational activities were indicated in the Annex, table (0-1). The Progress Indexes have been developed to evaluate the progression in each Strategic Objective, they were coded from A to L and ranked from 0 to 5. Equation (2-4) shows the formula used to conduction the progression process.

$$SO_n = \sum(WA_{SO} * A_{SO}) \qquad \text{Equation (2-4)}$$

Where; SO_n is the strategic objectives and n is from A to L, WA_{SO} refers to values of the indicators corresponding to each strategic objective, and A_{SO} represents the weight of each indicator corresponding to each strategic objective.

Figure (2-7) denotes the used indicators’ evaluation of the ICZM projects and policies governing the coastal areas. ICZM projects and initiatives results were not satisfactory (Ibrahim and Shaw, 2012), because of the following: Inadequate legal framework, Lack of capacity, Inadequate enforcement of any environment-related laws, Fragmentation of responsibilities at national and local levels, Lack of stakeholder involvement and public participation, Lack of integration, Lack of effective mechanisms for decentralization, Lack of institutional arrangement (Ibrahim and Shaw, 2012; Ibrahim and Hegazy, 2013; Ibrahim, 2013). Equally, quantifying the future impacts of any urban growth scenario was limited because of the lack of reliable data series in terms of temporal and spatial scale. Therefore, it is of great importance through mapping to figure out the implication of these policies on land resources. Consequently, it was proposed to conduct LULC change detection as a possible indicator to find out whether there is a disparity between land use policies and coastal zone management policies or not. LULC changes in the coastal areas, in particular in 'Lake Mariute and the beach', are of special interest as they are considered as coastal and environmental valuable resources and irreversible ecological zones falling at the heart of EEAA main concerns.

Table 2-3: Progress indicators

A	clear policy and regulatory framework
B	sustainable multiple uses
C	healthy environment
D	water quality
E	maintenance and rehabilitation of resources
F	sustainable land-use
G	improving infrastructure
H	shoreline erosion
I	stakeholder participation
J	public participation
K	committed coastal comunities
L	planning sustainable use of coastal resources

Figure 2-7: Chart shows the progress indicator system for ICZM project for Alexandria governorate

3. CHAPTER THREE: INVESTIGATION AREA AND DATA USED

3.1. Introduction to the study area

Egypt is a large and densely packed with population, particularly in the Nile Delta region and along the coastal areas. That is combined with current serious devastating environmental implications. Egypt's total land area is 995,450 km^2 The Delta region and the narrow valley of the Nile cover around 5.5% of the Egyptian surface area and occupied with 95% with the population, 25% of them are living in the Low Elevation Coastal Zone (LECZ) areas (Sánchez-Arcilla *et al.*, 2011; Frihy *et al.*, 1996; Ali and El-Magd, 2016), and the remaining 94.5 % of the country's area is dominated by a vast desert plateau. These coastal areas north of the Nile Delta produce about 30-40% of the agricultural production, around 50% of the industrial production, in the densely populated cities; e.g. Alexandria, Damietta, and Port Said. The fertile land in the Nile Delta region is among the most productive lands in the world in terms of the agricultural yield; e.g. many cereal and horticultural crops. Egypt's population is increasingly urbanized and expanding, the current population is about 99 million (Abou-Korin, 2014a; Elmenofi *et al.*, 2014; Hegazy, 2014; Khalifa, 2015). United Nations estimates the Egyptian population to be about 150 million by the year 2050. Around 43 % of that population lives in urban centers, which is almost or near the Nile River Valley. Most of these urban areas are growing dramatically without proper attention from the government, in terms of urban planning perspective and regulation, and becoming part of the informal settlements areas (Nassar and Elsayed, 2018; Sutton and Fahmi, 2001).

Alexandria governorate is the second biggest city in Egypt after Cairo (the Egyptian capital), and it is the center of development of the Northern coast on the Mediterranean Sea (Nassar and Elsayed, 2018), figure (3-1). Alexandria is considered the second industrial center of the country is acting as a central place in the transportation nodes. Because of its unique location on the Sea, Alexandria became an important and basic commercial center. The great history and the ancient civilization of the city, the economy, population, education institutes, hospitals and health centers, public facilities, cultural and various amusement places, monuments, and the astonishing beach have made Alexandria the mermaid of the Mediterranean Sea and hence a very attractive area for population. Its surface area is around 3,818 km^2 including around 1045 km^2 residential area occupied by 4 million inhabitants that could reach 6 million in the summer season (CAPMAS, 2008 - census of the year 2006). The coastline of Alexandria city extends about 80 km on the sea with this coast accommodating three harbors namely; the Western Harbor, which is the main harbor of the country that handles about 60% of the country trade, El'Dekhiela Harbor just west of the Western Harbor, and the Eastern Harbor which is a fishing and yachting harbor.

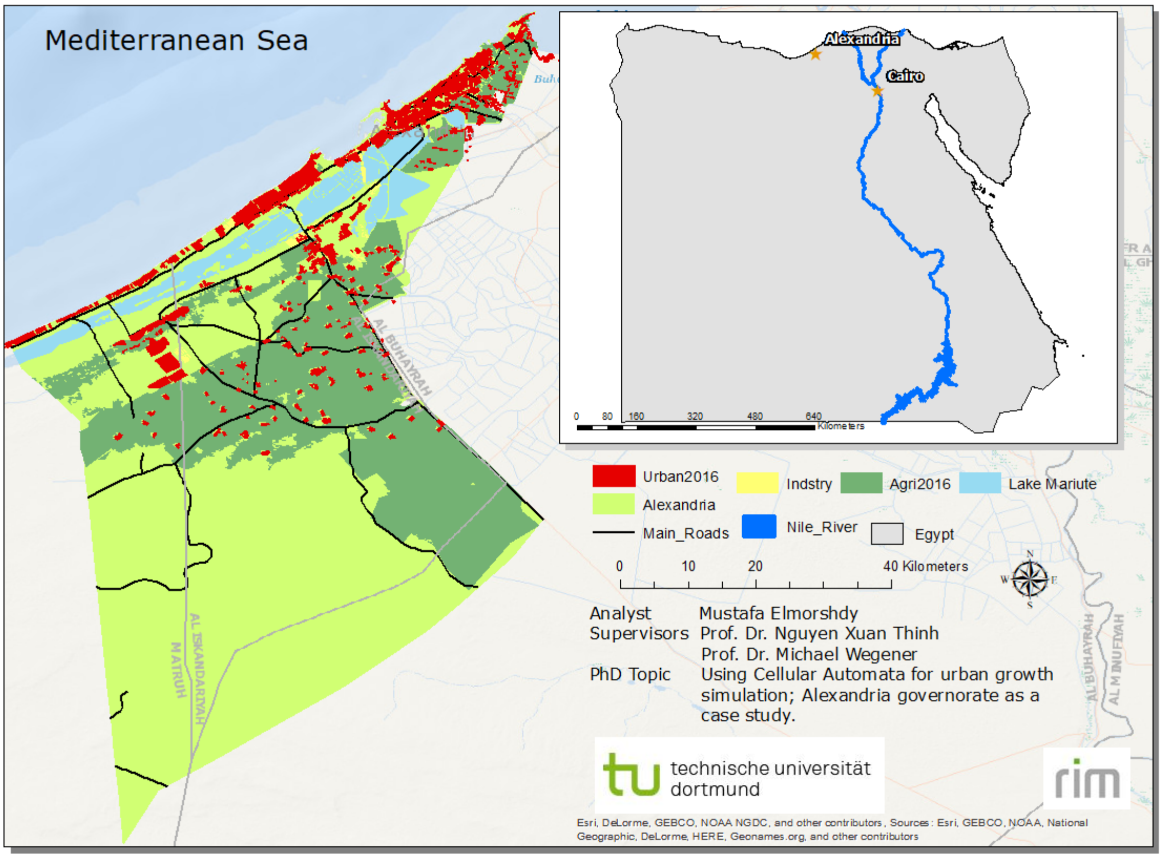


Figure 3-1: Investigation area, Alexandria governorate

Alexandria city is highly rich with various types of industries, constitutes around 30% of Egypt's industry, a very attractive coastal city for tourism, and produces around 11*103 tons per year from the marine fish (MSEA, 2009). Despite the good sewer system and two wastewater treatment plants with 1,320,000 m^3/day capacity, the city is subjected to stress from the land-based activities and unplanned communities developed, informal settlements and slums, agricultural waste, and heavily polluted industrial wastewater. These various forms of wastes can pass into the sea through four coastal recipient zones; Mex Bay, Western Harbor, Abu Qir Bay, and lake Mariute (Abu-Zeid *et al.*, 2011). The main economic activities in investigation area and mainland use/cover features are fisheries, agriculture (mainly crops), freshwater bodies (Lake Mariute and Airport farm Lake), open space areas or undeveloped areas (reclaimed for future uses - not specified yet), salt pans, beaches, and urban built-up areas.

As in figure (3-2) the informal areas, one-third of Alexandria's total population, with deteriorating buildings and infrastructure in the old and dense parts of the city, and fast urbanization of surrounding areas over reclaimed lands and other low-lying areas make the city particularly vulnerable to many risks. Alexandria urban core area (high density with multi-storey buildings and hierarchical road structure, in the area along the waterfront and going up to Matar Lake). Periurban unplanned growth zone (high density and tall buildings, less planned road structure, close to the urban core area and along the South- East rail tracks). Western inland expansion zone (less planned development featuring a lower density than the core urban zone, but with development possibilities on wastelands). At the same time, central areas have been growing vertically causing more congestion and higher demand for services.

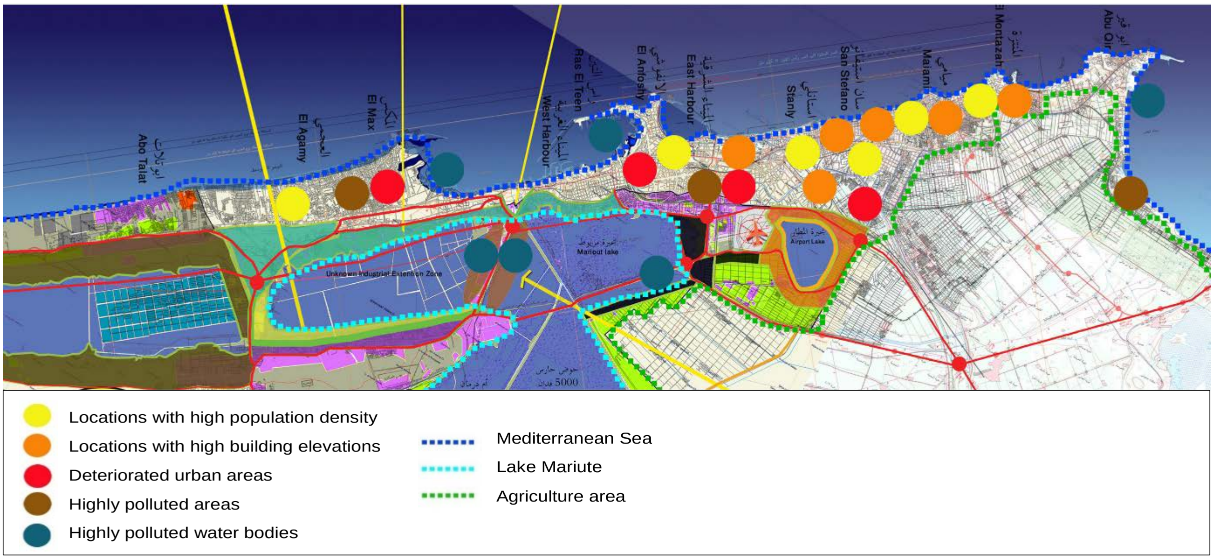


Figure 3-2: Deteriorated areas with various population densities over the study area (World Bank - Cities Alliance – GOPP, 2008).

Starting from the 1990s, national concern about informal housing began to appear in Alexandria governorate; e.g. establishment of the new port in El-Dekhila and some industrial sites in the west and southwest of the city, which was the main reason behind accelerated urban growth in that area (EEAA, 1999). The western part of the governorate became the main axis of urban development, so that, in the year 1990 presidential decree was launched to modify the western borders of Alexandria which extended about 81 km along Alexandria – Matrouh high road (EEAA/ESP, 2008). Due to the presidential decree, another new town with space about 315.48 km^2 and planned to accommodate about half a million inhabitants, called Burg Al-Arab was included to the governorate. The biggest district in Alexandria is the AI-Amrya district. It's a very important area for mixed economic activities; e.g. residential, petroleum industries, cement factories and building materials. In addition to that, it is considered as an important winter resort with a huge number of hotels and villas. The total area of the AI-Amrya district is 2166.37 km^2.

Table 3-1: Annual growth of population and area in Alexandria between 1855 and 2006 (Source: Author based (CAPMAS, 2008)

Period	Annual population growth rate (%)	Annual area growth rate (%)	Population/area
1855 - 1905	4.65	5.71	1.23
1905 - 1955	7.43	7.90	1.06
1955 - 1993	5.19	7.24	1.40
1993 - 2006	5.18	7.14	1.89

In the second half of the 20th century, the Alexandria governorate has experienced a relatively high rate of horizontal expansion in comparison to the previous rates as indicated in the table (3-1); which approximately means every 1% of population growth lead to 1.4% of physical expansion (CAPMAS, 2008). That great urban expansion required importantly intervention from the government to deal with the resulting planning problems throughout proposing effective policies manage to reduce the increase of informal settlement in the city (El-Raey, 1997). Between the years 2000 and 2016 Alexandria has experienced unplanned urban growth, land uses, and encroachment of the new local communities all over the city especially in croplands, then becoming part of the city (EEAA/MAP, 2005).

3.2. Urban growth phases in Alexandria governorate

In that section, four classic urban growth models were presented, namely; e.g. Concentric Zone Model, Sector Model, Multiple Nuclei Model, and Realm model (Anwar and Mohsin, 2015). The Concentric urban model was developed by Burgess in Chicago university in the year 1925 (Adhvaryu, 2010). This model encompasses five zones: Central Business District (CBD), Transition zone, residential (lower class) zone, residential (middle class) zone, and residential (upper class) zone as in figure (3-3_a). In that model, all activities are occurring around one central area, CBD. Whilst, the transition zone refers to the area converted from older residential to commercial due to the growth of the CBD. A concentric urban model presents neither information nor feedback regarding the impacts of transportation on the land-use changes (Adhvaryu, 2010). The second type is the Sector urban model, figure (3-

3_b), the model was developed by Homer Hoyt in the year 1939 after studying 100 different cities. While a city is growing, the activities which are emerged around the CBD would extend by time in specific directions that may follow roads or railways (Manso, 2010). One advantage of the model is that it allows new activities to be added to the periphery without redrawing the existing areas and uses as in the concentric model. In the year 1945, Harris and Ullman have developed the third one called Multiple Nuclei urban model, figure (3-3_c). One important character is that the urban activities don't evolve around single CBD or core, but rather several nodes and central points which could develop its residential community. James Vance in the year 1964 has introduced the fourth model, Realm urban model after morphology analysis for the San Francisco Bay area, figure (3-3_d). This model is characterized by its independent suburban sectors with its downtown and central city (Adhvaryu, 2010). In most of the cities especially in the developing countries, urban development doesn't follow the action/development plan (Smith, 1962; Burgess, 1925)

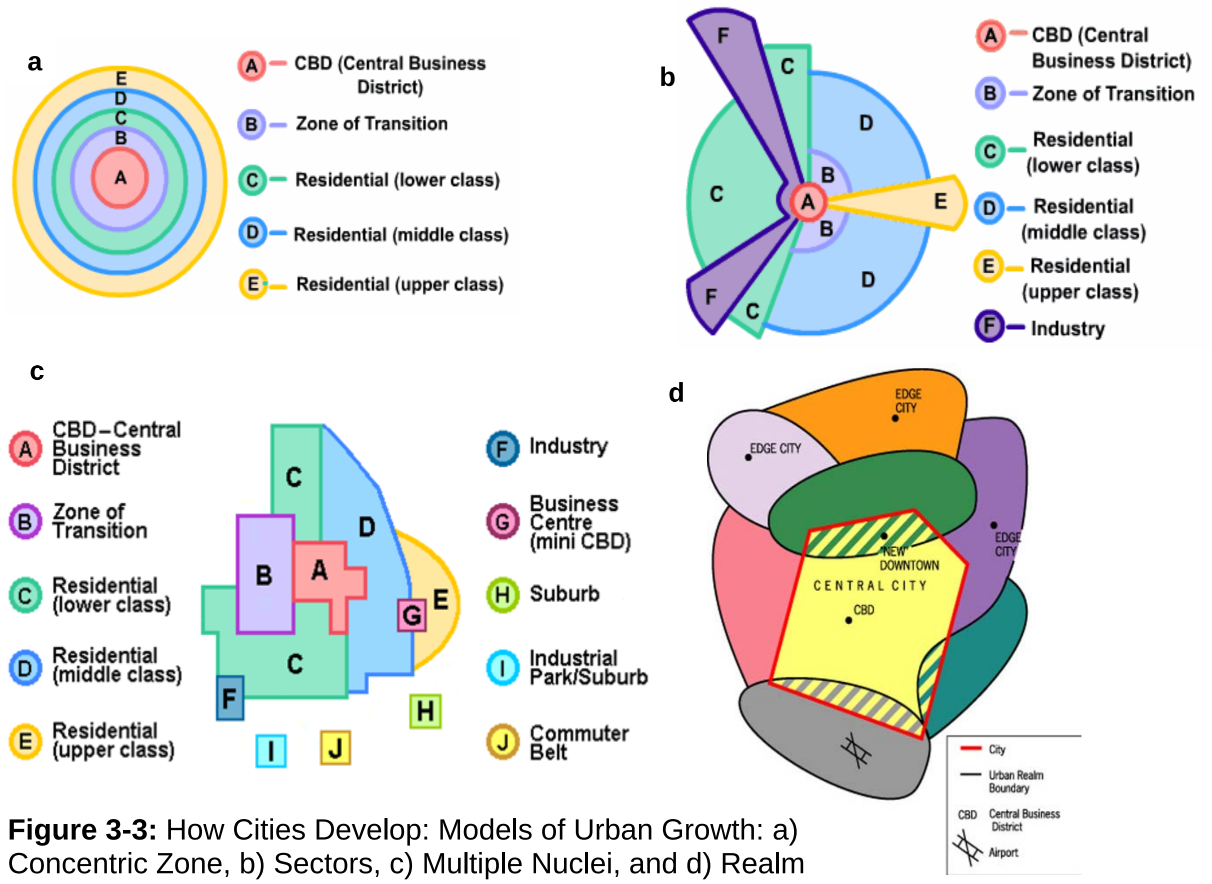


Figure 3-3: How Cities Develop: Models of Urban Growth: a) Concentric Zone, b) Sectors, c) Multiple Nuclei, and d) Realm Source (Smith, 1962; Burgess, 1925)

In these urban patterns, the population is split according to their income profiles. The city is longitudinal with the highest-class residential areas close to and parallel to the coast. South of this area is the middle-class districts, and behind the railway track and south of Mahmoudieh Canal are the low-income areas, usually informal. Nearby are some of the city's unplanned and informal areas.

These models have been applied to investigate the urban growth in the cities of the United States and Europe, where the driving factors are different from ones in developing countries. These urban models are static, and the cities aren't, and considering the temporal consequences is an important parameter, so that, and because of the previous reasons, it is not possible to use one of the aforementioned urban models to model the physical expansion for Alexandria governorate case study. However, the modern history of urban expansion in the Alexandria governorate can be divided into three chronological stages, each stage can represent a different urban model. In the first stage, the urban expansion took the circular shape to the north and the southeast in the first half of the 19th century, and to the south, west, and the east in the second half of the 19th century. This stage represents the concentric urban model. While in the first half of the 20th century (2nd stage), the Multiple Nuclei urban model can be applied. It's because of the expanded urban areas developed were united with five villages in the city, named; El-Hdara, El-Ramleh, El-Syeeouf, El-Mandra, and Abu-Qir. Four suburbs started to develop during the 19th century and continued to develop during the 20th century, named; Muharram Bek (south), El-Qabbari (west), Al-Attarin (at the CBD in the middle), Sidi Bisher (east). These four suburbs became secondary central cities for new urban development. Then a reciprocal attraction accoutred between the old city and these suburbs, and later the boundaries were merged. Starting from the second half of the 20th century (3rd stage) and so far, the Realm urban model is suitable to represent the contemporary urban growth situation. In that stage, the suburbs became independent urban centers and don't rely on the CBD. Seven suburbs (Realms) are coexisting with the traditional centers were identified as follows: Al-Montazah (residential in the north, industrial in the west, and agricultural in the south), Sidi Gaber (mainly residential), CBD (where Alexandria university and important cultural sites are existing), Qabary-Wardyan (occupied mainly by ports, residential and arsenal), Dekhila-Agamy (in the west, characterized with residential and industrial activities), Amrya-King Mariute (located south of Lake Mariute, dominated by industrial, agricultural and land development activities), and Burg Al-Arab (located in the far west, and dominated by tourism in the north and industry in the south), as indicated in the figure (3-4).

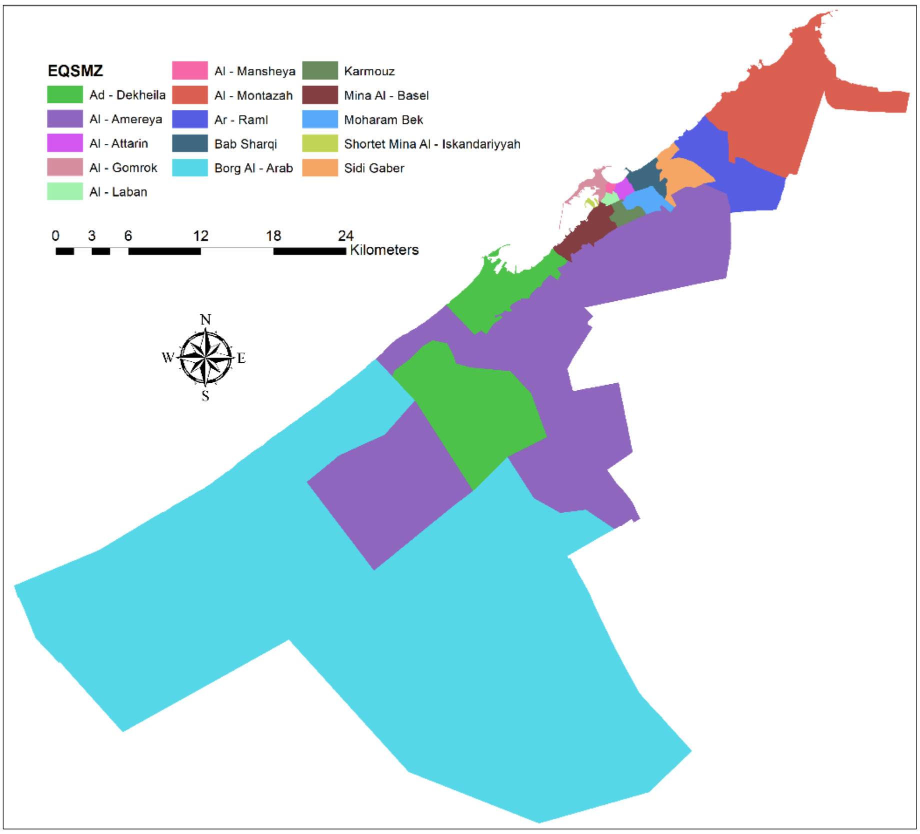


Figure 3-4: Qisms of Alexandria governorate

3.3. Planning system in Egypt (framework and environmental policy)

The planning system in Egypt has witnessed noticeable progress in urban development planning. However, there is still undesired environmental implications due to uncontrolled rapid urban expansion and unplanned urban developments in some location leading to the informal settlement. As shown in figure (3-5), Egypt is divided into seven economic areas (Greater Cairo, Alexandria, Delta, Canal, North Upper Egypt, South Upper Egypt, and Asyut) which are cascaded to five local units (on different levels) with a definite legal status forming: governorates, cities, Markaz (Kism), district (Hai), and villages (Shieakhah). Local government units are in charged to launch and manage public services and design industrial areas within their districts. The governorates are formed by a presidential decree and the president selects the governors. The governors form the main units of the local administration system in the country, with no political role. Markas (Kism), cities and Hai are formed by a decree from the prime minister. While, villages (Shieakhah) are formed by a decree from the governor according to the public council of the Markaz, and the approval of the local governorate (Tag-Eldeen, 2012). Egypt consists of 27 governorates with two Zeinab types: urban simple and complex. The central government is responsible for the execution and implementation of policies at higher levels and the governorate employees are selected by the central government. Since the year 1979, a parallel system was regularized to allow for elected “local popular council” to represent population on the governorate and district level (Khalifa, 2015; Khalifa and Connelly, 2009; Khalifa, 2012).

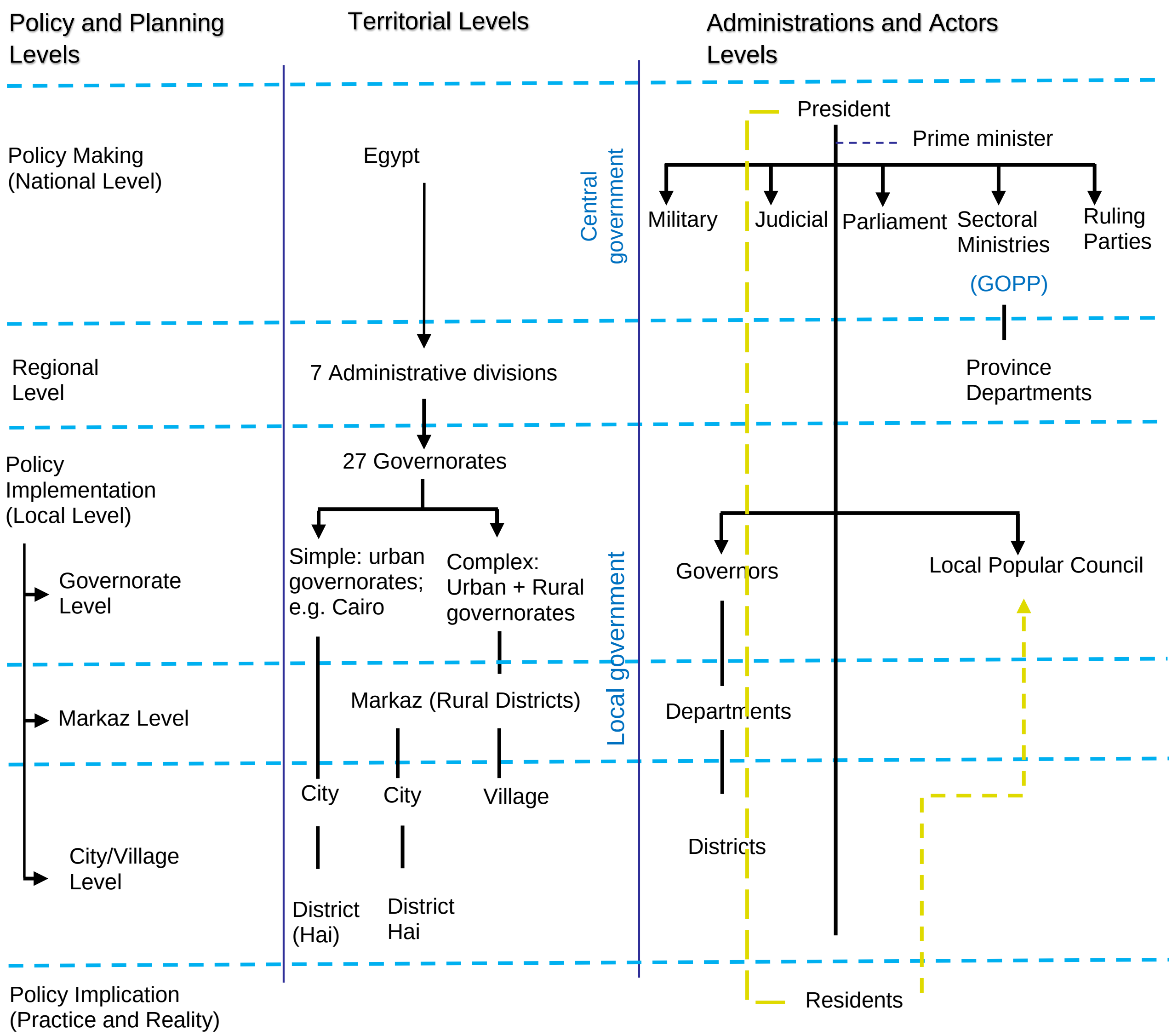


Figure 3-5: Spatial planning system in the Egyptian context
Source: based (Kenawy *et al.*, 2017; Tag-Eldeen, 2012)

As indicated in the figure (3-6), planning in Egypt starts at the national level through a socio-economic development plan (as stated in law 70 of 1973), which is divided at lower levels into plans, programs and projects. According to the local administration act 34 of 1979; projects are guided by the national development plan. Socio-economic national development plans direct public and private investments. The plans set objectives for different sectors of development. Accordingly, they are considered as the direct cause for the success or failure of investments’ relocation.

After the year 2005, the planning process was shifted to a strategic urban development plan focusses on urban development according to the building law 119 of 2008. This is considered the theoretical interpretation of how urban development is planned in Egypt, however, the development process in Egypt, in reality, is complex and involves many actors with blurred and duplicated roles. In that context, GOPP has initiated a holistic reform in the planning system by adopting the strategic urban planning approach aiming at ensuring stakeholders' involvement and achieving sustainable urban development (Khalifa and Connelly, 2009b). In that regard, two mega projects have been initiated in Egypt at the national level. These two projects namely Strategic and Detailed Urban Plans for the Egyptian Cities Project" (SDUPECP), and the second one is the "Strategic Urban Planning for Small Cities Project" (SUPSCP). The two projects targeted preparation of strategic urban plans for the entire Egyptian cities, 227 cities. SDUPECP targeted 177 large and medium-sized cities, and SUPSCP targeted 50 small-sized cities. Alexandria governorate was among the SDUPECP project (Khalifa, 2012).

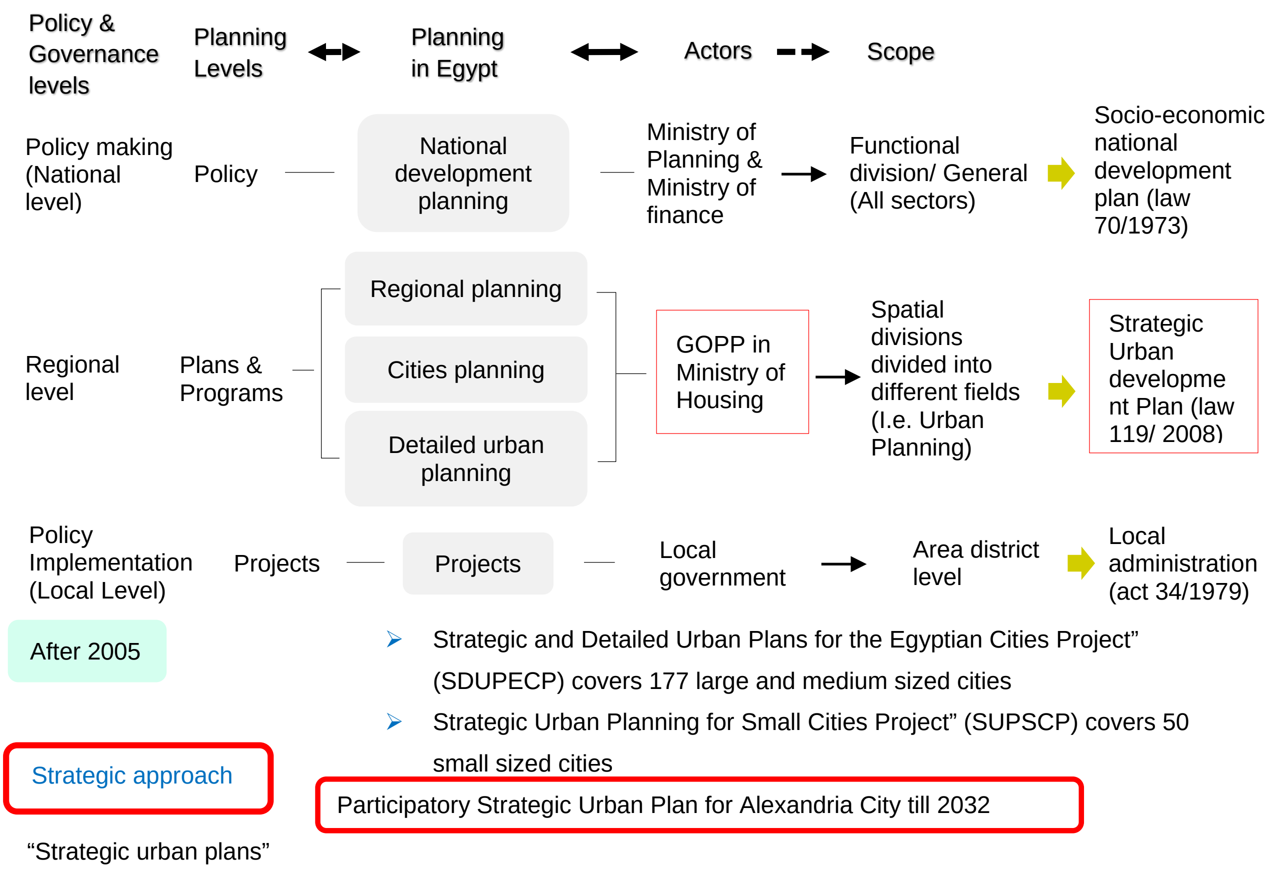


Figure 3-6: Urban development planning in Egypt for strategic urban plans
Source: based (Khalifa, 2012; Yousry, 2013)

3.4. Data collection

Availability of the spatial data is a wicked problem, especially in developing countries. Here arises the importance of the free source remote sensing satellite imageries, as a primary source for spatial data. Three sets of materials have been employed in the current study. The first data set used was obtained from the U.S. Geological Survey (USGS). Landsat 4 and 5 carry the TM sensors and image data files consist of seven spectral bands with 30 meters resolution. Landsat 7 satellite is equipped with Enhanced Thematic Mapper Plus (ETM+), the successor of TM. The observation bands are essentially the same seven bands as TM, and the newly added panchromatic band 8, with a high resolution of 15 m was added. The Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) are instruments onboard the Landsat 8 satellite, which was launched in February of 2013. Table (3-2) shows the different band characteristics of the satellite imageries for the different sensors. To cover all the investigation area, four scenes for each year were acquired with the following paths/rows: 177/38, 177/39, 178/38, and 178/39 for the years (1986, 1990, 2001, and 2016). The second set was a digital topographic map digitized from hardcopy topographic maps with a scale of 1: 50,000 were used mainly for geometric correction of the satellite images and some ground truth information, it was collected from General Organization for Physical Planning (GOPP).

Table 3-2: Remote sensing data used

Data type	Acquired date	Description	Source
Landsat 8_OLI	7, 16 Aug. & 15 Jul. 2016	4 scenes / 30m	United States Geological Survey (USGS)
Landsat 7 (ETM+)	25 Aug. & 14, 23 Jul. 2001	4 scenes / 30m	United States Geological Survey (USGS)
Landsat 4-5 (TM)	10, 27 Aug. 1990	4 scenes / 30m	United States Geological Survey (USGS)
Landsat 4-5 (TM)	10, 27 Aug. 1986	4 scenes / 30m	United States Geological Survey (USGS)
SPOT 7	8, 29 Mar. 2015 22 Jan.2015	3 scenes / 1.5 m	AIRBUS Defence and Space

The third set is based on GIS; ground information was collected between the year 2014 and the year 2017 for land features' classification, accuracy assessment, suitability analysis, and urban growth simulation. The collected data for that purpose is indicated in the table (3-3). Access to the socioeconomic areas and urban areas is considered a suitable indicator which is influencing the urban growth. In the current study, urban clusters (CBDs) were used and can reflect the impact of accessibility on urban growth development at different levels. Also, transportation has a vital role part in the urban growth process as it increases accessibility. The current study considered major roads (national, province-level roads and city arterial road) and minor roads (the remaining roads). In this study, the accessibilities were calculated as the Euclidean distance using Spatial Analyst in ArcGIS 10.2. It's very important to mention here that the traffic system changes dramatically over time and it's hard to simulate the dynamic process for long time spam. So, it was assumed that the transportation system remains unchanged during each time spam (from 1986 till 1990 for instance) from one hand. On the other hand, the updated transportation system was used for the next periods (from 1990 till 2001), to, consider the transportation' temporal dynamics. In other word, a layer of the transportation system for the year 2001 is used to simulate urban growth from the year 2001 till the year 2016 without changes in the transportation system during that time.

The political variables could be constraint or incentive for urban development. The political variable here is represented in master or action plans. The strategic urban plan 2032 for the Alexandria governorate was used for urban growth development scenarios. In that plan, the land-use map was provided indicating the planning regulations and land use type (assigned urban development areas) for each parcel.

Table 3-3: Input data used for the CA-based model implementation.

Category	**Variable**	**Source**
Strategic Urban Plan 2032	---	General Organization for Physical Planning
Physical	Beach/Coastline	Alexandria Research Centre for Adaptation to Climate Change
	Recreation	
	Hydrology	
	Schools	
	Utilities & facilities	
	Industry	
	DEM	Global Land Cover Facility (GLCF)
	Slope	Author
Administrative	Markaz and Qism	National Authority for Remote Sensing & Space Sciences
	Governorate	
	CBD	
Economic	Agriculture	National Authority for Remote Sensing & Space Sciences
	Urban areas 1986, 1990, 2001, 2016	
	Roads	
	CENSUS	Central Agency for Public Mobilization

		and Statistics
	Natural protected areas	National Authority for Remote Sensing & Space Sciences
Settlement system	Urban implementation action plans	Department of Planning and Urban Design, Faculty of Engineering, Ain Shams University
	Coastal development plans	
	Building density	
Relational system	Distance to transportation networks	Processed by the Author
	Distance to open space (undeveloped)	
	Distance to national parks	
	Distance to water resources	
	Distance to shoreline	
	Distance to agriculture areas	
	Distance from desert (rural)	

4. CHAPTER FOUR: METHODOLOGY

LULC changes seem to be an obvious choice to track and simulate the future trends of the urban growth process. LULC change detection and urban growth prediction, on the other hand, can properly be used by planners and geo-specialists during the preparation of the action plans and environmental planning. GIS, remote sensing and Cellular automata can facilitate the process of spatial information to be suited to adapt to the dynamic and changing the coastal cities; e.g. urban growth, water bodies, coastal erosion… etc. As long as spatial planning refers to the methods used to influence the distribution of the activities in space, it is then very important to integrate planning in the process of coastal zone management. In most developing countries, the interface between socioeconomic development, urban growth, and environmental change has not been well understood and modeled (Bürgi *et al.*, 2005; Walker, 1987; Allen and Barnes, 1985). As the urban land-use practices - through its development plans – haven't given adequate attention in the coastal cities in Egypt, the author in that chapter proposed an approach using remote sensing, GIS, and Cellular Automata technology aiming at monitoring, simulation, management, and prediction of urban growth from coastal zone management perspective.

4.1. Land Use/Cover change detection

In this section of methodology, to investigate whether there are disparities between land-use practices and the laws and policies used for governing the coastal city Alexandria or not; two different methods have been applied; the qualitative method and the quantitative method. In the qualitative method, all ICZM projects and initiatives along with spatial planning and urban development plans have been reviewed and assessed. The quantitative method is aiming at quantification of land-use changes. Then the visualization of the influence of the coastal management policies and laws on land uses was presented.

4.1.1. Database pre-processing

Landsat Thematic Mapper (TM 4-5), Enhanced Thematic Mapper Plus (ETM+ 7) and, and Landsat 8-Oli Satellite imagery were used as primary data source obtained from earth explorer website (*http://earthexplorer.usgs.gov/*). Remote sensing and GIS were utilized for the extraction of land cover classes and detection of LULC changes for the years of 1986, 1990, 2001 and 2016, by the means of ENVI 5.1 and ArcGIS

10.2 software. Before the image classification, pre-processing steps were applied for the study area as follows.

4.1.1.1. Geometric correction

Analysis and change detection of the multi-temporal Landsat imageries is based mainly on pixel-by-pixel analysis, so errors in the images' registration or geospatial location of the data will produce anomalous results. To have accurate results for multi-temporal remote sensing data (one misregistered pixel can generate wrong data); i.e. the Root Mean Square Error (RMSE) shouldn't be more than 0.05 pixel, according to the following distance equation (N.G. Kardoulas *et al.*, 1996; Mosavi *et al.*, 2013; Morad *et al.*, 1996):

$$RMSE = \sqrt{(x_r - x_i)^2 + (y_r - y_i)^2} \qquad \text{Equation (4-1)}$$

Where; x_i and y_i are the inputs x and y source coordinates, and x_r and y_r are the retransformed x and y source coordinates, to avoid the distortion generated because of the curvature shape of the earth and present it on a planer surface. The process geometric correction is conducted through transforming data from a grid system to another, by; Image-to-map transformation (Rectification) or image-to-image registration (Abd El-Kawy *et al.*, 2011), both methods were applied to ensure accurate per-pixel registrations (geo-referencing) for the satellite images. Topographic maps of scale 1: 50,000 were used for rectification of the satellite images using ground control points. The new projection which was added to the entire used input data for this study is as follows: Spatial Reference: WGS_1984_UTM_Zone_36N & Projection: Transverse_Mercator & Linear Unit: Meter. All satellite images were then resampled to 30 * 30 m in the ArcGIS environment using the nearest neighbor algorithm to maintain the radiometric properties of the original data.

4.1.1.2. Atmospheric Correction

Satellite imageries are usually contaminated by the effects of atmospheric particles through absorption and scattering of the radiation from the Earth's surface in the visible and near-infrared wavelengths (Alesheikh *et al.*, 2007). The value recorded at any pixel on the raw image does not represent the true ground-leaving radiance. Part of the brightness is due to the reflectance generated from the land features and the remainder is from the brightness of the atmosphere itself. So, atmospheric correction retrieves the surface reflectance of the raw imagery by removing the atmospheric effects, to improve the accuracy of image classification (Kamusoko *et al.*, 2014; Rawat and Kumar, 2015). Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH) technique was applied by the means of ENVI 5.1 (El-Zeiny and El-Kafrawy, 2017; Feyisa *et al.*, 2014) through two steps. First is to the conversion of DN to Radiance, in which the recorded digital numbers (DN) of the raw images were converted to physical values (radiance values) on each band independently. Second is the conversion of Radiance to Reflectance, in which the radiance values were converted to top of atmosphere (TOA) reflectance which refers to the surface reflectance values as they are received at the sensor (Ke *et al.*, 2015). In each step, and to investigate whether the different bands can be separated; a mathematical operation called "Band Math" was applied in IDL function in ENVI 5.1 software to the bands of the calculated surface reflectance images through the following equation (Singh, 2018):

$$(\text{B1 le } 0) * 0 + (\text{B1 ge } 10000) * 1 + (\text{B1 gt } 0 \text{ and B1 lt } 10000) * \text{float}\,(\text{b1})/10000 \qquad \text{Equation (4-2)}$$

Where B1 is a channel or band which will be applied for every channel to scale the reflectance values within the range of 0 to 1, where is the 100% reflectance. Finally, the sub-setting of the satellite images was carried out for the extraction of the final administrative borders of the study area.

4.1.1.3. Satellite imageries enhancement and visual interpretation

It increases the distinction between the various features in the images and optimizes the users and computer' abilities. In supervised classification, some features or classes are spectrally confused and can't be accurately separated, so, Tasseled Cap Transformation (TCT) was applied for the satellite imageries using ENVI 5.1. For Landsat TM data, the tasseled cap vegetation index consists of three factors: Brightness, Greenness, and Third. For Landsat 7 ETM data and Landsat 8-OLI data, the TCT produces 6 output bands: Brightness, Greenness, Wetness, Fourth (Haze), Fifth, Sixth. Figure (4-1) shows the output bands for each Landsat data type.

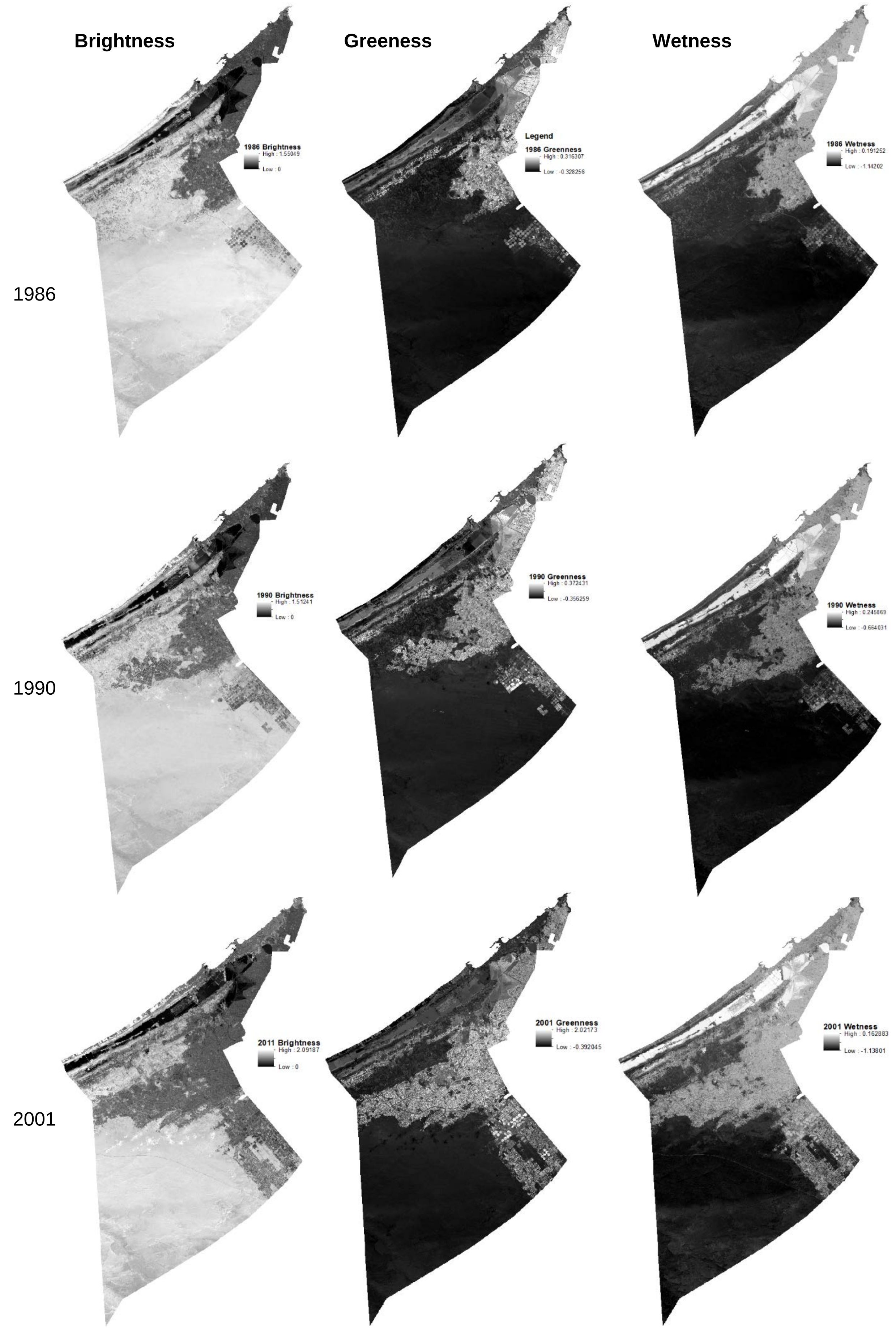


Figure 4-1: TCT for Alexandria governorate for the years 1986, 1990 and 2001

Conducting TCT was important as the resulting components are combined to refine and increase the accuracy of classified images. The brightness band shows more values for the land surface with no or low vegetation. Also, built-up areas and bare soil have higher values more than other classes in this band. Nevertheless, built-up and bare soil areas have lower values in the Greenness band. The Greenness band is associated with the green vegetation surface and the Wetness band is associated with soil moisture, water, and other moist features. Accordingly, it was feasible to define threshold' values generated by TCT to more efficiently distinguish the different land features in the classification process. These three bands are extremely important because of the misclassification and mixed pixels in the study area especially between water bodies and croplands classes.

