Predict and Simulate Sustainable Urban Growth by Using GIS and MCE Based CA. Case of Famagusta in Northern Cyprus

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Abstract: The research study utilizes Multi Criteria Evaluation (MCE) method in geographic information systems (GIS) environment and uses MCE suitability maps with Cellular Automata (CA) for predicting and simulating sustainable urban development scenarios in Famagusta City. It represents first scenario-based simulations of the future growth of Famagusta as “do-nothing” and “sustainable”. Under the do-nothing scenario, Markov Chain probability analysis with CA models is used with temporal land-use/cover datasets based on the images from 2002 and 2011. It shows that, Famagusta City is moving away from sustainable development. Future expansion of both medium-density and low-density urban zones are always located around existing built-up urban area along transportation lines. A similar model is employed by applying sustainable urban development policies by the policy driven scenario. As a main goal, sustainable urban development includes three main criteria, compactness, environmental protection, and social equity. Additionally, brownfield development, distance from center, soil characteristics, soil productivity, vegetation, environmental protection areas (EPA), distance from local services, distance from open space are used as criteria with Analytical Hierarchy Process (AHP). Having such a simulation with the combination of MCE, GIS, and CA has several advantages. Prediction of urban growth presents possible alternative development in the future; visualization of decision making easier for town planners and supports the spatial planning process; and creates more realistic results of our choices related to urban growth.

Keywords: sustainable urban development; geographical information systems; multi criteria evaluation; cellular automata

1. Introduction

It is well known that, after the publication of “Our Common Future”, the concept of sustainability has become an important concern in development literature and has been tried to be applied in all fields of economic activities, in many countries [1]. As a result of the Agenda 21 and the Barbados Conference in 1994, there has been evidence that various policies, programs, and measures were developed for Small Island Developing States (SIDS), and they are trying to improve the integration of development policies with sustainability. Particularly Agenda 21 strongly emphasizes that SIDS are extremely fragile integrated special systems. Because of their small size, limited resources, and isolation from markets, future development needs to be focused on alternative and integrated planning options. This protects the environment in the long term and creates economic benefits for local communities simultaneously which is called sustainable development. Moreover, land is a limited resource and it should be used for providing sustainable future. Land use planning is a process which can ensure that by achieving efficiency [2].

Planning for sustainable use of land resources has as its basic purpose to ensure that each area of land will be used so as to provide maximum socio-economic benefits without degradation of the land resource. Sustainable land use development ensures the use of land resources in an organized manner so that the needs of the present and future
generations can be best addressed [3]. Therefore, it is necessary to develop integrated land use planning support tools or systems that can deal with land use suitability assessment, land use change analysis in a definite period, land use assessment, land use allocation, and overall sustainability assessment, which is emphasized by different researchers. The integrated land use planning process should be combined with European Spatial Development Perspective (ESDP). ESDP promotes spatially balanced and equal distribution of the land use features functions. Therefore, it is necessary to adopt spatial planning policies for achieving planning and management in urban environment. This step requires using spatial planning as the main strategy and supports it with land use planning policies. Geographical information systems-based planning support tools and urban growth modeling techniques have been widely used in recent years for dealing with the decision-making process and planning support to increase sustainable urban growth policies. Urban growth developments are connected with elements that represent various dimensions of artificial and natural environment. Due to several growth strategies, the urban zones have a chance to see environmental degradation which is not desired. According to sustainable city debates, recognizing effective factors could be a useful idea in terms of accessing the urban policies [4].

2. Literature Review

Urban growth modeling tools have emerged which are reliable for urban planners and experts in different fields. These models mainly focus on supporting the decision-making process towards a sustainable development of urban regions. Liu et al. introduced the “integrated GIS-based analysis system” (IGAS) model that addresses land use suitability, change, evaluation, and allocation assessment for lake areas [5]. Alshuwaikhat and Nassef (1996) developed a spatial decision support system (SDSS) for managing and planning land resources of City Beish, in Saudi Arabia. SDSS includes a model for land use suitability analysis and allocation. It shows an example of implementation of GIS techniques where a wide approach is required for land use management [6]. What-if as the combination of decision support systems (DSS), planning support systems (PSS) for sustainable development have been suggested by different researchers for supporting the decision-making process in planning field and sustainable development [7–9].

There are different urban growths modeling tools for prediction and the simulation process. Traditional statistical tools such as Markov Chain analysis, multiple regression analysis, principal component analysis, factor analysis, and logistic regression, have been very successful in interpreting socio-economic activities. Luo and Wei (2009) constructed a model that uses explanatory spatial and social variables for Nanjing between 1988 and 2000 [10]. Wu and Yeh (1997) used logistic regression for modeling land development patterns in Guangzhou [11]. Lopez et al. (2001) used a model for predicting land cover and land use change in Morelia City, Mexico [12].

