



Landscape sensitivity-based scenario analysis using flus model: a case of Asarsuyu watershed

Berfin Şenik¹ · H. Serdar Kaya²

Received: 2 March 2020 / Revised: 15 September 2021 / Accepted: 11 November 2021 / Published online: 2 December 2021
© International Consortium of Landscape and Ecological Engineering 2021

Abstract

The landscape is a dynamic and multidimensional concept which includes natural and/or cultural components, ecosystems, relations and processes. The sustainability of landscapes depends on the harmony of these ecosystems. Particularly, it is important to identify areas where the landscape is sensitive within the basin and to restrict urban growth in these areas. However, the land cover change that occurs in the form of transformation from natural areas to cultural areas undermines the operability of the processes within the landscape. In this study, two different scenarios regarding land cover change have been developed using the FLUS model for Asarsuyu Watershed between the years 2018–2036 and 2036–2054. With these scenarios, the areas where landscape is sensitive are revealed and the urban growth is restricted in areas where landscape sensitivity is very high and high. In this respect, landscape sensitivity studies provide an important tool for guiding urban growth in an ecological framework.

Keywords Land cover change · Water infiltration · Erosion risk · Habitat fragmentation · Markov chain model · Watershed protection

Introduction

Landscapes are dynamic entities for which change is inevitable (Manolaki et al. 2020). As the main factors that trigger the change in the landscape could be defined by geomorphological and ecological processes that include tectonic, erosion and climate (Bogaert et al. 2004; Thomas 2012; D’Arcy and Whittaker 2014), this change is also associated with cultural (anthropogenic) processes such as population growth, urbanization and urban growth (Manolaki et al. 2020). In particular, the intensification of agriculture and urbanization and land abandonment are two opposing processes with profound consequences on landscape structure and function (Farina 2000). Although transformations in the landscape due to urban growth are not new, they have accelerated in recent years (Cortina 2011) and human impact on the

landscape has increased significantly during the twentieth century (Bogaert et al. 2004). The impacts of this transformation have transcended urban boundaries and had a global impact (Bradley and Altizer 2007; Pickard et al. 2017). Land use/land cover significantly affects the dynamics as well as the structure and function of many landscapes (Wu and Hobbs 2002). These changes in landscapes are seen as evolution and they cause diversity, complexity and loss of identity which are characteristic of landscapes (Antrop 2005).

Population growth, urbanization and land use/land cover change (LUCC) have an impact on water resources (Houet et al. 2010; Liu et al. 2008a; Van de Voorde et al. 2011), land surface temperature (Le-Xiang et al. 2006; Whitford et al. 2001), runoff and biodiversity (Whitford et al. 2001), habitat or landscape fragmentation (Conway and Lathrop, 2005; Van de Voorde et al., 2011), carbon sequestration and storage (Zofío and Prieto 2001) and soil quality (Houet et al. 2010; Safaei et al. 2019). After all, the landscape is a set of systems. Therefore, each natural and cultural component that creates the landscape and the structures and processes created by these components are also subject to change due to LUCC. This makes landscapes sensitive to change. Every landscape is sensitive to a certain degree and the land should be used by taking this sensitivity into account (Usher 2001).

✉ Berfin Şenik
berfinsenik@duzce.edu.tr

¹ Faculty of Forestry Department of Landscape Architecture, Duzce University, 81620 Duzce, Turkey

² Faculty of Architecture Department of Urban and Regional Planning, Istanbul Technical University, 34367 İstanbul, Turkey

As LUCC changes the landscape more rapidly and often irreversibly, sensitive landscapes should be taken into account in decision-making processes. In other words, sensitive areas in landscapes with potential for change should be identified and land use decisions should be made in line with this.

While there are many definitions of landscape sensitivity (Manolaki et al. 2020), it is often a context-specific and flexible term (McGlade 2002; Manolaki et al. 2020). Landscape sensitivity is defined as a conditional instability in the system that has the potential to cause rapid and irreversible changes due to deterioration in environmental processes (Thomas 2001). According to Brunnsden and Thornes (1979: 476), “The sensitivity of a landscape to change is expressed as the likelihood that a given change in the controls of a system will produce a sensible, recognizable, and persistent response”. The study of landscape sensitivity is applied in the context of land use impacts on natural systems (Thomas and Allison 1993). The concept of landscape sensitivity developed by Brunnsden and Thornes (1979) includes geomorphological processes. However, physical systems (rocks, superficial deposits, landforms, soil) and biological systems (plants, animals, people) (Usher 2001), which constitute landscape sensitivity, are directly related to hydrological and biological processes besides geomorphological processes. In this context, water infiltration, erosion risk, habitat fragmentation, whose natural and cultural landscape components are evaluated together and have an impact on landscape character, could be considered as ecological process parameters and landscape sensitivity could be evaluated (Karadağ and Şenik 2019). Therefore, erosion risk, water infiltration, habitat fragmentation could provide directly landscape sensitivity.

On the other hand, basin-based studies are necessary for ensuring proper land use in a way that does not endanger the ecosystems in the watershed, protection of natural resources, and effective and sustainable use of natural resources (Pandey et al., 2011). It is especially important to evaluate landscape changes with LUCC studies carried out at the watershed level (Boongaling et al. 2018; Feng et al. 2011). The urbanization process especially affects infiltration and runoff in the hydrological cycle (Ogden et al. 2011). In undeveloped watersheds, most precipitation is infiltrated into the soil, whereas in urban watersheds, water flows rapidly due to impermeable surfaces (Sohn et al. 2020; Wright et al. 2021). At the same time, soil erosion is triggered by the effects of urban expansion, topography, soil characteristics and precipitation (Chen et al. 2021a; Sujatha & Sridhar 2018). This process, which changes the hydrological cycle, also causes the transformation of naturally vegetated soil surfaces (Wang et al. 2018). Gradually, a landscape sensitivity emerges within the dynamics of the watershed itself. The basins form a natural boundary and each basin feeds the

region ecologically and spatially with its water potential. Although a basin is an ecosystem consisting of soil, water, vegetation and people, each basin has its own unique biophysical conditions with its land use types, soil structure, topography, climate, geology and geomorphology. Some changes in these characteristics may be a driving factor for degradation in the watershed (Basri & Chandra 2021). At this point, landscape sensitivity studies enable the sustainable balance of protection-use in the watershed.

Although the relationship between LUCC and landscape sensitivity is critical, landscape sensitivity studies which are considered an important strategy for ecological land use planning/management are extremely rare. Many existing studies related to landscape sensitivity have focused on topics such as a change in the landscape in terms of component, spatial pattern, environmental conditions (Knox 2001; Miles et al. 2001; Usher 2001;), tourism development (Jennings 2004), floods (Safeeq et al. 2015), visual landscape sensitivity quality (Fang et al. 2021; Haara et al. 2017; Wang & Qu 2018), landscape pattern across temporal and spatial scales (Chi et al. 2019), erosion (Kieu et al. 2020), the combination of ecological sensitivity, cultural sensitivity and visual sensitivity (Manolaki et al. 2020). Hence there is a lack of studies that directly examine the relationship between landscape sensitivity and LUCC on the watershed scale.

The most important tool to manage landscape changes with an ecological process is to understand LUCC and evaluate them with different scenarios (Alberti 2005; Conway and Lathrop 2005; Dadashpoor et al. 2019; Houet et al. 2010; Lathrop et al. 2007; Zebisch et al. 2004). “Land cover is the observed physical cover of Earth’s surface” (Duhamel 2012 p.8), while “land use refers to the manner in which these biophysical assets are used by people” (Cihlar & Jansen 2001, p.275). Many models have been developed for LUCC such as UrbanSim (Waddell, 2002), LTM (Pijanowski et al. 2006), CLUE-S (Verburg et al. 2002) and SLEUTH (Dietzel and Clarke 2007). However, models such as LTM and CLUE-S estimate the probability of individual land-use types separately and give the land grid the highest value (Liu et al. 2017). LTM (Aburas et al. 2016) and UrbanSim (Patterson and Bierlaire 2010) also require complex operational steps. On the other hand, SLEUTH is constrained by certain factors that do not change and evolve the simulation process (Aburas et al. 2016). Among these models, FLUS includes solutions for the disadvantages of other models such as CLUE-S, ANN-CA and performs better than other models (in terms of overall accuracy and Kappa coefficient) (Liang et al. 2018b; Liu et al. 2017) and was used in many studies (Fu et al. 2018; Guo et al. 2021; Huang et al. 2018; Liang et al. 2018a, 2018b; Liu et al. 2017; Wang et al. 2019; Yan et al. 2018; Zhao et al., 2019). This model is also used for different purposes and study areas such as the flood risk assessment (Lin et al. 2020), Landscape Ecological Risk

Assessment (Xu et al. 2021) and Eco-Fragile Region (Feng et al. 2021).

Turkey ratified the European Landscape Convention on 20 October 2000. The aim of the Convention was defined as “to promote landscape protection, management and planning, and to organize European co-operation on landscape issues”. On the other hand, the technical work of “Water Framework Directive Implementation Project in Turkey” which started in January 2002 completed in November 2003 and “Basin Protection Action Plan” was prepared for 25 river basins in Turkey (Ministry of Agriculture and Forestry 2012). In this context, it is important to develop conservation awareness in line with the natural boundaries of the basins where water is collected by gravity and forms an ecological unit.

In this study, we claimed that landscape sensitivity analyses, which could be demonstrated by processes such as water infiltration, erosion risk and habitat fragmentation, could be an important driving factor when making ecological land-use decisions. This general hypothesis was examined by comparing the land cover change scenarios in the study area (Asarsuyu Watershed) over a 16-year period (2036–2054). In this direction, areas with high water infiltration, erosion risk and habitat function were determined as the most sensitive areas of the landscape. Areas with high landscape sensitivity were determined as restricted areas and included in the scenario studies (years 2036 and 2056). The scenarios are based on the land cover change in the Asarsuyu Watershed between the years 2000 and 2018. For the land cover change between 2000 and 2018, five driving factors were used, namely slope, elevation, proximity to rivers, proximity

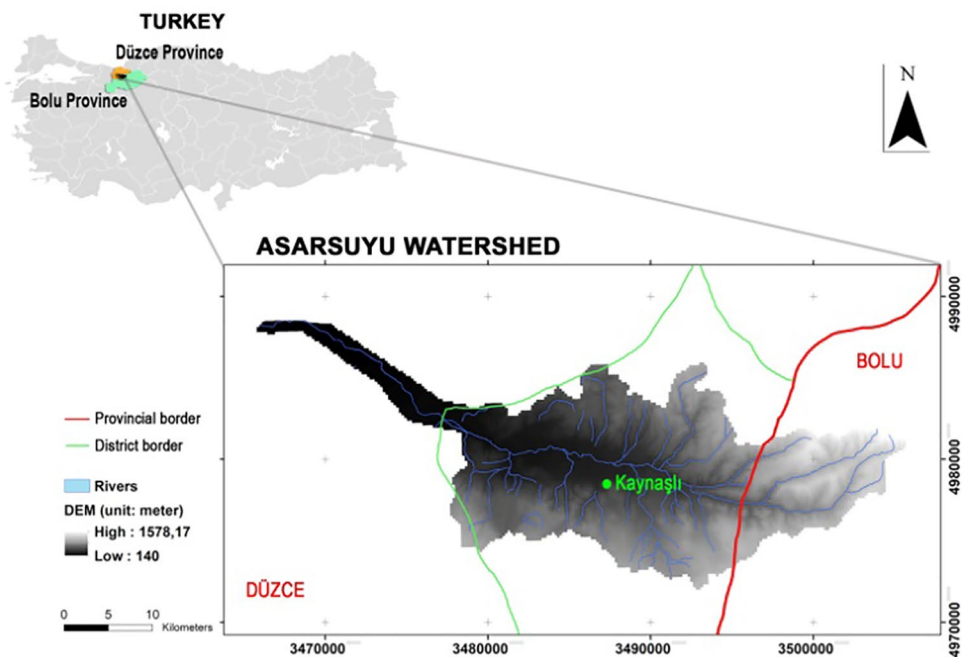
to roads and proximity to settlements. Subsequently, two scenarios were developed in the study. In the “Business as Usual” scenario, it is assumed that the land cover change trend in 2000–2018 will not change. In the second scenario to emphasize the importance of landscape sensitivity studies, areas where the landscape is sensitive, are identified and urban growth is restricted in these areas. Sensitive areas of the landscape were identified by water infiltration, erosion risk and habitat fragmentation analysis. The simulation process was realized with the FLUS model and land demand was determined using the Markov chain model. As a result, it is emphasized that watershed-based conservation awareness should be integrated into spatial planning studies and future urban growth should be limited in areas with landscape sensitivity.