4.1.2. Land Use/Cover features' extraction

To conduct LULC features extraction, a hybrid classification method was applied. Multi-temporal NDVI, NDWI, and SVM algorithm features derived from sixteen satellite imageries from 1986 to 2016 to assess land cover changes in the Alexandria governorate. Eight LULC types were identified (urban built-up, Lake, Fish Farms, Crop Lands, Desert, Undeveloped (open space), sandy beaches, Reclaimed), as described in table (4-1).

Table 4-1: Description of the different land use/cover classes in the investigation area

Class	Description
Urban built-up	Residential, commercial services, industrial, transportation, communications, mixed urban or built-up land, other urban or built-up land
Croplands	Vegetation, gardens, cultivated lands, rice and maize farms, groves, ornamental horticulture area
Open space	Piece of land that is undeveloped (has no buildings or other built structures or facilities) and is accessible to the public.
Reclaimed	Transition land state between desert and agricultural land and rural settlements
Lake Mariute	Permanent open water, lakes, reservoirs, streams, and canals
Fish farms	Involves raising fish commercially in enclosures such as fish ponds, or aquaculture
Sandy beach	Dunes are made of sand
Desert	barren area

Urban areas in the study area typically include a complex combination of building, open space, croplands and water bodies. A problem of the mixed pixel is created, where several land-use types are contained in one pixel. Also, there is Misclassification and spectral similarity was often found between Croplands and water bodies due to rice fields and many plantations in the Lake Mariute, as shown in the figure (4-2). So, because of misclassified pixels, firstly two indices were created to classify the satellite images: Normalized Difference Vegetation Index (NDVI) for vegetation areas through application of the equation [(NIR - R) / (NIR + R)] and Normalized Difference Water Index (NDWI) equation [(NIR - GREEN) / (NIR + GREEN)] for water bodies (Vermote *et al.*, 2016; Sarp and Ozcelik, 2018; Gautam *et al.*, 2015; Ding *et al.*, 2014). Table (4-2) shows the detailed of the used bands for each index with the corresponding image.

Table 4-2: Bands used for calculation indices for different imageries

	Landsat 4-7	**Landsat 8**
NDWI	(Band 5 – Band 2) / (Band 5 + Band 2)	(Band 6 – Band 3) / (Band 6 + Band 3)
NDVI	(Band 4 – Band 3) / (Band 4 + Band 3)	(Band 5 – Band 4) / (Band 5 + Band 4)

Figure 4-2: Rice fields and the contaminated Lake Mariute with plantations

While, supervised classification-based method was conducted using Support Vector Machine (SVM) Algorism in ENVI 5.1 software environment (Heumann, 2011; Ma *et al.*, 2017; Otukei and Blaschke, 2010; Singh *et al.*, 2014). SVM algorism is a supervised classification technique derived from statistical learning theory and always records accurate results from complex and noisy raw data (Masria *et al.*, 2015). SVM is one of the latest additions to the existing methods of image classification techniques. Recent research has demonstrated that SVM compares favorably with more established classification techniques (Kamusoko *et al.*, 2014). It separates the classes with a decision surface that maximizes the margin between the classes. The surface is often called the optimal hyperplane, and the data points closest to the hyperplane are called support vectors (Szuster *et al.*, 2011). The support vectors are the critical elements of the training set. SVM uses the pairwise classification strategy for multiclass classification. It is a binary classifier in its simplest form; it can function as a multiclass classifier by combining several binary SVM classifiers (creating a binary classifier for each possible pair of classes). The classified images were refined 3*3 majority analysis to remove odd pixels in the matrix and reduce noise in the output maps for better visualization.

4.1.2.1. Accuracy assessment

Depending on the acceptable level of error (must not be less than 85%), the author was able to determine whether the classification results are meeting the required level of accuracy or not. In this section of methodology, three accuracy matrices were applied, namely; overall accuracy, Kappa Coefficient, producer and user’s accuracy (Otukei and Blaschke, 2010; Sarp and Ozcelik, 2018; Singh *et al.*, 2014). The overall accuracy here investigates the proportion of the reference sites which were correctly mapped and expressed as a percentage. Kappa Coefficient can range from -1 to 1. A value of 0 indicated that the classification is no better than a random classification. A negative number indicates the classification is significantly worse than random. A value close to 1 indicates that the classification is significantly better than random. The producer’s accuracy clarifies the complement of the Omission Error and = [100%-Omission Error]. It is corresponding to the error of omission (exclusion). While, the user’s accuracy is the error of commission (inclusion) and = [100%-Commission Error] (Feyisa *et al.*, 2014; Frazier and Page, 2000; Aldwaik and Pontius, 2013).

The author has collected field verified ground reference locations (180 GCPs) for the test by the means of global Positioning System (GPS) distributed across the study area and distinct from the training areas used for the supervised classification (from 20 to 25 points were specified for each land-use type). These reference points have been processed in the environment of ArcGIS 10.2 and an Excel sheet to create the confusion matrix. It was important to have at least ten times the number of pixels for each class more than the total number of the classes; i.e. if there were eight land cover classes, then there should be eighty test pixels for each land cover, hence, a total of 640 test pixels. It is worthy to indicate here that, it is not always possible or doable to have an equal number of pixels for each class in a classification.

4.1.3. Land Use/Cover Change detection

Figure (4-3) shows the general steps of land cover change detection. By the means of ENVI 5.1 and ArcGIS 10.2 environment, a change matrix of various land types was produced to quantify changes (gains or losses) between the years 1986-1990 and 1990-2001 and 2001-2016.

In the literature, there were many techniques applied to record the image difference, ratios, and correlation. Simple change detection is sufficient, as it requires initial and final land cover maps (from-to) analysis (Chen *et al.*, 2003; Chowdhury *et al.*, 2018; Abd El-Kawy *et al.*, 2011; Alesheikh *et al.*, 2007; Brown, 2006; El-Asmar *et al.*, 2014; Iqbal and Khan, 2014; Al-Gaadi *et al.*, 2011; Masria *et al.*, 2015). In some cases, the image differences are associated with some confusion and problematic classes or phenology in the area of investigation. That, in turn, can exacerbate the change detection analysis especially in the light of limited availability and poor quality of satellite imageries. Therefore, the degree of post-classification success depends on the reliability of the maps generated by land features' extraction (image classification). Land-use changes mean the difference of certain land use within the time dimension. The post-classification detection method was used for performance

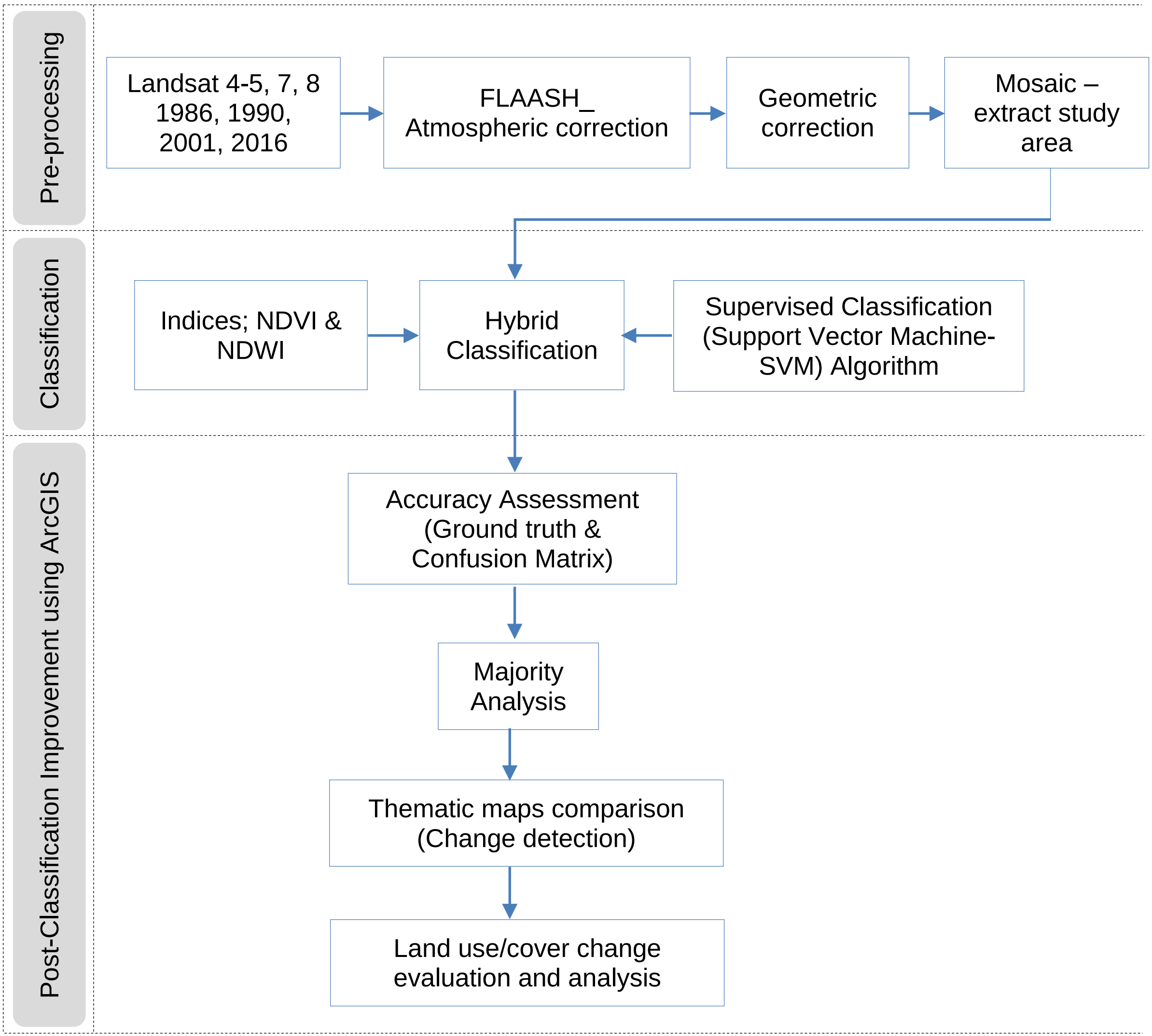


Figure 4-3: Flow chart of LULC classification and change detection method

LULC change detection by using pixel-based comparison. LULC changes for the years of 1986, 1990, 2001, 2016.

4.2. Land Suitability Analysis

To create a well-informed PSS platform used in decision-making process, it was important to have experts' knowledge, information of different formats, and develop an interactive technique between geo-specialists, planners, and decision-makers. Therefore, a Semi-structured interview for defining land suitability criteria for new residential areas was conducted. As indicated in table (4-3), twenty-three (23) experts, most of them involved in the decision-making process, have proposed ten criteria affecting residential development, namely; distance to residential areas, proximity to utilities, distance to schools, distance to recreational areas, distance to transportation, distance to industrial areas, proximity to croplands, proximity to coastline, proximity to water bodies, and land-use/cover map. These criteria were represented as map layers using ArcGIS. The experts have introduced their preferences in the form of numbers according to a scale (1 to 9 and 1/2 to 1/9). These values have been used to build the matrix which consists of the ten criteria. After the standardization of the matrix, the criteria weights (the relative importance of each criterion) were calculated. The experts also can keep providing with their feedback in the analysis and results through the sensitivity analysis, if the created matrices were not consistent.

Table 4-3: Criteria affecting suitable land for urban growth

Factors	**Description**
Distance to residential areas	Land-use/cover in which housing predominates
Proximity to Facilities and Utilities	Including electricity, gas, and water supply
Distance to Schools	Educational facilities
Distance to recreation areas	Areas used by the public for recreation including; gardens, environmental protected areas, parks, green open spaces
Proximity to Transportation system	Including main roads, railways
Distance to Industrial Areas	Geographical locations with extremely dense industrial activities including; petrochemical, ports, mining. It is usually heavily urbanized
Proximity to Croplands	Vast fields of mainly; maize, rice, cotton, vegetables, wheat, clover, beans
Proximity to Coastline	region where interaction of the sea and land occurs, made of sandy dunes
Proximity to Water Bodies	Freshwater resources of Lake Mariute and irrigation canals
Land-use type	Eight classes land use/cover map of the year 1986

Two techniques namely; Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) were integrated and widely applied to obtain preference weights of land suitability criteria and generate the decision map, respectively as in (Boroushaki and Malczewski, 2010; Chen and Paydar, 2012; Demesouka *et al.*, 2013; Dragan *et al.*, 2003; Hood *et al.*, 2006) based on facts, value judgments and extensively experts' knowledge of urban land use suitability (Khahro *et al.*, 2014; Latinopoulos and Kechagia, 2015; Malczewski, 2004; Chow and Sadler, 2010; Thinh *et al.*, 2004; Mosadeghi *et al.*, 2015). Figure (4-4) shows the general framework for land suitability analysis. In the next section, detailed processing procedures of methodology were investigated.

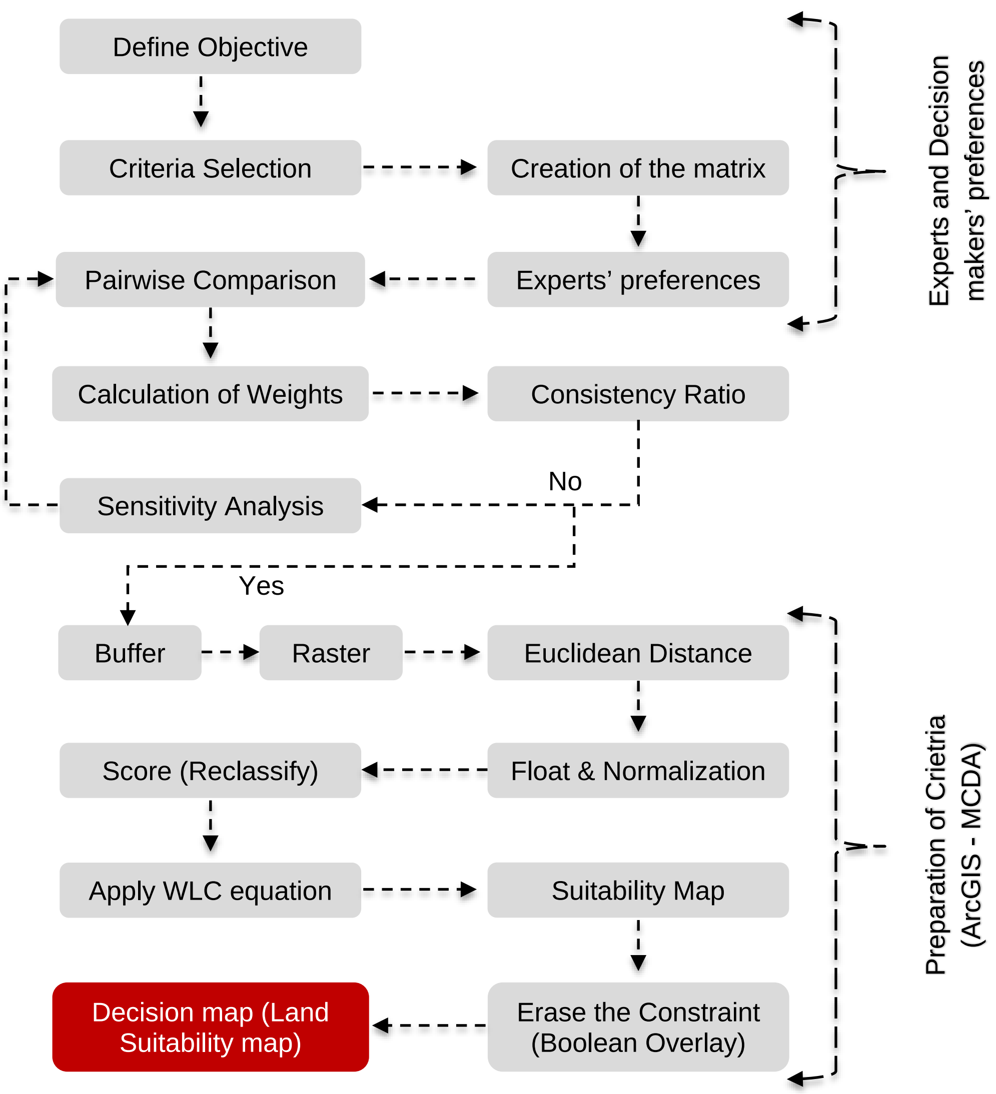


Figure 4-4: General framework for land suitability analysis (Source: Author)

4.2.1. Processing of the criteria layers for land suitability analysis

a) Buffer

Buffer in ArcGIS is a proximity analysis used to create polygons based on a specified distance from the original geometrical feature resulting a larger zone or region that surrounds and encompasses the feature as an output (Al Garni and Awasthi, 2017; Baskurt and Aydin, 2018; Comino *et al.*, 2016; Demesouka *et al.*, 2013; Gbanie *et al.*, 2013). In case the input feature is a line (e.g. roads, coastline, railways, or facilities and utilities); the 'end type' parameter controlling whether the ends will be round or flat, and 'side type' parameter controlling which side of the line creates the offsets. In the case of polygons, input features (water bodies or industrial areas) 'outside type' option only will be used, as indicated in the table (4-4).

Table 4-4: Buffer zones around different land use/cover features

Restriction Source	Minimum Buffer Distance (m)	Maximum Buffer Distance (m)	Used Buffer Distance (m)
Rivers	30	200	200
Streets	100	300	300
Parks	300	3000	1000
Industrial	1000	3000	1000

b) Raster

Given all the processing was conducted in the 2-D array of the input layers, the input data for suitability analysis were converted into raster. In the case of polygons; cells are usually given the value of the polygon found at the center of each cell. While in the case of polylines; cells were usually given the value of intersecting each cell, and not intersecting cells by a line were given NoData. In the case of points; cells were usually given the value of the points found within each cell and cells without points were given NoData values.

c) Distance

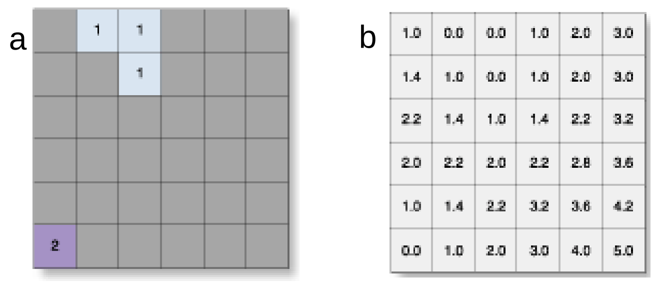


Figure 4-5: Euclidean distance on raster data

To assign the space that exists from a certain distance to another distance, Euclidean distance was used in ArcGIS environment (Hariz *et al.*, 2017; Irfan *et al.*, 2017; Mahdy and Bahaj, 2018; Rekha *et al.*, 2015; Pilehforooshha *et al.*, 2014). The

Euclidean distance here means the "ordinary" straight-line distance between two points in Euclidean space. It calculates for each cell the Euclidean distance to the closest source (input feature in the raster form).

As indicated in the figure (4-5_ a), number one here means a land-use feature, assume it is a road. The output Euclidean distance (4-5_ b) is the distance from the road to the surrounding cells, zero doesn't mean NoData, but means that the distance is zero. Figure (4-6) shows the resulting Euclidean distances for the used criteria.

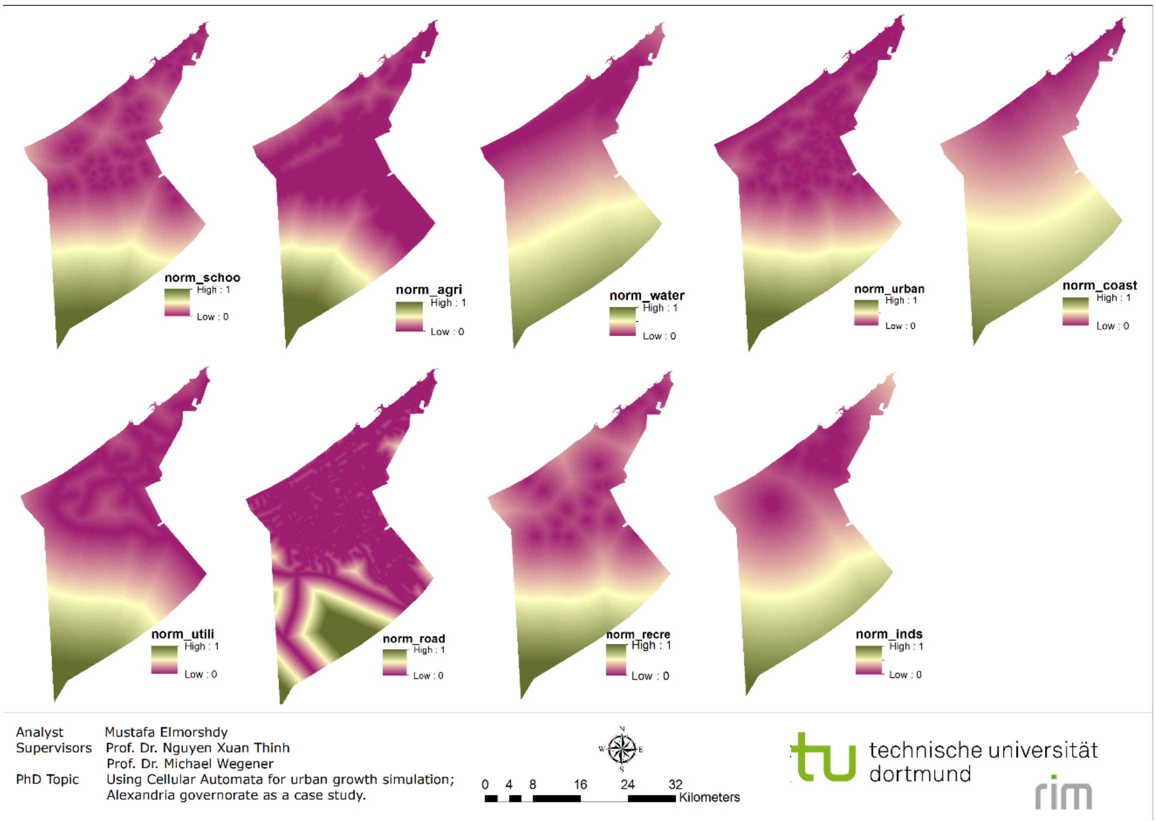


Figure 4-6: Suitability criteria; calculated Euclidean Distance

d) Normalization

Given the factors have different scales; standardization (normalization) is an important step, in which a common scale was given to all input factors used in the WLC to generate the decision map and overcome the problem of comparing different inputs (Rebolledo *et al.*, 2016; Vettorazzi and Valente, 2016; Comino *et al.*, 2016; Demesouka *et al.*, 2013). There are various methods and procedures for standardization, typically using the minimum and maximum values as scaling points, the linear scaling method was used in the standardization of the factors, as the following formula shows (Romano *et al.*, 2015):

$$x_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})} . SR \qquad \text{Equation (4-3)}$$

Where; R_i is the raw (original) score of the factor i, R_{min} is the minimum score, R_{max} is the maximum score, and SR is the standardized range.

e) Reclassify 'Score'

Figure (4-7) shows the reclassified criteria used for land suitability analysis (Abudeif *et al.*, 2015; Zolekar and Bhagat, 2015; Yalcin, 2008). Reclassification tools in the ArcGIS environment responsible for changing the old values in the raster layers into new values representing the importance of being close or far away from a certain feature (ranges from 1 to 9), as indicated in the figure (4-8). The land use/cover preferred by new urban areas were reclassified to higher values (e.g. recreational, facilities, schools, existing residential areas) and those less preferred were assigned lower values (e.g. industrial areas, water bodies).

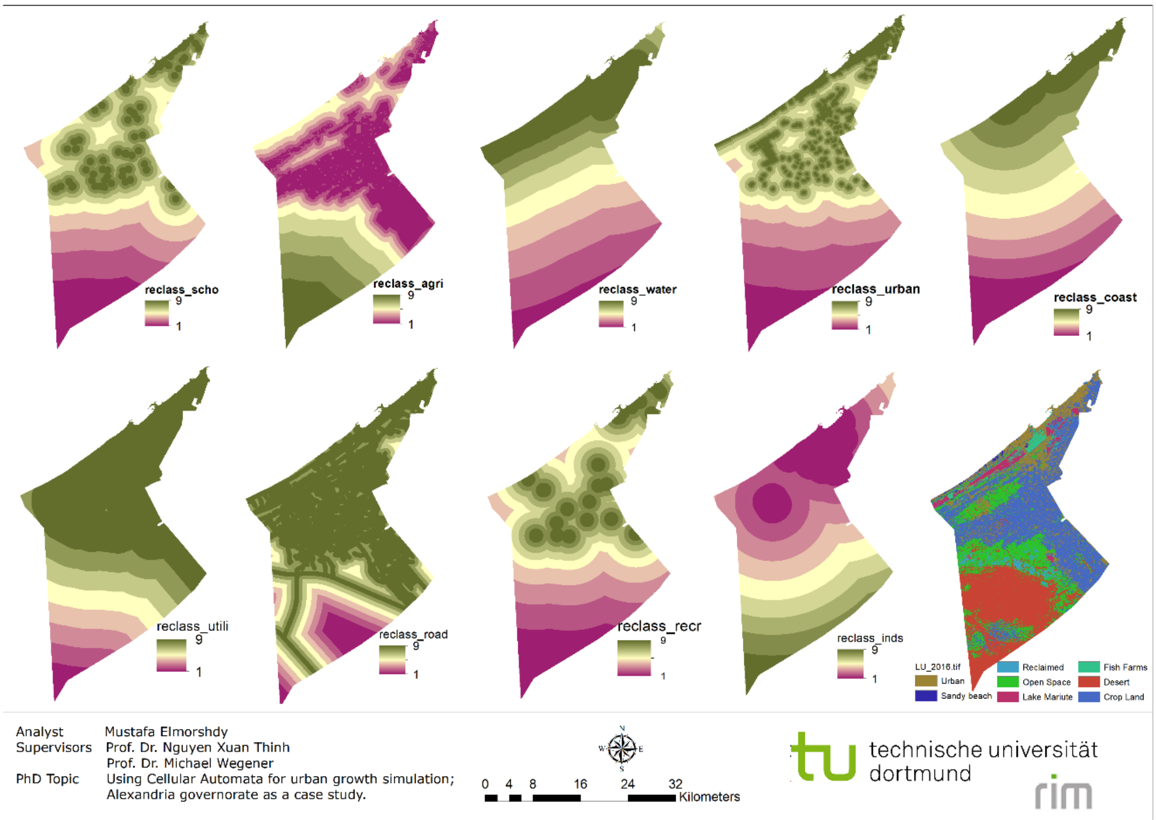


Figure 4-7: Suitability criteria; reclassified with assigned scores

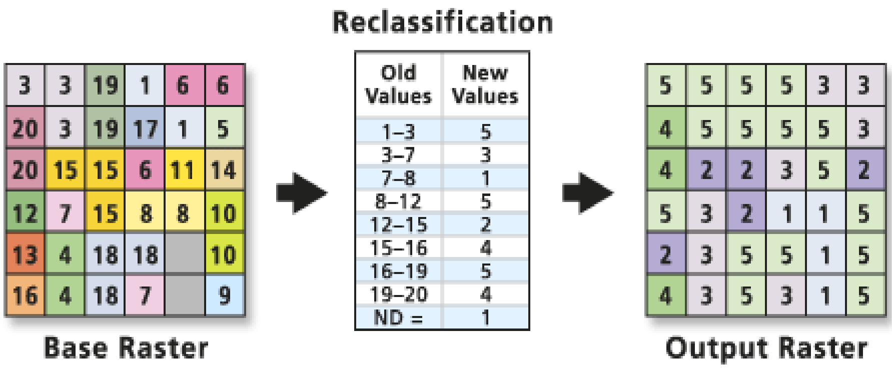


Figure 4-8: Reclassification of the raster values and adding scores

f) Weighting Criteria

In MCDM, information about relative importance can be accomplished through assigning a weight for each criterion (Sener *et al.*, 2010; Sindhu *et al.*, 2017; Pontius and Si, 2015; Pourebrahim *et al.*, 2011). The pairwise comparison method in AHP was used in the determination of the criteria weights. Comparison between the criteria based on two questions; which is more important with respect to the criterion? How strong? Based on the Saaty's nine-point weighing scale in the table (4-5), the criteria's importance was codified (Taheri *et al.*, 2015; Abudeif *et al.*, 2015; Al Garni and Awasthi, 2017; Boroushaki and Malczewski, 2008). Figure (4-6) shows a pairwise comparison matrix (ratio matrix) for land suitability ten factors.

Table 4-5: Saaty's nine-point weighing scale
Source: Author, modified based on (Saaty, 1987)

Description	**Index**	**Description**	**Inverted Index**
Equally important	1	Equally important	1/1
Equally or slightly more important	2	Equally or slightly less important	1/2
Slightly more important	3	Slightly less important	1/3
Slightly too much more important	4	Slightly to a way less important	1/4
Much more important	5	Way less important	1/5
Much too far more important	6	Way too far less important	1/6
Far more important	7	Far less important	1/7
Far more important to extremely more important	8	Far less important to extremely less important	1/8
Extremely more important	9	Extremely less important	1/9

Table 4-6: Pairwise comparison matrix (ratio matrix) for land suitability ten factors.

	Dist 2 Resid	Dist 2 Urtilities	Dist 2 Schools	Dist 2 Recreat.	Dist 2 Transport.	Dist 2 Industry	Dist 2 Agri.	Dist 2 Coastline	Land Use	Dist 2 Lakes
Dist 2 Resid	1	2	3	4	3	5	6	4	3	8
Dist 2 Urtilities	1/2	1	2	3	1/2	4	5	2	2	6
Dist 2	1/3	1/2	1	2	1/2	3	4	3	1/2	4

Schools										
Dist 2 Recreat.	1/4	1/3	1/2	1	1/3	2	3	1/2	1/2	4
Dist 2 Transport.	1/3	2	2	3	1	4	5	2	1/2	5
Dist 2 Industry	1/5	1/4	1/3	1/2	1/4	1	1/2	1/3	1/4	2
Dist 2 Agri.	1/6	1/5	1/4	1/3	1/5	2	1	1/2	1/3	1
Dist 2 Coastline	1/4	1/2	1/3	2	1/2	3	2	1	1/3	3
Land Use	1/3	1/2	2	2	2	4	3	3	1	4
Dist 2 Lakes	1/8	1/6	1/4	1/4	1/5	1/2	1	1/3	1/4	1

g) Consistency Ratio

To determine the inconsistency judgements to ensure the reliability of the AHP results, the Consistency Ratio (CR) was calculated (Boroushaki and Malczewski, 2008; Chow and Sadler, 2010; Khahro *et al.*, 2014; Liaghat *et al.*, 2013). The largest eigenvalue (λ_{max}) in any reciprocal matrix is equal to or greater than the number or rows or columns (n). In another word, if $\lambda_{max} = n$, that means that the pairwise comparison matrix is consistence, and the closer the values of (λ_{max}) to (n), the more consistent the comparisons. The value of the CR should be 10% (or 0.1) or less, otherwise it will not be accepted and need to be back to the experts (Chen *et al.*, 2010; Al Garni and Awasthi, 2017; Moeinaddini *et al.*, 2010; Rekha *et al.*, 2015). Calculation of the inconsistency of the pairwise comparisons can be conducted as follows: first calculation of Consistency Index (CI), equation (4-4) as (Al Garni and Awasthi, 2017; Singh *et al.*, 2017; Sener *et al.*, 2010; Tsangaratos *et al.*, 2017; Chow and Sadler, 2010);

$$CI = (\lambda_{max} - n)/(n-1)$$ Equation (4-4)

Also, measuring the coherence of the pairwise comparison can be obtained from the (CR) equation (4-5) as following (Mahdy and Bahaj, 2018; Sindhu *et al.*, 2017):

$$CR = \frac{CI}{RI}$$ Equation (4-5)

The consistency index (CI) divided on the ratio of Random index (RI) gives CR. RI depends on the number of elements being compared (i.e., size of pairwise comparison matrix) and takes the values as in table (4-7).

Table 4-7: Random Indices (RI) for matrices for various sizes.
(Al Garni and Awasthi, 2017; Tsangaratos *et al.*, 2017; Boroushaki and Malczewski, 2008)

n	1	2	3	4	5	6	7	8	9	10	11	12	13
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56

4.2.2. Weighted Linear Combination (WLC)

The decision suitability map for the year 1986 was developed by the summation of the multiplied each weight of each factor by its value through applying WLC (Salim, 2012). WLC technique is based on the following equation (4-6) (Abudeif *et al.*, 2015; Baskurt and Aydin, 2018; Berry and BenDor, 2015):

$$S = \sum W_i * X_i \qquad \text{Equation (4-6)}$$

Where; S means suitability, W_i means the weighting for the factor i, and X_i means the criterion score of factor I (Liaghat *et al.*, 2013). In the current research, freshwater resources, fish farms, and transportation were considered constraints, so, Boolean constraints were applied through the classification of the images with values 1 and 0, also called binary maps. Accordingly, the equation was slightly modified by multiplying the suitability calculated by the constraints, equation (4-7) (Abudeif *et al.*, 2015; Gbanie *et al.*, 2013; Mahdy and Bahaj, 2018):

$$S = \sum W_i * X_i * \prod c_j \qquad \text{Equation (4-7)}$$

Where; c_j here represents the score of the constraint j. Once the criteria maps are developed, the WLC aggregation method multiplies each standardized factor map (i.e., each raster cell within each map) by its corresponding weight and then sums the results. The sum of the set of factor weights for evaluation must be equal to '1', the resulting suitability\decision\composite map generated have the same range of values, because the used factors were standardized. The developed suitability model for suitability analysis was introduced in the Annex figure (0-1).

4.3. Development of the CA-based model and urban growth simulation

The developed CA-based model in this study is based on the theoretical premises proposed by (White and Engelen, 1993, 1994, 1997, 2000; Chen and Mynett, 2003). Implementation of CA algorithms on simulation of a real case study is much more complicated than an artificial case study simulation, which is due to the complex structure of the real city and the complex interaction of the development factors resulting in the urban development and growth patterns (Liao *et al.*, 2016; Nor *et al.*, 2017; Pontius *et al.*, 2008; Verstegen *et al.*, 2014; Shafizadeh and Helbich, 2013). In the current section, the author introduced a description of the mathematical formulas which were used to calculate the transition potential of the model:

4.4.1. Transition rules

In the area of investigation, the model estimates the transition potential for each cell obtained from combination of four factors: neighborhood, suitability, constraints, and stochasticity as indicated in the equation (4-8) (Jafari *et al.*, 2016; Santé *et al.*, 2010; Triantakonstantis and Mountrakis, 2012a; Chen and Mynett, 2003; Dahal and Chow, 2015; White and Engelen, 1994; Santé *et al.*, 2010; Barreira González *et al.*, 2015; Li Cheng, 2014). The definition of transition rule plays an important role in CA models (Feng *et al.*, 2016; Barredo and Demicheli, 2003; Li Cheng, 2014). The transition potential method was used to calculate the transition rules:

$$P_{ij} = S_{ij} * N_{ij} * CONS_{ij} * V_{ij} \qquad \text{Equation (4-8)}$$

Where; the transition potential P_{ij} can be practically defined as a function of the global suitability value S_{ij}, neighborhood effects N_{ij}, constraints $CONS_{ij}$ and stochastic perturbation V_{ij}, which have been widely considered to be relevant in the development of similar CA-based models (Barreira González *et al.*, 2015; Moreno *et al.*, 2008; Pan *et al.*, 2010; Dietzel and Clarke, 2007; Barredo and Demicheli, 2003).

Suitability: it represents the capacity of each space in the investigation area to accommodate urban use, considering several variables; e.g. slope, elevation, distance to water, or natural protected areas (Barreira González *et al.*, 2015; Boroushaki and Malczewski, 2008). Suitability is calculated as a function of global spatial variables based on WLC technique, equation (4-9) (Store and Kangas, 2001; Tian *et al.*, 2016):

$$S_{ij} = \sum X_{l,ij} * W_l \qquad \text{Equation (4-9)}$$

Where; xl, ij (l=0, 1, 2… n) represents the values of global factors for the cell (i, j), wl represents the corresponding weight of the global factor.

*Neighborhoo*d: is an inherent factor in the model, as it estimates the probability of the change in each cell from non-urban to urban state depending on the neighboring land uses and the distance to the central cell (Barreira González *et al.*, 2015; Zhao *et al.*, 2008). Neighborhood score was calculated according to equation (4-10):

$$N_{ij} = \sum_c W_{mn} \times I_{mn} \qquad \text{Equation (4-10)}$$

Where; Nij is the effect of neighborhood cells on the central cell (i, j) within the neighborhood space c; Wmn is the weight indicating the impact of the interaction between the central cell and cell (m, n) within the neighborhood (Zhao *et al.*, 2008).

Cells' weights in Neighborhood: weighting functions were applied to define the weights Wmn for cells within the neighbourhood, as indicated in equation (4-11) expresses calculation of weights of the cells in the neighborhood (Barredo and Demicheli, 2003; White and Engelen, 2000):

$$W_{mn} = exp(-\beta * D_{mn})$$ Equation (4-11)

Where; Dmn is the distance between the cell (m, n) to the central cell within a neighborhood. β is the exponent of the function.

Constraints: the total constraint score was calculated as in equation (4-12) (Store and Kangas, 2001; Abudeif *et al.*, 2015):

$$CONS_{ij} = \prod_{f=1}^{n} cons_{ij,f}$$ Equation (4-12)

Where; $CONS_{ij}$ is the total evaluated constraint score representing natural constraints to urban expansion. If $CONS_{ij}$=0, cell (i, j) is constrained and cannot be converted to urban land use. On contrast when $CONS_{ij}$=1, represents the binary value of constraint factor f for the cell (i, j) (Abudeif *et al.*, 2015). In this study, water bodies and roads are considered constraint areas. These restricted places for urban development can help and contribute actively in the formulation of future sustainable urban development action plans aiming at the reduction of the pollution levels and conserve the ecological balance in the cities.

Stochasticity: is also known as randomness. Considering the randomness and complex elements participate in the urban growth development are subject to a degree of uncertainty, which is a typical component of urban spatial processes (Barreira González *et al.*, 2015; White and Engelen, 1993, 1994; Zhao *et al.*, 2008; Barredo *et al.*, 2004). Thus, a stochastic disturbance parameter was introduced into the model, equation (4-13) determines Stochasticity:

$$V = 1 + (-\ln(rand))^{\propto}$$ Equation (4-13)

Where; $rand$ is a random value within the range from 0 to 3, and α is random variable which is used to control the degree of Stochasticity (degree of perturbation or dispersion) (White and Engelen, 1993; Santé *et al.*, 2010; Barreira González *et al.*, 2015; Mustafa *et al.*, 2014).

The definition of the four components of the CA-based models, which are: Lattice, cell state, neighborhood effects, and the transition rules are of great importance.

These components were defined as following (Pérez-Molina *et al.*, 2017; Feng *et al.*, 2016; She *et al.*, 2017):

- *Lattice*: the shape of the study area was selected of raster data in ArcGIS environment to be unified for all input layers and equal to Columns and Rows of 687*1214 and the size of each cell equals 100*100 m (Dahal and Chow, 2015; Malczewski, 2004; Barredo and Demicheli, 2003; Malczewski, 2004; Pan *et al.*, 2010; Li Cheng, 2014) after resampling the entire input raster data and layers.
- *Cell state*: two cell states were defined in the developed model, urban cell state with the value of 1 and the non-urban cell state with the value of 0, as in (Barredo and Demicheli, 2003).
- *Neighborhood*: in this study three types of the neighbourhood were defined; Moore, Von Neumann, and Von Neumann circular, as in (Chen and Mynett, 2003; Malczewski, 2004).
- *Transition rules*: transition rules were defined as following (Samat, 2006):
  - If the state of a cell is urban, then the state of the cell will not be changed in simulation periods.
  - If the state of a cell is constrained, then the state of the cell will not be changed in simulation periods.
  - If a cell is closer to the affecting factors, then its probability for transformation to the urban state will increase.
  - Cells with more urban state neighbors have more probability of transformation to an urban state.

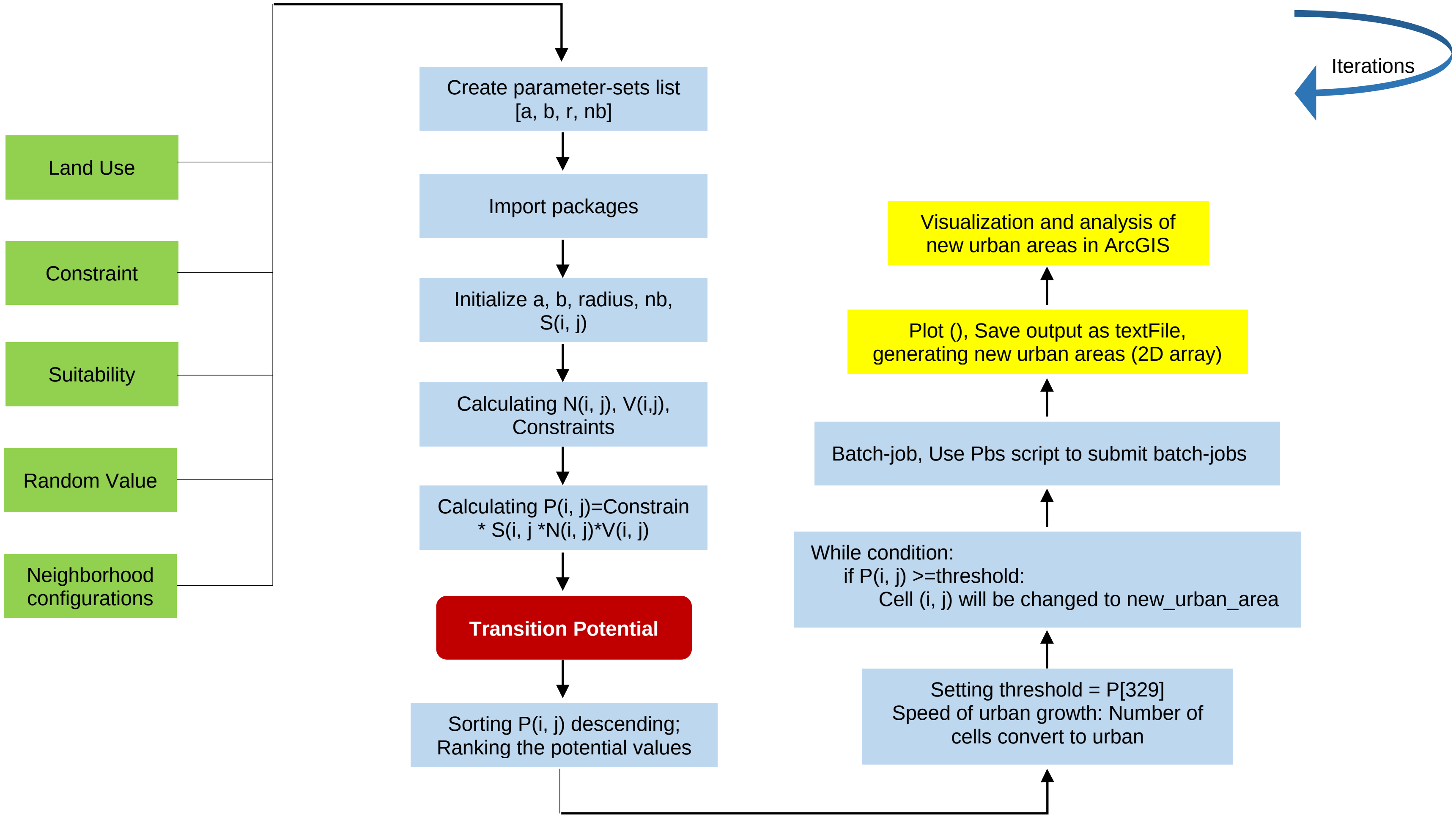


Figure 4-9: Framework of the CA-based standalone model for urban growth simulation (Source: the author)

The transition potential and the number of the cells transforming into urban were calculated, so, the cells with the highest probability values in each iteration will be changed (highest 329 cells in each iteration). The CA algorithm was scripted using Python programming language and works as indicated in the figure (4-9).

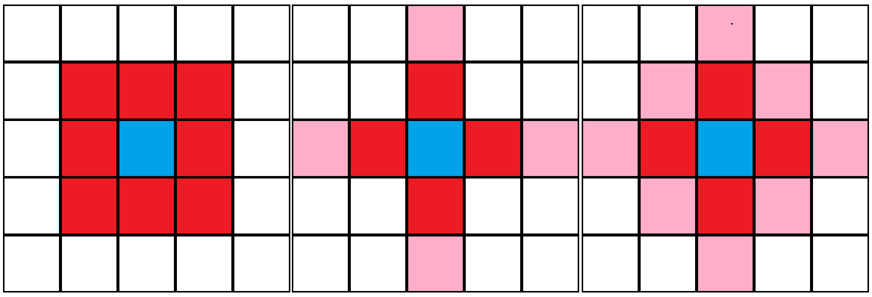
4.4.2. Parameters calibration

Monte Carlo methods are broad computational algorithms that rely on repeated random sampling (randomness) to generate numerical results and solve the problems that might be deterministic in principle (Serasinghe *et al.*, 2018; Malczewski, 2004; Barreira González *et al.*, 2015). This method in the calibration process is considered random experimentations, generating random and unknown results (Jat *et al.*, 2017a; Abonazel, 2018; Osman *et al.*, 2015). Monte Carlo methods tend to follow a particular pattern in their applications: a) define a domain of possible inputs, b) generate inputs randomly from a probability distribution over the domain, c) perform a deterministic computation on the inputs, and d) aggregate the results (Alaei *et al.*, 2018; Jantz *et al.*, 2016a; Li and Li, 2015). In Monte Carlo methods, the parameters' calibration process takes place through probability distribution for each variable and produce thousands of possible outputs (Yeh and Li, 2006b). In another word, performing a large number of trial runs (simulations), and inferring a solution from the collective results of the trial runs (throughout the utilization of a precision index). The calibration process aiming at identifies the best urban growth parameters which can effectively simulate the urban growth during the historical time starting from the year 1986, as a seed of simulation, till the year 2016.

Therefore, and in the essence of the aforementioned points, a wide range of random variables was utilized (from 0.0 to 3.0), exponent range (from 0.0 to 1.0), radius (from 1 to 6), and three types of neighborhoods as indicated in table (4-8) and figure (4-10) (Li Cheng, 2014). Hence, 6138 simulations were conducted through the combination of these four parameters. The best combination of the parameters (according to the percentage of agreement or figure of merit) was then utilized to predict urban growth development. For each simulation, 100 iterations were conducted, and the probability of the cells converted to urban land-use until the year 2016 was created. Then, a simulated map of urban growth of the year 2016 was matched with the observed one.

