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Using GIS for Analyzing the Effectiveness of Urban Growth Boundary in Karaj, Iran

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Abstract. Nowadays, physical development is essential in any integrated urban development program. The rapid expansion in the physical form of cities in an unplanned and uneven growth in line with the various causes of irregular migration is considered one of the significant problems in Iran's cities, resulting in urban sprawl. With its numerous economic and environmental impacts, sprawling urban areas forced urban experts to explore strategies to deal with this phenomenon. The primary purpose of this research is to evaluate the effectiveness of urban growth boundaries in the Iranian metropolis of Karaj. This paper prepared the required data to explain the studied problem. The study was conducted using survey techniques, field operations, and GIS software to evaluate the measure of success and effectiveness of the urban growth boundary. Moreover, analyses and quantification of the spatial dimension of the urban expansion have been extracted using multi-classification techniques by Envi, ArcMap, and Snap software. On the other hand, the study collects multi-temporal and multi-sensor satellite data, Landsat ETM with L8. The quantification and mapping of urban growth enabled us to quantify and spatially characterize urban growth and create a model to make sustainable cities. As a whole, outputs from our investigations highlight that the currently available free of charge long-term satellite time series provides an excellent low-cost tool for several applications, including urban growth analysis.

Keywords: Urban growth boundary · Urban containment policies · Change detection · Karaj (Iran)

1 Introduction

The issue of urban growth, along with management policies and control as a causal issue, affects many metropolitan and regional programs and plans (Khalili et al. 2018). The physical growth and expansion of the city is a process that, despite being affected by existing structures, has directly or indirectly involved all urban systems and structures. For this reason, if this process does not follow the spatial approach, it will have many adverse effects on various parts of the city, resulting in poverty and imbalance, economic problems and unemployment, psychological problems of city dwellers, large-scale migration to cities, the main result of which is marginalization. And the creation of slums.

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The change in the proportion of the urban population is the physical expansion outside the city plan and has involved cities with many problems. The dimensions and generality of this issue have further affected the cities of developing countries. However, if we think about the physical expansion of cities, we will see that cities are living organisms whose growth is an inevitable phenomenon. The city's physical development considered in this study is unplanned and scattered. In this regard, Nelson and Dawkins argue that "the uncontrolled expansion of urban growth and the dispersal of urbanization is due to many individual behaviors, especially the tendency for more space and the migration of minorities, as a result of some policies." Since invisible market groups cannot locate and allocate land use efficiently, public policies are needed to prevent the dispersal and control the rampant growth of cities. Cities are policies that inhibit urban growth, and their use by local governments is increasing (Nelson and Dawkins 2004). To this end, in the middle of the twentieth century, comprehensive plans were prepared for cities with the development of knowledge of planning and urban planning based on empirical-rational approaches. These plans proposed tools and strategies to deal with acute urban issues and problems, especially urban sprawl. One of these tools and strategies was the "boundary or urban growth boundary," whose mission was to prevent the uncontrolled physical growth of cities.

Previous studies have evaluated the effectiveness of urban growth boundaries in the studied areas (Ding 1996; Jun 2004; Bhatta 2009; Tayyebi et al. 2011; Guoen and Yuanyuan, 2012; Cho et al. 2006; Zheng et al., 2017; Chakraborti et al. 2018; Samat et al. 2021, Amer et al. 2021; Yi et al. 2022; Niu et al. 2022). Aware that developed countries imitate the majority of the planning system of developing countries, comprehensive plans were transferred to these countries within a short time interval and prepared for the cities and capitals of these countries. In comprehensive plans, policies range from the green belt to defining the physical urban growth boundaries (the urban growth boundary). Karaj was also one of the cities for which a comprehensive plan was prepared. In the comprehensive plans designed in Iran, the "urban growth boundary" policy has been used more or less from the beginning until now, and almost no such content change has occurred in them. The primary purpose of this study is to evaluate the success of the policy of urban growth control measures included in the Karaj metropolis's comprehensive plans and, in particular, the "urban growth boundary." In summary, this study tries to determine the degree of compliance of the planned urban growth boundary with actual conditions, determine the planning process and its implementation, and analyze the effectiveness and success of this policy.

