Environ Monit Assess (2023) 195:196
https://doi.org/10.1007/s10661-022-10785-3

Investigation of land cover (LC)/land use (LU) change affecting forest and seminatural ecosystems in Istanbul (Turkey) metropolitan area between 1990 and 2018

Selvinaz Gülçin Bozkurt · Lütfiye Kuşak · Ünal Akkemik

Received: 17 June 2022 / Accepted: 26 November 2022 / Published online: 13 December 2022

Abstract This study was conducted to examine the land cover (LC)/land use (LU) change affecting forest and seminatural ecosystems and the spatio-temporal development of urban expansion between 1990 and 2018 in the city of Istanbul, where urbanization is the most intense in Turkey. For this purpose, using Corine Land Cover (1990, 2000, 2006, 2012, and 2018) dataset, the land cover of the area was determined in 5 different classes (artificial surface, agriculture, forest, water bodies, water), maps were produced, and tabular data were created. The changes in LC/LU between 1990 and 2018 were determined according to the Puyravaud land cover change rate and hot spot analysis methods. According to our findings, we determined that urbanization in Istanbul expanded the most in the east-west direction, and the agricultural and forest areas gradually decreased by 3.02% and 6.66% respectively; urban areas increased at the same rate of 9.69%. It is predicted that this change will continue increasing until 2030 when the forecasting method is applied in the field. It has been determined that the most important reasons for this situation are local government policies, population growth, and economic development initiatives applied in the area. As a result, it has emerged that measures should be taken based on sustainability and naturalness approaches to design urban development plans and to protect natural areas on a large scale, in order to limit possible LC/LU conversion from natural structure to urbanization in the area.

Keywords Natural areas · Land cover · Land use · Geographical information systems · Hot spot analysis · Urbanization · Istanbul

S. G. Bozkurt (✉)
Interior Architecture and Environmental Design Department, Faculty of Engineering and Architecture, Fenerbahce University, Istanbul, Turkey
e-mail: sbozkurt00@gmail.com; gulcin.bozkurt@fbu.edu.tr

L. Kuşak
Department of Geomatics Engineering, Faculty of Engineering, Mersin University, Mersin, Turkey
e-mail: lutfiyekusak@mersin.edu.tr

Ü. Akkemik
Department of Forest Botany, Faculty of Forestry, Istanbul University-Cerrahpasa, Bahceköy-Sarıyer, Istanbul, Turkey
e-mail: uakkemik@iuc.edu.tr

Introduction

Human population is increasing, cities are overgrowing, and natural areas are being rapidly destroyed. Cities are increasingly exposed to environmental problems such as construction, improper land use, biodiversity losses, climate change, noise pollution, and water and air that negatively affect the quality of life (Westmacott, 1991; Doygun et al., 2010). Slowing down or stopping this process, which caused urban life to become unsustainable for people and nature, has required measures to improve environmental conditions. In this sense, the protection of natural areas is one of the most effective planning tools used to reduce the adverse effects of urbanization on people and wildlife. Limiting and directing land uses (Li et al., 2005), protecting habitats for plants and wildlife species (Attwell, 2000; Esbah, 2006), and reducing environmental pollution and heat island effects (Yıldızcı, 1982; Solecki et al., 2005) are also essential components in terms of regulating the urban microclimate (Shin & Lee, 2005). At the same time, natural areas are elements that regulate urban life in favor of people in psychological and sociological terms by improving urban aesthetics, strengthening urban belonging, providing recreational opportunities, facilitating the integration of urban people into social life, and providing the relationship between human and nature (Gül & Küçük, 2001; Grahn & Stigsdotter, 2003; Manlun, 2003; Ridder et al., 2004; Littke, 2015).

Changes in a city's land use pose a significant threat when the natural habitats of the biodiversity living in that city are destroyed or converted to anthropogenic land use. As a result, there is a great loss of species and habitats on earth. Therefore, since it will be challenging to determine how the biodiversity living in cities will respond to future change, it would be a more accurate and rational approach to consider the effects of future redistribution of land use patterns and protect natural areas within the framework of the principle of sustainability measures. For this purpose, studies on the negative effects of changes in land use in Turkey and in the world (in Italy by Falcucci et al. (2007), in Greece by Kolios and Stylios (2013), in Spain by Galiano and Olmo (2012), and in Portugal by Araya and Cabral (2010)) have gained importance. For this reason, in order to reorganize the ongoing land-use system, it is necessary to analyze the changes in land cover/land use (LC/LU) from the past to the present, determine the land uses that are considered to be effective (classification of land cover and its use according to its class nature) in the future, and to create suitable land use plans for natural potential in line with these data (Doygun et al., 2003).

Usually, LC/LU are two different terminologies used interchangeably. Land cover only describes the areas created by its physical characteristics (vegetative or human-made) of the land's surface, namely the distribution of physical characteristics such as settlements, soil, and vegetation. On the other hand, land use refers to the way people use land, often emphasizing the functional role of land for economic activities. The LC/LU model of a region results from natural and socio-economic factors and refers to the use of land by humans in time and space (Ruiz-Luna & Berlanga-Robles, 2003). In order to better understand landscape dynamics in a known period of sustainable management, the determination of LC/LU change is significant. There are many studies that use satellite images (e.g., Paul et al., 2021; Tariq et al., 2021; Thakur et al., 2021) as well as field studies (e.g., Muchuma et al., 2021) to monitor and record these changes.

In general, LC/LU changes are a pervasive and accelerating process resulting from natural events and anthropogenic activities that create changes that affect the natural ecosystem (Ruiz-Luna & Berlanga-Robles, 2003). LC/LU models that develop in forms that are not suitable for the natural values of the land (biodiversity, water, etc.) cause increasing planning problems for Turkey and the rest of the world. For this reason, today, this issue remains on the agenda as an essential research topic. Falcucci et al. (2007), who conducted research on this subject, stated that especially the Mediterranean Region countries, where population and tourism movements are intense, are more negatively affected by anthropogenic effects. In the same study, they stated that the change in LC/LU (between 1960 and 2000) in the Italian peninsula showed a change from Mediterranean-type vegetation and traditional agricultural production to the cultivation of artificial species (species such as mangoes that do not grow naturally in the area). By calculating LC/LU change, Kolios and Stylios (2013) found the presence of gradually increasing deforestation and transformation of the agricultural areas into urban areas in the Preveza peninsula of Greece. Galiano and Olmo (2012) examined the LC/LU change (between 1998 and 2004) in the Spanish province of Granada and found that agricultural areas decreased gradually, while urban areas increased. Araya and Cabral (2010), in their urban land use change analysis and modeling studies for Setúbal and Sesimbra in Portugal, determined that the area increased by 91.11% in urban areas between 1990 and 2006 and emphasized that this change threatens natural areas and agricultural lands. Regarding Istanbul, Kandemir (2012) examined the changes in land cover (between 2003 and 2010) in Akfırat and its surroundings (Tuzla-Istanbul) and determined that arable agricultural lands and forest areas decreased while urban settlements increased. Likewise, Koç (2006), in his study evaluating the 25-year period of Istanbul covering the years 1975–2000, found that the residential areas increased four times and some of the forest areas turned into urban areas. As can be understood from these studies, urban transformation is a major threat worldwide.

Urbanization in Turkey accelerated especially after the 1950s, with the development of the industrial sector, migration from Anatolian villages to traditional centers such as Istanbul, Izmir, Ankara, and Adana increased, and then, with the addition of different villages, urban sprawl gained speed throughout the country (Işık, 2005). However, the province that is most exposed to the effects of urbanization among these cities is Istanbul.

In this study, two of the most significant factors in choosing Istanbul as a research area are (1) the presence of natural areas that make up the seven important habitats of the city (Terkos Basin, Küçükçekmece Basin, West Istanbul Pastures, Ağaçlı Dune, Kilyos Dune, Bosphorus, Ömerli Basin) and a very rich flora with more than 2200 plant species (Akkemik, 2017), and (2) very fast LC/LU changes because of rapid urbanization. In addition, the forest areas in and around Istanbul, which have an important place in terms of biological diversity, are among the most critical bird migration accumulation areas in the world and host hundreds of thousands of waterfowl, raptor, and songbird species during the migration period. However, the intense population growth and urbanization in Istanbul today puts severe pressure on natural areas such as forest areas, water basins, rural settlements, and agricultural areas. In the city where approximately 15 million people live, the ever-increasing residential areas, and industrial and commercial activities are gradually destroying the natural areas to provide shelter and nutrition for this population (Akkemik, 2017). Along with urbanization and industrialization, a significant heat island effect and climate change have been observed in the area in recent years (Şimşek & Şengezer, 2012; Kuşak & Küçükali, 2019). In the climate data of Copernicus, it was determined that the temperature increased in the same way in London and Paris, where the rate of urbanization increased and it was noted that the night temperature in these cities was 40 °C higher than in rural areas (https://climate.copernicus.eu/demonstrating-heat-stress-european-cities). According to data received from the General Directorate of Meteorology between 1970 and 2019, Turkey's overall average temperature increased from 13.5 to 14.4 °C, while the annual average temperature of Istanbul increased by 1 °C to 4.5 °C. In addition to these adverse developments, the mega projects (3rd airport and 3rd bridge projects) built in the city have also negatively affected the LC/LU, making Istanbul the province with the most extraordinary LC/LU change in Turkey. In this context, the main problem is to find the dimension of LC/LU change in İstanbul, which is the most crowded and rapid growing megacity of Turkey. We aimed to make maps for the LC/LU changes using CORINE Land Cover (CLC), X. The CORINE Land Cover dataset is used to analyze LC/LU and observe its change over time, as well as to observe changes in agricultural, forest, and semi-natural areas in urban areas and ecologically sensitive places (Castanho et al., 2021). CLC dataset between the years 1990 and 2018 in Istanbul, the most populated city of the European continent, and to determine the effects of these changes on natural areas and to develop suggestions for the protection of these areas.

Material and method

In this study, we used the CLC dataset, prepared for the European Union member and surrounding countries monitoring the LC/LC for different years. The LC/LU change of the province of Istanbul was revealed in the ArcGIS 10.5 program (ESRI Inc, 2016) with the CLC dataset, and various statistical methods (Puyravaud analysis, hot spot analysis, etc.) which was prepared for the years 1990, 2000, 2006, 2012, and 2018. Additionally, a forecast application for the potential regional changes up to 2030 was made at the conclusion of the study (Fig. 1).

The reason for choosing the CLC dataset within the scope of the study is to make long-term observations of the change in forest areas. In such studies, satellite images may be preferred for more frequent (annual, monthly, weekly, and even daily) observations. However, the aim here is to reveal the change that the forest areas in the metropolitan city of Istanbul have experienced in 28 years. For this, a ready-made CLC dataset was preferred. ArcGIS 10.5 software (ESRI Inc, 2016) was used to analyze the CORINE data set.