Table 4-8: Parameters used in the calibration process

Parameters	α	β	r	nb
Description	Randomness	Exponent	Radius	Neighbourhood
Value/range	[0, 3]	[0, 1]	{1, 2, 3, 4, 5, 6}[3]	{0, 1, 2}[4]
Distribution	Uniform	Uniform	--	--



(a) (b) (c)

Figure 4-10: Types of used neighborhood types

(a) The red cells are the Moore neighborhood for the blue cell, (b) The red cells are the von Neumann neighborhood for the blue cell. The extended neighborhood includes the pink cells as well, and (c) The red cells are the von Neumann Circle neighborhood for the blue cell. The extended neighborhood includes the pink cells as well.

Various indicators have been introduced in literature to measure the goodness-of-fit between simulated and observed urban land use maps, as in (Almeida *et al.*, 2005; Lin *et al.*, 2008; Naghibi *et al.*, 2016) could be categorized under two groups named locational indicators and pattern indicators (Li Cheng, 2014). The locational indicators method provides a way to conduct a cell by cell comparison between simulated and observed maps, and it was applied in the current study (Figure of Merit). The Figure of Merit refers to the ratio of the intersection of the observed developed and simulated developed to the union of the observed developed and predicted developed (Camacho *et al.*, 2015; Mohammady *et al.*, 2014; García *et al.*, 2012; Liao *et al.*, 2016). The Figure of Merit can range from 0% to 100% (Afshar *et al.*, 2018). A higher value of the figure of merit indicates a higher agreement in terms of cell by cell comparison (García *et al.*, 2012; Mustafa *et al.*, 2014). Equation (4-14) was used to calculate the figure of merit (Afshar *et al.*, 2018) and equation (4-15) for calculation of the overall accuracy (also called percent of agreement or percent of the correct

[3] radius=1 means 3*3 neighborhood size, radius=2 means 5*5, radius=3 means 7*7 neighborhood size, radius=4 means 9*9 neighborhood size, radius=5 means neighbourhood size 11*11, radius 6 means 13*13 neighborhood size

[4] 0, 1, 2 refer to Moore neighbourhood, von Neumann neighbourhood, von Neumann Circle neighborhood

match) (Mohammady *et al.*, 2014; Sassan *et al.*, 2013). Both equations were used to evaluation of the goodness-of-fit between observed and simulated maps.

$$figure\ of\ merit = \frac{B}{A+B+C+D}$$ Equation (4-14)

$$overall\ accuracy = \frac{a+d}{a+b+c+d}$$ Equation (4-15)

Where; A, is the area of error due to observed developed and simulated as persistence & B, is the area of correct due to observed developed and simulated as developed & C, represents the area of error due to observed developed and simulated as incorrect gaining category & D, is the area of error due to observed persistence and simulated as developed. Given CA models simulate the changes of the state from non-urban to urban; the value of C should be equal to 0 (Mohammady *et al.*, 2014; García *et al.*, 2012; Mohammady, 2014; Liu *et al.*, 2017; Li Cheng, 2014). The results of calibration and validation, in particular, for the future scenarios still the main challenge, simply because there will be no observed data for the future urban situation, with which the simulated data would be compared (Barreira González *et al.*, 2015; Batisani and Yarnal, 2009a).

4.4.3. Design of the urban growth scenarios and prediction

Any proposed urban growth scenarios should be tightly linked to the concerns of decision-makers and planners, to addressing and investigating the key issues and the historical trend of urban growth in any area of investigation (Xiang and Clarke, 2003). The spatial distribution characteristics for the future scenarios can be controlled by adjustments of the parameters in section (4.4.2.). Therefore, various transition rules were prepared to carry out various growth scenarios through solving the following transition potential equation (4-16) (Li Cheng, 2014):

$$P_{ij} = f\left(x_{i,j,1}, x_{i,j,2}, \ldots\right) * \prod_{t=1}^{n} C_{i,j,t} * \Omega_{i,j} * V_{i,j}$$ Equation (4-16)

Where; P_{ij} is the transition potential, $f\left(x_{i,j,1}, x_{i,j,2}, \ldots\right)$ is the suitability scores and $x_{i,j,1}, x_{i,j,2}$ were standardized to a uniform suitability score ranges between [0, 1] for the cell (i,j) for urban land use. $\prod_{t=1}^{n} C_{i,j,t}$ indicates the constraints 'score, as the total constraint score ranging from 0 to 1 represents constraints to urban expansion. $\Omega_{i,j}$ depicts the Neighborhood effect for the cell (i,j) for urban land use, and $V_{i,j}$ denotes the random variables. It's important to know how to create various growth scenarios without changing the values which will be generated after the parameters' calibration process, as indicated in the section (4.4.2.). That was conducted throughout setting the land suitability (section 4.3.) by assigning the weighted values to the spatial layers, as shown in figure (4-11) (Xiang and Clarke, 2016b; Erener *et al.*, 2016), which in turn, can be used to derive the behavior-oriented/preference of the decision-makers and hence different transition rules.

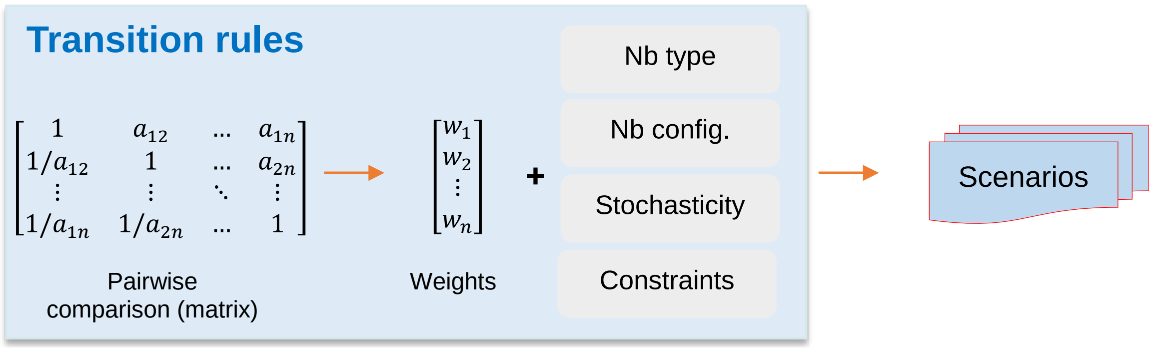


Figure 4-11: Land Suitability rule in the design of urban growth prediction scenarios

Five growth scenarios were simulated; Historical growth trends (Business as Usual), Baseline, maximum environment protection, traffic, and compact cities scenarios. These scenarios were proposed by the author and prepared by the 23 experts (as indicated in section 4.3).

Baseline Scenario; known as a default scenario in which the urban areas in the cities are growing as a "bottom-up" system or "self-organizing" without spatial planning policies controlling the cities layout. The baseline scenario assumes that there are no limitations for soil consumption and conversion from non-urban to urban land use. In some locations where there are no clear planning tasks and the lake of law enforcement, the baseline scenario could be regarded as a scenario, in which, the transformation is driven by socio-economic factors and some physical conditions. In that scenario, all the ten factors of the suitability have equal weights and the land-use features were assigned equal scores.

Business as Usual Scenario; supplies a criterion for comparison with alternative growth plans, simply because it assumes the permanence of urban growth as the factors for the growth stand unchanged. It reflects the historical growth trends on future development; i.e. the policy and decision-making implications of the urban growth under the same conditions. In that scenario, the transportation system and the residential were assigned the highest weights.

Traffic Scenario; Egypt is entering the high-speed national roads era which is going through and linking the governorates all over Egypt; e.g. Alexandria-Matrouh main road which is regarded as a new urban development axis. Alexandria governorate is considered one of the most developed areas in the republic concerning building high-speed roads system because of its location on the Mediterranean Sea and dense logistic activities. This scenario assumes that the new urban areas will be driven due to the influence of the existing and planned transportation system. Thus, high weights were assigned for the transportation system in that scenario.

Maximum Environmental Protection Scenario (or planning Strengthened Scenario); considers environment and natural resources preservation, strictly following the Strategic Urban plan (SUP) of Alexandria for the year 2032, so that, Alexandria city is more fit for human habitation. The SUP- Alex 2032 main objective was to establish a regulatory framework controlling the rapid urban growth emphasizing on three main issues: a) establishing a SUP- Alex 2032 reflecting the government's vision-enhancing the citizen participation in the decision-making process, b) improving the capabilities of the regional center and local partners involved in the planning process, c) implementation of a sound framework can ensure sustainable and long term city development. Hence, restriction layers were created and integrated into the land suitability maps to be avoided from any development. Theses layers are including national parks, water bodies, natural protected and environmental areas, and roads.

Compact City Growth Scenario; aiming at controlling the fast and unplanned urban growth process and changing the spatial type of growth, in the meanwhile, preserving the livability in the city. Hence, and according to the SUP- Alex 2032 submitted by GOPP, urban development in the undeveloped areas (open spaces) could be raised up and more formal residential growth would be supported and more control over unplanned growth accompanied.

Table (4-9) shows the weights were corresponding to the 10 factors of the suitability and the scores were corresponding to the land use/cover in each land use maps. Finally, the transition potential including; α, β, r, nb type, the suitability of each given piece of land (all cells of the investigation area) were assigned for conducting the prediction of the future urban development scenarios. Simulation of the urban growth from the year 1986 till the year 2016 was conducted with 100 iterations and prediction from the year 2016 till the year 2032, 54 iterations were implemented.

Table 4-9: Weights of each suitability scenario and the scores assigned for each land use/cover map used in each scenario

	S.1		S.2		S.3		S.4		S.5		LU_T
	W	Score	W	Score	W	Score	W	Score	W	Score	
Distance to Residential	0,1	4	0,2	7	0,110	7	0,057	3	0,25	9	urban
Proximity to Utilities	0,1	4	0,04	5	0,010	1	0,057	6	0,1	1	crop lands
Proximity to Schools	0,1	4	0,07	8	0,010	1	0,057	6	0,1	1	lake mariute
Proximity to Recreation	0,1	4	0,017	2	0,010	1	0,200	2	0,025	1	desert
Proximity to Transportation	0,1	4	0,5	8	0,810	1	0,057	8	0,3	1	sandy beach
Distance from Industrial Areas	0,1	4	0,03	0	0,010	1	0,057	0	0,1	1	fish farms
Proximity to Vegetation	0,1	4	0,03	6	0,010	1	0,200	2	0,025	1	reclaimed
Proximity to Coastline	0,1	4	0,06	9	0,010	1	0,157	2	0,025	1	open space
Distance from Water Bodies	0,1	---	0,023	---	0,010	---	0,100	---	0,025	---	---
Land Use	0,1	---	0,03	---	0,010	---	0,057	---	0,05	---	---

S.1= Baseline growth Scenario
S.2= Business as Usual Growth Scenarios
S.3= Traffic Scenario
S.4= Maximum Environmental Scenario
S.5= Compact Cities Growth Scenario

4.4.4. Uncertainty and sensitivity analysis

Spatial heterogeneity is a typical feature in the geographic environmental system and landscape data (Crosetto *et al.*, 2000; Moreau *et al.*, 2013). The uncertainty associated with these spatial data and input factors may affect model uncertainty, therefore, influence the model reliability and sensitivity (Fang *et al.*, 2002; Rajabi *et al.*, 2015; Sudret, 2008; Xu and Zhang, 2013). Understanding the impact of CA model' elements variations on the resulting outputs is of great importance in meaningful decisions and urban planning (Kocabas and Dragicevic, 2006). In that essence, the Sobol index was utilized as a method for global sensitivity analysis (Saltelli *et al.*, 2008). The Sobol index is working in the probabilistic framework (Chen and Jin, 2004). The output variance of the model decomposes into fractions which in turn attribute to the inputs of the model (Sobol', 2001; Tarantola *et al.*, 2000; Şalap-Ayça *et al.*, 2017; Saltelli and Annoni, 2010).

GSA capable of addressing the responses between the model inputs and nonlinear outputs; i.e. individually (first-order effects S_i) sensitivity indices and overall interactions (total order effectsS_{Ti}) sensitivity indices. The first-order index S_i referred to the main effect sensitivity and estimates directly the selected single variable's portion of the overall variance (Şalap-Ayça *et al.*, 2017; Sobol', 2001). While the total-order index S_{Ti} measures the total contribution of pairs of factors, i.e. first- and higher-order interactions of the selected single variable (Şalap-Ayça *et al.*, 2017; Saltelli and Annoni, 2010; Gómez-Delgado and Tarantola, 2006; Tang and Jia, 2014; Sobol', 2001). The first-order sensitivity index is explained as in formula (4-17) (Saltelli and Annoni, 2010; Sobol', 2001; Tang and Jia, 2014):

$$S_i = \frac{Var_{X_i}(E_{X_{\sim i}}(Y|X_i))}{Var(Y)}$$ Equation (4-17)

Where; X_i is the i-th factor and $X_{\sim i}$ refers to the matrix of all factors but (except) X_i, Y is the scalar output of interest, and $V(Y)$ is the total unconditioned variance. The meaning of the inner expectation operator is that the mean of Y is taken over all possible values of $X_{\sim i}$ while keeping X_i fixed. The numerator of that equation referring to the expected reduction in variance that would be obtained in X_i could be fixed. Also, the total sensitivity index is defined as in (Tang and Jia, 2014; Sobol', 2001; Saltelli and Annoni, 2010):

$$S_{Ti} = \frac{E_{X_{\sim i}}(Var_{X_i}(Y|X_{\sim i}))}{Var(Y)}$$ Equation (4-18)

The numerator of the total sensitivity index equations is the expected variance that would be left if all factors but X_i could be fixed. S_i and S_{Ti} are versatile and powerful measures (Saltelli and Annoni, 2010; Saltelli and Tarantola, 2002; Saltelli *et al.*, 2004; Saltelli *et al.*, 2008). S_i indicates the effect of the factor X_i by itselt, while, S_{Ti} denotes the total effect a factor including its all interactions with other factors (Saltelli and Tarantola, 2002; Saltelli *et al.*, 2004). Also, S_i *and* S_{Ti} could be equal for all factors, in case of additive Models (Saltelli and Annoni, 2010). If the main objective of the sensitivity analysis is to fix non-influential factors, exactly as in the current study, then S_{Ti} is the most appropriate measure to use. The randomness and neighbourhood types were employed to investigate their effectiveness on the CA-based model simulation results.

The implemented UA-SA approach in the current study was independent of the developed CA-based model structure. This, in turn, is a very important character, as it can deal with interacting effects and non-linear and complex models' sources. By the means of SALib package in Python, parameters' values were generated using the Saltelli sampler. The Saltelli sampler generates based on the formula: N*(2D+2) samples, where; N is the supplied argument and D is the number of inputs matrix of parameters. That is 1000*(2*2+2) = 6000 (simulations) times calculation for each cell, which will be a tremendous computing workload for the whole area. (Şalap-Ayça *et al.*, 2017; Abily *et al.*, 2016; Yang Mu, 2017).

4.4.5. Platform and pseudo code

4.4.5.1. Python and pseudo code

By the means of 'Python' programming language, a standalone CA-based model was developed, and the process of the simulation was conducted for the years 1990, 2001 and 2016 based on the data of the year 1986. Python is a high-level programming language. Created by Guido van Rossum and first released in 1991. It provides constructs that enable clear programming on small and large scales and supports multiple programming approaches including object-oriented, imperative, functional and procedural, and very reach with open-source and comprehensive libraries. Figure (4-12) shows some of these libraries were installed using pip, and

```
C:\>pip list
Package                        Version
----------------------------- -----------
backports.functools-lru-cache 1.4
certifi                       2017.11.5
chardet                       3.0.4
click                         6.7
click-plugins                 1.0.3
cligj                         0.4.0
cycler                        0.10.0
decorator                     4.1.2
descartes                     1.1.0
enum34                        1.1.6
idna                          2.6
matplotlib                    2.1.0
munch                         2.3.2
networkx                      2.0
numpy                         1.13.3
olefile                       0.44
pandas                        0.22.0
Pillow                        4.3.0
pip                           10.0.1
pyparsing                     2.2.0
pyproj                        1.9.5.1
python-dateutil               2.6.1
pytz                          2017.3
PyWavelets                    0.5.2
requests                      2.18.4
SALib                         1.1.3
scikit-image                  0.13.1
scipy                         1.0.0
setuptools                    28.8.0
Shapely                       1.6.4.post1
six                           1.11.0
urllib3                       1.22
```

figure (4-13) Pseudo Code of the transition potential part of the developed CA-based standalone model;

Figure 4-12: List of packages installed by pip in Python

Matplotlib - This is an object-oriented plotting library

SciPy - A scientific computing package for Python

SALib - PACKAGE CONTENTS [analyze, plotting, sample, test functions, util]

Pillow - adds image processing capabilities to your Python interpreter

Shapely - used for analysis, manipulation, and computation of planar geometric objects

Numpy - used to manipulate large multi-dimensional arrays of arbitrary records without sacrificing so much speed for small multi-dimensional arrays

```
def Transition_Potential(S=None, N=None, CONS=None, V=None):
        print "Transition Potential\n"
        var_list = [S, N, CONS, V]
        names_list = ['Land Suitability "S"','N', 'CONS', 'V']
        for var in var_list:
                i = var_list.index(var)
                if var == None:
                        var_list[i] = raw_input("Please Enter The value of "+ names_list[i] +"\n")
        P = float(var_list[0]) * float(var_list[1]) * float(var_list[2]) * float(var_list[3])
ef Land_Suitability(X=None, W=None):
        print "Land Suitability ********************************first equation\n"
        variables = [X, W]
        variables_names = ['Global Factor "X"', 'Weight "W"']
        for var in variables:
                i = variables.index(var)
                if var == None:
                        variables[i] = raw_input("Please Enter The values of "+ variables_names[i] +"
Separated by space\n").split(" ")
```

```
                for sub_var in variables[i]:
                        indx = variables[i].index(sub_var)
                        sub_var = float(sub_var)
                        variables[i][indx] = sub_var
        print variables
        X_length = len(variables[0])
        s_list = []
        for i in range(X_length):
                s_list.append(variables[0][i]*variables[1][i])
        S = 0
        for s in s_list:
                S += s
def Neighborhood (Wmn=None, I=None):
        print "Neighborhood *******************************second equation\n"
        variables = [Wmn, I]
        variables_names = ['Weight "Wmn"', 'I']
        for var in variables:
                i = variables.index(var)
                if var == None:
                        variables[i] = raw_input("Please Enter The values of "+ variables_names[i] +"
Separated by space\n").split(" ")
                for sub_var in variables[i]:
                        indx = variables[i].index(sub_var)
                        sub_var = float(sub_var)
                        variables[i][indx] = sub_var
        Wmn_length = len(variables[0])
        n_list = []
        for i in range(Wmn_length):
                n_list.append(variables[0][i]*variables[1][i])
        N = 0
        for n in n_list:
                N += n
def Neighborhood_Weight(B=None, D=None):
        print "Neighborhood Weight *******************************third equation\n"
        var_list = [B, D]
        names_list = ['"B"','Distance "D"']
        for var in var_list:
                i = var_list.index(var)
                if var == None:
                        var_list[i] = raw_input("Please Enter The value of "+ names_list[i] +"\n")
        Wmn = float(var_list[0]) * float(var_list[1])
def Constraints(*cons):
        print "Constraints  *******************************4th equation\n"
        if not cons:
                cons = raw_input("Please Enter The value of 'cons' \n").split()
        CONS = 1
        for no in cons:
                CONS *= no
        print CONS
        return CONS

def Stochastic(rand=None, a=None):
        print "Stochastic *******************************5th equation\n"
        if rand == None:
                rand = raw_input("Please Enter The value of 'rand' \n")
                if float(rand) <= 0 or float(rand) >= 1:
                        print "the value must be between 0 and 1 !!"
                        return Stochastic()
        if a == None:
                a =     raw_input("Please Enter The value of 'a' \n")
        V = float(1) + ((-math.log(float(rand)))**float(a))
        print V
        return V
```

Figure 4-13: Pseudo Code of the transition potential part of the developed CA-based standalone model

4.4.5.2. *Parallel jobs on HPC*

By the means of the normal PCs or even work station' PCs with 11 or more CPUs, it wouldn't be possible to conduct these massive numbers of simulations (thousands) in a period less than one year. For urban growth simulation and calibration: 31 randomness values (0.0 to 3.0), 11 exponent values (0.0 to 1.0), 3 neighbourhood types, and six radiuses in order to conduct 6138 simulations. Also, UA-SA required a large number of simulations (6000) to be conducted. Fortunately, it was possible to use High Performance Computing-HPC (*Die Hochleistungsrechner; Linux-HPC-Cluster an der TU Dortmund*) in the form of computing and parallel computing nodes, to overcome the time dilemma. The Linux HPC cluster at the TU Dortmund (LiDO) is available as a tool for scientific computing and limited in the NRW resource network. LiDO is a compute cluster system based on Distributed so many powerful compute nodes supported by specified CPU number, speed, and memory for each node type (Long, Middle, or Short). In the standard short queue, the maximum wall time is one hour with 256 jobs, eight and 48 hours for medium and long nodes respectively with also a maximum of 256 jobs that can be submitted at the same time. So, it is capable of conducting massive and parallel jobs at the same time (batch system). Jobs on cluster were distributed to nodes using Portable Batch System (PBS), without PBS, submission of the jobs is not possible (for each node type), figure (4-14). Processes which are executed directly on the gateways are killed immediately, so that, WinSCP and PuTTY were used, figures (0-2), (0-3), (0-4) in the annex. WinSCP is a software used for file transfer to and from the HPC server, while, PuTTY is used to interact with the HPC server directly. PuTTY is just a command-line interface to the server and WinSCP is a file transfer application. Batch jobs were submitted to execution queues via gateways (lidong1.itmc.tu-dortmund.de or lidong2.itmc.tu-dortmund.de).

```
#!/bin/bash
###### PBS options for a serial job ##############################################

### e.g. short,med,long,ultralong
#PBS -q med
#PBS -l walltime=08:00:00,nodes=1:ppn=1:ib
###PBS -l walltime=10:00:00,nodes=4:ib

#PBS -N MustafaJob
### [b]egin, [a]bort, [e]nd
### Default: no notification
#PBS -m bae

#PBS -M mustafa.elmorshdy@yahoo.com

### If you do not care about standard output, use "PBS -o /dev/null"
### Default: Name of jobfile plus ".o" plus number of PBS job
#PBS -o output.$PBS_JOBID.${step}.dat

### This option redirects stdout and stderr into the same output file
### (see PBS option -o).
#PBS -j oe

source /sysdata/shared/sfw/Modules/default/init/bash
### Load modules needed
### module load [compiler modules][MPI modules]
module load gcc/7.2.0 openblas/0.2.17
###module load openmpi/gcc7.2.x/2.1.1/nonthreaded/infiniband
module load openmpi/intel18.0.x/2.1.1/nonthreaded/infiniband

### The following command, if uncommented by deleting the hash sign in front of 'cat',
### saves the name of the compute node (to which the job is submitted by the batch system).
### This information may be useful when debugging.
### This information can also be retrieved while the job is being executed via "qstat -f jobid".
###
### Be sure to use a unique file name (!), though, to avoid concurrent write access
### which may happen when multiple jobs of yours are started simultaneously.
cat $PBS_NODEFILE > $HOME/pbs-machine.$PBS_JOBID.${step}

### Go to the application's working directory
cd $HOME/simulation/sobol

### Start the application
###mpirun -np 94 ./batch_job.sh
###./batch_job.sh
python run_sobol.py ${step}
```

Figure 4-14: Example of PBS script used for submission of the simulation jobs for medium node queue type

5. CHAPTER FIVE: RESULTS AND DISCUSSION

5.1. Land Use/cover classification and change detection

The used classification approach of the combined supervised and indices-based classification has proven high efficiency. A total of 180 GCPs were used for accuracy assessment. A traditional assessment method of the classification accuracy was conducted to calculate the overall accuracy and Kappa Coefficient as indicated in the table (5-1). The overall accuracy ranges from 91% to 95%, and the values close to 1 indicates that the classification is significantly better than random, in terms of Kappa coefficient.

Table 5-1: Accuracy assessment of Support Vector Machine – supervised classification

	1986	**1990**	**2001**	**2016**
Overall accuracy	95.5441%	91.5441%	92.0976%	94.0992%
Kappa coefficient	0.9499	0.9001	0.9111	0.9336

Table 5-2: Accuracy assessment through confusion matrix generated by ENVI

Classes \ Year	1986		1990		2001		2016	
	Prod.	User	Prod.	User	Prod.	User	Prod.	User
Urban	97.88	98.81	85.44	81.66	89.54	91.10	96.47	98.80
Croplands	95.14	95.74	75.62	85.03	82.33	81.77	93.14	90.65
Lake Mariute	93.18	93.47	92.21	89.19	85.93	86.98	99.80	97.14
Desert	95.45	97.21	98.87	98.21	90.39	97.77	77.45	85.68
Fish Farms	95.45	96.51	99.77	97.46	99.83	99.32	100	100
Reclaimed	91.38	88.40	90.63	89.62	80.62	82.89	97.06	99.80
Sandy beach	97.73	96.00	85.10	90.19	74.44	74.06	100	98.65
Undeveloped	87.93	88.28	95.26	91.34	95.37	87.70	86.47	80.18

Both producer and user's accuracy are consistently high, as shown in the table (5-2). The user and producer accuracy for any given land use/cover features are not the same. This means that even though 95% of the references undeveloped areas were correctly identified as "undeveloped areas", only 87% of these areas were identified as “undeveloped areas” in the classification were undeveloped areas. Confusion in different land use/cover features giving low accuracy values for some years due to the problem of mixed pixels and spectral similarities. The accuracies are higher than the minimum accuracy set by USGS (Anderson *et al.*, 1976), so that, the classified features can be used as the data source for post-classification comparison and further analysis as investigated in further working step.

According to figure (5-1) and tables (5-3) and (5-4), there is a remarkable high rate of land reclamation in the year 1986, a very high rate of land cultivation till the year 2001. Between the years 1986 and 1990, the study area has witnessed a low rate of encroachment of agriculturally productive land and the formation of new urban areas. However, the Alexandria governorate has encountered a high wave of urban growth and new settlements formation especially in the agricultural areas from the year 2001 till 2016. These changes in the land use/cover led to degradation of the croplands and waterlogging in some locations of the study area, especially within 20 km of landwards along the coastline. It is obvious from the multi-temporal maps in figure (5-1) that there is a steady increase in the croplands, hand in hand with an increase in urban areas. Therefore, the Egyptian government adopted policies regarding increasing the agricultural land, so that, realize self-sufficiency and through maximization of food production by increasing the cultivated land 1.2 % annually (Tellioglu and Konandreas, 2017). The data in table (5-3) reveals that in the year 1986, urban built-up areas about 142.7 km^2 (3.8%) and remarkably increased to be 255.8 km^2 (6.8 %), 358.8 km^2 (9.5 %), 472.3 km^2 (12.6 %) for the years 1990, 2001, and 2016 respectively. Also, the changes are obvious in the various classes, whether negative (decrease of the feature surface area) or positive (increase) between the years 1986 and 2016. Due to the sever urbanization activities and inadequate environmental ad building laws enforcement; environmental protected sites (e.g. sandy beach and of the freshwater resources) and croplands in the study area were vulnerable to shrinkage and encroachment by urban land use. For instance; Lake Mariute decreased from 194 km^2 (5 %) in the year 1986 to 131.9 km^2 (3.5 %) in the year 2001 and continued to decrease to reach 107.5 km^2 (2.8 %) in the year 2016. Besides, sandy beach surface area decreased from 32.47 km^2 (0.87 %) in the year 1986 to 21.08 km^2 (0.56 %) in the year 2001 and continued to decrease to be 15.86 km^2 (0.42 %) in the year 2016.

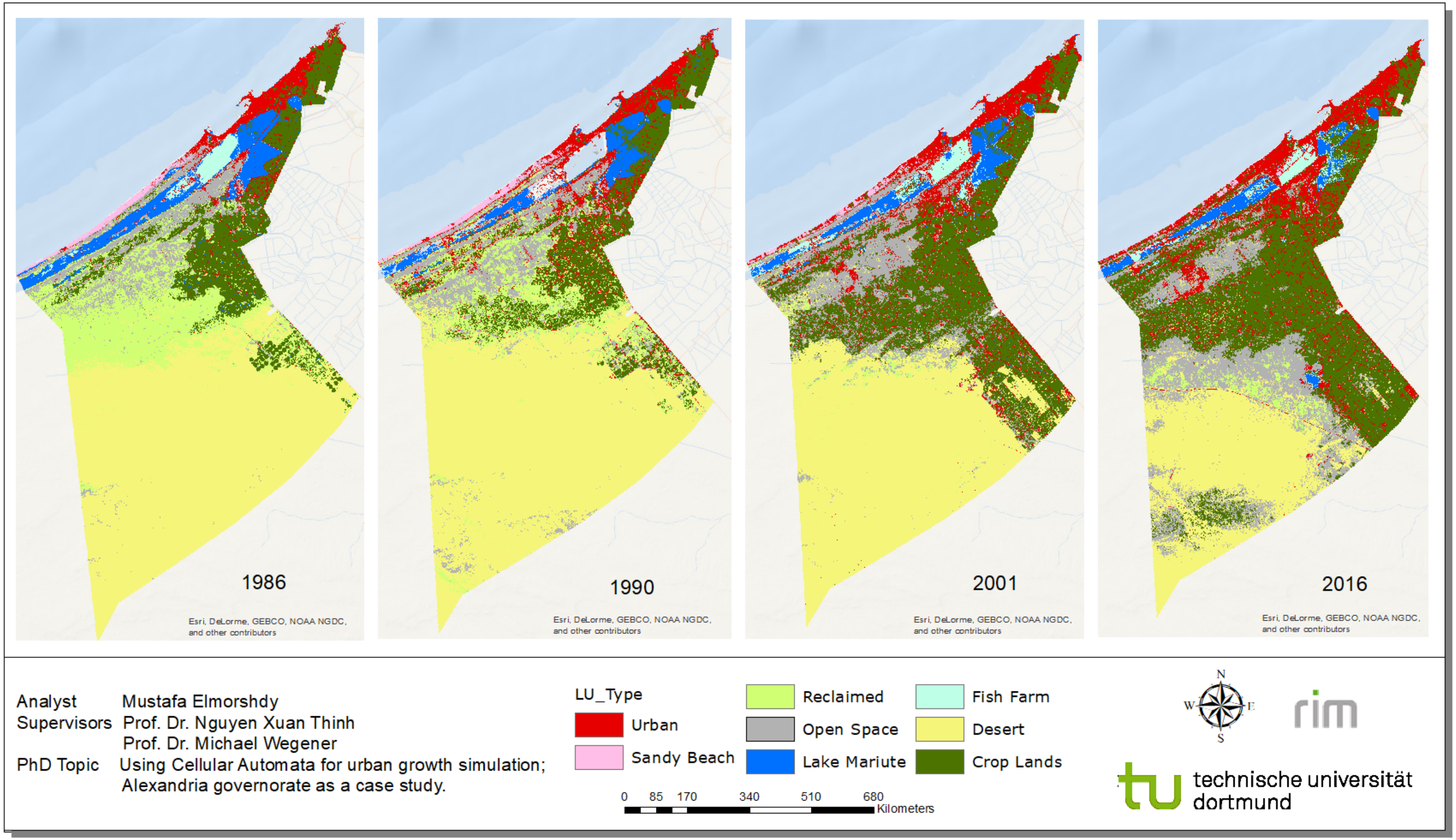


Figure 5-1: Changes in land use/cover features from the year1986 till 2016 using Landsat satellit imageries

Table 5-3: Changes in land use/cover in different classes for the years 1986, 1990, 2001, 2016 (km² and %), based on Landsat Satellite Imageries

LU Type	1986		1990		2001		2016		1986-1990	1990-2001	2001-2016
	km²	%	km²	%	Km²	%	km²	%	km²	km²	Km²
Urban	142.70	3.81	255.86	6.83	358.86	9.57	472.31	12.60	113.16	103.00	113.45
Croplands	475.71	12.69	497.38	13.27	936.36	24.97	1256,73	33.53	21.67	438.98	320.37
Lake Mariute	194.04	5.18	127.64	3.41	131.95	3.52	107.59	2.87	-66.40	4.31	-24.36
Open Space	306.17	8.17	377.54	10.07	491.95	13.12	724.57	19.33	71.37	114.41	232.62
Reclaimed	620.17	16.55	426.97	11.39	41.34	1.10	73.02	1.95	-193.21	-385.63	31.68
Desert	1917,3	51.16	1953,84	52.13	1670,3	44.55	1015,45	27.09	36.53	-283.58	-654.81
Fish Farms	59.25	1.58	75.74	2.02	97.44	2.60	82.27	2.20	16.49	21.70	-15.17
Sandy beach	32.47	0.87	32.75	0.87	21.08	0.56	15.86	0.42	0.28	-11.68	-5.22
Total	3747,83	100	3747,72	100	3749,23	100	3747,79	100	----	----	----

Table 5-4: Land use/cover classes change matrix and land encroachment from 1986-1990, 1990-2001 and 2001-2016 (km^2)

LU Type		Year 1986								
		Urban	Croplands	Lake Mariute	Open space	Reclaimed	Desert	Fish Farms	Beach	Class total
Year 1990	Urban	115.15	49.33	14.37	40.49	26.34	2	5.78	2.33	255.86
	Croplands	19.69	351.54	20.45	3.33	86.32	14.77	1	0.06	497.38
	Lake Mariute	1.87	3.56	117.1	0.09	0.36	0.01	4.56	0.01	127.64
	Open Space	3.39	14.03	2.33	213.65	104.16	35.53	1.44	2.94	377.54
	Reclaimed	0.93	53.13	10.74	35.6	263.26	62.62	0.63	0.01	426.97
	Desert	0.01	3.84	0.09	7.61	139.37	1802.34	0.02	0	1953.84
	Fish Farms	1.24	0.12	27.98	0.46	0.17	0	45.55	0.21	75.74
	Sandy beach	0.26	0.04	0.72	4.9	0.11	0	0.17	26.55	32.75
	Class change	27.56	124.17	76.94	92.52	356.92	114.96	13.71	5.92	0
	Difference	113.16	21.67	- 66.4	71.37	- 193.21	36.53	16.49	0.28	0
		Year 1990								
		Urban	Croplands	Lake Mariute	Open space	Reclaimed	Desert	Fish Farms	Beach	Class total
Year 2001	Urban	151.81	47.85	3.92	68.23	44.8	25.59	5.65	10.39	358.86
	Croplands	66.47	418.96	9.72	47.06	222.64	166.97	2.66	1.68	936.36
	Lake Mariute	3.07	11.28	97.5	0.4	3.64	0.07	15.6	0.01	131.95
	Open Space	17.5	11.37	0.53	214.85	121.78	118.95	2.08	4.68	491.95

	Reclaimed	0.07	0.01	0	6.99	1.38	32.87	0	0.02	41.34
	Desert	0.77	1.04	0.01	33.5	26.89	1607.83	0.02	0.01	1670.26
	Fish Farms	15.21	6.52	15.31	3.6	6.53	0.89	48.95	0.12	97.44
	Sandy beach	1.22	0.14	0.15	3.82	0.69	0.11	0.43	14.49	21.08
	Class change	105.18	80.69	30.71	164.38	427.49	354.71	27.12	18.39	0
	Difference	101.88	436.71	3.74	112.71	- 387.53	- 292.28	21.37	- 11.81	0
		Year 2001								
		Urban	Croplands	Lake Mariute	Open space	Reclaimed	Desert	Fish Farms	Beach	Class Total
Year 2016	Urban	239.79	91.62	4.12	85.55	0.87	19.49	23.58	7.19	472.59
	Croplands	97.95	800.36	22	181.2	4.73	138.18	11.18	0.91	1257.46
	Lake Mariute	1.77	3.18	79.97	0.84	0.02	4.08	16.46	0.01	107.66
	Open Space	10.16	24.59	0.06	207.38	27.37	452.5	0.4	2.43	725.12
	Reclaimed	0.06	0.06	0	3.24	4.83	64.53	0.01	0.35	73.09
	Desert	1.93	10.38	0.02	10.21	3.13	989.63	0.06	0.04	1016.36
	Fish Farms	5.5	5.63	25.3	0.85	0.22	1.46	43.14	0.08	82.33
	Sandy beach	1.15	0.14	0.09	2.55	0.15	0.12	2.33	9.32	15.87
	Class change	119.07	136	51.98	284.57	36.51	680.62	54.29	11.75	0
	Difference	113.73	321.1	- 24.29	233.17	31.75	- 653.89	- 15.11	- 5.2	0

The remarkable croplands increase along the last thirty years was according to a plan from the Egyptian government targeting food security, figure (5-2) “*the agricultural development strategy towards 2017 concentrated on achieving self-sufficiency in cereals, targeting an annual agricultural growth rate of 4.1%, and continuing the land reclamation program of 150,000 feddans*[5] *annually*” (Tellioglu and Konandreas, 2017). Therefore, the cultivated land is greatly increasing to be: 475.7 km^2 (12.7 %), 497.38 km^2 (13.3 %), 936.4 km^2 (24.9 %), 1256.7 km^2 (33.5 %) for the years 1986, 1990, 2001, 2016 respectively. As indicated in figure (4-2) methodology chapter, there is misclassification between the rice fields and water bodies, so there is around 14 km^2 wrongly classified pixels between those two land features.

In order to articulate the encroachment of different land use features during the last

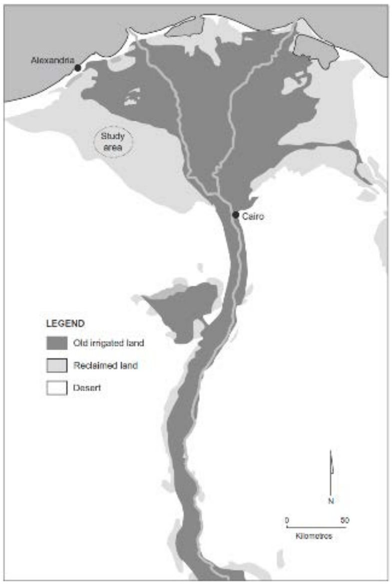


Figure 5-2: Cultivated areas (dark grey) and locations of the new areas to be reclaimed (grey)
Source: Danish Institute for International Studies)

30 years, the change detection matrix, table (5-4), was created to investigate the land use/cover features which were converted into urban built-up areas:

Freshwater bodies: between the years 1986-1990, 1990-2001, and 2001-2016 around 14 km^2, 3.9 km^2, and 4 km^2 of freshwater bodies have been converted to urban land use, respectively. Also, around 27.9 km^2, 15.3 km^2, and 25.3 km^2 of the water bodies have been converted into fish farms (as an important source for food production) between the years 1986-1990, 1990-2001, and 2001-2016, respectively. In addition, Lake Mariute was dried up in some parts to accommodate part of the

[5] A feddan is a unit of area and is used in Egypt. A feddan is divided into 24 kirat (Arabic) and one kirat equals 175 m²: 1 feddan = 24 kirat = 60 m × 70 m = 4200 m² = 0.420 hectares = 1.037 acres

continuous demand for industrial land and wood storehouse's purposes, and also are being used for salt extraction (Sabkha or Salt pans) as well. Figure (5-3) shows the increase and decrease of different classes in the last 30 years.

Sandy beach: due to the unplanned urban development and in the light of the absence of Environmental Assessment studies and effective laws enforcement, 2.3 km^2, 10.4 km^2, and 7.2 km^2 of the sandy beach have been converted into other land uses; e.g. urban built-up area. Also, around 3 km^2, 4.7 km^2, and 2.3 km^2 into undeveloped area that will be used in the future, most probably for built-up area between the years 1986-1990, 1990-2001, and 2001-2016 respectively.

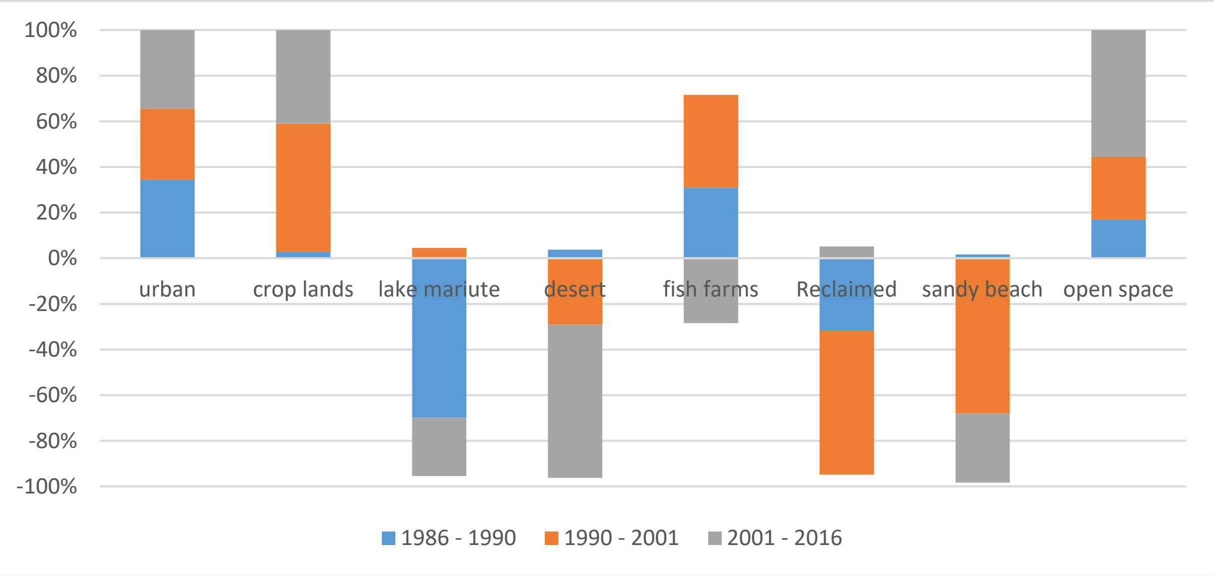


Figure 5-3: Percentage change for various LULC classes from 1986 to 2016.

Given the cheap price of the cultivated land and the limitations (gaps) existing in building law, around 49 km^2, 47 km^2, and 91.6 km^2 of the cultivated lands have been violated by the built-up area for the years 1986-1990, 1990-2001, and 2001-2016 respectively. Furthermore, around 14 km^2, 11 km^2, and 24 km^2 have been converted into undeveloped land for the years 1986-1990, 1990-2001, and 2001-2016, respectively, to be used for other purposes in the future, apparently, for urban built-up areas, as denoted in figure (5-4).

The agriculture sector accounts for roughly 14.8 % of GDP. Also, agriculture contributes about 30% to Egypt's commodity exports, which makes it a major revenue-generator. And, of Egypt's overall labor force, 30% work in the agricultural sector, mostly in the Nile Delta (Tellioglu and Konandreas, 2017). The cheap price of the cultivated land and gaps in the building laws triggers the farmers to sell their lands or even construct houses for themselves. Figure (5-4) gives some ideas on how the process is conducted. Then the municipality comes and destructs any buildings on the croplands, afterward, the owners can reconstruct their houses again without any intervention from the authorities. The landlords started to trick the authority by installing fences and stones around the land, to the municipality come and destruct them. Thereafter, the houses were constructed again without losing so much money.

Figure 5-4: Dredging the cultivated land and construction of houses; informal settlements
Source: Author

Built-up density per each spatial unit all over the study area was calculated in that part of the study throughout calculation of the Urbanization Intensity Index (UII) in the last 30 years from the year 1986 to 2016, based on the equation (5-1) (Shaw and Das, 2018; Suja *et al.*, 2013; Li Cheng, 2014):

$$UII_{i,t-t+n} = \frac{\frac{(ULAi,t+n-ULAi,t)}{n}}{TLAi} \qquad \text{Equation (5-1)}$$

Where; $UII_{i,t-t+n}$ is an index of the intensity of urbanization within a spatial unit i during a period t to $t+n$. $ULAi,t+n$ and $ULAi,t$ are the areas of urban land use for years $t+n$ and t respectively and n denotes the number of years. $TLAi$ is the total area of the spatial unit i (Shaw and Das, 2018). As denoted in the figures (5-5_a) and (5-5_b), the variation in the built-up cover percentage distribution has been represented in the frame of gradient extending from the city center (which was delineated based on recommendation from the experts) and through the entire

Alexandria governorate to visualize the pace and magnitude of urbanization from the year 1986 and till 2016. These buffer zones in figure (5-5_b) represent the spatial unit to characterize the Spatio-temporal trend of built-up growth at certain distances from the CBD. It is evident from the study that the outer zones beyond 10 km of the city center record the most concentrated urban built-up cover. It's also noticed from the figure (5-5_b) that there is an inverse relationship between the percentage distribution of settlement and the distance from the CBD. The most populated areas located within 20 km along the coastline (North West) and towards the cultivated areas (in the south). It is resulted by the natural resistance of Lake Mariute, other water bodies, the north coast, and also being close to the other existing urban clusters which are affording full accessibility to the public services. There is an increasing urban trend captured in both directions North West and towards south from the center to the outermost buffer zones.