SLEUTH (slope, land use, excluded area, urban area, transportation, and hillshade), which is developed by Prof. Dr. Keith C. Clarke, has been applied in many different case studies for predicts the actual growth and simulate scenario based future alternatives [13] (Silva and Clarke 2002). Feng and Liu (2009) use SLEUTH in Dongguan City for analyzing urban growth prediction and tests different scenario alternatives [14]. Rafiee et al. (2009) applied SLEUTH in the Mashad zone of Iran with three different scenarios, historical urban growth, environmentally-oriented, and urban sprawl, respectively [15].

Cellular Automata (CA) has been broadly utilized for modeling of urban growth and urban forms under future scenario alternatives [16–20].

CA is a “dynamic model that can be used to simulate the evolution of natural and human systems”. They were first developed in the 1940s and 1950s by Ulam and Von Neumann in the study of behavior of complex systems. CA shows a powerful simulation environment represented by a grid space of raster, in which a set of transition rules determine the attribute of each given cell, taking into account the attributes of cells within its vicinities. A large and increasing volume of work shows that CA is a proper tool for
modeling spatial dynamics. CA has been attractive for urban planners due to its spatial nature. Moreover, CA can develop complicated patterns with straight codes. Wu (1998) presented a prototype called SimLand for simulating land development and change by combining GIS-based CA with multi criteria evaluation (MCE)-based transition codes in Guangzho, China [17]. The simulation of land changes includes a complex decision-making process and distinctive spatial patterns could be revealed. Barredo et al. (2003) developed an application of an urban CA in the city of Dublin [21]. Zhang et al. (2011) used Markov Chain analysis within CA to present Shanghai’s urban growth. This model simulates landscape changes within three different scenario frameworks such as “baseline”, “service-oriented center”, and “manufacturing dominant center” [19]. Vaz et al. (2012) suggested combining urban development modeling with MCE for the Algarve in order to assist choosing the optimum development alternative for the case, keeping sustainability as input development policy [20]. Adhikari and Southworth (2012) reported that simulation forest cover changes for environmental management in a national park area [22]. Kityuttachai et al. (2013) compared actual and predicted land use changes for sustainable planning and development for the coastal zone in Thailand by using CA [23]. Oztürk (2015) coupled multi-layer perceptron with CA for urban growth simulation in Samson, Turkey [24]. Vaz and Arsanjani (2015) combined MCE and CA-Markov for integrating existing and planned strategies related to urban growth of the Greater Toronto Area [25]. Wang et al. (2020) used boosted regression trees for driving methods for calibrating suitability maps for predicting land use spatial patterns by using CA [26]. These methods and GIS-based applications show the extensive usage of geo-information technologies in various areas such as regional planning, urban planning, environmental management, etc. In conclusion, these systems have been fundamental instruments in developing quantitative prediction, modeling, and spatial analysis. Therefore, possible future growth simulation and analysis can safely be applied for supporting the sustainable urban development of Famagusta. CA models are convenient for discovering many principal theoretical issues in dynamics and evaluation. A GIS-based CA system should be developed to simulate the changes of urban structure for Famagusta in that manner. Operating a GIS environment makes experts’ works easier while monitoring, evaluating, analyzing, and detecting the spatial and temporal changes. The output of such integrated CA and GIS systems would be a land use and cover map with defined land use classes, such as urban, open land, forestry area, water resource, etc., that are possible to change within alternative scenarios. This output can assist experts or managers to simulate future growth and evaluate strategies or policies in the decision-making process. From this point, it is important to set up an application to construct sustainable urban growth policies for different land use types by using GIS and MCE. Moreover, these policies should be adopted into CA urban growth model to predict and simulate future development alternatives of Famagusta. These steps are explained for the case area within the following sections.

This research generally aims to suggest a model which predicts and simulates the urban growth of Famagusta using an integrated GIS, MCE, and CA model under two different development scenarios. It intends to focus on establishing a model and implementing it to one case study, Famagusta. The model for the case study is expected to be used for further studies in related fields. Additionally, it tries to search for the reasons behind the uncontrolled and unorganized land use development process in Famagusta, to develop a model based on planning support tools for the integrated land use planning approach and to assess land use suitability and land use change for creating future land use development alternatives by using planning support tools.

3. Famagusta City

Famagusta is located on the eastern coast of the island of Cyprus in the Eastern Mediterranean Sea (Figure 1). It has an area of 120 km² and a population of 40,920 [27]. Similar to other cities, Famagusta is also faced with a wide range of economic, social, and environmental issues and problems from a sustainable urban growth perspective. For
example, fragmented and incoherent growth continued the sprawling of urban development towards the urban periphery, with heavy traffic circulations and congestion on main arteries due to the linear commercial growth, etc. There is no doubt that rapid urban growth brought many problems to the built environment.

