Environmental Energy and Economic Research 2024 8(2): S080
DOI 10.22097/EEER.2024.433352.1309

Research Article

Spatial Analysis of Urban Sprawling with an Emphasis on Ecological Infrastructure Integrity (Case Study: Miandoab City)

Sayedeh Alemohammad [a], Saeedeh Nasehi [b], Ali Asghar Alemohammad [c], Majid Ramezani Mehrian [d,*], Reza Farhadi [e]

[a] Faculty of Governance, University of Tehran, Tehran, Iran
[b] Environmental Planning, University of Tehran, Tehran, Iran
[c] Urban planning, Islamic Azad University, Kerman, Iran
[d] Institute for Research and Development in the Humanities (SAMT), Tehran, Iran
[e] Faculty of Geography, University of Tehran, Tehran, Iran

Received: 2 October 2023 /Accepted: 14 January 2024

Abstract
The sprawling growth of urban settlements is a dominant spatial process in many cities of developing countries. This development's most severe apparent effect is the loss of ecological infrastructure. In this way, consequently, the ecosystem services that have been provided for human settlements for thousands of years will be lost. Urban ecological infrastructure is also very effective in climate change and energy consumption. This research aims to spatially analyze the sprawling growth of Miandoab City with an emphasis on ecological infrastructures. In this regard, first, land cover maps have been prepared. Then the future land cover is simulated and predicted by the CA-MARKOV chain method. Also, the metrics of the number of patches, the patch size, and the patch cohesion of spots have been calculated for all land cover types in the landscape. In addition, the urban expansion intensity in different directions and changes in the density of built land cover have been estimated. According to the findings, Miandoab City has experienced a very sprawling growth until 2023, during which the structural integrity of green infrastructure and bare lands has been severely destroyed in favor of built land cover. The direction of physical-spatial development of the city has been towards the eastern suburbs. Most of the bare lands and intensive growth potential are in these areas. Solutions with three strategies (protective, defensive, and opportunistic) have been presented for balancing physical-spatial development and increasing urban and extra-urban ecological infrastructure integrity.
Keywords: Urban sprawling growth, Green infrastructures, Bare lands, Simulation, structural integrity, landscape metrics

Introduction

During the last half-century, the unstoppable growth of urban settlements has been accompanied by attracting 55% of the world's population. This amount will be 86% by 2050 (United Nations, 2018; Chan & Vu, 2017). Based on various environmental sciences (especially urban planning and environmental planning), the creation, growth, and evolution of any city are physical-spatial representations of environmental, economic, social, and

* Corresponding author E-mail: mehrian@samt.ac.ir

cultural dimensions (Bratley & Ghoneim, 2018; Ehrlich et al., 2018; Milan & Creutzig, 2016; Sharifi, 2019). To know where a city has developed and to identify where it will/ should be developed, we need to analyse the urban growth pattern and predict its future. There are types of city development patterns such as radial, star, linear, checkerboard, and centralized. But the physical-spatial development of the city, which is constantly changing due to human and natural factors, occurs in two main patterns, sprawl and compact (Abdi et al., 2020; Faraji et al., 2018; Movahed & Ahmadi, 2018; Xu et al., 2018).Since the middle of the 20th century, urban sprawling has been referred to as the low-density and discontinuous development of suburbs and the linear development around the transportation axes. Urban sprawling refers to uncontrolled suburbanization that occurs only when urban expansion exceeds the area needed to accommodate the added population and urban functions disperse outside administrative boundaries (Arvin & Poor Ahmad, 2021; Bagheri & Tousi, 2018; Hamidi & Ewing, 2014; Oueslati et al., 2015; Zhang et al., 2018). Although urban growth leads to natural resources consumption and using the capacity of natural sinks, urban sprawling growth is more unsustainable due to the following reasons:

Encroaching on agricultural lands, gardens, pastures, and forests, losing the quality of landscapes, increasing urban abandoned spaces, threatening biodiversity, deteriorating The organic city core (OCC), not mixing uses, reducing access to urban services, increasing the cost of creating and maintaining infrastructure, lengthening the travel distance and time, increasing congestion and traffic accidents, increasing dependence on motor vehicles, increasing fuel consumption and greenhouse gas emissions, decreasing air quality, increasing the family's economic vulnerability to fuel price changes, increasing water and electricity consumption demand, weakening of the local economy, socio-economic polarization, decreasing walking, and public health, reducing security and local vitality, reducing the people interactions (Garrido-Cumbrera et al., 2018; Monkkonen et al., 2018; Navamuel et al., 2018; Nel et al., 2017; Pozoukidou & Ntriankos, 2017; Sarvar & Asghary, 2021). Meanwhile, unbridled development in built land cover causes the degradation of green infrastructures, loss of suburban bare lands, and encroachment on the buffer of blue infrastructures. It is noticeable that the result of management measures that support these infrastructures can be seen at a slower speed compared to the development, reconstruction, and renovation of built lands (Dupras & Alam, 2015; Ferreira et al., 2021).

Ecological infrastructures include cultivated fields, gardens, green spaces and urban parks, riverside lands, river valleys, pastures, forests, and suburban bare lands. These complications are the only indications inspired by nature for planning urban areas. Taking over and destroying these infrastructures is associated with a conflict between private and public interests. Because the ecological-social costs of these changes are much higher than their economic benefits (Girma et al., 2019; Parker & Zingoni de Baro, 2019; Rahimi & Bazmeh, 2021; Ying et al., 2022). With the loss of ecological infrastructure, the ecosystem services that have provided for ancient human settlements for thousands of years are gradually and forever lost. The irreplaceable ecosystem services of these structures include these items: feeding underground water reservoirs, supplying fresh water, adjusting the climate, reducing the effect of heat islands, purifying the air, increasing carbon storage, creating habitats, providing migration routes and survival of animal populations, supplying unique landscapes and suitable spaces for recreation, increasing the feeling of belonging to the place and social interactions and improving community health (Nouri et al., 2021; Ostrowski & Falkowski, 2020; Rall et al., 2019; Wang & Banzhaf, 2018).

The urban heat island effect is caused by the replacement of natural land cover with heat-absorbing materials such as asphalt and concrete. Integrating green infrastructure into the urban design is a promising approach to mitigating the adverse effects of urban heat islands on climate, improving air quality, reducing energy demand for air conditioning and cooling, overall well-being, and public health (Marando et al., 2022). Some impacts of urban sprawl on energy consumption include: 1) Increased energy consumption and reduced energy efficiency because of longer daily travel. 2) increased energy consumption as a result of restoration efforts in degraded habitats. 3) Increased energy consumption for soil and land maintenance against erosion and flood. 4) Increased energy consumption due to the development of energy-intensive transportation systems, such as highways and airports (Li et al., 2023).

Until now, attention has been paid to different indicators to identify and evaluate the form and manner of the city's growth, such as the density of residential units, continuity of the urban texture, concentration of development, clustering of development, centrality of development, multinuclear development, mixing of uses, and accessibility to uses. Shanon's entropy model has been used to determine the amount of sprawling urban growth. Holdren's model has been used to determine the contribution of sprawling expansion to the city's growth (Darvishi et al., 2021; Ermini & Santolini, 2017; Kheirkhah & Nemati Mehr, 2021; Lityński, 2021; Salvati & Carlucci, 2016; Yue et al., 2016). The common discussion of all these methods and procedures is the need to consume land as one of the most limited natural resources. Because land cover/use change, as an irreversible process and the biggest threat to the landscape, should be the main factor in physical-spatial decision makings. Mapping and forecasting the spatiotemporal changing in land covers/ uses are possible due to the apparent differentiation of artificial and natural patches in aerial photos and satellite images (Ersoy et al., 2019; Nasehi et al., 2023; Rajput et al., 2021).