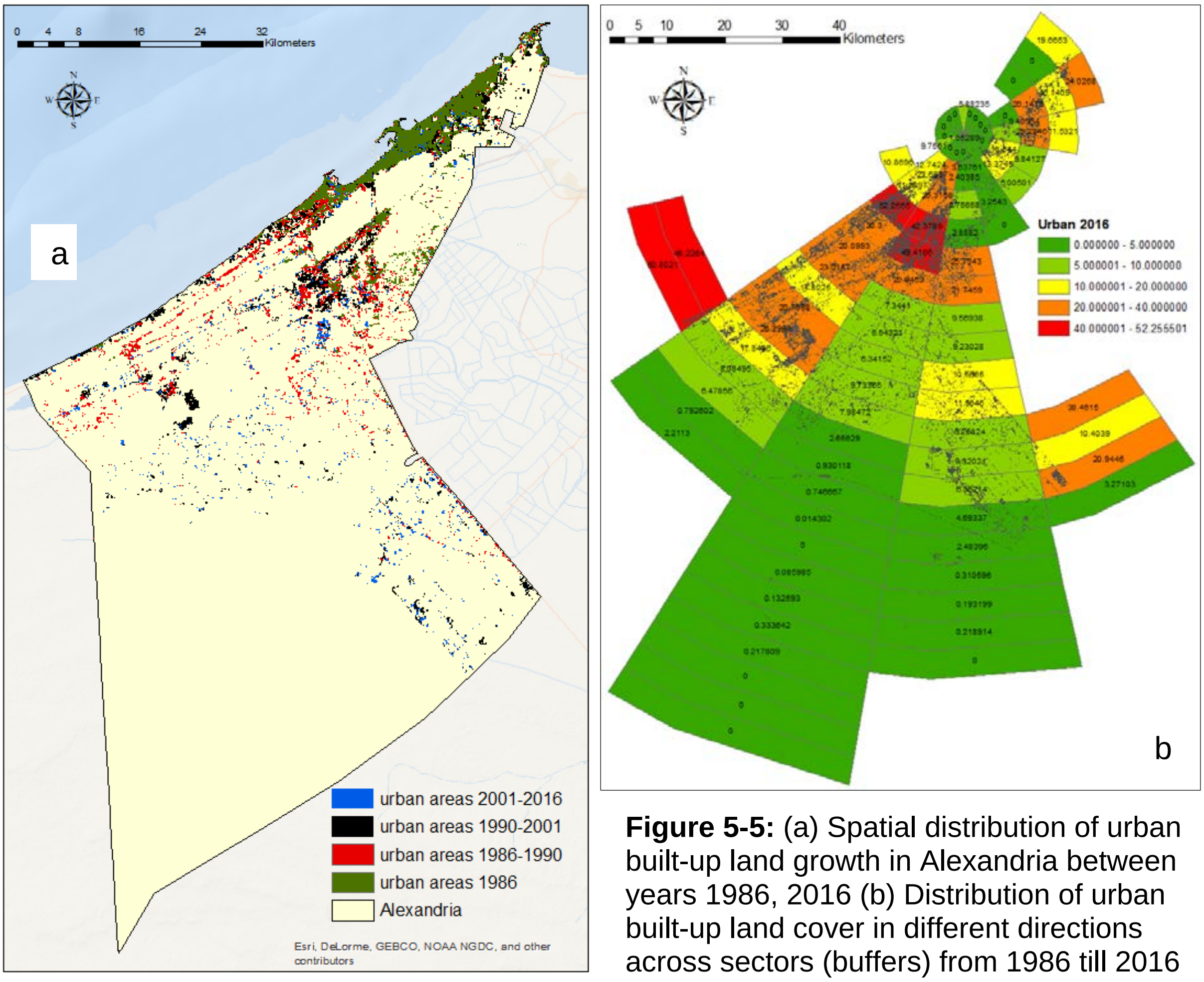
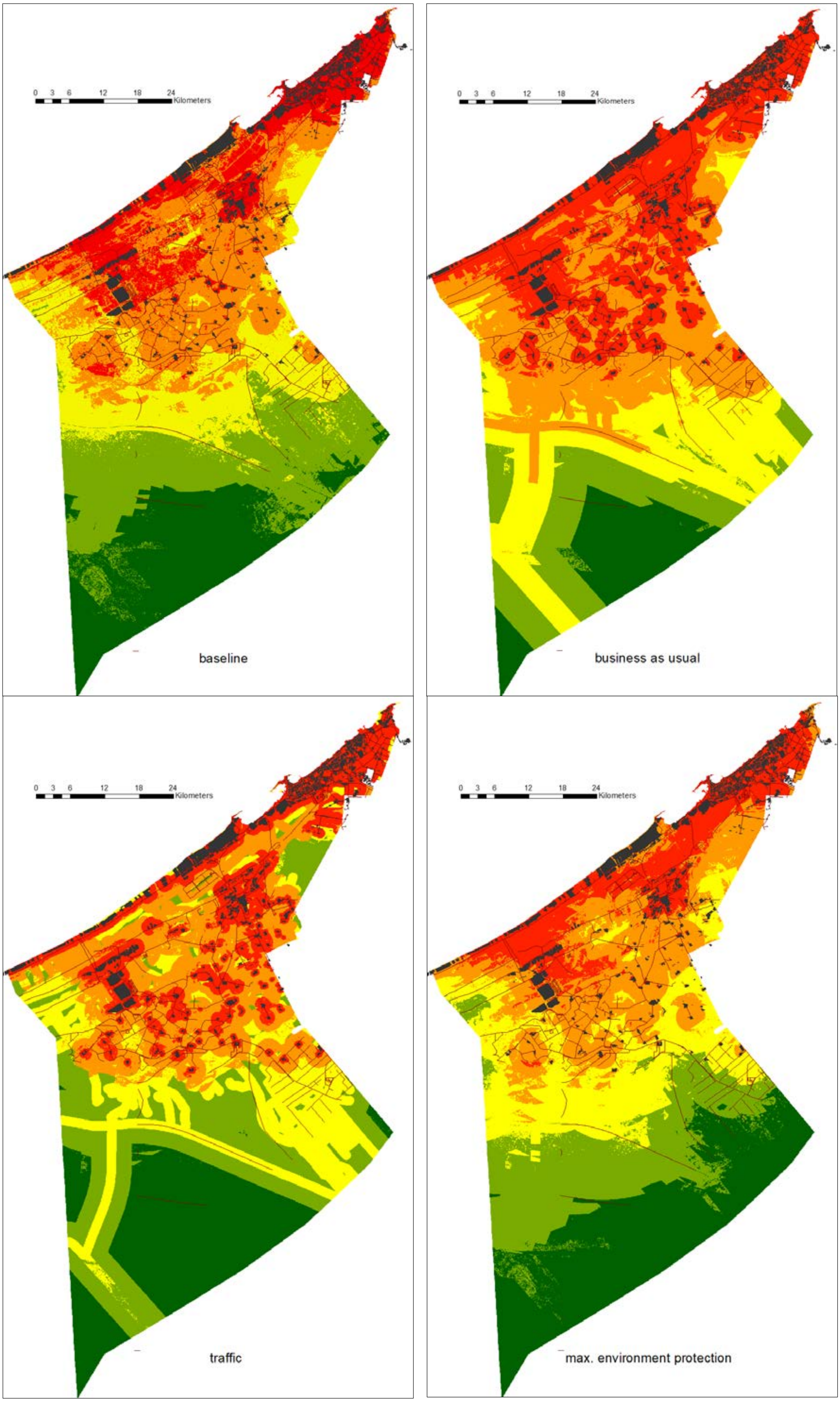


Figure 5-5: (a) Spatial distribution of urban built-up land growth in Alexandria between years 1986, 2016 (b) Distribution of urban built-up land cover in different directions across sectors (buffers) from 1986 till 2016

The built-up areas were almost more than doubled during the last quarter-century. During that period, waves of development resulted in a shift from the old central districts of Wassat, Gomrok and Gharb to the north-eastern (Montazah, Sharq) and south-western (Al Ameriyah) parts of Alexandria with a sprawling suburban pattern leading to encroachment and consumption of the cultivated land without adequate urban infrastructure, as can be observed in New Borg el Arab and Lake Mariute.

5.2. Land Suitability Analysis

As indicated in the section (4.4.3.) of design urban growth scenarios, these suitability maps were used in the prediction of the growth scenarios for the year 2032 as will be presented in the section (5.3.3.). The foremost step before using the land suitability maps for the development of the growth scenarios was to investigate the Consistency Ratio. The overall CR were 0.06%, 0.09%, 0.07%, 0.08%, 0.04% for the scenarios Baseline growth (S.1), Business as Usual (S.2), Traffic (S.3), Maximum Environmental (S.4), Compact Cities Growth (S.5), respectively, fulfilling the tolerable threshold ($CR \leq 0.10$). Finally, the Weighted Linear Combination (WLC) equation in the ArcGIS environment, the model builder has been applied to generate the decision map (suitability map). Figure (5-6) shows the suitable areas for new urban development for different scenarios and hence locations. Figure (5-7) shows the surface area for the entire suitability classes for the five suitability scenarios. The suitable areas are localized close to the transportation network, the existing residential areas, and the coastline of the city. The high suitable zones cover the reclaimed areas, open space (undeveloped areas), and huge parts of the cultivated lands. In the historical trend, as it was investigated in the land use/cover change detection in section 5.1. (Chapter 5) there was an encroachment of urban areas on the agricultural lands, and that historical trend is remarkable and reflected in the resulting land suitability map. Despite other human factors (e.g. market orientation rules) play their roles in urban development; physical suitability in the developed CA-based model has an important rule, as it reflects the on-site relationships between land properties and urban development.


0 3 6 12 18 24 Kilometers
baseline
0 3 6 12 18 24 Kilometers
business as usual
0 3 6 12 18 24 Kilometers
traffic
0 3 6 12 18 24 Kilometers
max. environment protection

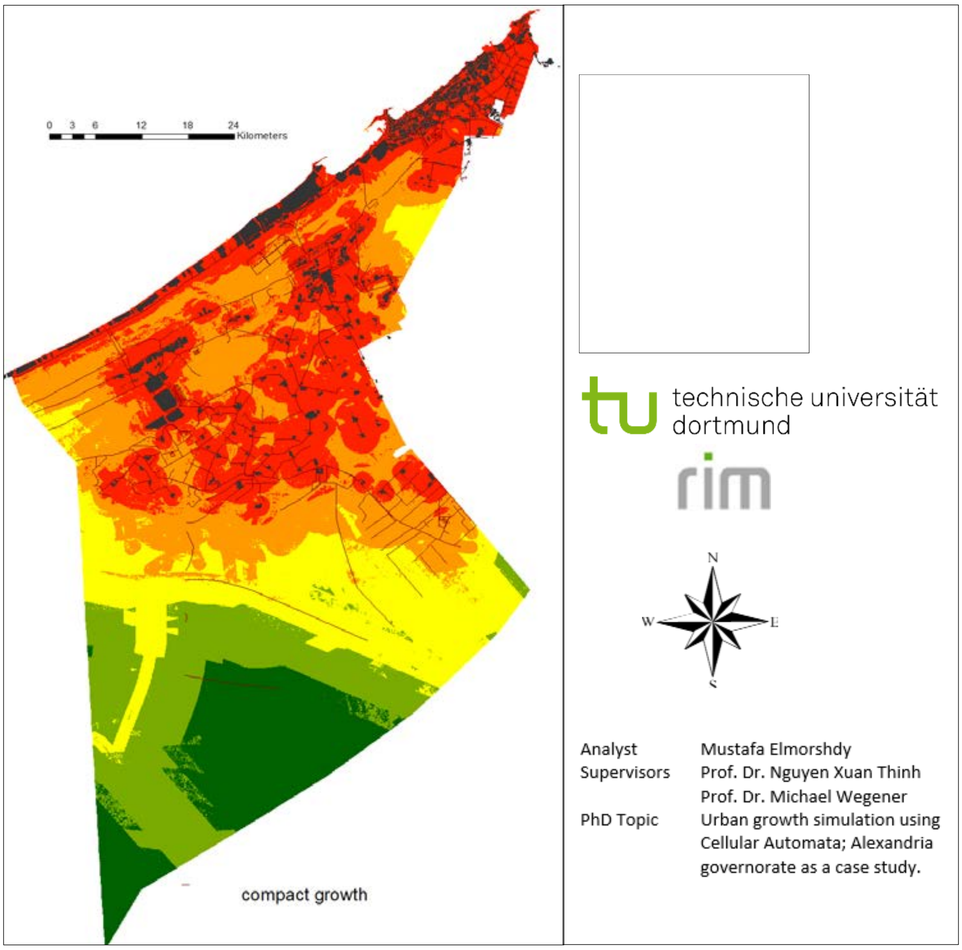
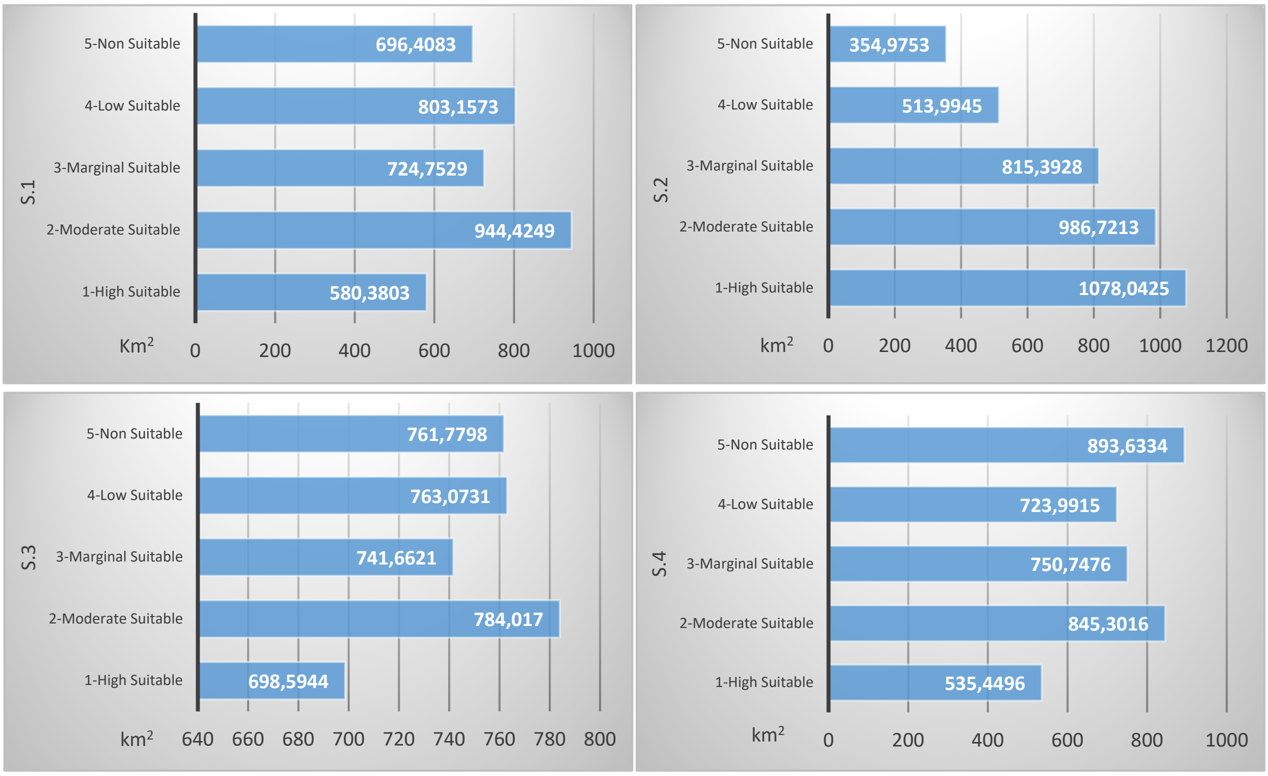
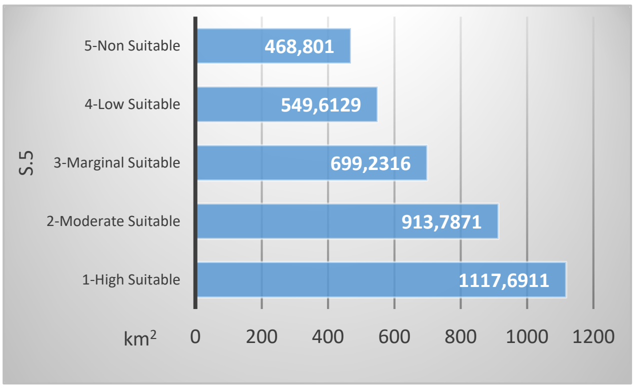


Figure 5-6: Land suitability maps used for various urban development scenarios; Baseline growth (S.1), Business as Usual (S.2), Traffic (S.3), Maximum Environmental (S.4), Compact Cities Growth (S.5)





Figures 5-7: Surface area of each suitability class for: S.1) Baseline, S.2) Business as usual, S.3) Traffic, S.4) Maximum environment proection, S.5) Compact cities growth scenarios in km^2.

5.3. Urban growth simulation

The simulation process was helpful to understand the self-organizing urban characterize and identify the techniques, reasons, distribution of urban sprawl more thoroughly (Jantz *et al.*, 2016b; Batty *et al.*, 1999; Triantakonstantis and Mountrakis, 2012b). Through assigning parameters' values as indicated in the table (4-8) in chapter 4, the urban growth simulation of Alexandria governorate from 1986 till 2016 was rebuilt with a statistical match degree between simulated and observed maps. As indicated in the methodology chapter (section 4.4.), the calibration process was accomplished via utilizing the Monte Carlo (MC) method. Results of urban growth simulation were generated as 2-D arrays, and then a script written in python was coded to generate the TIF format.

5.3.1. CA-based model calibration

Huge numbers of simulations of the model were computed through different combinations of the four factors [α, β, r, nb], as indicated in the table (4-8), in chapter 4. Neighborhood configurations including; neighborhood type (Moore, Von Neumann, Von Neumann Circular), neighborhood size (radius 1 till 6 or 3*3 till 11*11), random variables (0.0 till 3.0 with 0.1 increments), and exponent values ranging from 0.0 till 1.0 with 0.1 increments, were all estimated. The historical land use data were set as dependent variables, in which, 1 was assigned for change and 0 was assigned for no-change. While the standardized suitability weighted factors were set as independent variables. The model conducted 6138 simulations (comprises of 31 * 3 * 6 * 11) for 6138 different parameters' values combinations. The periods between the years 1986 – 1990, 1990 – 2001, and 2001 – 2016 of observed land use/cover data were used in the calibration process with the corresponding simulated years. The transformation rate of the cells from nonurban to urban was calculated to be 329 cells in each iteration, which means: in each iteration the highest transition potential values of 329 cells were transformed. The figure of merit was calculated for each simulation, thereafter, compared to the corresponding variables. The highest figure of merit values corresponding to the calibration parameters were selected, as indicated in the table (0-2) in the appendix, to measure the best performance of the model. 6138 figures of merits were generated. The Figures (5-8), (5-9), (5-10), (5-11), (5-12), (5-13) represent the figure of merit values resulted from various forms of parameters combinations. Figures (5-8) a, b, c, and d depict: randomness value [α =0.75], Von Neumann neighbourhood type, [β exponent value = 1], radius = 1 (3*3 neighborhood size) combination, generated the highest figure of merit value. Each of these figures investigates only one parameter vs the figure of merit values, which might not be accurate to select the best performance of the parameters individually. Therefore, figures from (5-9) to (5-13) were created to investigate more parameters vs figure of merit at the same time. Figures (5-9_a), (5-10_a), (5-11_a), (5-12_a), (5-13_a) figure of merit values were calculated at each random variable and radius, random variable and neighborhood types, exponent and neighborhood type, exponent and radius, radius and neighborhood type, respectively. Given the involvement of random variables, each simulation generates different results with different values of the figure of merit. Stochasticity is one of the basic components of the developed CA-based model for the current study, however, the stochasticity in the CA-based model maintains it stable (Barreira González *et al.*, 2015; Kocabas and Dragicevic, 2006). Figures (5-9_a) and (5-10_a) the model show that it can generate high values of figure of merit in the range of random variables [0.0 – 1.0], radius equal to 1 (3*3 nb size), and Von Neumann nb type.

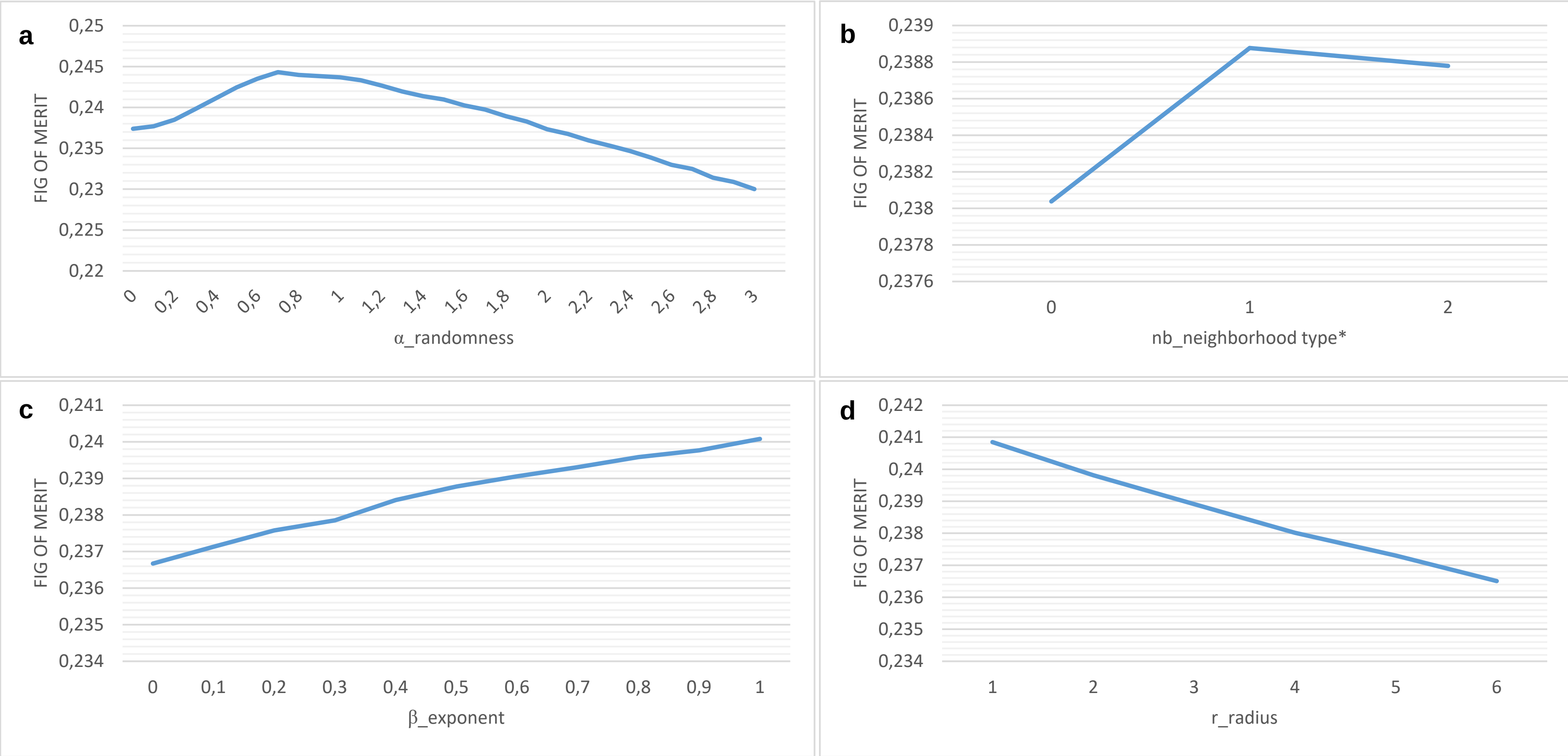


Figure 5-8: Highest figure of merit values corresponding to a) α- randomness, b) neighborhood type- nb, c) β- exponent, and d) radius-r

*0 =Moore neighborhood, 1 =Von Neumann neighborhood, 2 =Von Neumann Circle neighborhood

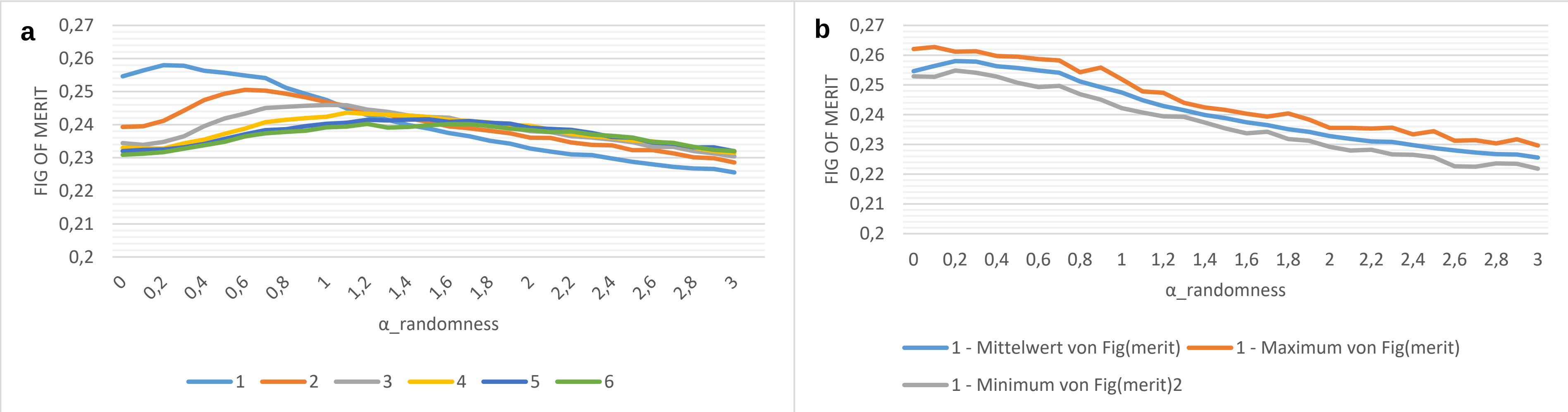


Figure 5-9: a) Figure of merit values corresponding to the randomness and the radius, b) Three lines representing the radius 1 (3*3 nb size) in the average, maximum, and minimum values of the figure of merit.

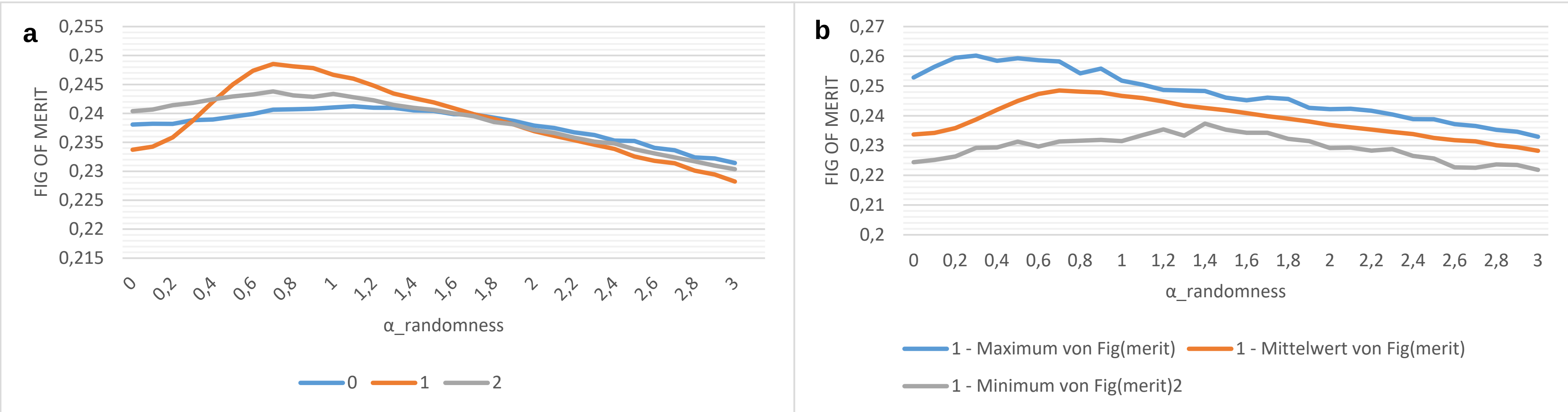


Figure 5-10: a) Figure of merit values corresponding to the randomness and the three neighborhood types b) Three lines representing the Von Neumann neighborhood type in the average, maximum, and minimum values of the figure of merit.

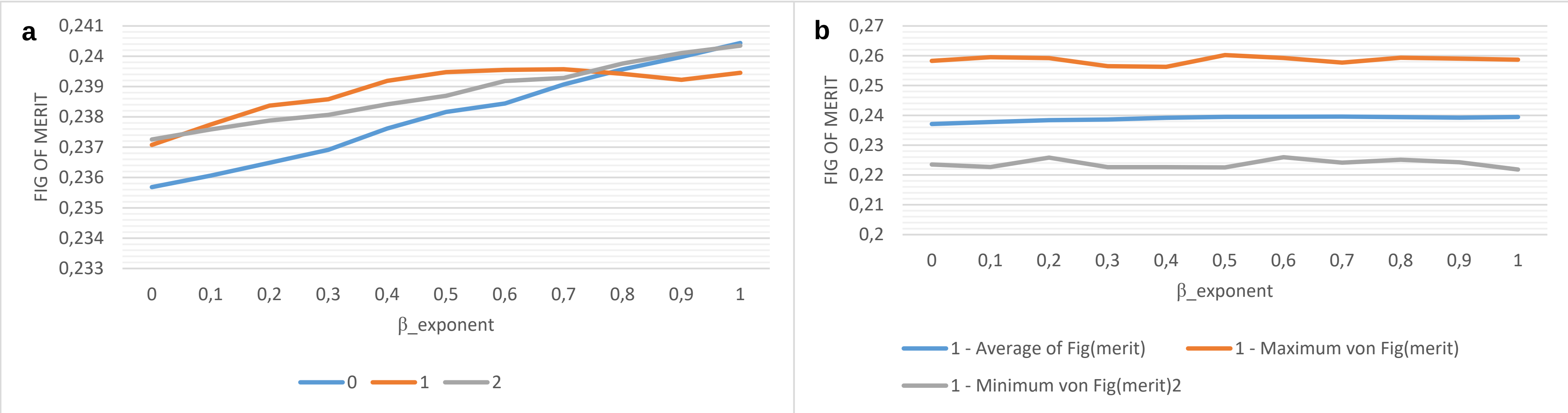


Figure 5-11: a) Figure of merit values corresponding to the β- exponent and the three neighborhood types b) Three lines representing the Von Neumann neighborhood type in the average, maximum, and minimum values of the figure of merit.

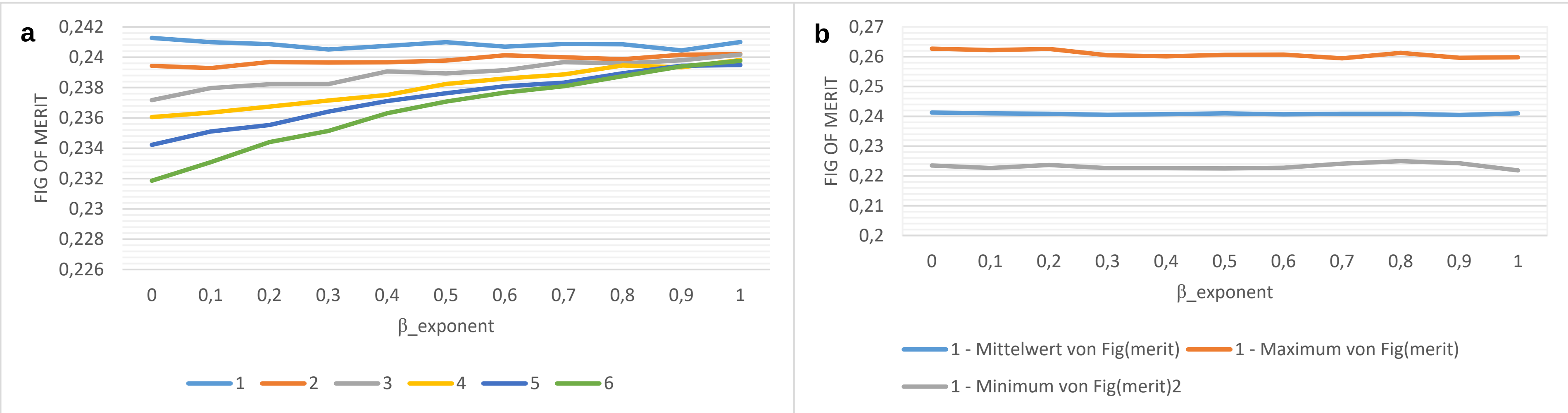


Figure 5-12: a) Figure of merit values corresponding to the β- exponent and the radius from 1 to 6, b) Three lines representing the Von Neumann neighborhood type in the average, maximum, and minimum values of the figure of merit.

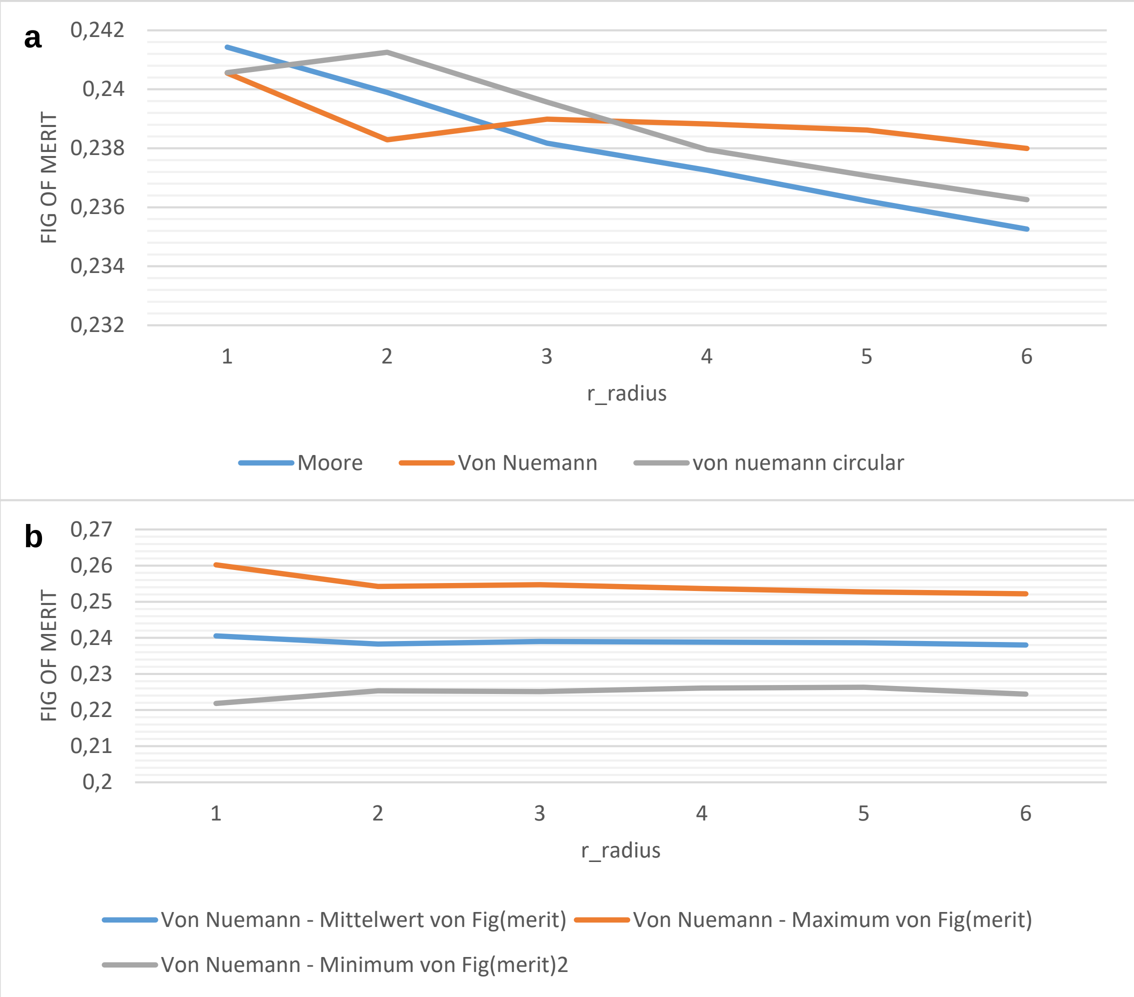


Figure 5-13: a) Figure of merit values corresponding to the randomness and the three neighborhood types, b) Three lines representing the Von Neumann neighborhood type in the average, maximun, and minimum values of figure of merit.

In the figure (5-11_a), the model shows that it can generate the highest figure of merit values in case of exponent value β =1 and Moore neighborhood type. Also, in figure (5-12_a): the model produces the highest figure of merit at β =1 and radius equal to 1 (3*3 nb size). While in the combination of Moore neighborhood type and radius =1, the model produces the highest figure of merit values, as shown in figure (5-13_a). Figures (5-9_b), (5-10_b), (5-11_b), (5-12_b), (5-13_b); show the max., min., and average figure of merit's values corresponding to radius (r =1) along with randomness axis, Von Neumann neighborhood along with randomness axis, Von Neumann neighborhood along with exponent axis, neighborhood size 3*3 (r =1) along with exponent axis, and Von Neumann neighborhood along with radius axis, repeatedly. From the aforementioned figures, there is a vast distance, in some areas, between the average and maximum lines, and average and minimum lines as well, denoting the instability and uncertainty. In figures (5-9_b) and (5-10_b), the best performance of random α is not stable in case of different neighboorhood configurations. In the figures (5-11_b) and (5-12_b), it is obvious that the values (average, min, and max) are almost having the same trend along the exponent β values. In the figures (5-13_a) and (5-13_b), Moore neighborhood performs the highest in case of r =1.

To avoid any confusion, figure (4-14) shows the interaction and the best combination of the four parameters used in the calibration process corresponding to the highest figure of merit value, from different views. The figure of merit' values change along with random variables, exponent values, in case of various neighborhood types and sizes. The von Neumann neighborhood type, the point 0.75 on the random (α) values axis, the point 1.0 exponent (β) axis, and neighborhood size (3*3) or r =1 of the parameters perform the best combination and highest figure of merit for the period between the years 2001 and 2016. These values were used in the case of prediction of the future urban growth scenarios till the year 2032.

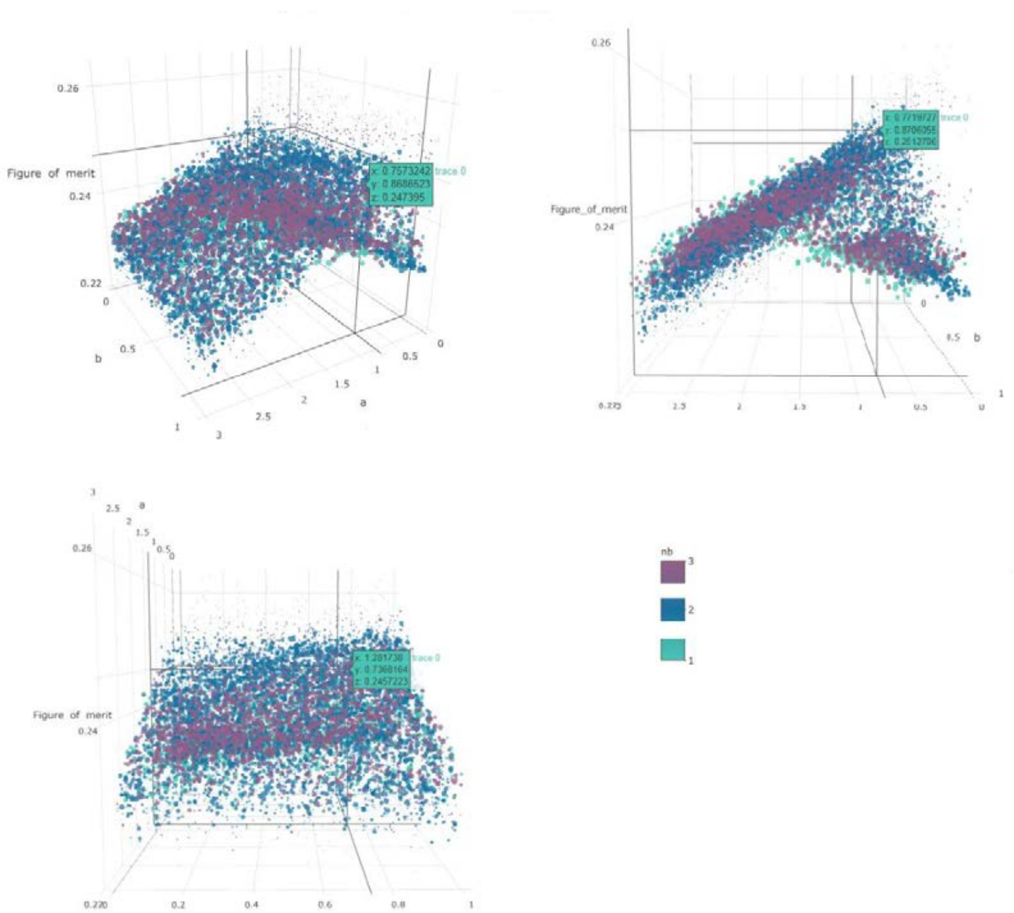
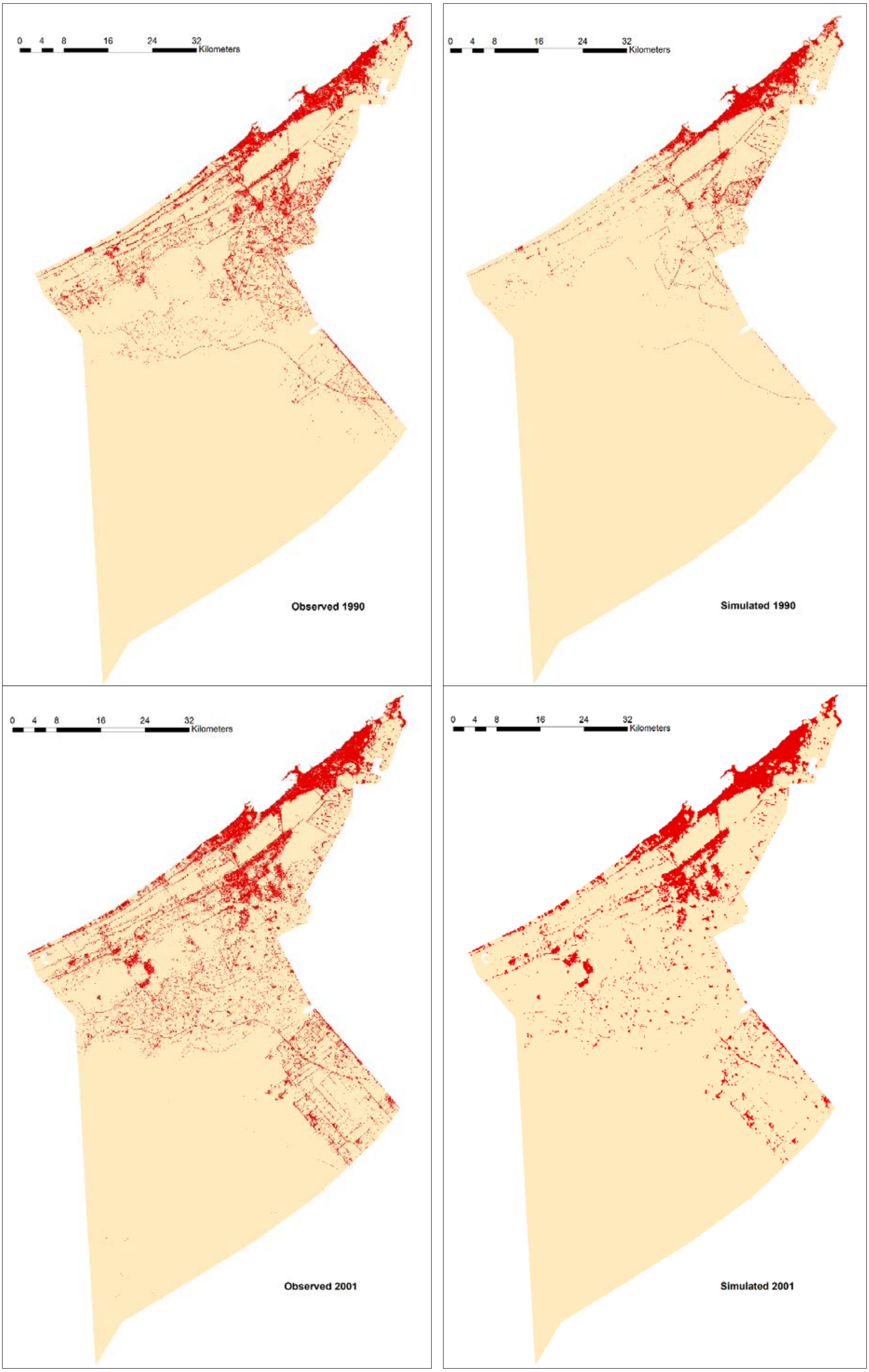


Figure 5-14: Combination of the calibrated four parameters corresponding to the highest figure of merit values


0 4 8 16 24 32 Kilometers
Observed 1990
0 4 8 16 24 32 Kilometers
Simulated 1990
0 4 8 16 24 32 Kilometers
Observed 2001
0 4 8 16 24 32 Kilometers
Simulated 2001

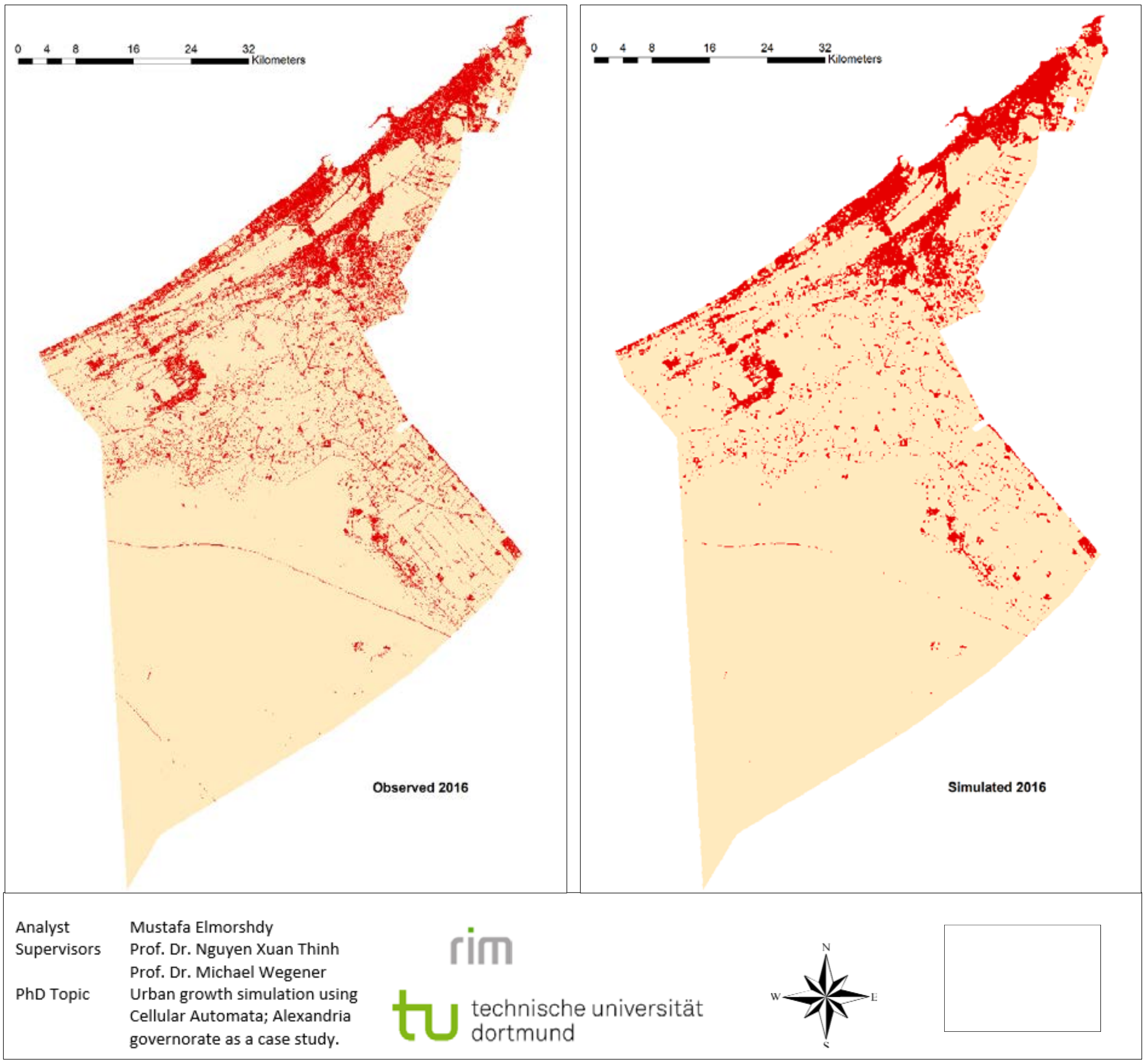


Figure 5-15: Simulated vs. observed results of urban growth simulation results for the years1990, 2001, and 2016.