Study area

Asarsuyu Watershed is located between Düzce and Bolu Province in Turkey (Fig. 1). The study area is located as a sub-basin of the Melen River Basin which is located in the Western Black Sea Basin, one of the 25 river basins of Turkey.

A large part of the study area (84.86%) consists of lime-free brown forest soil. The other 15.14% consists of, respectively, alluvial soil, brown forest soil and red-yellow podzolic soil. Its geological structure is composed of very consolidated calcareous rocks (32.55%), quaternary deposits (21.70%), less consolidated rocks (19.94%), very competent rocks (15.57%) and compact siliceous rocks (10.24%).

Fig. 1 The study area



According to the CORINE 2018 data, more than half of the study area consists of forests. More than half of these forests are covered with deciduous forests and the rest is mixed forests and coniferous forests, respectively.

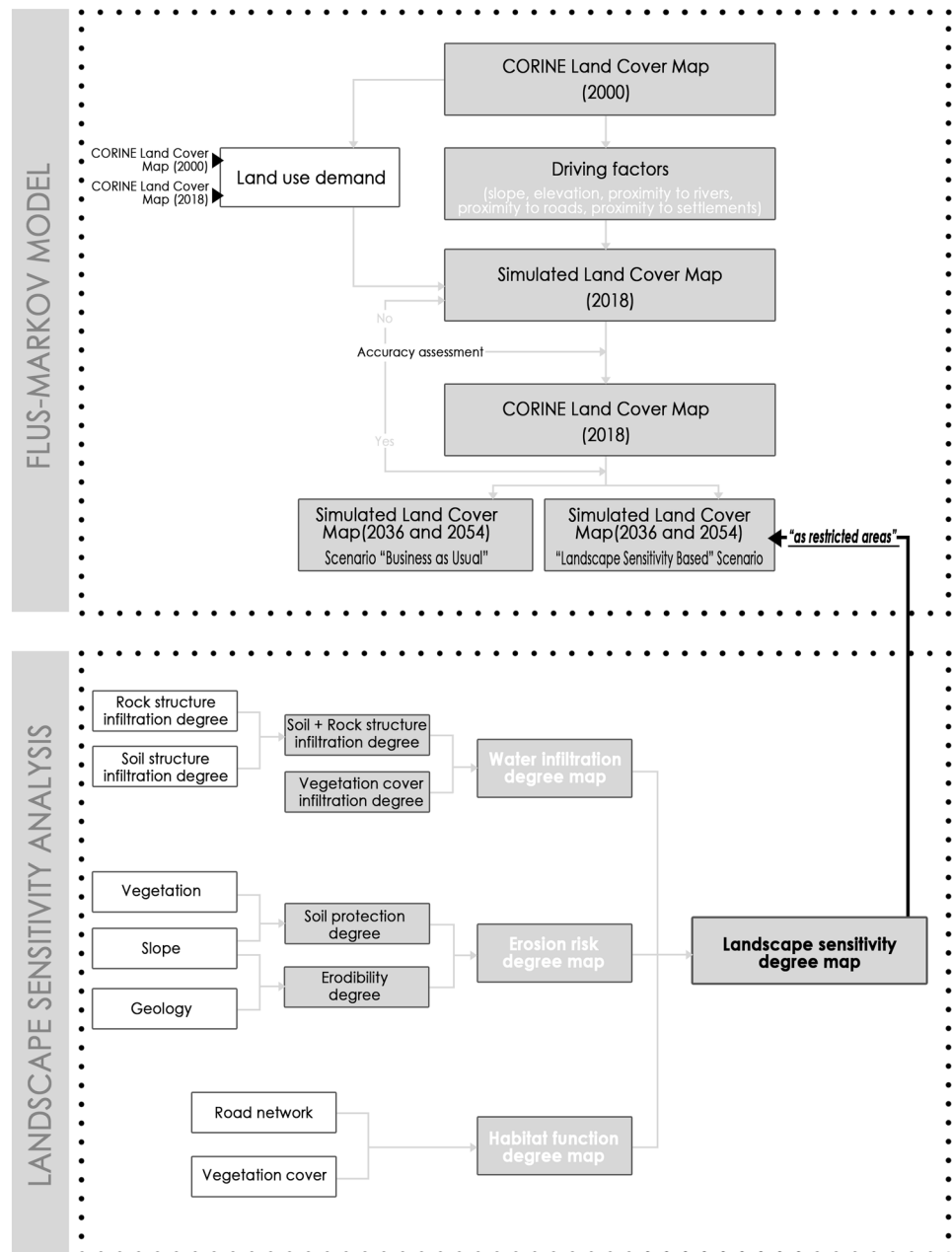
The study area is located in the first-degree seismic zone and the 12 November 1999 Düzce earthquake occurred on the North Anatolian Fault Zone like the 17 August 1999 Kocaeli earthquake. Düzce earthquake has caused heavy damage and loss of life in the district of Kaynaşlı, Düzce, and Bolu provinces (Utkucu et al. 2005). A serious urban growth process started to take place within the study area after the earthquake. This growth has developed around the D-100 and TEM (Trans-European Motorway) motorways

passing through the study area and causes pressure on ecosystems (forest ecosystems, river ecosystems) within the watershed boundary.

Method

The analyses within the scope of the study were evaluated in two contexts. These include landscape sensitivity analysis (water infiltration, erosion risk and habitat fragmentation) and scenario analysis based on the FLUS model and Markov chain model (Fig. 2). For the FLUS and Markov chain models, CORINE land cover data (2000 and 2018) were used to

Fig. 2 Flow chart of the method



determine land cover change (Kucsicsa et al. 2019). In addition, proximity to rivers, proximity to roads, proximity to the settlement, elevation and slope were used as the driving factors for the FLUS model. In addition, a landscape sensitivity map was used as restricted area data for the landscape sensitivity based urban growth scenario (Table 1).

FLUS model

The FLUS is a model which is carried out LUCC simulations and land-use scenarios under future natural and anthropogenic impacts (Chen et al. 2021b). Liu et al. (2017) developed the FLUS model. The model has been used successfully in many studies on LUCC simulation for several natural environments and socioeconomic driving forces (Zhao et al 2019; Yan et al 2018; Chen et al. 2021b; Feng et al. 2021; Guo et al. 2021; Xu et al. 2021). The FLUS is a model based on multiple cellular automata (CA) allocations, in which scenarios for land cover/land-use change are developed at a certain time. CA is widely used in the modeling of urban growth and simulation of complex systems (Mitsova et al. 2011; Liu et al. 2008b). In the model CA-based simulation is used in two stages. In the first stage, using artificial neural networks (ANN), the probability of occurrence of each type of land cover in a certain grid cell is determined. In other words, ANN provides to reveal the relationship between driving factors and land cover changes. In the second stage, elaborate self-adaptive inertia and competition mechanism are used to evaluate the interaction and competition between different land cover types (Liu et al., 2017). During CA iteration, the probability of allocating each type of land cover to cells is estimated, and the dominant type of land cover is allocated to the respective grid

cell. In the allocation process, either the existing land cover type does not change or changes to a different land cover type depending on combined probabilities and the roulette selection (to model the competition between urban land and nonurban land in each cell) (Liang et al., 2018b; Liu et al., 2017). Also the Markov chain is a stochastic model preferred for simulating randomly altering and continuous surfaces (Mansour et al., 2020). However, this model alone is not adequate to analyse LUCC, as it does not take into account the spatial distribution of each land type or the direction of urban growth. (Ghosh et al., 2017). For this reason, many hybrid models integrated with the Markov chain are used (da Cunha et al. 2021; Mishra et al. 2018; Okwuashi & Ndehedehe 2021; Rahnama 2020; Wang et al. 2021). At the same time, the land demand is estimated using the Markov Chain method (Aguejdad, 2021; Xie et al. 2020).

In this study, the FLUS model was used with landscape sensitivity analysis in the context of realization of landscape sensitivity-based land cover change in the study area and with the Markov chain model to the estimation of land demand for the years 2036 and 2054.

Model calibration and validation process: CORINE Land Cover database (available via the Copernicus Land Monitoring Service of the European Union) of 2000 and 2018 were used in the analysis process. In the study area, types of land cover (artificial surfaces, agricultural areas and forests) in the CORINE Land Cover database were adapted to Level 1 with a pixel size of 100 m × 100 m. There are many driving factors affecting land cover change. These could be socioeconomic (population, GDP, distance to town, etc.) and natural environment (elevation, slope, aspect, protected areas, etc.) (Zhao et al., 2019; Liu et al. 2017; Verburg et al. 2002). Positional driving factors

Table 1 The data used in this study. All raster datasets are transformed into the same resolution (100 m) and projection (ED_1950_UTM_Zone_36N) prior to model implementation

Data	Data year	Source	Data use
CORINE Land cover map (1/100.000)	2000, 2018	European Union Copernicus, https://land.copernicus.eu/pan-european/corine-land-cover	Model simulation
DEM (derived from topographic map (1/25.000))	2000	Ministry Of National Defense, General Directorate of Mapping	Landscape sensitivity analysis & Driving factor
River map (derived from topographic map (1/25.000))	2000	Ministry Of National Defense, General Directorate of Mapping	Driving factor
Forest management map (1/25.000)	2008	Ministry of Agriculture and Forestry	Landscape sensitivity analysis
Soil map (1/25.000)	2002	Ministry of Agriculture and Forestry	Landscape sensitivity analysis
Geology map (1/25.000)	1984	Ministry of Energy and Natural Resources, Mineral Research and Exploration General Directorate	Landscape sensitivity analysis
Hydrological soil group map (1/25.000)	2002	Produced from soil map	Landscape sensitivity analysis
Road map	2018	Open Street Map (https://www.openstreetmap.org/#map=10/40.9608/31.3380)	Driving factor
Settlements	2019	Google Earth (https://www.google.com.tr/intl/tr/earth/)	Driving factor

Fig. 3 Driving factors of land cover change

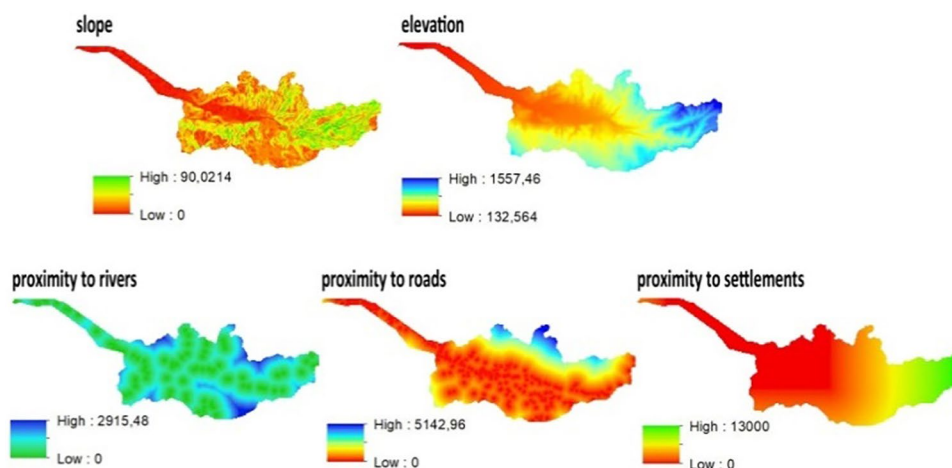


Table 2 Comparison of land cover change between 2000, 2018 (actual) and 2018 (predicted) in Asarsuyu Watershed

CORINE Land Cover	Actual area (km ²) in 2000	Actual area (%) in 2000	Actual area (km ²) in 2018	Actual area (%) in 2018	Predicted area (km ²) in 2018	Predicted area (%) in 2018
Artificial surfaces	12.42	9.11	13.46	9.87	13.55	9.94
Agricultural areas	38.20	28.02	40.95	30.03	40.92	30.02
Forests	85.71	62.87	81.94	60.09	81.85	60.04
Total	136.3	100.0	136.3	100.0	136.3	100.0



Fig. 4 Land cover change between 2000, 2018 (actual) and 2018 (predicted) in Asarsuyu Watershed

that direct land cover changes in the study area were evaluated according to previous studies and expert opinions. The driving factors used in the study were as follows: slope, elevation, proximity to rivers, proximity to roads and proximity to settlements (neighborhoods) (Fig. 3). These numeric variables were normalized to [0, 1] before the ANN-based probability of occurrence estimation in the FLUS model.