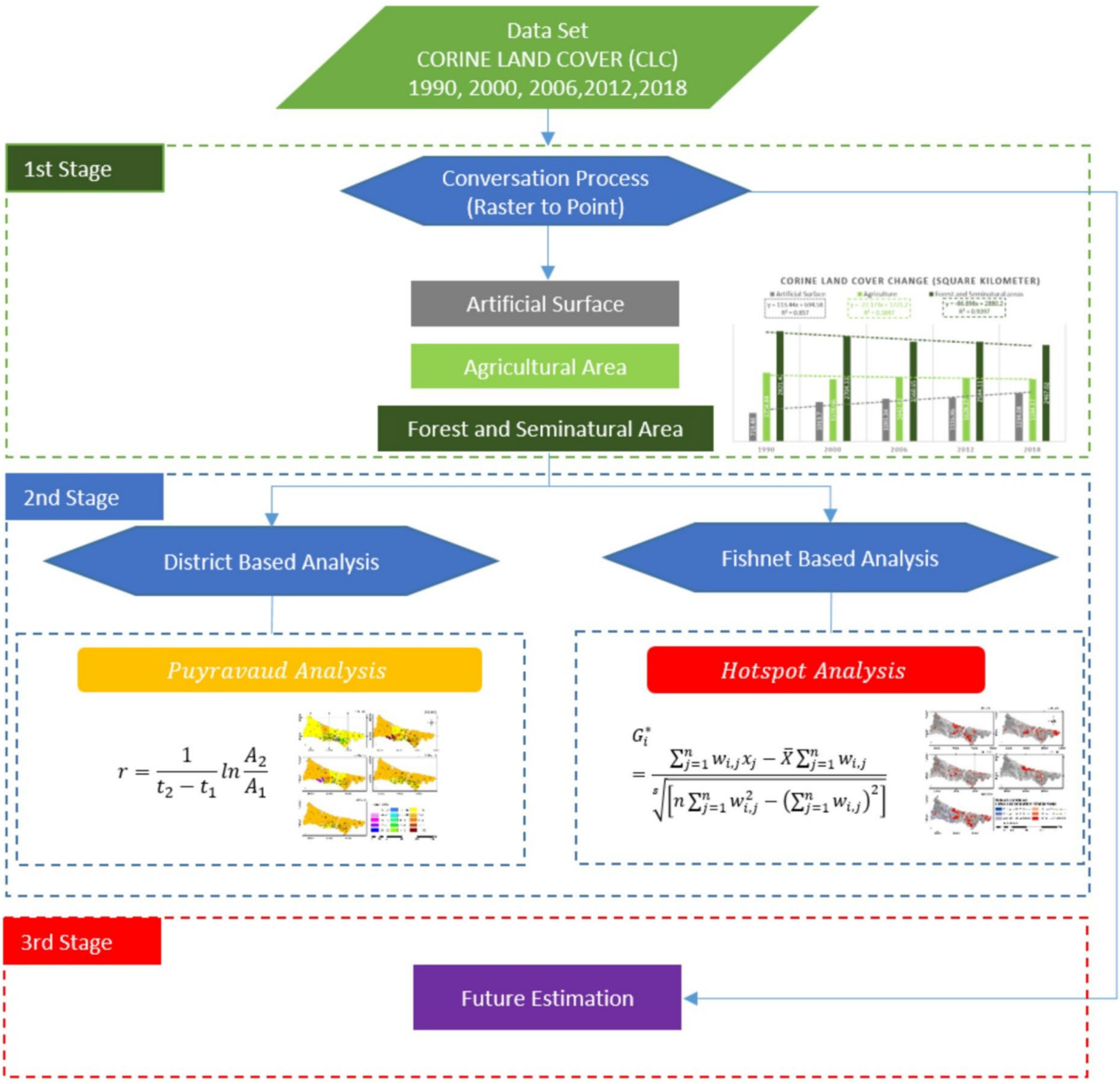

Fig. 1 Flow chart of study

Research area

The research area covers the entire administrative boundaries of Istanbul (Fig. 2). Istanbul is at the intersection of two peninsulas in a very strategic location at the junction of the Asian and European continents and is located at the geographical coordinates of 41°00′49″ N, 28°57′18″ E. Istanbul's climate is more of a transitional climate.

The native vegetation of Istanbul consists of forest, sclerophyllous trees and shrubs (maquis), pseudomaquis (maquis plant communities adapted to the Black Sea climate, modified, humid character, more tree-sized), and coastal plants. According to the Istanbul Regional Directorate of Forestry, about 45% of the city is covered with forest areas.

While 3% of the forest areas are degraded, 42% are in the normal forest category. Forest areas exhibit a very variable structure consisting of different tree species combinations depending on macro and microclimatic characteristics (Istanbul Provincial Environmental Status Report, 2012). With the effect of the

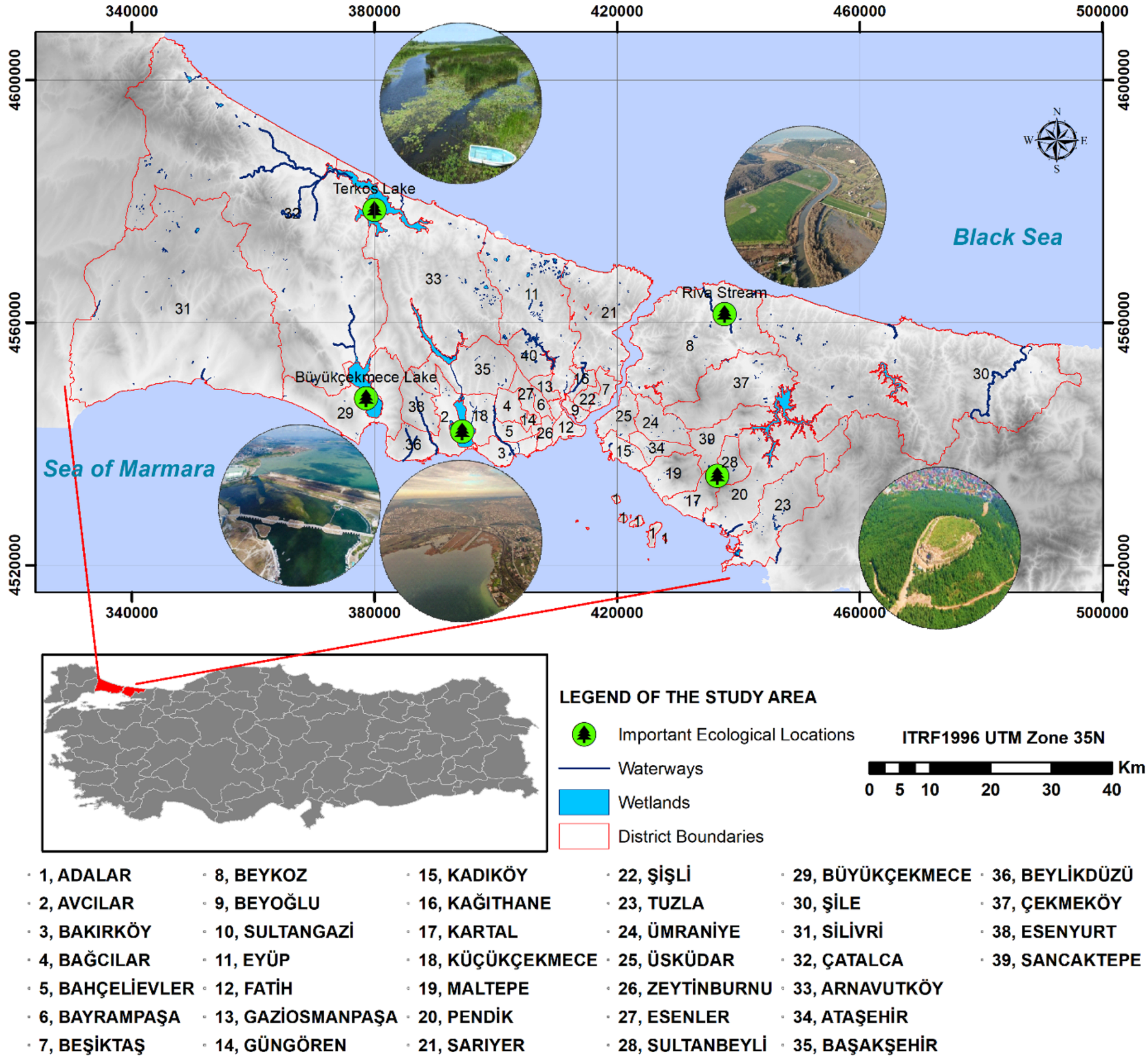

Fig. 2 The location of İstanbul on the map of Turkey

climate, humid plant species have developed in the northern parts of the city and relatively drier plant species have developed in the southern part. There are approximately 2200 plant species native in Istanbul, of which only 55 are endemic plants grown in the area (Akkemik, 2017). Some of the endemic plants are as follows: Istanbul crocus (*Crocus olivieri* subsp. *istanbulensis* B.Mathew), Istanbul snowdrop (*Galanthus plicatus* subsp. *byzantinus* (Baker) DAWebb), Kilyos centaury (*Centaurea kilaea* Boiss.,) and Bosphorus flax (*Linum tauricum* ssp. *bosphori* P.H.Davis), wavy pea or Istanbul nazendesi (*Lathyrus undulatus* Boiss.), and Sultan pelemiri (*Cephalaria tuteliana* Kuş & Gokturk). One hundred forty-two of the Istanbul plants are woody and there is only one endemic woody taxon (*Abies nordmanniana* subsp. *equi-trojani* (Asch. & Sint. ex Boiss.) Coode & Cullen) and it is protected as a nature conservation area on an area of 460.000 m^2. Byfield et al. (2010) stated that 7 of the 122 important plant areas in Turkey are in Istanbul and should be protected. Avcı et al. (2015) also stated that there are 45 coastal sand dunes on the Turkish coasts and 3 of them are on the Black Sea coasts of Istanbul. Four main natural ecosystems have been defined within the forests, sclerophyllous forests (maquis), open areas, important plant areas, and coastal dunes in Istanbul. These are (1) forest ecosystems, (2) riparian ecosystems, (3) scrub and open field ecosystems (screlophyllous ecosystems), and (4) dune ecosystems. The specie compositions of these ecosystems are different from each other (Akkemik, 2017; Table 1).

The land structure of Istanbul is generally represented with low lands. The highest point of Istanbul is Aydos Mountain between Kartal and Pendik districts, and its altitude is 537 m. There are three notable lakes in Istanbul. The largest one is Terkos Lake, which is located 50 km far from the city center on the Black Sea coast and has an area of 25 square km. The Terkos Lake is followed by Büyükçekmece and Küçükçekmece lakes. The most significant stream in Istanbul is Riva Stream. The Riva Stream is the most considerable stream of Kocaeli Peninsula; it flows into the Black Sea from the Riva Village of Beykoz (Istanbul Provincial Environmental Status Report, 2012) (Fig. 2).

Method

Obtaining CORINE data, creating maps, and values

CORINE data series, which stands for Co-ORdinated INformation on the Environment was created by the European Community (EC) and has been used for about 40 years. The CORINE data set shows the LC/LU prepared for the European Union member and surrounding countries. While creating this data set, both satellite images and terrestrial measurements are used. CORINE program includes CORINE Land Cover, CORINE Air, CORINE Hydro, and CORINE Biotopes. CORINE Land Cover is the de facto standard for LC/LU monitoring at the Pan-European level. The CORINE Land Cover dataset was established in 1985 and is now one of the most widely used products from the Copernicus Land Monitoring Service. The land cover datasets are produced according to a common standard and represent the status for the reference years 1990, 2000, 2006, 2012, and 2018. LC/LU datasets of Europe produced by national agencies and coordinated by the European Environment Agency (EEA) (Aune-Lundberg & Strand, 2021; Castanho et al., 2021; Cole et al., 2022; Feranec et al., 2010; György et al., 2021; Konukcu et al., 2017; Kosztra et al., 2017). The Ministry of Forestry and Water Affairs is responsible for the preparation of the CLC datasets in Turkey. The CORINE data set has a pixel size of 100 m × 100 m. Therefore, a pixel represents an area of 10,000 square meters. CORINE dataset includes artificial surface, agriculture, forest, water bodies, and water levels. The next level has 15 labels. The third level includes 44 labels. Every level has been defined and illustrated in the technical guideline.

In this study, the CLC dataset was analyzed for 1990, 2000, 2006, 2012, and 2018 years of the province of Istanbul. The coordinate system of the Istanbul district map used in the production of the maps is defined in the 35N region of the ITRF96 datum UTM projection. Tabular data of the CLC dataset is organized and classified by symbology. Pixel values were obtained by using raster to point, one of the conversation tools, in order to statistically evaluate the land cover and use of CLC dataset over the years.