Evaluating changes in the structure of the landscape can provide a more accurate basis for monitoring and predicting physical-spatial changes in settlements and making decisions in this field. Each land cover/use plan should pay high attention to ecological infrastructure protection. The simultaneous measurement of landscape metrics (such as extent, shape, proximity, continuity, connection, centrality, and aggregation) is the preventive and forward-looking approach for policy-making to support these infrastructures (Alemohammad et al., 2022; Arekhi, 2015; Liu & Yang, 2015; Ramezani Mehrian, 2022; Saeed Sabaee et al., 2016). The process of urban sprawling development continues at a higher rate in developed countries, especially in middle cities. For stopping this process and controlling its effects on ecological infrastructure, it is necessary to consider appropriate solutions as the basis of urban planning (Liu et al., 2018; Nedovic-Budic et al., 2016; Ziari et al., 2014).

Rapid and exogenous urbanization in Iran, as a developing country, has been associated with heterogeneous distribution and centralized growth. The distribution ratio of the urban and rural population of Iran has been completely reversed in recent decades (Bardi Anamoradnezhad, 2016).

The objectives of this research are as follows for Miandoab City as one of the middle cities in Iran: evaluate the changes in the land covers, predict its future, determine the direction of city development, analyse the structure of the landscape, and then provide solutions to improve the spatial development process with an emphasis on the ecological infrastructure integrity.

Study area

Miandoab City, the centre of Miandoab county in West Azarbaijan province, is located in the south of Lake Urmia at 57 36 to 59 36 north latitude and 4 49 to 8 49 east longitude. The (OCC) texture is distinguished by the small blocks, and compacted and winding alleys, and includes the current location of Vakil Zandi village and the old market. The population of this city in 1996 and 2016 was 17224 and 134425 respectively. At the same time, the urban area was 84 Ha and 3545 Ha, respectively. The population of this city has increased by 4.16 times in the space of sixty years, and the area of this city has increased by 21.5 times during the same period. As a result, the population density has increased from 205 people per Ha to 38 people per Ha. Urban physical growth has occurred at a faster rate than the growth of population, and for each citizen, more land has been used. Figure 1 shows the location of the study area. In terms of administrative divisions, this city has six districts. A significant part of the most important river of Urmia lake basin, Zarrineh Rood River, passes through this city.

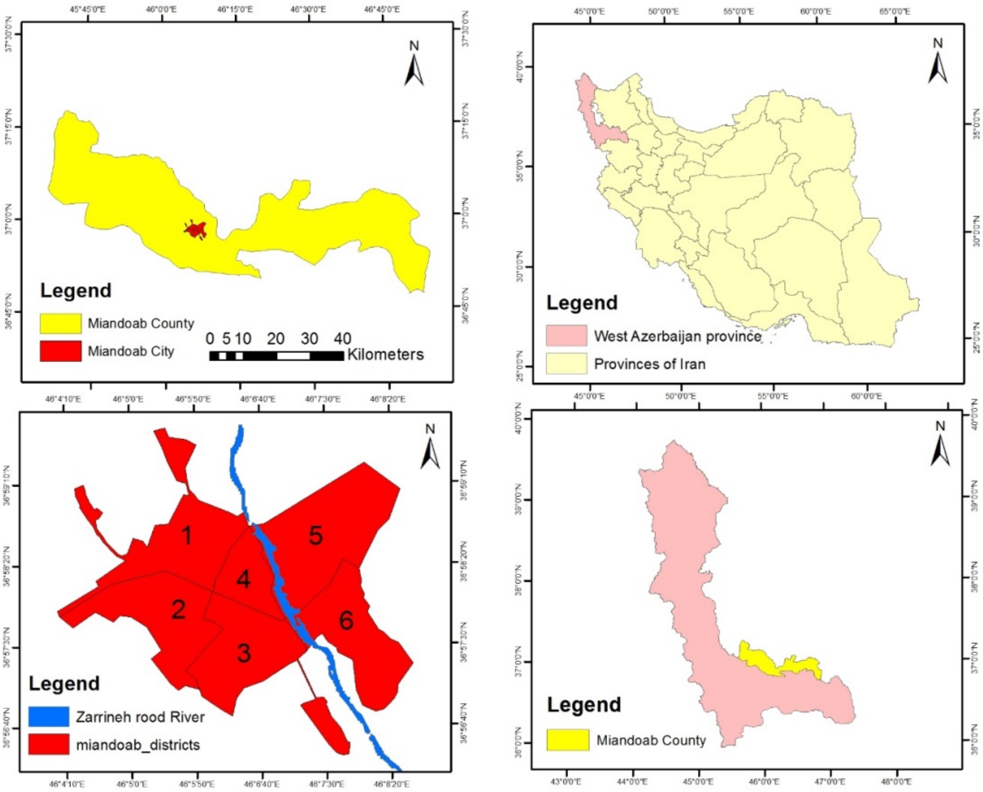

Figure 1. Local situation of Miandoab City

Materials and methods

The general method of the current research is analytical-comparative and includes five general steps. In Figure 2, Details of the research methodology framework are displayed and explained.

In the first step, the trend of land cover changes has been evaluated. According to the research purpose and the study area situation, four land cover categories have been considered including built lands, green infrastructures, blue infrastructures, and bare lands. In this research, all land covers except built land cover are considered as ecological infrastructure. Four-time land cover maps (1996, 2006, 2016, and 2023) have been prepared using Landsat satellite images. After correcting the satellite images geometrically and atmospherically, training samples have been prepared using Google Earth and field survey. In Table 1, the specifications of satellite images are available. Then the satellite images have classified by using training samples, the supervised classification method, and the maximum likelihood algorithm in Idrisi software. The maximum likelihood algorithm is one of the most common supervised classification patterns, in which each pixel is assigned to the class with the highest probability of belonging (Taghadosi et al., 2019; Yousef et al., 2011).

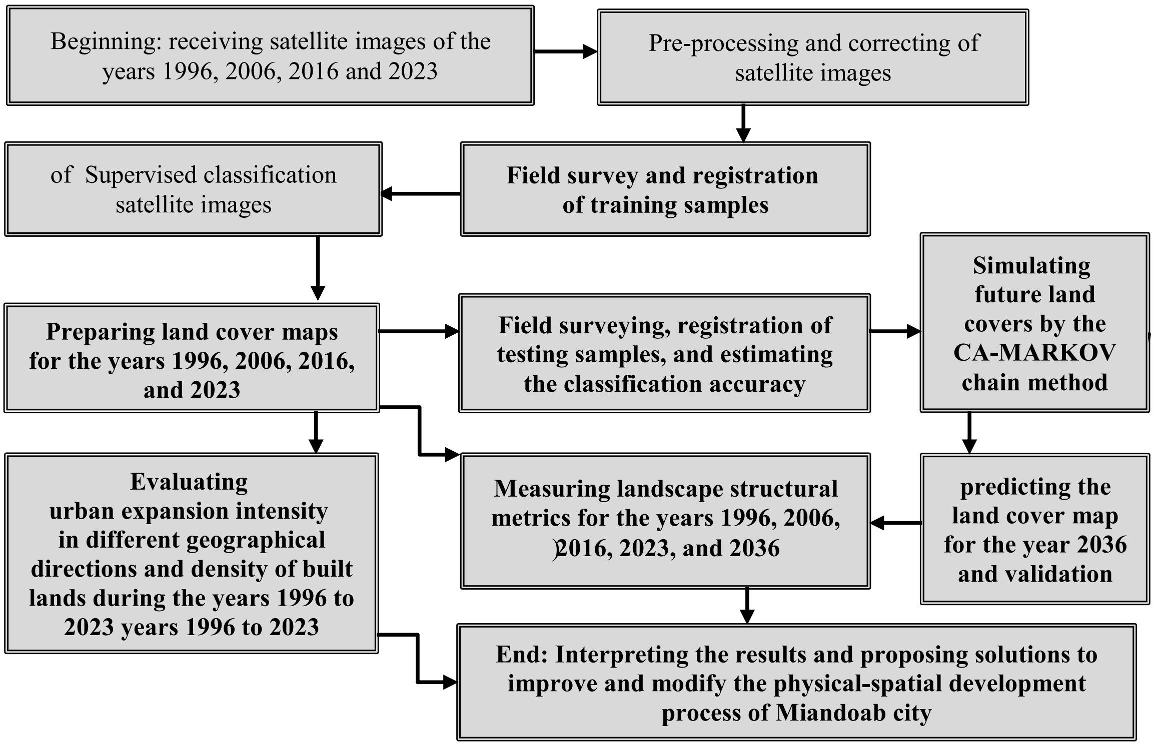

Figure 2. Details of the research methodology framework

Table 1. The specifications of used satellite images

Source	The date of receiving the satellite image	Sensor	Path/Row	Spatial resolution (meter)
USGS	1996/08	TM	138/34	30 *30
USGS	2006/07	ETM	138/34	30 *30
USGS	2016/07	OLI	138/34	30 *30
USGS	2023/07	OLI	138/34	30 *30

Comparison with existing maps, field surveys, and registration of test samples (randomly in the form of polygon data by GPS) have been done to check the classification accuracy. The overall accuracy and kappa coefficient were calculated by the error matrix method (according to Table 2, classification accuracy was acceptable).