Figure 1. Location map of Famagusta City.

4. Model and Materials

The urban growth of Famagusta City is predicted for the current conditions and development trends, which is called the do-nothing scenario. Then, a similar model is employed by applying sustainable urban growth policies by the policy driven scenario (spatially integrated urban growth). Therefore, the model application starts with the prediction of urban growth and it is explained to present an unsustainable future of Famagusta City. In other words, it tries to present that Famagusta City is getting away from sustainable practices.

4.1. Prediction of Urban Growth under the Do-Nothing Scenario

Application of model for urban growth involves a primary understanding of how cities are built. In other words, it is required to understand which factors are the reasons for urban change. In this manner, the factors that are related to urban change should be defined by monitoring temporal land use datasets. This step is the beginning of the CA model application for the case study (Figure 2). Monitoring land use changes by time series satellite images requires development of these images within a GIS environment. Since Famagusta City growth has been changing since 1974, different land use datasets have been constructed by using 25,000 and 5000 scaled maps for years 1986 and 2002, 2007 land cover map, 2011 satellite images, etc. are used for the development of time series land use datasets. This process is detailed in the data development process section.
4.1.1. Data Development Process

The required data layer and spatial attributes were generated by creating digital layers or updating existing ones. These digital thematic maps were developed by employing the following commonly used procedures such as scanning the available primary paper maps, geo referencing the scanned maps to earth coordinates, on screen digitization of the primary maps, locating the GPS coordinates and entering in the database as latitude and longitude, conversion of the latitude and longitude data into the point data using the software, and editing existing layers. These are used in order to create digital layers and their databases (Table 1).
Table 1. Spatial criteria source and attributes of spatial data used in the case.

| Name.                              | Map (Data Formats)                                                                 | Source                      |
|------------------------------------|----------------------------------------------------------------------------------|-----------------------------|
| Road Network                       | Road Layer (Shapefile)                                                           | Famagusta Municipality       |
|                                    | 2011 Satellite Images Worldview − 2, 0.5 m resolution, pansharpened satellite image |                             |
| Urban Areas (Residential, Industrial, Tourism, etc.) | 1963–1972–1974 Urban Maps                                                        | Town Planning               |
|                                    | 1986–1997 5000 Scaled Maps                                                        |                             |
|                                    | Land Cover Map (2007) 4 m grid                                                   |                             |
|                                    | Landcover raster data develop from Ikonos (2007) 4 m resolution multi-spectral satellite image |                             |
|                                    | 2011 Satellite Images                                                            |                             |
|                                    | Land Use Survey (Field Survey)                                                    |                             |
| Surface Water Resources (Dams, Rivers, etc.) | 1/25,000 Hydrology Maps                                                           | Waterworks                  |
|                                    | Land Cover Map (2007)                                                            |                             |
| Ground Water Resources (Aquifers)  | 1/25,000 Geology Maps                                                             | Geology-Mining              |
|                                    | Land Cover Map (2007)                                                            |                             |
| Environmentally Sensitive Areas    | NATURA 2000 Sites Map (Shapefile)                                                | Environmental Protection    |
| Cultural Heritage Sites            | Excel Sheets with Latitude, Longitude Values                                     | Antiquities                 |
| Soil Classification (Primary Soil, Secondary Soil, etc.) | Soil Classes Map (Shapefile)                                                     | Agriculture                 |
| Vegetation (Forestry, Sandy Dunes, etc.) | Land Cover Map (2007)                                                           | TPD                         |
|                                    | 2011 Satellite Images                                                            |                             |
| Slope and Aspect                   | Digital Elevation Model 30 m resolution Digital Elevation Model                   | Mapping Office              |

All required geographical information from land use maps by 2002 and 2011 were transferred into a grid lattice. The 25 × 25 grid lattice was first developed as an ESRI shapefile format then table attributes columns for each different year were defined for 2002 and 2011. These columns were populated according to the land use classes (Figure 3).
4.1.2. Analyzing Land Use Changes with Temporal Images