In the study, 5 neurons in the input layer due to the use of 5 driving factors, 12 neurons in the hidden layer and 3 neurons in the output layer (for each type of land cover; artificial areas, agricultural areas, forests) were used. Two percent of the total pixels including the Asarsuyu Watershed were uniformly selected as the training set. The 3 × 3 Moore neighborhood was selected in the simulation module when compared to Liu et al. 2017 study. The model calibration and

Table 3 Land use demand

	Artificial surfaces	Agricultural areas	Forests
Initial Pixel Number (2000)	1268	3813	8568
Future Pixel Number (2018)	1374	4087	8188

validation process are applied to the period from 2000–2018 (Table 2 and Fig. 4).

Calculating the land demand, 2000 and 2018 CORINE Land Cover database was used and the spatial change was calculated in ESRI ArcGIS 10.1 software in percent and km² (Table 3). Subsequently, in line with the expert opinions, the cost (conversion) matrix that best reflects the usual change

Table 4 Cost matrix

	Artificial surfaces	Agricultural areas	Forests
Artificial surfaces	1	0	0
Water bodies	0	0	0
Agricultural areas	1	1	0
Forests	1	1	1

Table 5 Weight of neighborhood

	Artificial surfaces	Agricultural areas	Forests
Weight of neighborhood	1	0.9	0.1

in the watershed was created (Table 4). With this matrix, the temporal dynamics of the simulations are determined and form possible and impossible conversion sequences between land-use types. If the conversion is allowed, the corresponding cell value is assigned to 1 (one), and if not allowed, 0 (zero) is assigned. The model uses a neighboring effect similar to traditional CA models. It is assumed that each land use type has different neighborhood effects. Neighborhood weights for individual land cover types in the study area are determined by expert opinions (Table 5).

For the accuracy assessment results, three accuracy indexes were calculated. According to results, the overall accuracy is 0.87, the Kappa coefficient is 0.80 and the Fom (Figure of Merit) is 9%. Overall accuracy is over 85% (Thomlinson et al. 1999), Kappa coefficient greater than 0.79 (Maingi et al. 2002) shows that the analysis has high accuracy. The Fom value is superior to the Kappa coefficient in the accuracy assessment of the change obtained by simulation (Pontius et al. 2008). Nevertheless, the Fom value of 9% is not highly accurate. Pontius et al. (2008) also reported Fom values of some studies (range from 1 to 59%) and some Fom values in the studies are below 9%. According to Estoque and Murayama (2012), the Fom value of the short-period simulation result is relatively lower than the long-period one and as the observed net change decreases, the Fom value decreases (Liu et al. 2017). In this context, the simulation period in this study is relatively short (2000–2018) and observed net change is 8.44%.

Scenario simulation: Many models for simulation of land-use change exist; however studies involving the combination of different models yield good results (Verburg and Overmars 2009; Castella et al. 2007). In this study, the Markov chain and FLUS model are used together for the simulation of land cover. Land demands were obtained by the Markov chain model. The Markov chain is a model, based on a stochastic process, used to predict future probabilities by taking advantage of changes

in the past and present (Muller and Middleton 1994) and it is successfully applied in many studies (Fu et al. 2018; Arsanjani et al. 2011). First, the change of land cover between 2000 and 2018 was analysed and the probability of occurrence data was obtained. Then the year 2018 was accepted as the initial year. Subsequently, the same land demands, cost matrix, and weight of neighborhood were used for both scenarios and the future situation of the land cover was estimated. This whole process was carried out using the FLUS model. FLUS model and Markov chain model were run with GeoSOS-FLUS software (<http://www.geosimulation.cn/FLUS.html>).

Two different scenarios have been developed within the scope of the study to show that landscape sensitivity studies are an important tool for ecologically sustainable land cover change, namely business as usual and landscape sensitivity-based urban growth. The content and scope of the scenarios are given below as follows:

- *Business as usual:* In this scenario, it is assumed that the previous urban growth trend (2000–2018) will not change. Therefore cost matrix and weight of neighborhood tables used in the model calibration and validation process are also used in business as usual scenario. The land demand in the periods of 2018–2036 and 2036–2054 could be calculated.
- *Landscape sensitivity based urban growth:* In this scenario, it is assumed that the previous urban growth trend (2000–2018) will not change. Therefore, cost matrix and weight of neighborhood tables used in the model calibration and validation process are also used in landscape sensitivity based urban growth scenario. However, in contrast to the previous scenario, in the “Self-adaptive inertia and competition mechanism CA” stage, the areas where landscape sensitivity is very high and high are determined as “restricted areas” (Fig. 5). Accordingly, “0” value is given to areas where landscape sensitivity is very high and high. Thus, the land cover in grid cells was prevented from turning into another land cover type. In areas where landscape sensitivity is medium, low and very low, “1” value is given. Here, the conversion of the land cover in the grid cells to another land cover type is not restricted and land cover change is allowed. Within the watershed boundaries, areas with high water infiltration, erosion risk and habitat function correspond to areas with high landscape sensitivity. The land demand in the periods of 2018–2036 and 2036–2054 could be calculated.

Landscape sensitivity analysis

The determination of landscape sensitivity was carried out in three following stages: water infiltration, erosion risk and habitat fragmentation.

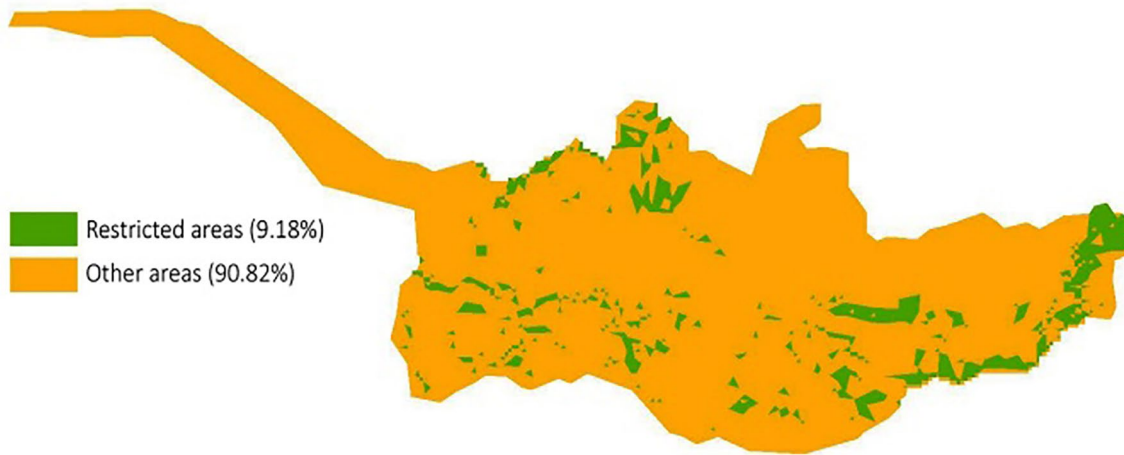


Fig. 5 Restricted areas of the study area

Water infiltration: Although water, the most fundamental natural resource, is renewable due to its cyclical nature, the hydrological cycle and water resources are highly heterogeneous in terms of time and space (Yang et al. 2021). The cycle, which is of critical importance for the continuity of physical and ecological processes, is being changed by human influence in many basins (also river basin landscape) around the world (Gulahmadov et al. 2021). The cyclic process of water is important for the functioning of vital activities in landscapes with a mosaic of ecosystems. Sustainability of the water cycle depends on considering landscapes as feeding and discharging areas of aquifers. Water infiltration is the main stage controlling the relationship between surface water and groundwater (Neris et al. 2012; Ward and Robinson 1989). On the other hand, soil properties (Basri & Chandra 2021; Neris et al. 2012; Cousin et al. 2003), vegetation cover (de Almeida et al. 2018; Mehta et al. 2008),

geological structure (Karadağ 2019; Cousin et al. 2003) play a very important role in this process. Also land cover significantly affects water infiltration (Carlesso et al. 2011). In this study, the method which is called water infiltration is used which is based on revealing the degrees of infiltration zones (Şahin et al. 2014; Uzun et al. 2012, 2015; Uzun and Gültekin 2011; Buuren 1994) (Fig. 6).

To obtain the infiltration zones theoretically, the rock permeability values have been revealed. Then, to determine the permeability values of soil structure, soil permeability map was prepared using the pre-made methods of soil structures and permeability levels (Şahin et al. 2014; Uzun et al. 2012, 2015;). Both maps were overlapped, and the infiltration zones map was obtained according to soil and rock structure. Infiltration values were added to this method, which was previously applied as soil and rock permeability according to vegetation cover, and total infiltration value

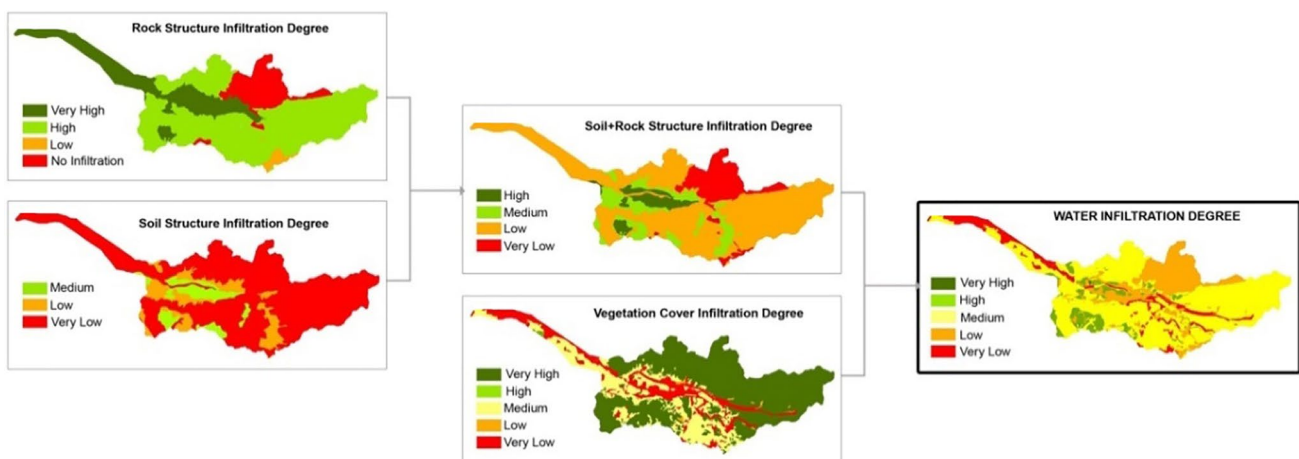


Fig. 6 The method of water infiltration analysis

was reached according to three variables. Permeability and infiltration values were evaluated according to expert opinions. Soil permeability values were obtained from soil map and rock permeability values were obtained from the geology map. The forest management map of 2008 was updated with the CORINE 2018 land cover map (for settlements and agricultural areas) and vegetation cover map was created. Water infiltration degree was used here (scale from 1 to 5) as follows: 0 for no infiltration, 1 for very low infiltration (very low sensitivity), 2 for low infiltration (low sensitivity), 3 for medium infiltration (medium sensitivity), 4 for high infiltration (high sensitivity), and 5 for very high infiltration (very high sensitivity). The analyses were performed using ESRI ArcGIS 10.1 software. According to the analysis results, 63.23% of the study area has medium water infiltration, 20.21% has low water infiltration, 9.44% has very low water infiltration, 7.0% has high water infiltration, and 0.12% has very-high water infiltration.