In the second step, land covers in the future (2036) have been predicted using Idrisi software. It is simulated by the CA-Kamarkov chain method and automatic cells method based on the probability matrix of land use conversion. for estimating the accuracy of land cover prediction, the Kappa coefficient has been calculated. This value was higher than 71% indicating the validity of the simulation. In the third step, some metrics of the landscape have been calculated by Fragstats software for land covers in 1996, 2006, 2016, 2023, and 2036.

Table 2. Classification accuracy of satellite images

Year	Kappa coefficient	Overall accuracy
1996	72%	80%
2006	75%	82%
2016	74%	81%
2023	76%	83%

Based on the principles of landscape ecology, larger ecological patches are better. Also, the proximity and connection among ecological patches are more appropriate for supporting ecological functions. Also, shapes closer to the circle increase ecological functions (Alemohammad et al., 2022; Arekhi, 2015; He et al., 2018; McGarigal, 2017; Monteiro et al., 2020). In this research, based on these principles, following metrics have been selected and calculated by a software called Fragstats:

- Number of Patches (*NP*): this metric shows the number of spots related to a type of land cover.
- Class Area (*CA*): this metric is an area of land that is occupied by one type of land cover (Ha). Based on equation 1, a_{ij} is the area of patch j of land cover i.

$$CA = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{10000}\right) \quad (1)$$

- Mean Patch Size (*MPS*): This metric calculates by an arithmetic average from the total size of patches for each land cover (Ha). In equation 2, n is the number of patches.

$$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10000}\right) \quad (2)$$

- Patch cohesion index (Cohesion): This index measures the continuity and cohesion of patches (between 0 and 100). This metric is a simultaneous description of the shape and connectivity of the patches. In equation 3, p_{ij} is the patch perimeter, z is the total surface of the study area.

$$COHESION = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right] \cdot \left[1 - \frac{1}{\sqrt{Z}}\right]^{-1} \cdot (100) \quad (3)$$

In the fourth step, the density of built land cover (in concentric zones around the OCC) and the urban expansion intensity (in different geographical directions) have been estimated. To analyze the city's sprawling growth, ten concentric zones have been drawn at 500-meter intervals from the OCC. The density of built land cover in these zones has been calculated during the years 1996 to 2023, which means dividing the total area of built land covers in each zone by the total area of that zone. Equation 4 is related to the intensity of urban expansion (I_{ue}). ΔUi is the difference in urban expansion during the first year and the last year. TA is the total city area. Δt is the number of years (Lityński, 2021; Salem et al., 2021). Iue has been calculated for different directions during the years 1996 to 2023 in GIS software.

$$I_{ui} = \frac{\Delta Ui \times 100}{TA \times \Delta t} \quad (4)$$

In the fifth step, solutions have been presented according to the process of physical-spatial changes and the predicted conditions for the future to guide the planning of the urban and suburban landscape, with an emphasis on ecological infrastructure integrity.

Results

The changes in the levels of land cover types and the predicted values for the future are according to Figures 3 and 4 and the diagram of Figure 5. From 1996 to 2023, built lands increased from about 744 Ha to more than 1492 Ha. Also, green infrastructure has increased from more than 3376 Ha to about 2763 Ha. In addition, the blue infrastructure has increased from about 100 Ha to about 152 Ha. Bare lands have reached from about 1324 Ha to about 1137 Ha. More than 360 Ha of green infrastructure, more than 4 Ha of blue infrastructure, and 472 Ha of bare lands have been converted into built lands. More than 612 Ha of green infrastructure have been turned into bare lands. Based on the simulation, the speed of changes and the sprawling growth will be reduced in the future. A more uniform distribution of land cover types will emerge compared to the past. It is expected that by 2036, about 4 Ha of green infrastructure and 24 Ha of bare lands will be turned into built lands. Also, about 161 Ha of green infrastructure will be turned into blue infrastructure. With the continuation of the current trend, the major change in the future will include the transformation of green infrastructures into bare lands.