Following grid development for the case area, cell attributes were updated accordingly for different land use types. Thirteen different land use and cover types; low dense urban, medium dense urban, university, industry, small industry, open land, forest/grass, bar ground, Mediterranean grass, water, wetland, open-Varosha, urban-Varosha were updated for 2002 and 2011 years (Figures 4 and 5). Then changes for each land use class were detected (Figure 6). Computer aided overlapping technique was used for analyzing changes and inputting table attribute values. As can be seen from Figure 6, between 2002 and 2011, there were so many changes open land to low dense urban class in the Tuzla region, open land to university, industry and open land to medium dense urban areas in the regions of Karakol, Sakarya, and Çanakkale. On the other hand, urban-Varosha class has limited growth or change. Due to the political deadlock on the Cyprus problem and also property issues, the Varosha region has not been invested in by governmental organizations since 1974. In other words, the urban-Varosha land use class has very limited growth. Therefore, the existing trend, which is not open for growth, is applied for the urban-Varosha land use class in the do-nothing scenario. In addition to land use changes, land cover changes were also analyzed. From 2002 to 2011, open areas have been subject to transform into low-dense, medium-dense, university, industry, and low industry classes.
Forest/grass and Mediterranean grass areas also transform to low dense, industry, and university (Figure 6). After development of land use change maps for 2002 and 2011, the Markov Chain tool is used for calculating transition probability between land use types.

Figure 4. The 2002 land use map.
Figure 5. The 2011 land use map.
4.1.3. Markov Chain Analysis with Land Use Maps

In general, the Markov Chain is a discrete random process with the Markov property whereby the probability distribution for the system at the next step and all future steps depends only on the current state of the system and not additionally on the state of the system at previous steps. When land use change is predicted by the Markov Chain, land
use is regarded as a stochastic process and different land use types (such as low dense urban university, industry) as the states of a chain; land use types at the next step are related to the current state and do not depend on land use at any previous step. Markov Chain analysis is a convenient tool for modeling land use change when changes in the landscape are difficult to describe, and it also serves as an indicator of the direction and magnitude of change in the future since it has capabilities of descriptive power and simple trend projection of land use change. A homogenous Markov Chain can be represented mathematically as follows [19] (Equations (1) and (2)):

\[
Q_{t+1} = Q_t P^n
\]

\[
\begin{pmatrix}
q_1 \\
q_2 \\
\vdots \\
q_m 
\end{pmatrix}_{t+1} = 
\begin{pmatrix}
q_1 \\
q_2 \\
\vdots \\
q_m 
\end{pmatrix}_t 
\begin{pmatrix}
p_{11} & p_{12} & \cdots & p_{1m} \\
p_{21} & p_{22} & \cdots & p_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
p_{m1} & p_{m2} & \cdots & p_{mm} 
\end{pmatrix}^n
\]

where:

- \(n\) = number of time steps;
- \(m\) = number of states;
- \(Q_t\) = vector of initial states at an initial time, \(t\);
- \(Q_{t+1}\) = vector of states at the next time, \(t + 1\);
- \(P\) = transition probabilities matrix.

The IDRISI Andes MARKOV module was used to generate the transition area matrix for target simulation periods, and Appendix A presents transition probabilities during 2002 and 2011 with starting year 2002 as one example of the results of Markov chain analysis. According to the transition probabilities, open land class has many possibilities to convert to low dense, medium dense, university, industry, and small industry. It has the highest probability values to convert, low dense, medium dense, university, and industry land use types. Additionally, Mediterranean grass has a higher probability to transform into low-dense urban class than forest/grass or bare ground.

4.1.4. Using MCE and AHP to Develop Suitability Maps

Generating adequate transition rules plays a key role in a CA model. In this study, the transition rules are expressed by a collection of suitability maps which take into consideration both the total suitability of each land use type and the neighborhood effect. The MCE [28] and AHP [29] methods were used to generate the group of suitability maps in scenario development.

MCE is based on the combination of several criteria to form a decision. Criteria can be classified as factors and constraints. A factor is a criterion that enhances the suitability of a specific alternative for the activity under consideration. A constraint limits the alternatives under consideration while it classifies the areas into two classes: unsuitable (value 0) or suitable (value 1). However, for continuous factors, a weighted linear combination (WLC) is a usual technique and was used in this study (Equation (3)):

\[
\text{Suitability } S = \sum_{j=1}^{n} W_j X_{ij}
\]

where:

- \(W_j\) = Relative importance weight of criteria \(j\);
- \(X_{ij}\) = the standardizing value of area \(i\) under criterion \(j\);
- \(n\) = is the number of criteria.

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

According to the land use maps 2002 and 2011, land use categories in Famagusta show tendency to prefer to allocate where a road development exists. In other words, they select an area which is close to an existing road network. Additionally, they also tend to get closer to similar land-use categories. Therefore, distance to road and distance to existing classes have been added as factors within the do-nothing scenario (Table 2).

**Table 2. Factors and exclusionary zones (constraints) for the do-nothing scenario.**

| Constraints                      | Low Dense | Medium Dense | University | Industry | Small Industry |
|----------------------------------|-----------|--------------|------------|----------|----------------|
| Existing Land use developments   | *         | *            | *          | *        | *              |
| Free Zone and Harbour            | *         | *            | *          | *        | *              |
| Military Zones                   | *         | *            | *          | *        | *              |
| The campus of EMU                | *         | *            | *          | *        | *              |
| Surface Waters                   | *         | *            | *          | *        | *              |
| Cultural Heritage Zones          | *         | *            | *          | *        | *              |
| Factors                          |           |              |            |          |                |
| Distance to roads                | *         | *            | *          | *        | *              |
| Distance to similar class        | *         | *            | *          | *        | *              |

*: Used constraints and factors.