Revealing the percentages of LC/LU change on the basis of districts

After the conversation process, the changes in the forest areas within the districts of the whole Istanbul, the deforestation percentages were determined with the formulas prepared by Puyravaud and FAO (Food and Agriculture Organization of the United Nations) in order to reveal the changes in the forest areas of Istanbul province and in the forest areas in 38 districts. The formula developed by Puyravaud for calculating the annual rate of deforestation (Puyravaud, 2003) has also been used by land cover change researchers (e.g., Rodríguez et al., 2013; Tovar et al., 2013; Schulz et al., 2010; Teixeira et al., 2014; Sancar et al., 2009; Peiman, 2011; Vittek et al., 2014; Munsi et al., 2010). The Puyravaud formulation is as follows:

$$r = \frac{1}{t_2 - t_1} ln \frac{A_2}{A_1} \quad (1)$$

While the annual rate of change is expressed with r in the formula, t_1 represents the start time, t_2 represents the end time, A_1 represents the initial land cover amount, and A_2 represents the subsequent land cover amount (Puyravaud, 2003; Rodrigez et al., 2013). In the study, forest and seminatural areas and their changes were revealed with the help of pixel data obtained with the CLC dataset. Calculations were made on the basis of both Istanbul and districts with

Table 1 Natural ecosystems in Istanbul and their key species (derived from Akkemik, 2017)

Forest ecosystems (mainly northern forests)	Riparian ecosystems	Screlophyllous ecosystems and open areas	Dune ecosystems
Woody plants	Woody plants	Woody plants	Herbaceous plants
Acer campestre L.	*Alnus glutinosa* (L.)	*Anthyllis hermanniae* L.	*Jurinea kilaea*
Carpinus betulus L.	Gaertn.*Alnus glutinosa*	*Arbutus unedo* L.	*Isatis arenaria*
Corylus avellana L.	*Fraxinus angustifolia* Vahl.	*Calicotome villosa* (Poir.) Link.	*Ammophila arenaria* (L.) Link
Daphne pontica L.	*Salix alba* L.	*Cercis siliquastrum* L.	*Asperula littoralis* Sm.
Fagus orientalis Lipsk	*Salix caprea* L.	*Cistus cretigus* L.	*Atriplex prostrata* subsp. *polonica* (Zapal.) Uotila
Fraxinus excelsior L.	*Salix cinerea* L.	*Cistus salviifolius* L.	*Cakile maritima* Scop.
Fraxinus angustifolia Vahl.		*Erica arborea* L.	*Calystegia soldanella* (L.) R. Br.
Ligustrum vulgare L.	Herbaceous plants	*Erica verticillatamanipuliflora* Salisb.	*Centaurea kilaea Boiss.Centaurea kilaea*
Mespilus germanica L.	*Alisma lanceolatum* With.	*Genista monspessulana* (L.) L.A.S.Johnson	*Convolvulus persicus* L.
Quercus cerris L.	*Alisma plantago-aquatica* L.	*Genista tinctoria* L.	*Crambe maritima* L.
Quercus frainetto Ten.	*Allium siculum* Ucria	*Jasminum fruticans* L.	*Crithmum maritimum* L.
Quercus ilex L.	*Anemone nemorosa* L.	*Laurus nobilis* L.	*Cyperus capitatus* Vand.
Quercus infectoria G.Olivier	*Butomus umbellatus* L.	*Lavandula stoechas* L.	*Eryngium maritimum* L.
Quercus petraea (Matt.) Liebl.	*Ficaria verna* L.	*Osyris alba* L.	*Euphorbia paralias* L.
Quercus robur L.	*Lamium galleobdolon* (L.) L.	*Phillyrea latifolia* L.	*Glaucium flavum* Crantz
Ruscus aculeatus L.	*Leucojum aestivum* L.	*Pistacia lentiscus* L.	*Juncus effusus* L.
Tilia tomentosa Moench	*Lysimachia nummularia* L.	*Pistacia terebinthus* L.	*Jurinea kilaea* Azn.
Ulmus minor Mill.	*Lythrum salicaria* L.	*Quercus coccifera* L.	*Kali australis* (R. Br.) Akhani & Roalson
	Nasturtium officinale R. Br.	*Spartium junceum* L.	*Lactuca tatarica* (L.) C. A. Mey.
Herbaceous plants	*Persicaria decipens* (R.Br.) K.L.Wilson		*Lepidotrichum uechtritzianum* (Bornm.) Velen. & Bornm.
Ajuga reptans L.	*Petasites hybridus* (L.) G. Gaertn., B. Mey. & Scherb.	Herbaceous plants	Leymus racemosus (Lam.) Tzvelev
Campanula persicifolia L.	*Ranunculus peltatus* Schrank.	*Acinos alpinus* Moench.	*Maresia nana* (DC.) Batt.
Cirsium hypoleucum DC.	*Senecio aquaticus* Hill.	*Asphodelus aestivus* Brot.	*Matthiola fruticulosa* (L.) Maire
Colchicum micranthum Boiss.	*Stellaria aquatica* (L.) Scop.	*Carthamus lanatus* L.	*Matthiola sinuata* (L.) W.T.Aiton
Cruciata laevipes Opiz		*Centaurea salonitana* Vis.	*Medicago littoralis* Loisel.
Cyclamen coum Mill.		*Centaurea solstitialis* L.	*Medicago marina* L.
Doronicum orientale Hoffm.		*Cephalaria tuteliana* Kus&Göktürk	*Otanthus maritimus* (L.) Hoffm. & Link
Epimedium pubigerum (DC.) C.Morren & Decne		*Cirsium byzantinum* Steud.	*Pancratium maritimum* L.
Fragaria vesca L.		*Crepis vesicaria* L.	*Polygonum maritimum* L.
Helleborus orientalis Lam.		*Crupina crupinastrum* (Moris) Vis.	*Scirpoides holoschoenus* (L.) Soják
Lathyrus laxiflorus (Desf.) Kuntze		*Erysimum smyrnaeum* Boiss. & Balansa	*Senecio vernalis* Waldst. & Kit.
Lathyrus undulates Boiss.		*Lupinus albus* L.	*Silene thymifolia* Sm.
Lilium martagon L.		*Origanum vulgare* L.	*Stachys maritima* Gouan

Table 1 (continued)

Forest ecosystems (mainly northern forests)	Riparian ecosystems	Screlophyllous ecosystems and open areas	Dune ecosystems
Ornithogalum refractum Kit.ex Schltdl.		*Ornithogalum comosum* L.	*Taeniopetalum obtusifolium* (Sibth. & Sm.) Pimenov
Primula vulgaris Huds.		*Prospera autumnale* (L.) Speta	*Taraxacum megalorhizon* (Forssk.) Hand.-Mazz.
Scilla bifolia L.		*Rhagadiolus stellatus* (L.) Gaertn.	*Teucrium scordium* L.
Stellaria holostea L.		*Scleranthus perennis* L.	*Verbascum haussknechtii* Heldr. ex Hausskn.*Centaurea kilaea*
Symphytum tuberosum subsp.*nodosum* (Schur) Soó		*Sedum annuum* L.	*Xanthium strumarium* L.
		Teucrium polium L.	
		Tuberaria guttata (L.) Fourr.	
		Verbascum sinuatum L.	

the help of the Puyravaud Formula. The summary statistic method in ArcGIS 10.5 was used while performing the operations on the basis of districts.

Interpretation of forest and seminatural areas based on years with hot spot analysis

Heat maps and other density analyses can illustrate where the data is grouped, but they do not give statistical information on the relationships between these clusters. Hot spot analysis is a spatial analysis and mapping technique interested in the identification of clustering of spatial phenomena. These spatial phenomena are depicted as points in a map and refer to locations of events or objects. In many studies, hot spot analyses are preferred, including those that monitor public health, epidemics (Wu et al., 2022; Chinpong et al., 2022), crime zones (Chakravorty, 1995; Kortas et al., 2022), traffic accidents (Hazaymeh et al., 2022), real estate (Guerri et al., 2022), demographic analyses (Islam et al., 2022), and ecological assessments (Nelson & Boots, 2008; Rossi & Becker, 2019). Today, hot spot analysis is one of the preferred methods to statistically express the change in forests and other natural areas (e.g. Pasha et al., 2016; Saranya et al., 2022; Tantipisanuh & Gale, 2022; Xu et al., 2022).

Hot spot analysis targets each event and statistical analysis of other events according to a certain distance around that event. The z-score and *p*-value are used in the interpretation of the results. In hot spot analysis, first of all, projected point, line, or polygon vector data that provides the position data of the events is required. This data must have descriptive attribute information, such as size, quantity, and time. The standard methods that should be used include data identification, spatial autocorrelation/clustering in data testing, hot spot mapping, and hot spot analysis. It should be determined whether the data is in a cluster and whether there are geographic autocorrelations before doing a hot spot analysis. Several methods, including the Neighborhood Nearest Index (NNI), Moran's I (global), Geary's C, Getis-Ord General G (global), and standard deviation ellipses, are employed for this assessment. Moran's I or Geary's C, Getis-Ord General G (global) techniques (Eq. 2) were preferred in this study.

G_i* value is calculated using below formula Eq. 1.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \overline{X}\sum_{j=1}^{n} w_{i,j}}{s\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

$$\overline{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - \left(\overline{X}\right)^2} \quad (2)$$

where X_j is the attribute value for feature j, $W_{i,j}$ is the spatial weight between feature i, and n is equal to the total number of feature. $\overline{X}$ is the mean of all attribute values for feature. S is the standard deviation of all attribute values for feature. Where G_i* statistic value is not recalculated since it is a z-score.

Inverse distance, journey time, fixed distance, K nearest neighbors, and contiguity are popular approaches for conceptualizing spatial connections for the hot spot analysis. These approaches make the fundamental distinction between traditional spatial statistics and non-spatial statistics. As a result of the hot spot analysis made by choosing one of the aforementioned approaches, a table and result map are formed. The values presented in the Gi Bin field indicate that if the values have a +/−3 value, they are 99% safe in terms of statistics, and if they have a +/−2 value, they are in the 95% confidence interval. If the data is clustered at 0, there is no statistical significance; if it has +/−1 values, it indicates that it is within the 90% confidence interval (Anselin, 1995; Ord & Getis, 1995; Karlström & Ceccato, 2000; Anselin & Rey, 2010; Fischer et al., 2010; Getis & Ord, 2010; ESRI, 2022a, b).

As a consequence of the analysis, z-score and *p*-value are made when the attribute table is checked and the hot spot maps are created. The z-score and *p*-value in this table allow the statistical significance of the data to be measured with each other. It may be claimed that the events are comparable if the z-score value is high compared to the *p*-value is low and the hot spot result is high. The cold spot value is revealed if the z-score value has a low negative value and the *p*-value value is low. There has been no geographical clustering if the z-score value is near to 0. If a region has hot spots, the events are above normal, and if it has cold spots, the events are below average.

In this study, we statistically interpreted the distribution of forest areas in five different time periods using the hot spot analysis in ArcGIS 10.5. Spatial relationships were conceptualized using the inverse distance model. The distances were calculated using the Euclidean distance method. For this purpose, fishnet analysis was used since the smallest district area is Güngören with 7.2 square km and the largest district area is Çatalca with approximately 111.5 square km. The area to include the entire Istanbul is divided into a grid of squares of 1 km × 1 km = 1 square km using fishnet analysis. As a result of this division, 13,350 grid areas were formed. Whether this area will be sufficient or not, the sample area adequacy has been tested by using CLC data consisting of 532,245, which is obtained using raster to point conversation process, pixels for Istanbul. While finding the sample size the following equation (Eq. 3) was used:

$$\text{Sample size} = \frac{\frac{\ddagger^2 xp(1-p)}{e^2}}{1 + \left(\frac{\ddagger^2 xp(1-p)}{e^2 N}\right)} \tag{3}$$

where *N* is number of pixel study area, and *e* is margin of error and *z* is z-value in the equation. *p* is the sample proportion.

Result of sample size formula, the sample size was found to be 665 pixels with a 99% confidence interval, a 5% margin of error and 53,225 number of pixels. Results of the fishnet analysis greater than sample size, we decided to use 13,350 grid areas for the hot spot analysis. The number of forest and seminatural points in each grid area was determined by summary statistics. Hot spot analysis was performed with the help of these data sets. The results of hot spot analysis, the distribution of forests and semi-natural areas on the basis of location was evaluated statistically.

Detection of forest and seminatural LC/LU change areas with geospatial methods and visualization

The hot spot method was used to determine the usage functions of the change in forest areas. After determining the statistically significant change zones, the usage function of the forest areas was evaluated and mapped.

Estimating the LC/LU change rates in the area in the future with the estimation method

The Excel forecasting tool was used for the forward forecasting process. This tool is based on the linear regression equation.

$$\begin{aligned} y &= a + bx \\ a &= \bar{y} - b\bar{x} \\ b &= \frac{\sum (x-\bar{x})(y-\bar{y})}{\sum (x-\bar{x})^2} \end{aligned} \tag{4}$$

where the *a* is constant (intercept) and *b* is coefficient (slope of the line) in the equation. The values of $\bar{x}$ and $\bar{y}$ are the sample means (averages) of the known *x*-values and *y*-values (https://www.ablebits.com/office-addins-blog/excel-forecast-function-formulaexamples/).

Results

Determination of Istanbul's land cover classes and LC/LU change

The land structure of Istanbul was classified and mapped for 5 different years (1990, 2000, 2006, 2012, 2018) according to CLC dataset, divided into sub levels 3 (Fig. 3) and level 1, included artificial surface, agriculture, forest, water bodies, water (Table 2).