Erosion risk: Soil is a dynamic structure that has a relation/connection with all the components that make up the landscape both underground and aboveground. Therefore, a change that may take place here could lead to disruption of the processes that create the landscape. Erosion is the situation where the topsoil is moved from its location due to various factors. Erosion leads to deterioration of land and ecosystem functions (Jiu et al. 2019). Accordingly, erosion risk and landscape sensitivity are evaluated together in studies (Bou Kheir et al. 2006; Thomas 2001). The presence of vegetation cover (Carvalho et al. 2015; Bou Kheir et al. 2006), the land slope (Jiu et al. 2019), and geological structure (Sommer et al. 2008; Bou Kheir et al. 2006) are important factors that affect erosion. In this context, the method

developed in the determination of erosion risk in the study area (Uzun et al. 2015; Şahin and Kurum 2002; MAPA / ICONA, 1991; MOPU 1985; MAPA/ICONA, 1983) was used (Fig. 7).

In this analysis, first, vegetation map and slope map were overlapped and soil protection map was obtained. Second, The geology and slope maps were overlapped and an erodibility map was obtained. Finally, a potential erosion risk map was obtained by overlapping and evaluating both maps (soil protection and erodibility). The forest management map of 2008 was updated with the CORINE 2018 land cover map (for settlements and agricultural areas), and vegetation cover map was created. Geological data were obtained from the geology map, and the slope map was obtained from the DEM data produced from the topographic map. Soil protection and erodibility values were evaluated according to expert opinions. A scale between 1 and 5 was used to evaluate the degree of erosion risk as follows: very severe areas of erosion risk, 5 (very high sensitivity); severe areas 4 (high sensitivity); medium areas 3 (sensitivity medium); low areas 2 (low sensitivity), and very low areas 1 (very low sensitivity). Settlements were excluded from the evaluation and 0 (no value) points were given. The analyses were performed using ESRI ArcGIS 10.1 software. According to the analysis results, 30.90% of the study area has high, 23.56% has very low, 12.36% has medium, 11.27% has low, and 5.67% has very high erosion risk. The rest of the 16.24% were considered to have no erosion risk as they were located in settlements.

Habitat fragmentation: Large and small ecosystem parts that make up the landscape constitute the landscape mosaic as a whole and this mosaic consists of the following three

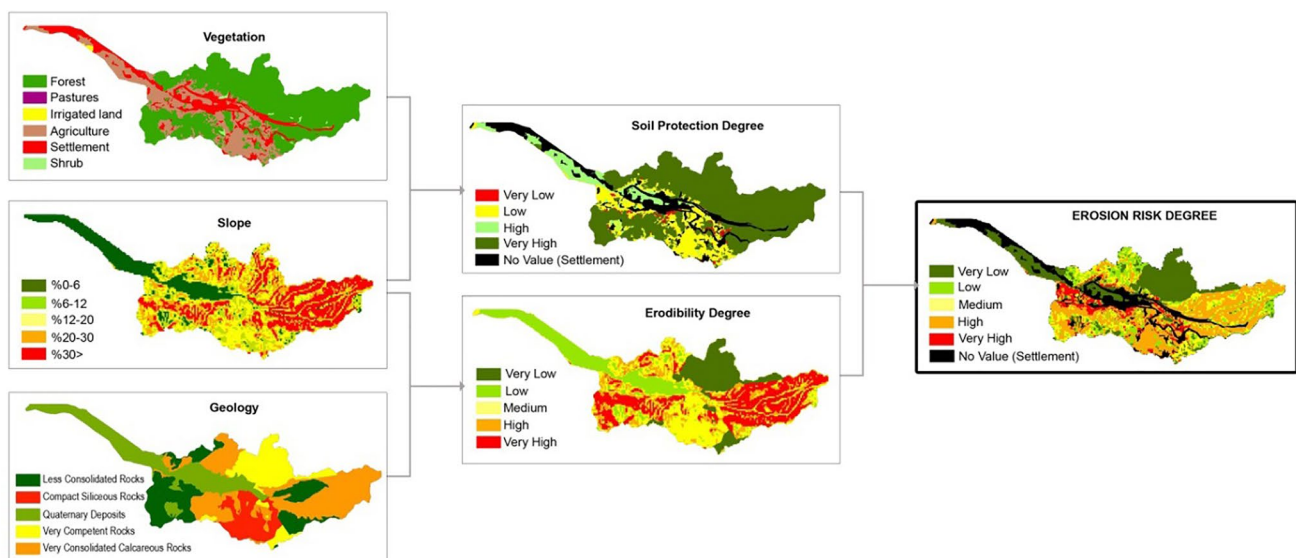


Fig. 7 The method of erosion risk analysis

main elements: landscape matrix, landscape patch and landscape corridors (Odum and Barret, 2005). While a landscape patch with natural elements constitutes a habitat for a species, landscape corridors (e.g. a river) that provide linkage between these landscape patches also ensure that different species coexist and thus support biodiversity. Urban ecosystems, however, are areas located in natural and/or semi-natural ecosystems and often have significant ecological impacts. The change in human activities and land cover is one of the most important anthropogenic effects that alter the number and shape of habitats (Bierwagen 2006; Syphard et al. 2005). Qualitative and quantitative changes that will disrupt the structural and functional continuity of habitats bring about fragmentation and “habitat fragmentation is a landscape-level process” (McGarigal and Cushman 2002). Therefore, defining and evaluating landscapes as a mosaic is particularly important in areas where cultural habitats resulting from centuries of human use have significant protection values (Bennet and Saunders, 2010). In this context, landscape sensitivity of habitats (forests, pastures, etc.) in human dominant areas also increases.

In this study, the fragmentation status of habitats formed by forests, glade, pasture, and shrub was determined. In this direction, 6 patch classes, including mixed forest, coniferous forest, broad-leaved forest, glade, pasture and shrub within the watershed boundaries, were created. The reason for this is the evaluation of patch classes in forest cover according to each other in terms of patch size and number, patch edge, patch shape, and core areas. At this stage, the forest management map of 2008 was updated with the CORINE 2018 land cover map (for settlements and agricultural areas), and vegetation cover map was created. Before the analysis, it was envisaged to include the impact of the road network on the habitat within the watershed boundaries. In this direction, a buffer zone is created around the road network in such a way that a 4-m effect zone is formed. The buffer zone map of the road network obtained in the next step was overlapped with

the vegetation cover map containing the habitats. This output map was adopted as the basic data for the analysis of habitat fragmentation. These data were then analysed at the class level with the Patch Analyst module, which was developed by Rempel (2010) as an interface to ESRI ArcGIS 10.1. Habitat function values were evaluated according to expert opinions. A scale between 1 and 5 was used to evaluate the degree of habitat function as follows: very high areas of habitat function, 5; high areas of habitat function, 4; medium areas of habitat function, 3; low areas of habitat function, 2, and very low areas of habitat function, 1 (Fig. 8).

In this context, the statistics obtained after patch analysis for patch size and number, patch edge, patch shape, and core areas (Table 6). Based on the statistical data in Table 2 and the criteria for determining the habitat function of Uzun, et al. (2015), a result map (habitat function map) was produced. Landscape ecology-based analyses are performed on the landscape, patch type (patch class) and patch scales. However, it was found appropriate to carry out a class-level analysis for the measurement of the habitat function of the landscape. Thus, the fragmentation status of each class has been revealed, and habitat function levels have been determined at the level of patch classes of the landscape.

According to the analysis results, 69.06% of the study area has low, 23.69% has high, 5.57% has medium, 0.93% has very low, and 0.75% has very high habitat function.

Results

At the stage of landscape sensitivity, three maps obtained as a result of water infiltration, erosion risk and habitat fragmentation analyses were overlapped and areas sensitive to the landscape were identified (Fig. 9). Similar to other analyses, a scale between 1 and 5 was used to evaluate the degree of landscape sensitivity as follows: very high areas of landscape sensitivity, 5; high areas of landscape sensitivity,

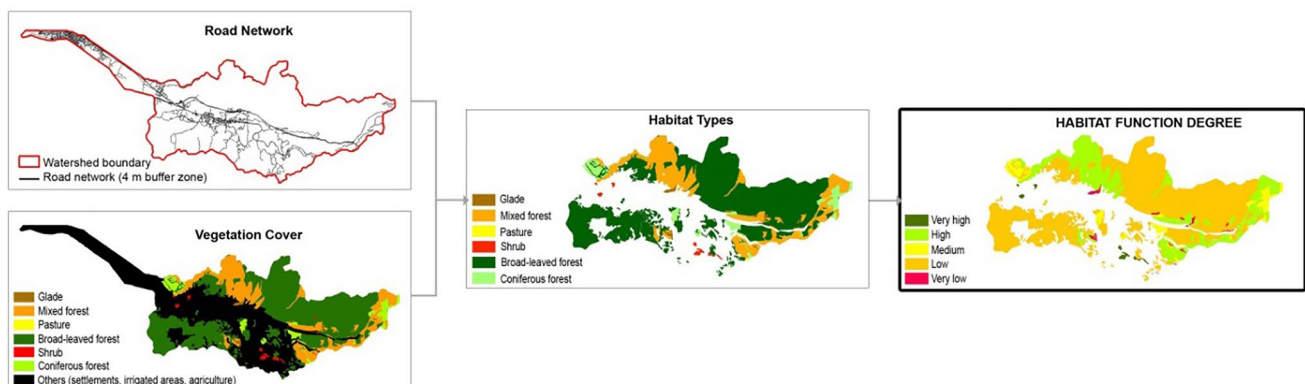


Fig. 8 The method of habitat fragmentation analysis

Table 6 Patch analysis results of the patch–corridor matrix model forest patches in Asarsuyu Watershed

Class	Shrub	Pasture	Glade	Coniferous forest	Mixed forest	Broad-leaved forest
AWMSI (area weighted mean shape index)	1.65	1.91	1.76	1.97	2.83	2.61
MSI (mean shape index)	1.46	2.23	1.96	1.86	1.96	1.81
MPAR (mean perimeter-area ratio)	178.53	1861.50	8780.65	1846.56	2696.21	3497.91
MPFD (mean patch fractal dimension)	1.28	1.52	1.44	1.45	1.43	1.46
AWMPFD (area weighted mean patch fractal dimension)	1.29	1.42	1.33	1.31	1.31	1.28
TE (total edge)	10,193.65	2108.73	19,914.10	86,256.45	175,508.80	268,311.90
ED (edge density)	1.21	0.25	2.37	10.26	20.88	31.92
MPE (mean patch edge)	1698.94	527.18	765.93	1181.60	2166.78	1850.43
MPS (mean patch size)	10.51	0.67	2.89	6.41	24.59	40.04
NumP (number of patches)	6.00	4.00	26.00	73.00	81.00	145.00
MedPS (median patch size)	7.66	0.57	1.13	1.47	1.90	0.98
PSCoV (patch size coefficient of variance)	63.54	82.85	152.87	188.94	430.57	709.52
PSSD (patch size standard deviation)	6.68	0.56	4.42	12.11	105.89	284.11
TLA (total landscape area)	8406.84	8406.84	8406.84	8406.84	8406.84	8406.84
CA (class area)	63.05	2.70	75.12	467.92	1992.00	5806.05
TCA (total core area)	4922.61	–	4922.61	4922.61	4922.61	4922.61
TCAI (total core area index)	6.85	–	2.88	19.54	50.96	73.85
CAD (core area density)	0.08	–	0.04	0.23	0.59	0.44

4; medium areas of landscape sensitivity, 3; low areas of landscape sensitivity, 2, and very low areas of landscape sensitivity, 1. The analyses were performed using ESRI ArcGIS 10.1 software.

