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Exploring patterns and consequences of land consumption in a coastal city-region

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Abstract

Background: The rapid expansion of built-up areas and land consumption with unsustainable spatial patterns in coastal urban areas has become a global major concern due to its far-reaching consequences for human daily life, environmental sustainability, and living organisms. However, the research on this phenomenon in these areas has received less attention. To fill this gap, we conducted a study to explore the spatial patterns of land consumption at both micro- and macro-levels and to evaluate its consequences in terms of sustainable development in a coastal city-region of Mazandaran Province in northern Iran. To achieve these two goals, we combined two methods of urban land density function and landscape expansion index (LEI) to explore spatial patterns of land consumption and also evaluated the sustainability of the region with two methods of the hierarchical analytical process (AHP) and urban sustainability index (USI).

Results: The spatial patterns of land consumption in the city-region of Mazandaran from 1996 to 2016 at the macro-level changed from a decentralized-sprawl to a centralized-sprawl pattern. At the micro-level, the dominant spatial pattern of land consumption in the city-region changed gradually from the outlying pattern towards the edge expansion and infilling patterns. Also, the spatial pattern of the built-up patches in the majority of the urban areas had conformity with the dominant pattern of the region. Besides, the spatial patterns of land consumption in the region were in an unsustainable state and were changing towards more unsustainability. The absence of urban containment policies and plans could lead to further destruction of the natural environment and increase its unsustainability.

Conclusions: Our results indicate that the urban areas of the coastal Mazandaran have the same behavior in the spatial pattern of land consumption at the macro- and micro-levels and all are in the same direction and follow the dominant pattern of the region.

Keywords: Land consumption, Land use change, Spatial pattern, Urban growth, Sprawl, Sustainability, Consequence, Urban area

Introduction

Land consumption is a process of land use changes from non-urban (agricultural and natural) uses to urban uses, through the construction of buildings and the necessary infrastructure to meet human needs (Angel et al. 2011). Clearly, it is not the land that is being consumed, but the term "consumption" simply refers to the loss of ecosystem services (or even all ecosystems) in a very short period of time due to physical changes in land cover. The obvious outcomes of this phenomenon are the spatial expansion of urban land consumption with a significant change in land cover characteristics, urban shape, spatial imbalance (Araya and Cabral 2010), change in density and land use pattern, reduction of environmental quality and fragmentation of natural resources (Angel et al. 2011; Bencardino and Iovino 2014), which will eventually lead to environmental changes such as the rise of minimum temperatures, change of precipitation patterns, reduced ability of food production, reduced biodiversity, extinction of

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animals, and loss of property and human life (Grekousis and Mountrakis 2014; Grimm et al. 2008).

To address the crises and negative consequences of the land consumption phenomenon, many efforts have been done to identify spatial patterns of urban expansion and land consumption at both macro- and micro-levels and analyze these patterns concerning the efficiency of land storage resources and compliance with criteria of sustainable development (Dong et al. 2019; Grekousis and Mountrakis 2015; Chakraborty et al. 2022). The recognition, analysis, and disclosure of the expansion patterns of built-up areas and their evaluation based on sustainable development criteria provide a basis for spatial planning and its sustainability and the promotion of policies and strategies for future urban development (Dong et al. 2019).

In the most existing studies, the main focus was on the trend of urban expansion and the phenomenon of land consumption, which can be divided into two major categories. First, scholars such as Jiao (2015), Dong et al. (2019), and Peiser (2001) have only studied the spatial patterns at the macro-level. Macro-pattern usually refers to spatial patterns and changes in land consumption that are either compact or sprawl. The main characteristic of these patterns is the amount of density, the directions of urban expansion, and the amount of land consumption. The second category has studied the patterns of land consumption only at the surface of the urban patches and grading of non-urban lands and the natural environment (Forman, 1995). Scholars such as Sun et al. (2019), Wu et al. (2015), and McGarigal et al. (2015) have used urban landscape metrics, not spatially but quantitatively, in terms of complexity, dispersion, compactness, and centrality. Also in this category, authors such as Forman (1995), Liu et al. (2010), Zhao et al. (2015), Shi et al. (2012), and Wilson et al. (2003) have presented indicators such as landscape expansion index (LEI), proximity expansion index (PEI) and have provided various patterns such as edge, infilling, outlying patterns as well as complementary patterns such as isolated, linear, and cluster.

Spatial patterns at both macro- and micro-levels have been performed in only a small number of studies (e.g., Xu et al. 2019). These scholars believe that a full understanding of spatial patterns requires consideration of both macro- and micro-levels. Because the main reason for the change in macro-patterns of land consumption is the creation of new urban patches, the research on the spatial relationships between new urban patches and existing urban patches is necessary for indicating the characteristics of urban expansion and land consumption at the micro-level. It can help set the rules and policies for those urban patches that have caused major changes in land resources and lead to consistent and controlling policies (Xu et al. 2019; Batty 2008; Liu et al. 2017; Zeng et al. 2014).

In the field of measuring the sustainability of land consumption phenomenon and its spatial patterns, studies conducted in this field (such as spatial patterns of land consumption) can be divided into several categories. First, scholars such as Boggia and Cortina (2010), Van Dijk and Mingshun (2005), and Altwegg et al. (2004) have used various indicators such as population density, energy efficiency, GDP growth rate, and per capita green land for measuring different dimensions of sustainable development in the region, regardless of the pattern of expansion of built-up lands and its level of sustainability. In another category, authors such as Pili et al. (2017), Dong et al. (2019), Schneider and Woodcock (2008), and Barbosa et al. (2017) by considering the landscape metrics and methods such as the Moran index and urban land density function, have evaluated spatial patterns of land consumption and their degree of sustainability or unsustainability. They believe that compact and centralized patterns are sustainable and sprawl patterns are moving towards unsustainability. The compact and centralized patterns lead to increased density, limited land consumption, and reduced vehicle and energy use. Thus, it is more sustainable and productive than sprawl patterns. The third type of research that constitutes a very small share of the total research on sustainability evaluation can be found in studies by scholars such as Xian et al. (2019) who explore the spatial pattern of land consumption along with its evaluation based on different dimensions of sustainable development. In this research, the spatial patterns of land consumption in an urban area have been studied at the micro-level and the level of its sustainability has been evaluated based on indicators such as energy efficiency, the productivity of built-up lands, economic productivity, and population productivity.

In addition, studies in coastal areas are also very rare, even though land consumption in these types of areas is widespread, which has contributed to its environmental unsustainability (Hinrichsen 1998; McGranahan et al. 2005; UN-Habitat 2009). An increased population in these areas due to the attractiveness of tourism, industry, services, and logistics leads to an increase in the need for agriculture and housing and the expansion of built-up areas, causing severe pressure on coastal lands (Hinrichsen 1998; McGranahan et al. 2005; UN-Habitat 2009). This ultimately leads to the destruction of coastal ecosystems and reduces biodiversity and sustainability (Parkes et al. 2003; Cohen et al. 1997). For this reason, since the 1980s, the United Nations Environment Program/Global Action Plan (UNEP/GPA) has sought to protect coastal environments through sustainable land use planning

(Turner et al. 2003; Fan et al. 2018). Despite its importance and the attempts of the United Nations in this field, only a limited number of studies such as Zhang et al (2019); Yao (2013); Yılmaz and Terz (2021), and Akubia (2019) have dealt with the issue of land consumption in coastal areas, the majority of which have discussed the increase in land consumption, per capita and its intensity. However, the status of consistent and sustainable land consumption patterns in coastal areas to provide effective programs and solutions and achieve sustainable development goals in these areas has not been properly addressed.

In the meantime, the coastal city-region of Mazandaran Province is one of the valuable regions of Iran in terms of environmental conditions (location along the Caspian seacoast and the presence of Hyrcanian forests), high agricultural capacity, and many small and medium-sized cities around them. In the last two decades, this region has been faced with unplanned and uncontrolled constructions and as a result of high rate of land consumption, expansion of built-up lands, and severe destruction of agricultural and forest lands. However, like many coastal urban areas, studies on this area are very rare. To fill out this gap, the current paper aims to explore the spatial patterns and consequences of land consumption in the coastal city-region of Mazandaran. Specifically, the aim of this paper is threefold: (1) analyzing the trend of land cover changes in the coastal city-region of Mazandaran from 1996 to 2016; (2) exploring spatial patterns of land consumption in a region with a unique coastal natural values; (3) measuring the consequences of these patterns on sustainability of the region.

Materials and methods

Study area

The research area is the coastal city-region of Mazandaran with a northern latitude of 35° 47′ to 36° 35′ and eastern longitude of 50° 34′ to 54° 10′ located in the northern part of Iran along the Caspian Sea and the Alborz Mountains. This city-region includes an area of about 27,000 km^2 and a population of about 3.3 million in 2016. It has a dense forest cover with high annual rainfall of about 678 mm (Statistics Centre of Iran 2018). The city-region of Mazandaran is very important due to its natural lands and high agriculture-based economic capacity (Dadashpoor and Salarian 2020). This city-region is one of the most fertile regions of Iran due to its proximity to the Caspian Sea and plains in the northern part and mountainous and high areas in the southern part. It has unique climatic conditions, beautiful natural landscapes, and various habitats and wildlife sanctuaries which are home to more than 250 species of plants and animals. Physiographic conditions, land shape, climatic conditions, and location of this region in terms of occurrence and enjoyment of local rainfall flows in Siberia and the Mediterranean Sea have created the large and small waterways and rivers that play an important role in fertility and diversity of aquatic and other plants/animal species in this area.

According to the divisions of Iran in 2016, this region consists of 22 urban areas (counties) with different areas, some of which are plains and some are coastal plains. However, among these 22 urban areas, a number of them, such as Simorgh, Miandrood, and Abbasabad in 1996 and 2006 had not yet been established as a county and were part of other urban areas. For this reason, their statistical data was not available in the first period but with the growing population of these areas; in later political divisions, they became known as independent counties. In addition, to determine the impact of location (location in the central, eastern, western, and southern city-regions) and different geographical features (plains and coastal areas) of urban areas as well as the impact of population size and their population density on spatial patterns and sustainability, was decided to select different urban areas in terms of geographical location, population size, and population density. Eventually, out of 22 urban areas, only 11 urban areas of Amol, Babol, Sari, Ghaemshahr (plains), and Mahmoudabad, Nowshahr, Noor, Tonekabon, Babolsar, Neka, and Behshahr (coastal-plains) in all 3 years of 1996, 2006 and 2016 were selected and examined (Fig. 1). The general characteristics of the selected urban areas are given in Table 1.

In the last three decades, the urban population of this region increased from 2,602,008 in 1996 to 3,283,582 in 2016, while the area of built-up land increased from 248,019 ha in 1996 to 744,059 ha in 2006 and 999,547 ha in 2016 (Statistics Centre of Iran 2018). Some of the reasons for such growth are beautiful natural and ecological landscapes and the mild and humid weather, which attract the population from the surrounding areas (especially from the capital of Iran, Tehran) to construct the second homes in this region (Dadashpoor and Salarian 2020; Zarei et al. 2016). Also, the unplanned and uncontrolled constructions, land speculation, and reduced efficiency and profitability of the agricultural sector in the region have caused a lot of agricultural and forest lands to be destroyed and brought serious threats to the environmental conditions of the region.