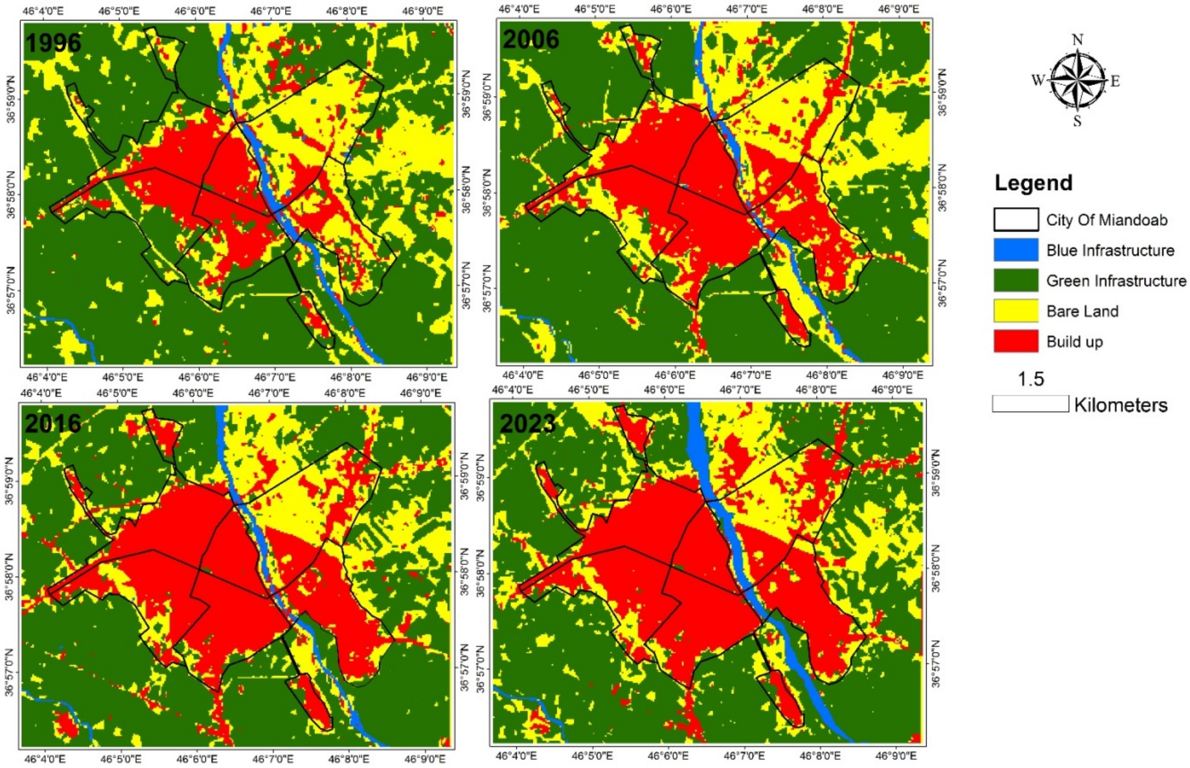

Figure 3. Land covers in 1996, 2006, 2016 and 2023

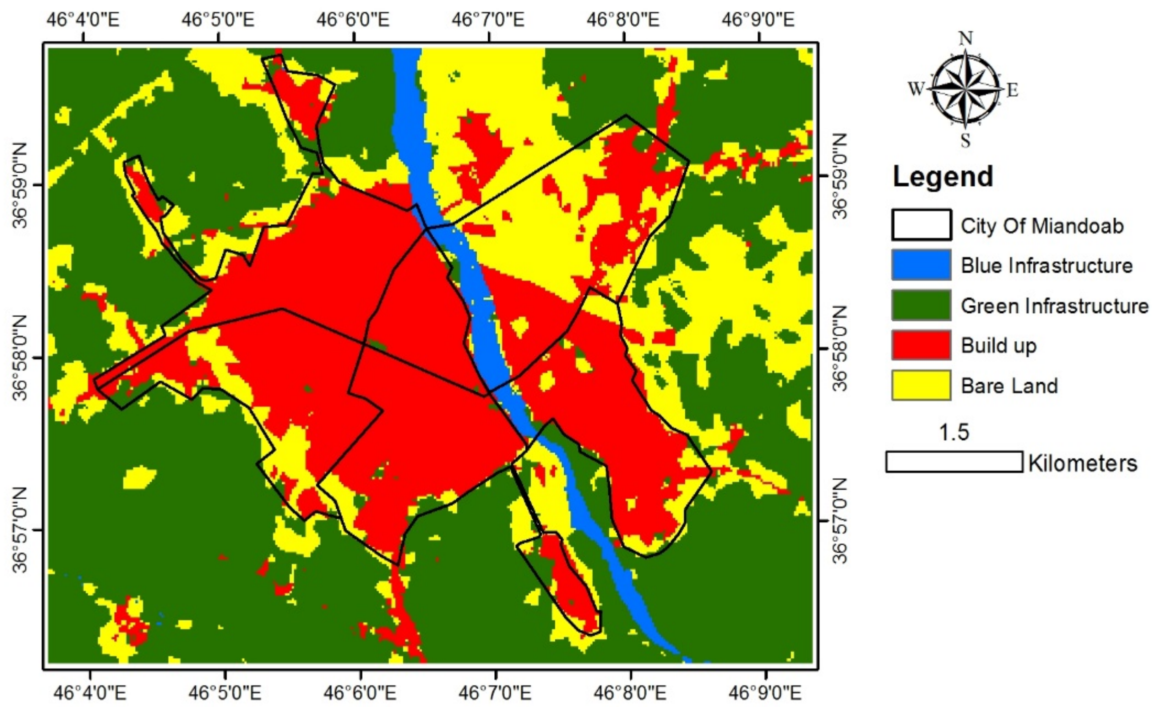

Figure 4. Predicted land covers for 2036 for different urban districts

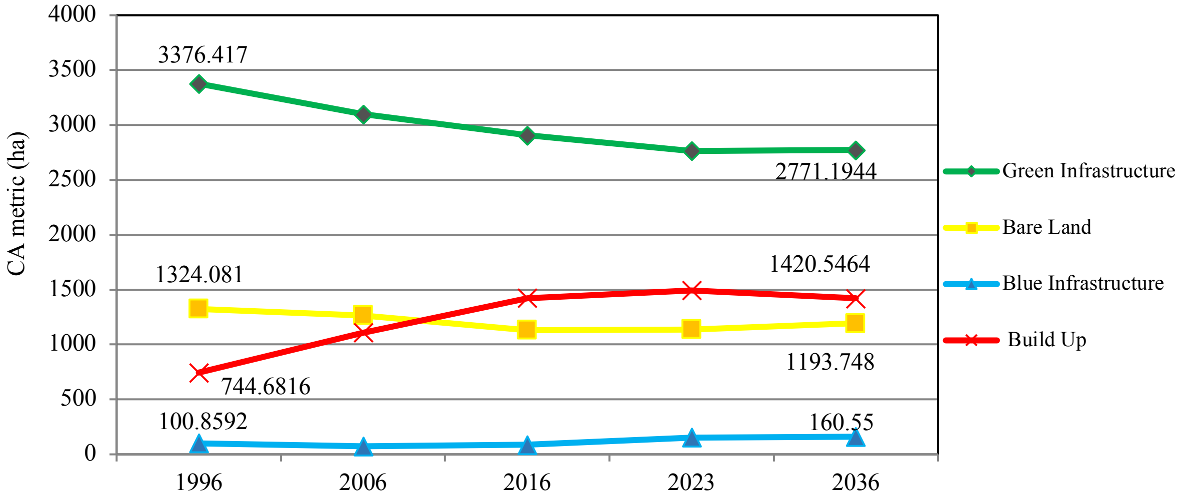

Figure 5. Changes in the areas of land covers (CA metric)

According to the diagrams in Figures 6 to 8, NP, MPS, and cohesion for four types of land cover have changed from the past (1996) until now (2023) as follows: NP for built land cover has decreased from 268 to 146. MPS of these lands has increased from about 2 Ha to more than 10 Ha. The cohesion index for these lands has increased from about 97 to 98.5. The patches of built land cover have decreased in number but increased in size, accumulation, and connection. The total surface of this land cover was increased. Therefore the structural integrity of built land cover has risen.

NP for green infrastructure has increased from 162 to 170. MPS of these lands has decreased from about 20 Ha to about 16 Ha. The cohesion index for these lands has reduced from more than 99 to 98.5. These data mean that the patches of green infrastructure have increased in number but decreased in size, accumulation, and connection. The total surface of this land cover was reduced. Therefore the structural integrity of green infrastructures has been reduced. NP for bare land cover has increased from 335 to 459. MPS of these lands has increased from about 4 Ha to about 2.5 Ha.

The cohesion index has decreased from more than 97 to about 95.5. At the same time, the total surface of this land cover has decreased. Therefore the structural integrity of the bare land cover has been reduced. What can be argued is that built land cover changes have caused opposite changes in the structural characteristics of green infrastructures and bare land cover. In simple words, the unbridled development of built lands has caused the fragmentation and loss of two other land cover types.

NP for blue infrastructures has decreased from 32 to 5. MPS of these lands has increased from about 3 Ha to more than 30 Ha. The cohesion index has increased from about 94.5 to about 97.5. In this region, the total surface of this infrastructure has increased. Therefore, the structural integrity of the blue infrastructure has risen.

The main reason for increasing the structural integrity of the blue infrastructure was the unbridled construction of dams and the construction of cement structures to direct and collect surface water in the Zarrineh Rood River Valley. Based on the predicted values of these metrics and indexes for 2036, built land cover growth might relatively be stopped which can be reduced the threats against the integrity of the ecological infrastructure. In such a way, it is expected to see a decrease in the NP and an increase in MPS and cohesion for green infrastructures and bare land cover.

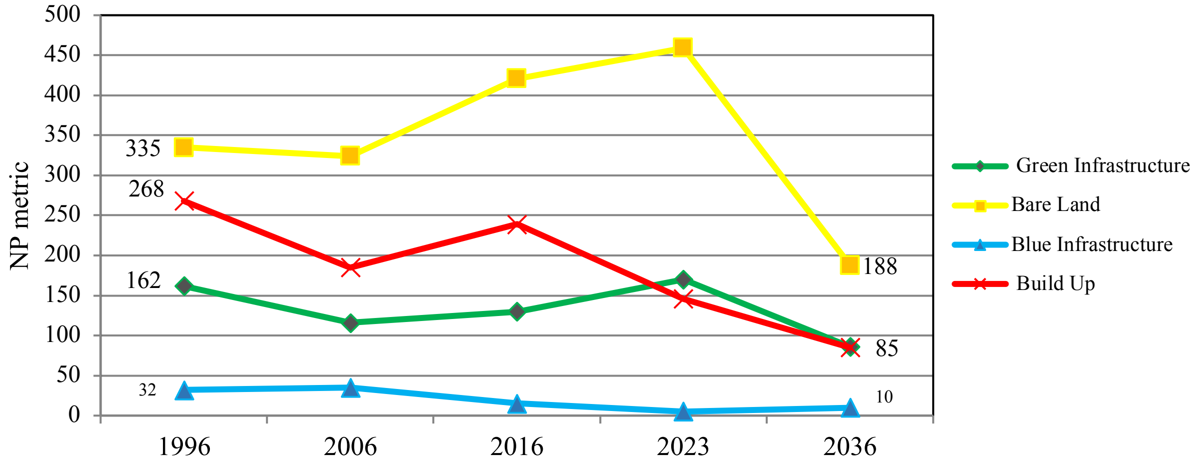

Figure 6. Changes in the number of patches for different land covers (NP)