The main difference between the two different scenarios in the study is whether or not it is based on landscape sensitivity. When the results of landscape sensitivity analysis in Asarsuyu Watershed are examined, 46.20% of the study area has medium, 26.43% has low, 17.70% has very low, 9.61% has high, and 0.07% has very high landscape sensitivity. Consequently, landscape sensitivity was determined to

be low/very low in areas where the settlement was located; the landscape sensitivity of the areas where mixed forests and Rhododendron density is high/very high. Areas, where landscape sensitivity is high and very high, are considered as restricted areas in the second scenario. According to the 2018 CORINE land cover data, 82.4% of the restricted areas are forests and 17.6% are agricultural areas. Artificial surfaces in the study area were excluded from the assessment of landscape sensitivity. Therefore, for the protection and sustainability of sensitive landscapes in the watershed, the conversion of forests to agricultural areas or artificial

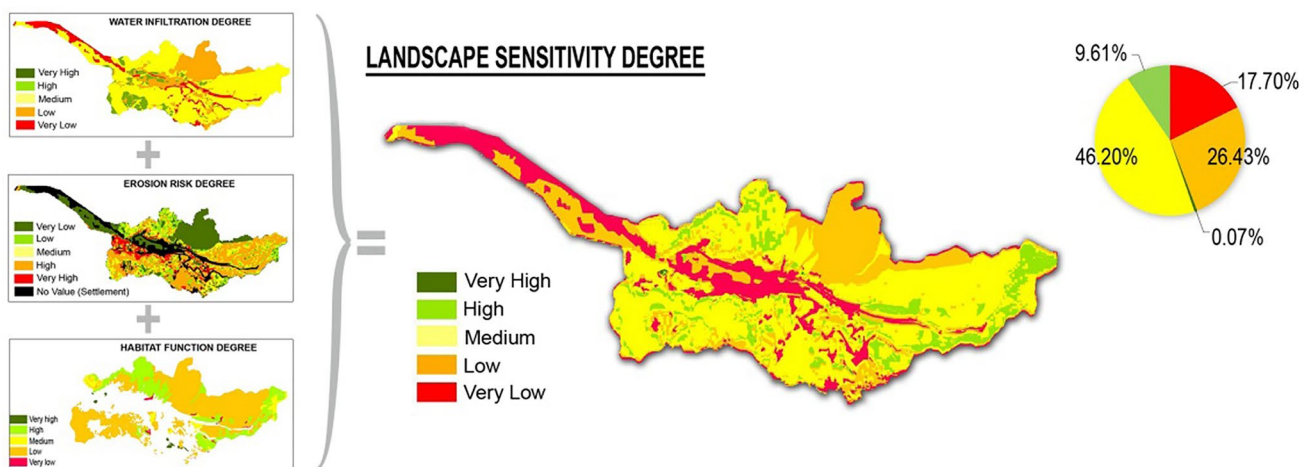


Fig. 9 The method of landscape sensitivity analysis

surfaces and the conversion of agricultural areas to artificial surfaces are restricted according to land cover change potential in the study area.

As the result of scenario analysis, the same cost matrix and land demand inputs are used; in both scenarios, an increase is observed in agricultural areas and artificial surfaces due to losses in forests for the years 2036 and 2054 (Table 7 and Fig. 10).

In the first scenario (business as usual), some losses in forests and agricultural areas were also realized in areas where landscape sensitivity is very high and high. On the other hand in the landscape sensitivity based urban growth scenario, losses in forests and agricultural areas have occurred in areas where landscape sensitivity is medium, low and very low. Thus, it is aimed to conserve the areas where landscape sensitivity is high and very high for 2018 and beyond. However, it should be noted that the increase in artificial surfaces during the period from 2000 to 2054 is of concern for watershed protection (Table 7).

Discussion

Landscapes conceptually emerge as a result of natural and anthropogenic interactions that convey a different character to the land (Atik et al. 2015). Accordingly, it does not

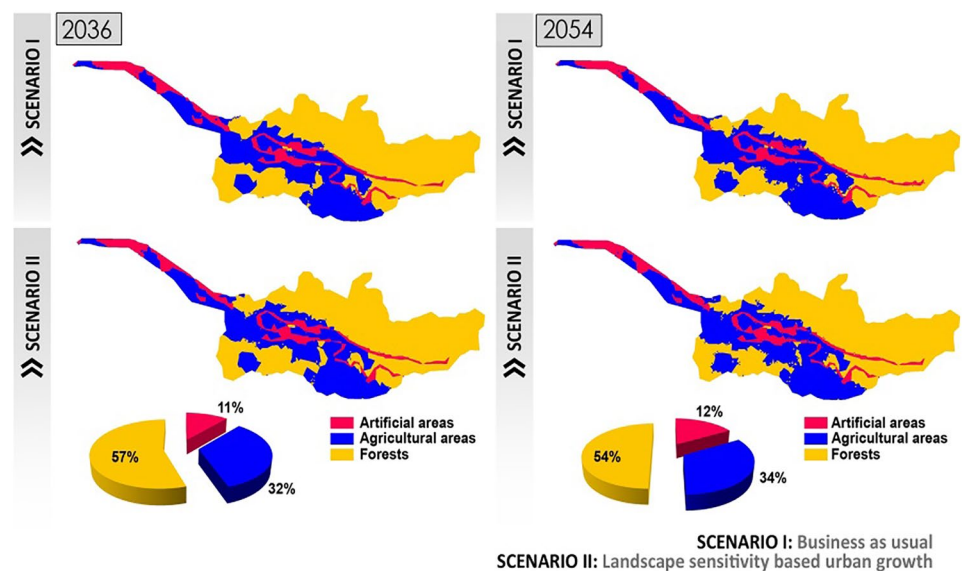
just contain objects; it involves different processes such as growth, decay, flow, and transformation. This combination of landscape forms complex spatial mosaics (Thomas 2001). According to Farina (2008); “the landscape could be considered a semiotic interface between resources, where organisms function as interpreters”. These processes, which are in close relationship with each other, may change due to human activities and some natural processes (disasters, etc.). Landscape, shaped by ecological and geomorphological processes (Swanson ve diğerleri 1988; Renwick 1992), also interacts with land cover change. Urbanization and the expansion of agricultural areas, increasing urban population leads to fragmentation/loss of natural landscapes and their transformation into impermeable surfaces, water supply problem and gradually decreasing biodiversity that supports ecosystem functioning (Das & Das 2019; Luo et al. 2020; Shao et al. 2021; Wu et al. 2021).

Aquatic ecosystems directly or indirectly support life (Higgins et al. 2021). Therefore, while the water conservation function regulates the water cycle with processes such as surface runoff, infiltration, and percolation on a spatial scale, it can reduce the effects of processes such as drought and floods on a temporal scale (Li et al. 2021). In this respect, Higgins et al. (2021) support watershed boundary-governed processes. Nevertheless, watersheds around rapidly urbanizing areas are highly sensitive to these changes due to their

Table 7 Percentages of change in land cover by years

Land Cover Type	% of area in 2000	% of area in 2018	% of area in 2036	% of area in 2054
Artificial surfaces	9.1	9.9	11.1	12.3
Agricultural areas	28.0	30.0	32.4	34.5
Forests	62.9	60.1	57.5	54.2
Total	100.0	100.0	100.0	100.0

Fig. 10 Land cover change simulation for the years 2036 and 2054



rich ecosystems (Zhu et al. 2021). Although a basin is an ecosystem consisting of soil, water, vegetation and people, each basin has its own unique biophysical conditions with its land use types, soil structure, topography, climate, geology and geomorphology. Some changes in these characteristics may be a driving factor for degradation in the watershed (Basri & Chandra 2021). For instance, in areas with water infiltration before urbanization and population movement in the basin, it is seen that surface flow discharge increases with LUCC (Ophiyandri et al. 2021). In this respect, the biggest threat to sustainable urban watershed management is the uncontrollable LUCC (Adegboyega 2021). Therefore, for the ecological protection of the watershed, decision makers need to consciously formulate and implement watershed protection policies (Adegboyega 2021; Zhu et al. 2021). Eventually, understanding these processes of the landscape in a watershed and revealing the effects of human activities on these processes is important in terms of turning the relationship between urban growth and landscape sensitivity in a positive way. Land cover undergoes a constant change as it is under the influence of natural and cultural processes. The determination of this change is very important for revealing the relationship between land cover dynamics and ecological processes (Koffi et al. 2008). According to Costanza et al. (1997), landscape alterations because of urban growth have a serious impact on the functions of ecosystems and regulate the benefits derived from processes (physical, biological, etc.) occurring in these natural systems. Especially in small-scale watersheds, land use change could affect ecosystems on a larger scale and subsequently lead to landscape change (Feng et al. 2011). Hence examining LUCC models and watershed-level processes is essential in land use and water resource planning and management (Lin et al. 2007).

Landscape sensitivity studies, on the other hand, focus on the natural and anthropogenic origins that affect the landscape and try to understand the processes that result in a change in the landscape community (Knox 2001). In other words, it makes inferences about “why, when, where, how often and how quickly” (Miles et al. 2001). Also, studies on landscape change generally focus on spatial pattern analysis, but draw less attention to the functions and processes of the landscape (Chen et al. 2009). Studies that comprehensively examine the spatio-temporal processes and causes of landscape changes, especially at the watershed level, are very important but rare (Zhu et al. 2021). In this sense, landscape sensitivity studies contribute to a holistic view of the impacts. It gives clues about how to follow a policy against this change. Landscape sensitivity studies at the basin/watershed level also allow the changes in the basin landscape to be handled with natural boundaries with the effect of urbanization.

Turkey, with 1.519 m³ per capita amount of water “water-stressed” is considered a country. Turkey Statistical

Institute, Turkey’s population is predicted to reach 100 million in 2030. In this case, the amount of water per capita is expected to be 1.120 m³/year. In other words, increasing the population, the booming economy and growing city with Turkey, “water-poor” is moving towards becoming. In addition, agriculture is the sector that uses the most water with a share of 73% (WWF 2014). Asarsuyu Watershed is a sub-basin of the Western Black Sea Basin, which is one of Turkey’s 25 river basins. Moreover, it is foreseen that rainfall will decrease when projections are analyzed in all basins in Turkey in the 2041–2070 and 2071–2099 period and 2–3 °C of warming will occur in the future period 2016–2040 in the Western Black Sea region (Turkish State Meteorological Service 2015). In this regard, the importance of integrated studies at basin (or watershed) level increases. This is possible by identifying sensitive ecosystems and directing urban growth to more suitable areas outside sensitive areas.