2 Study Area

Karaj is the capital of Alborz Province in Iran, spanning between latitudes 35°67′–36°14′N and longitudes 50°56′– 51°42′E and covers a total area of about 141 km^2. (Iranian Statistics Center 2016). Over the last three decades, Karaj has been experiencing a significantly growing, primarily due to its socioeconomic attractions. Past developments and challenges have led to environmental, socio-cultural, political-security, economic, and spatial (Sakieh et al. 2014) (Fig. 1).

Karaj, in 1956, had a population of fifteen thousand people. However, in 2016, the population of Karaj city reached 1592492 people. The area of the city has increased from

about 3900 ha in 1956 to about 17000 ha now. Karaj is a city whose main structure and texture is the product of developments in Iran from 1340 onwards and the achievement of the Renaissance in the country.

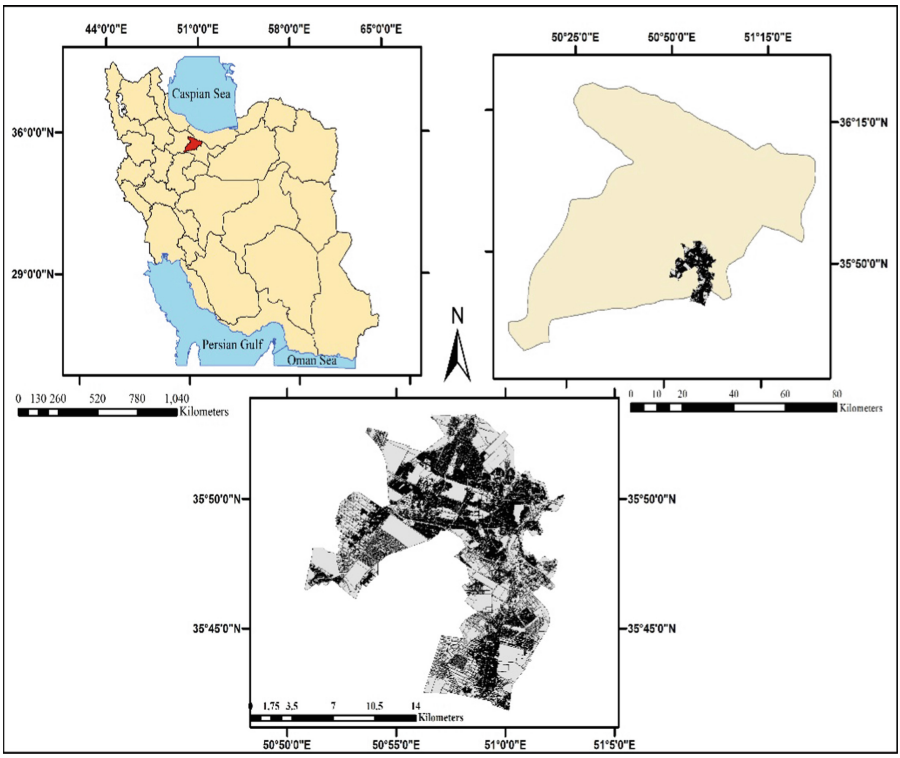

Fig. 1. The study area of Karaj City, Iran

3 Material and Methodology

Multi-temporal data sets of Landsat ETM 2008 and L8 (OLI) 2014 images were collected from the USGS and GLCF websites for the study area. Image processing was done using Arc GIS 10.8 and Envi 5.3 software tools. The analyses were addressed to detect the changes in the urban areas based on comparing the outputs obtained from the classification and geospatial analysis of the past and present data (Santarsiero et al. 2022). Table 1 summarizes the data used for remote sensing analysis and overlay analysis.

Table 1. Data collection properties of the study area of Karaj

Satellite	Sensor	Resolution (M)	Acquisition date
Landsat	ETM	30 m	Aug 2008
Landsat	L8	30 m	Jul 2014

Quantitative methods such as distance measurement analysis using GIS and ENVI software have been used to examine the degree of compliance between planned urban growth and constructed boundaries. Overlay analysis has also been used to compare land cover images of the Karaj metropolis in different years. To highlight the process of rapid urban development in Karaj, images of land use status in 2008, when the comprehensive plan was approved, were extracted until 2014. It was then examined through remote sensing analysis. The trend of urban development from 2008 to 2014 was determined through the overlay analysis of land use coverage in 2008 and 2014.

