Megaron, Vol. 19, No. 1, pp. 51–60, April 2024

Megaron
https://megaron.yildiz.edu.tr - https://megaronjournal.com
DOI: https://doi.org/10.14744/megaron.2024.85226

Article

Spatio-temporal change of the morphology in west corridor development region of Ankara city and 2022-2039 growth estimation

Öznur IŞINKARALAR*

Department of Landscape Architecture, Kastamonu University Faculty of Engineering and Architecture, Kastamonu, Türkiye

ARTICLE INFO

Article history
Received: 21 December 2022
Revised: 15 February 2024
Accepted: 04 March 2024

Key words:
Ankara; cellular automata-Markov chain; fractal geometry; sustainable development; urban morphology.

ABSTRACT

The land is needed for many activities in cities due to rapid urbanization and population growth taking place on a global scale. In order to meet the demands of the increasing population, cities grow towards extensive rural lands and try to meet the citizens' needs for land spatially used for housing, transportation, industrial facilities, and education facilities. The change in urban morphology is one of the most discussed topics in planning from the past to the present, consisting of uniquely complex phenomena. The traditional method of urban science offers approaches based on Euclidean geometry, based on the assumption of uniform growth. However, urban morphology has a multidimensional fractal structure, and it is insufficient to understand the city as a living organism that evolves, changes, and develops very quickly. Since urban growth and expansion are an inevitable reality intertwined with economic growth, spatial changes in cities as living organisms are inevitable. Population growth worldwide is one of the most critical parameters affecting cities' growth. Unplanned growth in cities causes many environmental problems, such as unplanned urbanization. Monitoring and forecasting land changes in urban growth and expansion processes are significant in producing effective regional and urban planning policies. In this process, the concept of urban morphology comes to the fore. In this context, the fractal dimension analysis emerges as a technique of interest. Decreases and increases in fractal values gain meaning by being associated with processes such as expansion and growth observed in cities. Fractal geometry, on the other hand, provides the opportunity to evaluate this complex structure quantitatively. At the same time, it offers a new mathematical framework for describing urban morphology. The study aimed to investigate the development process of the development zone in the western corridor of Ankara, with a fractal analysis to be made at the urban scale through its morphological change. The temporal changes in urban form and texture between 2005-2022 and the morphological character of Ankara are questioned through fractal analysis. The study was carried out in two stages. In the first stage, the western corridor of Ankara was analyzed on an urban scale, and the morphological change in 2039 was estimated within the scope of two different scenarios. The compact growing scenario (G_C) proposes a growth model within the boundaries of the determined area. The spreading-growing scenario (G_S) assumes a spreading-growth behavior into the land cover, regardless of field boundaries. The G_C scenario defines areas where growth will not occur outside the determined western development zone. On the other hand, the G_S covers the growth areas produced by assuming that the entire urban geography is suitable for settlement without any restrictions. After defining the scenarios, fractal blots from 2005, 2013,

***Corresponding author**
*E-mail adres: obulan@kastamonu.edu.tr

2022, and 2039 were obtained, and fractal analysis was carried out using the box-counting method. At the same time, it showed that urban spatial richness increased, as the value of 1.63 in 2005 reached 1.85 in G_C and 1.98 in growing by G_S in 2039. As a result of the analysis, it was concluded that the changes in the fractal dimensions obtained at the urban scale, the West development corridor experienced a rapid urbanization process from 2005 to the present, and this process showed urban expansion in the east-west direction.
Increases in fractal dimensions also indicate an increase in the complexity of the urban fabric, in other words, spatial richness. The simulation results of the year 2039 using the Cellular Automata - Markov chain method also support these results. Compact and spreading growth approaches produced within the scope of the research resulted in different growth behaviors of the city. While the growth is more controlled in the model restricted by the research area boundaries, the expansion pressure of the city is quite remarkable in the scenario where there is no restriction. The data obtained by this method for West Ankara, which is determined as the development direction of the city with the plan decisions, has significant potential in evaluating the current situation and future spatial patterns. Therefore, the research offers a new perspective to describe the complexity of the urban system. In addition, it is thought to have a guiding quality in the planning processes. The research offers a current perspective and innovation with a scenario-based model based on fractal geometry to describe the complexity of urban morphology.

Cite this article as: Işınkaralar, Ö. (2024). Spatio-temporal change of the morphology in west corridor development region of Ankara city and 2022-2039 growth estimation. Megaron, 19(1), 51–60.

INTRODUCTION

Due to rapid urbanization and population growth, more land is needed in cities for many activities, such as housing, transportation, production, and recreation. Sustainable land use is essential for sustainable development (Fu et al., 2022). In order to meet the demands of the increasing population, cities grow towards large rural lands and try to meet the needs of the citizens for land uses such as housing, transportation, industrial facilities, and education facilities spatially. Urban growth and sprawl are a spatial reflection of rapid urbanization that poses a challenge to sustainable urban development. Rapid urban development challenges spatial planning frameworks and requires holistic approaches to deal with urban development's negative environmental, social, and economic impacts (Artmann et al., 2019).

Along with the change in the use of urban space, the macro form of the city is also changing. The processes of urban growth and change in the urban macro form are of great concern worldwide (Wang & Zheng, 2022; Wang et al., 2022). The most important reason for this situation is that urbanization and population growth will continue with this process, and people will need more livable areas (IPCC, 2021). On the one hand, the increase in the urban population continues. On the other hand, the migration processes from rural areas to urban areas in developing countries increase the need for space. Therefore, urban areas are geographies where processes such as land degradation and social and environmental problems are experienced, and they are areas that offer economic opportunities to improve the quality of life. The spread of urban land to a broader geography has many economic, ecological, and social consequences. Developing planning tools for local governments to produce policies within the sustainable development goal of urban multidimensional dynamics is necessary.