According to this classification, a large part of Istanbul, whose surface area is 5322.45 square km, consists of forest areas and these areas are mostly concentrated in the north of the province. While agricultural areas are in the second place in the land cover classes, artificial surfaces are in the third place (Table 2). There was a 6.66% decrease in the forest and seminatural areas of Istanbul and a 3.02% decrease in the agricultural lands from 1990 to 2018 (Table 2; Figs. 4 and 5). It is seen that the decreasing areas have a negative similarity with the increase in artificial surfaces and are almost equal to the sum of these changes.

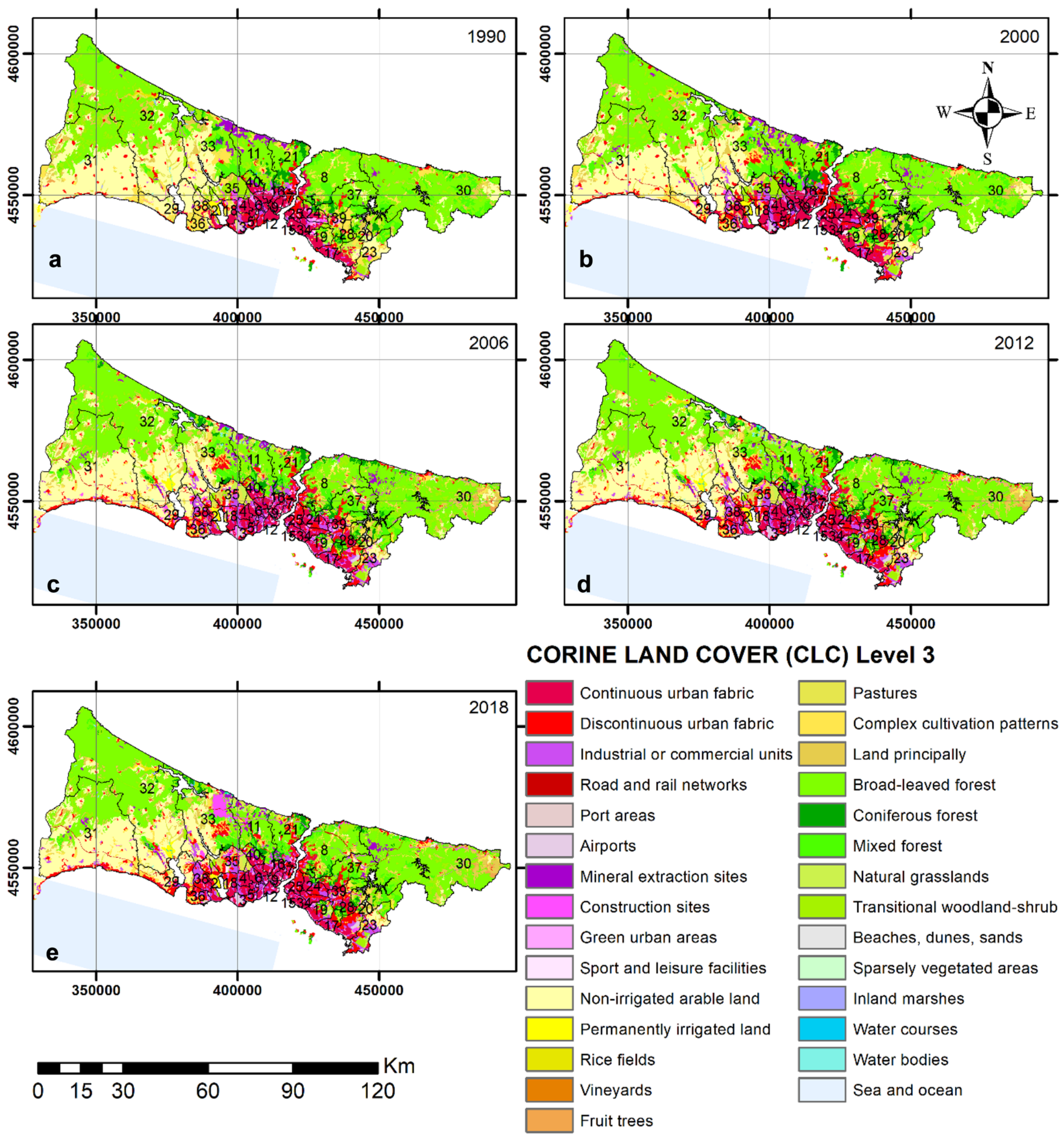

Fig. 3 CORINE Land Cover maps (level 3) of Istanbul for the years of (**a**) 1990, (**b**) 2000, (**c**) 2006, (**d**) 2012, and (**e**) 2018

Table 2 Level 1 CLC datasets area of square kilometer and change ratios of Istanbul

Land classes	1990	2000	2006	2012	2018	1990–2018 (%)
Artificial surface	718.48	1013.70	1091.34	1116.86	1234.08	9.69
Agriculture	1754.84	1578.66	1642.42	1628.27	1594.17	−3.02
Forest and seminatural area	2821.40	2704.33	2560.65	2544.11	2467.02	−6.66
Water bodies	3.39	3.02	2.81	4.51	4.51	0.02
Water	24.34	22.74	25.23	28.70	22.67	−0.03

According to the results of the correlation analysis performed using the data in Table 2, there is a −0.838 and −0.961 negative correlation between artificial surfaces and agricultural, forest, and seminatural areas, respectively. The correlation between forest and seminatural areas and agricultural surfaces was found to be 0.655.

In the study, we found dramatic changes in sparsely vegetated areas and transitional woodland/shrub within forest and seminatural areas. The ratio of sparsely vegetated areas was 33% in 1990, and dramatically decreased to 11% in 2018. When transitional woodland/shrub areas are evaluated, they decreased from 32% in 1990 to 15% in 2018 (Fig. 5).

Determination of Istanbul's LC/LU change according to Puyravaud analysis

The distribution of forest and seminatural land classes in the total area, which is prepared by using Table 2, have changed dramatically in the last 30 years (Fig. 6).

The percentages of LU/LC (deforestation) changes were determined by statistically determining the spatial changes of Istanbul (Table 3) and its districts (Table 4) using the Puyravaud method. Accordingly, it has been observed that forest and seminatural areas have decreased significantly from 1990 to 2018. The amounts of these changes from 2006–2012 to 2012–2018 range from 0.054 to 0.171, this value for the entire time period of 1990–2018 is 0.479 (Table 3).

As for the changes in the distribution of the forest areas in the districts of Istanbul, clear differences were observed in 26 of 38 districts (Table 4, Fig. 7). In the period of 1990–2000, it was determined that the deforestation, and the deterioration in other areas in Üsküdar district was −53.423%. In this period, after Üsküdar, a change of −21.378 was detected in Ataşehir (Fig. 7a). In the period of 2000–2006, although there is much less change compared to the previous period in most of the districts, the changes in Ataşehir, Esenyurt, and Kağıthane are rather high and −47.544%, −19.123%, and −16,780%, respectively (Fig. 7b). In the other periods, however, no significant change was observed (Fig. 7c, d). When the time period between 1990 and 2018 is evaluated in general, a change of −17.823% was observed in Ataşehir as the highest ratio (Fig. 7e).

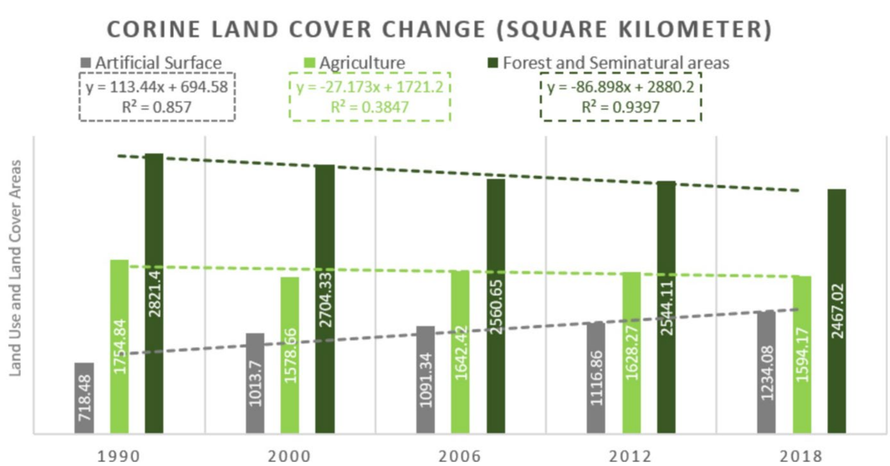

Fig. 4 Istanbul's land use and land cover area's temporal variation graph using the CLC dataset

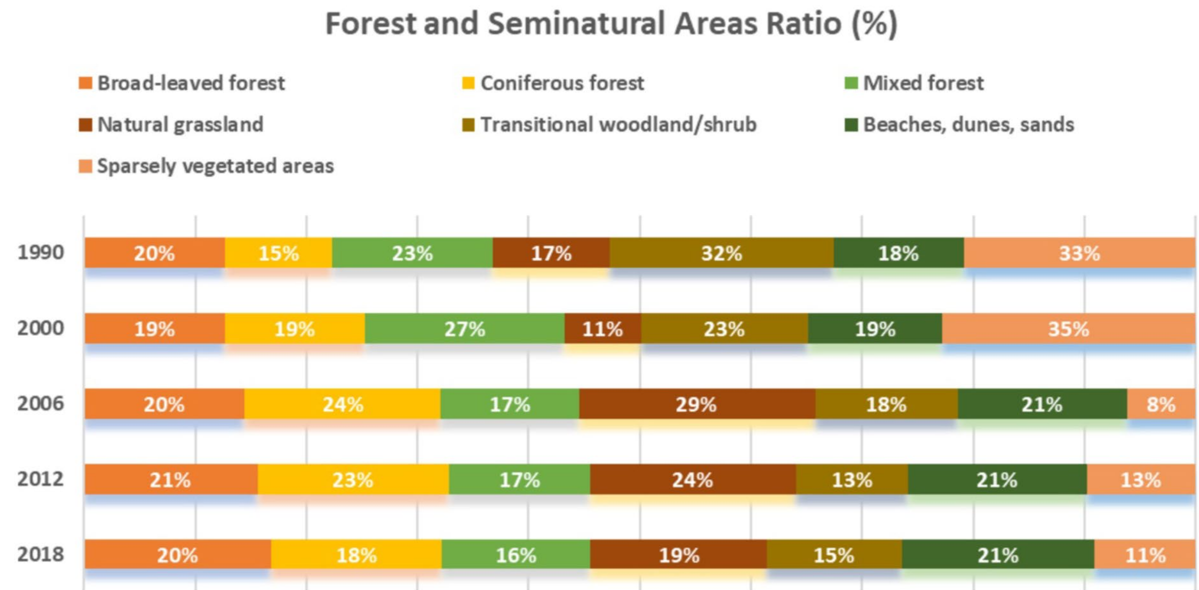

Fig. 5 Graphical representation of forest and seminatural areas ratio in Istanbul according to CLC dataset

Interpretation of forest and seminatural area in the study area with hot spot analysis

In the hot spot analysis, first, spatial autocorrelation (Moran's I) analysis was performed for the z-score evaluations (Table 3). As result, the distance threshold was found as 1029.1632 meters. Expected index, variance, and *p*-value were the same for all periods and were calculated as −0.000075, 0.000068, and 0.00000, respectively. The highest Moran's Index value is 0.7363 belongs to the 2000 period. The highest z-score values are 89.3694 in the 2000 period and the lowest 84.8419 in the 2018 period (Table 5).