4 Results

This study used overlay analysis to examine the compliance between the planned boundary and the actual boundary in both quantitative and morphological terms. Before land cover and land use analysis, the remote sensing method was used to complete the existing Karaj land boundary extraction. Remote sensing analysis is a technique that is often used for geographic processing. Thus, the latest land cover information was processed from the Karaj metropolis so that the actual boundary built on the land of Karaj was identified.

To evaluate the efficiency of the urban growth boundary in the Karaj metropolis, by identifying the level of compliance between the projected boundary in the plan and the actual boundary, the researcher can conclude to what extent the policies have successfully controlled urban growth and dispersion. This section presents empirical evidence on the success of the 2008 plan's urban growth boundary, as evaluated by compliance. Three general parts of this part: (1) urban development in 2008–2014, (2) the level of compliance between the actual boundary built in 2014 and the urban growth boundary planned in the 2008 plan; (3) Details of developments that occurred outside the urban growth boundary (Azizi et al. 2019).

After analyzing the distance and classifying land use information, the lands constructed in the metropolis of Karaj at the time of preparation of the comprehensive plan (2008) have been estimated at 9620 ha. After six years and in 2014, the area of land built in Karaj has changed to 12033. The cultivated land has increased by about 2400 ha in 6 years, which shows a growth rate of 25.08% (Fig. 2).

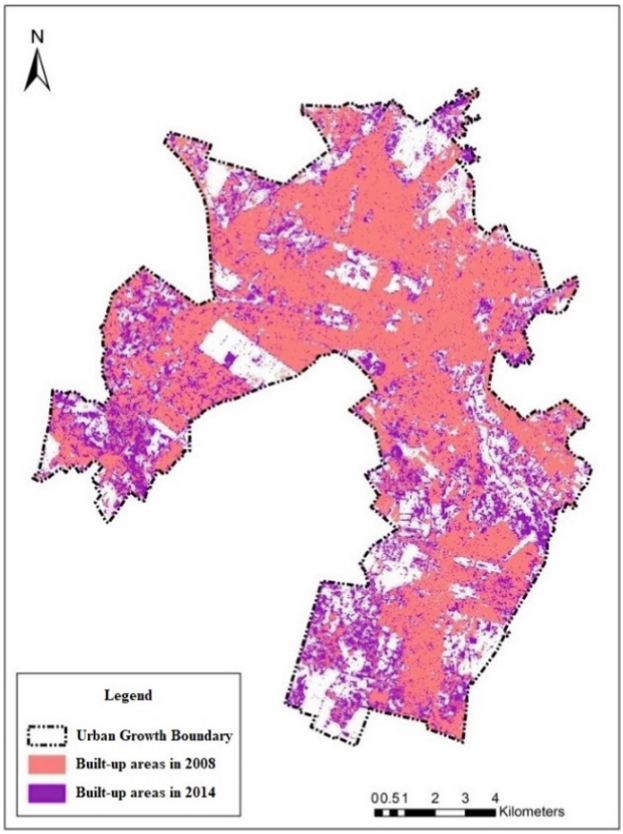

Fig. 2. Evolution of built-up areas in Karaj from 2008 to 2014

When we compare the urban morphology of 2008 with 2014, we find that most lands built-in 2014 have expanded in the vicinity of the lands built-in 2008. As can be seen in the picture, during the comprehensive plan period of 2008, most of these increases occurred in the western and southern parts of Karaj. The majority of these developments have resulted from the conversion of barren and agricultural lands into urban lands so that 24 km^2 of agricultural lands, barren lands, and orchards have undergone land use changes and gone under construction. The details of these changes and developments of the user class are detailed in Table 2.