It is effective in constructing and developing cities, depending on the city's history, geographical features, location, climate, land structure, socio-demographic characteristics, and animal and plant resources. In other words, all spatial parameters related to cities shape the urban growth rate and urban morphology (Su et al., 2022). Oliveira (2018) defines urban morphology as the science that studies the physical form of cities and the significant factors and processes that shape them over time. Urban morphology studies change in the physical structure and shape of settlements over time and focuses on growth/change patterns and processes (Carmona et al., 2003). Marshall & Caliskan (2011) describe urban morphology as an abstract shadow of physical reality. Accordingly, urban morphology includes reflecting urban processes on the field with the help of abstract metrics and shapes represented as maps.

The concept of compactness explains urban growth processes in terms of new residential areas being disconnected or coming together intensively and frequently. The compact city approach is a growth model that benefits public health regarding land use and transportation in shortening distances (Stevenson et al., 2016). However, while the adverse effects of urban sprawl (for example, longer transport times, loss of fertile soils, reduction or loss of ecosystem services (ES), on the one hand, encourage compact urban development, it also has disadvantages. The dilemma of its impact on environmental quality (e.g., absence of green spaces) and reducing social disadvantages are discussed as the "compact city paradox" (Neuman, 2005; Artmann et al., 2019). As another urban growth concept, urban expansion and urban sprawl differ from each other. Urban expansion is defined as a general physical process that includes the reproduction of the material structure of cities in the temporal process (Inostroza, 2018). Urban sprawl, on the other hand, expresses a dispersed urban development behavior (Burchfield et al., 2006). Especially in recent years, the results of urban growth and the future state of urban morphology are essential in the literature. As a result of the technological developments experienced, the methods used in urban growth, morphology, and development are gaining importance. Fractals are geometric constructs that exhibit repeating textures and patterns at all scales, utterly different from new and traditional geometric constructs, and are used from the architectural scale to the urban scale (Çağdaş et al., 2006; Ediz & Gürsakal, 2010). Fractal analysis is one of the remarkable methods in determining the complexity level of urban growth and enabling it to be measured quantitatively. Fractal analysis, an approach considering cities as complex systems, is a numerical method used to evaluate irregular, fragmented, and fractured urban forms (Chen, 2013). Accurate and effective urban morphology estimation and measurement are vital in identifying future urban problems.

In light of the above evaluations, the general purpose of the study is to investigate the development process of the development corridor in Ankara's western corridor with a fractal analysis to be made at the urban scale through its morphological change. In this context, the temporal changes in urban form and texture between 2005 and 2039 and the morphological character of the Western development corridor were questioned through fractal analysis. Thus, while shedding light on local decision mechanisms in terms of planning, it provides an empirical approach to applying the fractal method to urban textures.

MATERIAL AND METHODS

Study Area: Development of the morphology of the city of Ankara in the planning process

In the planning processes that Ankara has experienced from the past to the present, the development of the western part of the city begins with the Jansen plan, and growth is foreseen in this part of the city in the following periods. In this context, this study aimed to reveal the spatial and temporal changes in the morphology of the West Development corridor, a region of Ankara's urbanization effect, between 2005 and 2039 by fractal analysis. According to the 2023 Capital Ankara Master Plan Report, the western corridor development area of the city of Ankara is defined as the "Western Planning area." The city's western corridor was planned to produce a new expansion strategy for the north-south-oriented urban development that had continued until the plan period. The area includes Batıkent, Eryaman, Sincan, and Etimesgut development areas, areas where the rural and natural character is preserved, and Kazan and Ayaş district centers. With these features, the development of the said region, which includes the region, urban, semi-urban, and rural areas together, is also explained in a dual structure (Figure 1).

The city of Ankara, significant throughout history, has initiated various studies to address many problems and establish planned development, especially after becoming the capital city in 1924. In the planning studies, the direction of urban growth and development, which would affect the form of the city, was initially investigated. While one group advocated for the development of the old city, another group argued that the old city had insufficient infrastructure and that a new Ankara should be established. With the development decision for the city of Ankara, the 'Lörcher Plan', thought to organize the old city center and connect it with the new city center, was implemented. This plan adopted a more protective approach to the old city center and proposed a regular settlement pattern for the new development areas. After 30 years, new problems emerged due to rapid population growth and urbanization, necessitating a new city plan. As the Lörcher plan proved inadequate, the Jansen plan was adopted in 1932, proposing a city form surrounding the Ankara castle.

With the increase in the number of immigrants due to urbanization, a new plan was required. In 1957, these problems were addressed with the Yücel-Uybadın plan, and the city macroform was expanded. A compact urban setup integrated with green zones was attempted for the city. During the 1990s, the city of Ankara became a metropolitan city. The most notable feature of the Yücel-Uybadın plan is the absence of the urban form-seeking concern present in the Lörcher and Jansen plans. Instead, existing plans and layouts were developed further. In this context, an axis extending to the west of the city was defined in the Yücel-Uybadın plan, predicting growth in this direction.