Data sources and analytical methods

Land use/cover mapping

Land use/cover data for the years 1996, 2006, and 2016 was obtained from the database of the US Geological Survey (USGS) with 30×30 m spatial resolution (Table 2). First, this database was developed from

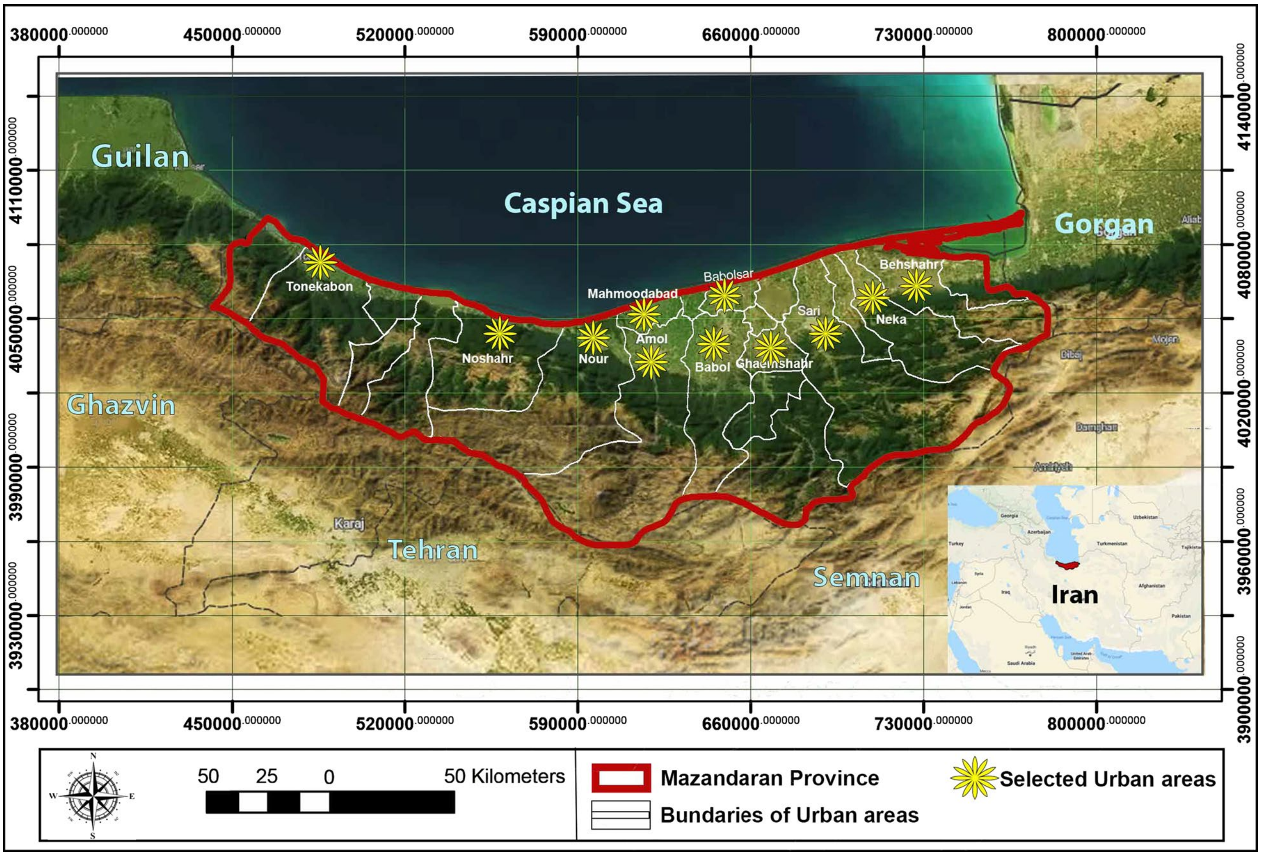

Fig. 1 Geographical location of the selected study areas

Table 1 General characteristics of the selected urban areas

Urban areas	Area (km^2)	Population (persons)			Population density (persons/km^2)	Immigration (persons)	
		Population (1996)	Population (2006)	Population (2016)	Population density (average 1996–2016)	Immigration (1996–2006)	Immigration (2006–2016)
Amol	3074.4	297,743	343,747	401,639	113.10	54,673	42,954
Babol	1578.1	421,068	469,591	531,930	300.49	74,397	55,294
Sary	3248.4	422,461	495,360	559,351	151.58	84,790	63,447
Ghaemshahr	371	260,447	295,135	309,199	776.98	47,061	34,548
Behshahr	1416.3	144,546	156,195	208,847	119.93	18,903	13,396
Neka	1358.8	98,827	105,652	119,511	79.48	18,359	11,408
Mahmoodabad	262.8	83,436	90,502	98,407	345.44	19,339	13,237
Tonekabon	1732.2	174,030	194,719	218,964	113.10	46,193	26,389
Noshahr	1716.5	100,300	118,481	138,913	69.46	31,244	20,418
Babolsar	246.5	155,265	175,302	195,222	711.01	37,525	23,322
Nour	2675	100,360	105,894	121,531	40.85	19,443	14,494

Source: Statistics Centre of Iran (2018)

Table 2 Data related to satellite images in the coastal city-region of Mazandaran

Path	Raw	1996		2006		2016		Spatial resolution (m)
		Data time	Sensor	Data time	Sensor	Data time	Sensor	
163	34	1996.08.18	Landsat5	2006.06.26	Landsat5	2016.09.26	Landsat8	30
	35	1996.08.18		2006.07.28		2016.09.26		30
164	34	1996.04.19		2006.07.19		2016.08.16		30
	35	1996.05.05		2006.07.19		2016.08.16		30
165	34	1996.06.13		2006.09.12		2016.08.23		30
	35	1996.06.13		2006.09.12		2016.08.23		30

Landsat TM 5 and Landsat TM 8 (cloud and snow cover less than 5%). After mosaicking the received images and preparing a single image of the region, atmospheric and radiometric corrections of the images were performed within Envi5.1 software to have the region's land cover classification with a minimum error. The images obtained in band 5 (near-infrared), band 4 (red), and band 3 (green) were used to create a false-color composite. Then, the sampling was done by ROI and polygon tools according to the acquired classes. Finally, the region's land cover in the three years 1996, 2006, and 2016 was classified into 5 categoriess based on the pixel algorithm and supervised classification method. The categories are as follows:

- Built-up land (urban, rural, industrial lands, and inter-city roads);
- Grassland (farmlands, gardens, green spaces, and sparsely vegetated lands);
- Forest (lands with dense vegetation and trees);
- Water body (sea, permanent/seasonal rivers, water basins); and
- Unused land (lands without vegetation and idle lands, mountains, sandy lands, salt marshes, and rolling terrains).

After producing the land cover maps, their accuracy was measured. To this end, the Kappa coefficient was calculated and the conformity of the maps with Google Earth was examined. The Kappa coefficient was 87.27% and 88.91% for the maps of 1996 and 2016. The coefficient was 77.64% for the land cover map of 2006 due to cloud and snow stains and noise in the image. After classifying the land cover maps and constructing their raster file, the built-up land classes in all three periods were separated from the other land cover classes to obtain the land consumption patterns.

Analytical methods

There are many analytical methods to explore the spatial patterns of land consumption at the macro- and micro-levels. Some of these methods are quantitative, among which are Shannon's entropy, Moran's *I*, Geary's coefficient, Holdren method (Diksha and Kumar 2017; Xian et al. 2019), land-use intensity (Barbosa et al. 2017), *k*-cluster analysis (Zhang et al. 2010), and landscape criteria (Sun et al. 2014; Zhao et al. 2019; Wu 2015). Some other methods focus on the spatial analysis of the land consumption patterns, for instance, urban land density function (Dong et al. 2019; Jiao 2015) and the indexes such as LEI, PEI, and Expansion index (EI), Jaggedness degree, and Identification method (ID) value (Forman, 1995; Liu et al. 2010; Zhao et al. 2015; Shi et al. 2012; Chen et al. 2018; Xu et al. 2007). Among these methods, the best method for analyzing patterns at the macro-level is the urban land density function, which was applied to show how the density of the built-up area is distributed. At the micro-level, the combination of two LEI and ID methods was used.

Besides, many methods have been suggested to address various aspects of sustainability. Methods such as the Barometer of Sustainability (Bossel 1999), Radar (AMOEBA) (Wong 2006), Dashboard of sustainability (Hardi and Atkisson 1999), urban sustainability index (USI) (Zhang 2002) and also multivariate analysis and evaluation methods such as AHP and Analytical Network Process (ANP) are among of the most important methods in this field. In this paper, the AHP method and the USI index were employed to evaluate sustainability.

Urban land density function

To achieve the spatial patterns of land consumption at the macro-level, initially, concentric loops were created in incremental, step-by-step, and buffer form from the main commercial centers (CBDs) of the selected urban areas using multi-ring buffer tools and within the ArcGIS10 software. Then, the density of the built-up areas was calculated in each loop for each urban area in all three periods. The density of the built-up area is obtained from the division of the built-up area by the area of the whole ring except for the area of water bodies. The density of the rings of urban areas was fitted using Matlab R2010b software, Curve fitting tools, and the Trust region algorithm, according to the error of least squares and the following formula. Having acquired the density function graphs of the built-up areas, three parameters of α, c, and D were obtained for each urban area and the given timepoints:

$$f(r) = \frac{1-c}{1+e^{\alpha((2r/D)-1)}} + c \quad (1)$$

$$r = \frac{D}{2}\left(\frac{1}{\propto} ln\frac{1+x}{x-c} + 1\right) \quad (2)$$

In this formula, $f(r)$ is the density of urban land; r is the distance to the city center; e is the Neper value; and α, c, and D are fixed values. Parameter D indicates the expansion range of the urban areas and the parameter α indicates the slope of the curve and is a criterion for determining compactness and sprawl. Also, parameter c represents the background density of a city. x is the density of the core, inner, and suburban areas, which is 75% for the core, 50% for the inner, and 25% for the suburban areas (Jiao 2015). Then, based on the formulas r and $f(r)$, the radius and density of the core, inner, and suburban areas were calculated since the difference in the density of each area causes the difference in the spatial patterns of land consumption.

Urban landscape expansion index (LEI)

In this section, combining the views of Liu et al. (2010) and Shi et al (2012) based on the LEI index proposed to analyze urban expansion patterns at one or more periods, two values of ID and LEI were calculated for the new patches. Using these methods, the land consumption patterns at the micro-level can be classified into four categories:

$$LEI = \frac{A_0}{A_0 + A_V} \times 100\% \quad (3)$$

In this formula, A_0 is the intersection area between the buffer of new and old patches; A_v is the intersection area between the buffer of the existing patches and the non-built-up layers (empty lands) (Liu et al. 2010). The ID is always equal to one or zero. If ID = 1, we have the infilling expansion of the types (i), (iii), and (iv); if ID = 0 and LEI > 50, we have type 2 infilling pattern; if ID = 0 and LEI < 50, we have the edge-expansion pattern; and if ID = 0 and LEI = 50, we have the outlying or leapfrog pattern (Shi et al. 2012).