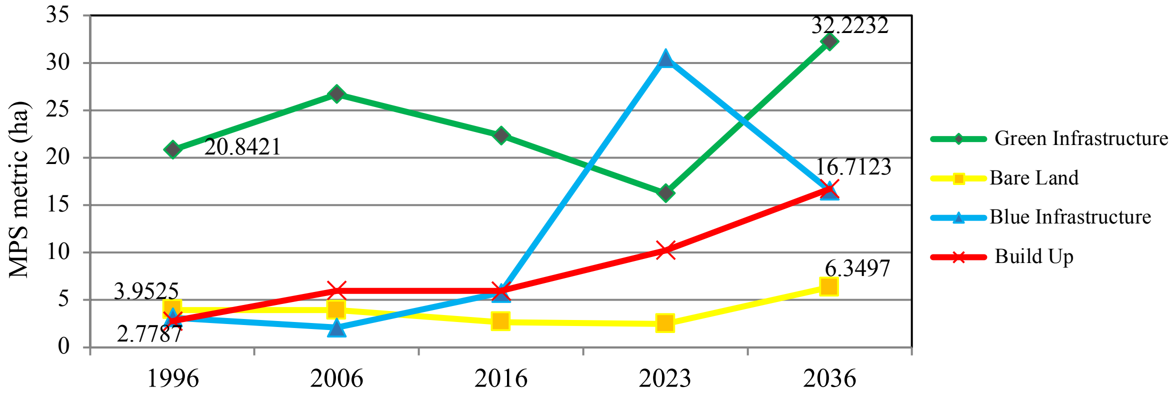

Figure 7. Changes in the mean patch size for different land covers (MPS)

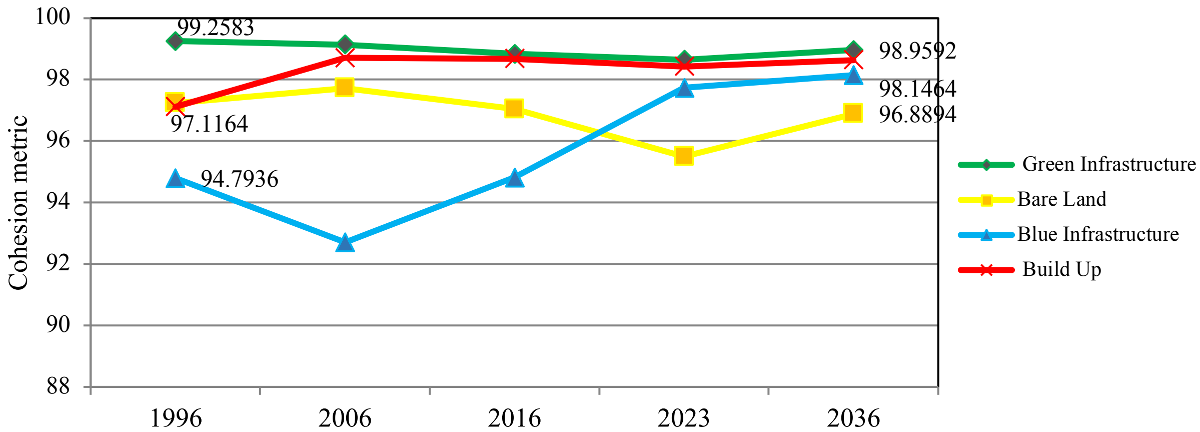

Figure 8. Changes in patch cohesion index for different land covers (Cohesion)

According to Figure 9, the orientation of the city growth was in all directions, but urban expansion intensity is more towards the ESE, ENE, and SSE directions in District 5 and District 6. Based on calculations, the urban expansion intensity has increased over time, which indicates the city's sprawling growth. Figure 10 shows the density of built land cover in different zones over the years. By moving away from OCC, the built land covers density decreases. The closer we go to zone 1, the higher the percentage of built land. In other words, development is more compacted in the inner zones. This feature also shows the city's sprawling growth.

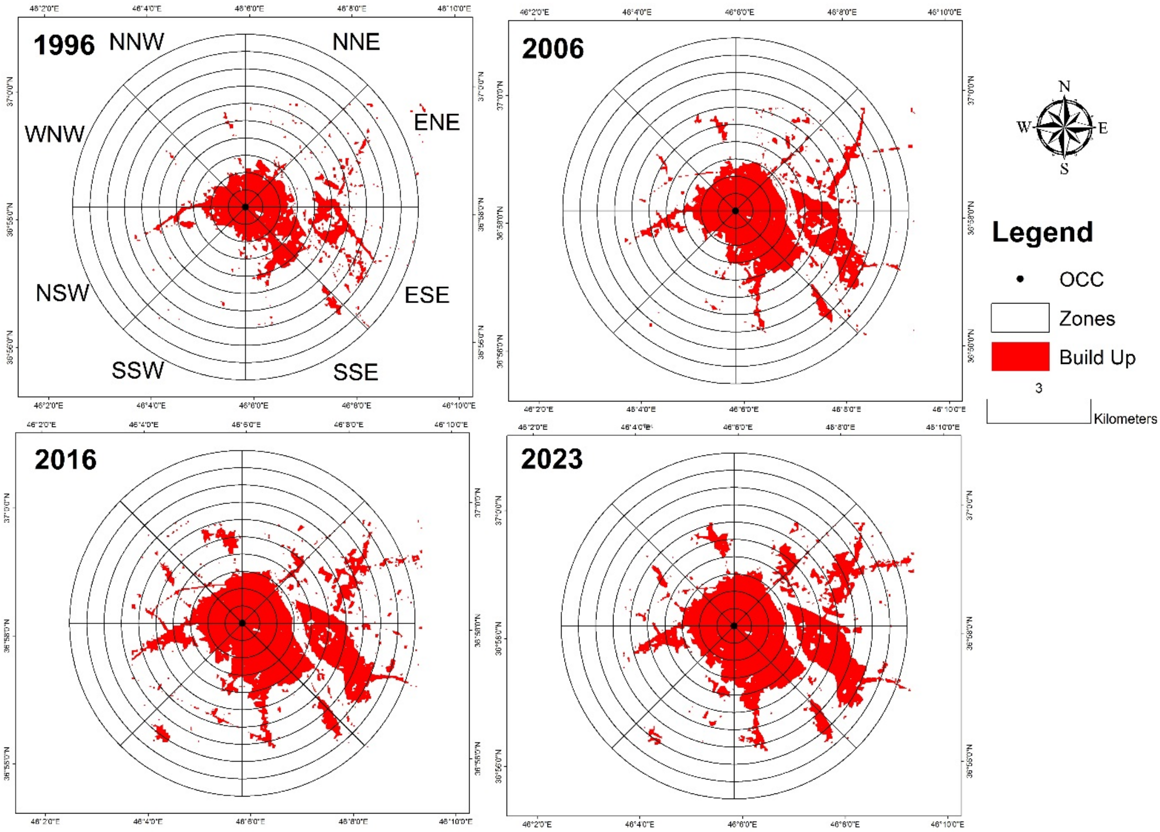

Figure 9. Sprawling city growth during increasing of built land cover (1996 to 2023)