Method

This study aimed to reveal the morphology change between 2005 and 2039. In this context, firstly, the temporal-spatial change of the city was estimated according to scenarios produced with different approaches. Then, the

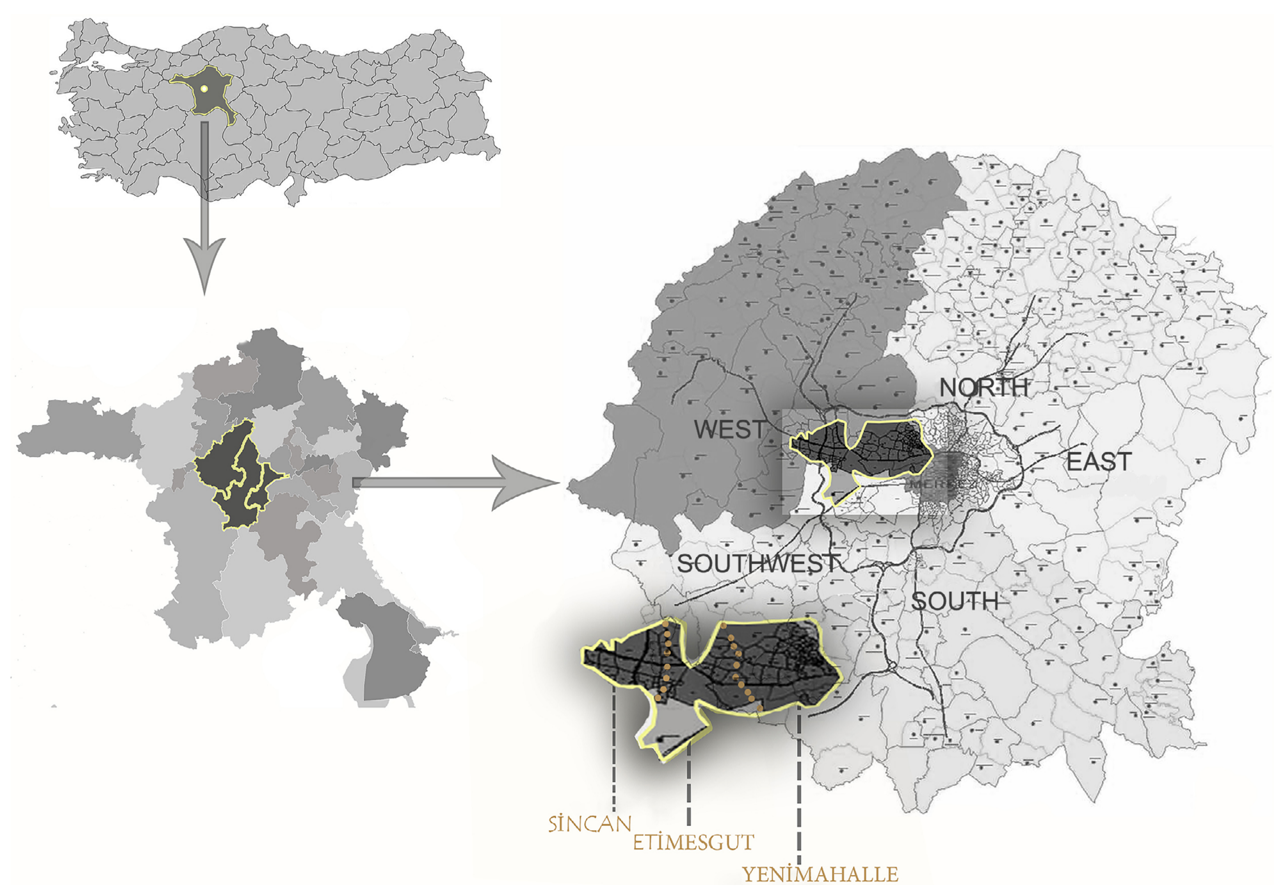

Figure 1. Study area location map.

fractal structure of the settlement spot, created with the city's development, was measured by the box-counting technique. In fractal analysis, this work uses a Box Count estimator, which is based on the simple idea that a single box initially covers the time series graph (Caballero et al., 2022). The box is divided into four quadrants, and the number of cells required to cover the curve is counted, which is advantageous for numerical interpretation.

Urban Growth Forecast: The estimation of urban land use and growth is a central topic of discussion in proactive planning and sustainable development goals. Thanks to temporal-spatial techniques, it is possible to analyze and forecast urban growth on a global and regional scale. These methods also help to determine urban growth dynamics (Lu et al., 2019; Baqa et al., 2021). Various models are used to analyze changes in urban growth (Guan et al., 2011; Azari et al., 2016; Ghosh & Das, 2017; Li et al., 2017; Singh et al., 2018; Shen et al., 2020; Dey et al., 2021). Since the 1990s, many urban growth models have been developed. The SLEUTH urban growth model is one of the most popular and has been used in many projects worldwide (Ayazli, 2019). Among these methods, the cellular automata (CA) model's advantage in modeling spatial variation in complex systems and the long-term prediction advantage of the Markov chain model have been integrated, developing the CA-Markov chain model, which is an effective method for simulating urban growth change and transformation. This method is frequently used to predict and measure urbanization dynamics (Keshtkar & Voigt, 2016; Baqa et al., 2021; Isinkaralar et al., 2023). CA-based models are mostly preferred to mitigate the damage caused by urban sprawl (Terzi & Kaya, 2011; Tong & Feng, 2020; Ayazli et al., 2022; Yılmaz et al., 2022; Isinkaralar & Varol, 2023). These models are significantly influenced by spatial scale, neighborhood configuration, and the choice of probability threshold (Xia et al., 2019). Neighborhood effects are crucial for CA models because these are bottom-up techniques that rely on interactions between nearby cells (Barreira-González & Barros, 2017).