The hot spot maps for 5 different periods show hot and cold areas for Istanbul (Fig. 8). In 1990, the natural areas in the north of Istanbul are hot regions with

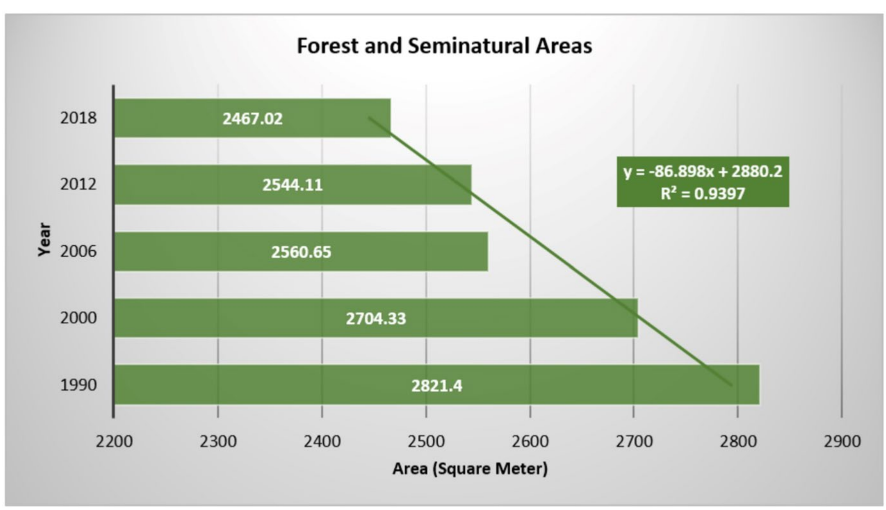

Fig. 6 Temporal change of forest and seminatural areas in Istanbul

Table 3 Deforestation and change seminatural areas for Istanbul as a Puyravoud formula

Years	***r* %**
1990–2000	−0.424
2000–2006	−0.910
2006–2012	−0.054
2012–2018	−0.171
1990–2018	−0.479

the 99% confidence level (Fig. 8) on the contrary, while southern areas reflected the cold regions.

When the other years were examined, it was determined that an imbalance started to occur in the southern parts, where the hot regions of the natural areas began to change. Cold spot areas are generally seen in urban areas. It is noteworthy that these areas later became increasingly irregular. Likewise, natural areas are hot spot areas. However, over the years, the statistical distributions of these areas began to show inconsistencies. Important changes in hot and cold regions were observed (Table 6).

A dramatic decrease in total G_i* forest areas also reveals the extreme clustering in forest areas (Fig. 9). Compared to the period of 1990, in the following periods, there was an increase in hot spot points at the 99% confidence level.

Determination of LC/LU change by geospatial statistical and qualitative (visual) methods

The Puyravaud analysis can only show the change in the coverage of the forest and seminatural areas. For more information in the interpretation of changing areas, we examined whether the change in forest areas show a statistically significant changes locally. As result, forest and seminatural areas have been transformed into artificial and agricultural areas

Table 4 Deforestation and change seminatural areas for districts as a Puyravoud formula

	1990–2000	**2000–2006**	**2006–2012**	**2012–2018**	**1990–2018**
Arnavutköy	0.222	0.352	−0.319	−3.950	−0.760
Ataşehir	−21.378	−47.544	0.000	0.000	−17.823
Avcilar	4.010	−13.683	−1.164	0.000	−1.749
Bağcilar	−2.877	0.000	0.000	0.000	0.000
Başakşehir	−2.723	−11.640	−9.008	−1.056	−5.623
Beykoz	−0.394	−1.596	0.039	−0.346	−0.549
Büyükçekmece	0.000	−73.445	59.016	0.000	−3.092
Çatalca	−0.088	−0.017	−0.108	−0.006	−0.060
Çekmeköy	−0.767	−1.307	−0.114	−1.211	−0.838
Esenyurt	−2.389	−19.123	0.000	0.000	0.000
Eyüp	−0.362	0.409	0.235	−1.370	−0.285
Kağithane	−1.596	−16.780	7.048	−3.154	−3.332
Kartal	−1.864	0.751	0.268	0.000	−0.447
Küçükçekmece	0.000	0.000	−0.505	0.000	0.000
Maltepe	−0.751	−2.827	−0.466	0.000	−0.974
Pendik	−1.258	−1.243	−0.168	−0.850	−0.934
Sancaktepe	−3.897	−0.552	−0.157	0.000	−1.543
Sariyer	−0.678	−0.806	0.190	−0.929	−0.573
SİLİVRİ	−0.278	−0.214	−0.041	−0.030	−0.160
Sultanbeyli	−7.679	−0.027	0.108	0.000	−2.725
Sultangazi	−1.903	−3.805	−0.348	−0.536	−1.684
Şile	−0.192	−1.563	−0.014	−0.041	−0.415
Şişli	0.000	0.000	0.000	0.000	0.000
Tuzla	−0.893	−2.805	−0.390	0.062	−0.990
Ümraniye	−7.146	−2.583	1.550	−1.779	−3.155
Üsküdar	−53.423	0.000	0.000	0.000	0.000

Gray color shows that according to the Puyravud formula, deforestation and natural areas have decreased in districts of Istanbul

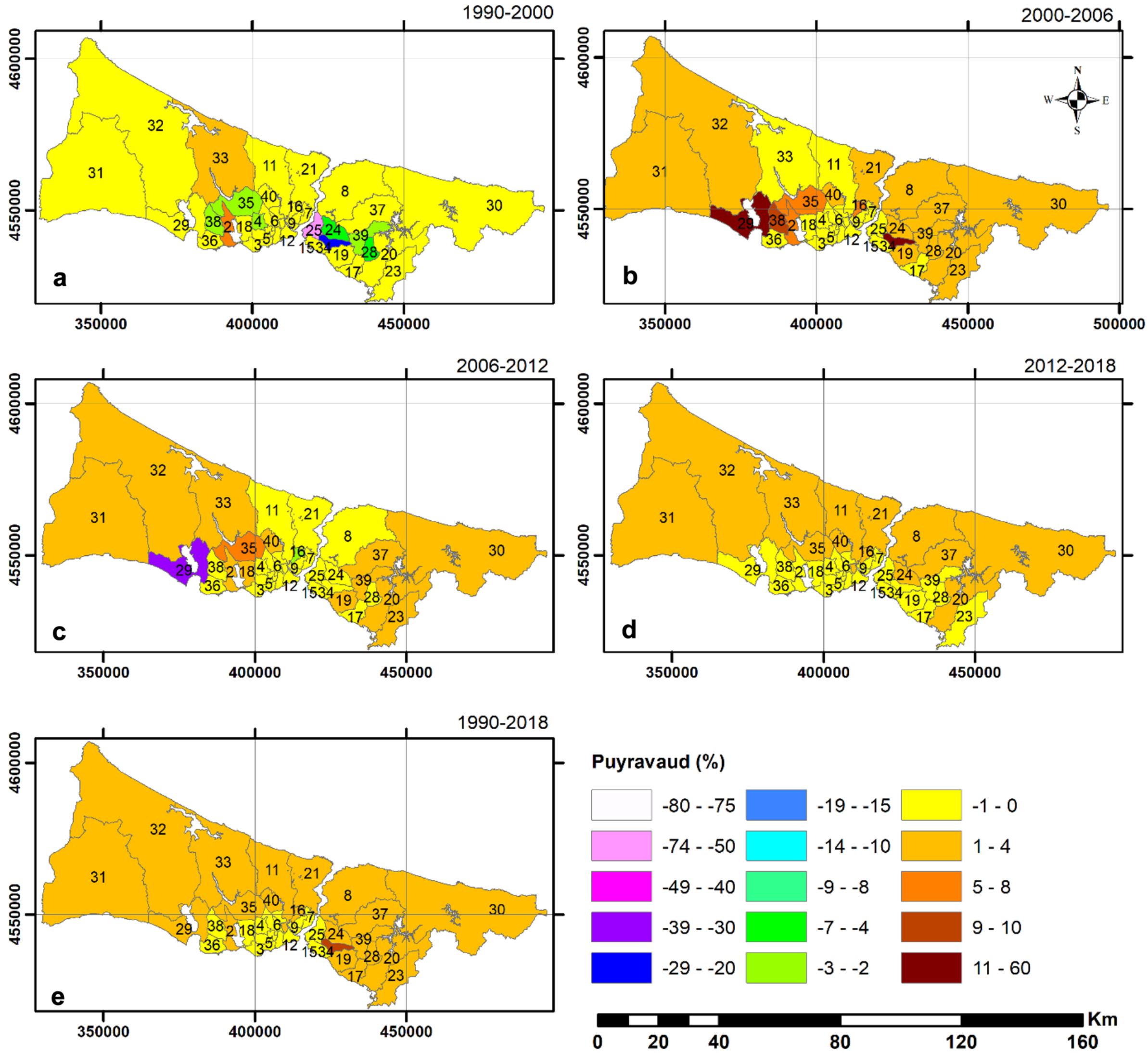

Fig. 7 Puyravaud maps; (**a**) 1990–2000, (**b**) 2000–2006, (**c**) 2006–2012, (**d**) 2012–2018, (**e**) 1900–2018 deforestation and change seminatural areas for districts

(Fig. 10). Particularly, hot spots can be seen clearly in these graphics (Fig. 10). During 1990–2000, changes concentrated mainly in the middle belt of the city (Fig. 10a). Later in 2000–2006 and 2006–2012, hot points distributed to natural areas around the city (Fig. 10b, c). In the period of 2012–2018, because of megaprojects (3rd bridge, Northern Marmara Highway and Istanbul Airport) on natural areas in the northern part of the city, changes concentrated in the northern forest areas (Fig. 10d). Thus, LC/LU changes occurred in whole land area of Istanbul in different time intervals.

Table 5 Spatial autocorrelation (Moran's *I*) values and z-scores for 5 periods of natural areas

Era	Moran's index	z-Score
1990	0.7355	89.2783
2000	0.7363	89.3694
2006	0.7190	87.2690
2012	0.7149	86.7800
2018	0.6990	84.8419

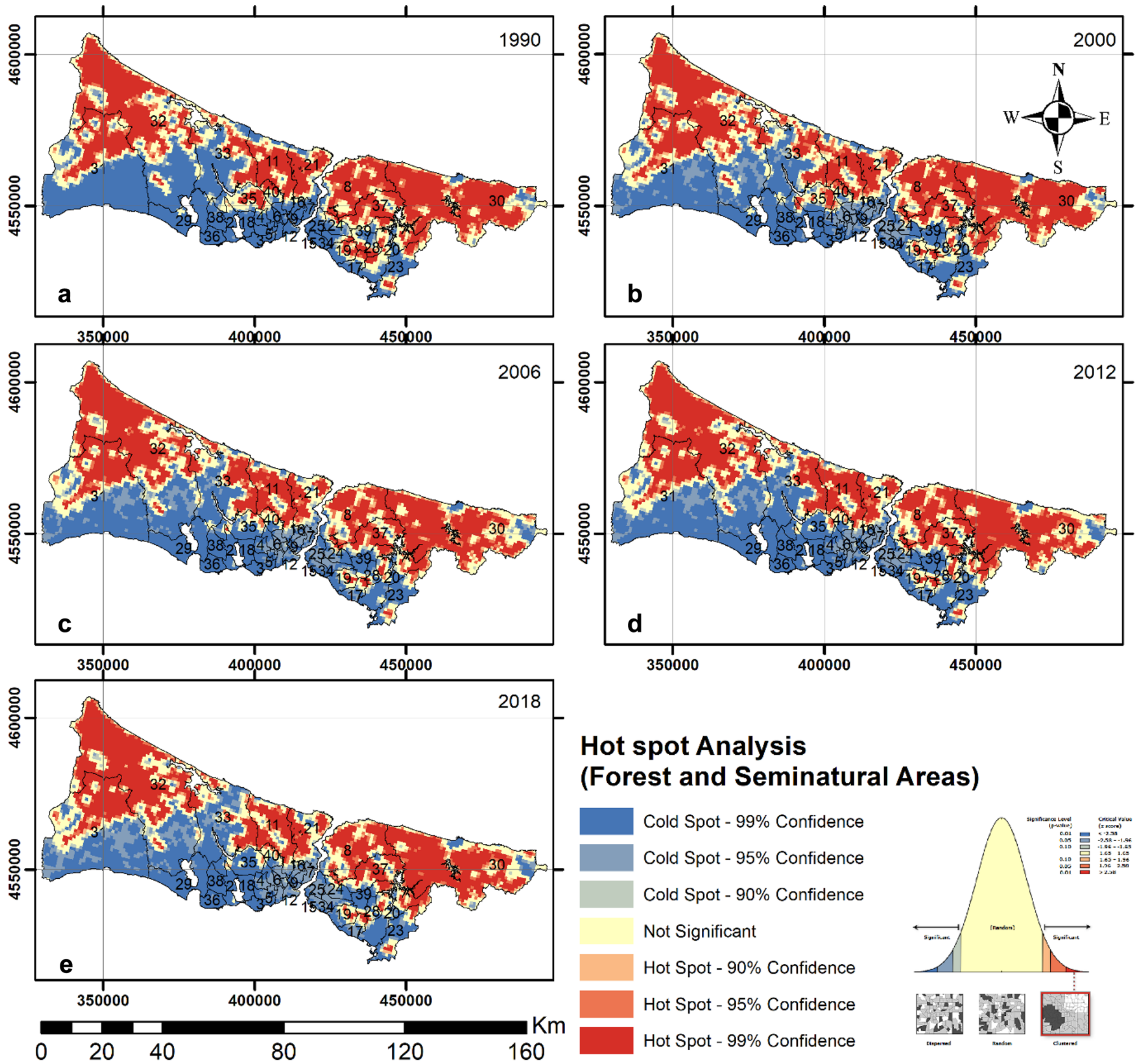

Fig. 8 Hot spot analysis maps for the years of (**a**) 1990, (**b**) 2000, (**c**) 2006, (**d**) 2012, (**e**) 2018 for forest and seminatural areas