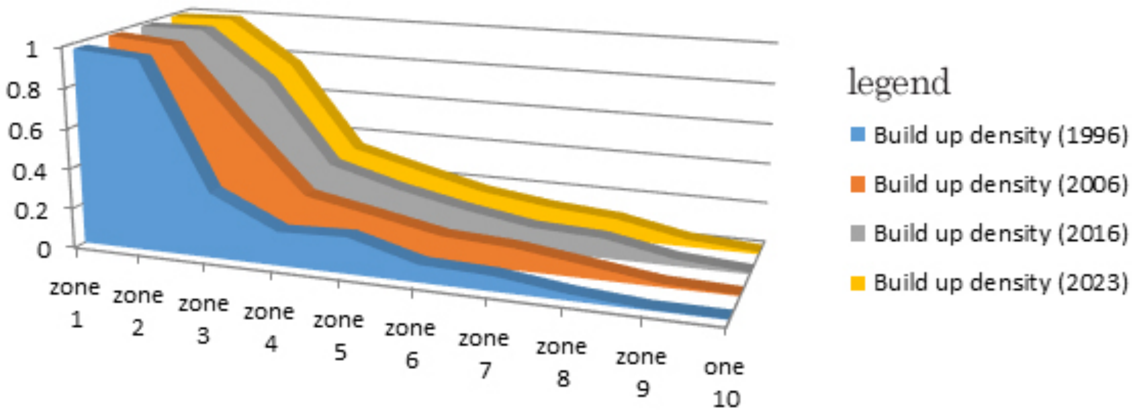

Figure 10. Changes in the built land cover density in concentric zones (1996 to 2023)

Based on the land cover changes between 1996 and 2023, 613 Ha of green infrastructure and 187 Ha of bare lands have been converted into built lands. Also, the direction of physical-spatial development of the city has been towards the eastern and southeastern suburbs. Currently, the most of bare lands and, as a result, the compacted growth potential (for converting these lands to build lands), are located in areas 5, 2, and 6, respectively. Considering the significant presence of bare lands in District 5, it is better to locate the city's future development towards the east and northeast. In addition, the distribution of urban green infrastructure among the city districts is not spatially balanced. regions 4, 6, and 3 respectively have the lowest percentage of green infrastructure area compared to the total area. The findings of this research confirm the results of some other studies in Miandoab City, as follows:

The biggest change in land cover in Miandoab City and its surrounding suburbs includes the conversion of agricultural green lands to build lands. During the sprawling physical-spatial development of Miandoab City, the lack of green spaces and city parks is very noticeable. In this city, the green space indicator is in the worst condition compared to other indicators of urban life quality (Lotfi et al., 2011; Mohammadi et al., 2012; Sadr Mousavi, 2017). A serious threat to the ecological infrastructures in the urban suburb is Ignoring the potential of reviving and renovating the worn OCC texture and ignoring the potential of increasing building floors (most of these city houses are very big villas) (Fakhraei & Abdi, 2012; Kheirkhah & Nemati Mehr, 2021; Parizadi et al., 2022; Rahnemaei et al., 2012; Rajabi & Maleki Nezamabad, 2015). In general, according to the findings of this research and other studies related to the sprawling growth of this city, there is no need for development outside the current built limits for the coming decades. As a result, the policy of increasing the urban boundaries should not be included in the legal framework and the physical-spatial development agenda of this city.

The main policies against the sprawling urban growth threats are using the existing capacities in low-density cities. Such as internal development inside legal urban boundaries, compact growth, and smart growth. These policies have aimed to create compacter, more flexible cities, away from the problems of the modern city, while at the same time protecting the landscape (especially the ecological infrastructure) and the urban community vitality (Abdullahi & Pradhan, 2017; Artmann et al., 2019; Lee & Lim, 2018; Mehrafzun et al., 2019; Tao et al., 2019; Tappert et al., 2018). For responding the landscape changes and increasing the urban ecological infrastructure integrity, solutions can be presented in the form of three types of strategies. Where the existing condition of these infrastructures is suitable, it is important to provide solutions with a conservative strategy.

The purpose of the defensive strategy is to prevent land transformation or control this structural degradation. An opportunistic strategy is essential for reviving damaged ecological infrastructures, for example, by converting the little amount of other land cover/uses into these infrastructures (Ahern, 2011; Parivar et al., 2013; Yazdanpanah et al., 2015). Also for appropriate and balanced physical-spatial development in the future and increasing ecological infrastructure integrity, spatial solutions in Table 3 are proposed.

The main spatial steps of any city development include the primary core formation, dispersion, and then concentration. In simple words, urban area development starts from an old center and moves to the outside and the new development centers. After that, the urban growth pattern continues towards the connection of built patches and filling open spaces until saturation. In most middle cities in the world, the second stage is dominant (Bhatta, 2012; Herold et al., 2005; Kaviani et al., 2015). The city of Miandoab has been formed concentrically around the market by forming the primary core.

The methodology and results of this research can be a reference for monitoring the manner and direction of urban development for guiding, modifying, and improving the decisions of physical-spatial development to support the urban ecological infrastructure. This methodology has generalizability and validity for use in other urban areas (because of the logical process, various stages, and a suitable and simple framework). It can help to study the urban sprawling growth and its impacts on green infrastructures and provide suitable spatial solutions in Iran and other countries.

Conclusion

According to the findings of this research, this city has experienced so unbridled growth in the dispersion step (until 2023). During this time, the structural integrity of green infrastructure and bare lands has been severely degraded. It is predicted that until 2036, the sprawling growth process will be reduced. Also, the distribution of land covers will be simpler compared to the past.

Table 3. Solutions for improving Miandoab City development process with emphasis on supporting ecological infrastructure

Strategies	Solutions
Conservative strategy	1- Maintaining large green patches and small green patches around them and strengthening their connection to improve their supporting functions for each other. 2- Maintaining and strengthening the vegetation of green roads, sidewalks, highways, and open lands to increase the continuity and connectedness of ecological infrastructure.
Defensive strategy	3- Determining the Zarineh Rood River valley buffer against the influence of conflicting land uses and organizing its riverside cover 4- Internal development by using urban bare lands instead of converting the surrounding green infrastructure into built lands. 5- Internal development by using the legal increase in the density of building floors and the reconstruction of abandoned buildings in the OCC to prevent the movement of the population to the suburb and to prevent further changes in the ecological infrastructure.
Opportunistic strategy	6- Assessing the feasibility of allocating land to urban parks and green spaces with an emphasis on the lack and unfair distribution of green infrastructures 7- Increasing the extent and strengthening the connection of small gardens and greenways with cooperative planning to reclaim land ownership in favor of these green infrastructures.

In comparison with the separated use of methods, the integrated application of the assessment procedure of land cover/use changes in urban areas and the assessment procedure of landscape structural changes can provide more reliable spatial information to analyze the changes in the urban growth pattern and its future (Anabestani et al., 2021; Bahmanpour & Valian, 2022; De Montis et al., 2019; Hataminejad et al., 2021; Magidi & Ahmed, 2019; Mahmoudzadeh & Masoudi, 2019; Norouzi Gelehkolaie et al., 2022; Omidpour et al., 2020; Zou et al., 2022). However, the simultaneous application of the procedure of predicting the future land cover with the two methods mentioned above has been used in limited studies (Anabestani et al., 2021; Nasehi et al., 2023), including the present research, and has caused differentiation and added value.

In general, this research innovations includes attention and emphasis on the following items: 1) five-time analysis of land cover and landscape structural changes by revealing the past, present and future conditions, 2) Investigating the urban expansion intensity in different geographical directions, 3) Investigating the distribution of built land density in concentric zones around OCC, and 4) Providing the solutions with three strategic orientations (protective, defensive and opportunistic).

References

Abdi, T. J., Sarrafi, M., & Razaviain, M. (2020). Study of Urban physical development by using quantitative models Shannon entropy, Holdren and Moran (Case Study: Kashmar city). Sustainable Development & Geographic Environment, 1(1), 53-72.

Abdullahi, S., Pradhan, B. (2017). Compact City Modeling (Case Study of Kajang City, Malaysia). In: Pradhan, B. (eds). Spatial Modeling and Assessment of Urban Form. Springer, Cham.

Ahern, J. (2011). From fail-safe to safe-to-fail: Sustainability and resilience in the new urban world. Landscape and urban planning, 100(4), 341-343.

Alemohammad, S., Yavari, A.R., Malekmohammadi, B., Salehi, E., & Amiri, M. J. (2022). Landscape conservation and protected areas (case of Dena, Iran). Environmental Monitoring and Assessment, 194(2), 54.

Anabestani, A., Anabestani, Z., & Akbari, E. (2021). Analysis of structural changes in the landscape and urban development patterns using multi-time satellite imagery-Case study: Mashhad Metropolitan. Scientific-Research Quarterly of Geographical Data (SEPEHR), 30(119), 189-206.