After the decision of factors and constraints to each land use type, general constraint maps were developed and converted into byte format in order to use it in the modeling process. Establishing factor weights is one of the most complicated aspects of MCE, for which AHP is one of the most commonly used approaches. AHP was developed by Saaty (1980) and is based on the principle that decisions can be effectively made from a descending hierarchy from general criteria to sub-criteria, and at each particular level comparisons are made. In this study, distance to road factor is only used as factor criteria for suitability map development under the do-nothing scenario. The fuzzy transformation method is used for conversion distance values in 0–255 integer type raster map for cellular automata modeling in IDRISI. Fuzzy transformation rescales and normalizes the values in raster map (Figure 7).

Simple additive weighting method (SAW) was used to prepare a suitability map for land use types. This method is the most often used technique for spatial multi-criteria decision making. The technique is also referred to as weighted linear combination (WLC) or scoring method.

In this method, the decision maker directly assigns weights of “relative importance” to each attribute. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative on that attribute, and summing the criteria’ over all attributes. With a SAW, criteria sets are combined by applying a weight to each followed by a summation of the results in the suitability map.

Since there are many constraints within the case area, GIS-based constraint mapping was developed to eliminate unsuitable sites for each class and to narrow down the amount of the area for further analysis. Then constraint and factor criteria maps are combined for MCE suitability maps in IDRISI with the decision support tool (Figure 8). In general,
constraints elements given above, classified as 0, and possible areas for growth classified as 1. Distance to road fuzzy transformed map and constraints maps multiplied by using raster calculator. As can be seen from Figure 8, 0 value represents the limitations for any function to spread in the study area. Higher values have higher suitable zones for low-dense urban, medium urban, university, or industry functions for spreading.

Figure 7. Fuzzy transformation. (a) Distance to road map, (b) Distance to road fuzzy transformed map.

Figure 8. Combination of constraints and factors for suitability map for the do-nothing scenario.
These constraint suitability maps are then imported into CA for defining suitability matrices for each land use type. Additionally, these maps are combined with transition probabilities for cellular automata modeling in the IDRISI environment. Finally, modeling urban growth for 2011 with these MCE maps and comparing them with the actual 2011 land use map is needed for checking accuracy and reliability of the model. The following section explains the accuracy results.

4.1.5. Comparison for Accuracy

Checking the accuracy of the model is another important step for urban growth modeling. Visual comparison and computer aided overlay are used for the simulated land use map and actual land use map differences in an IDRISI environment. Visual comparison presents whether the modeled urban form fits with the actual urban form or not. Figure 9 presents that existing linear form with land use class locations formed accordingly for the case area.

![Figure 9. Visual comparison of simulated and actual land use for 2011. (a) Simulated land use 2011. (b) Actual land use 2011.](image)

It also gives a visual idea about the different land use types whether they fit each other in terms of form and shape. As can be seen from above, the EMU campus and industry zones almost look like the actual zones in the 2011 land use map. This can be seen in medium dense urban areas too. Moreover, the small industry zone has very similar shape with the actual land use in 2011. This shows that simulated 2011 land use for Famagusta has significant similarities with actual land use in 2011. In addition to visual comparisons, the geographical accuracy method is used for checking how much area or pixel for each class is matched between modeled and actual land use maps. The IDRISI macro modeller tool is used for each land use class with multiplying simulated land use type with actual land use types. Overlayed cells for each class compared with actual land use cells and accuracy ratios are given in Table 3.

After checking the accuracy ratios for the do-nothing scenario, possible land use development for 2020 was simulated in an IDRISI environment in order to obtain information about future development alternatives in Famagusta (see Figure 10).
Table 3. Simulation accuracy for the do-nothing scenario.

| LAND USE TYPES     | Existing 2011 CELLS | Simulated 2011 OVERLAYERED CELLS | Modeling Accuracy PERCENT |
|-------------------|---------------------|---------------------------------|---------------------------|
| LOW DENSE         | 2513                | 1605                            | 0.63867887                |
| MEDIUM HOUSING    | 8636                | 7943                            | 0.919754516               |
| UNIVERSITY        | 1436                | 1260                            | 0.877437326               |
| INDUSTRY          | 1205                | 941                             | 0.780912863               |
| SMALL_INDUSTRY    | 402                 | 388                             | 0.965174129               |
| TOTAL             | 14,192              | 12,137                          | 0.855200113               |

| LAND COVER TYPES  | OPEN 40,668         | OPEN 40,668                      | 1                         |
| FOREST            | 9186                | 9186                            | 1                         |
| BARE              | 1895                | 1895                            | 1                         |
| MEDI GRASS        | 13,882              | 13,882                          | 1                         |
| WATER             | 500                 | 500                             | 1                         |
| WETLAND           | 315                 | 315                             | 1                         |
| OPEN_VAROSHA      | 7555                | 7555                            | 1                         |
| URBAN_UVAROSHA    | 11,031              | 11,031                          | 1                         |