Urbanization spot data for the years 2005, 2013, and 2022 were obtained from the Google Earth program. The obtained data were arranged in the ArcGIS program (in Geotiff format) and made suitable for analysis. Then, the morphology change calibration (kappa values) between 2005 and 2013 was obtained, and the Ankara West Development corridor morphology simulation in 2039 was estimated using the CA-Markov chain method in the IDRISI Selva program. Kappa coefficients evaluate how well terrain classification or modeling performs beyond chance agreement (van Vliet et al., 2011). Simulation estimation was done using the CA-Markov chain method in the IDRISI Selva program.

The CA-Markov chain method is an analysis that uses the transition probability to predict future states based on the current state and the next state. It models land use change when spatial changes are difficult to define. This analysis indicates the future direction and magnitude of change (Huang et al., 2020). The Markov estimation is applied according to the following formula (Jianping et al., 2005):

$$S(t+1) = P_{ij} \times S(t) \quad (1)$$

Here, S(t) and S(t+1) mean row vectors at time step t and time step t+1; P stands for the transition probability matrix for the previous time interval calculated as follows:

$$||P_{ij}|| = \begin{Vmatrix} P_{11} & P_{12} & P_{1n} \\ P_{21} & P_{22} & P_{2n} \\ P_{n1} & P_{n2} & P_{nn} \end{Vmatrix} \; (0 \le P_{ij} < 1 \text{ and } \textstyle\sum_{n1} P_{ij} = 1) \quad (2)$$

P_{ij} represents the probability of transitioning from land use type i to j.

Scenario Design: Developing alternative scenarios in urban growth forecasts provides an opportunity to identify possibilities. Two future urban growth scenarios were developed in the study. The compact growing (G_C) scenario proposes a growth model within the boundaries of the determined area. The spreading-growing (G_S) scenario assumes a spreading-growth behavior into the land cover, regardless of field boundaries. The G_C scenario defines areas where growth will not occur outside the determined western development zone. Therefore, urban growth has been limited. On the other hand, the G_S scenario covers the growth areas produced by assuming that the entire urban geography is suitable for settlement without any restrictions.

Fractal Analysis The physical changes of cities cause the formation of simple and regular complex textures. Understanding the growth behavior, one of the essential indicators of physical changes, and especially determining the urban growth trends, is a crucial requirement in urban studies. A practical and comprehensive analysis in this context will guide the determination of a city's current problems and future needs (Öztürk, 2017). Zoned land in an urban area (excluding transportation land and squares) is morphologically similar to Fournier dust (Zhao et al., 2021). Urban land segments are separated from each other by hierarchical streets (axes), whereas the building terrain in a rural area is more random and has an irregular spatial organization. While the urban area is a hierarchical, high-density, and stacked fractal pattern, the rural area shows a random, low-density, and dispersed spatial distribution. In this context, the fractal structure is a current discussion area in urban studies.

Fractals are used to describe the complexity of patterns in terms of the basic order of naturally occurring patterns and artificial phenomena. Batty & Longley (1994) adaptation of fractal theory to urban studies brought a new approach to complex urban growth within the scope of two-dimensional structures such as urban borders, land use, urban form, and growth. The fractal dimension is a ratio that does not have to be an integer but reflects the gap-filling capacity of a pattern at varying scales (Zhao et al., 2021).

After defining the scenarios, fractal spots from 2005, 2013, 2022, and 2039 were obtained, and each image was arranged in Photoshop in 792×500 pixels and 300 dpi format. Fractal analysis was then performed using the box-counting method in the Harfa 5.5 (Harmonic and Fractal Image Analysis 5.5) program. Line segments and box-counting methods are frequently used in fractal dimension (D) calculation methods in fractal analysis by Mandelbrot (1977), Bovill (1996), and Ediz & Ostwald (2012). In urban planning studies, the box-counting method is mainly preferred. D takes a value between 1 and 2. The fact that D is high, a value close to 2, shows that the rate of unused areas in the urban stain is low. High D represents urban spatial richness, spatial efficiency, and compact cities, while low D represents situations where spatial efficiency and spatial richness are low. Fractal analysis is a practical, easy, and accessible method for accurate numerical measurement of urban spaces (Chen, 2018).

The fractal dimension is defined using the below equation:

$$D_{\delta 1\text{-}\delta 2} = \frac{\log N(\delta_2) - \log N(\delta_1)}{\log({}^1/_{\delta 2}) - \log({}^1/_{\delta 1})}$$

Where D represents the Fractal dimension by the box-counting method, δ_1 and $\delta 2$ express that elevation is initially filled with a big grid and the edge length of the grid boxes and side length of the smaller box, $N(\delta_1)$ and $N(\delta_2)$ explain the number of grid boxes intersected by the line image and the number of intersected boxes.

RESULTS

Model Verification and Calibration

The morphology stain maps of the West Development corridor for 2005 and 2013, and the simulation results for 2022 were obtained and compared with the existing 2022 morphology stain. The visual comparison shows that the simulated blot has a similar spatial pattern to the reference blot (Figure 2).

The Kappa index, calculated to evaluate the accuracy of the simulation results quantitatively, shows that it is an excellent model for locating the future change of the West development corridor (Table 1).