Arekhi, S. (2015). Application of landscape metrics in assessing land use changes' trend by using remote sensing and GIS case study: Dehloran desert area. Geography and Development, 13(40), 59-68.

Artmann, M., Kohler, M., Meinel, G., Gan, J., & Ioja, I.C. (2019). How smart growth and green infrastructure can mutually support each other—A conceptual framework for compact and green cities. Ecological Indicators, 96, 10-22.

Arvin, M., & Poor Ahmad, A. (2021). Theoretical Explanation of Polycentric Compact City Structure to Create a Sustainable Urban form. Geography and Territorial Spatial Arrangement, 11(41), 253-286.

Bagheri, B., & Tousi, S. N. (2018). An explanation of urban sprawl phenomenon in Shiraz Metropolitan Area (SMA). Cities, 73, 71-90.

Bahmanpour, H., & Valian, T. (2022). Evaluation and analysis of the trend of land landscape changes in urban green spaces of Tehran. Comprehansive Studies in Urban Management, 2(8), 24-36.

Bardi Anamoradnezhad, R. (2016). Analysis of the spatial planning and urban development pattern in Iran. Research and Urban Planning, *7*(26), 93-112.

Bhatta, B. (2012). Urban growth analysis and remote sensing: a case study of Kolkata, India 1980–2010. Springer Science & Business Media.

Bratley, K., & Ghoneim, E. (2018). Modeling urban encroachment on the agricultural land of the eastern Nile Delta using remote sensing and a GIS-based Markov chain model. Land, 7(4), 114.

Darvishi, Y., Gholami Nor Abad, H., & Momenpourakerdi, S. (2021). Smart urban growth spatial analysis using VIKOR (Case Study of Ardabil). Geographical Engineering of Territory, 4(2), 427-444.

De Montis, A., Ganciu, A., Cabras, M., Bardi, A., & Mulas, M. (2019). Comparative ecological network analysis: An application to Italy. Land Use Policy, 81, 714-724.

Dupras, J., & Alam, M. (2015). Urban sprawl and ecosystem services: a half century perspective in the Montreal area (Quebec, Canada). Journal of Environmental Policy & Planning, 17(2), 180-200.

Ehrlich, M. V., Hilber, C. A., & Schöni, O. (2018). Institutional settings and urban sprawl: Evidence from Europe. Journal of Housing Economics, 42, 4-18.

Ermini, B., & Santolini, R. (2017). Urban sprawl and property tax of a city's core and suburbs: Evidence from Italy. Regional Studies, 51(9), 1374-1386.

Ersoy, E., Jorgensen, A., & Warren, P. (2019). Identifying multispecies connectivity corridors and the spatial pattern of the landscape. Urban For. Urban Green. 40, 308–322. Urban Forestry & Urban Greening, (40), 308-322.

Fakhraei, S., & Abdi, M. (2012). The Study of effective Factors in the Migration of villagers to Miandoab in 2010. Sociological studies, 4(13), 33-46.

Faraji, A., Yousefi, Z., & Alian, M. (2018). Urban Sprawl, Compact City, Urban Form, Sustainable Development, Smart Growth, Tehran. Journal of Sustainable Architecture and Urban Design, 6(1), 23-38.

Ferreira, J. C., Monteiro, R., & Silva, V. R. (2021). Planning a green infrastructure network from theory to practice: The case study of Setúbal, Portugal. Sustainability, 13(15), 8432.

Garrido-Cumbrera, M., Ruiz, D. G., Braçe, O., & Lara, E. L. (2018). Exploring the association between urban sprawl and mental health. Journal of Transport & Health, 10, 381-390.

Girma, Y., Terefe, H., Pauleit, S., & Kindu, M. (2019). Urban green infrastructure planning in Ethiopia: The case of emerging towns of Oromia special zone surrounding Finfinne. Journal of urban management, 8(1), 75-88.

Hamidi, S., & Ewing, R. (2014). A longitudinal study of changes in urban sprawl between 2000 and 2010 in the United States. Landscape and urban planning, 128, 72-82.

Hataminejad, H., Hatami, A., & Moradi, A. (2021). Analysis of spatial growth patterns of khorramabad city with the ecological approach of the landscape.
He, C., Huang, Q., Liu, Z., & Wu, J. (2018). Urban Landscape Ecology: Processes, Impacts, and Sustainability. Beijing: Science Press.
Herold, M., Couclelis, H., & Clarke, K. C. (2005). The role of spatial metrics in the analysis and modeling of urban land use change. Computers, Environment and Urban Systems, 29(4), 369-399.
Kaviani, A., Farhoodi, R., & Rajabi, A. (2015). Analysis of Urban Growth Pattern in Tehran City by Landscape Ecology Approach. Geographical Urban Planning Research (GUPR), 3(4), 407-429.
Kheirkhah, Z., & Nemati Mehr, M. A. (2021). Elements and indicators of urban form: A meta-synthesis study. Space Ontology International Journal, 10(2), 45-60.
Lee, J. H., & Lim, S. (2018). The selection of compact city policy instruments and their effects on energy consumption and greenhouse gas emissions in the transportation sector: The case of South Korea. Sustainable Cities and Society, 37, 116-124.
Li, Q., Yang, L., Huang, S., Liu, Y., & Guo, C. (2023). The Effects of Urban Sprawl on Electricity Consumption: Empirical Evidence from 283 Prefecture-Level Cities in China. Land, 12(8), 1609.
Lityński, P. (2021). The intensity of urban sprawl in Poland. ISPRS International Journal of Geo-Information, 10(2), 95.
Liu, T., & Yang, X. (2015). Monitoring land changes in an urban area using satellite imagery, GIS and landscape metrics. Applied Geography, 56, 42-54.
Liu, Z., Liu, S., Qi, W., & Jin, H. (2018). Urban sprawl among Chinese cities of different population sizes. Habitat international, 79, 89-98.
Lotfi, S., Faraji, A., A, M. M., & Azimi, A. (2011). Analysing Urban Quality of Life Using Entropy Method and SAW Technique Case Study: Urban Texture of Miyandoab. Geographical Planning of Space(1(1), 69-85).
Magidi, J., & Ahmed, F. (2019). Assessing urban sprawl using remote sensing and landscape metrics: A case study of City of Tshwane, South Africa (1984–2015). The Egyptian Journal of Remote Sensing and Space Science, 22(3), 335-346.
Mahmoudzadeh, H., & Masoudi, H. (2019). The analysis of structural landscape changes in Tabriz city using landscape ecology principles with an emphasis on the connectivity concept. Town and Country Planning, 11(2), 179-204.
Marando, F., Heris, M. P., Zulian, G., Udías, A., Mentaschi, L., Chrysoulakis, N., . . . Maes, J. (2022). Urban heat island mitigation by green infrastructure in European Functional Urban Areas. Sustainable cities and society, 77, 103564.
McGarigal, K. (2017). Landscape metrics for categorical map patterns. Lecture notes.
Mehrafzun, M., Zanganeh, A., Shamaei, A., Prizadi, T., & Karami, T. (2019). Spatial Capacity Measurement of Intermediate Development of Boroujerd. Environmental Management, (49), 156-179.
Milan, B. F., & Creutzig, F. (2016). Municipal policies accelerated urban sprawl and public debts in Spain. Land Use Policy, 54, 103-115.
Mohammadi, J., Ahadian, M., & Azadi Qataar, S. (2012). Analysis and Evaluation of Sustainable Distribution and Development of Urban Green Spaces (Case Study: Miandoab City). Urban Management Journal, 10(29), 259-276.
Monkkonen, P., Comandon, A., Escamilla, J. A. M., & Guerra, E. (2018). Urban sprawl and the growing geographic scale of segregation in Mexico, 1990–2010. Habitat international, 73, 89-95.
Monteiro, R., Ferreira, J. C., & Antunes, P. (2020). Green infrastructure planning principles: An integrated literature review. Land, 9(12), 525.
Movahed, A., & Ahmadi, M. (2018). Planning for redevelopment of abandoned urban lands; emphasizing infill development approach (Case study: district 19 of Tehran). Physical Social Planning, 5(1), 59-76.
Nasehi, S., Alemohammad, S., Ramezani Mehrian, M., & Mobarghei Dinan, N. (2023). Formulating sustainability strategies for urban green infrastructures by using the landscape changes assessment (Tehran Metropolitan District 2). Geography and Environmental Sustainability, 13(2), 95-114.
Navamuel, E. L., Morollón, F. R., & Cuartas, B. M. (2018). Energy consumption and urban sprawl: Evidence for the Spanish case. Journal of Cleaner Production, 172, 3479-3486.