Since the purpose of the urban growth boundary is to control urban development until all the new developments have taken place in the form of the urban growth boundary, it can be said that the result of planning and design is by the plan. Analysis of satellite images and Google Earth software shows that in 2008 when the urban growth boundary was prepared in the comprehensive plan, many changes were taking place in the physical outskirts of Karaj (especially in the west and south). Also, it seems that these added spots and settlements, although delayed, have been gradually integrated within the legal limits of the municipality, and no plan has been made to manage (or remove) them. In the lack of

Table 2. Amount and area of land use and change the share of each of them (square kilometer)

		Initial State						
		Unclassified	Agricultural land	Built land	Barren land	Green land	Row total	Class total
Final State	Unclassified	223.94	0	0	0	0	223.94	223.94
	Agricultural land	0	5.51	0.04	1.48	3.21	10.25	11.59
	Green land	0	1.71	0	0.03	3.66	5.4	5.98
	Barren land	0	0.78	3.2	29.39	0.3	33.67	42.21
	Built land	0	2.01	34.16	13.2	0.25	49.62	82.09
	Class total	223.94	19.66	39.56	52.88	10.34	0	0
	Class Changes	0	14.15	5.39	23.49	6.69	0	0
	Image Difference	0	−8.07	42.54	−10.67	−4.37	0	0

laws and regulations, the system for dealing with the city's actual situation has frequently disregarded (beyond the legal boundaries) contexts, resulting in the over-expansion of these contexts.

A morphological comparison was made through land use analysis between the urban growth boundary and the actual boundary made up to 2014 (Fig. 3). As can be seen, many developments have taken place in the western part of the Karaj metropolis outside the urban growth boundaries and connected to its physical fabric. These developments outside the urban growth boundary are 3.17 km^2, equal to 13.20% of the total increase in the area built in 2008–2014 (2400 ha). This statistic shows that the urban growth boundary has not effectively controlled the urban growth of Karaj, at least in the west. In addition, most illegal extensions in 2008 and the start of the comprehensive plan have not been eliminated, and the expansion around them has continued.

However, despite the expansion outside the urban growth boundary, there is still a large amount of land within the city and the urban growth boundary, which is included in the classification of satellite images in the form of barren lands (Fig. 4). At the end of the comprehensive plan period, the area of these lands is about 5279 ha. With an increase of approximately 2400 ha of urban land between 2008 and 2014, approximately 41 km^2 of barren land remains within the legal urban growth boundaries, demonstrating that, despite the possibility of development within the urban growth boundaries, much of the activity construction has occurred outside the urban growth boundaries.