Table 6 Percentage of forest and seminatural areas hot spot analysis confidence results

	Total Gi values (100*100 square meter)	Cold spot (99%)	Cold spot (95%)	Cold spot (90%)	No significant	Hot spot (90%)	Hot spot (95%)	Hot spot (99%)
1990	9959	19.83	6.43	3.35	40.35	3.62	12.06	14.36
2000	9711	19.28	6.46	3.79	41.42	4.06	7.92	17.08
2006	9524	19.23	7.17	3.01	42.40	4.32	7.41	16.46
2012	9497	19.36	7.29	3.50	41.75	3.87	7.10	17.13
2018	9427	19.57	7.46	3.25	41.93	3.56	7.98	16.25

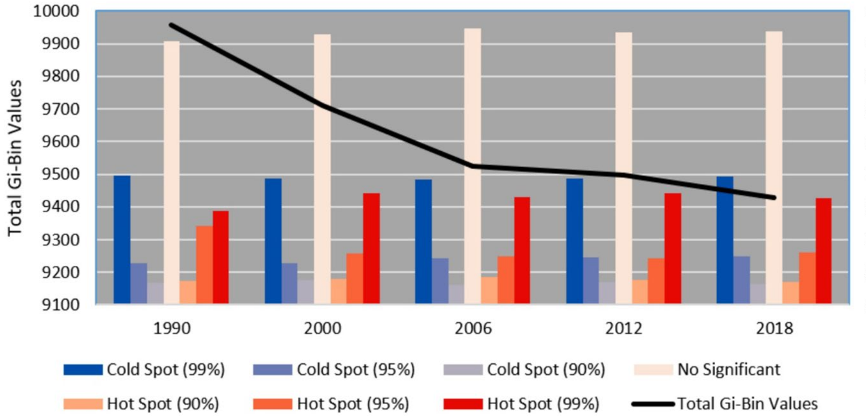

Fig. 9 Total G_i*-Bin values of the forest and seminatural areas hot spot analysis

After determining the statistically significant change zones, the usage function of the forest and seminatural areas was examined. After evaluating the results, it was revealed to which areas the changing areas shifted from the forest characteristic (Fig. 11).

The forest areas that changed in the 1990–2000 period are mostly seen in areas where settlement is dense. Among these regions, Sarıyer and Ataşehir are the districts, which occurred dramatically changes (Fig. 11a). In the years 2000–2006, the changed areas spread up to the district of Şile, where is in the northern border of Istanbul (Fig. 11b). In the period of 2006–2012, the changes in forest areas still continue and it is seen that it has spread to Pendik (Fig. 11c).

In the period of 1990–2000, we clearly observed that there has been a significant transformation from forest areas to artificial surfaces (Fig. 11a). In the period of 2000–2006, this transformation experienced in forest areas has been extended to agricultural lands (Fig. 11b). In the period of 2006–2012, there were much less transformations compared to other periods, and in this period, artificial surfaces and agricultural land transformations were encountered from forests (Fig. 11c). As also seen in the hot spot analysis, the period of 2012–2018 is the period, which occurred dramatically changes because of constructing Istanbul Airport, Northern Marmara Highway and the 3rd Bridge, which were referred as megaprojects (Fig. 11d).

Determination of LC/LU change with the forecasting method

In order to estimate the possible LC/LU change of the area in the next 10 years, the situation of artificial surfaces, agriculture, and forest areas was evaluated by applying the forecasting method. The statistical results of the forecasting model are shown in Table 7 as results (Table 7).Accordingly, it was concluded that artificial surfaces will increase almost twice as much in 2030 compared to 1990 (Fig. 12a), while agricultural areas will decrease by 11.20% (Fig. 12b) and forest areas by 20% (Fig. 12c).

Discussion

Since Istanbul has been an important culture, trade, and production city for the country from past to present, it has been constantly receiving immigrants from rural areas and recently from abroad. For this reason, the population doubled between 1990 and 2015, when industry and trade were concentrated (Gökburun, 2017). Due to the increase in population and trade, the urban area has increased in the city, the LC/LU exchange has accelerated, and the natural areas (forests, etc.) have gradually decreased. In this

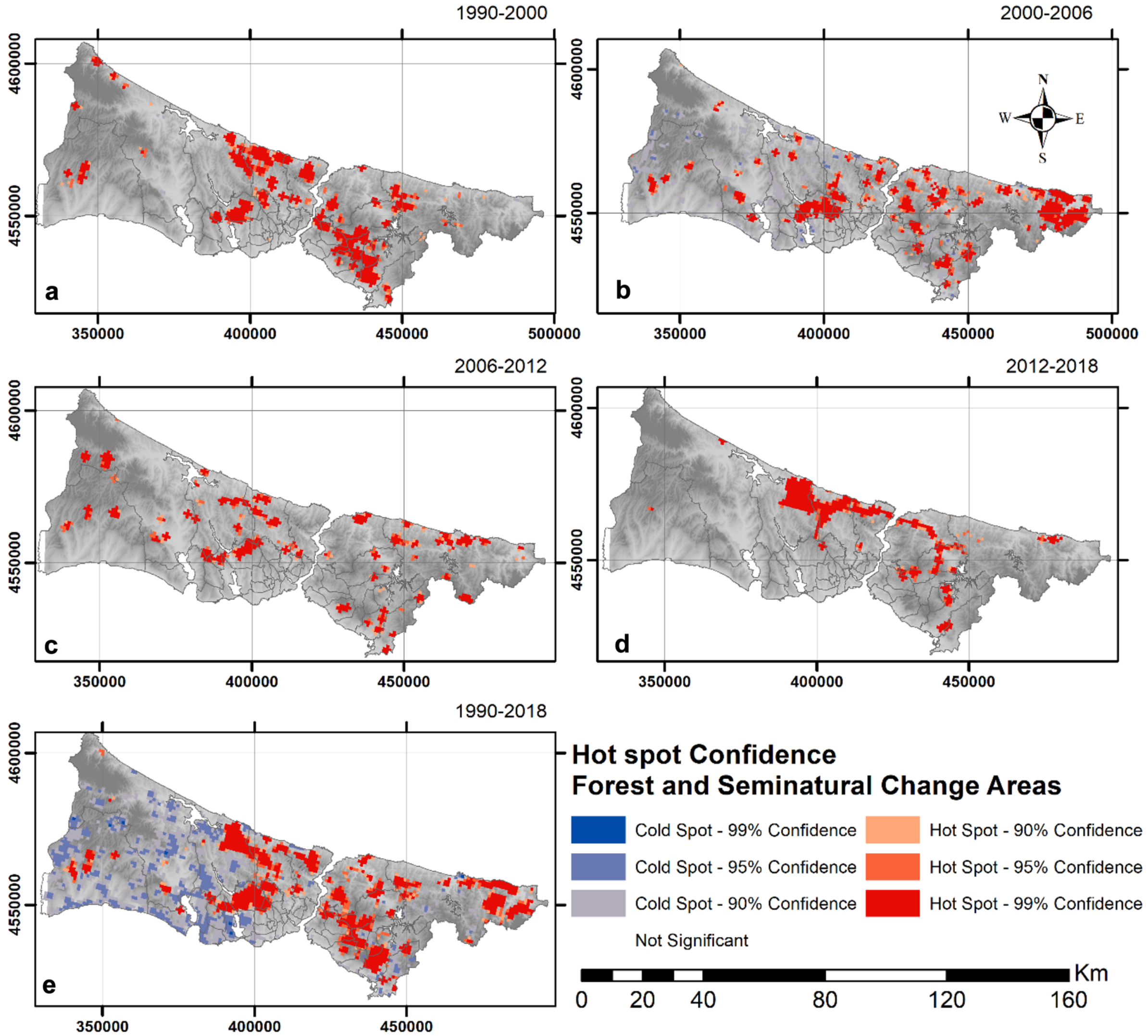

Fig. 10 Hot spot analysis results for forest area change for the years of (**a**) 1990–2000, (**b**) 2000–2006, (**c**) 2006–2012, (**d**) 2012–2018, (**e**.) 900–2018.

study, the land use of Istanbul was determined qualitatively and quantitatively according to CLC dataset, and it was determined that the LC/LU changed dramatically. These changes were revealed by making maps, and by using Puyravaud land change, rate, and hot spot analyzes. According to these analyzes:

- Between 1990 and 2018, forest areas decreased by 6.66% and agricultural areas decreased by 3.02% in Istanbul. On the other hand, artificial surfaces showed a similar increase of 9.69%.
- According to the hot spot analysis, the hot (woodland) regions decreased, while the cold (urban-artificial surface) regions increased. The increase in cold surfaces, especially on a district basis, has increased more in Sarıyer, Ataşehir, Şile, and Pendik districts with the effect of three megaprojects called Istanbul Airport, Northern Marmara Highway, and the 3rd Bridge.
- According to Puyravaud analysis, the greatest change was observed for the period of 2000–2006 with a −0.910 (*r* value) change. In the period of 1990–2018, there was a −0.479 (*r* value) change.

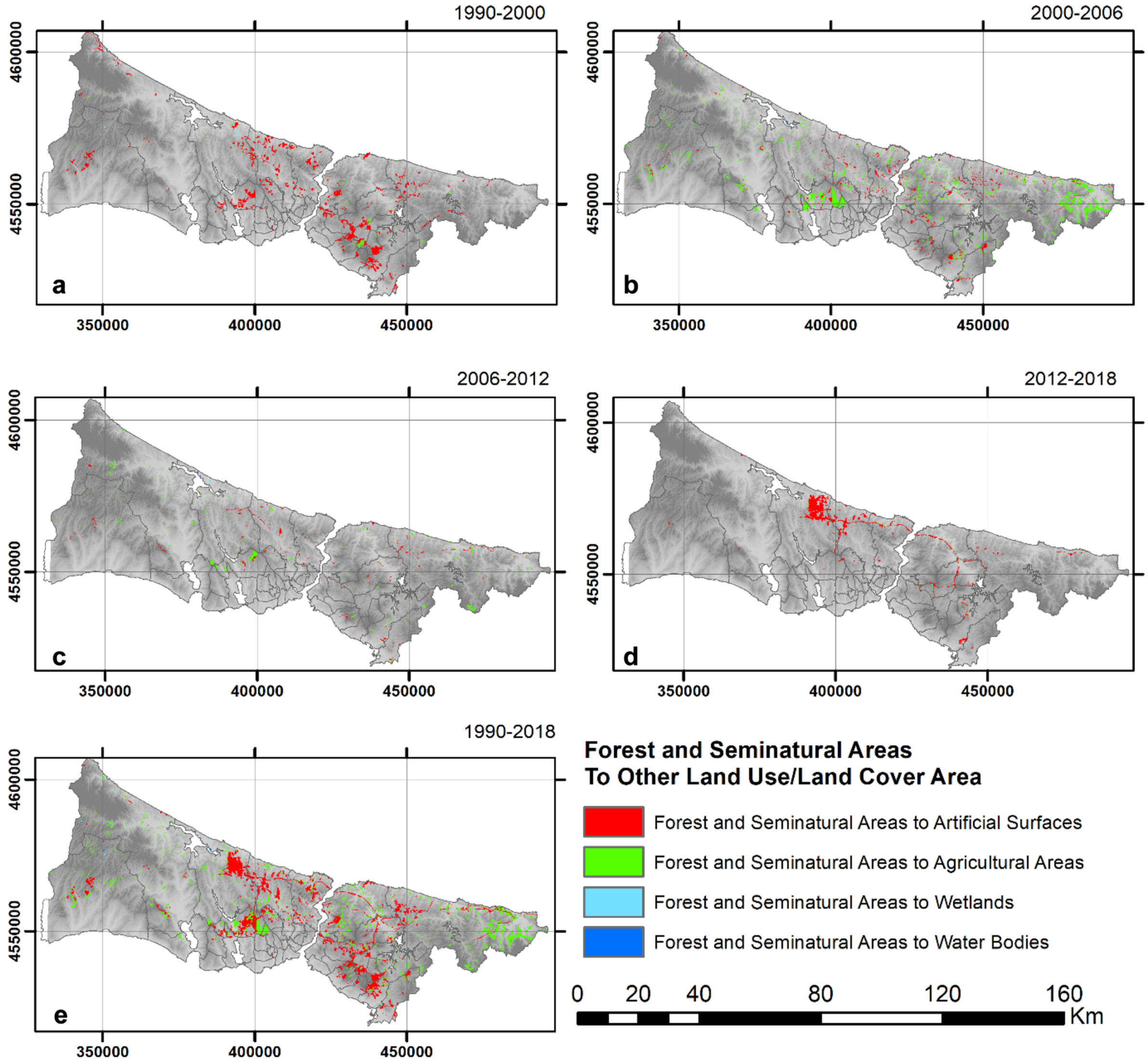

Fig. 11 Forest and seminatural areas to other land use/land cover area for years of (**a**) 1990–2000, (**b**) 2000–2006, (**c**) 2006–2012, (**d**) 2012–2018, (**e**)1900–2018

Almost all of these changes were observed in 26 out of 38 districts.