Infilling expansion pattern points to the non-urban lands surrounded by the urban and built-up lands that turn into built-up lands over time due to the land-use change. In this pattern, new urban patches are formed within the existing patches. In the edge expansion pattern, the newly expanded area starts to expand from the edge of the existing patches, and there is a spatial connection between the new and old urban patches. Finally, in the outlying or leapfrogging pattern, the new urban patches develop distant from the existing patches without any spatial connection to them (Zhao et al. 2015).

Evaluation of the relationship between land consumption and sustainability

In general, studies on the relationship between built-up land expansion and sustainable development show that many methods and indicators have been used (Oswald and McNeill 2009; Waheed et al. 2009). However, among the methods available in recent years, the use of indicators has been the best and most widely used methods for measuring sustainability, and various local and international sources (such as UNCHS, OECD, EEA, WHO, …) have provided a wide range of sustainability indicators (Bell and Morse 2013; Verma and Raghubanshi 2018; Boyko et al. 2012). To measure sustainability in this section, a combination of AHP and USI methods (based on the selection of various indicators of sustainable development) was used. The AHP method was developed in 1970 by Saaty (1980). This method has been the most popular tool in the field of decision-making because of its simplicity and rationality (Alam and Mondal 2019). AHP is a hierarchical approach to the making of multi-criteria decisions, allowing for joining the quantifiable criteria with non-quantifiable ones, including such criteria which may be objectively measured and also such which cannot be evaluated this way, so only a subjective appraisal remains (Wolnowska and Konicki 2019). The idea of this method is a decomposition of a complex problem into simpler elements and applying the experts' opinions for in-pair comparison (Bian et al. 2017). The AHP process follows four major steps:

1. Setting up a hierarchy of mutually connected decision elements, with the following components: main objective, criteria, and options. Hierarchies are presented in the form of a tree (Saaty 1994). This hierarchy can be seen in step one of Fig. 2.

2. Developing a comparison matrix of the criteria importance and the variants of decision elements at each level of hierarchy based on expert opinions and using Saaty's scale of relative importance (Table 3). In this scale, relative importance values among attributes such as 3, 5, 7, and 9 refer to the conditions of 'slight importance', 'strong importance', 'very strong importance', and 'absolute importance'. Values 2, 4, 6, and 8 are assigned as intermediate values with relative importance among them.

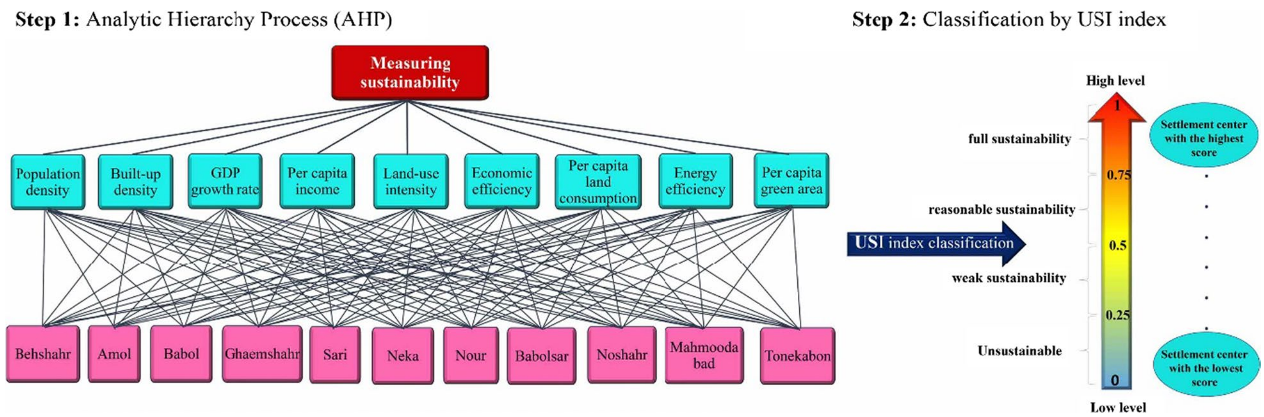

Fig. 2 AHP and USI classification for measuring sustainability of land consumption patterns

Table 3 Saaty's scale of relative importance

Value	Importance
1	Same importance
3	Slight importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

The result of this step is the creation of a matrix $A=[a_{ij}]$ having the dimensions $n \times n$:

$$A = \begin{bmatrix} 1 & a_{12}\ldots & a_{1n} \\ \frac{1}{a_{12}} & 1\ldots & a_{2n} \\ \ldots & \ldots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}}\ldots & 1 \end{bmatrix}$$

3. The weights for the criteria are calculated by the geometric mean method. Then calculate the priority vector P which is the normalized eigenvector of the matrix. The comparison matrix A is normalized as

$$\boldsymbol{W}_i = \sqrt[n]{a_{i1} * a_{i2} * \ldots\ldots.. * a_{ij}} \quad (4)$$

$$\boldsymbol{P}_i = \frac{W_i}{\sum_{i=1}^{n} W_i} \quad (5)$$

4. Finally, the overall AHP score for all options from the option list is derived by the sum of the product of its relative priority in each criterion and the relative priority of respective criteria is given as

$$\boldsymbol{S}_K = \sum_{i=1}^{n} P_i * S_{ik} \quad (6)$$

where S_K is the final weight assigned to the kth option, n indicates the number of criteria groups, P_i is the weight of the ith criteria group, and S_{ik} is the score of the kth option for the ith criteria.

According to López Chao et al. (2020), the selection of appropriate indicators as the most important step in data collection is the basis of any framework of measurement and each indicator should be selected in such a way that the current situation and development trends of urban areas are fully consistent with sustainable development goals. Bell and Morse (2013) have presented 6 characteristics for selecting sustainability evaluation indicators: (1) Related to the subject under research, (2) Measurable, (3) Practical, (4) Ability to update according to changing conditions, (5) Available, (6) Affordable. Therefore, among all the sustainability measurement indicators provided by various studies, 9 indicators from all dimensions of sustainable development (social, economic, physical, and environmental) were selected. Also, the data of selected indicators in accordance with the criteria provided by Bell and Morse (2013) were available, affordable, practical, and measurable for the coastal city-region of Mazandaran in the period 1996 to 2016.

In the next step, using the AHP method (including target, criterion, and option), the nine-point scale of Saaty, and expert opinions, the pairwise comparison matrix was formed for the selected criteria and the normalized weight of each criterion was calculated using geometric means. Also, the pairwise matrix of 11 selected urban areas was created according to the criteria, the existing

Table 4 Selected indicators for measuring the sustainability of land consumption patterns

Dimensions	Indicators	References	Sustainability
Social-physical	Population density	Schneider and Woodcock (2008), Dong et al. (2019), UNCHS (1996), UNCSD (2001), OECD (1993), EEA (2014), WHO (2012), Alberti (1996), Moussiopoulos et al. (2010)	The high density indicates sustainability and low per capita land consumption
	Built-up density	Barbosa et al. (2017), Pili et al. (2017), OECD (1993), EEA (2014), WHO (2012)	High density indicates sustainability and low sprawl
	Land-use intensity	Barbosa et al. (2017), OECD (1993), Yang et al. (2018)	The more is the intensity of land use, the more sustainable and efficient is the land consumption
Economic	Per capita income	Dijk and Mingshun (2005), UNCHS (1996), Moussiopoulos et al. (2010)	Per capita GDP is a suitable criterion to identify the standard level of living in a region. The high value of this indicator shows a higher quality of life and a positive impact on sustainability
	GDP growth rate	Xian et al. (2019), UNCHS (1996), UNCSD (2001), OECD (1993)	The positive GDP growth rate shows the economic prosperity of the region. The negative GDP growth rate indicates economic stagnation and unsustainability
	Economic efficiency	Xian et al. (2019), UNCSD (2001), Moussiopoulos et al. (2010)	The positive value of this indicator shows the high efficiency and sustainability
Environmental	Energy efficiency	UNCSD (2001), OECD (1993), EEA (2014)	
	Per capita green area	Zhang et al. (2010), EEA (2014), WHO (2012), OECD (1993)	The high per capita indicates the sustainability of the environment
	Per capita land consumption	Dong et al. (2019), UNCSD (2001), OECD (1993), EEA (2014)	Sprawl cities with high per capita land consumption and high dependence on cars lead to more consumption of fossil fuels, more emission of greenhouse gases, and less sustainability

statistical data, and the comparison of the options to each other in the two periods of 1996–2006 and 2006–2016, and the final score was calculated (Table 4).

In the socio-physical dimension, three criteria of population density, built-up land density, and land-use intensity were selected. A positive change and the increase in all indicators point to less sprawl and more efficient land consumption, and also to more sustainability. From an economic dimension, three criteria of per capita gross domestic product (per capita income), the growth rate of gross domestic product, and the amount of productivity were selected based on economic performance. The high level of these criteria and their increase in each period represent the high living standard, economic prosperity, and low consumption of land in the region, which ultimately has a positive impact on sustainability. From the environmental dimension, three criteria of energy efficiency, per capita green area, and per capita land consumption were selected. An increase in energy efficiency and per capita green area for each urban area means less land/energy consumption and more sustainability from an environmental point of view. However, unlike the previous two criteria, as the per capita land consumption increases, the sustainability of the region increases.

Finally, the sustainability of selected urban areas was measured based on the USI index, developed by Zhang (2002) and used in various studies (such as Zhang (2002), Van Dijk and Mingshun (2005), Xiao et al. (2010), and Borah and Borah (2021)) for measuring sustainability of urban areas. This index is an effective tool to complete the AHP method in measuring and classifying the level of sustainability which is a value between 0 and 1 and the sum of the weights of all indicators (score 1 = most complete and best, score 0 = equivalent to most incomplete and weakest). The selected scores are calculated based on the USI index and the sustainability classification provided by Pearce and Giles (1995). This index is divided into 4 classes, each of which represents a level of sustainability (see Fig. 2). If the final score is less than 0.25, the region is unsustainable; if it is between 0.5 and 0.75, sustainability is reasonable; and if it is greater than 0.75, sustainability is perfect (Van Dijk and Mingshun 2005).