As indicated in the table (5-5), the values of the four parameters were not the same for calibration of the other periods from 1986 to 1990 and from 1990 to 2001. That confirms that randomness and weight of neighborhood factor and configurations play a role here. Von Neumann neighborhood type and sometimes Moore type; show the most simulation fit to the observed urban land use, which could be attributed to the significant distortions between the cells in different directions. The randomness between 0.2, 0.35, and 0.75 corresponding to the periods 1986-2001, 2001-2016, and 1986-2016, respectively. That means these two parameters have high sensitivity and uncertainty influencing the interaction between the parameters and resulting values of outputs. Therefore, a sensitivity analysis was conducted.

Table 5-5: Calibration results of the CA-based model during different periods

Parameter	**1986 - 1990**	**1990 - 2001**	**2001 - 2016**
Randomness α	0.2	0.35	0.75
Exponent β	1.0	1.0	1.0
Radius	1	1	1
Neighborhood type	Von Neumann	Moore	Von Neumann

After the model was calibrated, simulation of urban growth in Alexandria governorate for the periods 1986-1990, 1990-2001, 2001-2016 was conducted. Figure (5-15) shows the simulated vs observed urban land use. There is a remarkable good match between the observed and simulated urban extent, as it is clear from the figure. Even though, and attributed to the path dependence, uncertainty factor, and randomness in the urbanization process; it is difficult to generate 100 % correct and matching urban locations for all simulated maps. Therefore, the simulated maps were overlaid with the observed ones for the years 1990, 2001, and 2016 to identify the four groups of cells, according to equation (4-14), which are; observed change simulated as persistence (A- error), observed persistence simulated as change (D- error), observed change simulated as change (B- correct), and observed persistence simulated as persistence (correct). Figure (5-16) shows the maps of spatial distribution of corrects and errors of the simulation results from A, B, and D. As indicated in the figure, the errors in the simulated results are located in the south-east area in Alexandria, there are areas cultivated lands and weren’t considered as areas for new potential urban areas for future development in the model (colored with black and also indicates error). In other cases, there could be changes from non-urban to urban in the real world and are not covered in the simulated results of the model. Furthermore, errors originate from the complexity of the urban system and urban growth process due to the unpredictable changes in the land features whether by nature or human-induced, as indicated in section 5.1. That can explain the error’s source existing on the fringes and rural areas and in the agricultural areas in the simulated new urban cells. Missing one or more of urban growth driving factors in the developed CA-based model could be also responsible for generating simulation errors.

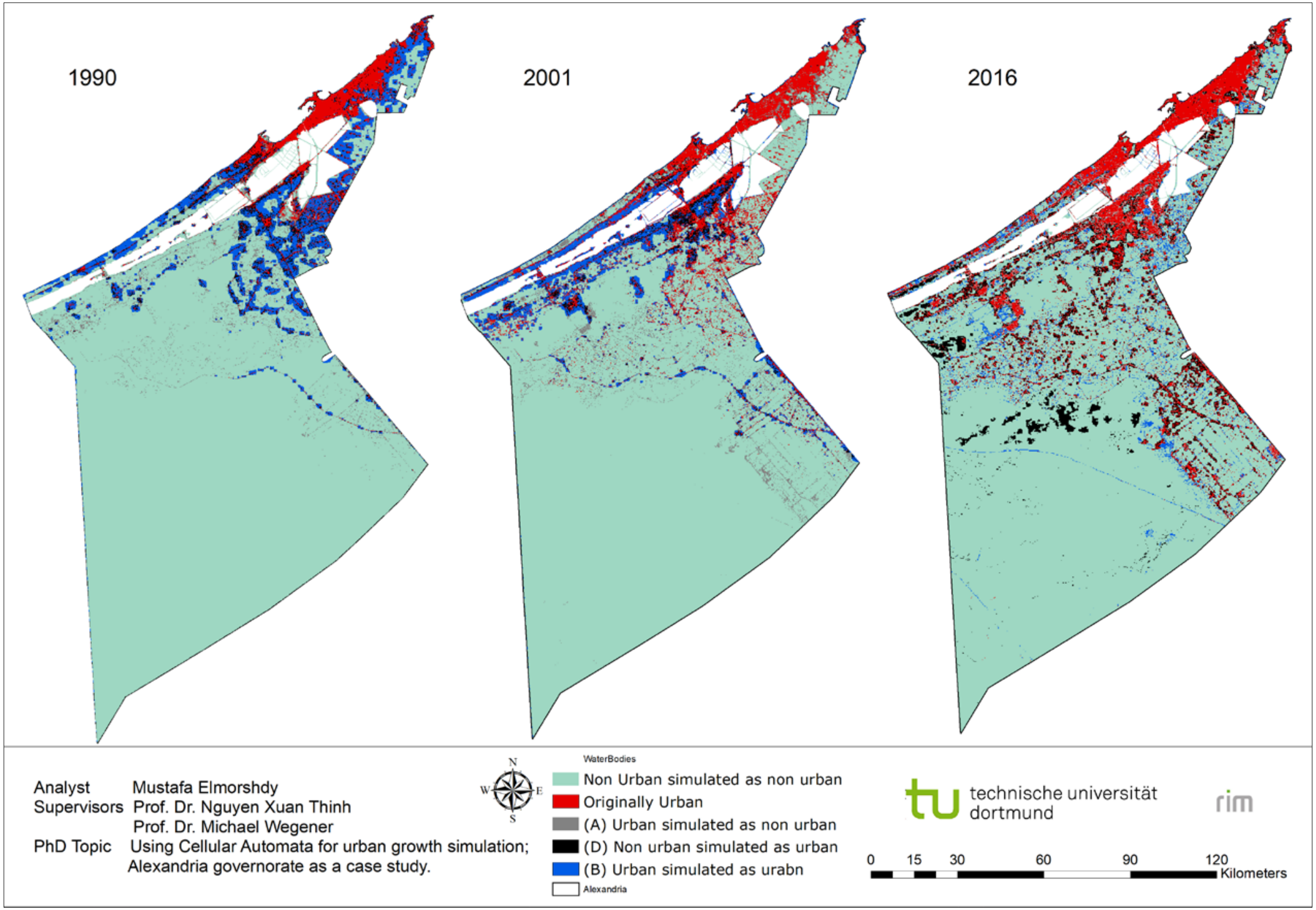


Figure 5-16: Urban growth simulated versus observed in Alexandria from 1986 to 2016 (three maps of Spatial distribution of corrects and errors of the simulation results) error (A), correct (B), and error (D)

The figure of merit method assesses the accuracy based on the pixel coincidence and overlay between the simulated and reference (observed) maps in a realistic way using the entire area of investigation with fixed land use. The overall spatial accuracy ranges from 87.6% to 90 % which is very acceptable and high enough. As (Mustafa *et al.*, 2014) stated in their article "*the overall agreement due to location for several previous studies are ranging between 69-92% and 4.5-38 % for all built-up cells and new simulated built-up cells, respectively*". The values of the figure of merit reveal that the simulations of the years 1990 and 2001 are more matching with the reference ones in comparison to the year of 2016. That could be attributed to the rapid and uncontrolled urban growth which was witnessed in the last two decades, as explained in the section (5.1.).

5.3.2. Results of uncertainty and sensitivity analysis

A cross-section of the figure (5-14) shows that the values of the figure of merit increase slightly when β value increases. The higher the value of β, the higher the figure of merit and the more stable; i.e. β parameter is not sensitive (very stable). Despite the randomness values range from 0 to 0.5 corresponding to the highest values of the figure of merit, the value of randomness 0.75 clear to be the best. Starting from the α = 0.75, the values of the figure of merit start to decrease. That means when α is greater than 0.75, it is unstable. So that, it is, preliminary, could be confirmed that α ranges from 0.0 - 1.0 corresponding to values of the figure of merit ranges from 0.22 – 0.27 are the most stable values along with both Moore and Von Neumann nb types. Therefore, UA-SA needs to be conducted for α and neighborhood types as they are affecting the stability of the model. Python SALib package was used to calculate the Sobol's index typically with a confidence level of 95% through conducting 6000 simulations [1000*(2*2+2)] (Henderson-Sellers and Henderson-Sellers, 1996; Fang *et al.*, 2002). The results show that the sensitivity differs, the Nb parameter shows no significant first-order effects, while α denotes significant first-order effects, resulting in almost zero and about 0.05, respectively. Nb is –ve but almost equals to zero, which means nb has lower sensitivity on the results of the model. While α independent parameters on the results. Generally in Sobol analysis, if the index has larger than 0.05 that means the parameter has high sensitivity. Total order (S_T) means α +nb have an impact on the results, table (5-6).

Table 5-6: Results of first and total indices of sensitivity analysis

Parameters	S_1 index	S_T index
Randomness values - α	0.05887315	0.99846593
Neighborhood type - nb	- 0.00358216	0.96833395

5.3.3. Results and analysis of the urban growth prediction scenarios

According to the calibration results, the developed standalone CA-based model is very reliable and capable of urban growth simulation and prediction. Therefore, the model was used to predict urban growth in Alexandria for the year 2032 using five scenarios; Business as Usual scenario, Maximum environmental Protection scenario, baseline scenario, traffic scenario, and compact cities growth scenario. The probability of transformation for the cells from non-urban to urban state for each scenario was determined mainly based on the land suitability maps and then the potential values of the cells. The potential values were sorted descendingly from high to low values. In each iteration; the highest 329 potential values of the non-urban cells change into urban cells. These transformed cells and all existent cells were determined through direct probability using the formula (5-2) (Li Cheng, 2014):

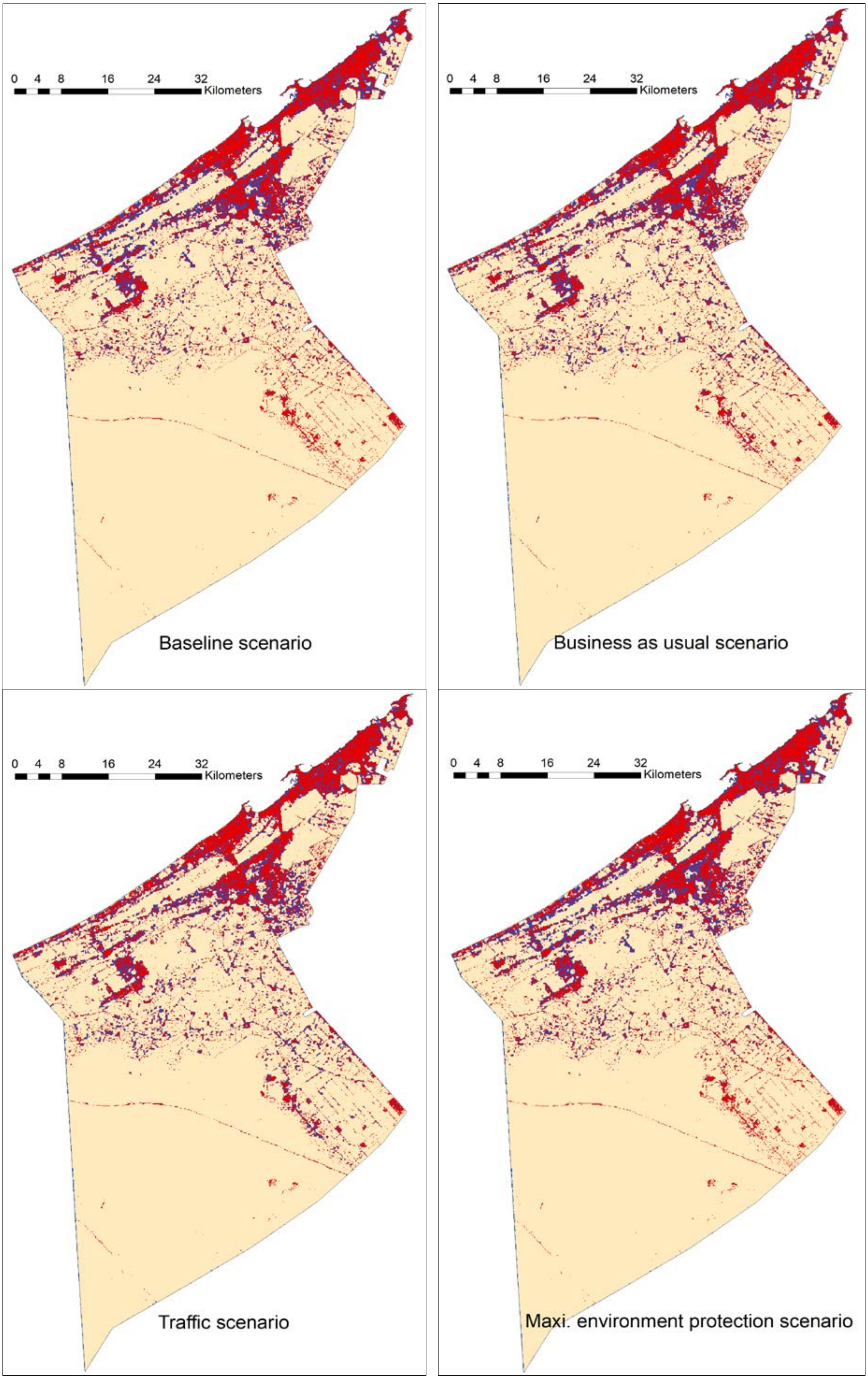
$$P^n = \frac{M_n}{S_s} \qquad \text{Equation (5-2)}$$

Where; M_n indicates the number of transformed cells, S_n indicates the number of all cells that were located in the class n and P^n is the direct probability of cell located in row-x and column-y in suitability map (Li Cheng, 2014).

As indicated in the equation (4-11), the parameter β controls the weight function and assigning the weight for each cell in the neighborhood. It is popular in some weighting functions that the distant cells receive smaller weights and also the large neighborhood size. The current study considered the relatively small neighborhood size 3*3 or r =1, which means the neighborhood effect focused on the non-urban areas close to the existing urban areas. Which in turn, highly reflected on the predicted results, the new urban areas are generated around the city center and also on the peripherals around existing urban clusters. In the results of LULC change detection (section 5.1.), it was obvious that the new urban areas for each year are existing close to the old urban areas, except in some cases due to encroachment of the agricultural areas, as explained in the same section. So, here comes the role of the random variable (α) to control the degree of stochasticity and reflects the complexity of the urban growth process and produces leap-frog growth of urban land uses; i.e. generating new urban cells in new locations called seeds. This in turn, generates non-continuous urban land use growth. The higher the random variables, the higher the stochasticity level in the urban growth process, the more the dispersion level of the urbanization process and urban pattern. Based on these growth quantities and using the method described above, the model locates different growths for the urban built-up areas for the year 2032 starting from the year 2016 with an annual iteration. All five urban growth scenarios indicated an increase in urban built-up areas. Figures (5-17) and (5-18) show the predicted, percentage and distribution of the new urban areas, respectively, as indicated below:

Baseline urban growth scenario; the growth in urban land between 2016 and 2032 identified an increase of 119.14 km^2. The predicted urban land use due to conversion of about 51.5 km^2 of the agricultural land, 30.6 km^2 undeveloped land, 20 km^2 of the desert, and 10 km^2 of the freshwater resources. In that scenario, the urban clusters were increased from 102 in the year 2016 to be 127 in the year 2032. Results of the scenario denote that the croplands, naturally protected areas, and coastal areas close to the transportation system or urban areas could be under risk of getting vanished because of the taking place urban growth activities.

Business as usual scenario; the growth in urban land between 2016 and 2032 was identified an increase of 153.4 km^2 and divided between high and low density urban built-up land use over the entire study area. The predicted new urban areas were generated due to conversion of about 71.5 km^2 of the agricultural land, 40 km^2 of open space (undeveloped land), 15 km^2 of the desert, and 15 km^2 of the freshwater resources. The urban clusters decreased from 102 in the year 2016 to 97 in the year 2032. That implies that smaller urban clusters were extended outward fringes and join together forming larger urban clusters on the agricultural lands. It was figured out that by the year 2032 districts/Qisms; e.g. Addekheila and Borg Alarab could be merged with other clusters in the south of the governorate forming new potential urban centers and hence new realms. These areas which are close to the city center could form a basin of agricultural land together with an urban core east-south and west-south of Alexandria governorate. In that scenario, the agricultural lands are vulnerable to a real risk of getting vanished because of the urban growth activities.


0 4 8 16 24 32
Kilometers
Baseline scenario
0 4 8 16 24 32
Kilometers
Business as usual scenario
0 4 8 16 24 32
Kilometers
Traffic scenario
0 4 8 16 24 32
Kilometers
Maxi. environment protection scenario

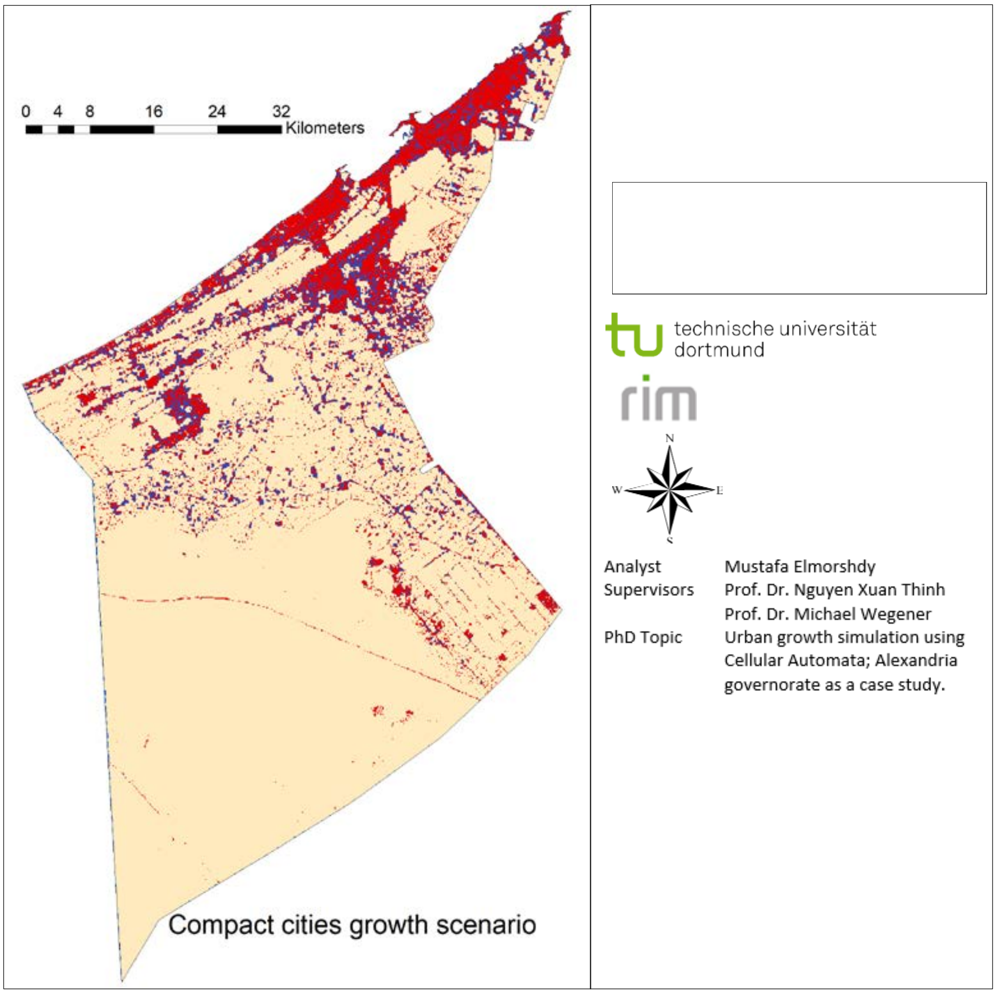


Figure 5-17: Predicted new urban areas for the year 2032 starting from the year 2016 for the predesigned five urban growth scenarios.

Traffic scenario; the predicted new urban areas were increased by about 91.12 km^2 in the year 2032. The existing of the transportation system increased the urban probability to be more dispersed across most of the study area. About 37 km^2 of the cultivated land was converted to urban areas, 34 km^2 of open space (undeveloped land), and 15 km^2 of the desert. Furthermore, the urban clusters generated in this scenario estimated to be 110 instead of 102 clusters in the year 2016 and located close to the transportation network.

Maximum environment protection scenario; the urban growth was estimated to be 76 km^2 divided between high and low density and distribution over the study area. To prevent urban development in the agricultural and environmentally sensitive areas, constraints were applied in the used land suitability map for that scenario. By the year 2032, the predicted urban land use generated due to conversion of 29.34 km^2 of the agricultural land, about 40 km^2 of open space (undeveloped land specified for development), 10 km^2 of the desert in the study area. The number of urban clusters were reduced from 102 in 2016 to 91 in 2032. The new urban areas were extended along the coastline and around the exiting urban areas with a little encroachment on cultivated lands and sensitive areas, which means fewer clusters due to the constraints implemented. This scenario is considered less harmless on environmental and natural resources.

Compact cities growth scenario; the predicted urban areas for the year 2032 were estimated to be about 96.55 Km^2 due to the transformation of 30.8 km^2 of the cultivated land, 29 km^2 of open space (undeveloped land), 9 km^2 of the desert into urban land use. Furthermore, the urban clusters generated in this scenario estimated to be 103 instead of 102 clusters in the year 2016. That implies on one hand, smaller urban clusters were extended outward fringes and join together forming larger urban clusters on the agricultural lands. On the other hand, formulation/construction of new urban clusters whether on agricultural lands or undeveloped open spaces, but very few. As aforementioned, the target of that scenario was to encourage the urban development in the open space areas (undeveloped lands) towards the south and west according to the specified locations in the SUP- Alex 2032 of Alexandria governorate; e.g. the urban growth in the Qisms specified for new urban development (locations specified in Al Amereya). It was figured out that by the year 2032 districts/Qisms; e.g. (locations specified south of Lake Mariute) could be merged with other clusters in the south of the governorate forming new potential urban centers and hence new realms.

All simulation results support the conclusion that land-use transition from non-urban to urban occurs mainly in agricultural land and open spaces that are scattered around the city. The urban growth at most resulting from the centers of urban areas to the fringes, as long as the transportation networks are existing. Encroachment of the urban areas in the croplands and cultivated areas was very remarkable. However, the indicated prediction results advise the importance of compact city growth and maximum environmental protection growth scenarios. In 2016, the urban settlement was found to be grown in a linear pattern in the southern part of the south-west direction across the croplands, reclaimed, and open space (undeveloped areas) parallel to the coast. However, in every directional slice, we can find a compact pattern of settlement in the buffer just contiguous to the city center except for the rice fields' zones, which is regarded as a very strategic crop.

It is obvious from the table (5-7) that the maximum environmental protection growth scenario generates the lowest new urban areas ($76km^2$). That could be referred to the high restrictions made on environmentally sensitive areas such as cultivated lands, open/public gardens, water bodies... etc. As indicated in the figure (5-18), it is clear that the distribution and percentages of the new urban areas are away from the restricted features in the south and east and located mainly towards the west and along the coastal line. Besides, and according to the SUP-Alexanddria 2032, the new urban built-up areas were generated mostly on the areas specified for future urban development. The compact city growth scenario encountered less new urban growth in the cultivated and environmentally sensitive areas, but rather around the existing urban clusters and then close to the transportation areas. Also, that scenario reflects a realistic urban growth for the governorate for the year 2032. Accordingly, both scenarios would be recommended for the urban growth development for Alexandria governorate for the year 2032 to ensure more sustainable and environmentally friendly urban growth development. SPOT-7 image with 1.5 m resolution was utilized to conduct Zonal Statistics to figure out which land-use type converted to new urban built-up areas during the prediction process between the year 2016 and 2032.

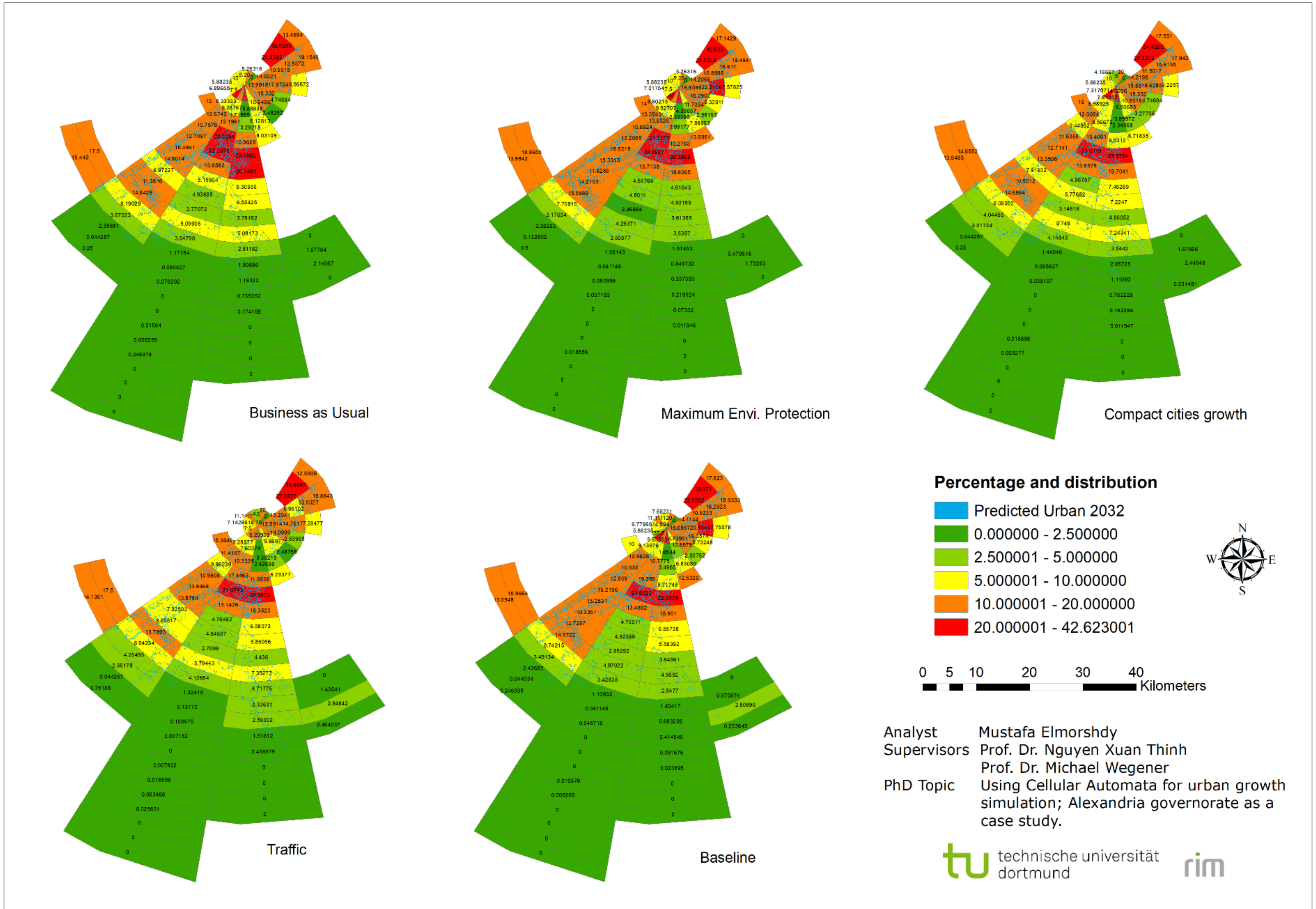


Figure 5-18: Percentage and distribution of the predicted new urban areas for the five scenarios in the year 2032

Table 5-7: Transformed land features into urban land use during the simulation for the year 2032 (%)

LU Type	Baseline growth (S.1)	Business as Usual (S.2)	Traffic (S.3)	Maximum Environmental (S.4)	Compact Cities Growth (S.5)
Croplands	15,4	27	14,4	6,8	19,2
Lake Mariute	1,1	0,9	1	0,3	0,8
Desert	5,2	0,2	1,3	10,2	0,2
Sandy beach	4,9	8,7	5,4	1,8	5,2
Fish Farms	0,8	1,1	2,6	1,3	0,4
Reclaimed	4,3	9,3	5,2	5,4	9,2
Undeveloped	10,2	5,8	9,7	20,1	20,8

According to SUP- Alex for the year 2032, the City is expected to grow from 4.1 to 6.8 million (65% population growth rate) putting pressure on the environment, especially in case of informal settlement. The prediction results showed that the sensitive areas around Lake Mariute and South of Abu Quir are not fully protected. The most affected areas within Alexandria city are along the northern border of Lake Mariute and in the southern part of the city between Gharb and Abu Quir districts.

The New Borg El Arab New Urban Community (recently planned town) was planned to reduce commuting between Alexandria's core city and industrial areas, prevent urban sprawl on agricultural land and absorb future urban sprawl targeting 570,000 inhabitants for the year 2030. However, the growth trend is densified and spread east of the city center. The informality is the key feature of the Alexandrian housing market. The population of these informal areas was estimated to be around 1,584,000 inhabitants representing about 40% of the total population of the city and 17.2% of the urbanized areas. SUP- Alex 2032 introduced 8,500 hectares (85 km^2) for future residential developments. As introduced in the figures (5-19) and (5-20) most of the predicted areas are located on the cultivated lands because the specified lands for development as formal residential areas are quite expensive.

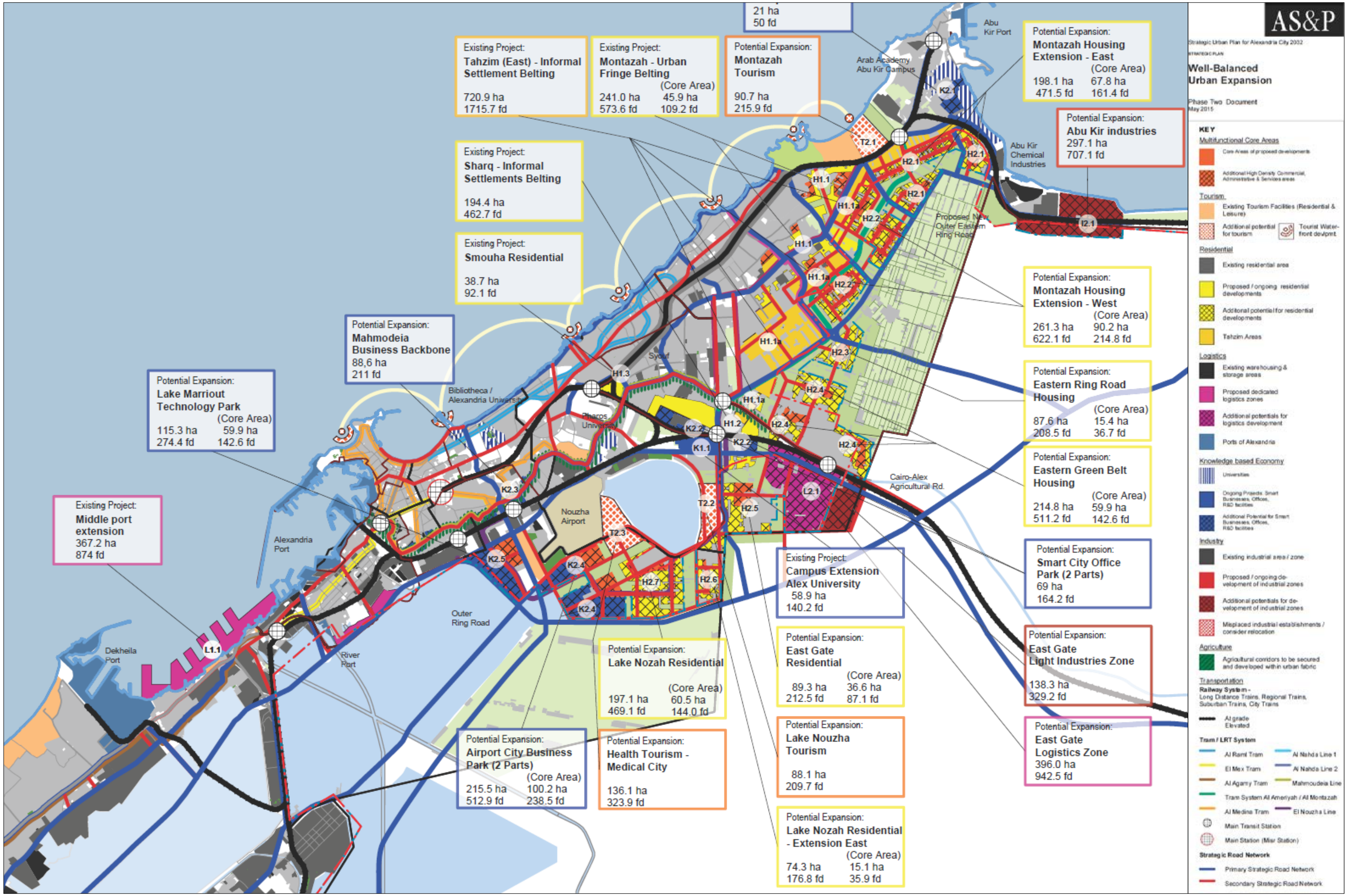


Figure 5-19: Strategic Urban Plan for the year 2032, Alexandria governorate (AS&P, 2013, 2014)

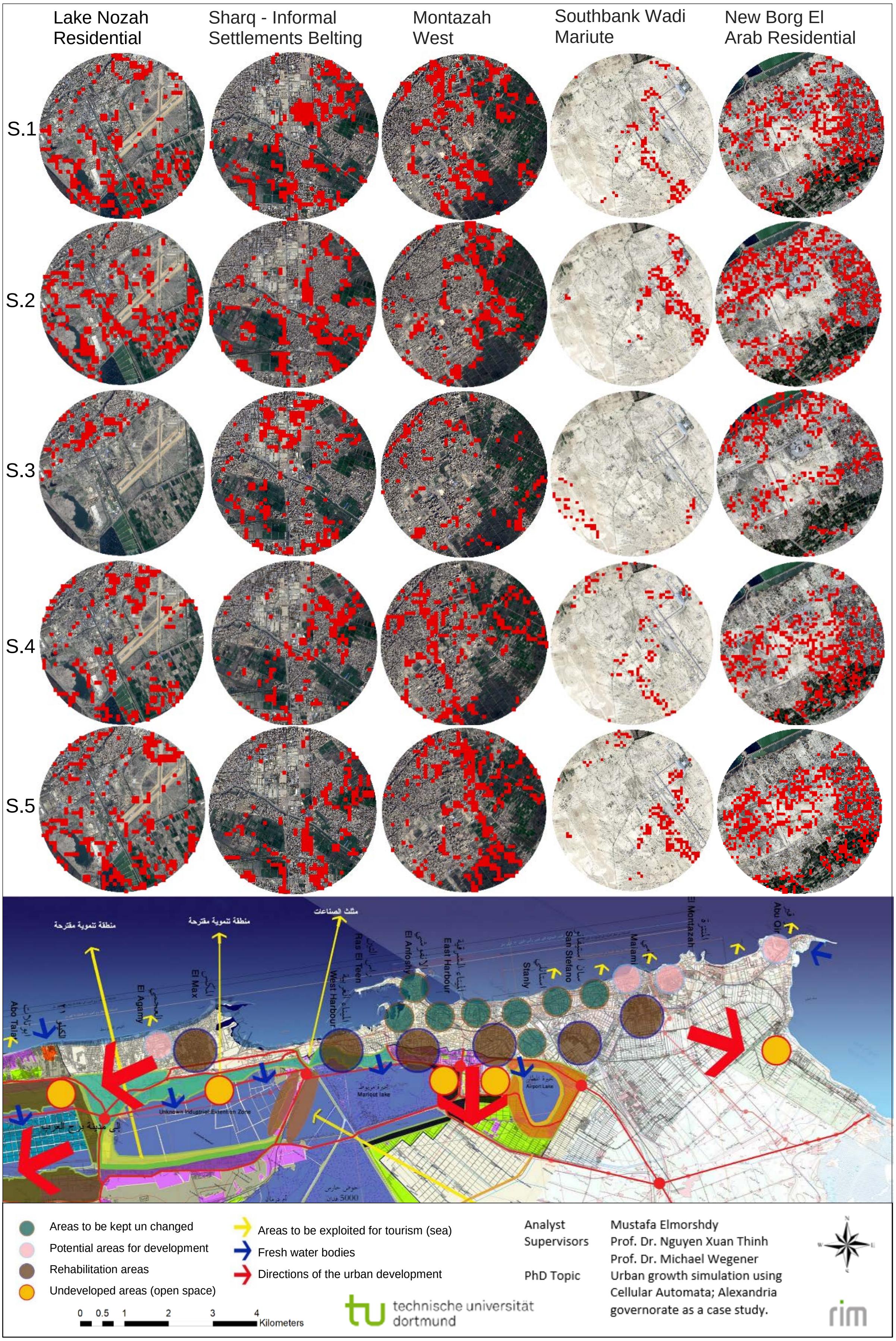


Figure 5-20: Potential places and directions of urban development based on SUP- Alex 2032

6. CHAPTER SIX: Sustainable approach for urban growth management

6.1. Cellular Automata importance in urban planning and management

Knowing the future physical expansion of urban development plays a vital role in successful urban planning and management measures. CA-based models are capable of presenting a holistic understanding of the interactions between urban system components to correctly predict future urban growth. As was conducted in the current study; studying the interactions between social, environmental and economic variables in land-use and urban development dynamics was conducted and approved great importance. CA-based models are effectively capable of simulating the spatial evolutions with different development perspectives/scenarios and produce various future development patterns/scenarios useful for decision-making processes.

According to the definition of the urban planning set by the school of urban planning, McGill University in Canada, it was defined as “a technical and political process concerned with the land development, use of land, planning permission, protection and use of the environment, public welfare, and the design of the urban environment including; air, water, and the infrastructure such as transportation, communications, power networks…. etc.” (school of urban planning, 2017). CA-based models are inherently bottom-up and efficiently used to evaluate planning actions and strategies, exploration of spatial dynamics, territorial analysis and deploying its complex nature. Furthermore, CA formulation can offer a promising perspective in sustainable urban growth development and planning and confront environmental dynamics. CA models take into account possible developments during the simulation period, providing better simulation to mimic spatial development and the possibility to manage an acceptable simulation and prediction processes with a high degree of accuracy and confidence level. Defining control policies and guiding the urban growth process is one of the main duties of urban authorities. Thus, spatial analysis and development process and also complex urban system evolution modeling can be employed as an appropriate support tool by planners to realize and interpret the urban development and growth mechanisms.

Many tools have been widely used in attaining sustainable planning and development; e.g. Environmental Assessment (EA), and its two generations namely

Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) (Hegazy, 2015b; Thompson *et al.*, 2013).

6.1.1. Strategic Environmental Assessment (SEA)

Figure (6-1) shows the tiering concept of SEA and its integration during the projects. EA is a process for highlighting the consequences of any new development activities on the environment. EIA is considered the first generation of EA. (Dalal-Clayton and Sadler, 1999) defined the EIA as a systematic process that examines in advance the environmental consequences of any development activities. EIA was used firmly in the process of urban planning in some countries, but in a later stage in the planning process, after the decisions have been taken (Thompson *et al.*, 2013; Hegazy, 2015b). Thereby, the planners and the urban scholars would rather need an EA tool, or a framework used at an earlier stage of the planning process, so that, better address of the environmental issues can be realized.

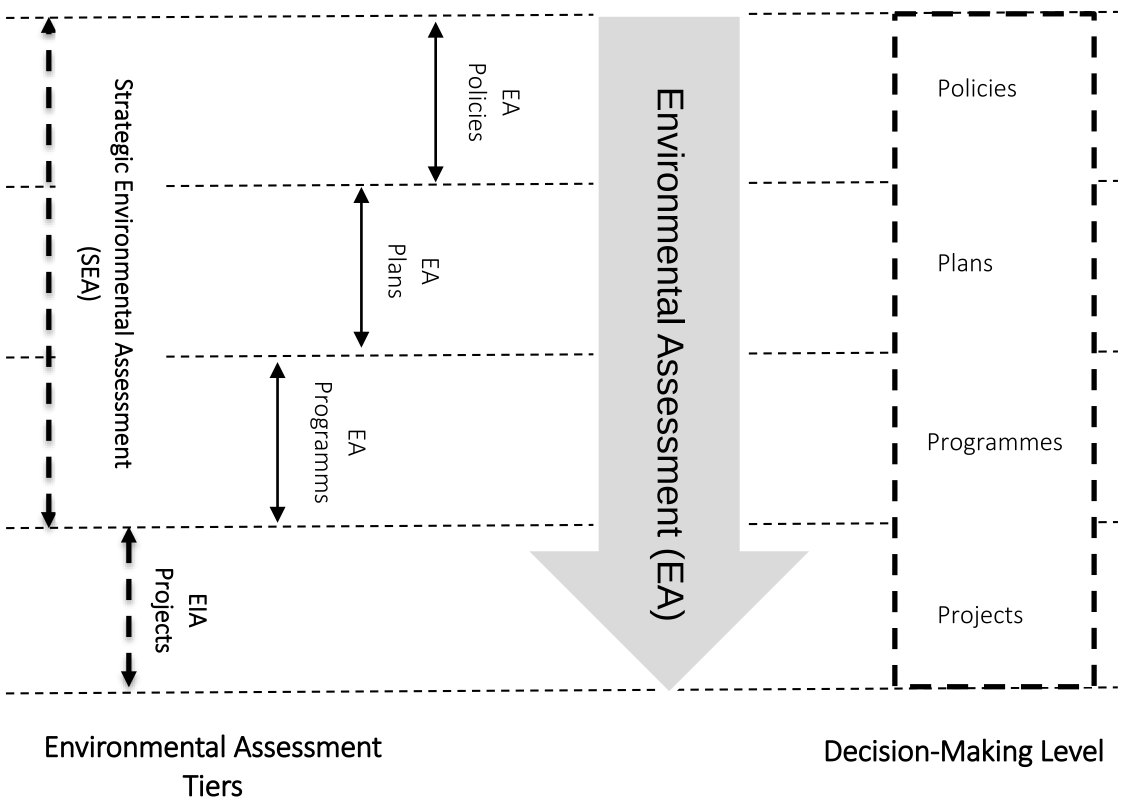


Figure 6-1: Tiering Concept and SEA

Based on the law 4/1994, the EEAA was established and in charged to define the environmental policies, setting priorities and implementing initiatives with a context of sustainable development throughout applications of EIA. However, the indicated environmental degradation in chapters 4 and 5 denote that EIA and ICZM projects are not effective tools in achieving sustainability in the planning process (Hegazy, 2015b). SEA became widely used in the strategic decision-making process level (Rojas *et al.*, 2013). SEA is not like one size tool fits all planning processes and systems, but rather, each planning system has to establish its SEA model taking into consideration local and national policies, planning laws and legislations (Noble and Nwanekezie, 2017; Monteiro and Partidário, 2017; Belčáková, 2016). SEA was defined as “a proactive process to strengthen the role of environmental issues in strategic decision making” (European Parliament/ EC/42, 2001) has gained a widespread recognition and approval in achieving environmental sustainability (Thompson *et al.*, 2013; Bidstrup and Hansen, 2014; Belčáková, 2016; Malekpour *et al.*, 2015).

ICZM is highly promoted to be utilized as a tool for sustainable development for the coastal areas, along with spatial planning. However, sustainable management of urban growth in the coastal cities still missing environmental and socio-economic perceptions. Accordingly, SEA is considered as an aiding tool has a high ability in enhancing the influence of the environmental authorities and increase the coordination between various and concerned sectors at all levels and scales in the process of planning (Lobos and Partidario, 2014; Thompson *et al.*, 2013; Daini, 2002). SEA could effectively be initiated early in the ICZM or any other strategic projects/plans when the potential vision is being prepared (Daini, 2002; Dalal-Clayton and Sadler, 1999). As in figure (6-2), SEA is being implemented in parallel with the planning, programming and policy definition process to ensure that they are fully included and appropriately addressed at the earliest stage of decision-making, considering socio-economic principles and must be completed before its adoption (Gao *et al.*, 2017; Geneletti *et al.*, 2017; He *et al.*, 2011; Lamorgese and Geneletti, 2013; Li *et al.*, 2014). So, SEA enables the integration of environmental issues and concerns in the planning process will be ensured to achieve sustainable development. SEA operates at a strategic level and requests neither sophisticated modeling nor complicated data gathering. The key determinants of success are institutional cooperation, public participation and stakeholder engagement, and transparency (Bidstrup and Hansen, 2014; Gao *et al.*, 2017)(Belčáková, 2016; Bidstrup and Hansen, 2014; Dalal-Clayton and Sadler, 1999; Fischer *et al.*, 2002; Lamorgese and Geneletti, 2013; Li *et al.*, 2014; Monteiro and Partidário, 2017; Noble and Nwanekezie, 2017; European Parliament/ EC/42, 2001). Article (19) in ICZM

Protocol calls for SEA application to the plans and the programs affecting the coastal areas. Considering the fragility of coastal cities, the responsible institutions need to ensure the process of environmental assessment for public and private projects and the inter-relationships between the seawards and landwards in the coastal cities. Besides, the institutions also need to formulate a SEA of plans and programs.

SEA Directive (2001/42/EC) requires that systematic environmental assessment be considered for plans and programs prepared (for agriculture, forestry, fisheries, energy, industry, transport, waste management, water management, telecommunications, tourism, town and country planning or land use) which set the framework for future development consent of projects listed in Annex I and II to the EIA Directive (85/337/EEC), and require an assessment under Article 6 or 7 of the Habitats Directive (92/43/EEC) (European Parliament/ EC/42, 2001). Land suitability analysis that has been conducted in an earlier chapter (4) is considered as an excellent example of the integration of the environmental and sustainability criteria throughout the planning process. That was through the identification of suitable or unsuitable locations for new urban development and in the assessment of alternative potentials in the policies, plans and programs.

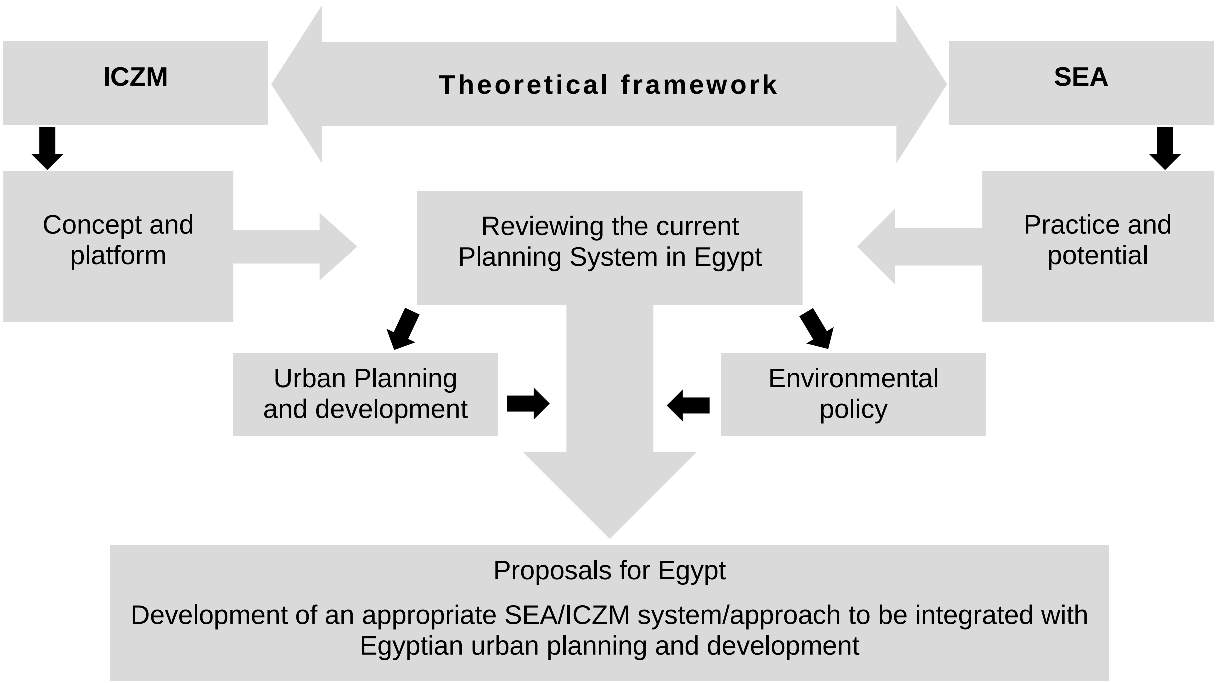


Figure 6-2: Flow chart of the of the SEA-ICZM sustainable approach development.