- The forecasting results showed that the artificial surfaces will be almost double, while the agricultural and forested areas will gradually decrease by 2030.

This situation has shown similar characteristics in cities such as Shanghai, China; Tokyo, Japan; Mexico, United Mexican State; and Lagos, Nigeria, where urbanization is intense in the world. Examining the LC/LU change of the city of Shanghai between 1979 and 2009, Yin et al. (2010) found that urbanization

Table 7 Statistical value of artificial surfaces, agricultural, forest, and seminatural areas in 2030 according to the forecasting method

Statistic	Artificial surfaces	Agricultural areas	Forest and seminatural areas
Alpha	0.90	0.75	0.00
Beta	0.00	0.00	0.00
Gamma	0.00	0.00	0.00
MASE	0.34	0.71	0.28
SMAPE	0.03	0.03	0.01
MAE	3,506.56	4114.19	2002.89
RMSE	4,419.39	5239.90	2350.12

accelerated at an unprecedented scale and rate in Shanghai over the specified period, resulting in a significant reduction in farmland and natural areas. In addition, Cui and Shi (2012) emphasized that compared to 1980 in Shanghai, land use types changed significantly in 2008, residential and construction areas were greatly expanded, and cultivated lands decreased. Ruiz-Luna and Berlanga-Robles (2003) found that natural vegetation and agricultural areas are gradually decreasing due to urban growth and development in Northwest Mexico. Millington and Tansey (2006) examined the LC/LU change of Lagos between 1984 and 2002 and found that the forest, low-density residential, and agricultural lands in the area were under threat. Bagan and Yamagata (2012) emphasized that large changes in land use and land cover occurred in the Tokyo metropolitan area during the period 1972–2011 with the rapid suburban growth accompanying the population concentration. With this study, as discussion above and similarly to many big cities in the world, we determined that due to the increase in population and urbanization movements in Istanbul, most of the agricultural and forest areas have been transformed into urban/built areas (for example, housing, industry, and public lands) and other uses (for example, parks), as well. We can also state that urbanization and land transformation processes from natural areas to artificial surfaces are similar in Istanbul as in other major cities of the world.

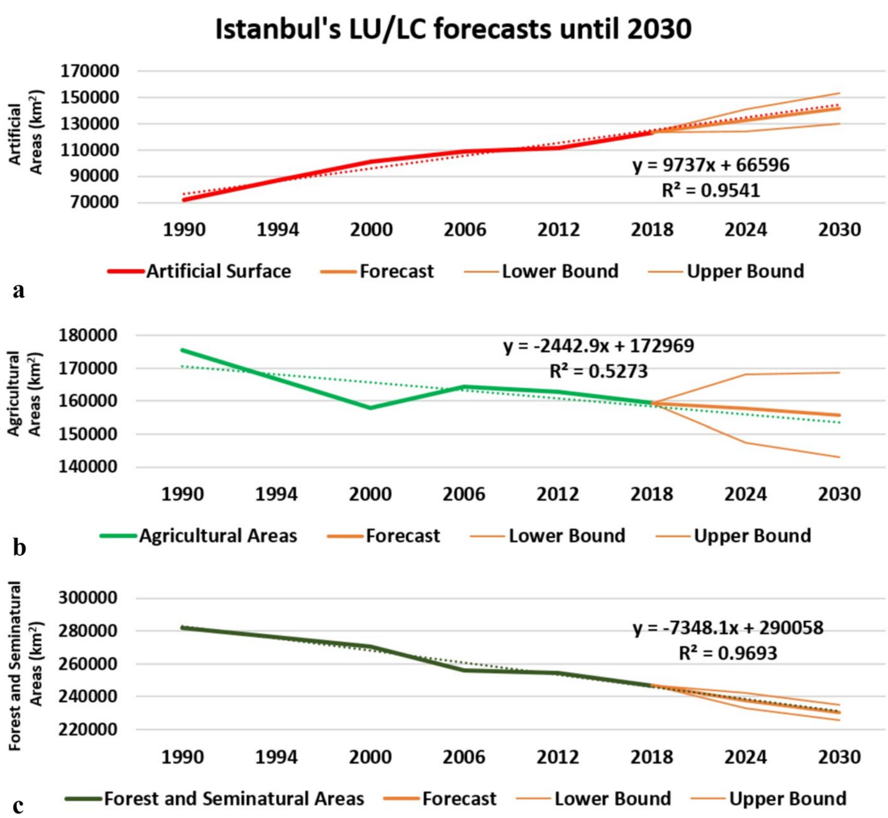

Fig. 12 Graphical representation of the estimated values of (**a**) artificial surfaces, (**b**) agricultural areas, (**c**) forest and seminatural areas in 2030 according to the forecasting method

Conclusions

Rapid population growth and urbanization are the most serious and one of the top threats in the world. This issue caused significant changes in the LC/LU in Istanbul, especially in the last 30 years. Istanbul lost a large amount of agricultural and forest areas, and these areas were transformed into urban artificial areas. As expected, this situation brought many serious environmental problems, including traffic, air pollution, urban heat islands, and increasing tree mortality in Istanbul, and it will continue in the future. The applied methods here in this study have been preferred due to being an easy and understandable methods in the analysis of spatial and temporal models of urban growth and land change, and in understanding and analyzing urban dynamics. The analyses also showed that urban expansion in Istanbul is strongly associated with irregular zoning movements, population density increase, and industrialization, especially as a result of incorrect planning decisions taken by central and local governments.

In conclusion, because of being dramatically changed, in the land areas of Istanbul, the government and local administration should (1) protect the agricultural and forest areas, (2) not open them to settlement and industrial areas, and (3) make laws for the planned development of urban areas.

We can suggest that the governmental authorities should take into account the population capacity of İstanbul, and ensure their sustainability by giving special statuses to areas that need to be protected in this megacity.

Availability of data and material Our manuscript has no associated data.

Code availability Not applicable

Declarations

Ethics approval Not applicable

Conflict of interest The authors declare no competing interests.

References

Attwell, K. (2000). Urban land resource and urban planting-case studies from Denmark. *Landscape and Urban Planning, 52*, 145–163. https://doi.org/10.1016/S0169-2046(00)00129-8

Aune-Lundberg, L., & Strand, G. H. (2021). The content and accuracy of the CORINE Land Cover dataset for Norway. *International Journal of Applied Earth Observation and Geoinformation, 96*, 102266. https://doi.org/10.1016/j.jag.2020.102266

Araya, Y. H. & Cabral, P. (2010). Analysis and modeling of urban land cover change in Setúbal and Sesimbra, Portugal. *Remote Sensing*, 2: 1549-1563. https://doi.org/10.3390/rs2061549

Akkemik, Ü. (2017). *Natural Plants of Istanbul*. ÇEKÜL Foundation Publications, 1152 pages.

Anselin, L. (1995). Local indicators of spatial association—LISA. *Geographical analysis, 27*(2), 93–115.

Anselin, L., & Rey, S. J. (2010). Perspectives on spatial data analysis. In *Perspectives on spatial data analysis* (pp. 1-20). Springer, Berlin, Heidelberg.

Avcı, M., Avcı, S., & Akkurt, S. (2015). Coastal dune vegetation in Turkey. A geographical perspective. Proceedings of the Twelfth International Conference on the Mediterranean Coastal Environment MEDCOST 2015, 06-10 October, Varna, Bulgaria, E. Özhan (Editor).

Bagan, H., & Yamagata, Y. (2012). Landsat analysis of urban growth: How Tokyo became the world's largest megacity during the last 40 years. *Remote Sensing of Environment, 127*, 210–222.

Byfield, A., Atay, S., & Özhatay, N. (2010). Important plant areas in Turkey: 122 Key Turkish Botanical Sites, WWF Turkey, Istanbul, 464 p.

Castanho, R. A., Naranjo Gomez, J. M., Vulevic, A., & Couto, G. (2021). The land-use change dynamics based on the corine data in the period 1990–2018 in the european archipelagos of the macaronesia region: Azores, canary islands, and madeira. *ISPRS International Journal of Geo-Information*. https://doi.org/10.3390/ijgi10050342

Chakravorty, S. (1995). Identifying crime clusters: The spatial principles. *Middle States Geographer, 28*, 53–58.

Chinpong, K., Thavornwattana, K., Armatrmontree, P., Chienwichai, P., Lawpoolsri, S., Silachamroon, U., & Rotejanaprasert, C. (2022). Spatiotemporal epidemiology of tuberculosis in Thailand from 2011 to 2020. *Biology, 11*(5), 755.

Cole, B., Smith, G., de la Barreda-Bautista, B., Hamer, A., Payne, M., Codd, T., Johnson, S. C. M., Chan, L. Y., & Balzter, H. (2022). Dynamic landscapes in the UK driven by pressures from energy production and forestry—Results of the CORINE Land Cover map 2018. *Land*. https://doi.org/10.3390/land11020192

Cui, L., & Shi, J. (2012). Urbanization and its environmental effects in Shanghai, China. *Urban Climate, 2*, 1–15.

Demonstrating heat stress in European cities, Implemented by ECMWF as part of The Copernicus Programme. Retrieved March 14, 2021, from https://climate.copernicus.eu/demonstrating-heat-stress-european-cities

Doygun, H., Berberoğlu, H., & Alphan, H. (2003). The determination of land use changes by using remote sensing in Burnaz coastal dunes Hatay. *Ecology, 12*(48), 4–9.

Doygun, H., İlçim, A., Atmaca, M., & Oğuz, H. (2010). *Biotope Mapping in the City of Kahramanmaraş*. Scientific and Technological Research Council of Turkey (Unpublished), Kahramanmaraş.

Esbah, H. (2006). Examining the city parks in Aydin in terms of some ecological quality criteria. *Ecology, 15*(58), 42–48.

ESRI Inc. (2016). ArcMap (version 10.5). Software. Redlands, CA: Esri Inc, 2016.

ESRI (Environmental Systems Research Institute, Inc). (2022a). Hot spot analysis (Getis-Ord Gi*) (spatial statistics), Retrieved from: https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/hot-spot-analysis.htm

ESRI (Environmental Systems Research Institute, Inc). (2022b). Modeling spatial relationships, Retrieved from: https://pro.arcgis.com/en/pro-app/2.8/tool-reference/spatial-statistics/modeling-spatial-relationships.htm#GUID-729B3B01-6911-41E9-AA99-8A4CF74EEE27

Excel forecasting functions. Retrieved March 14, 2021, from https://www.ablebits.com/office-addins-blog/excel-forecast-function-formulaexamples/

Falcucci, A., Maiorano, L., & Boitani, L. (2007). Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. *Landscape Ecology, 22*, 617–631.

Feranec, J., Jaffrain, G., Soukup, T., & Hazeu, G. (2010). Determining changes and flows in European landscapes 1990–2000 using CORINE Land Cover data. *Applied Geography, 30*, 19–35. https://doi.org/10.1016/j.apgeog.2009.07.003

Fischer, M. M., Reismann, M., & Scherngell, T. (2010). Spatial interaction and spatial autocorrelation. In *Perspectives on spatial data analysis* (pp. 61-79). Springer, Berlin, Heidelberg.

Galiano, R., & Olmo, C. (2012). Land cover change analysis of a Mediterranean area in Spain using different sources of data: Multi-seasonal landsat images, land surface temperature, digital terrain models and texture. *Applied Geography, 35*(1–2), 208–218.