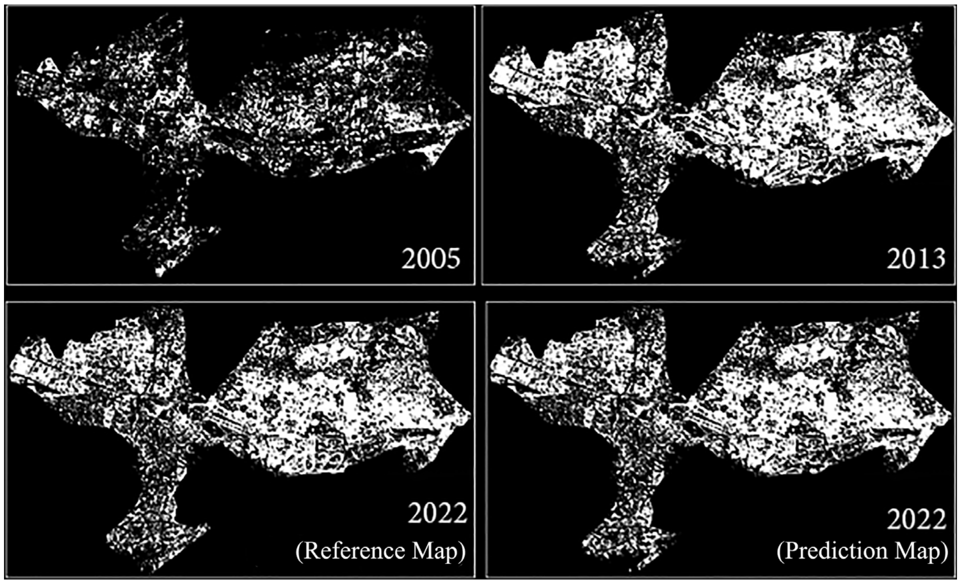

Figure 2. Urbanization spot reference and forecast map for 2022.

Table 1. Kappa values

Kappa statistics	Value
K_{no}	0.9844
$K_{location}$	0.9648
$K_{locationStrata}$	0.9648
$K_{standard}$	0.9333

Values close to 1 indicate the perfection of the model.

Urban Morphology Prediction and Fractal Analysis

The Ankara West Development corridor's morphology has been discussed in four different periods (2005, 2013, 2022, and 2039). Based on the urban morphology data of the years 2005 and 2022, the estimation of the urban growth model of the Ankara West Development corridor for 2039 was calculated using the CA-Markov chain method. It is predicted that urban form development will significantly develop in the east-west directions. Additionally, the development of urban morphology was evaluated as a fractal stain. The fractal size of the urbanization blot was calculated as 1.65 in 2005, 1.70 in 2013, and 1.73 in 2022. On the other hand, the fractal size in 2039, within 34 years from 2005, was calculated as 1.85 according to the KB scenario and 1.98 according to the LW scenario (Figure 3).

A transition area matrix map was created in the Idrisi Selva program to more clearly determine the change in the urbanization spot between 2005 and 2039. According to the map given in Figure 4, it has been determined that urbanization will increase dramatically in the Ankara West Corridor region until 2039. It is predicted that the urban settled area, which had an area of 431.26 hectares in 2005, will increase by 1047.75 hectares according to the G_C scenario, reach 1479.01 hectares in 2039, and reach 3207.67 hectares by increasing by 2776.41 hectares according to the G_S scenario.

DISCUSSION AND CONCLUSION

Since urban growth and expansion are an inevitable reality intertwined with economic growth, the spatial changes in cities as living organisms are inevitable. Population growth worldwide is one of the most decisive parameters affecting cities' growth. Unplanned growth in cities causes many environmental problems, such as unplanned urbanization. Monitoring and forecasting land changes in urban growth and expansion processes are significant in producing effective policies within the scope of regional and urban planning. In this process, the concept of urban morphology comes to the fore. Since urban growth is predicted to cause different environmental and physical problems in the future, determining the scope and boundaries of growth is considered a requirement (Chen et al., 2017; Chen, 2018; Wang & Zheng, 2022; Wang et al., 2022).

The characteristics of the model can be summarized as follows: The fractal analysis method on urban morphology offers a new perspective in evaluating temporal and spatial changes. Within the scope of the study, the fractal analysis method was used to question the changing form of the western development corridor of the city of Ankara in line with urbanization and the temporal and spatial changes in the urban texture. As a result of the analysis, it was concluded that the changes in the fractal dimensions obtained at the urban scale show that the West development corridor experienced a rapid urbanization process from 2005 to the