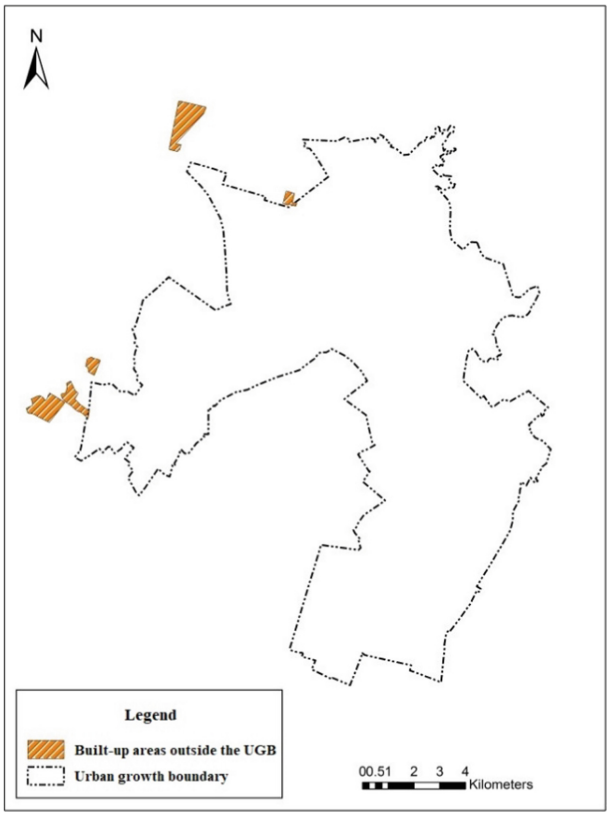

Fig. 3. Built-up areas outside the urban growth boundary

The boundary containment ratio (BCR) is one of the indicators presented by Han et al. (2009) that deals with the degree of containment in urban growth boundaries. This index is measured by calculating the ratio between areas built outside the urban growth boundary (3.17 km^2) and areas built within the urban growth boundary (52.79 km^2). The higher the ratio, the lower the degree of success and effectiveness of the urban growth boundary. The ratio of this index for the Karaj metropolis is calculated to be 0.13. In this paper, due to the lack of necessary information and resources, only the extensions outside the boundary and connected to the west of Karaj have been calculated and taken into account; naturally, the value of this index has a low number. Although this index is low at first glance and shows the success of the urban growth boundary in curbing urban development, as mentioned, because only the developments west of Karaj were considered, this index indicates the failure of the urban growth boundary in the siege of urban development in Karaj.

According to the above analysis, it can be seen that the urban growth boundary has not effectively restrained and besieged the new developments of the Karaj metropolis. So that 13.20% of the increase in land built-in 2008–2014 has spread beyond urban growth limits. However, from a quantitative point of view, the total amount of land increase made

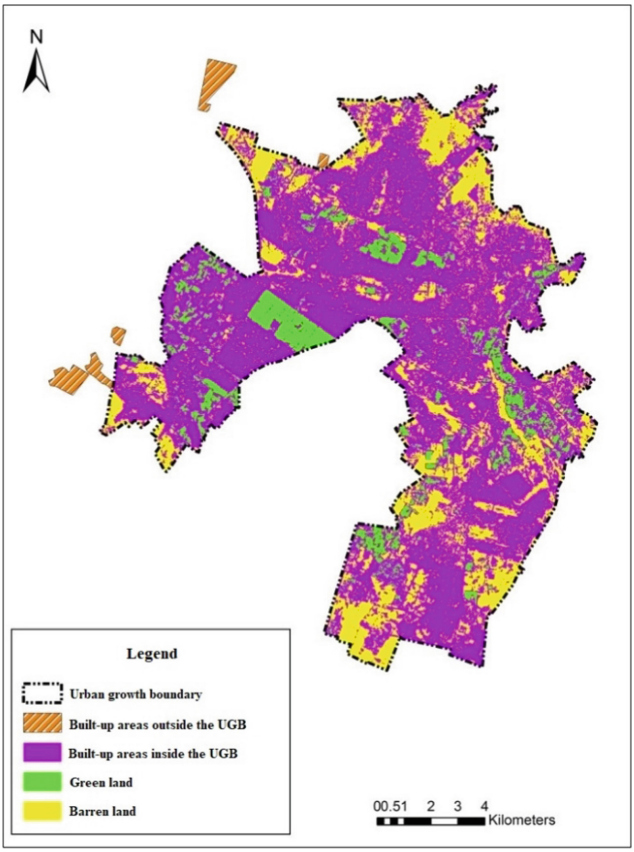

Fig. 4. Barren lands inside the urban growth boundary

in 2008–2014, both inside and outside the urban growth boundary, is 27.3 km^2 (including lands developed outside the urban growth boundary) smaller. One of the available lands for development inside the boundary is the comprehensive plan of 2008 (approximately 41.02 m^2). That indicates that until 2014, the urban growth boundary had somewhat limited urban development. In other words, there is a quantitative (numerical) adaptation in the period 2008–2014. Of course, it is necessary to mention that this adaptation is partly due to the large area of the Karaj metropolitan boundary in the comprehensive plan. Table 3 provides an overview of the above analysis (Figs. 5 and 6).

Table. 3 A summary of the UGB's effectiveness analysis

Indicators	Values
Area of increased built-up land during 2008–2014 (A1 + A2)	27.3 Km^2
Area of increased built-up areas inside the UGB during 2008–2014 (A1)	24.13 Km^2
Area of increased built-up areas the outside UGB during 2008–2014 (A2)	3.17 Km^2
Area of urban land allowed by UGB in 2008 (A3)	52.79 Km^2
Area of barren land inside the UGB in 2014 (A4)	41.02 Km^2
The boundary containment ratio (BCR) (A2/A1)	0.13

(Zheng 2014)