Application of the SEA and ICZM system varies from a country to another according to many factors; e.g. political, cultural, legal, environmental and participatory context of the country (European Parliament/ EC/42, 2001; Fischer et al., 2002; Cerreta and

Toro, 2012; Hegazy, 2014; Tulu, 2014). By law, all governorates need to have their own strategic and detailed plan from which their regulations emanate. SEA can be regarded as an integral and parallel part of the planning process which provides the environmental evidence and supports more informed decision-making and identifying new opportunities through a thorough examination of development options and contributes to conflict resolution over the use of shared resources. That requires new forms of cooperation between urban, suburban, and rural areas to foster a new governance arrangement. Therefore, it is important to highly consider the following; a) a coherent set of sectoral policies and a cross-cutting approach, focusing on housing and informal activities, and environment on different scales, b) temporal integration; i.e. moving back and forth between strategy formulation and operational implementation.

6.1.2. SEA and Planning support system

There is often a difference in knowledge and information between experts, decision/policymakers (officials), and the public. This difference or gap could hinder achieving sustainability and a sound decision-making process on how the resources can be sustainably managed and planned. Hence arises the importance of SEA rationale in ‘real ad flexible’ decision making/planning support system/decision support system aiming at filling that gap (Fischer, 2003). The political system is always changing and resisting at the same time any administrative environmental mandatory at the strategic level in the process of decision making (Fischer, 2003; Fischer *et al.*, 2002). Therefore, SEA needs to be incorporated in the political system, to, realize the transparency and good governance in the decision making/planning support system/decision support system. To provide a fertile land which facilitates SEA implementation, some conditions must be afforded; e.g. Political will, Legal mandate, Environmental institutions’ capacity, Environmental education and awareness, EIA process implementation, Technical know-how (Azcárate *et al.*, 2013; Gachechiladze-Bozhesku and Fischer, 2012; Fischer *et al.*, 2002).

Environmentalists, planners, urban scholars and researchers in their literature stated that SEA can be conceptualized as framework structural elements that need to be integrated into legal, administrative, and planning procedures and practices. Also, SEA system can have different form depending on the sector and the administrative level to which it was designed to be applied (Azcárate *et al.*, 2013; Bidstrup and Hansen, 2014; Dalal-Clayton and Sadler, 1999; European Parliament/ EC/42, 2001;

Fischer *et al.*, 2002). Hegazy (2015b) stated that the “SEA system consists of three main components called the ‘SEA composition triangle’ named; legislation, administration and process, each has a set of structural elements (Building Blocks) that provide the context for strategic decision-making”. Table (6-1) presents all elements of the core structural components of the SEA system.

Table 6-1: Framework of the Strategic Environmental Assessment core components. (Source: Compiled by the author based on (Hegazy, 2015a; Connelly, 2017)

Component	Element
SEA legislations (identifying what legislative requirements and provisions have control over SEA system and process)	Strong **legislative basis** (**Legal provisions**) gives more legal power to SEA implementation and findings
	The administrative level identifies the coverage of SEA through the full different planning hierarchy: e.g. national, regional, local.
	The strategic actions are tiered, therefore, there are associated tiering in SEA; i.e. policies, plans, programs, projects. That means, higher-level proposal leads to the development of lower-level proposals, which ensure greater efficiency in SEA at different levels.
	SEA process must be **Integrated** within the preparation of the **planning** proposals through the policies, plans and programs.
SEA administrations (official mechanisms, institutional and organizational structures responsible for SEA process)	The **initiator** is responsible for promoting the application of SEA to strategic proposals
	The conductor is the organization/institution that examines the environmental consequences of PPP whether consistency with the objectives of sustainable development or not.
	The reviewer is an independent body who examines the SEA statement, process, findings before being used in the decision-making process.
	Inspector is responsible for ensuring that the SEA results are taken into consideration not only during decision making but also in the implementation of the proposed actions.
SEA process (how could the SEA process be operated)	Through the **screening** step, it could be figured out whether the proposed actions of SEA have significant effects on the environment and hence achieving sustainability or not.
	Scoping can be conducted at any rate in the SEA process. It focuses on the essential requirements of the SEA. Also identifying the development alternatives that meet environmental, economic and social objectives.
	The SEA process would not be meaningful without a clear **impact assessment** of strategic actions. This Assessment allows the decision-maker to consider which development alternative is the best, to, achieve the objectives at the lowest cost and highest benefit to the environment.
	Mitigation measures can be introduced during the SEA process and aiming at improving the environmental performance of the strategic actions to be considered during the decision-making process.
	Reporting work includes the findings of the assessment process, these reports should contain objectives and proposed alternatives and actions, environment baseline description, environmental impacts of the proposed actions, possible mitigation measures, analysis and comments of any potential problem. It is essential for a transparent SEA.
	Review is a tool that assesses the quality of the presented information, identifying any contradiction or uncertainty, and counteracting any bias, and then integrated in the decision making of the strategic actions.

	Consultation and public participation is an important stage which can improve the planning process by informing the decision-makers with the needs of the stakeholders, hence, improve the planning process and development. This stage can be integrated at any stage in the SEA process. Also, the findings of SEA should be available for public and local authorities in an early stage, so that, they can express their opinions on the draft plans before submission to the legislative procedures.
	Monitoring the implementation of the strategic actions adopted by SEA is an important action to ensure the successful achievement of its purposes through a comparison of the results and performance with the proposed plans. The monitoring process is usually conducted during the implementation stage by the means of s set of indicators.

Decision-makers, especially on the ministerial level should be aware that, effectiveness and success of the ICZM comes from its promotion of integration of all the sectoral policies and guidelines concerning the coastal zones (horizontal integration) and all the administrations at the national, regional and local level (vertical integration), a bottom-up approach in coastal management based on scientific knowledge and holistically viewing the coastal system, considering all the coastal subsystems (physical, ecological, social, economic and legal-administrative) to achieve a balanced development (Borhan *et al.*, 2003; González-Riancho *et al.*, 2007). In light of the aforementioned urban problems, it has become urgent to formulate a promising tool that can achieve sustainable urban development. It was recommended to integrate SEA into the urban planning system in the framework of the national strategy of planning in Egypt (Hegazy, 2015b).

7. CHAPTER SEVEN: CONCLUSION

Coastal cities of Egypt, in particular, Alexandria and Nile Delta region are experiencing very rapid and unplanned urban growth leads to the destruction of croplands, natural resources, and informal settlements formation. Egyptian coastal areas along the Mediterranean and Red Seas have become one of the most dynamic places of urban growth. This strong residential growth spurred by increasing the urban areas resulted in critical changes in the patterns of the urban growth and landscape of these areas; e.g. encroachment of the agriculture lands and freshwater resources like Lake Mariute in Alexandria governorate. In the investigation area, there are vast open spaces and undeveloped areas that could be very suitable potential areas for future development, as was introduced in chapter 5. Subsequently, a reliable and realistic tool for urban growth simulation and prediction is highly needed taking into consideration the public needs as long as the preferences of the decision-makers. That tool is capable to determine the effect of various planning scenarios on the urban growth process to answer all ‘what-if’ questions of the planners and decision-makers during the preparation of the development and strategic plans before implementation, therefore, they can recognize the future state of urban expansion. In the current PhD study, a standalone CA-based model was developed for that purpose. This CA-based model was combined with land suitability analysis to consider the restricted areas for development; e.g. water bodies, roads, and recreational areas. Besides, it is possible in the CA model to add more variables like stochasticity, and also change the weights of the factors for observing the impact of each factor and the variables on the urban growth process. By running CA simulations, it is expected to know the potential scenarios for urban growth, also, identifies the most environmentally suitable areas for urban development activities and produce a suitability index for urban development. Hence, avoiding the areas vulnerable to natural disasters and potential climate change threats…. etc. as indicated in the coastal issues.

MCDM was to identify suitable urban areas for new urban areas development, using GIS-MCE (AHP and WLC). In that essence, ten environmental and economic factors that have a principal effect on urban development were identified, including residential areas, utilities and facilities, schools, recreational areas, transportation, industrial areas, croplands, coastline, water bodies, and land use/cover map. This may serve as a spatial decision supporting system tool to be integrated with the CA-based model to investigate PSS platform and support sustainable urban land-use planning and management. In that essence, five land suitability layers served as the primary tool to distinguish between the urban growth scenarios, namely: Baseline, Historical growth trends (Business as Usual), Traffic, maximum environmental protection, and compact cities growth scenarios, were developed by the support of 23 experts.

The results show that there is a disparity between the land-use practices and changes and the existing policies and laws governing the coastal cities in Egypt. The management plans and policies for the coastal cities in Egypt are sector-based. The Egyptian planning system has conflicting objectives of pursuing urban growth development and preserving the environment and the natural resources from degradation the urban growth takes priority over the environment. The current study demonstrated that the locations are more likely to be converted to the urban area if they are surrounded by more urban land and close to transportation networks. Neighborhood configuration was utilized to consider the possible effects of spatial interactions between the central cells (seeds) and neighboring cells. This implies that urban land use planning plans can be tested and identified to help the decision-makers to further grasp the urban growth in any investigation area. It was concluded that these planning drivers were commonly employed in regional planning have possible effects on future urban development in the study area.

ICZM plans and projects can't standalone to sustainably manage and develop the coastal areas, but it requires the urgent and explicit integration of spatial planning in its plans, policies, and strategies. The segmentation of the management process, inadequate stakeholder involvement, lack of public participation, centralized management, and top-bottom approaches, lack of skilled staff, poor geospatial data and information, leverage and inefficient law enforcement; are the main reasons for unsuccessful coastal areas management and ineffective urban development plans, which are reflected on land use practices and changes (as indicated in the results of chapter 5). ICZM strategy isn’t a coastal management strategy; it is rather a tool/project to enhance coordination in inter-institutional strategic planning. Because of that, it is important to have planning laws and policies which coherently investigate the environment and coastal issues in its development approaches and the implementation process. Accordingly, SEA is considered as an aiding tool has a high ability in enhancing the influence of the environmental authorities and increase the coordination between various and concerned sectors at all levels and scales in the process of planning (Lobos and Partidario, 2014; Thompson *et al.*, 2013; Daini, 2002). SEA could effectively be initiated early in the ICZM or any other strategic projects/plans when the potential vision is being prepared (Daini, 2002; Dalal-Clayton and Sadler, 1999).

7.1. Recommendations in terms of spatial planning in the Egyptian context

According to (GOPP, 2008), only 3.5% of the Egyptian land is cultivated and 7.6% is severely dense populated out of 1 million km^2 as a total surface area of Egypt. The total population is around 90 million inhabitants and the percentage of people living in urban areas 43% and 57% are living in the rural ones. This compactness and high population density derived the people to suffer from limited access to natural resources, high competition between land users, industrial development and urbanization encroachment on the agriculture land, uncontrolled and rapid urban growth (Connelly, 2009, 2017; Khalifa and Connelly, 2009). So, in that regard, successful lessons and experiences of coastal cities management and development worldwide, which could be transferrable and applicable in the Egyptian context, are introduced as follows:

- The political regime in Egypt hampers the stakeholders to practice participation in the planning process due to the lack of trust between the government and society. The political relationship between society and the government is still very hostile towards explicit public involvement or participation in the policy-making or even normal political issues (Connelly, 2009). Besides, the opposition, civil society organizations, and local entities are heavily regulated and monitored by law and could be easily harassed in case of showing any signs of real opposition. Consequently, creation of a suitable framework, new approaches for education and raising the awareness, improving the economic situation, transparency, and accountability will for sure change Egypt from being an authoritarian country to a participatory society able to freely and effectively participate in the decision-making process,
- Decision-makers, especially on the ministerial level, should be aware that, effectiveness and success of ICZM projects and/or urban development plans come from its promotion of integration of all the sectoral policies and guidelines concerning the coastal cities (horizontal integration) and all the administrations at

the national, regional and local level (vertical integration), a bottom-up approach in coastal management based on scientific knowledge and holistically viewing the coastal system, considering all the coastal subsystems (physical, ecological, social, economic and legal-administrative) to achieve a balanced development (González-Riancho et al. 2007; Borhan et al. 2003),

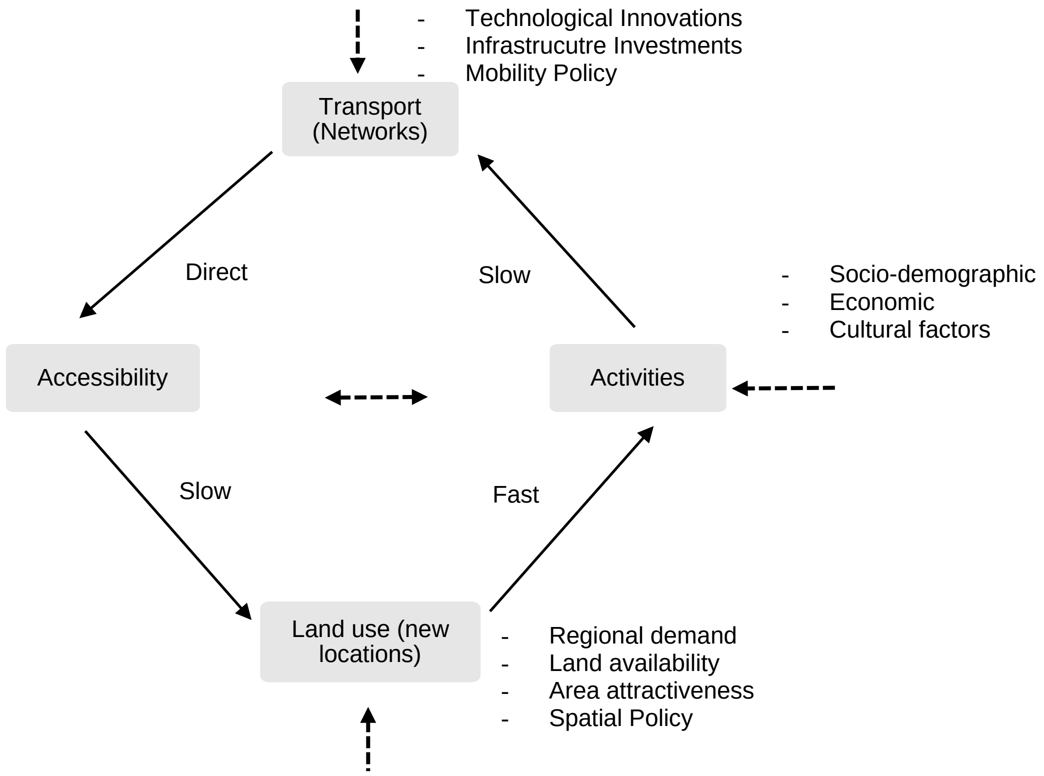
- The planning system and management approaches are strongly centralized, so good coordination between ministries and EEAA, which is leading the committee and moving towards decentralization by involving the regional offices of EEAA, will help in the articulation of ICZM projects and successfully integrate SEA,
- SEA was recommended to be utilized as an evaluation tool for the planning process, environmental integration, and socio-economic consideration of the proposed integrative planning approach for the sustainable development of coastal cities. SEA can also be a part of the planning process of ICZM because of its ability to evaluate the environmental aspects affected by the plan and propose measures opposing negative environmental impacts related to the implementation of the plan,
- Considering the potential impacts of climate change during the formulation of land use and planning policies especially in the low-lying coastal areas,
- Delineation of informal areas in the city and preparation of detailed plans to develop these areas,
- In the light of poor spatial information and data, it is important to develop an information-sharing mechanism and units that will ease and increase the horizontal integration between the ministries involved in the planning process for coastal areas,
- Construction a spatial database by the means of the GIS system.

7.2. Limitations of the study and further research

Understanding the systemic nature of urban mobility and urban development planning, and insightful understanding of the use of urban land, transport systems, and the activities of urban households and firms which are related to each other; is of great importance (Wegener, 1995). The strong connection between urban forms and transportation is remarkable in the tight relation between the suburban entities and the cars or public transport in compact urban centers (Manso, 2010). An important question arises here regarding the causality's direction: "*does spatial planning development (urbanization) determine the development of transportation systems?*

Or the reverse applies?" (Wegener and Fürst, 1999). The planners and geographers stated that the influence is reciprocal, as urban growth and transport usage have mutual reinforcement on each other according to what is known as the transport land use feedback cycle (Moghaddam, 2017) as indicated in the figure (7-1). The transport land use feedback cycle can provide a useful framework for exploring the relationship between developments in cities and mobility (Kasraian *et al.*, 2016; Bertolini, 2012).

Figure 7-1: Land use transportation feedback cycle
Source: (Wegener and Fürst 1999)



It is obvious from the figure that urban development is not only depending on the accessibility situation but also the land availability, environmental capacity, spatial policies, regional demand and economic situation. Likewise, characteristics of firms, households, and the socio-economic context in a region: play a very important role (more important than spatial factors) in the emergence and adaptation of the patterns of activities. Furthermore, the development of the transportation system is not only based on the demand for movement from a location to another but mainly relies on the supply side; e.g. technological innovation, infrastructure investments, and mobility policies. The change in the patterns of activities can be accomplished fast, within years or days, while the change in the land use development and transportation system require much more time, could be decades. The interaction and dynamism between transportation and successful land use and urban development need to be simulated. The policies acknowledge these dynamisms that combines the development of the public transport system with compact urbanization around must be considered. Furthermore, it was recommended in further research to evaluate the results of the urban growth for future scenarios. However, the problem lies in that the difficulty in reaching the experts and selecting criteria for evaluation, in addition to the lack of required data (Wegener, 1995; Wegener and Fürst, 1999; Manso, 2010; Kasraian *et al.*, 2016; Bertolini, 2012; Adhvaryu, 2010). So, it is highly recommended to study and simulate the interaction between urban expansion and transportation systems.

References

Abd-Alah, A.M.A. (1999), “Coastal zone management in Egypt”, *Ocean & Coastal Management*, Vol. 42 No. 9, pp. 835–848.

Abd El-Kawy, O.R., Rød, J.K., Ismail, H.A. and Suliman, A.S. (2011), “Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data”, *Applied Geography*, Vol. 31 No. 2, pp. 483–494.

AbdeL-Latif, T., Ramadan, S.T. and Galal, A.M. (2012), “Egyptian coastal regions development through economic diversity for its coastal cities”, *HBRC Journal*, Vol. 8 No. 3, pp. 252–262.

Abedini, A. and Azizi, P. (2016), “Prediction of future urban growth scenarios using SLEUTH model (Case study: Urmia city, Iran)”, *Int. J. Architect. Eng. Urban Plan, 26(2): 161-172, December 2016*.

Abily, M., Bertrand, N., Delestre, O., Gourbesville, P. and Duluc, C.M. (2016), “Spatial Global Sensitivity Analysis of High Resolution classified topographic data use in 2D urban flood modelling”, *Environmental Modelling & Software*, Vol. 77, pp. 183–195.

Abonazel, M.R. (2018), “A Practical Guide for Creating Monte Carlo Simulation Studies Using R”, *International Journal of Mathematics and Computational Science*, No. Vol. 4, No. 1, 2018, pp. 18-33.

Abou-Korin, A.A. (2014a), “Small-size urban settlements. Proposed approach for managing urban future in developing countries of increasing technological capabilities, the case of Egypt”, *Ain Shams Engineering Journal*, Vol. 5 No. 2, pp. 377–390.

Abou-Korin, A.A. (2014b), “Small-size urban settlements. Proposed approach for managing urban future in developing countries of increasing technological capabilities, the case of Egypt”, *Ain Shams Engineering Journal*, Vol. 5 No. 2, pp. 377–390.

Abudeif, A.M., Abdel Moneim, A.A. and Farrag, A.F. (2015), “Multicriteria decision analysis based on analytic hierarchy process in GIS environment for siting nuclear power plant in Egypt”, *Annals of Nuclear Energy*, Vol. 75, pp. 682–692.

Aburas, M.M., Ho, Y.M., Ramli, M.F. and Ash’aari, Z.H. (2016), “The simulation and prediction of spatio-temporal urban growth trends using cellular automata models. A review”, *International Journal of Applied Earth Observation and Geoinformation*, Vol. 52, pp. 380–389.

Abu-Zeid, K.M., Yasseen, A., Steen, P., Sharp, P. and Elrawady, M. (2011), “Integrated Urban Water Management (IUWM) Strategic Plan”, The Center for Environment and Development for the Arab Region and Europe (CEDARE), Egypt.

Adhvaryu, B. (2010), “Enhancing urban planning using simplified models. SIMPLAN for Ahmedabad, India”, *Progress in Planning*, Vol. 73 No. 3, pp. 113–207.

Afshar, A.H., Tajbakhsh, S.M., Memarian, H. and Moradi, K. (2018), “Performance comparison of land change modeling techniques for land use projection of arid watersheds”, *Global J. Environ. Sci. Manage.,4(3): 263-280, Summer 2018*.

Agarwal, C., Green, G.M., Grove, J.M., Evans, T.P. and Schweik, C.M. (2002), “A review and assessment of land-use change models: dynamics of space, time and human choice”, Gen. Tech. Rep. NE-297. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 61 p.

Aguilera, F., Valenzuela, L.M. and Botequilha-Leitão, A. (2011), “Landscape metrics in the analysis of urban land use patterns. A case study in a Spanish metropolitan area”, *Landscape and Urban Planning*, Vol. 99 No. 3-4, pp. 226–238.

Al Garni, H.Z. and Awasthi, A. (2017), “Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia”, *Applied Energy*, Vol. 206, pp. 1225–1240.

Alaei Moghadam, S., Karimi, M. and Habibi, K. (2018), “Simulating urban growth in a megalopolitan area using a patch-based cellular automata”, *Transactions in GIS*, Vol. 22 No. 1, pp. 249–268.

Al-Ahmadi, F. and Hames, A. (2009), “Comparison of Four Classification Methods to Extract Land Use and Land Cover from Raw Satellite Images for Some Remote Arid Areas, Kingdom of Saudi Arabia”, *Journal of King Abdulaziz University-Earth Sciences*, Vol. 20 No. 1, pp. 167–191.

Al-Ahmadi, K., See, L., Heppenstall, A. and Hogg, J. (2009), “Calibration of a fuzzy cellular automata model of urban dynamics in Saudi Arabia”, *Ecological Complexity*, Vol. 6 No. 2, pp. 80–101.

Aldwaik, S.Z. and Pontius Jr., R.G. (2013), “Map errors that could account for deviations from a uniform intensity of land change”, *International Journal of Geographical Information Science*, Vol. 27 No. 9, pp. 1717–1739.

Alesheikh, A.A., Ghorbanali, A. and Nouri, N. (2007), “Coastline change detection using remote sensing”, *International Journal of Environmental Science & Technology*, Vol. 4 No. 1, pp. 61–66.

Al-Gaadi, K.A., M.S. Samdani and V.C. Patil (2011), “Assessment of Temporal Land Cover Changes in Saudi Arabia Using Remotely Sensed Data”, Middle-East Journal of Scientific Research 9 (6): 711-717 No. ISSN 1990-9233.

Ali, E.M. and El-Magd, I.A. (2016), “Impact of human interventions and coastal processes along the Nile Delta coast, Egypt during the past twenty-five years”, *The Egyptian Journal of Aquatic Research*, Vol. 42 No. 1, pp. 1–10.

Aljoufie, M., Zuidgeest, M., Brussel, M., van Vliet, J. and van Maarseveen, M. (2013), “A cellular automata-based land use and transport interaction model applied to Jeddah, Saudi Arabia”, *Landscape and Urban Planning*, Vol. 112, pp. 89–99.

Al‐kheder, S., Wang, J. and Shan, J. (2008), “Fuzzy inference guided cellular automata urban‐growth modelling using multi‐temporal satellite images”, *International Journal of Geographical Information Science*, Vol. 22 No. 11-12, pp. 1271–1293.

Allen, Julia C. and Barnes, Douglas F. (1985), “The Causes of Deforestation in Developing Countries”, *Annals of the Association of American Geographers75(2), 1985, pp 163-184*.

Almeida, C.M.D., Monteiro, A.M.V., Câmara, G., Soares‐Filho, B.S., Cerqueira, G.C., Pennachin, C.L. and Batty, M. (2005), “GIS and remote sensing as tools for the simulation of urban land‐use change”, *International Journal of Remote Sensing*, Vol. 26 No. 4, pp. 759–774.

Anderson, J.R., Hardy, E.E., Roach, J.T. and Witmer, R.E. (1976), “A Land Use and Land Cover Classification System for Use with Remote Sensor Data”, *United States Geological Survey Professional paper; 964*.

Andrews, B., Gares, P.A. and Colby, J.D. (2002), “Techniques for GIS modeling of coastal dunes”, *Geomorphology*, Vol. 48 No. 1-3, pp. 289–308.

Anwar, M.M. and Mohsin, M. (2015), “Identification of Land Uses through the Application of Multiple Nuclei Model in Bahawalpur City, Pakistan: Planning Perspectives”, *Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 47 (3) 411-414 (2015)*.

Arabinda, L. (2003). Integrating GIS and Multicriteria Decision Making Techniques for Land Resource Planning. Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geoinformatics, Enschede, the Netherlands.

Areizaga, J., Sanò, M., Medina, R. and Juanes, J. (2012), “A methodological approach to evaluate progress and public participation in ICZM. The case of the Cantabria Region, Spain”, *Ocean & Coastal Management*, Vol. 59, pp. 63–76.

AS&P, Strategic Urban Plan for Alexandria City 2032. Finalizing Phase 1: Presentation of key results, February 2014, 70p.

AS&P, Strategic Urban Plan for Alexandria City 2032. Phase 1 City Profile Report, Vol 1 and Vol 6, September 2013, 87p.

Aspinall, R. (2004), “Modelling land use change with generalized linear models--a multi-model analysis of change between 1860 and 2000 in Gallatin Valley, Montana”, *Journal of environmental management*, Vol. 72 No. 1-2, pp. 91–103.

Attané, I. and Courbage, Y. (2001), “DEMOGRAPHY IN THE MEDITERRANEAN REGION, SITUATION AND PROJECTIONS. Plan Bleu. 2001. La démographie en Méditerranée. Paris, Economica. (Les Fascicules du Plan Bleu n°11)”.

Azcárate, J., Balfors, B., Bring, A. and Destouni, G. (2013), “Strategic environmental assessment and monitoring. Arctic key gaps and bridging pathways”, *Environmental Research Letters*, Vol. 8 No. 4, p. 44033.

Bach, M.P., Čeljo, A. and Zoroja, J. (2016), “Technology Acceptance Model for Business Intelligence Systems. Preliminary Research”, *Procedia Computer Science*, Vol. 100, pp. 995–1001.

Banihabib, M.E., Hashemi-Madani, F.-S. and Forghani, A. (2017), “Comparison of Compensatory and non-Compensatory Multi Criteria Decision Making Models in Water Resources Strategic Management”, *Water Resources Management*, Vol. 31 No. 12, pp. 3745–3759.

Barredo, J.I. and Demicheli, L. (2003), “Urban sustainability in developing countries’ megacities. Modelling and predicting future urban growth in Lagos”, *Cities*, Vol. 20 No. 5, pp. 297–310.

Barredo, J.I., Kasanko, M., McCormick, N. and Lavalle, C. (2003), “Modelling dynamic spatial processes. Simulation of urban future scenarios through cellular automata”, *Landscape and Urban Planning*, Vol. 64 No. 3, pp. 145–160.

Barredo, J.I., Demicheli, L., Lavalle, C., Kasanko, M. and McCormick, N. (2004), "Modelling Future Urban Scenarios in Developing Countries: An Application Case Study in Lagos, Nigeria", *Environment and Planning B: Planning and Design 2004, volume 32, pages 65 - 84*.

Barreira González, P., Aguilera-Benavente, F. and Gómez-Delgado, M. (2015), "Partial validation of cellular automata based model simulations of urban growth. An approach to assessing factor influence using spatial methods", *Environmental Modelling & Software*, Vol. 69, pp. 77–89.

Baskurt, Z.M. and Aydin, C.C. (2018), "Nuclear power plant site selection by Weighted Linear Combination in GIS environment, Edirne, Turkey", *Progress in Nuclear Energy*, Vol. 104, pp. 85–101.

Batisani, N. and Yarnal, B. (2009a), "Uncertainty awareness in urban sprawl simulations. Lessons from a small US metropolitan region", *Land Use Policy*, Vol. 26 No. 2, pp. 178–185.

Batisani, N. and Yarnal, B. (2009b), "Urban expansion in Centre County, Pennsylvania. Spatial dynamics and landscape transformations", *Applied Geography*, Vol. 29 No. 2, pp. 235–249.

Batty, M., Xie, Y. and Sun, Z. (1999), "Modeling urban dynamics through GIS-based cellular automata", *Computers, Environment and Urban Systems*, Vol. 23 No. 3, pp. 205–233.

Belčáková, I. (2016), "Strategic Environmental Assessment – An Instrument for Better Decision-Making Towards Urban Sustainable Planning", *Procedia Engineering*, Vol. 161, pp. 2058–2061.

Bell, S., Correa Peña, A. and Prem, M. (2013), "Imagine coastal sustainability", *Ocean & Coastal Management*, Vol. 83, pp. 39–51.

Berry, M., Hazen Brett G., MacIntyre Rhonda L. and Flamm Richard O. (1996), "Lucas: A System for Modeling Land-Use Change", *IEEE Computational Science and Engineering, 1070-9924/96/$5.00 © 1996 IEEE*.

Berry, M. and BenDor, T.K. (2015), "Integrating sea level rise into development suitability analysis", *Computers, Environment and Urban Systems*, Vol. 51, pp. 13–24.

Bertolini, L. (2012), "Integrating Mobility and Urban Development Agendas. A Manifesto", *disP - The Planning Review*, Vol. 48 No. 1, pp. 16–26.

Bidstrup, M. and Hansen, A.M. (2014), "The paradox of strategic environmental assessment", *Environmental Impact Assessment Review*, Vol. 47, pp. 29–35.

Billé, R. and Rochette, J. (2015), "The Mediterranean ICZM Protocol. Paper treaty or wind of change?", *Ocean & Coastal Management*, Vol. 105, pp. 84–91.

Borhan, M.A., Farouk, M.A. and Hamdy, T.A. (2003), "Country Report on Egyptian ICZM Experiences with Special Reference to Sharm El- Sheikh Southern Sinai", No. Arab Republic of Egypt, Ministry of State for Environmental Affairs, Egyptian Environmental Affairs Agency, Coastal and Marine Zones Division.

Boroushaki, S. and Malczewski, J. (2008), "Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS", *Computers & Geosciences*, Vol. 34 No. 4, pp. 399–410.

Boroushaki, S. and Malczewski, J. (2010), “Using the fuzzy majority approach for GIS-based multicriteria group decision-making”, *Computers & Geosciences*, Vol. 36 No. 3, pp. 302–312.

Bowen, R.E. and Riley, C. (2003), “Socio-economic indicators and integrated coastal management”, *Ocean & Coastal Management*, Vol. 46 No. 3-4, pp. 299–312.

Bozdağ, A., Yavuz, F. and Günay, A.S. (2016), “AHP and GIS based land suitability analysis for Cihanbeyli (Turkey) County”, *Environmental Earth Sciences*, Vol. 75 No. 9, p. 1.

Braimoh, A.K. and Onishi, T. (2007), “Spatial determinants of urban land use change in Lagos, Nigeria”, *Land Use Policy*, Vol. 24 No. 2, pp. 502–515.

Brown, I. (2006), “Modelling future landscape change on coastal floodplains using a rule-based GIS”, *Environmental Modelling & Software*, Vol. 21 No. 10, pp. 1479–1490.

Burgess, E.W. (1925), “The Growth Of The City: An introduction to a Research Project. In Robert E. Park and Ernest W. Burgess (eds).”, *The City, pp. 47-62 Chicago: University of Chicago Press.*

Bürgi, M., Hersperger, A.M. and Schneeberger, N. (2005), “Driving forces of landscape change - current and new directions”, *Landscape Ecology*, Vol. 19 No. 8, pp. 857–868.

Camacho Olmedo, M.T., Pontius, R.G., Paegelow, M. and Mas, J.-F. (2015), “Comparison of simulation models in terms of quantity and allocation of land change”, *Environmental Modelling & Software*, Vol. 69, pp. 214–221.

CAPMAS (2008). 2006 Census, Final Results, Alexandria. Cairo-Egypt, Central Agency for Public Mobilization and Statistics (CAPMAS).

Caruso, G., Rounsevell, M. and Cojocaru, G. (2005), “Exploring a spatio‐dynamic neighbourhood‐based model of residential behaviour in the Brussels periurban area”, *International Journal of Geographical Information Science*, Vol. 19 No. 2, pp. 103–123.

Cerreta, M. and Toro, P. de (2012), “Strategic Environmental Assessment of Port Plans in Italy. Experiences, Approaches, Tools”, *Sustainability*, Vol. 4 No. 12, pp. 2888–2921.

Chang, Da-Young (1996), “Applications of the extent analysis method of fuzzy AHP”, *European Journal of Operational Research 95 (1996) 649-655*.

Charlier, R. H. (Eds) and Bologa, A. S. (2000), “Using Today's Scientific Knowledge for the Black Sea Area's Development Tomorrow. Integrated Coastal Zone Management and GIS”, No. IOI - BSOC Leadership Seminar, Proceeding, 2000, 97-108.

Chen, J., Gong, P., He, C., Pu, R. and Shi, P. (2003), “Land-Use/Land-Cover Change Detection Using Improved Change-Vector Analysis”, *Photogrammetric Engineering & Remote Sensing*, Vol. 69 No. 4, pp. 369–379.

Chen, Q. and Mynett, A.E. (2003), “Effects of cell size and configuration in cellular automata based prey–predator modelling”, *Simulation Modelling Practice and Theory*, Vol. 11 No. 7-8, pp. 609–625.

Chen, Y. and Paydar, Z. (2012), “Evaluation of potential irrigation expansion using a spatial fuzzy multi-criteria decision framework”, *Environmental Modelling & Software*, Vol. 38, pp. 147–157.

Chen, Y., Yu, J. and Khan, S. (2010), “Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation”, *Environmental Modelling & Software*, Vol. 25 No. 12, pp. 1582–1591.

Cheng, J. and Masser, I. (2003), “Urban growth pattern modeling. A case study of Wuhan city, PR China”, *Landscape and Urban Planning*, Vol. 62 No. 4, pp. 199–217.

Cheng, J. and Masser, I. (2016), “Understanding Spatial and Temporal Processes of Urban Growth. Cellular Automata Modelling”, *Environment and Planning B: Planning and Design*, Vol. 31 No. 2, pp. 167–194.

Chen, W. and Jin, R. (2004), “Analytical variance-based global sensitivity analysis in simulation-based design under uncertainty”.

Chow, T.E. and Sadler, R. (2010), “The consensus of local stakeholders and outside experts in suitability modeling for future camp development”, *Landscape and Urban Planning*, Vol. 94 No. 1, pp. 9–19.

Chowdhury, M., Hasan, M.E. and Abdullah-Al-Mamun, M.M. (2018), “Land use/land cover change assessment of Halda watershed using remote sensing and GIS”, *The Egyptian Journal of Remote Sensing and Space Science*.

Clarke, K. (2008), “A Decade of Cellular Urban Modeling with SLEUTH: Unresolved Issues and Problems”, *Ch. 3 in Planning Support Systems for Cities and Regions (Ed. Brail, R. K., Lincoln Institute of Land Policy, Cambridge, MA, pp 47-60*.

Clarke, K.C. (2014), “Cellular Automata and Agent-Based Models”, in Fischer, M.M. and Nijkamp, P. (Eds.), *Handbook of Regional Science*, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 1217–1233.

Clarke, K.C., Hoppen, S. and Gaydos, L. (1997), “A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area”, *Environment and Planning B: Planning and Design*, Vol. 24 No. 2, pp. 247–261.

Clarke, K.C., Stacy Hoppen and Leonard J. Gaydos (1995), “Methods And Techniques for Rigorous Model Calibration of a Cellular Automaton Model of Urban Growth”, *working Paper. Land Tenure & Use, Urban Commons. North America, United States*.

Comber, A., Carver, S., Fritz, S., McMorran, R., Washtell, J. and Fisher, P. (2010), “Different methods, different wilds. Evaluating alternative mappings of wildness using fuzzy MCE and Dempster-Shafer MCE”, *Computers, Environment and Urban Systems*, Vol. 34 No. 2, pp. 142–152.

Comber, A.J. (2008), “The separation of land cover from land use using data primitives”, *Journal of Land Use Science*, Vol. 3 No. 4, pp. 215–229.

Comino, E., Bottero, M., Pomarico, S. and Rosso, M. (2016), “The combined use of Spatial Multicriteria Evaluation and stakeholders analysis for supporting the ecological planning of a river basin”, *Land Use Policy*, Vol. 58, pp. 183–195.

Connelly, S. (2009), “Deliberation in the face of power. Stakeholder planning in Egypt”, *Policy and Society*, Vol. 28 No. 3, pp. 185–195.

Connelly, S. (2017), “Deliberation in the face of power. Stakeholder planning in Egypt”, *Policy and Society*, Vol. 28 No. 3, pp. 185–195.

Crosetto, M. and Tarantola, S. (2010), “Uncertainty and sensitivity analysis. Tools for GIS-based model implementation”, *International Journal of Geographical Information Science*, Vol. 15 No. 5, pp. 415–437.

Crosetto, M. and Tarantola, S. and Saltelli, A. (2000), “Sensitivity and uncertainty analysis in spatial modelling based on GIS”, *European Commission, Joint Research Centre, Institute for Systems Informatics and Safety, TP 361, 21020 Ispra, Italy*, No. Agriculture, Ecosystems and Environment 81 (2000) 71–79.

Dahal, K.R. and Chow, T.E. (2015), “Characterization of neighborhood sensitivity of an irregular cellular automata model of urban growth”, *International Journal of Geographical Information Science*, Vol. 29 No. 3, pp. 475–497.

Daini, P. (2002), “Reviewing 1990s SEA/EIA in the Aosta Valley (Italy) by a set-oriented perspective”, *Environmental Impact Assessment Review*, Vol. 22 No. 1, pp. 37–77.

Dalal-Clayton, B. and Sadler, B. (1999), *Strategic environmental assessement: A rapidly evolving approach / by Barry Dalal-Clayton and Barry Sadler, Environmental planning issues*, no. 18, IIED, London.

Darius M. Adams, Ralph J. Alig, J.M. Callaway, Bruce A. McCarl and Steven M. Winnett (1996), “The Forest and Agriculture Sector Optimization Model (FASOM): Model Structure and Policy Applications”, *U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, Research Paper PNW-RP-495.*

Deadman, P., Robert, D. Brown and Gimblett, R. (1993), “Modelling Rural Residential Settlement Patterns with Cellular Automata”, *Journal of Environmental Management 37, 147-160*.

Deep, S. and Saklani, A. (2014), “Urban sprawl modeling using cellular automata”, *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 17 No. 2, pp. 179–187.

Demesouka, O.E., Vavatsikos, A.P. and Anagnostopoulos, K.P. (2013), “Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system. Method, implementation and case study”, *Waste management (New York, N.Y.)*, Vol. 33 No. 5, pp. 1190–1206.

Dendoncker, N., Rounsevell, M. and Bogaert, P. (2007), “Spatial analysis and modelling of land use distributions in Belgium”, *Computers, Environment and Urban Systems*, Vol. 31 No. 2, pp. 188–205.

Dewan, A.M. and Yamaguchi, Y. (2009), “Land use and land cover change in Greater Dhaka, Bangladesh. Using remote sensing to promote sustainable urbanization”, *Applied Geography*, Vol. 29 No. 3, pp. 390–401.

Dietzel, C. and Clarke, K.C. (2007), “calibration--Dietzel_Clarke_tgis2007”, *Keith Clarke, Department of Geography, University of California-Santa Barbara, Santa Barbara, CA 93106, USA.*

Ding, Y., Zhao, K., Zheng, X. and Jiang, T. (2014), “Temporal dynamics of spatial heterogeneity over cropland quantified by time-series NDVI, near infrared and red reflectance of Landsat 8 OLI imagery", *International Journal of Applied Earth Observation and Geoinformation*, Vol. 30, pp. 139–145.

Dragan, M., Feoli, E., Fernetti, M. and Zerihun, W. (2003), "Application of a spatial decision support system (SDSS) to reduce soil erosion in northern Ethiopia", *Environmental Modelling & Software*, Vol. 18 No. 10, pp. 861–868.

Dragićević, S., Lai, T. and Balram, S. (2015), "GIS-based multicriteria evaluation with multiscale analysis to characterize urban landslide susceptibility in data-scarce environments", *Habitat International*, Vol. 45, pp. 114–125.

Drexhage, J. and Murphy, D. (2010), "Sustainable Development: From Brundtland to Rio 2012. Background Paper prepared for consideration by the High Level Panel on Global Sustainability at its first meeting, 19 September 2010", *International Institute for Sustainable Development (IISD)*.

Dubovyk, O., Sliuzas, R. and Flacke, J. (2011), "Spatio-temporal modelling of informal settlement development in Sancaktepe district, Istanbul, Turkey", *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 66 No. 2, pp. 235–246.

Dulcic, Z., Pavlic, D. and Silic, I. (2012), "Evaluating the Intended Use of Decision Support System (DSS) by Applying Technology Acceptance Model (TAM) in Business Organizations in Croatia", *Procedia - Social and Behavioral Sciences*, Vol. 58, pp. 1565–1575.

Eckmann, T., Roberts, D. and Still, C. (2008), "Using multiple endmember spectral mixture analysis to retrieve subpixel fire properties from MODIS", *Remote Sensing of Environment*, Vol. 112 No. 10, pp. 3773–3783.

EEAA (1999), "The Arab Republic of Egypt: Initial National Communication on Climate Change", Prepared for the United Nations Framework Convention on Climate Change UNFCCC.

EEAA/ESP (2008), "Strategy for Implementing Integrated Coastal Zone Management Process in Egypt", No. Egyptian Environmental Affairs Agency, Environmental Sector Programme, Cairo, Egypt.

EEAA/MAP (2005), "In the Framework of the Implementation of the SAP to address Pollution in the Mediterranean from Land-Based Activities", National Action Plan, Mid-term Report, Egyptian Environmental Affairs Agency, Mediterranean Action Plan.

El-Asmar, H.M., El-Kafrawy, S.B. and Taha, M.M. (2014), "Monitoring Coastal Changes along Damietta Promontory and the Barrier Beach toward Port Said East of the Nile Delta, Egypt", *Journal of Coastal Research*, Vol. 297, pp. 993–1005.

El-Asmar, H.M., Mahmoud, H. A., El-Kafrawy, S.B., Oubid-Allah, A.H., Turkya, A.M. and Mostafa A.K. (2015), "Monitoring and assessment the coastal ecosystem at hurghada, Red Sea coast, Egyypt", Vol.5, No.6, 2015 Journal of Environment and Earth Science No. ISSN 2225-0948.

Elmenofi, G.A., El Bilali, H. and Berjan, S. (2014), "Governance of rural development in Egypt", *Annals of Agricultural Sciences*, Vol. 59 No. 2, pp. 285–296.

El-Raey, M. (1997), "Vulnerability assessment of the coastal zone of the Nile delta of Egypt, to the impacts of sea level rise", *PI I S0964 - 5691(97)00056 - 2*, Ocean &

Coastal Manaoement, Vol. 37, No. 1, pp. 29-40 No. © 1998 Elsevier Science Ltd. All rights reserved.

El-Zeiny, A. and El-Kafrawy, S. (2017), “Assessment of water pollution induced by human activities in Burullus Lake using Landsat 8 operational land imager and GIS”, *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 20, S49-S56.

Erener, A., Mutlu, A. and Sebnem Düzgün, H. (2016), “A comparative study for landslide susceptibility mapping using GIS-based multi-criteria decision analysis (MCDA), logistic regression (LR) and association rule mining (ARM)”, *Engineering Geology*, Vol. 203, pp. 45–55.

European Parliament/ EC/42 (2001), “Directive of the European Parliament And Of The Council on the assessment of the effects of certain plans and programmes on the environment in Luxembourg”.

Fabbri, K.P. (1998), “A methodology for supporting decision making in integrated coastal zone management”, *Ocean & Coastal Management*, Vol. 39 No. 1-2, pp. 51–62.

Fang, S., Wente, S., Gertner, G.Z., Wang, G. and Anderson, A. (2002), “Uncertainty analysis of predicted disturbance from off-road vehicular traffic in complex landscapes at fort hood”, *Environmental management*, Vol. 30 No. 2, pp. 199–208.

Farhoodi, R., Gharakhlou-N, M., Ghadami, M. and Khah, M.P. (2009), “A Critique of the Prevailing Comprehensive Urban Planning Paradigm in Iran. The Need for Strategic Planning”, *Planning Theory*, Vol. 8 No. 4, pp. 335–361.

Feng, Y., Liu, Y. and Batty, M. (2016), “Modeling urban growth with GIS based cellular automata and least squares SVM rules. A case study in Qingpu–Songjiang area of Shanghai, China”, *Stochastic Environmental Research and Risk Assessment*, Vol. 30 No. 5, pp. 1387–1400.

Ferretti, V. and Pomarico, S. (2013), “Ecological land suitability analysis through spatial indicators. An application of the Analytic Network Process technique and Ordered Weighted Average approach”, *Ecological Indicators*, Vol. 34, pp. 507–519.

Feyisa, G.L., Meilby, H., Fensholt, R. and Proud, S.R. (2014), “Automated Water Extraction Index. A new technique for surface water mapping using Landsat imagery”, *Remote Sensing of Environment*, Vol. 140, pp. 23–35.

Fischer, T.B. (2003), “Strategic environmental assessment in post-modern times”, *Environmental Impact Assessment Review*, Vol. 23 No. 2, pp. 155–170.

Fischer, T.B., Wood, C. and Jones, C. (2002), “Policy, Plan, and Programme Environmental Assessment in England, the Netherlands, and Germany. Practice and Prospects”, *Environment and Planning B: Planning and Design*, Vol. 29 No. 2, pp. 159–172.

Fitz, H.C., DeBellevue, E.B., Costanza, R., Boumans, R., Maxwell, T., Wainger, L. and Sklar, F.H. (1996), “Development of a general ecosystem model for a range of scales and ecosystems”, *Ecological Modelling*, Vol. 88 No. 1-3, pp. 263–295.

Frazier, P.S. and Page K.J. (2000), “Water Body Detection and Delineation with Landsat TM Data”, *American Society for Photogrammetric Engineering & Remote Sensing Vol. 66, No. 12, December 2000, pp. 1461-1467.*

Fresco, L.O. and Veldkamp, A. (1996), “CLUE: a conceptual model to study the Conversion of Land Use and its Effects”, *Ecological Modelling 85 (1996) 253-270*, No. 0304-3800/96/$15.00 © 1996 Elsevier Science B.V. All rights reserved. SSDI 0304-3800(94)00151-0.