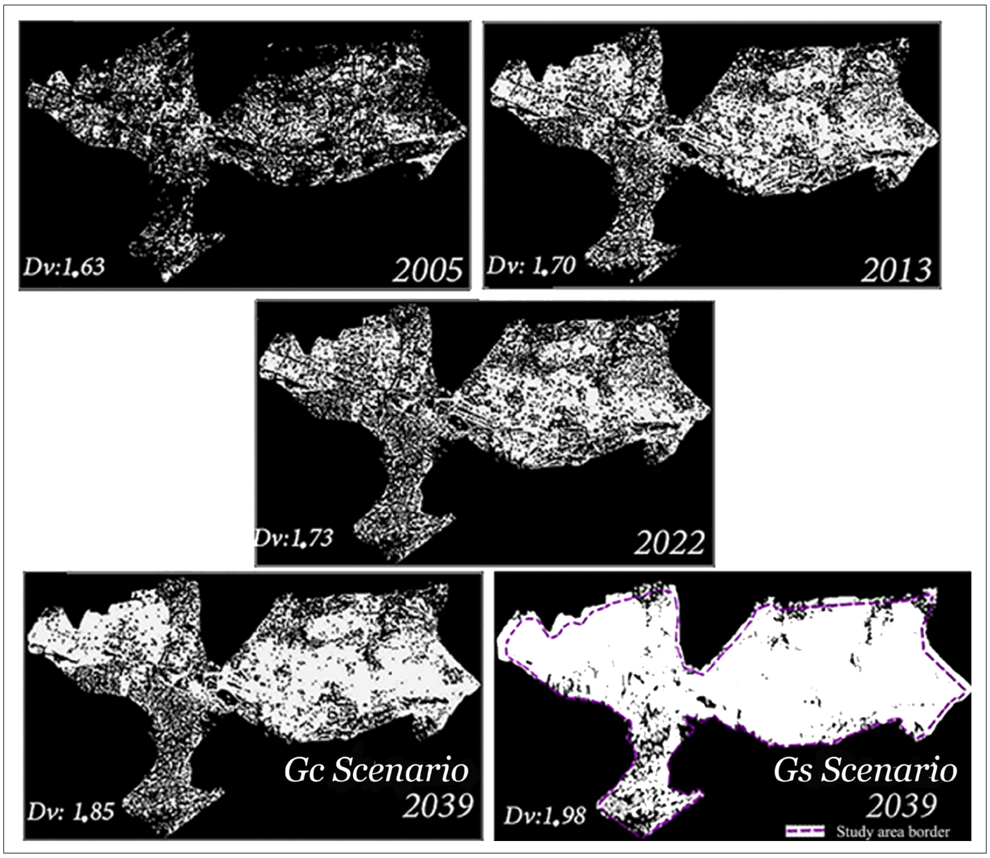

Figure 3. Urbanization spots and fractal dimension of Ankara West Development Corridor between 2005-2039.

present, and this process showed urban expansion in the east-west direction. When the fractal analysis results of 4 different periods are evaluated, increases in numerical values reveal that the urbanization process and urban growth have increased. Increases in fractal dimensions also indicate an increase in the complexity of the urban fabric, in other words, spatial richness. The simulation results of the year 2039 using the CA-Markov chain method also support these results. The urbanization process is predicted to increase, and the urban morphology will expand in this direction.

The main benefit of the model is that its flexible structure provides a comparable approach to the complexity level of the research field. Factors such as the increasingly complex structures of cities, their ever-growing and diversifying parts, and the intense interaction between managers make it difficult to perceive cities as a whole. With new approaches emerging in the 21st century, cities have been defined as dynamic, non-linear, complex systems in constant change and transformation. Evaluating and analyzing this complexity becomes a requirement. Fractals are fundamental to analyzing these complex network relationships (Lionar & Ediz, 2020). Using fractal geometry, especially in cities and systems, provides advantages for illustrating certain specific processes of spatial organization and inventing new articulations, especially for dynamic interpretation (Frankhauser & Pumain, 2022). As a result of the study, it has been determined that fractal analysis is an effective method for evaluating temporal and spatial patterns and their changes to understand urban morphology. Compact and spreading growth approaches produced within the scope of the research resulted in different growth behaviors of the city. While the growth is more controlled in the model, restricted by the research area boundaries, the expansion pressure of the city is quite remarkable in the scenario where there is no restriction.

The data obtained by this method for West Ankara, which is determined as the development direction of the city with the plan decisions, has substantial potential in evaluating the current situation and future spatial patterns. In this study, fractal analysis was used as a tool to emphasize the change process. In today's uncertain world, it is impossible to make definitive forecasts for the future. In today's cities, where planning theory gains new dimensions daily, a one-dimensional deterministic approach to viewing the city weakens decision processes. It is impossible to predict the socio-spatial processes, political aspects, global threats

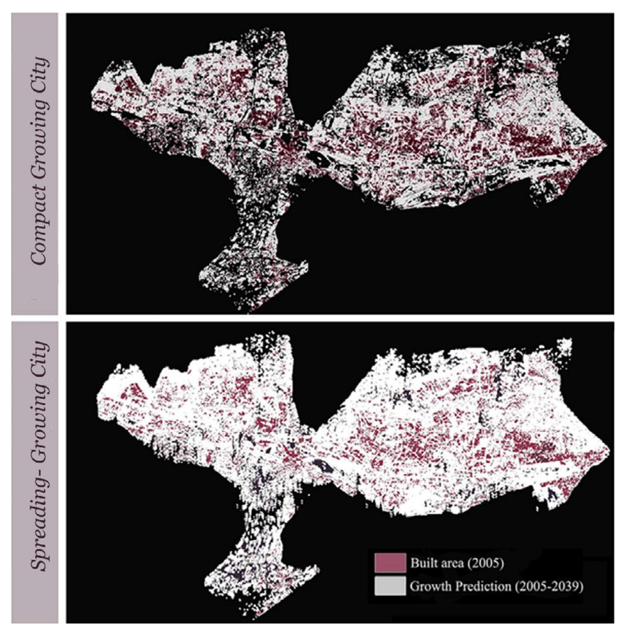

Figure 4. Urbanization spot change between 2005-2039 depending on the scenarios.

and changes, and natural risks that may be experienced in the city. However, growth predictions are required to draw attention to problems such as ecological damages, land losses, socio-spatial problems, and changes in the quality of life brought about by cities' growth and to manage the process. Cities are seen as self-organizing, dynamic, complex systems. From this perspective, the city change in the research is based on the principle of order in disorder in complex systems. The CA-Markov chain method analyzes spatiotemporal probabilities, thus predicting the city's future by participating in the multidimensional network dynamics experienced in the temporal context. The type of growth in the scenario where the forecasts do not constrain the city stands out regarding how decision-makers intervene. In this context, the study is thought to facilitate our perception of urban areas, offer a new perspective that evolves from a deterministic framework to a cause-effect relationship, and have a guiding quality in planning processes.