Figure 10. Simulated land use 2020 under the do-nothing scenario.
4.2. Simulate Sustainable Urban Growth for Famagusta City

In order to simulate Famagusta City for sustainable urban growth, the literature review for sustainable urban growth policies and then defining these policies with local experts is required. Moreover, these policies are converted into spatial criteria set and inputted into MCE-based cellular automata for sustainable urban growth modeling (Figure 11).

Sustainable urban growth policies were constructed from not only literature but also local experts’ interview as that is explained in the previous section. These are grouped into three mains and sub policies that can be converted into spatial criteria for a multi-criteria evaluation process [30–34] (Table 4). Each policy is transferred to spatial parameters for improving the land suitability degree within MCE-based urban growth modeling under the sustainability scenario. In other words, they are defined as site selection criteria for different land use classes.

Table 4. Summary of policy and criteria selection from literature review.

| GOAL                      | POLICY                           | SUB-POLICY                                      | SPATIAL CRITERIA               |
|---------------------------|----------------------------------|-------------------------------------------------|--------------------------------|
| Sustainable Urban         | Physical Compactness (Compact    | Re-use (re-develop) existing urban areas        | Brownfield Areas               |
| Urban Development         | Urban Form)                      | Increasing density of areas close to city center| Distance from city center      |
|                           | Environmental Protection         | Selecting suitable soil for urban development    | Soil Characteristics           |
|                           |                                   | Protection of Soil Productivity                 | Soil Productivity              |
|                           |                                   | Discourage growth in natural areas              | Vegetation                     |
|                           |                                   | Protection of Natural 2000 Sites                | Protection of Natural Areas    |
|                           | Social Equity                    | Ensuring equal accessibility of basic services   | Distance from local services   |
|                           |                                   | Ensuring equal accessibility to open spaces     | Distance from open spaces      |
4.2.1. Criteria Description

In the following section, the criteria (physical, environmental, or social) that are used for the sustainable urban growth scenario are explained.

Brownfield Areas

Brownfield development is necessary for regenerating urban space and reaching physical compactness within the urban environment. Therefore, possible areas for brownfield development were scanned and detected within Famagusta City. Free zone, small industry zone and some factories were detected that are suitable for regeneration projects and ranked according to their importance (Figure 12a,b). Due to the availability of empty spaces in the free zone, this area has higher weights.

![Figure 12. Cont.](image-url)
Figure 12. Cont.
Distance from CBD (City Center)

Distance from the city center is another criterion for reaching compact urban growth. For Famagusta City, there is no central business district. Therefore, the crossing point of the main commercial axes is assumed as the city center point. From that point, distance from the city center calculated and transformed into 0–255-byte map (Figure 12c,d).

Soil Characteristics

It is well known that soil characteristic is another critical factor for construction costs and it is suggested to select proper and suitable soil types for sustainable urban growth. Unsuitable site selection for housing function particularly in the Tuzla region is one of the main urban growth problems in Famagusta. From this point, different geological formations within the case area were researched and ranked accordingly. There are many different soil formations and these are given as follows (Table 5).

Table 5. Soil characteristics in Famagusta City.

| Formation | Classification       |
|-----------|----------------------|
| Q6ba      | Quaternary           |
| Q2a       | young quaternary     |
| Qmg       | early Pleistocene    |
| Q4b       | young quaternary     |
| Q6ak      | Quaternary           |
| Tmç       | young Pliocene       |
| Q4akk     | young quaternary     |
| Q5ab      | young quaternary     |

Q6ba, Q6ak, Q5ab, and Q4akk formations are not suitable for dense construction. They should be improved with different materials. On the other hand, Q2a and Qmg have stable ground characteristics. Q4b format has this feature if it is improved with cement. Additionally, Çamlıbel Marl does not have stable ground if hillsides or slopes are included. However, it has consolidated characteristics since it constitutes the main body of the region. Therefore, it does not have any disadvantage for building construction. From that point, the rank order for soil characteristics is given as Qmg, Q2a, Q4b, Tmç, and the others (Figure 12e,f).
Soil Productivity

Agricultural land classification should be understood for suitability analysis for different land use types. In general, land is classified into eight groups according to soil, slope, and other properties. The 1st and 2nd classes are reserved for agricultural activities with the 3rd, 4th, 5th, 6th, and 7th are suitable for dry agriculture and forestry. Therefore, areas within the 1st and 2nd classes were classified as exclusionary areas for any land use classes. According to the agricultural department, there is no complete soil productivity map for Famagusta City. Therefore, some parts of the case area are missing (Figure 12g,h).