In this study, the FLUS model, which is prominent in recent years and landscape sensitivity analysis, which is an important tool for ecologically sustainable urban growth, has been put forward and their reasons explained. Determination of the watershed-based landscape sensitivity and simulating the land cover by a competent method (FLUS model and Markov Chain model) enabled to evaluate the possible changes in the study area in accordance with ecological principles and to data products that could be a base for spatial plans.

There are also some limitations in the study. Due to limited data possibilities, five different driving factors were used in the study. However, apart from these, there are driving factors that will affect the LUCC. In the context of driving forces, meteorological data (precipitation, temperature, etc.) can be considered in the context of bioclimatic comfort. In the context of socioeconomic factors, driving factors such as population density and gross domestic product (GDP) can be taken into account. These factors depend on the landscape characteristics of the study area. However, the driving factors mentioned in many studies are an important parameter (Feng et al. 2021; Guo et al. 2021; Xu et al. 2021). In addition, within the scope of the study, landscape sensitivity analyses were handled with the natural processes of the landscape in the context of water infiltration, erosion risk and habitat fragmentation. Different sensitivity studies such as visual sensitivity (Fang et al. 2021; Wang 2018), cultural sensitivity (Manolaki et al. 2020) can be evaluated together in future studies, as well as other different natural processes of the landscape (geomorphological and ecological process) methodically can be added to the frame. The characteristics of the study area are also decisive in this regard. In the selection of sensitivity parameters, the natural and cultural landscape characteristics of the study area and ecological formations present important bases (Karadağ and Şenik 2019).

The FLUS model is also a model based on ‘bottom-up’ cellular automata. Also, the Markov chain model is used as the ‘top-down’ model to estimate land demand (Liang et al. 2018a, b). Integration of ‘bottom-up’ and ‘top-down’ models prevent to separate between the macro land use demand projection and the local change allocation (Liu et al. 2017). Nevertheless, the Markov chain model provides appropriate data to create one urban growth scenario (Liang et al. 2018a, b). Therefore, different approaches should be preferred in multiple urban growth scenarios.

Conclusion

The landscape is exposed to change for many natural and cultural reasons and this change could reveal landscape sensitivity. In the study, considering the land cover change in the Asarsuyu Watershed in the years 2000–2018, simulation modeling was made with FLUS for the watershed, based on two different scenarios in 2036 and 2054. In one of the scenarios, “Business as usual”, it is assumed that the land cover development in 2000–2018 will continue. For the second scenario, the map obtained as a result of the landscape sensitivity analysis created an input as a “restricted area”. Thus, water infiltration, erosion risk, and habitat fragmentation analyses were conducted for the landscape sensitivity analysis within the watershed boundary and the resulting three maps were overlapped in the final stage and the areas where the landscape in the watershed was sensitive were determined.

The land cover change of the watershed between 2000 and 2018 was obtained by CORINE land cover data and the increase in artificial surfaces and agricultural areas and decrease in forests were observed. Since CORINE land cover provides data at a resolution of 100 m, water bodies cannot be included as land cover types. For this reason, three land cover types were analysed according to Level 1 (CORINE). It is also assumed for two scenarios (business as usual and landscape sensitivity based urban growth) that the trend of land cover change (2000–2018) will continue in the future. FLUS model and Markov Chain model have been used together due to successful results for land cover simulation in many studies (Chen et al. 2021b; Feng et al. 2021; Fu et al. 2018; Guo et al. 2021; Huang et al. 2018; Liang et al. 2018a, b; Xu et al. 2021; Zhao et al. 2019). In both scenarios, artificial surfaces and agricultural areas increased due to the decrease in forests. However, in the second scenario, the transformation of sensitive landscapes to artificial surfaces was restricted by using landscape sensitivity data. On the other hand, the increasing trend of artificial surfaces will significantly affect the amount of water in the watershed due to climatic changes in temperature and precipitation. Moreover, agricultural activities are carried out intensively

in the watershed and there is an increase in agricultural areas between 2018 and 2054. In this context, land-use decisions are a water use decision that also affects the sectoral distribution of water. Therefore, landscape sensitivity studies at the basin level contribute to the protection, development, and sustainability of the ecosystem characteristics of areas where water infiltration is high and aquifers feed, areas with high erosion risk, areas with high habitat function and degradation are low. In addition, it plays an important role in ecological decisions in land cover simulation studies. Consequently, the evaluation of landscape sensitivity analyses as a driving factor in ecological-based spatial/land use planning studies is a critical tool for the protection, development and maintenance of existing landscapes.

References

- Aburas, M. M., Ho, Y. M., Ramli, M. F., & 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, 52: 380–389.
- Adegboyega, S. A. A. (2021). Multi-temporal land use/land cover change detection and urban watershed degradation in Olorunda Local Government Area, Osun State, Nigeria. Applied Geomatics, 1–18.
- Alberti M (2005) The Effects of Urban Patterns on Ecosystem Function. *Int Reg Sci Rev* 28(2):168–192. <https://doi.org/10.1177/0160017605275160>
- de Almeida, W. S., Panachuki, E., de Oliveira, P. T. S., da Silva Menezes, R., Sobrinho, T. A., de Carvalho, D. F. (2018): Effect of soil tillage and vegetal cover on soil water infiltration. -Soil and Tillage Research, 175: 130–138.
- Antrop M (2005) From holistic landscape synthesis to transdisciplinary. *Landscape Res Landscape Planning: Aspects Integration Edu Appl* 12:27
- Arsanjani, J. J., Kainz, W., Mousivand, A. J. (2011): Tracking dynamic land-use change using spatially explicit Markov Chain based on cellular automata: the case of Tehran. -International Journal of Image & Data Fusion, 2(4): 329–345.
- Atik M, Işikli RC, Ortaçesme V, Yildirim E (2015) Definition of landscape character areas and types in Side region, Antalya-Turkey with regard to land use planning. *Land Use Policy* 44:90–100
- Basri, H., & Chandra, S. Y. (2021, February). Assessment of infiltration rate in the Lawe Menggamat Sub-Watershed, Aceh Province, Indonesia. In IOP Conference Series: Earth and Environmental Science (Vol. 667, No. 1, p. 012069). IOP Publishing.
- Bennett, A. F., & Saunders, D. A. (2010): Habitat fragmentation and landscape change. -Conservation biology for all, 93: 1544–1550.
- Bierwagen, B. G. (2006): Connectivity in urbanizing landscapes: The importance of habitat configuration, urban area size, and dispersal. -Urban Ecosystems, 10(1): 29–42.
- Bogaert J, Ceulemans R, Salvador-Van Eysenrode D (2004) Decision tree algorithm for detection of spatial processes in landscape transformation. *Environ Manage* 33(1):62–73
- Boongaling CGK, Faustino-Eslava DV, Lansigan FP (2018) Modeling land use change impacts on hydrology and the use of landscape metrics as tools for watershed management: The case of an ungauged catchment in the Philippines. *Land Use Policy* 72:116–128

- Bou Kheir, R., Cerdan, O., Abdallah, C. (2006): Regional soil erosion risk mapping in Lebanon. -*Geomorphology*, 82(3–4): 347–359.
- Bradley, C. A., Altizer, S. (2007): Urbanization and the ecology of wildlife diseases. -*Trends in Ecology & Evolution*, 22(2): 95–102.
- Brunsdon, D., Thornes, J. B. (1979): Landscape sensitivity and change. -*Transactions of the Institute of British Geographers*, 4(4): 463–484.
- Buuren, M. V. (1994): The Hydrological Landscape Structure as a Basis for Network Formulation; A Case Study for The Regge Catchment-NL, In: E.A. Cook and H.N. van Lier (Eds), -*Landscape Planning and Ecological Networks*, 117–137, Elsevier, Amsterdam.
- Carlesso, R., Spohr, R. B., Eltz, F. L. F., Flores, C. H. (2011): Runoff estimation in southern Brazil based on Smith's modified model and the Curve Number method. -*Agricultural Water Management*, 98(6): 1020–1026.
- Carvalho, D. F. D., Eduardo, E. N., Almeida, W. S. D., Santos, L. A., Alves Sobrinho, T. (2015): Water erosion and soil water infiltration in different stages of corn development and tillage systems. -*Revista Brasileira de Engenharia Agrícola e Ambiental*, 19(11): 1072–1078.
- Castella, J. C., Kam, S. P., Quang, D. D., Verburg, P. H., Hoanh, C. T. (2007): Combining top-down and bottom-up modelling approaches of land use/cover change to support public policies: Application to sustainable management of natural resources in northern Vietnam. -*Land use policy*, 24(3): 531–545.
- Chen L, Tian H, Fu B, Zhao X (2009) Development of a new index for integrating landscape patterns with ecological processes at watershed scale. *Chin Geogra Sci* 19(1):37–45
- Chen Z, Huang M, Zhu D, Altan O (2021b) Integrating remote sensing and a markov-FLUS model to simulate future land use changes in hokkaido. *Japan Remote Sensing* 13(13):2621
- Chen, S., Liu, W., Bai, Y., Luo, X., Li, H., & Zha, X. (2021a). Evaluation of watershed soil erosion hazard using combination weight and GIS: a case study from eroded soil in Southern China. *Natural Hazards*, 1–26.
- Chi Y, Zhang Z, Gao J, Xie Z, Zhao M, Wang E (2019) Evaluating landscape ecological sensitivity of an estuarine island based on landscape pattern across temporal and spatial scales. *Ecol Ind* 101:221–237
- Cihlar J, Jansen LJ (2001) From land cover to land use: a methodology for efficient land use mapping over large areas. *Prof Geogr* 53(2):275–289
- Conway T. M., Lathrop R. G. (2005): Alternative land use regulations and environmental impacts: assessing future land use in an urbanizing watershed. -*Landscape and Urban Planning*, (71): 1–15.
- Cortina A (2011) Landscape ethics: a moral commitment to responsible regional management. *Ramon Llull J Appl Ethics* 2(2):163
- Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M. (1997): The value of the world's ecosystem services and natural capital. -*Nature* 387: 253–260.
- Cousin, I., Nicoulaud, B., Coutadeur, C. (2003): Influence of rock fragments on the water retention and water percolation in a calcareous soil. -*Catena*, 53(2): 97–114.
- da Cunha, E. R., Santos, C. A. G., da Silva, R. M., Bacani, V. M., & Pott, A. (2021). Future scenarios based on a CA-Markov land use and land cover simulation model for a tropical humid basin in the Cerrado/Atlantic forest ecotone of Brazil. *Land Use Policy*, 101, 105141.
- D'Arcy M, Whittaker AC (2014) Geomorphic constraints on landscape sensitivity to climate in tectonically active areas. *Geomorphology* 204:366–438
- Dadashpoor H, Azizi P, Moghadasi M (2019) Land use change, urbanization, and change in landscape pattern in a metropolitan area. *Sci Total Environ* 655:707–719
- Das M, Das A (2019) Dynamics of Urbanization and its impact on Urban Ecosystem Services (UESs): A study of a medium size town of West Bengal. *Eastern India J Urban Manag* 8(3):420–434
- Dietzel, C., Clarke, K. C. (2007): Toward optimal calibration of the SLEUTH land use change model. -*Transactions in GIS*, 11: 29–45.
- Duhamel, C. (2012). Land use, Land cover, including their classification. *Encyclopedia of life support system*.
- ESRI (2012): ArcGIS Desktop: Release 10.1. Environmental Systems Research Institute, Redlands.
- Estoque, R. C., & Murayama, Y. (2012): Examining the potential impact of land use/ cover changes on the ecosystem services of Baguio city, the Philippines: A scenariobased analysis. -*Applied Geography*, 35(1–2): 316–326.
- Fang YN, Zeng J, Namaiti A (2021) Landscape visual sensitivity assessment of historic districts—A case study of wudadao historic district in Tianjin. *China ISPRS Int J Geo-Inform* 10(3):175
- Farina A (2000) Landscape ecology in action. Springer-Science+Business Media, Dordrecht
- Farina, A. (2008): The Landscape as a Semiotic Interface between Organisms and Resources. -*Biosemiotics*, 1(1): 75–83.
- Feng Y, Luo G, Lu L, Zhou D, Han Q, Xu W, Li C (2011) Effects of land use change on landscape pattern of the Manas River watershed in Xinjiang. *China -Environ Earth Sci* 64(8):2067–2077
- Feng D, Bao W, Fu M, Zhang M, Sun Y (2021) Current and future land use characters of a national central city in eco-fragile region—a case study in Xi'an city based on FLUS model. *Land* 10(3):286
- Fu Q, Hou Y, Wang B, Bi X, Li B, Zhang X (2018) Scenario analysis of ecosystem service changes and interactions in a mountain-oasis-desert system: a case study in Altay Prefecture. *China -Sci Rep* 8(1):12939
- Ghosh P, Mukhopadhyay A, Chanda A, Mondal P, Akhand A, Mukherjee S, Hazra S (2017) Application of Cellular automata and Markov-chain model in geospatial environmental modeling-A review. *Remote Sensing Appl: Soc Environ* 5:64–77
- guejrad, R. (2021) The influence of the calibration interval on simulating non-stationary urban growth dynamic using CA-markov model. *Remote Sensing* 13(3):468
- Gulakhmadov N, Chen Y, Gulakhmadov A, Rakhimova M, Gulakhmadov M (2021) Quantifying the relative contribution of climate change and anthropogenic activities on runoff variations in the central part of tajikistan in central Asia. *Land* 10(5):525
- Guo, H., Cai, Y., Yang, Z., Zhu, Z., & Ouyang, Y. (2021). Dynamic simulation of coastal wetlands for Guangdong-Hong Kong-Macao Greater Bay area based on multi-temporal Landsat images and FLUS model. *Ecological Indicators*, 125, 107559.
- Haara A, Store R, Leskinen P (2017) Analyzing uncertainties and estimating priorities of landscape sensitivity based on expert opinions. *Landsc Urban Plan* 163:56–66
- Higgins J, Zablocki J, Newssock A, Krolopp A, Tabas P, Salama M (2021) Durable freshwater protection: A framework for establishing and maintaining long-term protection for freshwater ecosystems and the values they sustain. *Sustainability* 13(4):1950
- Houet T, Loveland TR, Hubert-Moy L, Gaucherel C, Napton D, Barnes CA, Saylor K (2010) Exploring subtle land use and land cover changes: a framework for future landscape studies. *Landscape Ecol* 25(2):249–266
- Huang, Y., Huang, J. L., Liao, T. J., Liang, X., & Tian, H. (2018): Simulating urban expansion and its impact on functional connectivity in the Three Gorges Reservoir Area. -*Science of the total environment*, 643: 1553–1561.
- Jennings S (2004) Landscape sensitivity and tourism development. *J Sustain Tour* 12(4):271–288