Frihy, O.E., Dewidar, K.M. and El-Raey, M.M. (1996), “Evaluation of coastal problems at Alexandria, Egypt”, *Ocean & Coastal Management, Vol. 30, Nos 2-3. pp. 281-295, 1996*.

Fuglsang, M., Münier, B. and Hansen, H.S. (2013), “Modelling land-use effects of future urbanization using cellular automata. An Eastern Danish case”, *Environmental Modelling & Software*, Vol. 50, pp. 1–11.

Gachechiladze-Bozhesku, M. and Fischer, T.B. (2012), “Benefits of and barriers to SEA follow-up — Theory and practice”, *Environmental Impact Assessment Review*, Vol. 34, pp. 22–30.

Gangai, I.P.D. and Ramachandran, S. (2010), “The role of spatial planning in coastal management—A case study of Tuticorin coast (India)”, *Land Use Policy*, Vol. 27 No. 2, pp. 518–534.

Gao, J., Christensen, P. and Kørnøv, L. (2017), “Indicators' role. How do they influence Strategic Environmental Assessment and Sustainable Planning - The Chinese experience”, *The Science of the total environment*, Vol. 592, pp. 60–67.

García, A.M., Santé, I., Boullón, M. and Crecente, R. (2012), “A comparative analysis of cellular automata models for simulation of small urban areas in Galicia, NW Spain”, *Computers, Environment and Urban Systems*, Vol. 36 No. 4, pp. 291–301.

Gautam, V.K., Gaurav, P.K., Murugan, P. and Annadurai, M. (2015), “Assessment of Surface Water Dynamicsin Bangalore Using WRI, NDWI, MNDWI, Supervised Classification and K-T Transformation”, *Aquatic Procedia*, Vol. 4, pp. 739–746.

Gbanie, S.P., Tengbe, P.B., Momoh, J.S., Medo, J. and Kabba, V.T.S. (2013), “Modelling landfill location using Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA). Case study Bo, Southern Sierra Leone”, *Applied Geography*, Vol. 36, pp. 3–12.

Geertman, S. (2003), “Reflections on Planning Support”, *URU & Nexpri Utrecht University, P.O.Box 80115, 3508 TC Utrecht, The Netherlands*.

Geertman, S. and Stillwell, J. (2003), *Planning Support Systems in Practice*, Springer Berlin Heidelberg, Berlin, Heidelberg.

Geertman, S. and Stillwell, J. (2009), “Planning Support Systems. Content, Issues and Trends”, in Sui, D.Z., Tietze, W., Claval, P., Gradus, Y., Park, S.O., van der Wusten, H., Geertman, S. and Stillwell, J. (Eds.), *Planning Support Systems Best Practice and New Methods*, *The GeoJournal Library*, Vol. 95, Springer Netherlands, Dordrecht, pp. 1–26.

Geneletti, D. (2008), “Incorporating biodiversity assets in spatial planning. Methodological proposal and development of a planning support system”, *Landscape and Urban Planning*, Vol. 84 No. 3-4, pp. 252–265.

Geneletti, D., La Rosa, D., Spyra, M. and Cortinovis, C. (2017), “A review of approaches and challenges for sustainable planning in urban peripheries”, *Landscape and Urban Planning*, Vol. 165, pp. 231–243.

Ghavami, S.M., Taleai, M. and Arentze, T. (2016), “Socially rational agents in spatial land use planning. A heuristic proposal based negotiation mechanism”, *Computers, Environment and Urban Systems*, Vol. 60, pp. 67–78.

Gigović, L., Pamučar, D., Lukić, D. and Marković, S. (2016), “GIS-Fuzzy DEMATEL MCDA model for the evaluation of the sites for ecotourism development. A case study of “Dunavski ključ” region, Serbia”, *Land Use Policy*, Vol. 58, pp. 348–365.

Gilruth, P.T., Marsh, S.E. and Itami, R. (1995), “A dynamic spatial model of shifting cultivation in the highlands of Guinea, West Africa”, *Ecological Modelling*, Vol. 79 No. 1-3, pp. 179–197.

Glanville, W.A. de, Vial, L., Costard, S., Wieland, B. and Pfeiffer, D.U. (2014), “Spatial multi-criteria decision analysis to predict suitability for African swine fever endemicity in Africa”, *BMC veterinary research*, Vol. 10, p. 9.

Gómez‐Delgado, M. and Tarantola, S. (2006), “GLOBAL sensitivity analysis, GIS and multi‐criteria evaluation for a sustainable planning of a hazardous waste disposal site in Spain”, *International Journal of Geographical Information Science*, Vol. 20 No. 4, pp. 449–466.

González-Riancho, P., Sanò, M., Medina, R., García-Aguilar, O. and Areizaga, J. (2009), “A contribution to the implementation of ICZM in the Mediterranean developing countries”, *Ocean & Coastal Management*, Vol. 52 No. 11, pp. 545–558.

González-Riancho, P., Medina, R., Sanò, M. and Borhan, M. (2007), “Towards an ICZM Plan for the Western Mediterranean Coast of Egypt”, Environmental Hydraulics Institute “IH Cantabria”. Ocean & Coastal Research Group, Universidad de Cantabria. No. Av. de Los Castros s/n 39005.

Gorsevski, P.V., Donevska, K.R., Mitrovski, C.D. and Frizado, J.P. (2012), “Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection. A case study using ordered weighted average”, *Waste management (New York, N.Y.)*, Vol. 32 No. 2, pp. 287–296.

Grošelj, P. and Zadnik Stirn, L. (2018), “Evaluation of several approaches for deriving weights in fuzzy group analytic hierarchy process”, *Journal of Decision Systems*, Vol. 27 No. sup1, pp. 217–226.

Guan, C. and Rowe, P.G. (2016), “Should big cities grow? Scenario-based cellular automata urban growth modeling and policy applications”, *Journal of Urban Management*, Vol. 5 No. 2, pp. 65–78.

Hajehforooshnia, S., Soffianian, A., Mahiny, A.S. and Fakheran, S. (2011), “Multi objective land allocation (MOLA) for zoning Ghamishloo Wildlife Sanctuary in Iran”, *Journal for Nature Conservation*, Vol. 19 No. 4, pp. 254–262.

Hardie, I.W. and Parks, P.J. (1997), “Land Use with Heterogeneous Land Quality: An Application of an Area Base Model”, *Amer. J. Agr. Econ. 79 (May 1997): 299-310. Copyright 1997 American Agricultural Economics Association*.

Hariz, H.A., Dönmez, C.Ç. and Sennaroglu, B. (2017), “Siting of a central healthcare waste incinerator using GIS-based Multi-Criteria Decision Analysis”, *Journal of Cleaner Production*, Vol. 166, pp. 1031–1042.

Hassan, G.F. (2012), “Regeneration as an approach for the development of informal settlements in Cairo metropolitan”, *Alexandria Engineering Journal*, Vol. 51 No. 3, pp. 229–239.

Hassan, Z., Shabbir, R., Ahmad, S.S., Malik, A.H., Aziz, N., Butt, A. and Erum, S. (2016), “Dynamics of land use and land cover change (LULCC) using geospatial techniques. A case study of Islamabad Pakistan”, *SpringerPlus*, Vol. 5 No. 1, p. 812.

He, C., Okada, N., Zhang, Q., Shi, P. and Li, J. (2008), “Modelling dynamic urban expansion processes incorporating a potential model with cellular automata”, *Landscape and Urban Planning*, Vol. 86 No. 1, pp. 79–91.

He, J., Bao, C.-K., Shu, T.-F., Yun, X.-X., Jiang, D. and Brwon, L. (2011), “Framework for integration of urban planning, strategic environmental assessment and ecological planning for urban sustainability within the context of China”, *Environmental Impact Assessment Review*, Vol. 31 No. 6, pp. 549–560.

Hegazy, I.R. (2014), “Urban strategies and environmental policy. Towards urban sustainability within the Egyptian context”, *Environmental Development*, Vol. 11, pp. 190–207.

Hegazy, I.R. (2015a), “Informal settlement upgrading policies in Egypt. Towards improvement in the upgrading process”, *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, Vol. 9 No. 3, pp. 254–275.

Hegazy, I.R. (2015b), “Integrating strategic environmental assessment into spatial planning in Egypt”, *Environmental Development*, Vol. 15, pp. 131–144.

Hegazy, I.R. and Moustafa, W.S. (2013), “Toward revitalization of new towns in Egypt case study. Sixth of October”, *International Journal of Sustainable Built Environment*, Vol. 2 No. 1, pp. 10–18.

Henderson-Sellers, B. and Henderson-Sellers, A. (1996), “Sensitivity evaluation of environmental models using fractional factorial experimentation”, *Ecological Modelling*, Vol. 86 No. 2-3, pp. 291–295.

Hersperger, A.M., Oliveira, E., Pagliarin, S., Palka, G., Verburg, P., Bolliger, J. and Grădinaru, S. (2018), “Urban land-use change. The role of strategic spatial planning”, *Global Environmental Change*, Vol. 51, pp. 32–42.

Heumann, B.W. (2011), “An Object-Based Classification of Mangroves Using a Hybrid Decision Tree—Support Vector Machine Approach”, *Remote Sensing*, Vol. 3 No. 11, pp. 2440–2460.

Hood, A., Cechet, B., Hossain, H. and Sheffield, K. (2006), “Options for Victorian agriculture in a “new” climate. Pilot study linking climate change and land suitability modelling”, *Environmental Modelling & Software*, Vol. 21 No. 9, pp. 1280–1289.

Hongrun, J., Zengxiang, Z., Lijun, Z., Jinfeng, W., Shengrui, Z., Xiao, W. and Xiaoli, Z. (2016), “Driving forces and their interactions of built-up land expansion based on the geographical detector – a case study of Beijing, China”, *International Journal of Geographical Information Science*, Vol. 30 No. 11, pp. 2188–2207.

Hopkins, L. D. (1999), “Structure of a planning support system for urban development”, *Environment and Planning II Planning and Design 1999, volume 26*, pp. 333–343.

Horelli, L. (2013), “New Approaches to Urban Planning. Insights from Participatory Communities”, *Aalto University School of Engineering Department of Real Estate, Planning and Geoinformatics YTK – Land Use Planning and Urban Studies Group. Finland*, No. ISBN 978-952-60-5191-8 (pdf).

Hu, Y., Garcia-Cabrejo, O., Cai, X., Valocchi, A.J. and DuPont, B. (2015), “Global sensitivity analysis for large-scale socio-hydrological models using Hadoop”, *Environmental Modelling & Software*, Vol. 73, pp. 231–243.

Hu, Z. and Lo, C.P. (2007), “Modeling urban growth in Atlanta using logistic regression”, *Computers, Environment and Urban Systems*, Vol. 31 No. 6, pp. 667–688.

Hunt, J.D., Kriger, D.S. and Miller, E.J. (2005). Current Operational Urban Land - Use–Transport Modelling Frameworks: A Review, Transport Reviews, 25:3, 329-376, DOI:10.1080/0144164052000336470

Iacono, M., Levinson, D., El-Geneidy, A. (2008). Models of Transportation and Land Use Change: A Guide to the Territory. Journal of Planning Literature, Vol. 22, No. 4. Copyright © 2008 by Sage Publications. DOI: 10.1177/0885412207314010.

Ibrahim, H.S. (2013), “Towards an effective framework for coastal zone management. The Egyptian experience”, *Journal of Coastal Conservation*, Vol. 17 No. 3, pp. 601–613.

Ibrahim, H.S. and Hegazy I. (2013), “Decentralization in the Egyptian coastal management”, Volume 16, Number 2, February 2013: pp.1-12 No. Journal of Coastal Development. ISSN 1410-5217.

Ibrahim, H.S. and Shaw, D. (2012), “Assessing progress toward integrated coastal zone management. Some lessons from Egypt”, *Ocean & Coastal Management*, Vol. 58, pp. 26–35.

Iqbal, M.F. and Khan, I.A. (2014), “Spatiotemporal Land Use Land Cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan”, *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 17 No. 2, pp. 209–229.

Irfan, M., Koj, A., Sedighi, M. and Thomas, H. (2017), “Design and development of a generic spatial decision support system, based on artificial intelligence and multicriteria decision analysis”, *GeoResJ*, Vol. 14, pp. 47–58.

Itami, R.M. (1994), “Simulating spatial dynamics: cellular automata theory”, Landscape and Urban Planning 30 (1994) 27-47 No. SSDI0169-2046(94)05003-K 1994 Elsevier Science B.V.

Jafari, M., Majedi, H., Monavari, S., Alesheikh, A. and Kheirkhah Zarkesh, M. (2016), “Dynamic Simulation of Urban Expansion Based on Cellular Automata and Logistic Regression Model. Case Study of the Hyrcanian Region of Iran”, *Sustainability*, Vol. 8 No. 8, p. 810.

Jankowski, P., Fraley, G. and Pebesma, E. (2014), “An exploratory approach to spatial decision support”, *Computers, Environment and Urban Systems*, Vol. 45, pp. 101–113.

Jantz, C.A., Goetz, S.J., Donato, D. and Claggett, P. (2010), “Designing and implementing a regional urban modeling system using the SLEUTH cellular urban model”, *Computers, Environment and Urban Systems*, Vol. 34 No. 1, pp. 1–16.

Jantz, C.A., Goetz, S.J. and Shelley, M.K. (2016a), “Using the Sleuth Urban Growth Model to Simulate the Impacts of Future Policy Scenarios on Urban Land Use in the Baltimore-Washington Metropolitan Area”, *Environment and Planning B: Planning and Design*, Vol. 31 No. 2, pp. 251–271.

Jantz, C.A., Goetz, S.J. and Shelley, M.K. (2016b), “Using the Sleuth Urban Growth Model to Simulate the Impacts of Future Policy Scenarios on Urban Land Use in the Baltimore-Washington Metropolitan Area”, *Environment and Planning B: Planning and Design*, Vol. 31 No. 2, pp. 251–271.

Jat, M.K., Choudhary, M. and Saxena, A. (2017a), “Application of geo-spatial techniques and cellular automata for modelling urban growth of a heterogeneous urban fringe”, *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 20 No. 2, pp. 223–241.

Jat, M.K., Choudhary, M. and Saxena, A. (2017b), “Application of geo-spatial techniques and cellular automata for modelling urban growth of a heterogeneous urban fringe”, *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 20 No. 2, pp. 223–241.

Javadian, M., Shamskooshki, H. and Momeni, M. (2011), “Application of Sustainable Urban Development in Environmental Suitability Analysis of Educational Land Use by Using Ahp and Gis in Tehran”, *Procedia Engineering*, Vol. 21, pp. 72–80.

Jenerette, D.G. and Jianguo, W. (2001), “Analysis and simulation of land-use change in the central Arizona, Phoenix region, USA”, *Landscape Ecology 16: 611–626, 2001.*

Jeong, J.S. and Ramírez-Gómez, Á. (2017), “Renewable energy management to identify suitable biomass facility location with GIS-based assessment for sustainable environment”, *Energy Procedia*, Vol. 136, pp. 139–144.

Jiang, H. and Eastman, J.R. (2000), “Application of fuzzy measures in multi-criteria evaluation in GIS”, *International Journal of Geographical Information Science*, Vol. 14 No. 2, pp. 173–184.

Jokar Arsanjani, J., Helbich, M., Kainz, W. and Darvishi Boloorani, A. (2013), “Integration of logistic regression, Markov chain and cellular automata models to simulate urban expansion”, *International Journal of Applied Earth Observation and Geoinformation*, Vol. 21, pp. 265–275.

Kamusoko, C. and Gamba, J. (2015), “Simulating Urban Growth Using a Random Forest-Cellular Automata (RF-CA) Model”, *ISPRS International Journal of Geo-Information*, Vol. 4 No. 2, pp. 447–470.

Kamusoko, C., Gamba, J. and Murakami, H. (2014), “Mapping Woodland Cover in the Miombo Ecosystem. A Comparison of Machine Learning Classifiers”, *Land*, Vol. 3 No. 2, pp. 524–540.

Karmakar, S., Laguë, C., Agnew, J. and Landry, H. (2007), “Integrated decision support system (DSS) for manure management. A review and perspective”, *Computers and Electronics in Agriculture*, Vol. 57 No. 2, pp. 190–201.

Kasraian, D., Maat, K., Stead, D. and van Wee, B. (2016), “Long-term impacts of transport infrastructure networks on land-use change. An international review of empirical studies”, *Transport Reviews*, Vol. 36 No. 6, pp. 772–792.

Ke, Y., Im, J., Lee, J., Gong, H. and Ryu, Y. (2015), “Characteristics of Landsat 8 OLI-derived NDVI by comparison with multiple satellite sensors and in-situ observations”, *Remote Sensing of Environment*, Vol. 164, pp. 298–313.

Kenawy, E., Osman, T. and Alshamndy, A. (2017), “What Are the Main Challenges Impeding Implementation of the Spatial Plans in Egypt Using Ecotourism Development as an Example?”, *Social Sciences*, Vol. 6 No. 3, p. 75.

Khahro, S.H., Matori, A.N., Chandio, I.A. and Talpur, M.A.H. (2014), “Land Suitability Analysis for Installing New Petrol Filling Stations Using GIS”, *Procedia Engineering*, Vol. 77, pp. 28–36.

Khalifa, M.A. (2011), “Redefining slums in Egypt. Unplanned versus unsafe areas”, *Habitat International*, Vol. 35 No. 1, pp. 40–49.

Khalifa, M.A. (2012), “A critical review on current practices of the monitoring and evaluation in the preparation of strategic urban plans within the Egyptian context”, *Habitat International*, Vol. 36 No. 1, pp. 57–67.

Khalifa, M.A. (2015), “Evolution of informal settlements upgrading strategies in Egypt. From negligence to participatory development”, *Ain Shams Engineering Journal*, Vol. 6 No. 4, pp. 1151–1159.

Khalifa, M.A. and Connelly, S. (2009), “Monitoring and guiding development in rural Egypt. Local sustainable development indicators and local Human Development Indices”, *Environment, Development and Sustainability*, Vol. 11 No. 6, pp. 1175–1196.

Kira Gee, Andreas Kannen, Bernhard Glaeser and Horst Sterr (2004), “National ICZM strategies in Germany: A spatial planning approach”, Coastline Reports 2, ISSN 0928-2734, 23 - 33.

Kirtland, D., Gaydos, L., Clarke, C., DeCola, L., Acevedo, W. and Bell, C. (1994), “An Analysis of Human-Induced Land Transformations in the San Francisco Bay/Sacramento Area”, *World Resources Review Vol. 6 No. 2*.

Klosterman, R.E. (1995), “the appropriateness of geographic information systems for regional planning in the developing world”, *Comput. Environ. and Urban Systems, Vol. 19. No. 1*, pp. 1–13.

Klosterman, R.E. (1997), “Planning Support Systems: A New Perspective on Computer-Aided Planning”, *Journal of Planning Education and Research 17*, pp. 45–54.

Klosterman, R.E. and Pettit, C.J. (2016), “An Update on Planning Support Systems”, *Environment and Planning B: Planning and Design*, Vol. 32 No. 4, pp. 477–484.

Kocabas, V. and Dragicevic, S. (2006), “Assessing cellular automata model behaviour using a sensitivity analysis approach”, *Computers, Environment and Urban Systems*, Vol. 30 No. 6, pp. 921–953.

Laarhoven, P.J.M. and Pedrycz, W. (1983), “a fuzzy extension of saaty’s priority theory”, *Fuzzy Sets and Systems 11 (1983) 229-241, North Holland*.

Lagarias, A. (2012), “Urban sprawl simulation linking macro-scale processes to micro-dynamics through cellular automata, an application in Thessaloniki, Greece”, *Applied Geography*, Vol. 34, pp. 146–160.

Lamorgese, L. and Geneletti, D. (2013), “Sustainability principles in strategic environmental assessment. A framework for analysis and examples from Italian urban planning”, *Environmental Impact Assessment Review*, Vol. 42, pp. 116–126.

Landis, J.D. (1995), “Imagining Land Use Futures. Applying the California Urban futures Model”, *Journal of the American Planning Association*, Vol. 61 No. 4, pp. 438–457.

Landis, J. and Zhang, M. (1998), “The second generation of the California urban futures model. Part 1: Model logic and theory”, *Environment and Planning A 1998, volume 30, pages 657 - 666*.

Landis, J.D., Monzon, J.P., Reilly, M. and Cogan, C. (1998), “Development and Pilot Application of the California Urban and Biodiversity Analysis (CURBA) Model”, *1998 ESRI International User Conference, October 7-9, 1998*.Latinopoulos, D. and Kechagia, K. (2015), “A GIS-based multi-criteria evaluation for wind farm site selection. A regional scale application in Greece”, *Renewable Energy*, Vol. 78, pp. 550–560.

Lau, K.H. and Kam, B.H. (2016), “A Cellular Automata Model for Urban Land-Use Simulation”, *Environment and Planning B: Planning and Design*, Vol. 32 No. 2, pp. 247–263.

Levia, D.F. (1998), “Farmland conversion and residential development in North Central Massachusetts”, *Land Degradation & Development*, Vol. 9 No. 2, pp. 123–130.

Li Cheng (2014). Monitoring and analysis of urban growth process using Remote Sensing, GIS and Cellular Automata modeling: A case study of Xuzhou city, China. A doctorate dissertation submitted to the Faculty of Spatial Planning at TU Dortmund University in partial fulfillment of the requirements for the degree of Doctor of Engineering, Germany.

Li, T. and Li, W. (2015), “Multiple land use change simulation with Monte Carlo approach and CA-ANN model, a case study in Shenzhen, China”, *Environmental Systems Research*, Vol. 4 No. 1, p. 80.

Li, W., Xie, Y. and Hao, F. (2014), “Applying an improved rapid impact assessment matrix method to strategic environmental assessment of urban planning in China”, *Environmental Impact Assessment Review*, Vol. 46, pp. 13–24.

Li, X. and Yeh, A.G.-O. (2000), “Modelling sustainable urban development by the integration of constrained cellular automata and GIS”, *International Journal of Geographical Information Science*, Vol. 14 No. 2, pp. 131–152.

Li, X. and Yeh, A.G.-O. (2002), “Neural-network-based cellular automata for simulating multiple land use changes using GIS”, *International Journal of Geographical Information Science*, Vol. 16 No. 4, pp. 323–343.

Liaghat, M., Shahabi, H., Deilami, B.R., Ardabili, F.S., Seyedi, S.N. and badri, H. (2013), “A Multi-Criteria Evaluation Using the Analytic Hierarchy Process

Technique to Analyze Coastal Tourism Sites", *APCBEE Procedia*, Vol. 5, pp. 479–485.
Liao, J., Tang, L., Shao, G., Su, X., Chen, D. and Xu, T. (2016), "Incorporation of extended neighborhood mechanisms and its impact on urban land-use cellular automata simulations", *Environmental Modelling & Software*, Vol. 75, pp. 163–175.
Lin, J. and Li, X. (2015), "Simulating urban growth in a metropolitan area based on weighted urban flows by using web search engine", *International Journal of Geographical Information Science*, Vol. 29 No. 10, pp. 1721–1736.
Lin, Y.-P., Lin, Y.-B., Wang, Y.-T. and Hong, N.-M. (2008), "Monitoring and Predicting Land-use Changes and the Hydrology of the Urbanized Paochiao Watershed in Taiwan Using Remote Sensing Data, Urban Growth Models and a Hydrological Model", *Sensors (Basel, Switzerland)*, Vol. 8 No. 2, pp. 658–680.
Linard, C., Tatem, A.J. and Gilbert, M. (2013), "Modelling spatial patterns of urban growth in Africa", *Applied geography (Sevenoaks, England)*, Vol. 44, pp. 23–32.
Liu, R., Zhang, K., Zhang, Z. and Borthwick, A.G.L. (2014), "Land-use suitability analysis for urban development in Beijing", *Journal of environmental management*, Vol. 145, pp. 170–179.
Liu, Y., Hu, Y., Long, S., Liu, L. and Liu, X. (2017), "Analysis of the Effectiveness of Urban Land-Use-Change Models Based on the Measurement of Spatio-Temporal, Dynamic Urban Growth. A Cellular Automata Case Study", *Sustainability*, Vol. 9 No. 5, p. 796.
Lobos, V. and Partidario, M. (2014), "Theory versus practice in Strategic Environmental Assessment (SEA)", *Environmental Impact Assessment Review*, Vol. 48, pp. 34–46.
Local Authorities and Urban Development (AFD) (2015), "Alexandria: Regenerating the city. A contribution based on AFD experiences".
Long, Y., Gu, Y. and Han, H. (2012), "Spatiotemporal heterogeneity of urban planning implementation effectiveness. Evidence from five urban master plans of Beijing", *Landscape and Urban Planning*, Vol. 108 No. 2-4, pp. 103–111.
Luo, J. and Wei, Y.D. (2009), "Modeling spatial variations of urban growth patterns in Chinese cities. The case of Nanjing", *Landscape and Urban Planning*, Vol. 91 No. 2, pp. 51–64.
Ma, L., Li, M., Ma, X., Cheng, L., Du, P. and Liu, Y. (2017), "A review of supervised object-based land-cover image classification", *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 130, pp. 277–293.
MacDonald, M.L. (1996), "A Multi-Attribute Spatial Decision Support System for Solid Waste Planning", *Comput., Environ. and Urban Systems, Vol. 20, No. 1,*, pp. 1–17.
Mahdy, M. and Bahaj, A.S. (2018), "Multi criteria decision analysis for offshore wind energy potential in Egypt", *Renewable Energy*, Vol. 118, pp. 278–289.
Majumder, M. (2015), "Multi Criteria Decision Making", in Majumder, M. (Ed.), *Impact of Urbanization on Water Shortage in Face of Climatic Aberrations*, *SpringerBriefs in Water Science and Technology*, Springer Singapore, Singapore, pp. 35–47.

Malczewski, J. (2004), “GIS-based land-use suitability analysis. A critical overview”, *Progress in Planning*, Vol. 62 No. 1, pp. 3–65.

Malekpour, S., Brown, R.R. and Haan, F.J. de (2015), “Strategic planning of urban infrastructure for environmental sustainability. Understanding the past to intervene for the future”, *Cities*, Vol. 46, pp. 67–75.

Manso, G. (2010), “A Contribution to Urban Transport System Analyses and Planning in Developing Countries”, in Pina Filho, A.C.d. and Pi, A.C. de (Eds.), *Methods and Techniques in Urban Engineering*, InTech.

Mardani, A., Jusoh, A., MD Nor, K., Khalifah, Z., Zakwan, N. and Valipour, A. (2015), “Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014”, *Economic Research-Ekonomska Istraživanja*, Vol. 28 No. 1, pp. 516–571.

Marzban, C. (2013), “Variance-Based Sensitivity Analysis. An Illustration on the Lorenz'63 Model”, *Monthly Weather Review*, Vol. 141 No. 11, pp. 4069–4079.

Masria, A., Nadaoka, K., Negm, A. and Iskander, M. (2015), “Detection of Shoreline and Land Cover Changes around Rosetta Promontory, Egypt, Based on Remote Sensing Analysis”, *Land*, Vol. 4 No. 1, pp. 216–230.

Masria, A., Negm, A., Iskander, M. and Saavedra, O. (2014), “Coastal Zone Issues. A Case Study (Egypt)”, *Procedia Engineering*, Vol. 70, pp. 1102–1111.

Mateo, J.R.S.C. (2012), “Multi-Criteria Analysis”, in San Cristóbal Mateo, J.R. (Ed.), *Multi Criteria Analysis in the Renewable Energy Industry*, *Green Energy and Technology*, Springer London, London, pp. 7–10.

McGill University, School of Urban Planning (2017). About urban planning. Montréal (Québec), Canada, H3A 0C2.

Meentemeyer, R.K., Tang, W., Dorning, M.A., Vogler, J.B., Cunniffe, N.J. and Shoemaker, D.A. (2013), “FUTURES. Multilevel Simulations of Emerging Urban–Rural Landscape Structure Using a Stochastic Patch-Growing Algorithm”, *Annals of the Association of American Geographers*, Vol. 103 No. 4, pp. 785–807.

Ménard, A. and Marceau, D.J. (2016), “Exploration of Spatial Scale Sensitivity in Geographic Cellular Automata”, *Environment and Planning B: Planning and Design*, Vol. 32 No. 5, pp. 693–714.

Mertens, B. and Lambin, E.F. (1997), “Spatial modelling of deforestation in southern Cameroon”, *Applied Geography*, Vol. 17 No. 2, pp. 143–162.

Miller, H.J. (2003), “What about people in geographic information science? ☆”, *Computers, Environment and Urban Systems*, Vol. 27 No. 5, pp. 447–453.

Ministry of State for Environmental Affairs (MSEA) (2009), “Alexandria Integrated Coastal Zone Management Project (AICZMP)”, Environmental and Social Impact Assessment (ESIA), Arab Republic of Egypt.

Mitsova, D., Shuster, W. and Wang, X. (2011), “A cellular automata model of land cover change to integrate urban growth with open space conservation”, *Landscape and Urban Planning*, Vol. 99 No. 2, pp. 141–153.

Moeinaddini, M., Khorasani, N., Danehkar, A., Darvishsefat, A.A. and Zienalyan, M. (2010), “Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study. Karaj)”, *Waste management (New York, N.Y.)*, Vol. 30 No. 5, pp. 912–920.

Moghaddam, D.K. (2017). Transport Networks, Land Use and Travel Behaviour: a Long Term Investigation. Dissertation submitted to obtain the degree of doctor at the Delft University of Technology.

Mohamed, R.S., Bakr, A.F. and Anany, Y.M. (2017), “New Urban Indicators for Evaluating Urban Polices in Egypt. City Capacity and Capability (Capa 2)”, *Procedia Environmental Sciences*, Vol. 37, pp. 53–67.

Mohammadi, M., Sahebgharani, A. and Malekipour E. (2013), “Urban Growth Simulation through Cellular Automata (CA), Analytic Hierarchy Process (AHP) and GIS; Case Study of 8th and 12th Municipal Districts of Isfahan”, *Geographia Technica, Vol. 08, No. 2, 2013, pp 57 to 70*.

Mohammady, S. (2014), “A Swarm Optimization Based Method for Urban Growth Modelling”, *Environmental Research, Engineering and Management*, Vol. 69 No. 3.

Mohammady, S., Delavar, M.R. and Pahlavani, P. (2014), “Urban Growth Modeling using an Artificial Neural Network A Case Study of Sanandaj City, Iran”, *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-2/W3, pp. 203–208.

Mokarram, M. and Hojati, M. (2017), “Using ordered weight averaging (OWA) aggregation for multi-criteria soil fertility evaluation by GIS (case study. Southeast Iran)”, *Computers and Electronics in Agriculture*, Vol. 132, pp. 1–13.

Monteiro, M.B. and Partidário, M.R. (2017), “Governance in Strategic Environmental Assessment. Lessons from the Portuguese practice”, *Environmental Impact Assessment Review*, Vol. 65, pp. 125–138.

Montgomery, B., Dragićević, S., Dujmović, J. and Schmidt, M. (2016), “A GIS-based Logic Scoring of Preference method for evaluation of land capability and suitability for agriculture”, *Computers and Electronics in Agriculture*, Vol. 124, pp. 340–353.

Morad, M., Chalmers, A.I. and O’Regan, P.R. (1996), “The role of root-mean-square error in the geo-transformation of images in GIS”, *International journal of geographical information systems*, Vol. 10 No. 3, pp. 347–353.

Moreau, P., Viaud, V., Parnaudeau, V., Salmon-Monviola, J. and Durand, P. (2013), “An approach for global sensitivity analysis of a complex environmental model to spatial inputs and parameters. A case study of an agro-hydrological model”, *Environmental Modelling & Software*, Vol. 47, pp. 74–87.

Moreno, N., Wang, F. and Marceau, D.J. (2008), “An Object-Based Land-Use Cellular Automata Model to Overcome Cell Size And Neighborhood Sensitivity”, *Geocomputing Laboratory, Department of Geomatics Engineering, University of Calgary, Canada*.

Mosadeghi, R., Warnken, J., Tomlinson, R. and Mirfenderesk, H. (2015), “Comparison of Fuzzy-AHP and AHP in a spatial multi-criteria decision making model for urban land-use planning”, *Computers, Environment and Urban Systems*, Vol. 49, pp. 54–65.

Mosavi, M.R., Azad, M.S. and EmamGholipour, I. (2013), “Position Estimation in Single-Frequency GPS Receivers Using Kalman Filter with Pseudo-Range and Carrier Phase Measurements”, *Wireless Personal Communications*, Vol. 72 No. 4, pp. 2563–2576.

Motevalli, S., Hosseinzadeh, M.M., Derafshi, K., Gharehchahi, S. and Moharam, A. (2012), “Coastline Change Detection using Remote Sensing and GIS at Tonekabon Coast Area during 1984 and 2010, Mazandaran Province, Iran”, No. Life Sci J 2012;9(4):4174-4181] (ISSN:1097-8135).

Motlagh, Z.K. and Sayadi, M.H. (2015), “Siting MSW landfills using MCE methodology in GIS environment (Case study. Birjand plain, Iran)”, *Waste management (New York, N.Y.)*, Vol. 46, pp. 322–337.

Mousavi, S.H., Danehkar, A., Shokri, M.R., Poorbagher, H. and Azhdari, D. (2015), “Site selection for artificial reefs using a new combine Multi-Criteria Decision-Making (MCDM) tools for coral reefs in the Kish Island – Persian Gulf”, *Ocean & Coastal Management*, Vol. 111, pp. 92–102.

Mu Yang (2017). Urban Flood Simulation and Integrated Flood Risk Management – Case Study in Changsha Central City, China. Dissertation submitted in partial fulfillment of the requirements of the degree “Doctor of Engineering (Dr.-Ing.)” of the Faculty of Spatial Planning at the Technical University of Dortmund, Germany.

Mukhtar, M.E., Younes, D.E., Abdulhakim, E. and Farag, A. (2013), “Performance of Supervised Classification for Mapping Land Cover and Land Use in Jeffara Plain of Libya”, IPCBEE vol.55. 7 © (2013) IACSIT Press, Singapore. International Conference on Food and Agricultural Sciences No. DOI: 10.7763/IPCBEE.

Musakwa, W., Tshesane, R. and Kangethe, M. (2017), “The strategically located land index support system for human settlements land reform in South Africa”, *Cities*, Vol. 60, pp. 91–101.

Mustafa, A., Saadi, I., Cools, M. and Teller, J. (2014), “Measuring the Effect of Stochastic Perturbation Component in Cellular Automata Urban Growth Model”, *Procedia Environmental Sciences*, Vol. 22, pp. 156–168.

N.G. Kardoulas, A.C. Bird and A.I. Lawan (1996), “Geometric Correction of SPOT and Landsat Imagery: A Comparison of Map and GPS-Derived Control Points”, *American Society for Photogrammetric Engineering and Remote Sensing, Vol. 62, No. 10, October 1996, pp. 1173-1177.*

Naghibi, F., Delavar, M.R. and Pijanowski, B. (2016), “Urban Growth Modeling Using Cellular Automata with Multi-Temporal Remote Sensing Images Calibrated by the Artificial Bee Colony Optimization Algorithm”, *Sensors (Basel, Switzerland)*, Vol. 16 No. 12.

Nassar, D.M. and Elsayed, H.G. (2018), “From Informal Settlements to sustainable communities”, *Alexandria Engineering Journal*, Vol. 57 No. 4, pp. 2367–2376.

Nelson, A.C. (1992), “Preserving Prime Farmland in the Face of Urbanization. Lessons from Oregon”, *Journal of the American Planning Association*, Vol. 58 No. 4, pp. 467–488.

Noble, B. and Nwanekezie, K. (2017), “Conceptualizing strategic environmental assessment. Principles, approaches and research directions”, *Environmental Impact Assessment Review*, Vol. 62, pp. 165–173.

Nor, A.N.M., Corstanje, R., Harris, J.A. and Brewer, T. (2017), “Impact of rapid urban expansion on green space structure”, *Ecological Indicators*, Vol. 81, pp. 274–284.

Omidipoor, M. and Samani, N.N. (2017), “IMPACT OF SPATIAL FILTER ON LAND-USE CHANGES MODELLING USING URBAN CELLULAR AUTOMATA”, *ISPRS*

- *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-4/W4, pp. 429–433.
Osman, T., Divigalpitiya, P. and Arima, T. (2015), "Modeling urban growth scenarios in Cairo Metropolitan Region 2035", *CUPUM 2015 - 14th International Conference on Computers in Urban Planning and Urban Management.*
Osthorst, W. and Lange, H. (2007), "Integrated Coastal Zone Management (ICZM) as a Challenge to Spatial Planning: On Vision-Building and Decision-Making. An Empirical Evaluation of Applied Planning in Germany." artec-paper Nr. 147 No. ISSN 1613-4907, artec | Forschungszentrum Nachhaltigkeit, Universität Bremen.
Otukei, J.R. and Blaschke, T. (2010), "Land cover change assessment using decision trees, support vector machines and maximum likelihood classification algorithms", *International Journal of Applied Earth Observation and Geoinformation*, Vol. 12, S27-S31.
Pan, Y., Roth, A., Yu, Z. and Doluschitz, R. (2010), "The impact of variation in scale on the behavior of a cellular automata used for land use change modeling", *Computers, Environment and Urban Systems*, Vol. 34 No. 5, pp. 400–408.
PAP/RAC - EEAA (2009), "National ICZM Strategy for Egypt", ICZM Priorities and Objectives Workshop, Priority Actions Programme Regional Activity Centre, Egyptian Environmental Affairs Agency, Egypt.
Pérez-Molina, E., Sliuzas, R., Flacke, J. and Jetten, V. (2017), "Developing a cellular automata model of urban growth to inform spatial policy for flood mitigation. A case study in Kampala, Uganda", *Computers, Environment and Urban Systems*, Vol. 65, pp. 53–65.
Pettit, C., Bakelmun, A., Lieske, S.N., Glackin, S., Hargroves, K.'., Thomson, G., Shearer, H., Dia, H. and Newman, P. (2018), "Planning support systems for smart cities", *City, Culture and Society*, Vol. 12, pp. 13–24.
Pickaver, A.H., Gilbert, C. and Breton, F. (2004), "An indicator set to measure the progress in the implementation of integrated coastal zone management in Europe", *Ocean & Coastal Management*, Vol. 47 No. 9-10, pp. 449–462.
Pijanowski, B.C., Tayyebi, A., Doucette, J., Pekin, B.K., Braun, D. and Plourde, J. (2014), "A big data urban growth simulation at a national scale. Configuring the GIS and neural network based Land Transformation Model to run in a High Performance Computing (HPC) environment", *Environmental Modelling & Software*, Vol. 51, pp. 250–268.
Pilehforooshha, P., Karimi, M. and Taleai, M. (2014), "A GIS-based agricultural land-use allocation model coupling increase and decrease in land demand", *Agricultural Systems*, Vol. 130, pp. 116–125.
Platt, R.H. (2010), "THE FARMLAND CONVERSION DEBATE. NALS AND BEYOND∗", *The Professional Geographer*, Vol. 37 No. 4, pp. 433–442.
Poelmans, L. and van Rompaey, A. (2009), "Detecting and modelling spatial patterns of urban sprawl in highly fragmented areas. A case study in the Flanders–Brussels region", *Landscape and Urban Planning*, Vol. 93 No. 1, pp. 10–19.
Pontius, R.G., Boersma, W., Castella, J.-C., Clarke, K., Nijs, T. de, Dietzel, C., Duan, Z., Fotsing, E., Goldstein, N., Kok, K., Koomen, E., Lippitt, C.D., McConnell, W.,

Mohd Sood, A., Pijanowski, B., Pithadia, S., Sweeney, S., Trung, T.N., Veldkamp, A.T. and Verburg, P.H. (2008), “Comparing the input, output, and validation maps for several models of land change”, *The Annals of Regional Science*, Vol. 42 No. 1, pp. 11–37.

Pontius, R.G. and Neeti, N. (2010), “Uncertainty in the difference between maps of future land change scenarios”, *Sustainability Science*, Vol. 5 No. 1, pp. 39–50.

Pontius, R.G. and Si, K. (2015), “Spatial Decision Support Systems”, in *International Encyclopedia of the Social & Behavioral Sciences*, Elsevier, pp. 136–141.

Pontius, R.G., Walker, R., Yao-Kumah, R., Arima, E., Aldrich, S., Caldas, M. and Vergara, D. (2007), “Accuracy Assessment for a Simulation Model of Amazonian Deforestation”, *Annals of the Association of American Geographers*, Vol. 97 No. 4, pp. 677–695.

Pourebrahim, S., Hadipour, M. and Bin Mokhtar, M. (2011), “Integration of spatial suitability analysis for land use planning in coastal areas; case of Kuala Langat District, Selangor, Malaysia”, *Landscape and Urban Planning*, Vol. 101 No. 1, pp. 84–97.

Qiu, L., Zhu, J., Pan, Y., Hu, W. and Amable, G.S. (2017), “Multi-criteria land use suitability analysis for livestock development planning in Hangzhou metropolitan area, China”, *Journal of Cleaner Production*, Vol. 161, pp. 1011–1019.

Rafiee, R., Mahiny, A.S., Khorasani, N., Darvishsefat, A.A. and Danekar, A. (2009), “Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM)”, *Cities*, Vol. 26 No. 1, pp. 19–26.

Rahman, M.A., Rusteberg, B., Gogu, R.C., Lobo Ferreira, J.P. and Sauter, M. (2012), “A new spatial multi-criteria decision support tool for site selection for implementation of managed aquifer recharge”, *Journal of environmental management*, Vol. 99, pp. 61–75.

Rahman, M.A., Rusteberg, B., Uddin, M.S., Lutz, A., Saada, M.A. and Sauter, M. (2013), “An integrated study of spatial multicriteria analysis and mathematical modelling for managed aquifer recharge site suitability mapping and site ranking at Northern Gaza coastal aquifer”, *Journal of environmental management*, Vol. 124, pp. 25–39.

Rajabi, M.M., Ataie-Ashtiani, B. and Simmons, C.T. (2015), “Polynomial chaos expansions for uncertainty propagation and moment independent sensitivity analysis of seawater intrusion simulations”, *Journal of Hydrology*, Vol. 520, pp. 101–122.

Ramachandra, T. V., Bharath, H. A., Vinay, S. and Niranjan, V.J. (2016), “Modelling and Visualization of Urban Trajectory in 4 cities of India”, No. 32nd Annual Symposium on Space Science and Technology, At ISRO-IISc Space Technology Cell, 7-8 January 2016, Volume: 32.

Rawat, J.S. and Kumar, M. (2015), “Monitoring land use/cover change using remote sensing and GIS techniques. A case study of Hawalbagh block, district Almora, Uttarakhand, India”, *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 18 No. 1, pp. 77–84.

Rebolledo, B., Gil, A., Flotats, X. and Sánchez, J.Á. (2016), “Assessment of groundwater vulnerability to nitrates from agricultural sources using a GIScompatible logic multicriteria model", *Journal of environmental management*, Vol. 171, pp. 70–80.

Rekha, N.P., Gangadharan, R., Ravichandran, P., Mahalakshmi, P., Panigrahi, A. and Pillai, S.M. (2015), "Assessment of impact of shrimp farming on coastal groundwater using Geographical Information System based Analytical Hierarchy Process", *Aquaculture*, Vol. 448, pp. 491–506.

Reynolds, J.F. and Stafford Smith, D.M. (2002), *Global desertification: Do humans cause deserts?, Dahlem workshop report*, Vol. 88, Dahlem University Press, Berlin.

Rikalovic, A., Cosic, I. and Lazarevic, D. (2014), "GIS Based Multi-criteria Analysis for Industrial Site Selection", *Procedia Engineering*, Vol. 69, pp. 1054–1063.

Rodríguez, I., Montoya, I., Sánchez, M.J. and Carreño, F. (2009), "Geographic Information Systems applied to Integrated Coastal Zone Management", *Geomorphology*, Vol. 107 No. 1-2, pp. 100–105.

Rojas, C., Pino, J. and Jaque, E. (2013), "Strategic Environmental Assessment in Latin America. A methodological proposal for urban planning in the Metropolitan Area of Concepción (Chile)", *Land Use Policy*, Vol. 30 No. 1, pp. 519–527.

Romano, G., Dal Sasso, P., Trisorio Liuzzi, G. and Gentile, F. (2015), "Multi-criteria decision analysis for land suitability mapping in a rural area of Southern Italy", *Land Use Policy*, Vol. 48, pp. 131–143.

Rudel, T.A. (2005), *Tropical Forests*, Columbia University Press, New York Chichester, West Sussex.

Russo, P., Lanzilotti, R., Costabile, M.F. and Pettit, C.J. (2018), "Towards satisfying practitioners in using Planning Support Systems", *Computers, Environment and Urban Systems*, Vol. 67, pp. 9–20.

Saaty, R.W. (1987), "The Analytic Hierarchy Process-What It Is And How It Is Used", *Math Modelling, 4922 Ellsworth Avenue, Pittsburgh, PA 15213, U.S.A*, No. Vol. 9, No. 3-5, pp. 161-176.

Sabaei, D., Erkoyuncu, J. and Roy, R. (2015), "A Review of Multi-criteria Decision Making Methods for Enhanced Maintenance Delivery", *Procedia CIRP*, Vol. 37, pp. 30–35.

Saeidi, S., Mohammadzadeh, M., Salmanmahiny, A. and Mirkarimi, S.H. (2017), "Performance evaluation of multiple methods for landscape aesthetic suitability mapping. A comparative study between Multi-Criteria Evaluation, Logistic Regression and Multi-Layer Perceptron neural network", *Land Use Policy*, Vol. 67, pp. 1–12.

Sakieh, Y., Salmanmahiny, A., Jafarnezhad, J., Mehri, A., Kamyab, H. and Galdavi, S. (2015), "Evaluating the strategy of decentralized urban land-use planning in a developing region", *Land Use Policy*, Vol. 48, pp. 534–551.

Şalap-Ayça, S., Jankowski, P., Clarke, K.C., Kyriakidis, P.C. and Nara, A. (2017), "A meta-modeling approach for spatio-temporal uncertainty and sensitivity analysis. An application for a cellular automata-based Urban growth and land-use change model", *International Journal of Geographical Information Science*, Vol. 32 No. 4, pp. 637–662.

Salih, A.A., Ganawa, E.-T. and Elmahl, A.A. (2017), "Spectral mixture analysis (SMA) and change vector analysis (CVA) methods for monitoring and mapping land degradation/desertification in arid and semiarid areas (Sudan), using Landsat imagery", *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 20, S21-S29.

Salim, M.G. (2012), "Selection of groundwater sites in Egypt, using geographic information systems, for desalination by solar energy in order to reduce greenhouse gases", *Journal of Advanced Research*, Vol. 3 No. 1, pp. 11–19.

Saltelli, A. and Annoni, P. (2010), "How to avoid a perfunctory sensitivity analysis", *Environmental Modelling & Software*, Vol. 25 No. 12, pp. 1508–1517.

Saltelli, A. and Tarantola, S. (2002), "On the Relative Importance of Input Factors in Mathematical Models", *Journal of the American Statistical Association*, Vol. 97 No. 459, pp. 702–709.

Saltelli, A., Marco Ratto, Terry Andres, Francesca Campolongo, Jessica Cariboni, Debora Gatelli, Michaela Saisana and Stefano Tarantola (2008), "Global Sensitivity Analysis. The Primer", *John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England*, No. ISBN 978-0-470-05997-5.