Results

Land use/cover changes

As Fig. 3 shows, in the last 20 years, the highest area of the city-region of Mazandaran was the grassland, forest, and unused land. Over time, from 1996 to 2016, the area of land covered with vegetation and agricultural lands decreased, and the area of built-up and unused lands increased. From 1996 to 2006, about 600 km^2 (5.6%) of the forests in the city-region of Mazandaran had degraded due to conversion into agricultural, residential, and facilities, inappropriate and destructive exploitation by

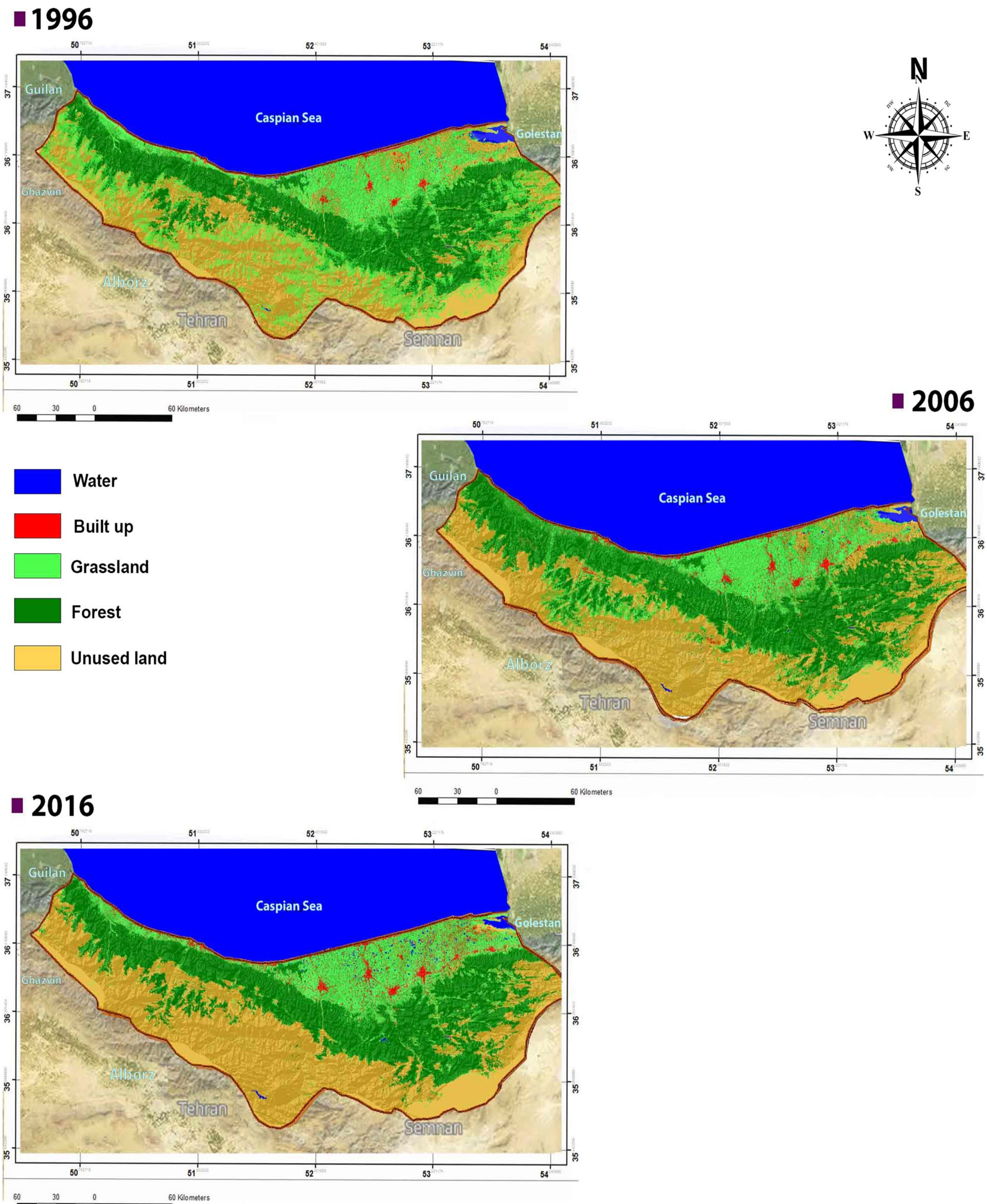

Fig. 3 Land use/cover changes in the three time periods of 1996, 2006, and 2016

Table 5 Area of land use/cover classes in the city-region of Mazandaran

Classes	1996	1996–2006	2006	2006–2016	2016
	Area (km^2)	Percentage of changes	Area (km^2)	Percentage of changes	Area (km^2)
Built-up	248.019	200%	744.059	34.3%	999.547
Water body	258.474	− 0.8%	256.286	− 4.2%	245.453
Grassland	6738.827	− 3.1%	6531.475	− 13.1%	5673.853
Forest	10,718.49	− 5.6%	10,118.49	− 4.4%	9675.301
Unused land	9232.405	3.4%	9545.905	11.1%	10,602.062

tourists, implementation of development projects such as the construction of highways, and destructive livestock of forest dwellers. However, from 2006 to 2016, a small share of the previously destroyed forests (about 4.4%) was restored and reforested (Table 5). The area of grassland and agricultural lands in the region was reduced over time, due to the degradation of agricultural lands and their conversion into the built-up lands (most of them were the second homes and recreational complexes, industries, and services (about 3.1% in 1996–2006 and about 13.1% in 2006–2016). The expansion of the built-up lands and extensive destruction of the natural lands in the last two decades indicate a lack of land consumption restraint plan for the region. Accordingly, while the built-up lands covered about 0.9% of the region in 1996, gradually increased to 2.7% in 2006 and 3.7% in 2016. However, the rate of change and land consumption from 1996 to 2006 was much more than that from 2006 to 2016 (about 166% more). Water bodies have experienced little changes over the past two decades due to the climatic characteristics of the region which has prevented their destruction and consequent constructions. However, this trend has been slightly different in each period due to the seasonal nature of some rivers and canals.

Spatial patterns of land consumption

Macro-patterns

Table 6 shows the parameters α, c, and D for the urban areas in each period. In addition, in Fig. 4, the fitted density curve of the built-up areas based on the concentric rings in the years 1996, 2006, and 2016 are shown. The expansion trend of the built-up areas and the three main areas (core-inner-suburbs) are shown for deeper understanding. Parameter D indicates the expansion range of the urban areas. According to the value of D, the range of all urban areas has expanded over the past two decades and their D level has increased. Also, the growth of parameter D indicates that the range of urban areas increased at a relatively average pace (about 1 km per decade). The average expansion of urban lands in the city-region of Mazandaran was about 9.57 km in 1996, 10.7 km in 2006, and 11.52 km in 2016, which represents an increase of 1.08 times. Parameter α indicates the slope of the curve and is a criterion for determining compactness and sprawl. The larger this parameter, the greater the slope of the curve and the slower the rate of decrease in urban land density. As a result, the suburban area is narrower, the core area is wider, and the spatial pattern of land consumption is more compact. As can be seen in Table 6, none of the urban

Table 6 Fitted parameters of the selected urban areas

Urban areas	1996				2006				2016			
	α	C	D	R^2	α	C	D	R^2	α	C	D	R^2
Amol	3.61	0.02	9.77	0.94	2.36	0.00	10.00	0.84	2.05	0.04	10.44	0.83
Babol	3.02	0.05	10.59	0.82	2.62	0.04	11.45	0.81	3.49	0.04	14.06	0.81
Sari	2.71	0.02	10.59	0.82	2.60	0.08	11.39	0.76	2.37	0.04	11.90	0.77
Ghaemshahr	2.92	0.01	10.52	0.81	2.62	0.04	10.95	0.77	2.87	0.03	12.32	0.78
Behshahr	4.51	0.03	10.11	0.80	4.17	0.09	10.55	0.84	3.44	0.16	11.01	0.84
Neka	6.46	0.04	8.87	0.86	3.98	0.11	11.03	0.87	4.25	0.11	11.08	0.89
Mahmoodabad	6.44	0.04	8.64	0.98	4.27	0.07	9.79	0.86	4.14	0.10	10.05	0.92
Tonekabon	7.80	0.06	7.04	0.89	3.06	0.06	10.39	0.84	3.27	0.06	11.09	0.91
Noshahr	4.14	0.03	10.09	0.84	4.00	0.01	11.26	0.91	4.27	0.04	13.01	0.97
Babolsar	4.55	0.04	10.01	0.94	3.16	0.09	10.28	0.88	3.34	0.11	10.84	0.87
Nour	5.74	0.03	9.14	0.94	4.24	0.04	10.16	0.87	4.80	0.08	11.49	0.89

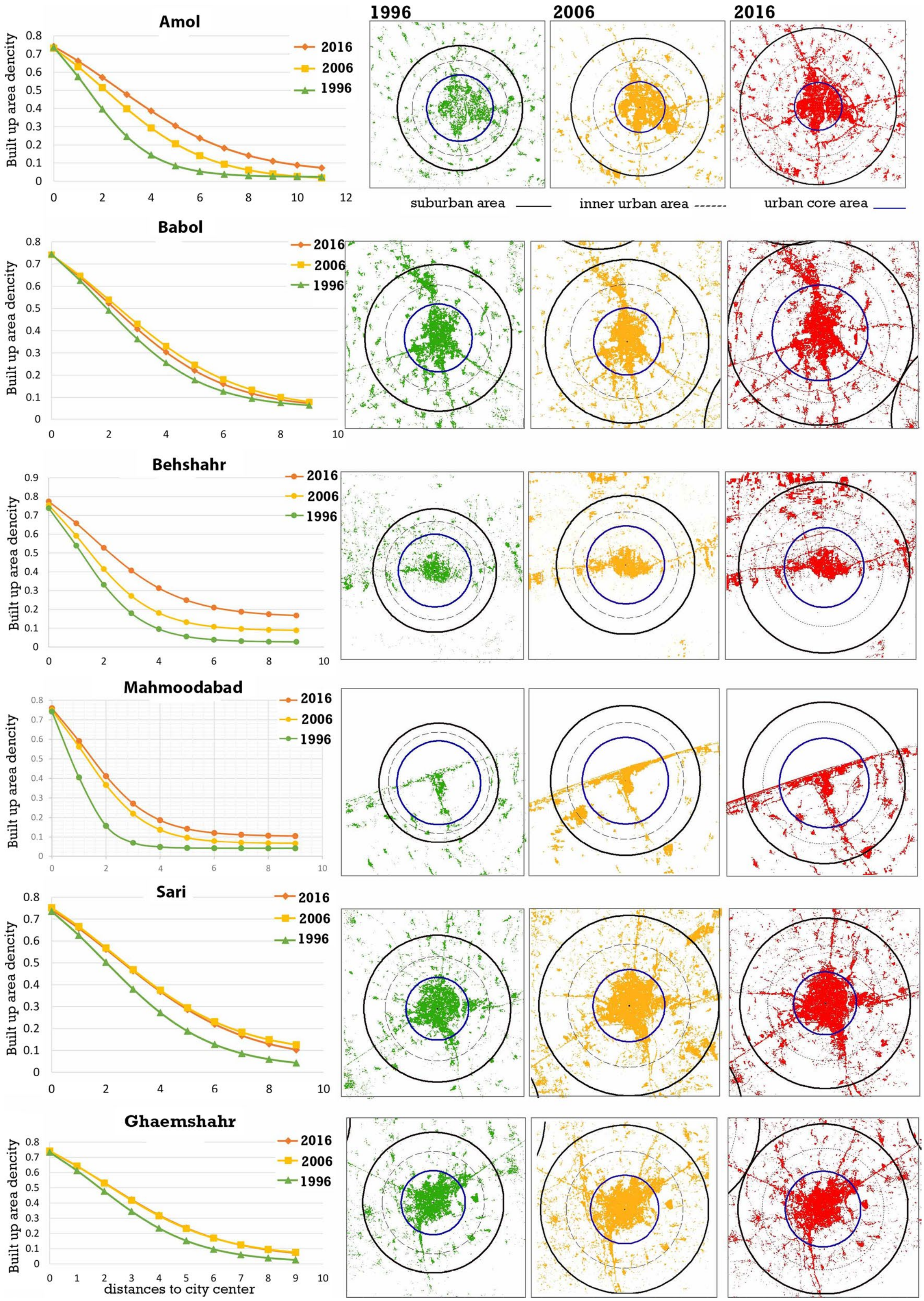

Fig. 4 Fitted distribution curves of the built-up areas in 1996, 2006, and 2016 and the expansion map of the built-up areas