Getis, A., & Ord, J. K. (2010). The analysis of spatial association by use of distance statistics. In *Perspectives on spatial data analysis* (pp. 127-145). Springer, Berlin, Heidelberg.

Gül, A., & Küçük, V. (2001). The research of Isparta and the open-green areas in urban. *Faculty of Forestry Journal Süleyman Demirel University, 2*, 27–48.

Gökburun, İ. (2017). Population development and inclusive distribution in İstanbul (1950-2015). *Journal of Anatolian Cultural Research*, 2017, 1 (3), 110-130.

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry and Urban Greening, 2*, 1–18. https://doi.org/10.1078/1618-8667-00019

Guerri, G., Crisci, A., Cresci, I., Congedo, L., Munafò, M., & Morabito, M. (2022). Residential buildings' real estate values linked to summer surface thermal anomaly patterns and urban features: A Florence (Italy) case study. *Sustainability, 14*(14), 8412.

György B., Kosztra, B., Maucha, G., Patak, R., Kleeschulte, S., Hazeu, G., Vittek, M., Schröder, C., & Littkopf, A. (2021). *CORINE Land Cover Product User Manual (Version 1.0)*, Copernicus Land Monitoring Service.

Hazaymeh, K., Almagbile, A., & Alomari, A. H. (2022). Spatiotemporal analysis of traffic accidents hotspots based on geospatial techniques. *ISPRS International Journal of Geo-Information, 11*(4), 260.

Işık, Ş. (2005). Urbanisation and urbanisation models in Turkey. *Aegean Geographical Journal, 14*, 57–71.

Islam, M. Z., Islam, M. M., Rahman, M., & Khan, M. (2022). Exploring hot spots of short birth intervals and associated factors using a nationally representative survey in Bangladesh. *Scientific Reports, 12*(1), 1–10.

Istanbul Provincial Environmental Status Report. (2012). Retrieved January 26, 2020, from https://webdosya.csb.gov.tr/db/istanbul/icerikbelge/icerikbelge43891.pdf

Kandemir, N. (2012). Analyzing land cover changes with Gis and satellite images in Akfırat and its surroundings (Tuzla - Istanbul), Northwest Turkey. MSc Thesis (Unpublished), Sakarya University, Institute of Social Sciences, Sakarya.

Karlström, A., & Ceccato, V. (2000). A new information theoretical measure of global and local spatial association.

Kolios, S., & Stylios, C. D. (2013). Identification of land cover/land use changes in the greater area of the Preveza peninsula in Greece using Landsat satellite data. *Applied Geography, 40*, 150–160.

Koç, A. (2006). Determination of land use changes in Istanbul between 1975-2000 with landsat mss and landsat etm+ data. *Istanbul University Faculty of Forestry Journal*, *56* (2), 15-34.

Konukcu, F., Albut, S., & Alturk, B. (2017). Land use/land cover change modelling of ergene river basin in Western Turkey using CORINE land use/land cover data. *Agronomy Research, 15*, 435–443.

Kortas, F., Grigoriev, A., & Piccillo, G. (2022). Exploring multi-scale variability in hotspot mapping: A case study on housing prices and crime occurrences in Heerlen. *Cities, 128*, 103814.

Kosztra, B., Büttner, G., Hazeu, G., & Arnold, S. (2017). *Updated CLC illustrated nomenclature guidelines, European Environment Agency*. Environment Agency Austria; EAA Spittelauer Lände 5 1090 Wien Austria.

Kuşak, L., & Küçükali, U. F. (2019). Outlier detection of land surface temperature: Küçükçekmece Region. *International Journal of Engineering and Geosciences, 4*(1), 1–7. https://doi.org/10.26833/ijeg.404426

Li, F., Wang, R., Paulussen, J., & Liu, X. (2005). Comprehensive concept planning of urban greening based on ecological principles: A case study in Beijing China. *Landscape and Urban Planning, 72*, 325–336. https://doi.org/10.1016/j.landurbplan.2004.04.002

Littke, H. (2015). Planning the green walkable city: Conceptualizing values and conflicts for urban green space strategies in Stockholm. *Sustainability, 7*, 11306–11320. https://doi.org/10.3390/su70811306

Munsi, M., Malaviya, S., Oinam, G., & Joshi, P. K. (2010). A landscape approach for quantifying land-use and land-cover change (1976–2006) in middle Himalaya. *Regional Environmental Change, 10*, 145–155. https://doi.org/10.1007/s10113-009-0101-0

Muchuma, K. F., Obando, J., & Kweyu, R. (2021). Land use/land cover change detection using geospatial techniques and field survey on Chetambe Hills in Bungoma County, Kenya. *Middle East Journal of Applied Science & Technology*, 4(1), 80-93, January-March 2021, Available at SSRN: https://ssrn.com/abstract=3815289

Manlun, Y. (2003). Suitability analysis of urban green space system based on GIS. MSc Thesis (Unpublished), International Institute for Geo-Information Science and Earth Observation, The Netherlands.

Millington A. C., & Tansey, K. T. (2006). Retrieved January 20, 2022, from Land use/land cover change detectıon in metropolitan Lagos (Nigeria): 1984-2002. http://www.asprs.org/a/publications/proceedings/reno2006/0002.pdf

Nelson, T. A., & Boots, B. (2008). Detecting spatial hot spots in landscape ecology. *Ecography, 31*(5), 556–566.

Ord, J. K., & Getis, A. (1995). Local spatial autocorrelation statistics: Distributional issues and an application. *Geographical Analysis, 27*, 286–306. https://doi.org/10.1111/j.1538-4632.1995.tb00912.x

Pasha, S. V., Reddy, C. S., Jha, C. S., Rao, P. V. V. P., & Dadhwal, V. K. (2016). Assessment of land cover change hotspots in Gulf of Kachchh, India using multi-temporal remote sensing data and GIS. *Journal of the Indian Society of Remote Sensing, 44*, 905–913. https://doi.org/10.1007/s12524-016-0562-9

Paul, S., Saxena, K. G., Nagendra, H., & Lele, N. (2021). Tracing land use and land cover change in peri-urban Delhi, India, over 1973–2017 period. *Environmental Monitoring and Assessment*. https://doi.org/10.1007/s10661-020-08841-x

Peiman, R. (2011). Pre-classification and post-classification changedetection techniques to monitor land-cover and land-use change using multi-temporal Landsat imagery: A case study on Pisa Province in Italy. *International Journal of Remote Sensing, 32–15*, 4365–4381. https://doi.org/10.1080/01431161.2010.486806

Puyravaud, J. P. (2003). Standardizing the calculation of the annual rate of deforestation. *Forest Ecology and Management, 177*, 593–596.

Ridder, D. K., Adamec, V., Banuelos, A., Bruse, M., Bürger, M., Damsgaard, O., Dufek, J., Hirsch, J., Lefebre, F., Perez Lacorzana, J. M., Thierry, A., & Weber, C. (2004). An integrated methodology to assess the benefits of urban green spaces. *Science and the Total Environment, 334–335*, 489–497. https://doi.org/10.1016/j.scitotenv.2004.04.054

Ruiz-Luna, A., & Berlanga-Robles, C. A. (2003). Land use, land cover changes and costal lagoon surface reduction associated with urban growth in northwest Mexico. *Landscape Ecology, 18*, 159–171. https://doi.org/10.1023/A:1024461215456

Rodríguez, N., Armenteras, D., & Retana, J. (2013). Land use and land cover change in the Colombian Andes: Dynamics and future scenarios. *Journal of Land Use Science, 8*(2), 154–174. https://doi.org/10.1080/1747423X.2011.650228

Rossi, F., & Becker, G. (2019). Creating forest management units with Hot Spot Analysis (Getis-Ord Gi*) over a forest affected by mixed-severity fires. *Australian Forestry, 82*(4), 166–175.

Saranya, K. R. L., Lakshmi, T. V., & Reddy, C. S. (2022). Analysing the trends in annual forest loss hotspots in the regional landscape of Eastern Ghats, India. *Remote Sensing Applications: Society and Environment, 26*, 100731. https://doi.org/10.1016/j.rsase.2022.100731

Sancar, C., Özen, T. S., & Kadioğulları, A. İ. (2009). Land use-cover change processes in Urban fringe areas: Trabzon case study Turkey. *Scientific Research and Essay, 4*(12), 1454–1462. https://doi.org/10.5897/SRE.9000624

Schulz, J. J., Cayuela, L., Echeverria, C., Salas, J., & Marı´a, J. & Benayas, R. (2010). Monitoring land cover change of the dryland forest landscape of Central Chile (1975–2008). *Applied Geography, 30*, 436–447. https://doi.org/10.1016/j.apgeog.2009.12.003

Solecki, W. D., Rosenzweig, C., Parshall, L., Pope, G., Clark, M., Cox, J., & Wiencke, M. (2005). Mitigation of the heat island effect in urban New Jersey. *Environmental Hazards, 6*, 39–49. https://doi.org/10.1016/j.hazards.2004.12.002

Shin, D. H., & Lee, K. S. (2005). Use of remote sensing and geographical information system to estimate green space temperature change as a result of urban expansion. *Landscape and Ecological Engineering, 1*, 169–176.

Şimşek Kuşçu, Ç., & Şengezer, B. (2012). The importance of green spaces in minimizing urban heat in the Istanbul Metropolitan Area. *Megaron, 7*(2), 116–128.

Tantipisanuh, N., & Gale, G. A. (2022). Identification of areas highly vulnerable to land conversion: A case study from Southern Thailand. *Environmental Management, 69*, 323–332. https://doi.org/10.1007/s00267-021-01576-6

Tariq, A., Shu, H., Siddiqui, S., Imran, M., & Farhan, M. (2021). Monitoring land use and land cover changes using geospatial techniques, a case study of Fateh Jang, Attock, Pakistan. *Geography, Environment, Sustainability,* 14, 41–52. https://doi.org/10.24057/2071-9388-2020-117

Thakur, S., Maity, D., Mondal, I., Basumatary, G., Ghosh, P. B., Das, P., & De, T. K. (2021). Assessment of changes in land use, land cover, and land surface temperature in the mangrove forest of Sundarbans, northeast coast of India. *Environment, Development and Sustainability, 23*, 1917–1943. https://doi.org/10.1007/s10668-020-00656-7

Teixeira, Z., Teixeira, H., & Marques, J. C. (2014). Systematic processes of land use/land cover change to identify relevant driving forces: Implications on water quality. *Science of the Total Environment, 470–471*, 1320–1335. https://doi.org/10.1016/j.scitotenv.2013.10.098

Tovar, C., Seijmonsbergen, A. C., & Duivenvoorden, J. F. (2013). Monitoring land use and land cover change in mountain regions: An example in the Jalca grasslands of the Peruvian Andes. *Landscape and Urban Planning, 112*, 40–49. https://doi.org/10.1016/j.landurbplan.2012.12.003

Vittek, M., Brink, A., Donnay, F., Simonetti, D., & Desclée, B. (2014). Land cover change monitoring using landsat MSS/TM satellite image data over West Africa between 1975 and 1990. *Remote Sensing, 6*(1), 658–676. https://doi.org/10.3390/rs6010658

Westmacott, R. (1991). Scale economics: Ecological theory and planning practice in urban landscapes. *Landscape and Urban Planning, 21*, 21–29. https://doi.org/10.1016/0169-2046(91)90030-P

Wu, X., Mao, R., & Guo, X. (2022). Equilibrium of tiered healthcare resources during the COVID-19 pandemic in China: A CASE STUDy of Taiyuan, Shanxi Province. *International Journal of Environmental Research and Public Health, 19*(12), 7035.

Xu, B., Qi, B., Ji, K., Liu, Z., Deng, L., & Jiang, L. (2022). Emerging hot spot analysis and the spatial–temporal trends of NDVI in the Jing River Basin of China. *Environmental Earth Sciences, 81*, 1–15. https://doi.org/10.1007/s12665-022-10175-5

Yıldızcı, A. C. (1982). Urban green space planning and the example of Istanbul. Associate Professor's thesis (Unpublished). ITU Faculty of Architecture, Istanbul.

Yin, J., Zhong, H., Xu, S., Wang, J., & Wu, J. (2010). Monitoring urban expansion and land use/land cover changes of Shanghai metropolitan area during the transitional economy (1979–2009) in China. *Environmental Monitoring and Assessment, 177*, 609–621.