Saltelli, A., Tarantola Stefano, Campolongo Francesca and Ratto Marco (2004), "Sensitivity analysis In practice: a guide to assessing scientific models", *John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England*, No. ISBN 0-470-87093-1.

Samat, N. (2006), "Characterizing the scale sensitivity of the cellular automata simulated urban growth. A case study of the Seberang Perai Region, Penang State, Malaysia", *Computers, Environment and Urban Systems*, Vol. 30 No. 6, pp. 905–920.

Sánchez-Arcilla, A., Mösso, C., Sierra, J.P., Mestres, M., Harzallah, A., Senouci, M. and El-Raey, M. (2011), "Climatic drivers of potential hazards in Mediterranean coasts", *Regional Environmental Change*, Vol. 11 No. 3, pp. 617–636.

Sanò, M., Gonzalez-Riancho, P., Areizaga, J. and Medina, R. (2010), "The Strategy for Coastal Sustainability. A Spanish Initiative for ICZM", *Coastal Management*, Vol. 38 No. 1, pp. 76–96.

Sanò, M. and Medina, R. (2012), "A systems approach to identify sets of indicators. Applications to coastal management", *Ecological Indicators*, Vol. 23, pp. 588–596.

Sanò, M., Richards, R. and Medina, R. (2014), "A participatory approach for system conceptualization and analysis applied to coastal management in Egypt", *Environmental Modelling & Software*, Vol. 54, pp. 142–152.

Sanò, M., Fernandez, F., Pino, G. R., and Medina, R. (2007), "GIS Implementation for ICZM in the Mediterranean Coast of Egypt", No. Instituto de Hidráulica Ambiental "IH Cantabria", Universidad de Cantabria.

Santé, I., García, A.M., Miranda, D. and Crecente, R. (2010), "Cellular automata models for the simulation of real-world urban processes. A review and analysis", *Landscape and Urban Planning*, Vol. 96 No. 2, pp. 108–122.

Sarp, G. and Ozcelik, M. (2018), "Water body extraction and change detection using time series. A case study of Lake Burdur, Turkey", *Journal of Taibah University for Science*, Vol. 11 No. 3, pp. 381–391.

Sassan M., Delavar Mahmoud R. and Pijanowski Bryan C. (2013), "Urban Growth Modelling with Artificial Neural Network and Logistic Regression. Case Study: Sanandaj City, Iran", *Romanian Review of Regional Studies, Volume Ix, Number 2, 2013*.

Schetke, S., Haase, D. and Kötter, T. (2012), "Towards sustainable settlement growth. A new multi-criteria assessment for implementing environmental targets into strategic urban planning", *Environmental Impact Assessment Review*, Vol. 32 No. 1, pp. 195–210.

Sener, S., Sener, E., Nas, B. and Karagüzel, R. (2010), "Combining AHP with GIS for landfill site selection. A case study in the Lake Beyşehir catchment area (Konya, Turkey)", *Waste management (New York, N.Y.)*, Vol. 30 No. 11, pp. 2037–2046.

Serasinghe Pathiranage, I.S., Kantakumar, L.N. and Sundaramoorthy, S. (2018), "Remote Sensing Data and SLEUTH Urban Growth Model. As Decision Support Tools for Urban Planning", *Chinese Geographical Science*, Vol. 28 No. 2, pp. 274–286.

Shafizadeh Moghadam, H. and Helbich, M. (2013), "Spatiotemporal urbanization processes in the megacity of Mumbai, India. A Markov chains-cellular automata urban growth model", *Applied Geography*, Vol. 40, pp. 140–149.

Sharifi Mohammad Ali and Rodriguez Erasmo (2002), "Design and development of a planning support system for policy formulation in water resources rehabilitation. the case of Alca´zar De San Juan District in Aquifer 23, La Mancha, Spain", *Journal of Hydroinformatics 04 (3)*, pp. 157–175.

Shaw, R. and Das, A. (2018), "Identifying peri-urban growth in small and medium towns using GIS and remote sensing technique. A case study of English Bazar Urban Agglomeration, West Bengal, India", *The Egyptian Journal of Remote Sensing and Space Science*, Vol. 21 No. 2, pp. 159–172.

She, J., Guan, Z., Cai, F., Pu, L., Tan, J. and Chen, T. (2017), "Simulation of Land Use Changes in a Coastal Reclaimed Area with Dynamic Shorelines", *Sustainability*, Vol. 9 No. 3, p. 431.

Silva, E. and Clarke, K. (2002), "Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal", *Computers, Environment and Urban Systems*, Vol. 26 No. 6, pp. 525–552.

Sindhu, S., Nehra, V. and Luthra, S. (2017), "Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis. Case study of India", *Renewable and Sustainable Energy Reviews*, Vol. 73, pp. 496–511.

Singh, A. and Singh, K.K. (2018), "Unsupervised change detection in remote sensing images using fusion of spectral and statistical indices", *The Egyptian Journal of Remote Sensing and Space Science*.

Singh, C. K. (Eds.). (2018). Geospatial Applications for Natural Resources Management. CRC Press.

Singh, L.K., Jha, M.K. and Chowdary, V.M. (2017), "Multi-criteria analysis and GIS modeling for identifying prospective water harvesting and artificial recharge sites for sustainable water supply", *Journal of Cleaner Production*, Vol. 142, pp. 1436–1456.

Singh, S.K., Srivastava, P.K., Gupta, M., Thakur, J.K. and Mukherjee, S. (2014), "Appraisal of land use/land cover of mangrove forest ecosystem using support vector machine", *Environmental Earth Sciences*, Vol. 71 No. 5, pp. 2245–2255.

Smith, P. J. (1962), "Calgary: A Study in Urban Pattern", *Economic Geography, 38:4, 315-329, DOI: 10.2307/142261*.

Sobol', I.M. (2001), "Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates", *Mathematics and Computers in Simulation 55 (2001) 271–280*, No. 0378-4754/01/$20.00 © 2001 IMACS. Published by Elsevier Science B.V.

Soliman, A.M. (2012), ""Nothing More to Lose": Ashwaayat and Land Governance in Egypt", *Integration Land Governance into the Post-2012 Agenda, Harnessing Synergies for Implementation and Monitoring Impact, Annual World Bank Conference on Land and Poverty, Washington DC, March 24-27, 2014*.

Soltani, A., Hewage, K., Reza, B. and Sadiq, R. (2015), "Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management. A review", *Waste management (New York, N.Y.)*, Vol. 35, pp. 318–328.

Song, Y., Ding, C. and Knaap, G. (2006), "Envisioning Beijing 2020 through sketches of urban scenarios", *Habitat International*, Vol. 30 No. 4, pp. 1018–1034.

Stephan Kamps, C.T. (2008), "A planning support system for assessing strategies of local urban planning agencies", *6th International Conference of Territorial Intelligence" Tools and methods of Territorial Intelligence", Besançon, 2008, Oct 2008, Besançon, France. <halshs-00985648>*.

Stephenne, N., Beaumont, B., Hallot, E., Wolff, E., Poelmans, L. and Baltus, C. (2016), "SUSTAINABLE AND SMART CITY PLANNING USING SPATIAL DATA IN WALLONIA", *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-4/W1, pp. 3–10.

Stevens, D., Dragicevic, S. and Rothley, K. (2007), "iCity. A GIS–CA modelling tool for urban planning and decision making", *Environmental Modelling & Software*, Vol. 22 No. 6, pp. 761–773.

Stevens, K.B., Gilbert, M. and Pfeiffer, D.U. (2013), "Modeling habitat suitability for occurrence of highly pathogenic avian influenza virus H5N1 in domestic poultry in Asia. A spatial multicriteria decision analysis approach", *Spatial and spatio-temporal epidemiology*, Vol. 4, pp. 1–14.

Store, R. and Kangas, J. (2001), "Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling", *Landscape and Urban Planning*, Vol. 55 No. 2, pp. 79–93.

Su, S., Xiao, R. and Zhang, Y. (2012), "Multi-scale analysis of spatially varying relationships between agricultural landscape patterns and urbanization using geographically weighted regression", *Applied Geography*, Vol. 32 No. 2, pp. 360–375.

Sudret, B. (2008), "Global sensitivity analysis using polynomial chaos expansions", *Reliability Engineering & System Safety*, Vol. 93 No. 7, pp. 964–979.

Suja, R., Letha J. and Varghese J. (2013), “Evaluation of Urban growth and expansion using Remote sensing and GIS”, *International Journal of Engineering Research & Technology (IJERT). ISSN: 2278-0181.*, Vol. 2 Issue 10.

Sutton, K. and Fahmi, W. (2001), “Cairo's urban growth and strategic master plans in the light of Egypt's 1996 population census results”, *Cities*, Vol. 18 No. 3, pp. 135–149.

Swallow, S.Z., Talukdar, P. and Wear, D.N. (1997), “Spatial and Temporal Specialization in Forest Ecosystem Management under Sole Ownership”, *Amer. J. Agr. Econ. 79 (May 1997): 311-326. Copyright 1997 American Agricultural Economics Association*.

Szuster, B.W., Chen, Q. and Borger, M. (2011), “A comparison of classification techniques to support land cover and land use analysis in tropical coastal zones”, *Applied Geography*, Vol. 31 No. 2, pp. 525–532.

Tabet, L. and Fanning, L. (2012), “Integrated coastal zone management under authoritarian rule. An evaluation framework of coastal governance in Egypt”, *Ocean & Coastal Management*, Vol. 61, pp. 1–9.

Tag-Eldeen, Z.N. (2012). Cross-Cultural Knowledge Development: The Case of Collaborative Urban Planning in Egypt. Doctoral Dissertation in Planning and Decision Analysis Stockholm, Sweden 2012

Taheri, K., Gutiérrez, F., Mohseni, H., Raeisi, E. and Taheri, M. (2015), “Sinkhole susceptibility mapping using the analytical hierarchy process (AHP) and magnitude–frequency relationships. A case study in Hamadan province, Iran”, *Geomorphology*, Vol. 234, pp. 64–79.

Tang, W. and Jia, M. (2014), “Global Sensitivity Analysis of a Large Agent-Based Model of Spatial Opinion Exchange. A Heterogeneous Multi-GPU Acceleration Approach”, *Annals of the Association of American Geographers*, Vol. 104 No. 3, pp. 485–509.

Tarantola, S., Crosetto, M. and Saltelli, A. (2000), “Sensitivity and uncertainty analysis in spatial modelling based on GIS”, *European Commission, Joint Research Centre, Institute for Systems Informatics and Safety, TP 361, 21020 Ispra, Italy*, Vol. 1999.

Taussik, J. (2007), “The opportunities of spatial planning for integrated coastal management”, *Marine Policy*, Vol. 31 No. 5, pp. 611–618.

Tellioglu, I. and Konandreas, P. (2017), “Agricultural Policies, Trade and Sustainable Development in Egypt”, Geneva: International Centre for Trade and Sustainable Development (ICTSD) and Rome: United Nations Food and Agriculture Organization (FAO).

Thapa, R.B. and Murayama, Y. (2012), “Scenario based urban growth allocation in Kathmandu Valley, Nepal”, *Landscape and Urban Planning*, Vol. 105 No. 1-2, pp. 140–148.

Thinh, N.X., Walz, U., Schanze, J., Ferencsik, I. and Göncz, A. (2004), “GIS-based multiple crieteria decision analysis and optimization for land suitability evaluation”, *Wittmann, J. & Wieland, R. (HRSG): Simulation in Umwelt-und Geowissenschaften. Shaker Verlag, S. 208-223*.

Thinh, N.X., and Vogel, R. (2005a). Modelling urban land use dynamics with GIS and Cellular Automata – A case study of the Dresden City Region since 1780. In: Filho, L., Gomez, M., & Rautenstrauch, C. (Eds.): Second International ICSC Symposium on Information Technologies in Environmental Engineering, Proceedings. Shaker Verlag, Aachen: 349-364.

Thinh, N.X., and Vogel, R. (2005b). Simulation of Land Use Dynamics through a Cellular Automata Model Based on GIS, Neighbourhood Analysis, and Compromise Programming. In: Hrebícek, J., & Rácek, J. (Eds.): EnviroInfo Brno 2005. Informatics for Environmental Protection. Networking Environmental Information. Masaryk University, Brno: 600-609.

Thompson, U.-C., Marsan, J.-F., Fournier-Peyresblanques, B., Forgues, C., Ogaa, A. and Jaeger, J.A. (2013), “Using Compliance Analysis for PPP to bridge the gap between SEA and EIA. Lessons from the Turcot Interchange reconstruction in Montréal, Québec”, *Environmental Impact Assessment Review*, Vol. 42, pp. 74–86.

Tian, G., Ma, B., Xu, X., Liu, X., Xu, L., Liu, X., Xiao, L. and Kong, L. (2016), “Simulation of urban expansion and encroachment using cellular automata and multi-agent system model—A case study of Tianjin metropolitan region, China”, *Ecological Indicators*, Vol. 70, pp. 439–450.

Triantakonstantis, D. and Mountrakis, G. (2012a), “Urban Growth Prediction. A Review of Computational Models and Human Perceptions”, *Journal of Geographic Information System*, Vol. 04 No. 06, pp. 555–587.

Triantakonstantis, D. and Mountrakis, G. (2012b), “Urban Growth Prediction. A Review of Computational Models and Human Perceptions”, *Journal of Geographic Information System*, Vol. 04 No. 06, pp. 555–587.

Triantakonstantis, D., Mountrakis, G. and Wang, J. (2011), “A Spatially Heterogeneous Expert Based (SHEB) Urban Growth Model using Model Regionalization”, *Journal of Geographic Information System*, Vol. 03 No. 03, pp. 195–210.

Tsangaratos, P., Kallioras, A., Pizpikis, T., Vasileiou, E., Ilia, I. and Pliakas, F. (2017), “Multi-criteria Decision Support System (DSS) for optimal locations of Soil Aquifer Treatment (SAT) facilities”, *The Science of the total environment*, 603-604, pp. 472–486.

Tulu, F. D. (2014), “Integration of strategic environmental assessment into regional planning”, Herald Journal of Geography and Regional Planning Vol. 3 (1) No. Copyright (c) 2014 Herald International Research Journals, ISSN 2350 – 2185.

UNEP, MAP, PAP (2001), *White paper: Coastal zone management in the Mediterranean*, United Nations Environment Programme. Mediterranean Action Plan. Priority Actions Programme, [Split, Croatia].

Van Niekerk, A., Du Plessis, D., Boonzaaier, I., Spocter, M., Ferreira, S., Loots, L. and Donaldson, R. (2016), “Development of a multi-criteria spatial planning support system for growth potential modelling in the Western Cape, South Africa”, *Land Use Policy*, Vol. 50, pp. 179–193.

Van Zuidam, R.A., Farifteh, J., Eleveld, M.A. and Tao, C. (1998), "Developments in remote sensing, dynamic modelling and GIS applications for integrated coastal zone management", *Journal of Coastal Conservation*, Vol. 4 No. 2, pp. 191–202.

Verburg, P.H., Nijs, T.C. de, van Ritsema Eck, J., Visser, H. and Jong, K. de (2004), "A method to analyse neighbourhood characteristics of land use patterns", *Computers, Environment and Urban Systems*, Vol. 28 No. 6, pp. 667–690.

Verburg, P.H., van Eck, J.R.R., Nijs, T.C.M. de, Dijst, M.J. and Schot, P. (2016), "Determinants of Land-Use Change Patterns in the Netherlands", *Environment and Planning B: Planning and Design*, Vol. 31 No. 1, pp. 125–150.

Vermote, E., Justice, C., Claverie, M. and Franch, B. (2016), "Preliminary analysis of the performance of the Landsat 8/OLI land surface reflectance product", *Remote Sensing of Environment*, Vol. 185, pp. 46–56.

Verstegen, J.A., Karssenberg, D., van der Hilst, F. and Faaij, A.P. (2014), "Identifying a land use change cellular automaton by Bayesian data assimilation", *Environmental Modelling & Software*, Vol. 53, pp. 121–136.

Vettorazzi, C.A. and Valente, R.A. (2016), "Priority areas for forest restoration aiming at the conservation of water resources", *Ecological Engineering*, Vol. 94, pp. 255–267.

Vojnovic, I. (2014), "Urban sustainability. Research, politics, policy and practice", *Cities*, Vol. 41, S30-S44.

Vonk, G., Geertman, S. and Schot, P. (2016), "Bottlenecks Blocking Widespread Usage of Planning Support Systems", *Environment and Planning A*, Vol. 37 No. 5, pp. 909–924.

Vonk, G. (2006), "Improving Planning Support. The use of Planning Support Systems for spatial planning", *A thesis has been submitted as a Ph.D degree in partial fulfilment of the requirements for the award of the degree of Doctor at Utrecht University, the Netherlands*.

Wagner, P. and Wegener, M. (2007). Urban Land Use, Transport and Environment Models, disP - The Planning Review, 43:170, 45-56, DOI: 10.1080/02513625.2007.10556988

Wahyudi, A. and Liu, Y. (2016), "Cellular Automata for Urban Growth Modelling", *International Review for Spatial Planning and Sustainable Development*, Vol. 4 No. 2, pp. 60–75.

Walker, Robert T. (1987), "Land Use Transition and Deforestation in Developing Countries", *Geographical Analysis, Vol. 19, No. 1 (Jan. 1987) © 1987 Ohio State University Press*.

Wang, Y.-M., Luo, Y. and Hua, Z. (2008), "On the extent analysis method for fuzzy AHP and its applications", *European Journal of Operational Research*, Vol. 186 No. 2, pp. 735–747.

Wang, W.T. and Liu Chao-Yueh (2005), "The Application of the Technology Acceptance Model: A New Way to Evaluate Information System Success", *School of Information Science and Policy, University at Albany 840 Washington Avenue, Albany, NY 12203*.

Ward, D., Phinn, S.R. and Murray, A.T. (2000), “Monitoring Growth in Rapidly Urbanizing Areas Using Remotely Sensed Data”, *The Professional Geographer*, Vol. 52 No. 3, pp. 371–386.

Wear, D.N., Robert, A. and Mangold, R. (1998), “People, Space and Time: Factors That will Govern Forest Sustainability”, *Transactions of the 63rd North American Wildlife and Natural Resources conference, 1998, March 20-25, Orlando, Fl. Washington, DC: Wildlife Management Institute 348-361.*

Wear, D.N., Liu, R., Michael Foreman, J. and Sheffield, R.M. (1999), “The effects of population growth on timber management and inventories in Virginia”, *Forest Ecology and Management*, Vol. 118 No. 1-3, pp. 107–115.

Wegener, M. (2012): Government or governance? The challenge of planning for sustainability in the Ruhr. In: Hartmann, T., Needham, B. (Eds.): *Planning by Law and Property Rights*. Farnham, Surrey, GB: Ashgate, 157-168.

Wegener, M. (1995), “Current and Future Land Use Models”, *Paper presented at the Land Use Model Conference organized by the Texas Transportation Institute,*

Wegener, M., and Fürst, F. (1999). Land-Use Transport Interaction: State of the Art. Deliverable D2a of the project TRANSLAND (Integration of Transport and Land use Planning). Dortmund: Universität Dortmund.

Weiland, U. (2010), “Strategic Environmental Assessment in Germany — Practice and open questions”, *Environmental Impact Assessment Review*, Vol. 30 No. 3, pp. 211–217.

White, R. and Engelen, G. (1993), “Urban Systems Dynamics and Cellular Automata: Fractal Structures between Order and Chaos”, Chau, Solmns & Fracrals Vol. 4. No. 4. pp. 563-583, 1994 No. Copyright © 1994 Elsevier Science Ltd. Printed in Great Britam All rights reserved 0960-0779/94$7.00 + .00.

White, R. and Engelen, G. (1994), “Urban Systems Dynamics and Cellular Automata: Fractal Structures between Order and Chaos”, *Chau, Solmns & Fracrals Vol. 4. No. 4. pp. 563-583, 1994*.

White, R. and Engelen, G. (1997), “Cellular automata as the basis of integrated dynamic regional modelling”, *Environment and Planning B: Planning and Design*, Vol. 24 No. 2, pp. 235–246.

White, R. and Engelen, G. (2000), “High-resolution integrated modelling of the spatial dynamics of urban and regional systems”, *Computers, Environment and Urban Systems*, Vol. 24 No. 5, pp. 383–400.

Wood, C.H. and Porro, R. (2002), *Deforestation and land use in the Amazon*, University Press of Florida, Gainesville.

World Bank - Cities Alliance - GOPP - Alexandria Governorate - Bibliotheca Alexandrina, Alexandria City Development Strategy, Process and results 2004-2008, 2008, 89p.

Wu, F. (2002), “Calibration of stochastic cellular automata. The application to rural-urban land conversions”, *International Journal of Geographical Information Science*, Vol. 16 No. 8, pp. 795–818.

Wu, F. and Webster, C.J. (1998), “Simulation of land development through the integration of cellular automata and multicriteria evaluation”, *Environment and Planning B: Planning and Design*, Vol. 25 No. 1, pp. 103–126.

Xiang, W.-N. and Clarke, K.C. (2003), “The Use of Scenarios in Land-Use Planning”, *Environment and Planning B: Planning and Design*, Vol. 30 No. 6, pp. 885–909.

Xiang, W.-N. and Clarke, K.C. (2016a), “The Use of Scenarios in Land-Use Planning”, *Environment and Planning B: Planning and Design*, Vol. 30 No. 6, pp. 885–909.

Xiang, W.-N. and Clarke, K.C. (2016b), “The Use of Scenarios in Land-Use Planning”, *Environment and Planning B: Planning and Design*, Vol. 30 No. 6, pp. 885–909.

Xie, Yichun (1996), “A Generalized Model for Cellular Urban Dynamics”, *Geographical Analysis, Vol. 28, No. 4 (October 1996) © 1996 Ohio State University Press*.

Xu, E. and Zhang, H. (2013), “Spatially-explicit sensitivity analysis for land suitability evaluation”, *Applied Geography*, Vol. 45, pp. 1–9.

Xu, Ruoning and Zhai, Xiaoyan (1992), “Extensions of the analytic hierarchy process in fuzzy environment”, *Institute of Fuzzy Systems & Knowledge Engineering, Guangzhou University, Guangzhou, 510050, China*, Fuzzy Sets and Systems 52 (1992) 251-257.

Yager, Ronald R. (1995), “Multicriteria Decision Making Using Fuzzy Quantifiers - Computational Intelligence for Financial Engineering, 1995. Proceedings of the IEEE/IAFE 1995”.

Yalcin, A. (2008), “GIS-based landslide susceptibility mapping using analytical hierarchy process and bivariate statistics in Ardesen (Turkey). Comparisons of results and confirmations”, *CATENA*, Vol. 72 No. 1, pp. 1–12.

Yang, Q., Li, X. and Shi, X. (2008), “Cellular automata for simulating land use changes based on support vector machines”, *Computers & Geosciences*, Vol. 34 No. 6, pp. 592–602.

Yeh, A.G.-O. and Li, X. (2006a), “Errors and uncertainties in urban cellular automata”, *Computers, Environment and Urban Systems*, Vol. 30 No. 1, pp. 10–28.

Yeh, A.G.-O. and Li, X. (2006b), “Errors and uncertainties in urban cellular automata”, *Computers, Environment and Urban Systems*, Vol. 30 No. 1, pp. 10–28.

Yousry. S (2013), “Revolutionizing the planning process in Egypt Decentralizing Powers and Actions”, *Ain Shams University, Department of Urban Design and Architecture. ©SB13-Cairo.*

Yuan, F., Sawaya, K.E., Loeffelholz, B.C. and Bauer, M.E. (2005), “Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing”, *Remote Sensing of Environment*, Vol. 98 No. 2-3, pp. 317–328.

Yüzer, M.A. (2004), “Growth estimations in settlement planning using a land use cellular automata model (LUCAM)”, *European Planning Studies*, Vol. 12 No. 4, pp. 551–561.

Zhang, J., Su, Y., Wu, J. and Liang, H. (2015), “GIS based land suitability assessment for tobacco production using AHP and fuzzy set in Shandong province of China", *Computers and Electronics in Agriculture*, Vol. 114, pp. 202–211.

Zhang, Q., Ban, Y., Liu, J. and Hu, Y. (2011), "Simulation and analysis of urban growth scenarios for the Greater Shanghai Area, China", *Computers, Environment and Urban Systems*, Vol. 35 No. 2, pp. 126–139.

Zhao, Y., Zhao, J. and Murayama, Y. (2008), "Modeling and predicting urban growth pattern of the Tokyo metropolitan area based on cellular automata", in Liu, L., Li, X., Liu, K., Zhang, X. and Chen, A. (Eds.), *Riga, Latvia, Sunday 24 August 2008*, SPIE, 71431Q.

Zhou, Kai (2011), "Planning Support Systems for Sustainable Urban Regeneration" *a thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Humanities. School of Environment and Development, University of Manchester*.

Zoghi, M., Houshang Ehsani, A., Sadat, M., javad Amiri, M. and Karimi, S. (2017), "Optimization solar site selection by fuzzy logic model and weighted linear combination method in arid and semi-arid region. A case study Isfahan-IRAN", *Renewable and Sustainable Energy Reviews*, Vol. 68, pp. 986–996.

Zolekar, R.B. and Bhagat, V.S. (2015), "Multi-criteria land suitability analysis for agriculture in hilly zone. Remote sensing and GIS approach", *Computers and Electronics in Agriculture*, Vol. 118, pp. 300–321.

Appendices

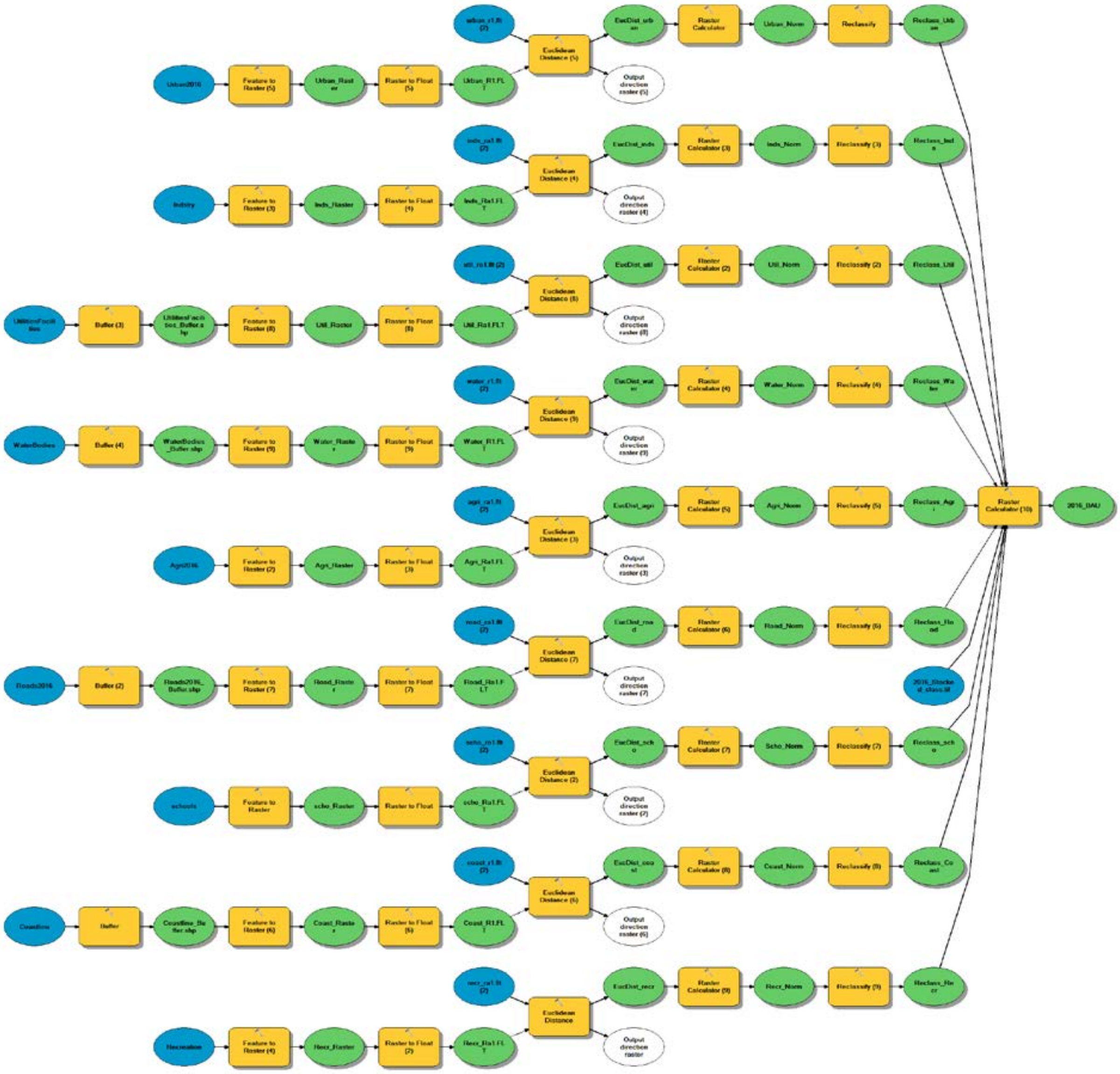


Figure 0-1: Flow chart of the Land Suitability Analysis developed using Model Builder in ArcGIS environment

Table 0-1: Detailed outcomes, strategic objectives and operational activities and the progress indicators have been used to evaluate the ICZM project in Alexandria governorate, Egypt.

Outcome /main action	Outputs /strategic objective	Progression indexes	Rate (0-5)	1st Year	2nd Year	3rd Year	4th Year	1-Year After	2-Years After	Operational activities
Improved Urban environment for Alexandria governorate	Strategic urban plan till the year 2032	A	2	2	2	2	2	2	2	Updating the city issues and existing strategies
										Workshops and working groups for more stakeholder's involvement
										Develop and agree on vision, long-term objectives, goals, and priorities for the city development
										Land use and space planning
										Improving local infrastructures
	Improved capabilities of local administrative and capacity building	B	2	2	2	2	2	2	2	Capacity building for human resources at local level
										Promote interaction between local stakeholders and planning departments with the central governorate on ministerial level
										Conduct development and intervention through: economic development, communication, management of Sea Level Rise threats negative impacts on environment
	Guidelines and management strategy	C	2	2	2	2	2	2	2	Improvement of the environmental quality and health
										Improving transportation system
										Urban management strategy
										Follow up, monitoring and assessment of the plan
Strengthening ICZM policy for Egypt	Maximizing coordination and cooperation between focal actor and other intermediaries	D	3	3	3	3	3	3	3	Promotion of coordination and cooperation between Alexandria governorate, EEAA, and central administrations
										Regulation of short/long-term funding mechanisms
										Multi-scale cooperation in formulating research agenda to support policy making and management decisions
	Stocktaking/update existing laws and regulations	E	4	4	4	4	4	4	4	Redistribution of tasks and responsibilities without overlapping
										Developing/update specific ICZM law or regulation
										Formulation of regulations concerning resource use and exploitation
	More stakeholder participation	F	4	4	4	4	4	4	4	Developing effective mechanisms for stakeholders' involvement
										Strategies for conflict resolution mechanisms among various users

										Promoting for holistic and participative management
Sustainable use of the coastal resources	Enforcing policies and measures included in the national water resources plan	G	1	1	1	1	1	1	1	Water framework directive principles Developing and implementing water collaborative planning
	Initiation of integrated activities management	H	2	2	2	2	2	2	2	Creating administrative bodies on local scale for integrated activities management Developing integrated primary activities and collaborative planning
	sustainable tourism activities	I	2	2	2	2	2	2	2	Establish administrative body for tourism development and activities management on local scale Developing tourism participative planning with other sectors
	Improving living conditions and livelihoods	J	0	0	0	0	0	0	0	Capital investment plan for the city development through; Political, technical, institutional, legal aspects of urban development
Promoting stakeholders, GOs sectors, NGOs entities' awareness	Promoting institutional capacity building in ICZM/sustainable planning, in order to strengthening effective coastal management	K	4	4	4	4	4	4	4	Adapting administrative structures to ICZM process Promoting ICZM capacity building to technicians working in administrative authorities and public agencies
	Promoting public education and awareness programs to create awareness by the valuable resources	L	3	3	3	3	3	3	3	Improving the involvement of local population in the decision-taking process Providing capacity building for collaborative and organizational development Increasing education on sustainable development

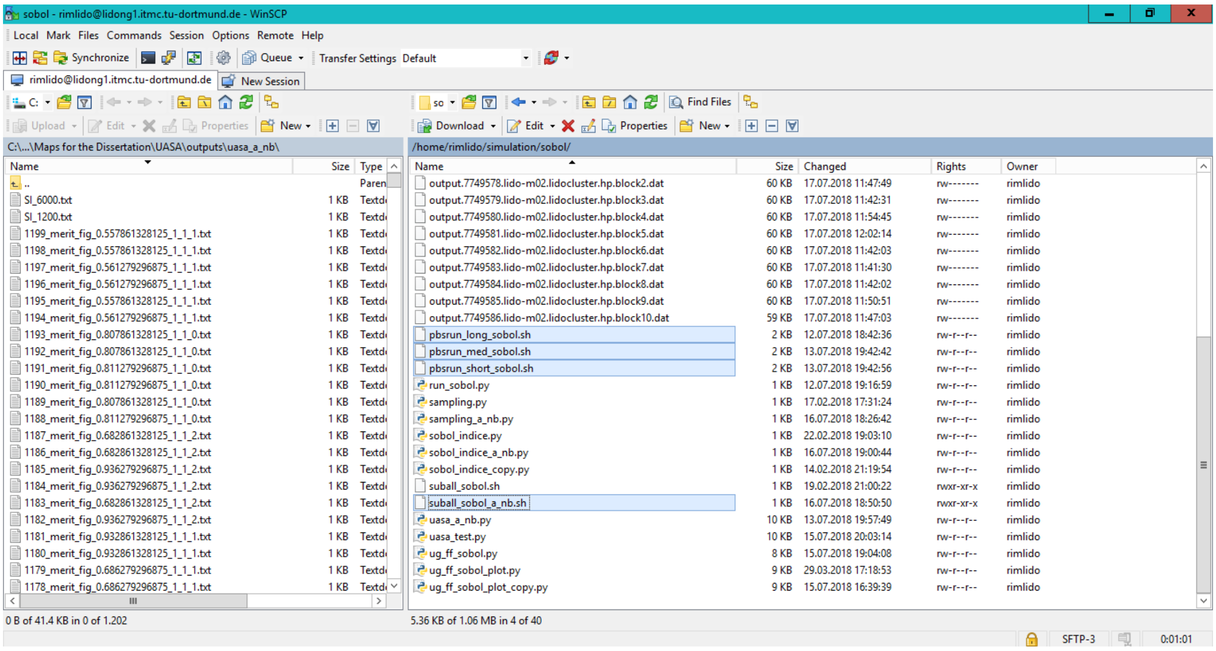


Figure 0-2: Window of the WinSCP used in transfere files from and to the HCP server

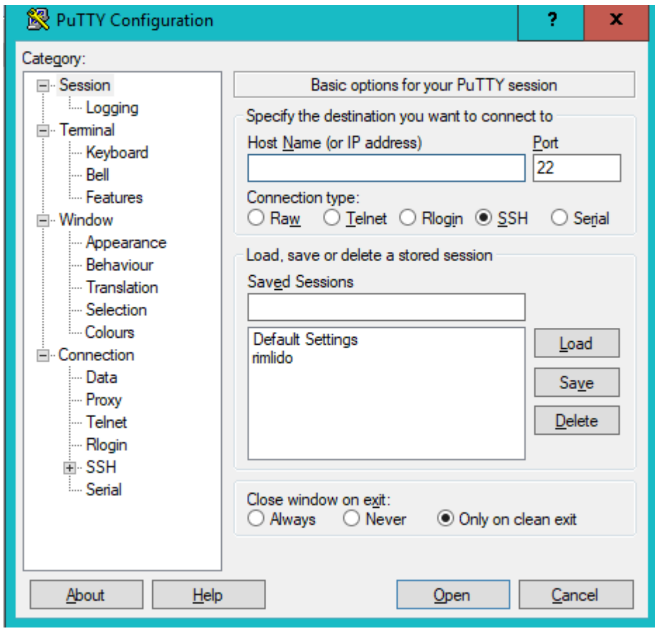


Figure 0-3: Window of PuTTY interface used as command line inetrface to interact with HPC server

```
rimlido@lido-gw01:~/simulation>qstat -u rimlido

lido-m02.lidocluster.hp:
                                                                          Req'd    Req'd       Elap
Job ID                  Username    Queue    Jobname          SessID  NDS   TSK    Memory   Time     S   Time
----------------------- ----------- -------- ---------------- ------ ----- ------ ------ --------- - ---------
6760355.lido-m02.lidoc  rimlido     long     MustafaJob        21020     1      1    --   24:00:00 R  01:53:30
6760357.lido-m02.lidoc  rimlido     long     MustafaJob        25979     1      1    --   24:00:00 R  01:53:30
6760359.lido-m02.lidoc  rimlido     long     MustafaJob        15706     1      1    --   24:00:00 R  01:53:30
6760361.lido-m02.lidoc  rimlido     long     MustafaJob        12619     1      1    --   24:00:00 R  01:53:30
6760363.lido-m02.lidoc  rimlido     long     MustafaJob        14201     1      1    --   24:00:00 R  01:53:29
6760365.lido-m02.lidoc  rimlido     long     MustafaJob         3230     1      1    --   24:00:00 R  01:53:29
6760367.lido-m02.lidoc  rimlido     long     MustafaJob        10794     1      1    --   24:00:00 R  01:53:29
6760369.lido-m02.lidoc  rimlido     long     MustafaJob        29507     1      1    --   24:00:00 R  01:53:29
6760371.lido-m02.lidoc  rimlido     long     MustafaJob         5207     1      1    --   24:00:00 R  01:53:29
6760373.lido-m02.lidoc  rimlido     long     MustafaJob         5743     1      1    --   24:00:00 R  01:53:29
6760377.lido-m02.lidoc  rimlido     long     MustafaJob        18639     1      1    --   24:00:00 R  01:53:28
6760379.lido-m02.lidoc  rimlido     long     MustafaJob        14902     1      1    --   24:00:00 R  01:53:28
6760381.lido-m02.lidoc  rimlido     long     MustafaJob        32048     1      1    --   24:00:00 R  01:53:28
6760383.lido-m02.lidoc  rimlido     long     MustafaJob         5556     1      1    --   24:00:00 R  01:53:28
6760385.lido-m02.lidoc  rimlido     long     MustafaJob        11301     1      1    --   24:00:00 R  01:53:28
6760387.lido-m02.lidoc  rimlido     long     MustafaJob        25235     1      1    --   24:00:00 R  01:53:26
6760389.lido-m02.lidoc  rimlido     long     MustafaJob         9723     1      1    --   24:00:00 R  01:53:26
6760391.lido-m02.lidoc  rimlido     long     MustafaJob        12003     1      1    --   24:00:00 R  01:53:26
6760393.lido-m02.lidoc  rimlido     long     MustafaJob        23811     1      1    --   24:00:00 R  01:53:26
6760395.lido-m02.lidoc  rimlido     long     MustafaJob         4502     1      1    --   24:00:00 R  01:53:25
6760399.lido-m02.lidoc  rimlido     long     MustafaJob        17163     1      1    --   24:00:00 R  01:53:25
6760401.lido-m02.lidoc  rimlido     long     MustafaJob         5089     1      1    --   24:00:00 R  01:53:25
6760403.lido-m02.lidoc  rimlido     long     MustafaJob        23571     1      1    --   24:00:00 R  01:53:25
6760405.lido-m02.lidoc  rimlido     long     MustafaJob         4732     1      1    --   24:00:00 R  01:53:25
6760407.lido-m02.lidoc  rimlido     long     MustafaJob        24859     1      1    --   24:00:00 R  01:53:24
6760409.lido-m02.lidoc  rimlido     long     MustafaJob         5572     1      1    --   24:00:00 R  01:53:24
6760411.lido-m02.lidoc  rimlido     long     MustafaJob         4135     1      1    --   24:00:00 R  01:53:24
6760413.lido-m02.lidoc  rimlido     long     MustafaJob        14186     1      1    --   24:00:00 R  01:53:24
6760415.lido-m02.lidoc  rimlido     long     MustafaJob        16085     1      1    --   24:00:00 R  01:53:24
6760417.lido-m02.lidoc  rimlido     long     MustafaJob         5541     1      1    --   24:00:00 R  01:53:24
6760421.lido-m02.lidoc  rimlido     long     MustafaJob         4619     1      1    --   24:00:00 R  01:53:23
6760423.lido-m02.lidoc  rimlido     long     MustafaJob         3532     1      1    --   24:00:00 R  01:53:23
6760425.lido-m02.lidoc  rimlido     long     MustafaJob        17431     1      1    --   24:00:00 R  01:53:23
6760427.lido-m02.lidoc  rimlido     long     MustafaJob        13592     1      1    --   24:00:00 R  01:53:23
6760429.lido-m02.lidoc  rimlido     long     MustafaJob         7232     1      1    --   24:00:00 R  01:53:23
6760431.lido-m02.lidoc  rimlido     long     MustafaJob        17444     1      1    --   24:00:00 R  01:53:21
6760433.lido-m02.lidoc  rimlido     long     MustafaJob        20901     1      1    --   24:00:00 R  01:53:21
6760435.lido-m02.lidoc  rimlido     long     MustafaJob        20086     1      1    --   24:00:00 R  01:53:21
6760437.lido-m02.lidoc  rimlido     long     MustafaJob        11430     1      1    --   24:00:00 R  01:53:21
6760439.lido-m02.lidoc  rimlido     long     MustafaJob         2253     1      1    --   24:00:00 R  01:53:21
6760443.lido-m02.lidoc  rimlido     long     MustafaJob        23495     1      1    --   24:00:00 R  01:53:20
6760445.lido-m02.lidoc  rimlido     long     MustafaJob        26216     1      1    --   24:00:00 R  01:53:20
6760447.lido-m02.lidoc  rimlido     long     MustafaJob         5910     1      1    --   24:00:00 R  01:53:20
6760449.lido-m02.lidoc  rimlido     long     MustafaJob          801     1      1    --   24:00:00 R  01:53:20
6760451.lido-m02.lidoc  rimlido     long     MustafaJob         8030     1      1    --   24:00:00 R  01:53:20
```

Figure 0-4: List of the submitted jobs on long queue node type through PuTTY to the rimlidong1 gateway.

Table 0-2: Figure of merit values resulted from calibration of the developed CA-based model

Number	**α**	**β**	**radius**	**neighborhood**	**A**	**B**	**D**	**Fig of merit**
1	0.1	0	1	0	22176	14496	18504	0.26272292
2	0.1	0.2	1	0	22180	14492	18508	0.26263139
3	0.1	0.1	1	0	22197	14475	18525	0.26224251
4	0	0.1	1	0	22180	14492	18624	0.26208044
5	0	0	1	0	22197	14475	18653	0.26163579
6	0.3	0.8	1	0	22238	14434	18566	0.26130562
7	0.2	0.2	1	0	22243	14429	18571	0.26119146
8	0.3	0.1	1	0	22248	14424	18576	0.26107732
9	0.1	0.6	1	0	22263	14409	18591	0.26073503
10	0.2	0.5	1	0	22268	14404	18596	0.26062097
11	0.1	0.3	1	0	22273	14399	18601	0.26050694
12	0	0.2	1	0	22258	14414	18673	0.26043906
13	0.3	0.5	1	1	22285	14387	18613	0.26023334
14	0	0.4	1	0	22267	14405	18698	0.26015893
15	0.2	0	1	0	22289	14383	18617	0.26014216
16	0.1	0.5	1	0	22292	14380	18620	0.26007379

17	0.3	0.1	1	2	22292	14380	18620	0.26007379
18	0.2	0.5	1	2	22302	14370	18630	0.25984594
19	0.2	1	1	0	22302	14370	18630	0.25984594
20	0.2	0.1	1	0	22303	14369	18631	0.25982316
21	0.2	0.8	1	0	22305	14367	18633	0.2597776
22	0.4	0.5	1	2	22308	14364	18636	0.25970926
23	0.2	0.9	1	0	22310	14362	18638	0.25966371
24	0.3	0.2	1	0	22310	14362	18638	0.25966371
25	0	0.3	1	0	22289	14383	18728	0.25962094
26	0.2	0.6	1	0	22313	14359	18641	0.25959539
27	0.2	0.6	1	2	22314	14358	18642	0.25957262
28	0.3	0.4	1	0	22316	14356	18644	0.25952708
29	0.2	0.1	1	1	22317	14355	18645	0.25950431
30	0.5	0.7	1	2	22318	14354	18646	0.25948154
- - - - - - -	- - -	- - - - -	- - - - - -	- - - - - - - - - - - -	- - - - - - - -	- - - - - - -	- - - - - - -	- - - - - - - - - - - -
6113	3	0.7	1	2	23909	12763	20237	0.22427033
6114	2.8	0.9	1	1	23910	12762	20238	0.22424881
6115	3	0.2	1	0	23911	12761	20239	0.2242273
6116	2.9	0.7	1	1	23915	12757	20243	0.22414126
6117	0	0.2	6	0	23916	12756	20244	0.22411976
6118	0.3	0	6	0	23936	12736	20264	0.22368976
6119	2.8	0.2	1	2	23936	12736	20264	0.22368976
6120	2.8	0.1	1	1	23938	12734	20266	0.22364677
6121	2.9	0.4	1	2	23939	12733	20267	0.22362528
6122	2.9	0.1	1	2	23940	12732	20268	0.22360379
6123	2.9	0.3	1	1	23940	12732	20268	0.22360379
6124	2.9	0	1	1	23945	12727	20273	0.22349636
6125	3	0.4	1	2	23945	12727	20273	0.22349636
6126	2.6	0.5	1	2	23960	12712	20288	0.22317416
6127	2.7	0.4	1	1	23972	12700	20300	0.22291652
6128	3	0.6	1	2	23980	12692	20308	0.22274482
6129	2.6	0.1	1	1	23984	12688	20312	0.22265899
6130	3	0.3	1	1	23986	12686	20314	0.22261608
6131	3	0.4	1	1	23986	12686	20314	0.22261608
6132	2.7	0.5	1	1	23990	12682	20318	0.22253027
6133	0.1	0.1	6	0	23999	12673	20327	0.22233723
6134	0	0.1	6	0	24013	12659	20341	0.22203708
6135	0.2	0	6	0	24019	12653	20347	0.22190849
6136	3	1	1	1	24022	12650	20350	0.2218442
6137	0.1	0	6	0	24052	12620	20380	0.22120171
6138	0	0	6	0	24083	12589	20420	0.22050375

EIDESSTATTLICHE VERSICHERUNG

Hiermit versichere ich an Eides statt, dass ich die vorliegende Dissertationsschrift zum Thema

“Urban growth monitoring, Simulation and management from Coastal cities management perspective using cellular automata, remote sensing and GIS: a case study of Alexandria governorate, Egypt”

selbstständig verfasst und keine anderen als die angegebenen Quellen benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus Quellen entnommen wurden, habe ich als solche gekennzeichnet.

Des Weiteren erkläre ich an Eides statt, dass diese Arbeit weder in gleicher noch in ähnlicher Fassung einer akademischen Prüfung vorgelegt wurde.

Dortmund, 24.07.2019 MUSTFA ELMORSHDY