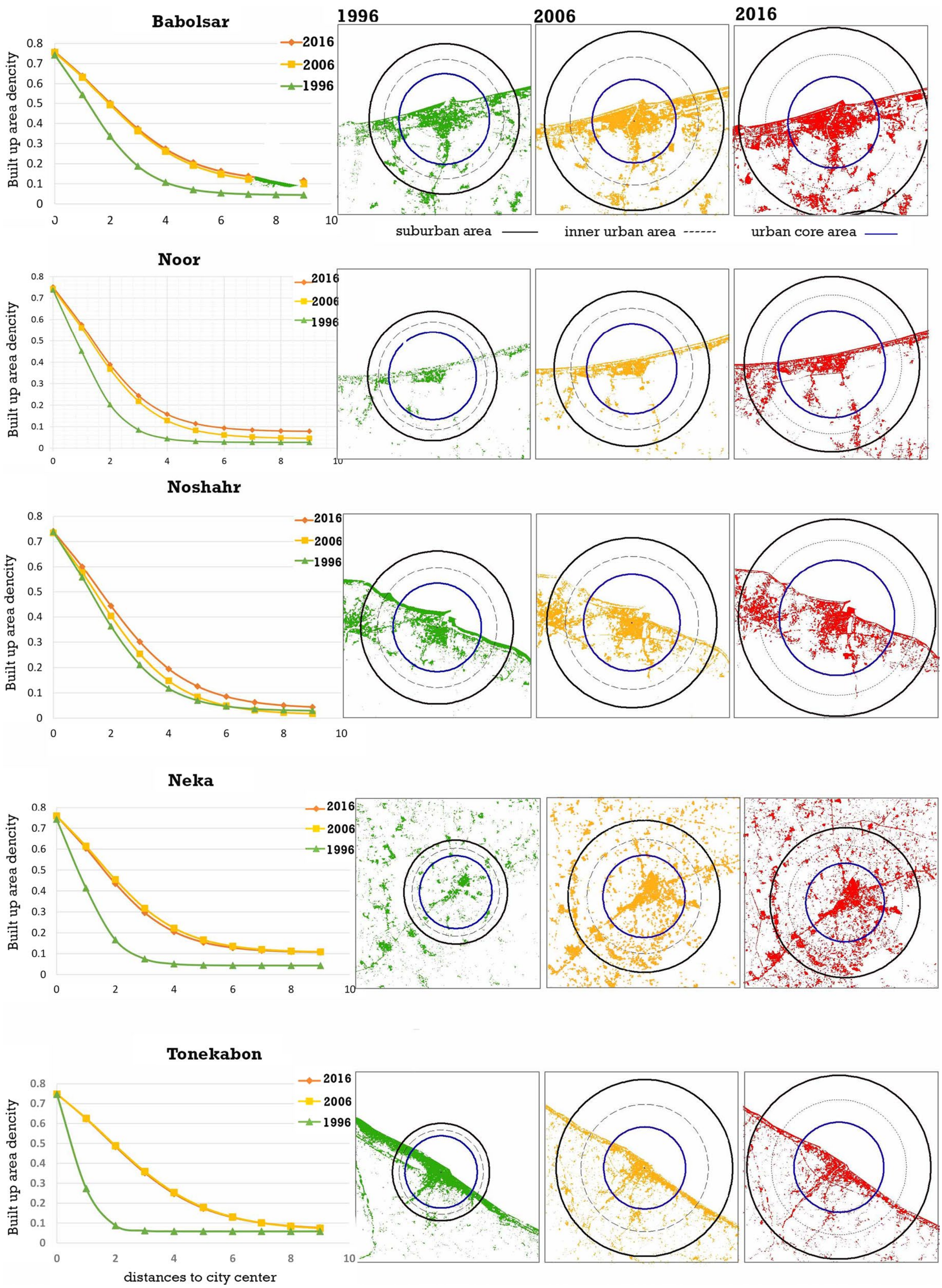

Fig. 4 continued

areas have large α and curved slopes, and all areas have small α. The α level decreases over these two decades, and the urban land density curve becomes flatter, indicating that the patterns are moving toward more sprawl.

Each curve shows the density distribution of the urban built-up areas at different distances from each urban area. If the curve has a steep slope and is close to the vertical axis, the urban area has a compact pattern and the density of the built-up area decreases rapidly, resulting in a narrow suburb and a large core. As can be observed in Fig. 4, none of the studied areas has a high-slope curve and compact pattern. The flat curve with a low slope and far from the vertical axis indicates the extended suburbs and the sprawl pattern in the built-up areas, indicating that all areas have low-slope curves and extended suburbs. Among the studied areas, the Amol curve has the lowest slope and the highest slope with about 4 to 5 percent belonging to Nour and Noshahr.

Another noteworthy feature of the built-up density curve is the distance between the curves of the different years. When the distance of two curves is large and there is a large jump such as the curves for Amol and Behshahr, it means that the density of the built-up area of that urban area has grown rapidly between the two periods. On the other hand, the existence of a small leap and a short distance of the curves indicates the very slow growth of urban areas, such as Babol and Noshahr. However, in some urban areas, it has not changed equally in two periods, and in one period a large leapfrog has taken place and in another period a small leapfrog has occurred, indicating a faster growth in one period than another such as Neka, Tonekabon, Babolsar, Nour, Mahmoodabad, and Sari, that has quickly grown in the two periods 1996–2006 than the period 2006–2016. Figure 4 shows the different types of growth leapfrogs in the built-up areas and the radius of the three main areas. For example, the radius of the core area of the plain city of Neka and the coastal city of Tonekabon decreased with a large leapfrog from 1996 to 2006, and the suburban areas have become larger. Instead, in the period 2006–2016, the radius of these two areas did not change much and the same size (represents an unbalanced leapfrog in two periods). In urban areas such as the coastal city of Noshahr and the plain city of Babol, the radius of the three main areas has slowly changed from 1996 to 2006, and the radius of the core area and its suburbs has increased (indicating a small leapfrog and a short distance between the two periods). Finally, the radius of the three main areas of the plain city of Amol has changed significantly from 1996 to 2016. Its core radius has decreased and its suburban radius has increased (indicating a large leapfrog and long distances between curves).

The results show the situation of the urban areas based on the density of the core and suburban areas (Fig. 5). When the density distribution and area of all three core, inner, and suburban areas are in equilibrium, each occupies 1.3% of the total area of the urban area and 1.3% of the total density of the urban area (density equal to 0.33). In contrast, when the density and radius of the three areas are out of equilibrium and move towards sprawl or compactness and centralization or decentralization, the area of the three areas decreases or increases by 1.3, and their density decreases by 0.33 or more.

The urban areas have sprawl patterns when the density of suburban areas is less than 0/33 and they have a compact pattern when this density is more than 0/33. Also, based on the density of the core area, urban areas have a decentralized pattern when the density of this area is less than 0/33 and it is centralized when this density is more than 0/33 (Dong et al. 2019; Jiao 2015).

In 1996, all the studied urban areas, except Sari, had a sprawl-decentralized pattern due to the low density of the core and suburban areas. None of the areas had a compact centralized/decentralized pattern. Moving from 1996 to 2006, the density of the core and suburban areas increased and the areas moved toward a centralized pattern. In 2006, the spatial pattern of Amol, Babol, and Ghaemshahr, along with the urban expansion process, changed into the sprawl-centralized pattern, whereas other areas maintained their sprawl-decentralized pattern (Fig. 5).

During this period, along with the density of the core area, the density of the suburban areas also increased from sprawl to compact. Thus, the pattern of urban areas was sprawl in this period, as in the previous period. Similarly, from 2006 to 2016, the density of these two main areas increased. One of the major reasons for the increased density of the core area was the reduction of the radius and extent of this area in all urban areas. For this reason, the pattern of areas moved toward centralization (closer to the city center and the service center). Also during this period, along with the density of the core area, the density of the suburban areas of the cities of Sari, Amol, Babol, and Ghaemshahr became more centralized, while the other areas were still decentralized. In this period, as in the previous period, all urban areas continued to maintain their sprawl pattern.

Micro-patterns

The results of the classification of spatial patterns of land consumption in 11 urban areas of the city-region of Mazandaran in the period 1996 to 2006 and 2006 to 2016 were conducted using LEI and ID indexes in the GIS environment for each urban land patch. According to Fig. 6

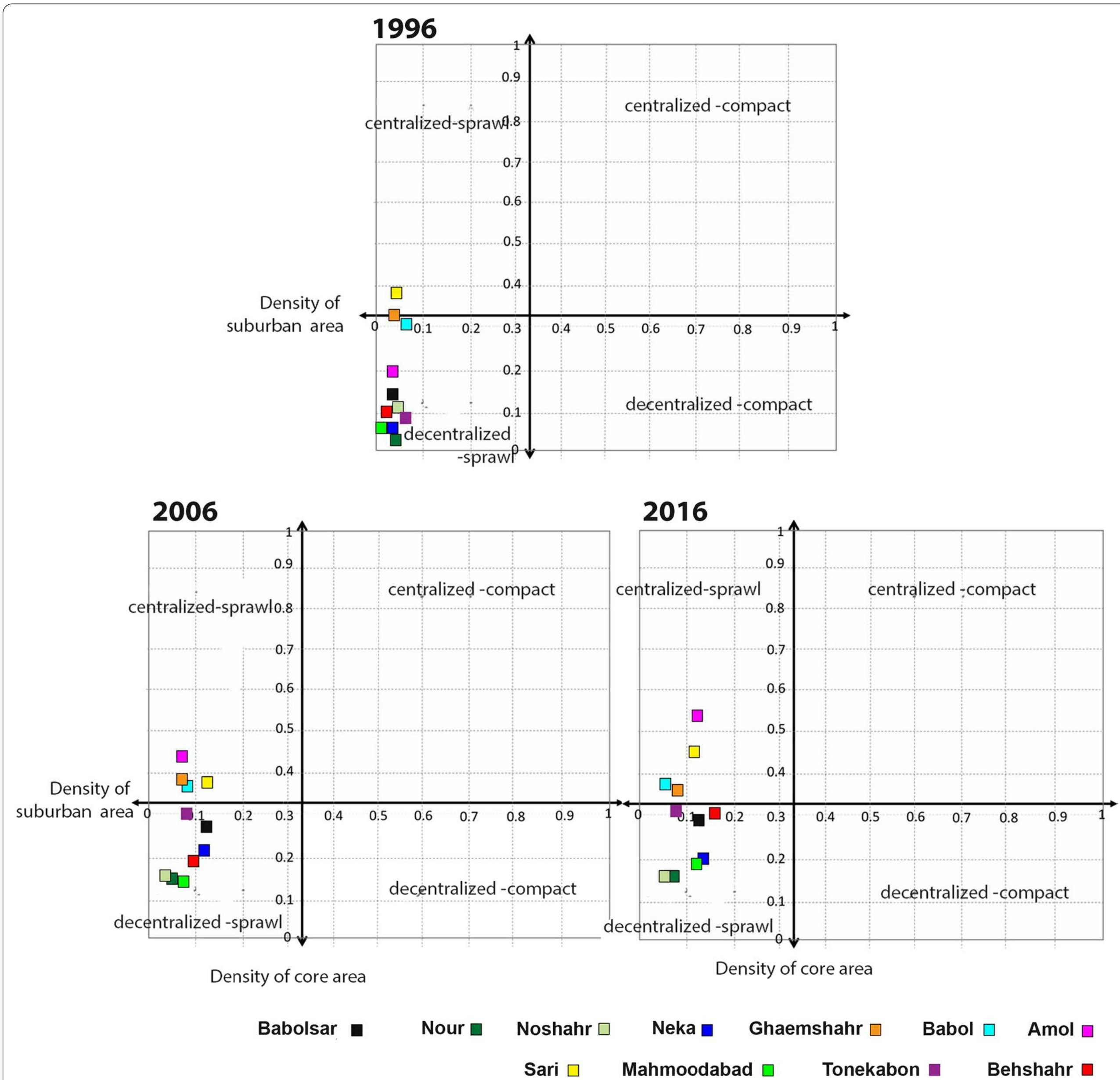

Fig. 5 Spatial patterns of land consumption based on the density of core and suburban areas in 1996, 2006, 2016