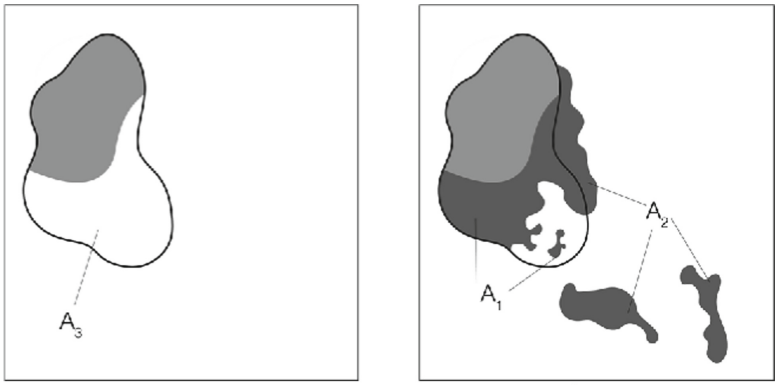

Fig. 5. Illustration of the areas and boundaries of analysis. (a) The start of the planning period; (b) The end of the planning period (Han et al. 2009; Zheng 2014).

In general, it can be inferred that until 2014, the level of morphological compliance between the urban growth boundary predicted in the comprehensive plan and the constructed boundary was low. A significant part of the new developments has occurred outside the urban growth boundary (in the western part of the Karaj metropolis), and the value of the urban growth inhibition index is 0.13. In contrast, the level of compliance is somewhat high as calculated by the size and breadth of uses.

By examining the lands built outside the urban growth boundary and the aerial images of the Karaj metropolis, it can be found that most of these lands have residential use and, in some cases, industrial use. In order to confirm the accuracy of the judgment, field research was conducted at four sites, which can be seen in Figs. 7, 8, 9 and 10.

Research has shown that site (a) is the residential town of Golha in the northwest of Karaj, and site (b) in the northwest is dedicated to the Baharestan industrial town and is located outside the legal growth zone of the city. Site (c) also has a residential use (Abrisham Town). Site (d), as shown in the picture, has a military use and is manifested outside the urban growth boundaries.

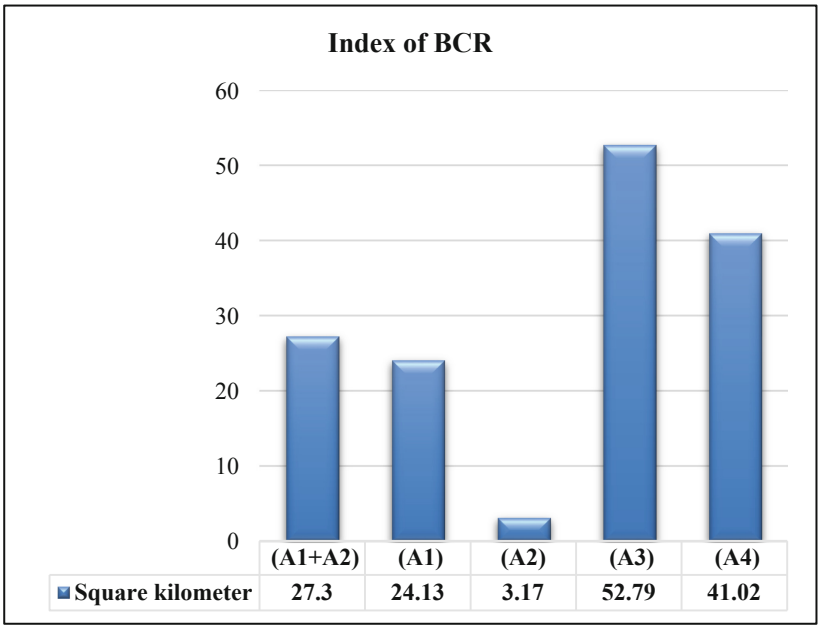

Fig. 6. Changes in boundary containment ratio (BCR)

Fig. 7. Site (a)

Fig. 8. Site (b)

Fig. 9. Site (c) (Google earth, 2020)

Fig. 10. Site (d) (Google earth, 2020)

By imposing restrictions on the growth of the city of Karaj based on their approved physical development plans and the relative increase in land prices in them, the low-income migrant population turned to villages near the two city centers to have both shelter and the opportunity to use the facilities of these cities. And have Tehran. In this way, agricultural lands and gardens were separated and made available to the people in small plots in charters. In the 1990s, the government approved converting these rural areas into cities.