- Jiu J, Wu H, Li S (2019) The Implication of land-use/land-cover change for the declining soil erosion risk in the Three Gorges Reservoir region, China. *Int J Environ Res Public Health* 16(10):1856
- Karadağ AA, Şenik B (2019) Landscape sensitivity analysis as an ecological key: the case of Duzce, Turkey. *Appl Ecol Environ Res* 17(6):14277–14296
- Karadağ, A. A. (2019): A Research on determination of vulnerable landscapes in terms of groundwater: Duzce case, Turkey. – *Fresenius Environmental Bulletin* 28(4A): 3231–3241.
- Kieu QL, Do TVH, Van HT (2020) Constructing a spatial analysis model in assessing the sensitivity of landscape erosion in mountainous regions of Vietnam. *SN Appl Sci* 2(10):1–13
- Knox JC (2001) Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley. *CATENA* 42(2–4):193–224
- Koffi, K. J., Deblauwe, V., Sibomana, S., Neuba, D. F. R., Champluvier, D., De Cannière, C., ... Lejoly, J. (2008): Spatial pattern analysis as a focus of landscape ecology to support evaluation of human impact on landscapes and diversity. In *Landscape Ecological Applications in Man-Influenced Areas* (pp. 7–32). Springer, Dordrecht.
- Kucsicsa, G., Popovici, E. A., Băltesanu, D., Grigorescu, I., Dumitraşcu, M., Mitrică, B. (2019): Future land use/cover changes in Romania: regional simulations based on CLUE-S model and CORINE land cover database. *-Landscape and ecological engineering*, 15(1): 75–90.
- Lathrop RG, Tulloch DL, Hatfield C (2007) Consequences of land use change in the New York-New Jersey Highlands, USA: Landscape indicators of forest and watershed integrity. *Landsc Urban Plan* 79(2):150–159
- Le-Xiang, Q. I. A. N. Hai-Shan, C., U. I. Chang, J. (2006): Impacts of land use and cover change on land surface temperature in the Zhujiang Delta. *-Pedosphere*, 16(6): 681–689.
- Li, X., Chen, G., Liu, X., Liang, X., Wang, S., Chen, Y., ... Xu, X. (2017): A new global land-use and land-cover change product at a 1-km resolution for 2010 to 2100 based on human–environment interactions. *-Annals of the American Association of Geographers*, 107(5): 1040–1059.
- Li, M., Liang, D., Xia, J., Song, J., Cheng, D., Wu, J., ... & Li, Q. (2021). Evaluation of water conservation function of Danjiang River Basin in Qinling Mountains, China based on InVEST model. *Journal of Environmental Management*, 286, 112212.
- Liang, X., Liu, X., Li, X., Chen, Y., Tian, H., Yao, Y. (2018a): Delineating multi-scenario urban growth boundaries with a CA-based FLUS model and morphological method. *-Landscape and urban planning*, 177: 47–63.
- Liang, X., Liu, X., Li, D., Zhao, H., & Chen, G. (2018b): Urban growth simulation by incorporating planning policies into a CA-based future land-use simulation model. *-International Journal of Geographical Information Science*, 32(11): 2294–2316.
- Lin, Y. P., Hong, N. M., Wu, P. J., Wu, C. F., & Verburg, P. H. (2007). Impacts of land use change scenarios on hydrology and land use patterns in the Wu-Tu watershed in Northern Taiwan. *Landscape and urban planning*, 80(1–2), 111–126.
- Lin, W., Sun, Y., Nijhuis, S., & Wang, Z. (2020). Scenario-based flood risk assessment for urbanizing deltas using future land-use simulation (FLUS): Guangzhou Metropolitan Area as a case study. *Science of the Total Environment*, 739, 139899.
- Liu, M., Hanqin T., Guangsheng C., Wei R., Chi Z., and Jiyuan L. (2008a): Effects of Land-Use and Land-Cover Change on Evapotranspiration and Water Yield in China During 1900–2000. *-Journal of the American Water Resources Association (JAWRA)* 44(5): 1193–1207.
- Liu, X., Li, X., Shi, X., Wu, S., Liu, T. (2008b): Simulating complex urban development using kernel-based non-linear cellular automata. *-Ecological modelling*, 211(1–2): 169–181.
- Liu, X., Liang, X., Li, X., Xu, X., Ou, J., Chen, Y., ... Pei, F. (2017): A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects. *-Landscape and Urban Planning*, 168: 94–116.
- Luo, Z., Shao, Q., Zuo, Q., & Cui, Y. (2020). Impact of land use and urbanization on river water quality and ecology in a dam dominated basin. *Journal of Hydrology*, 584, 124655.
- Maingi, J. K., Marsh, S. E., Kepner, W. G. & Edmonds, C. M. (2002): An accuracy assessment of 1992 Landsat-MSS derived land cover for the upper San Pedro Watershed (U.S./Mexico) (EPA/600/R-02/040) U.S. Environmental Protection Agency.
- Manolaki, P., Zotos, S., & Vogiatzakis, I. N. (2020). An integrated ecological and cultural framework for landscape sensitivity assessment in Cyprus. *Land Use Policy*, 92, 104336.
- Mansour, S., Al-Belushi, M., & Al-Awadhi, T. (2020). Monitoring land use and land cover changes in the mountainous cities of Oman using GIS and CA-Markov modelling techniques. *Land Use Policy*, 91, 104414.
- MAPA/ICONA (1983). Paisajes Erosivos en el Sureste Español: Ensayo de Metodología para el Estudio de su Cualificación y Cuantificación. Proyecto LUCDEME, 66p, España.
- MAPA/ICONA (1991). Metodología para el Diseño de Actuaciones Agrohidrologías en las Cuencas del Ambito Mediterraneo. Proyecto LUCDEME, pp. 1–31, España.
- McGarigal, K., Cushman, S. A. (2002): Comparative evaluation of experimental approaches to the study of habitat fragmentation effects. *-Ecological applications*, 12(2): 335–345.
- McGlade, J. (2002). Landscape sensitivity, resilience and sustainable watershed management: a co-evolutionary perspective. In *AQU-ADAPT Workshop*, October (pp. 25–27).
- Mehta, V. K., Sullivan, P. J., Walter, M. T., Krishnaswamy, J., DeGloria, S. D. (2008): Impacts of disturbance on soil properties in a dry tropical forest in Southern India. *Ecologyhydrology: Ecosystems, Land and Water Process Interactions*, *-Ecohydrogeomorphology*, 1(2): 161–175.
- Miles J, Cummins RP, French DD, Gardner S, Orr JL, Shewry MC (2001) Landscape sensitivity: an ecological view. *CATENA* 42(2–4):125–141
- Ministry of Agriculture and Forestry, (2012): Ormançılık ve Su Şurası 21–23 Mart 2013 havza yönetimi ve su bilgi sistemi çalışma grubu raporu. Su Yönetimi Genel Müdürlüğü, Ankara, Turkey.
- Mishra VN, Rai PK, Prasad R, Punia M, Nistor MM (2018) Prediction of spatio-temporal land use/land cover dynamics in rapidly developing Varanasi district of Uttar Pradesh, India, using geospatial approach: a comparison of hybrid models. *Applied Geomatics* 10(3):257–276
- Mitsova, D., Shuster, W., Wang, X. (2011): A cellular automata model of land cover change to integrate urban growth with open space conservation. *-Landscape and Urban Planning*, 99(2): 141–153.
- MOPU (1985). Metodología para la Evaluación de la Erosión Hídrica. Dirección General del Medio Ambiente, España.
- Muller MR, Middleton J (1994) A Markov model of land-use change dynamics in the Niagara Region, Ontario, Canada. *-Landscape Ecol* 9(2):151–157
- Neris, J., Jiménez, C., Fuentes, J., Morillas, G., Tejedor, M. (2012): Vegetation and land-use effects on soil properties and water infiltration of Andisols in Tenerife (Canary Islands, Spain). *-Catena*, (98): 55–62.
- Ogden, F. L., Raj Pradhan, N., Downer, C. W., & Zahner, J. A. (2011). Relative importance of impervious area, drainage density, width function, and subsurface storm drainage on flood runoff from an urbanized catchment. *Water resources research*, 47(12).
- Okwuashi, O., & Ndehedehe, C. E. (2021). Integrating machine learning with Markov chain and cellular automata models for modelling urban land use change. *Remote Sensing Applications: Society and Environment*, 21, 100461.