and Table 7, the LEI has an increasing trend. A significant share of the built-up patches (about 71%) expanded in the period 1996 to 2006 with an outlying pattern (ID = 0, LEI = 50), away from the existing patches. The remaining 29% of the patches were classified as follows: about 16.1% with edge-expansion pattern (0 < LEI < 50, ID = 0), about 3.2% with infilling type (ii) (ID = 0 and LEI > 50), and about 9.8% with infilling type (i), (iii) and (iv). This trend changed from 2006 to 2016 and the patches with an outlying pattern decreased to 53%; the patches with an edge-expansion pattern increased to 23.1%; the patches with the infilling type (ii) increased to 8.2%; patches with the infilling type (i) (iii) (iv) increased to 15.7%. On the whole, the dominant spatial pattern of land consumption in the city-region moved gradually from the outlying pattern towards the edge expansion and infilling patterns. Also, according to Fig. 6, the spatial pattern of the built-up patches in the majority of the urban areas had conformity with the dominant pattern of the region.

In the period 1996–2006, the majority of new urban patches were created away from the main areas without connection with the old patches. These patches have

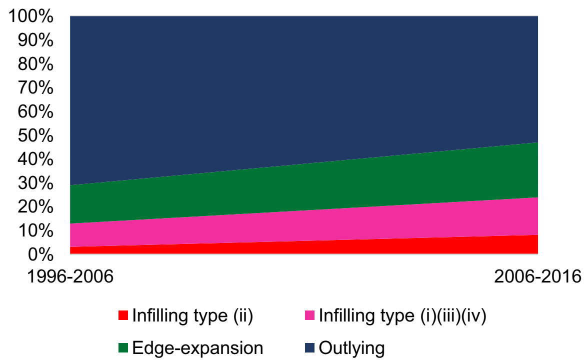

Fig. 6 Percentage of built-up patches in each micro-pattern in the city-region

formed along the seashore, road/rail transport lines, and agricultural lands and have formed a sprawl pattern. However, in the period 2006–2016, new patches were developed closer to the urban areas in connection with the old patches or within them. The results show that the micro-spatial pattern of land consumption in the city-region of Mazandaran is changing from the diffusion pattern (separate and discrete patches) to the coalescence pattern (interconnected patches within the old patches).

Sustainability of the land consumption patterns

The average score of sustainability in the city-region of Mazandaran was about 0/22 in the period 1996 to 2006 and about 0/16 from 2006 to 2016, which means that the region is situated in the unsustainability class (below the 0/25% class) according to the USI index classification. The path of the city-region of Mazandaran is moving towards unsustainability due to the 15% decrease in the average score of the second period compared to the first period. A closer look at the results and the average score of the three environmental, socio-physical, and economic dimensions (according to Tables 8 and 9) which are 0.05, 0.06, and 0.07, respectively, shows that the environmental sustainability of the region is weaker than its economic and social-physical sustainability. Of the 11 urban areas surveyed in both periods, the urban areas of Amol and Babol had the highest score of USI (0.25 to 0.36) with a weak level of sustainability, while the urban areas of Tonekabon in the first period and Neka in the second period had the lowest score (0.08 to 0.15) and the lowest levels of sustainability compared to other urban areas (Figs. 7, 8).

According to the comparison of the average score of the indicators given in Table 10, the three indicators of the physical-social dimension show that moving from the first period to the second period, the average score of all three indicators increased the sprawl of built-up lands and a decrease in their density. In this dimension, the lowest score in the first period was related to the population density index. In the second period, despite the decrease in the score level, this index was at a higher level than other indicators, and the two indicators of land-use intensity and land density were at a lower level than this index. This was due to the expansion of built-up lands with a sprawl pattern and a much lower density than in the first period. The greatest decrease in sustainability was related to the physical–social dimension of the Noor urban area.

In the interval between the two periods, the level of economic points, such as the other two dimensions, has decreased by 23%, which indicates a decrease in the standard of living and economic sustainability in this region. The level of per capita income index score is higher than other indicators and the level of economic growth index score in both periods is at the lowest

Table 7 Number of the built-up patches in each pattern

Period	Infilling type (ii)	Infilling type (i) (iii) (iv)	Edge-expansion	Outlying	All patches
1996–2006	2032	6282	10,350	45,630	64,294
2006–2016	6901	13,251	19,430	44,622	84,204

Table 8 Score of sustainability indicators

Dimensions	Social-physical			Economic			Environmental		
Indicators	Population density	Built-up density	Land-use intensity	Per capita income	GDP growth rate	Economic efficiency	Energy efficiency	Per capita green area	Per capita land consumption
Standard normalized weight	0.03	0.17	0.06	0.08	0.12	0.21	0.11	0.09	0.12

Table 9 Score of sustainability indicators of the selected urban areas

Periods	1996–2006									2006–2016								
Dimensions	Social-physical			Economic			Environmental			Social-physical			Economic			Environmental		
Urban areas	Population density	Built-up density	Land-use intensity	Per capita income	GDP growth rate	Economic efficiency	Per capita land consumption	Energy efficiency	Per capita green area	Population density	Built-up density	Land-use intensity	Per capita income	GDP growth rate	Economic efficiency	Per capita land consumption	Energy efficiency	Per capita green area
Amol	0.22	0.06	0.42	0.37	0.37	0.46	0.40	0.21	0.18	0.22	0.39	0.12	0.37	0.22	0.30	0.06	0.26	0.06
Babol	0.21	0.42	0.35	0.36	0.11	0.18	0.12	0.14	0.10	0.21	0.12	0.18	0.37	0.32	0.22	0.10	0.16	0.09
Ghaemshahr	0.23	0.24	0.03	0.12	0.07	0.14	0.15	0.32	0.04	0.23	0.06	0.02	0.10	0.11	0.12	0.12	0.19	0.02
Nour	0.04	0.42	0.32	0.17	0.07	0.03	0.32	0.04	0.09	0.04	0.02	0.07	0.12	0.34	0.05	0.03	0.05	0.07
Mahmoodabad	0.12	0.45	0.23	0.05	0.16	0.09	0.32	0.09	0.08	0.12	0.09	0.05	0.07	0.06	0.08	0.03	0.07	0.22
Sari	0.23	0.13	0.11	0.17	0.16	0.14	0.20	0.09	0.16	0.23	0.06	0.05	0.10	0.07	0.07	0.07	0.09	0.04
Behshahr	0.11	0.29	0.05	0.16	0.11	0.09	0.02	0.40	0.26	0.11	0.04	0.05	0.06	0.34	0.14	0.30	0.36	0.06
Babolsar	0.26	0.32	0.23	0.04	0.03	0.03	0.21	0.14	0.09	0.26	0.08	0.45	0.06	0.04	0.02	0.02	0.02	0.24
Noshahr	0.05	0.28	0.12	0.13	0.14	0.30	0.08	0.18	0.36	0.03	0.09	0.02	0.11	0.05	0.04	0.15	0.09	0.10
Tonekabon	0.04	0.07	0.11	0.12	0.24	0.19	0.04	0.09	0.04	0.04	0.11	0.18	0.10	0.06	0.03	0.10	0.04	0.36
Neka	0.10	0.05	0.03	0.19	0.14	0.14	0.31	0.06	0.11	0.09	0.11	0.07	0.03	0.03	0.06	0.04	0.02	0.02
Average of all urban areas	0.15	0.25	0.18	0.17	0.15	0.16	0.20	0.16	0.14	0.14	0.11	0.11	0.14	0.15	0.10	0.09	0.12	0.12