The concentration of urban centers in the east of the constituency is more than in the west due to the strong attractiveness of the labor market, Tehran services, and the comparative advantage of communication facilities in this sector. Being located in a standard communication network, daily use of services and employment and training facilities, and attracting the overflow of Tehran population are signs of functional connection with Tehran metropolis. Except for Karaj, most of these cities have become small, densely populated villages with very limited development capacity, as they are among the finest agricultural lands, and their growth has destroyed much of the region's environmental potential.

5 Conclusion

The Industrial Revolution and the subsequent developments that led to the urbanization revolution in the second half of the nineteenth century made the settlement of human beings in cities different and led to the unprecedented expansion of cities. Rapid urbanization disrupts land use patterns and poses severe threats to natural resources, so it is necessary to delineate urban growth boundaries (UGB) to encompass large-scale urban development (Ma 2020).

In the present century, scattered urban development is a common phenomenon in many metropolises and cities of Iran. Fundamental changes in social, economic, and political institutions have led to an increase in Iran's urban population of about 60% over

four decades. This excessive increase in population has led to the growth and expansion of cities, which manifested that the growth of cities in Iran has also led mainly to suburban expansion. One of the cities facing the problem of horizontal irregular growth is the city of Karaj. This city had the appearance of a garden city until 1345. However, with the growth of migration, destruction of gardens and green lands on the other hand and the transfer of agricultural water to Karaj, drying of gardens and the emergence of new urban neighborhoods, unprincipled construction along roads and connecting multiple systems around the outskirts of Karaj, it has become modern Karaj. One of the main challenges of this city is its physical development, which has led to the destruction of gardens and agricultural lands and increased the cost of urban services (Bozorgmehr et al. 2013) because the city of Karaj has gone through the process of urban development and evolution much faster than the natural pace and in a short time and has experienced uneven horizontal growth.

In order to counter the urban sprawl and distribution in Iran from the middle of the present century, comprehensive urban plans that had policies at the heart of controlling and limiting urban growth were used. In the framework of these comprehensive plans, urban growth control policies include the green belt, the boundary of urban services, And the city growth boundary (the city's physical growth zone). More than four decades after preparing the first comprehensive plans for Iranian cities and the definition of growth boundaries for cities, a comprehensive and accurate assessment of the success and effectiveness of these urban growth control tools has not yet been done. This factor caused this research to do this essential and selected its study sample in the metropolis of Karaj and by examining it to evaluate the success rate and effectiveness of the urban growth boundary.

The topic selected for this study is to evaluate and evaluate the success of urban growth control policies in the comprehensive plans of the Karaj metropolis. This macro goal assessed the compliance of the "urban growth boundary" policy planned in the comprehensive plans and its actual situation. Research findings show that the urban growth boundary has not effectively controlled urban development. Among the reasons that have contributed to the failure of the urban growth boundary are the plan's low quality, poor quality of implementation, and lack of political support from governments; Cited. From 2008 to 2014, some of the new developments have been located outside the urban growth boundary. When the ability to control the urban growth boundary was measured using the "boundary containment ratio" index, it was shown that the value of this index was 0.13, which indicates the inability of the urban plan to limit urban development in the Karaj metropolis.

Developments outside the growth of the Karaj metropolis mainly include residential and military settlements and industrial projects. Of course, their construction time is different, and as mentioned, some existed before the comprehensive plan was prepared, and some are still being developed and under construction. In short, all the reasons that have led to the failure and effectiveness of comprehensive plans and consequently the urban growth boundary can ultimately be summed up by policymakers' insufficient understanding of urban growth boundary and the resulting problematic urban management. To create a deeper understanding of the failure of the urban growth boundary in the comprehensive plans of the Karaj metropolis, the weaknesses of this research must be

filled. Therefore, further research on assessing the urban growth boundary of the Karaj metropolis can refine the above aspects and achieve better results.

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