Nedovic-Budic, Z., Knaap, G. J., Shahumyan, H., Williams, B., & Slaev, A. (2016). Measuring urban form at community scale: Case study of Dublin, Ireland. Cities, 55, 148-164.

Nel, O., López, J., Martín, J., & Checa, J. (2017). Energy and urban form. The growth of European cities on the basis of night-time brightness. Land Use Policy, 61, 103-112.

Norouzi Gelehkolaie, S., Hatami, A., & Parvizy, S. (2022). Analysis of Kermanshah Spatial Growth Patterns on Ecological Landscape Performance. Physical Social Planning, 9(3), 49-64.

Nouri, Z. S., Nouri, J., Habib, F., & Rafian, M. (2021). Environmental management for urban development around river valleys using a conceptual model. International Journal of Human Capital in Urban Management, 6(4), 351-364.

Omidpour, M., Sayahnia, R., & Rezaei, Y. (2020). The impact of urban growth and development trend on ecological network structure with resilience and landscape approach (case study of Hamedan). Iranian Journal of Remote Sensing & GIS, 12(2), 19-32.

Ostrowski, P., & Falkowski, T. (2020). Application of remote sensing methods to study the relief of lowland river valleys with a complex geological structure—A case study of the Bug River. Water, 12(2), 487.

Oueslati, W., Alvanides, S., & Garrod, G. (2015). Determinants of urban sprawl in European cities. Urban studies, 52(9), 1594-1614.

Parivar, P., Faryadi, S., Yavari, A. R., Salehi, E., & Harati, P. (2013). Developing the ecological sustainable strategies to increase urban environmental resilience:(case study: districts 1 and 3 of Tehran Municipality). Journal of Environmental Studies, 39(1), 123-132.

Parizadi, T., Mirzazadeh, H., Asghary, R., & Karimi, A. (2022). The study of physical development pattern with the approach of infill development case study: Miandoab city. Human Geography Research, 54(4), 1303-1321.

Parker, J., & Zingoni de Baro, M. E. (2019). Green infrastructure in the urban environment: A systematic quantitative review. Sustainability, 11(11), 3182.

Pozoukidou, G., & Ntriankos, I. (2017). Measuring and assessing urban sprawl: A proposed indicator system for the city of Thessaloniki, Greece. Remote Sensing Applications: Society and Environment, 8, 30-40.

Rahimi, M., & Bazmeh, F. (2021). The challenges of urban land use detection emphasizing the use of inefficient (Case study: area 8 of Kerman). Journal of Urban Social Geography, 8(2), 201-183.

Rahnemaei, M. T., Manochehri, A., & Faraji, A. (2012). Analyzing Urban Quality of life in old fabric of Miandoaab city. Urban Management, 28(9), 223- 240.

Rajabi, A., & Maleki Nezamabad, R. (2015). Spatial Distribution of Residential Landuse in Urban Density and a Review of Its Role in Sustainable Development Using GIS (Case Study: Miandoab City). Human Geography Research, 47(3), 529-541.

Rajput, T. S., Singhal, A., Routroy, S., Dhadse, K., & Tyagi, G. (2021). Urban policymaking for a developing city using a hybridized technique based on SWOT, AHP, and GIS. Journal of Urban Planning and Development, 147(2), 04021018.

Rall, E., Hansen, R., & Pauleit, S. (2019). The added value of public participation GIS (PPGIS) for urban green infrastructure planning. Urban Forestry & Urban Greening, 40, 264–274.

Ramezani Mehrian, M. (2022). Assessing the structural quality of green space network in urban environments-case study: District 16 of Tehran Municipality. Geographical Urban Planning Research (GUPR), 10(1), 81-99.

Sadr Mousavi, M. S. (2017). Evaluation and Simulation of Urban FringeLand-use Changes by Using CA-Markov Model (Case Study: Miandoab City). Geography and Planning, 20(58), 139-157.

Saeed Sabaee, M., Salman Mahiny, R., Shahraeini, S. M., Mirkarimi, S. H., & Dabiri, N. (2016). Use of landscape metrics in land use allocation. Town and Country Planning, 8(1), 155-175.

Salem, M., Bose, A., Bashir, B., Basak, D., Roy, S., Chowdhury, I. R., . . . Tsurusaki, N. (2021). Urban expansion simulation based on various driving factors using a logistic regression model: Delhi as a case study. Sustainability, 13(19), 10805.

Salvati, L., & Carlucci, M. (2016). Patterns of sprawl: The socioeconomic and territorial profile of dispersed urban areas in Italy. Regional Studies, 50(8), 1346-1359.

Sarvar, H., & Asghary, R. (2021). Analysis of the Public Spaces of Cities via a vitality approach: A Case Study of Ata Coastal Park of Miandoab. Spatial Planning, 11(4), 27-46.

Sharifi, A. (2019). Resilient urban forms: A macro-scale analysis. Cities, 85, 1-14.

Taghadosi, M. M., Hasanlou, M., & Eftekhari, K. (2019). Evaluating and comparing supervised classification algorithms With the aim of mapping soil salinity levels using Sentinel-2 satellite imageries. Scientific-Research Quarterly of Geographical Data (SEPEHR), 28(110), 37-52.

Tao, J., Wang, Y., Wang, R., & Mi, C. (2019). Do compactness and poly-centricity mitigate PM10 emissions? Evidence from Yangtze River Delta Area. International Journal of Environmental Research and Public Health, 16(21), 4204.

Tappert, S., Klöti, T., & Drilling, M. (2018). Contested urban green spaces in the compact city: The (re-) negotiation of urban gardening in Swiss cities. Landscape and urban planning, 170, 69-78.

Wang, J., & Banzhaf, E. (2018). Towards a better understanding of Green Infrastructure: A critical review. Ecological Indicators, 85, 758-772.

Xu, L., Huang, Q., Ding, D., Mei, M., & Qin, H. (2018). Modelling urban expansion guided by land ecological suitability: A case study of Changzhou City, China. Habitat international, 75, 12-24.

Yazdanpanah, M., Yavari, A.R., Zebardast, L., & Alemohammad, S. (2015). Urban Green Infrastructure Assessment for Their Regeneration in Tehran Landscape. Journal of Environmental Studies, 41(3), 613-625.

Ying, J., Zhang, X., Zhang, Y., & Bilan, S. (2022). Green infrastructure: Systematic literature review. Economic Research-Ekonomska Istraživanja, 35(1), 343-366.

Yousef, S., Tazeh, M., Mirzaee, S., Moradi, H., & Tavangar, S. (2011). Comparison of different classification algorithms in satellite imagery to produce land use maps (Case study: Noor city). Journal of RS and GIS for Natural Resources, 5(3) 67-76.

Yue, W., Zhang, L., & Liu, Y. (2016). Measuring sprawl in large Chinese cities along the Yangtze River via combined single and multidimensional metrics. Habitat international, 57, 43-52.

Zhang, C., Miao, C., Zhang, W., & Chen, X. (2018). Spatiotemporal patterns of urban sprawl and its relationship with economic development in China during 1990–2010. Habitat international, 79, 51-60.

Ziari, K., Ghadiri, M., & Dasta, F. (2014). Assessment and evaluation of the physical expansion pattern of Yazd city. Human Geography Research, 46(2), 272-252.

Zou, L., Wang, J., & Bai, M. (2022). Assessing spatial–temporal heterogeneity of China's landscape fragmentation in 1980–2020. Ecological Indicators, 136, 108654.