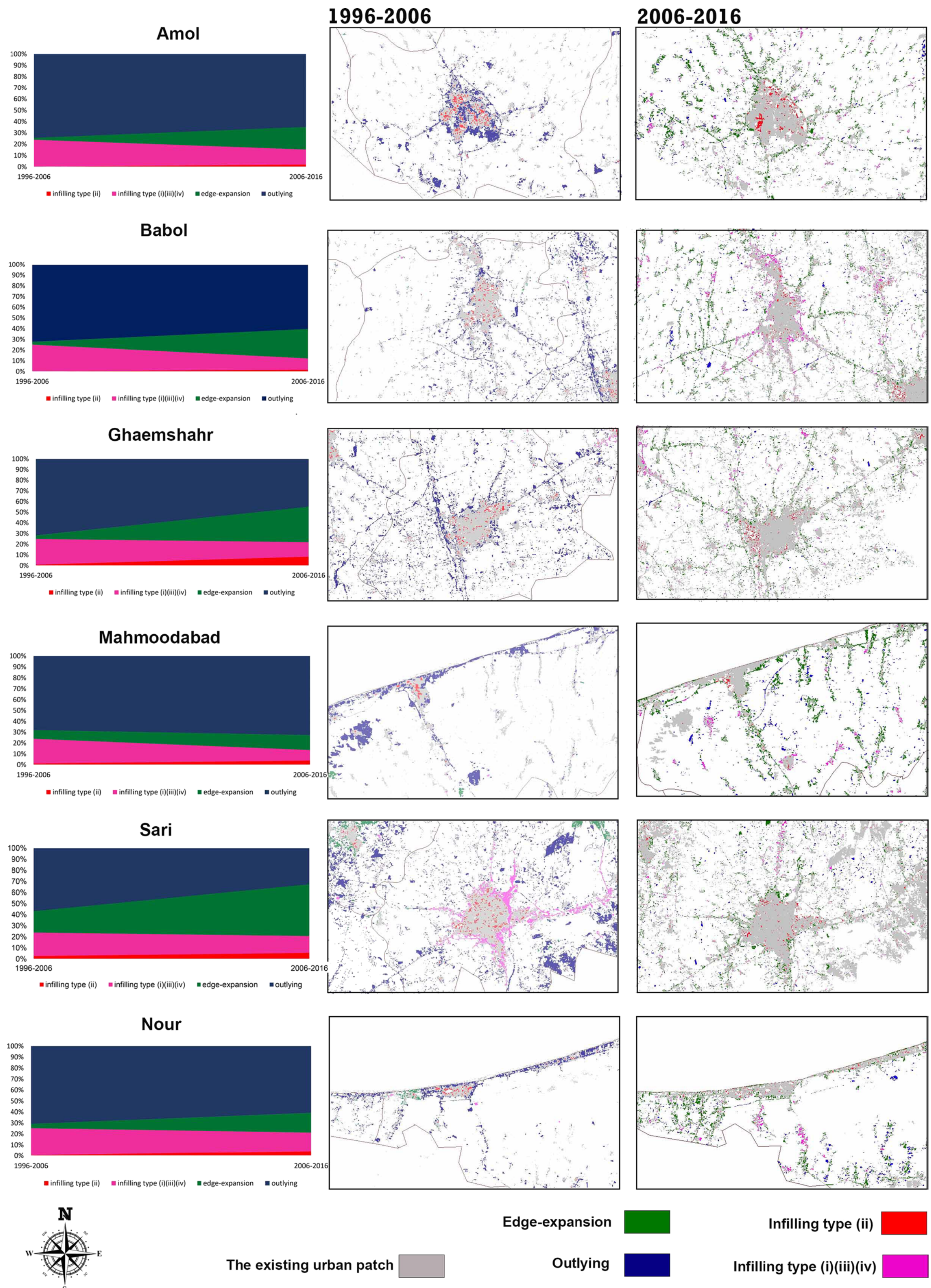

Fig. 7 Micro-spatial patterns of land consumption in the studied urban areas

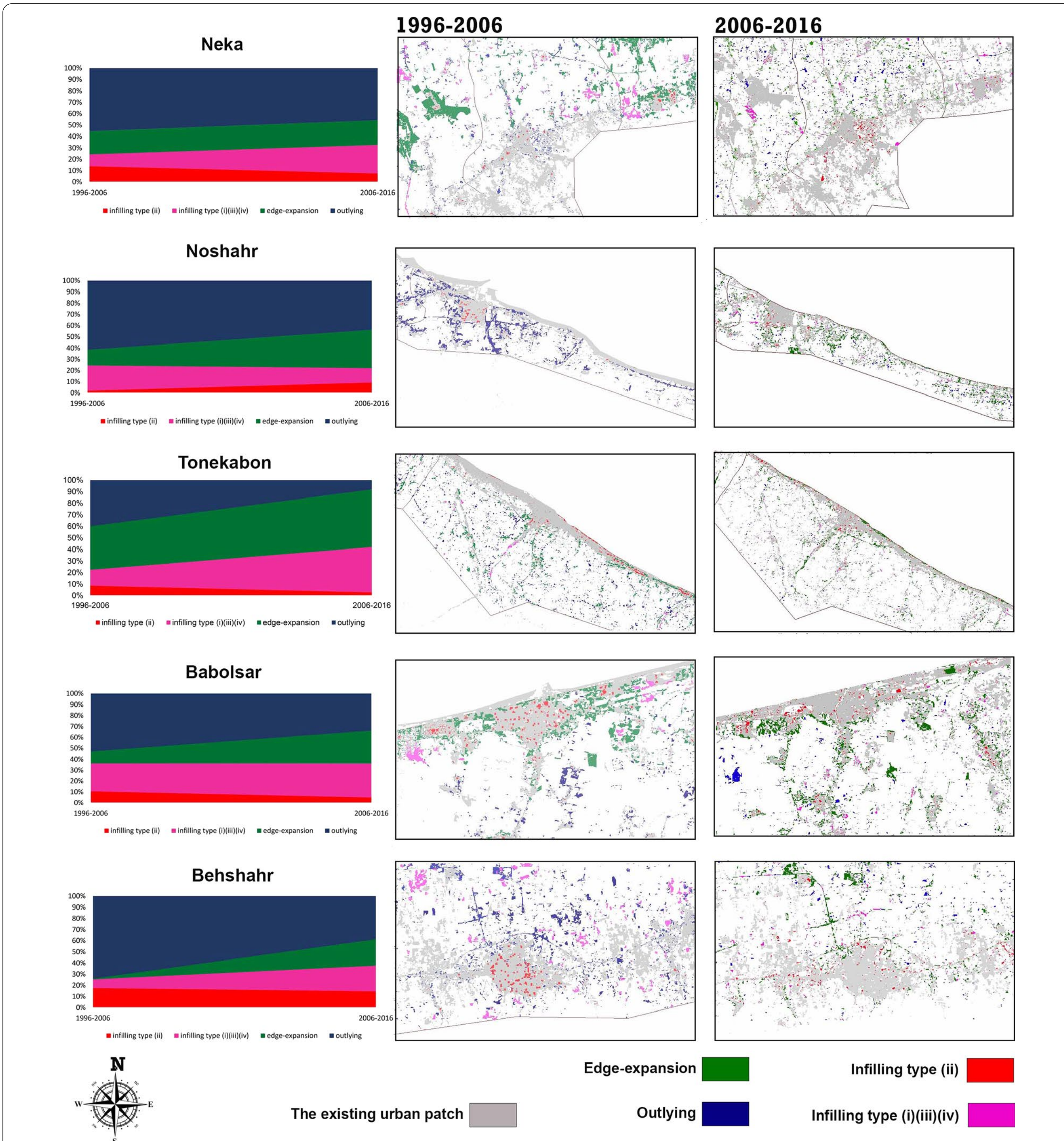

Fig. 7 continued

level. In the interval between the two periods, both the indicators of per capita income and economic productivity have decreased due to the constant average economic growth rate of the level of the built-up lands. The highest level of reduction of economic sustainability belongs to the Nowshahr region. Finally, in the environmental dimension, in the interval between two periods, the score level of all indicators in this dimension has decreased. The reason for this decrease is a decrease in the level of valuable green lands such as forests and wildlife habitats due to the expansion of built lands along with the decrease in energy efficiency due to the increase in energy consumption (especially carbon-producing fossil fuels). In this dimension, Neka urban

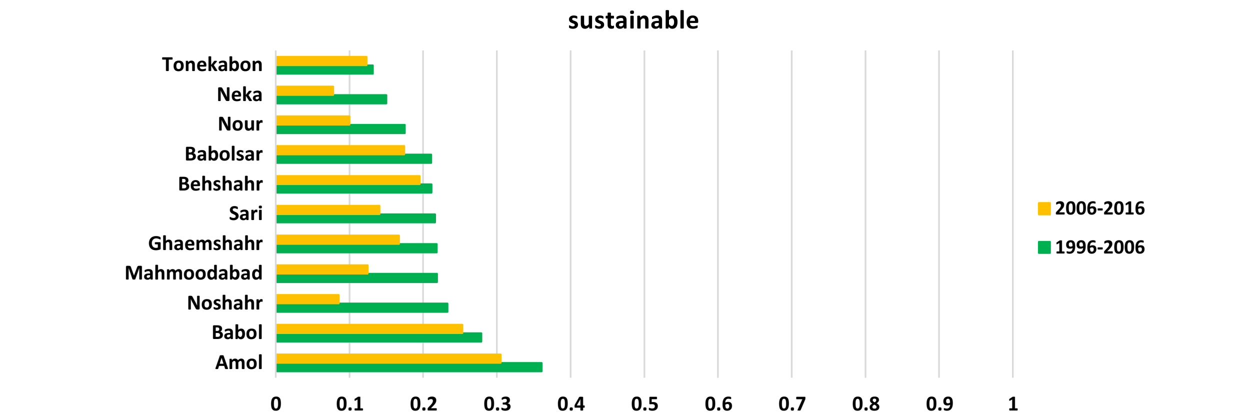

Fig. 8 Sustainability of the selected urban areas based on USI index

area experienced the highest decrease in environmental scores compared to 11 other urban areas.

Discussion

Land use/cover changes

According to the results of the analysis of land cover change in the city-region of Mazandaran from 1996 to 2016, many changes can be seen in this region. A large amount of valuable forest and agricultural lands have been destroyed and turned into built-up lands. A comparison of the two periods of 1996–2006 and 2006–2016 shows that the amount of land consumption in the first period was about three times that of the second period, which can be attributed to several reasons. The first reason is the use of incorrect urban land development programs and policies. The failure of government agencies to properly formulate development rules and regulations, unhealthy organizational relationships, and the use of problematic public policies such as horizontal expansion can intensify the trend of land consumption and create more challenges for those areas regarding land use and type of land consumption (see also Liu et al. 2015 and Savage and Lapping 2003). The second reason is the high number of immigrants and seasonal immigrants in this period who have been attracted to this region due to the development of infrastructure and the increase of communication routes in the city-region of Mazandaran, especially from the national capital of Iran.

Thus, many of the natural lands of the city-region of Mazandaran have been easily destroyed and turned into built-up lands. However, in the second period, with the introduction of environmental protected programs and the efficient urban and regional plans with more emphasis on compact patterns, along with taking action against the land grabbers and illegal builders in protected areas and their punishment, the development policies of the region have changed slightly from horizontal to vertical expansion and the land consumption of this period has decreased compared to the previous period.

Spatial patterns of land consumption

According to the analysis of spatial macro-patterns of land consumption in 11 urban areas in the city-region of Mazandaran, all urban areas during the last two decades, have experienced an extended sprawl trend and there is no difference between the spatial patterns of land consumption in the selected urban areas. However, it can be said that the difference between the results of this research and spatial patterns of land consumption in the city-region of Mazandaran is the speed of pattern change and increasing density of larger urban areas in the region compared to other small urban areas. However, there are three main reasons for the same spatial patterns of land consumption throughout the region. The first reason is the natural bed of the city-region of Mazandaran and its corridor structure along the Caspian Sea and Alborz mountains, which is due to the difficulty of access for users and the vast ecological bio-agricultural zone in the whole region has formed a polycentric structure. The fact is that development always flows from areas with growth control to those areas where land is cheap and growth control is low.