ETHICS: There are no ethical issues with the publication of this manuscript.

PEER-REVIEW: Externally peer-reviewed.

CONFLICT OF INTEREST: The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

FINANCIAL DISCLOSURE: The authors declared that this study has received no financial support.

REFERENCES

Artmann, M., Inostroza, L., & Fan, P. (2019). Urban sprawl, compact urban development and green cities. How much do we know, how much do we agree? Ecol Indic, 96, 3—9.

Ayazli, I. E. (2019). Monitoring of urban growth with improved model accuracy by statistical methods. Sustain, 11(20), 5579.

Ayazli, I. E., Yakup, A. E., & Bilen, O. (2022). Using the T-EFA method in a cellular automata-based urban growth simulation's calibration step. Trans GIS, 26(3), 1465—1484.

Azari, M., Tayyebi, A., Helbich, M., & Reveshty, M. A. (2016). Integrating cellular automata, artificial neural network, and fuzzy set theory to simulate threatened orchards: Application to Maragheh, Iran. GISci Remote Sens, 53(2), 183—205.

Baqa, M. F., Chen, F., Lu, L., Qureshi, S., Tariq, A., Wang, S., Jing, L., Hamza, S, & Li, Q. (2021). Monitoring and modeling the patterns and trends of urban growth using urban sprawl matrix and CA-Markov model: A case study of Karachi, Pakistan. Land, 10(7), 700.

Barreira-González, P., & Barros, J. (2017). Configuring the neighbourhood effect in irregular cellular automata based models. Int J Geogr Inf Sci, 31(3), 617—636.

Batty, M., & Longley, P. A. (1994). Fractal cities: A geometry of form and function. Academic Press.

Bovill, C. (1996). Fractal geometry in architecture and design. Design Science Collection. Birkhäuser.

Burchfield, M., Overman, H. G., Puga, D., & Turner, M. A. (2006). Causes of sprawl: A portrait from space. Q J Econ, 121(2), 587—633.

Caballero, Y., Giraldo, R., & Mateu, J. (2022). A spatial randomness test based on the box-counting dimension. AStA Adv Stat Anal, 106(3), 499—524.

Carmona, M., Tiesdell, S., Heath, T., & Oc, T. (2003). Public places urban spaces - The dimension of urban design. Architectural Press.

Chen, Y. (2013). Fractal analytical approach of urban form based on spatial correlation function. Chaos Solitons Fractals, 49, 47—60.

Chen, Y. G. (2018). Logistic models of fractal dimension growth of urban morphology. Fractals, 26(03), 1850033.

Chen, Y., Liu, X., & Li, X. (2017). Calibrating a Land Parcel Cellular Automaton (LP-CA) for urban growth simulation based on ensemble learning. Int J Geogr Inf Sci, 31(12), 2480—2504.

Çağdaş, G., Gözübüyük, G., & Ediz, Ö. (2006). Mimari tasarımda fraktal kurguya dayalı form üretimi. J Istanbul Kültür Univ, 2, 1—12.

Dey, N. N., Al Rakib, A., Kafy, A. A., & Raikwar, V. (2021). Geospatial modelling of changes in land use/land cover dynamics using Multi-layer perception Markov chain model in Rajshahi City, Bangladesh. Environ Challenges, 4, 100148.

Ediz, Ö., & Gürsakal, N. (2010). Bursa çarşı makroformundaki saçılmanın fraktal boyut ile belirlenmesi. Uludağ Üniv Mühendis Fak Derg, 15(2), 101—107.

Ediz, Ö., & Ostwald, M. J. (2012). The Süleymaniye Mosque: A computational fractal analysis of visual complexity and layering in Sinan's masterwork. Archit Res Q, 16(2), 171—182.

Frankhauser, P., & Pumain, D. (2022). Fractals and geography. In S. Carta (Ed.), Machine learning and the city: Applications in architecture and urban design (pp. 31—55). Wiley.

Fu, J., Bu, Z., Jiang, D., Lin, G., & Li, X. (2022). Sustainable land use diagnosis based on the perspective of production-living-ecological spaces in China. Land Use Policy, 122, 106386.

Ghosh, S., & Das, A. (2017). Exploring the lateral expansion dynamics of four metropolitan cities of India using DMSP/OLS night time image. Spatial Inf Res, 25, 779—789.

Guan, D. J., Li, H. F., Inohae, T., Su, W. C., Nagaie, T., & Hokao, K. (2011). Modeling urban land use change by the integration of cellular automaton and Markov model. Ecol Model, 222, 3761—3772.

Huang, Y., Yang, B., Wang, M., Liu, B., & Yang, X. (2020). Analysis of the future land cover change in Beijing using CA–Markov chain model. Environ Earth Sci, 79(2), 1—12.