Vegetation

From the natural protection perspective, it is important to protect the ecological uniqueness of the regional vegetation. Vegetation types related to agricultural activities and various types of forests should be excluded from evaluation to site selection for urban growth. Forest needle and forest eucalyptus were determined as exclusionary areas for evaluation. Grass, bare ground, irrigated agriculture, dry pasture, and grassland were selected in different zones for evaluation (Figure 12i,j).

Environmental Protection Areas

There are internationally recognized environmental areas in Famagusta City. Limni Forest Wetland and Gülseren Lagoon areas are listed as NATURA 2000 areas which are called wetlands. Therefore, these areas were added as constraints for evaluation. Areas within 500 m (Figure 12k,l).

Distance to Public Open Areas

Access to public open areas is essential in a sustainable community for the quality of life. Having these areas close to residents or housing environments reduces the need to travel. Public parks and open sport facilities are grouped under this criterion. Areas within 0–300 m and 300–1000 m and 1000 m+ zones were determined for the evaluation (Figure 12m,n).

Distance to Local Services

Like public open spaces, access to basic services is also essential in a sustainable community for the quality of life and the viability of the local economy. Having basic services close to residents also reduces the need to travel. Areas within 0–300 m and 300–1000 m and 1000 m+ zones were determined for the evaluation (Figure 12o,p).

4.2.2. Pairwise Comparison

Pairwise comparison matrices were formed by the interviews realized with various experts from different departments such as civil engineer, environmental engineer, town planner, architect geology engineer, etc. The experts are selected from different departments such as Town Planning, Geology and Mining, Famagusta Municipality, and Eastern Mediterranean University (EMU). They compare urban growth factors by deciding higher and less importance ones to each other. Within this process, consistency ratios (CR) were checked to verify the reliability of these experts’ choice (see Appendix B). According to Saaty (1980), CR should have a value of less than 10 percent. In this study, CR values have values lower than the 10 percent which indicate the consistency of the pairwise comparison (Table 6). After the development of the criteria sets, it is required to develop constraint map for urban growth simulation under the sustainable scenario. Therefore, general constraints for growth of the sustainable scenario were used and converted into byte format before the modeling process.
Table 6. Group weights of main criteria, criteria, and sub-criteria.

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

5. Results and Discussion

Under the do-nothing scenario, Figure 10 clearly shows that urban growth in Famagusta is diverging away from sustainability. It appears that the development in low dense areas is expanding away from local services along linear transportation routes in the Tuzla region. Industry areas are intensifying next to the industrial zone along the Nicosia-Famagusta main road and also divides Tuzla housing areas from university and medium dense areas. This situation does not support future accessibility to local services or open public spaces. Additionally, there are still unused spaces within the free zone region which is in opposition to the perspective of infill or brownfield development theories for sustainable urban growth. The do-nothing scenario simulation results are presenting similar problems which are explained by local experts in the previous section.

Under the sustainable urban growth scenario, urban growth in Famagusta is moving towards spatially more compact and denser within the center region which supports sustainable urban development policies (see Figure 13). Unlike the do-nothing scenario results, the free zone area and small industry zone developed with medium dense urban class according to the spatial criteria weights and transition area tables. This requires
Brownfield development activities for the selected areas. This also increases the accessibility of medium dense areas too to existing open spaces and local services. This will help to achieve social equity of sustainable urban development in Famagusta. In low dense urban areas, there is still the problem of accessibility to the city center, local services, and open spaces. The simulation presents that it is not very easy to change this tendency of urban sprawl and limit the low dense housing areas. In order to increase accessibility of these areas, Tuzla open spaces and local services should be planned and it is required to get land use suitability analysis for defining a new sub-center in the long-term period. University and industry zones were developed very similar to the do-nothing scenario results. Since these areas have been pre-defined by the central government, they were accepted as input from the planning perspective. Moreover, sustainability policies were mainly defined medium dense and low dense urban areas. Therefore, they showed similar spatial pattern for two different scenarios.