The second reason is the existence of the same geographical, physical, economic, and social conditions in the urban areas in the region. According to the available population statistics, there were not many physical, economic, and social gaps between the smaller and larger urban areas of the region. Due to the short geographical distances between rural and urban areas and the whole settlement region in Mazandaran, they gradually become almost the same and the spread of built-up patches has become sprawl throughout the region. This result is

Table 10 Final scores of the urban areas based on sustainability indicators and levels

Urban areas	1996 to 2006					2006 to 2016				
	Average score in each dimension			Final scores	Sustainability	Average score in each dimension			Final scores	Sustainability
	Social-physical	Economic	Environmental			Social-physical	Economic	Environmental		
Amol	0.11	0.17	0.08	0.36	Weak sustainability	0.14	0.12	0.04	0.31	Weak sustainability
Babol	0.16	0.08	0.04	0.28		0.10	0.12	0.04	0.25	Non-sustainability
Ghaemshahr	0.12	0.05	0.05	0.22	Non-sustainability	0.09	0.05	0.03	0.17	
Nour	0.10	0.03	0.04	0.18		0.02	0.06	0.02	0.10	
Mahmoodabad	0.13	0.04	0.05	0.22		0.06	0.03	0.04	0.12	
Sari	0.10	0.06	0.05	0.22		0.09	0.03	0.02	0.14	
Behshahr	0.09	0.05	0.08	0.21		0.05	0.08	0.07	0.20	
Babolsar	0.15	0.01	0.05	0.21		0.13	0.01	0.03	0.17	
Noshahr	0.07	0.09	0.07	0.23		0.03	0.02	0.04	0.09	
Tonekabon	0.03	0.08	0.02	0.13		0.04	0.02	0.06	0.12	
Neka	0.04	0.06	0.05	0.15		0.05	0.02	0.01	0.08	
Average of all urban areas	0.10	0.07	0.05	0.22	Non-sustainability	0.07	0.05	0.04	0.16	Non-sustainability

consistent with Jiao's (2015) findings who believes that the urban areas with the same geographical, social, and economic conditions have the same spatial patterns of land consumption. The third reason for the formation of this type of land consumption pattern can be returned to incorrect and inefficient rules and policies that led to sprawl development in the region.

The analysis of spatial micro-patterns of land consumption and the built-up patches over the two decades revealed a key role of the diffusion pattern in this region. According to Dietzel et al. (2005) and the urban growth phase theory, spatial urban evolution can be a general temporal oscillation between phases of diffusion and coalescence (Dietzel et al. 2005; Shi et al. 2012). Outlying growth corresponds with diffusion, and edge expansion and infilling represent coalescence (Xu et al. 2007; Shi et al. 2012). Despite that the land consumption patterns of the region were sprawl at the macro-level, the outlying pattern gradually changed into the infilling and edge-expansion patterns. The main reason for this can be a change in the development policy of the city-region of Mazandaran from horizontal expansion toward vertical one. The activity structure of the region was also a key factor in the formation of this pattern because the firms were more inclined to use the economies of agglomeration than the economies of scale and most firms were in a clustered pattern but on a small scale. This matter has affected the spatial pattern of the built-up patches and created a sprawl pattern with patched and agglomerated concentrations, almost turning the entire space of the region into a cohesive, organized, and homogeneous market.

Sustainability

Based on the results obtained from the analysis of 9 sustainability indicators, the situation of the city-region of Mazandaran is unsustainable or in a weak sustainability situation due to the pattern of sprawl-decentralized land consumption and its high per capita land consumption, and the results obtained in this research are somewhat are consistent with what has been suggested by Dong et al. (2019), Jabareen (2008) and Chakraborty et al. (2022) who show the impact of the type of land consumption patterns of an region on its sustainability. In these studies, sprawl-decentralized patterns lead to increased land consumption and ultimately lead to unsustainability, and conversely, compact patterns lead to a decrease in land consumption rate and move towards sustainability. However, the results show that despite a decrease in land consumption in the period 2006−2016 compared to the period 1996−2006 and also the movement of spatial patterns at the micro-level towards continuity, it was expected that the amount of sustainability would increase. However, what was observed was quite the opposite and the degree of sustainability decreased (see also Xian et al. 2019) and despite the pattern of sprawl land consumption, the area was in a sustainable condition and the rate of land productivity was positive. For this reason, it can be said that the type of land consumption pattern alone cannot represent and guarantee sustainability, and the research of land consumption rate along with the status of spatial patterns and their measurement based on all physical, economic, social, and environmental dimensions of sustainable development creates a comprehensive understanding of the situation and will help planners and policymakers to achieve a level of sustainability in a region.

Immigrants were among the reasons for the decreased degree of sustainability and sprawl pattern of expansion in the city-region of Mazandaran, which put extra pressure on its natural environment. Increased population and employment rate due to the expansion of industrial and residential towns and their location along the rivers and farms, on the one hand, and the double pressure caused by environmental pollution and its destruction, on the other hand, have reduced the food production and agricultural activities and turned them into service and industrial activities. Of course, a large part of agricultural lands has been transformed into industrial and non-agricultural uses to meet the basic needs of human societies. This has reduced the efficiency of agricultural activities, agricultural production, and economic values in the environment, causing an adverse effect on the sustainable growth of the region.

Another reason for the increased unsustainability and the movement of land consumption patterns toward unsustainable development can be the adoption of unsuitable horizontal expansion policies against the environmental conditions which has led to the exploitation and destruction of resources and agricultural lands. The existence of the Central Alborz protected areas and the Caspian Sea coastal strip will also lead to increased pollution of water resources, soil erosion, and disproportionate land use in the surrounding lands. On the other hand, the increased population due to incorrect policies and sprawl development has increased the demand for energy consumption, air pollution, and greenhouse gas emissions. Also, the development of tourism and improved position of the city-region of Mazandaran in this sector over the last 10 years have caused more pollution of pristine forest areas and aquatic destruction of river areas.

In summary, the analysis of the amount and spatial patterns of land consumption and the study of the relationship between the spatial patterns and the measurement of their sustainability show two basic points.

1. The relationship between spatial patterns of the city-region of Mazandaran at both macro- and micro-levels is inconsistent with that of Xu et al. (2019) who show that the behavior of patterns in both micro- and macro-levels has been completely different from each other. At the macro-level, the sprawl of the built-up lands, and at the micro-level, the movement towards the formation of infilling and close patches can be seen, which indicates the difference in the relationship between macro- and micro-patterns of regions based on different political, physical geographical and social contexts and needs to adopt distinct control policies and programs at both micro- and macro-levels and in accordance with the characteristics of each region.
2. Land use policies and laws (directly or indirectly related) and their consequences have effective role in the formation of sprawled spatial patterns and their direction towards unsustainability. It is predicted that if the amount of land consumption is not controlled with the strong and controlling laws, such a trend will continue and the pattern of land consumption will lead to more sprawl and wider destruction of agricultural and forest lands and the wider pollution of plant and animal environments. Some studies such as Liu et al. (2015), Deng et al. (2010), Cheng et al. (2020), Liu et al. (2014, 2016), Jiao (2015), and Sciara (2015) also emphasize the importance and consequences of (in)correct land use policies in the spatial expansion of land consumption, especially in coastal areas. Furthermore, change in policies and organizational factors (such as policies to strengthen economic growth), rural to urban change, and land use regulations are all effective in increasing land consumption in urban areas. Therefore, reforming the existing policies and laws for the development of built-up lands on both micro- and macro-levels is required to improve the current trend of land consumption and direct it towards sustainable development.

The most important measures on macro-levels are policy reform from horizontal to vertical expansion, infrastructure improvements and changes in the road network routes, promotion of regional development programs based on a sustainable development approach, giving priority to the protection of natural lands, as well as improving economic, social, environmental, and physical conditions. Besides, the classification of lands in the region based on their quality and value can be effective in preventing the destruction of valuable lands and managing the development of built-up lands with the least amount of damage to natural lands. On the other hand, at the micro-level, in addition to following the macro-expansion policy of the region, strict and controlling rules are needed to prevent the unauthorized formation of residential (especially second homes) and industrial patches, especially next to patches in naturally valuable areas (such as forest and protected areas). Agricultural and green lands should also be developed to prevent the further spread of land consumption and environmental pollution. Such strict rules are necessary, especially in areas where growth rates are high.

Conclusions

This paper aims to explore the spatial patterns of land consumption in the city-region of Mazandaran from 1996 to 2016 and analyze its consequences on sustainability indicators. The results show that the spatial pattern of land consumption in this region in the period 1996 to 2016 at the macro-level has changed from a sprawl-decentralized pattern to a sprawl-concentrated pattern. However, at the micro-level, the spatial pattern of land consumption is changing from the outlying pattern towards the edge expansion and infill patterns. Besides, the results of measuring the sustainability in each period showed that all urban areas are in unsustainable conditions or weak sustainability and are moving towards more unsustainability, which indicates the unsustainability of the land consumption pattern in the city-region of the Mazandaran during this period.

Our results suggest that the urban areas of the region have the same behavior in the spatial pattern of land consumption at the macro- and micro-levels and all are in the same direction and follow the dominant pattern of the region. There are three important points about the trend of land consumption patterns where are regarded as a contribution of this research. The first contribution is the effect of the size and level of importance of urban areas on the speed of change of spatial patterns. According to the obtained results, the land consumption pattern in larger urban areas of the city-region of Mazandaran (Amol, Babol, Sari, and Ghaemshahr) has changed faster than in other urban areas of the region, and of course, the environment and valuable forest and agricultural lands have been destroyed more rapidly than other areas, which can be attributed to the existence of more economic and social attractions in these urban areas than others. The second contribution is that despite the results of previous research, relation and directional correlation were not observed among the spatial patterns of land consumption in the city-region of Mazandaran at both micro- and macro-levels and the trend of patterns is opposite to each other, indicating the different impact of the applied policies and social, geographical and physical contexts of each region on the formation of spatial patterns. The third contribution is that typically with the reduction of land consumption and the movement of spatial patterns towards centralization at the macro-level and internal patterns and the reduction of fragmentation at the micro-level, the level of sustainability was expected to increase, because the centralized pattern is introduced as a sustainable pattern due to the greater proximity of the built-up land patches and the sprawl pattern is introduced unsustainable due to the more fragmentation of the patches than the edge and infilling patterns.

It was confirmed that concentration and reduction of fragmentation cannot be an indicator of sustainability, because, in this research, despite the movement of land consumption patterns towards concentration and also changing the pattern of patches towards the edge and infilling patterns, the sustainability of land consumption and increased sustainability of urban areas did not occur. The environment of the formation of built-up land patches and the impact that has on the biological, economic, and physical conditions of a region, policies guiding the pattern and rate of land consumption in a region along with other factors strongly affect the sustainability of the environment. Therefore, only the type of land consumption pattern cannot represent and guarantee sustainability, and like this research, the research of land consumption along with the analysis of spatial patterns and the measurement of their consequences on all physical, economic, social and environmental dimensions of sustainable development will create a comprehensive understanding of the situation in the region and will help planners and policymakers to achieve a level of sustainability in the region.

This research, despite its contributions concerning the spatial patterns of land consumption and level of sustainability in the coastal area, includes some limitations that need to be studied further. One of the limitations of this research is that it just focuses on a specific area with unique features. Further studies are needed to reveal the theoretical contribution of the research with more certainty. Therefore, it is recommended that future studies explore spatial patterns in diverse geographies to make the results more generalizable. It is also necessary to explain the variables and indicators for a deeper understanding of their impact on land consumption patterns. The second limitation of the research is that the amount and type of the transformation of different land covers/uses (forest, rangeland, agricultural land, and bare land) into the built-up lands and the process of their conversion are not specified. Thus, analyzing the consumption of different land covers and the process of their conversion into the built-up lands over a period of time is required to formulate effective policies and programs regarding land consumption control.

Author contributions

The authors designed, carried out field surveys, data analysis and writing of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Thedata sets generated during and/or analyzed during the current study areavailable from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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