Inostroza, L. (2018). The circularity of the urban ecosystem material productivity: The transformation of biomass into technomass in Southern Patagonia. Sustain Cities Soc, 39, 335—343.

IPCC. (2021). Climate Change 2021. https://www.ipcc.ch/report/ar6/wg2/

Isinkaralar, O., & Varol, C. (2023). A cellular automata-based approach for spatio-temporal modeling of the city center as a complex system: The case of Kastamonu, Türkiye. Cities, 132, 104073.

Isinkaralar, O., Isinkaralar, K., & Yilmaz, D. (2023). Climate-related spatial reduction risk of agricultural lands on the Mediterranean coast in Türkiye and scenario-based modelling of urban growth. Environ Dev Sustain, 25(11), 13199—13217.

Jianping, L., Bai, Z., & Feng, G. (2005). RS-and-GIS-supported forecast of grassland degradation in southwest Songnen plain by Markov model. Geo-spat Inf Sci, 8(2), 104—109.

Keshtkar, H., & Voigt, W. (2016). Potential impacts of climate and landscape fragmentation changes on plant distributions: Coupling multi-temporal satellite imagery with GIS-based cellular automata model. Ecol Inform, 32, 145—155.

Li, H., Xiao, P., Feng, X., Yang, Y., Wang, L., Zhang, W., Wang, X., Feng, W., & Chang, X. (2017). Using land long-term data records to map land cover changes in China over 1981–2010. IEEE J Sel Top Appl Earth Obs Remote Sens, 10, 1372—1389.

Lionar, M. L., & Ediz, Ö. (2020). Measuring visual complexity of Sedad Eldem's SSK Complex and its historical context: A comparative analysis using fractal dimensions. Nexus Netw J, 22(3), 701—715.

Lu, L., Weng, Q., Guo, H., Feng, S., & Li, Q. (2019). Assessment of urban environmental change using multisource remote sensing time series (2000–2016): A comparative analysis in selected megacities in Eurasia. Sci Total Environ, 684, 567—577.

Mandelbrot, B.B. (1977). Fractals: Form, chance and dimension. W.H. Freeman.

Marshall, S., & Caliskan, O. (2011). A joint framework for urban morphology and design. Built Environ, 37(4), 409—426.

Neuman, M. (2005). The compact city fallacy. J Plan Educ Res, 25(1), 11—26.

Oliveira, V. (2018). A course in urban morphology. In V. Oliveira (Ed.), Teaching Urban Morphology (pp. 317-334). Springer.

Öztürk, D. (2017). Shannon entropi ve fraktal analiz ile kentsel yayılmanın incelenmesi: Samsun örneği. In 16. Türkiye Harita Bilimsel ve Teknik Kurultayı (pp. 3—6).

Shen, W., Mao, X., He, J., Dong, J., Huang, C., & Li, M. (2020). Understanding current and future fragmentation dynamics of urban forest cover in the Nanjing Laoshan region of Jiangsu, China. Remote Sens, 12(1), 155.

Singh, S. K., Laari, P. B., Mustak, S. K., Srivastava, P. K., & Szabó, S. (2018). Modelling of land use land cover change using earth observation data-sets of Tons River Basin, Madhya Pradesh, India. Geocarto Int, 33(11), 1202—1222.

Stevenson, M., Thompson, J., de Sá, T. H., Ewing, R., Mohan, D., McClure, R., Roberts, I., Tiwari, G., Giles-Corti, B., Sun, X., Wallace, M., & Woodcock, J. (2016). Land use, transport, and population health: Estimating the health benefits of compact cities. Lancet, 388(10062), 2925—2935.

Su, Y., Wang, Y., Wang, C., Zhou, D., Zhou, N., Feng, W., & Ji, H. (2022). Coupling relationships between urban form and performance of outdoor environment at the pedestrian level. Build Environ, 213, 108514.

Terzi, F., & Kaya, H. S. (2011). Dynamic spatial analysis of urban sprawl through fractal geometry: The case of Istanbul. Environ Plan B Plan Des, 38(1), 175—190.

Tong, X., & Feng, Y. (2020). A review of assessment methods for cellular automata models of land-use change and urban growth. Int J Geogr Inf Sci, 34(5), 866—898.

van Vliet, J., Bregt, A. K., & Hagen-Zanker, A. (2011). Revisiting Kappa to account for change in the accuracy assessment of land-use change models. Ecol Model, 222(8), 1367—1375.

Wang, P., Gu, C., Yang, H., & Wang, H. (2022). The multiscale structural complexity of urban morphology in China. Chaos Solitons Fractals, 164, 112721.

Wang, S., & Zheng, X. (2022). Dominant transition probability: Combining CA-Markov model to simulate land use change. Environ Dev Sustain, 1—19.

Xia, C., Zhang, A., Wang, H., & Zhang, B. (2019). Modeling urban growth in a metropolitan area based on bidirectional flows, an improved gravitational field model, and partitioned cellular automata. Int J Geogr Inf Sci, 33(5), 877—899.

Yılmaz, D., Öztürk, S., & Işınkaralar, Ö. (2022). Kent imgesinin yapıtaşı olarak sokaklarda mekânsal zenginliğin fraktal geometri ile analizi. Kent Akademisi, 15(3), 1341—1358.

Zhao, C., Li, Y., & Weng, M. (2021). A fractal approach to urban boundary delineation based on raster land use maps: A case of Shanghai, China. Land, 10(9), 941.