- Ophiyandri, T., Istijono, B., Gromiko, A., & Hidayat, B. (2021). Study of retention and infiltration wells as a result of resettlement of the Batang Kuranji upper watershed. In IOP Conference Series: Materials Science and Engineering (Vol. 1041, No. 1, p. 012002). IOP Publishing.
- Pandey, A., Chowdary, V. M., Mal, B. C., Dabral, P. P. (2010): Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. -*Land Degradation & Development*, 22(3): 359–372.
- Patterson Z, Bierlaire M (2010) Development of prototype UrbanSim models. *Environ Plann B Plann Des* 37(2):344–366
- Pickard BR, Van Berkel D, Petrasova A, Meentemeyer RK (2017) Forecasts of urbanization scenarios reveal trade-offs between landscape change and ecosystem services. *Landscape Ecol* 32(3):617–634
- Pijanowski, B. C., Alexandridis, K. T., Mueller, D. (2006): Modelling urbanization patterns in two diverse regions of the world. -*Journal of Land Use Science*, 1: 83–108.
- Pontius, R. G., Boersma, W., Castella, J. C., Clarke, K., de Nijs, T., Dietzel, C., ... Koomen, E. (2008): Comparing the input, output, and validation maps for several models of land change. -*The Annals of Regional Science*, 42(1): 11–37.
- Rahnama, M. R. (2020). Forecasting land-use changes in Mashhad Metropolitan area using Cellular Automata and Markov chain model for 2016–2030. *Sustainable Cities and Society*, 102548.
- Rempel, R. (2010): Centre for Northern Forest Ecosystem Research. – <http://flash.lakeheadu.ca/~rempel/patch/images/patchanalyst.pdf> (Access date: 17.12.2019).
- Renwick WH (1992) Equilibrium, disequilibrium, and nonequilibrium landforms in the landscape. *Geomorphology* 5(3–5):265–276
- Safaei M, Bashari H, Mosaddeghi MR, Jafari R (2019) Assessing the impacts of land use and land cover changes on soil functions using landscape function analysis and soil quality indicators in semi-arid natural ecosystems. *CATENA* 177:260–271
- Safeeq M, Grant GE, Lewis SL, Staab B (2015) Predicting landscape sensitivity to present and future floods in the Pacific Northwest, USA. *Hydrol Process* 29(26):5337–5353
- Şahin, Ş., Kurum, E. (2002): Erosion risk analysis by GIS in environmental impact assessments: a case study—Seyhan Köprü Dam construction. -*Journal of environmental management*, 66(3): 239–247.
- Şahin, S., Percin, H., Kurum, E., Uzun, O., Bilgili, B. C. (2014): Landscape character analysis and assessment at the regional and sub-regional (Provincial) levels. TUBITAK KAMAG 1007 Program PEYZAJ-44 Project No 109G074 outcome where Ministry of Interior, Ministry of Environment and Urbanization, and Ministry of Forest and Water Affairs are Beneficiary Institutions and Ankara University is the Coordinating Institution, 146 Pages, Ankara - http://acikarsiv.ankara.edu.tr/brows_e/27272/Landscape_Character_Analysis_and_Assessment_at_the_Regional_and_Sub-Regional_Levels.pdf
- Shao Z, Sumari NS, Portnov A, Ujoh F, Musakwa W, Mandela PJ (2021) Urban sprawl and its impact on sustainable urban development: a combination of remote sensing and social media data. *Geo-Spatial Inform Sci* 24(2):241–255
- Sohn, W., Kim, J. H., Li, M. H., Brown, R. D., & Jaber, F. H. (2020). How does increasing impervious surfaces affect urban flooding in response to climate variability?. *Ecological Indicators*, 118, 106774.
- Sommer, M., Gerke, H. H., Deumlich, D. (2008): Modelling soil landscape genesis — A “time split” approach for hummocky agricultural landscapes. -*Geoderma*, 145(3–4), 480–493.
- Sujatha ER, Sridhar V (2018) Spatial prediction of erosion risk of a small mountainous watershed using RUSLE: a case-study of the palar sub-watershed in kodaikanal, south India. *Water* 10(11):1608
- Swanson FJ, Kratz TK, Caine N, Woodmansee RG (1988) Landform effects on ecosystem patterns and processes. *Bioscience* 38(2):92–98
- Syphard, A. D., Clarke, K. C., Franklin, J. (2005): Using a cellular automaton model to forecast the effects of urban growth on habitat pattern in southern California. -*Ecological Complexity*, 2(2): 185–203.
- Thomas MF (2012) Geodiversity and landscape sensitivity: a geomorphological perspective. *Scottish Geographical Journal* 128(3–4):195–210
- Thomas, D. S. G., Allison, R. J. (1993): *Landscape Sensitivity*. -Wiley, Chichester.
- Thomas, M. F. (2001): Landscape sensitivity in time and space - an introduction. -*Catena*, 42(2–4): 83–98.
- Thomlinson, J. R., Bolstad, P. V., Cohen, W. B. (1999): Coordinating methodologies for scaling landcover classifications from site-specific to global: steps toward validating global map products. -*Remote Sensing of Environment*, (70): 16–28.
- Turkish State Meteorological Service, (2015): New Scenario With Climate Projections And Climate Change in Turkey. mgm.gov.tr/FILES/iklim/iklim-degisikligi-projeksiyon2015.pdf (Access date: 15.12.2019).
- Usher, M. B. (2001): Landscape sensitivity: from theory to practice. -*Catena*, 42(2–4): 375–383.
- Utkucu, M., Çetin, C., & Alptekin, Ö. (2005): 12 Kasım 1999 Düzce depremi artçı depremlerinden hesaplanan b ve p değerlerinin uzaysal ve zamansal dağılımı ve gelecekteki sismik tehlike açısından değerlendirmeler (Spatial and temporal distribution of b and p values of 12 November 1999 Düzce earthquake estimated from its aftershocks and assessments for future earthquake hazard). -*Yerbilimleri (Earth Sciences)*, 26 (1): 75–91.
- Uzun, O., Dilek, F., Cetinkaya, G., Erduran, R., Aciksoz, S. (2012): Peyzaj planlama Konya ili Bozkir-Seydisehir-Ahirli-Yalihuuk ilçeleri ve Sugla golu mevkii peyzaj yönetimi koruma ve planlama projesi (Landscape management, protection and planning project for Konya province, Bozkir-Seydisehir-Ahirli-Yalihuuk districts and Sugla lake). Nature Conservation Ofce of the General Directorate of Nature Conservation and National Parks, Ministry of Environment and Forestry, Ankara, Turkey.
- Uzun, O., Muderrisoglu, H., Demir, Z., Kara, L. G., Gultekin, P., Gunduz, S. (2015): Yesilirmak basin landscape atlas. On behalf of Ministry of Forestry and Water Affairs, Directorate of Nature Conservation and National Parks, AKS Planning and Engineering Limited Company, 275 Pages, Ankara, Turkey.
- Uzun O, Gultekin P (2011) Process analysis in landscape planning, the example of Sakarya/Kocaeli. Turkey -*Scientific Research and Essays* 6(2):313–331
- Van de Voorde T, Jacquet W, Canters F (2011) Mapping form and function in urban areas: An approach based on urban metrics and continuous impervious surface data. *Landsc Urban Plan* 102(3):143–155
- Veldkamp, A., Verburg, P. H. (2004): Modelling land use change and environmental impact. - *Journal of Environmental Management*, 72(1–2): 1–3.
- Verburg PH, Soepboer W, Veldkamp A, Limpida R, Espaldon V, Mastura SS (2002) Modeling the Spatial Dynamics of Regional Land Use: the CLUE-S Model -*Environmental Management* 30:391–405
- Verburg, P. H., Overmars, K. P. (2009): Combining top-down and bottom-up dynamics in land use modeling: exploring the future of abandoned farmlands in Europe with the Dyna-CLUE model. -*Landscape ecology*, 24(9): 1167.
- Waddell P (2002) UrbanSim: Modeling urban development for land use, transportation, and environmental planning. *J Am Plann Assoc* 68(3):297–314

- Wang F, Qu X (2018) The study of urban landscape visual sensitivity assessments: a case study in the Zhongshan District of Dalian. *J Spat Sci* 63(2):325–340
- Wang P, Zheng H, Ren Z, Zhang D, Zhai C, Mao Z, He X (2018) Effects of urbanization, soil property and vegetation configuration on soil infiltration of urban forest in Changchun. *Northeast China Chinese Geographical Sci* 28(3):482–494
- Wang, Y., Shen, J., Yan, W., Chen, C. (2019): Backcasting approach with multi-scenario simulation for assessing effects of land use policy using GeoSOS-FLUS software. *-MethodsX*, 6: 1384–1397.
- Wang, S. W., Munkhnasan, L., & Lee, W. K. (2021). Land use and land cover change detection and prediction in Bhutan's high altitude city of Thimphu, using cellular automata and Markov chain. *Environmental Challenges*, 2, 100017.
- Ward RC, Robinson M (1989) *Principles of Hydrology*. McGraw-Hill, London, p 459
- Whitford, V., Handley, J., Ennos, R. (2001): City form and natural-process—indicators for the ecological performance of urban areas. *-Landscape Urban Plann.* (57): 91–103.
- Wright, M. S., Santelmann, M. V., Vaché, K. B., & Hulse, D. W. (2021). Modeling the impact of development policies and climate on suburban watershed hydrology near Portland, Oregon. *Landscape and Urban Planning*, 214, 104133.
- Wu L, Sun C, Fan F (2021) Estimating the Characteristic Spatiotemporal Variation in Habitat Quality Using the InVEST Model—A Case Study from Guangdong-Hong Kong-Macao Greater Bay Area. *Remote Sensing* 13(5):1008
- Wu, J., Hobbs, R. (2002): Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. *-Landscape ecology*, 17(4): 355–365.
- WWF, (2014): Turkey's Water Risks Report. http://awsassets.wwftr.panda.org/downloads/turkiyenin_su_riskleri_raporu_web.pdf (Access date: 15.12.2019).
- Xie, H., He, Y., Choi, Y., Chen, Q., & Cheng, H. (2020). Warning of negative effects of land-use changes on ecological security based on GIS. *Science of The Total Environment*, 704, 135427.
- Xu Q, Guo P, Jin M, Qi J (2021) Multi-scenario landscape ecological risk assessment based on Markov-FLUS composite model. *Geomat Nat Haz Risk* 12(1):1448–1465
- Yan, Y., Liu, X., Wang, F., Li, X., Ou, J., Wen, Y., & Liang, X. (2018): Assessing the impacts of urban sprawl on net primary productivity using fusion of Landsat and MODIS data. *-Science of the Total Environment*, 613: 1417–1429.
- Yang, D., Yang, Y., & Xia, J. (2021). Hydrological cycle and water resources in a changing world: A review. *Geography and Sustainability*.
- Zebisch M, Wechsung F, Kenneweg H (2004) Landscape response functions for biodiversity—assessing the impact of land-use changes at the county level. *Landsc Urban Plan* 67(1–4):157–172
- Zhao, Z., Guan, D., & Du, C. (2019): Urban growth boundaries delineation coupling ecological constraints with a growth-driven model for the main urban area of Chongqing, China. *-GeoJournal*, 1–17.
- Zhu Z, Liu B, Wang H, Hu M (2021) Analysis of the spatiotemporal changes in watershed landscape pattern and its influencing factors in rapidly urbanizing areas using satellite data. *Remote Sensing* 13(6):1168
- Zofio, J. L., Prieto, A. M. (2001): Environmental efficiency and regulatory standards: the case of CO2 emissions from OECD industries. *-Resource and Energy Economics*, 23(1): 63–83.