6. Conclusions

Land use suitability assessment, which is a crucial application in urban planning and land use management, provides a fundamental base for planning through the decision-making process. Many researchers and planners have created detailed applications for many case studies and explored different perspectives about land suitability assessment. In general, this study concentrates on using GIS and MCE to produce suitability maps as spatial factors of urban growth. Accordingly, it aims to construct sustainable urban
development goals and perspectives and convert them as spatial criteria choices. In this manner, land suitability assessment of Famagusta was utilized to reach sustainable urban development schemes by presenting within two different scenario-based future development alternatives, do-nothing and sustainable urban growth scenarios. Under do-nothing scenario, Markov Chain probability analysis with CA models is used with temporal land use datasets based on the images from 2002 and 2011. Additionally, general development trends converted into development factors and constraints to employ the suitability map for future development growth with MCE. Finally, the suitability map and Markov Chain probabilities combined with CA to have spatial growth simulation. The result shows that, Famagusta is moving away from sustainable development.

A similar model is employed by applying sustainable urban development policies by the policy driven scenario. As a main goal, sustainable urban development policies were separated into three main criteria, compactness, environmental protection, and social equity. Additionally, brownfield development, distance from center, soil characteristics, soil productivity, vegetation, environmentally protected areas, distance from local services, distance from open space were used as sub-criteria. Then, two different future development alternatives were obtained. Comparison of the two different scenario and their land use layouts present that Famagusta is moving away from sustainable spatial growth. Comparison of the two scenario-based spatial layout presents that compactness of the medium dense urban areas can be increased by using spatial sustainable growth policies; optimum usage of the available land can be achieved with sustainable spatial growth policy driven suitability analysis; small industry area should be renovated as medium-dense urban class to increase compactness; unused areas like free zone empty areas also should be used as to increase compactness. It is required to emphasize the advantages of the compact city too. Since the compact city is fundamental to spatial sustainable growth, the sustainable scenario shows convenient future development layout within this manner. This shows that an important spatial process can be achieved by the selection of the factors which are derived from the sustainable city concept and its key elements.

GIS and MCE-based CA model could be used as a spatial planning support tool for urban planners and decision makers in Famagusta. Such tool helps for testing administrative planning strategies or spatial goals, which influences the decision-making process in the planning process. This may help to understand spatial factors that affect development and consequently give a chance for assessing alternatives through sustainable urban development. Additionally, local experts and stakeholders can be benefited within this simulation environment by testing different spatial factors to improve sustainable spatial growth. Therefore, it should be noted that, spatial criteria may be changed according to the policy perspective or research concept. The GIS, MCE, and CA-based simulation study is the first application for Famagusta and these policies can be increased or decreased according to the data availability and participatory conditions for further studies. Finally, this study is a key to construct a common spatial factor set to reach sustainable spatial growth simulation which may not be found in the literature frequently. It also simulates scenario-based possible growth alternatives which present international policies and targets that are related to sustainable development goals in urban scale. Therefore, it has different implementation than the other examples in this field. Moreover, this pilot study uses factors derived from different disciplinary and shows unique suitability analysis for Famagusta. In this manner, it can be used for further research by planners, managers, etc.

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Appendix A

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

Appendix B

Table A1. Main Criteria Pairwise Comparison Matrix.

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

Consistency Ratio: 0.00.

Table A2. Physical Compactness Criteria Pairwise Comparison Matrix.

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

Consistency Ratio: 0.00.

Table A3. Environmental Protection Criteria Pairwise Comparison Matrix.

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

Consistency Ratio: 0.018.
Table A4. Social Equity Criteria Pairwise Comparison Matrix.

| Criteria                  | Distance from Local Services | Distance from Open Spaces | Weights |
|---------------------------|-----------------------------|---------------------------|---------|
| Distance from Local Services | 1                           | 1                         | 0.50    |
| Distance from Open Spaces  | 1                           | 1                         | 0.50    |

Consistency Ratio: 0.00.

Table A5. Brownfield Sub-Criteria Pairwise Comparison Matrix.

| Criteria                  | Free Zone | Small Industry Zone | Weights |
|---------------------------|-----------|---------------------|---------|
| Free Zone                 | 1         | 3                   | 0.75    |
| Small Industry Zone       | 1/3       | 1                   | 0.25    |

Consistency Ratio: 0.00.

Table A6. Distance to City Center Pairwise Comparison Matrix.

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

Consistency Ratio: 0.06.

Table A7. Soil Characteristics Pairwise Comparison Matrix.

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

Consistency Ratio: 0.029.

Table A8. Soil Productivity Pairwise Comparison Matrix.

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

Consistency Ratio: 0.0.

Table A9. Vegetation pairwise Comparison Matrix.

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

Consistency Ratio: 0.017.
Table A10. Distance to Natura200 Sites Pairwise Comparison Matrix.

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

Consistency Ratio: 0.0.

Table A11. Distance to Open Spaces Pairwise Comparison Matrix.

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

Consistency Ratio: 0.0.

Table A12. Distance to Local Services Pairwise Comparison Matrix.

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

Consistency Ratio: 0.0.

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