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ORIGINAL PAPER

# Digital mapping and predicting the urban growth: integrating scenarios into cellular automata—Markov chain modeling

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## Abstract

Predictive modeling and land use/land cover change studies in complex systems are well advanced. Cellular automata (CA)-Markov chain (MC) can be defined as one frequently preferred method for this purpose. This paper aims to adapt the CA-MC model to the simulation of residential areas in the city. The proposed method was tested in the city center of Kastamonu, Türkiye, using four time periods: 1985, 2011, 2015, and 2021. Spatio-temporal change maps were produced using ArcGIS 10.0 software. Land use simulation of the urban center, including residence units for 2031 and 2057, was performed using the integrated CA-MC technique. The method's suitability was demonstrated with the Kappa index of agreement values ($K_{standart}$: 0.93; $K_{location}$: 0.98; $K_{no}$: 0.98; and $K_{locationStrata}$: 0.95). Within the scope of the study, two different scenarios were designed as short term ($S_1$) and long term ($S_2$). According to the predictions for 2031, there was a residential area increase of 15% in $S_1$ and 29% in $S_2$. When we reach 2057, these growth values were measured as 50% according to $S_1$ and 72% according to $S_2$.

**Keywords** Geographic information · Growth modeling · Kappa statistic · Land degradation · LULCC · Spatial analysis

## Introduction

Urban population is expected to increase by 2.5 billion in the next thirty years (UN, 2019) and land degradation that occurs with this growth appears as a severe global problem researching worldwide (Chaplot, 2021; Hussein, 2021; Isinkaralar, 2022a; Kapović Solomun et al. 2021). Urban land is located at the intersection of individuals' relationships with the environment, and land is a fundamental resource for humanity (Booth et al. 2004; Seto and Shepherd 2009). Land use/land cover change (LULCC) can occur with the effect of both human-induced activities and natural processes (Garg et al. 2019; Genet, 2020; Liu et al. 2021). In addition, it is a multi-dimensional research topic (Dullinger et al. 2021; Weng et al. 2020) from local to global, such as the urban economy (Samie et al. 2020), ecological sustainability (Rimal et al. 2019; Kindu et al. 2018), and climate change (Ahmed et al. 2022; Roy et al. 2022; Yilmaz and Isinkaralar, 2021). It can be affected by many different factors and has a dynamic structure. However, it is known that the main driving force is the acceleration of migration to urban areas and the rapid urbanization that occurs as a result of the dynamics (Esbah, 2007; Ishtiaque et al. 2017; Isinkaralar, 2022b; Liu, 2018).

Land degradation is directly related to agriculture, forest water surface, etc., depending on the increase in built-up areas (Amir Siddique et al. 2021; Sonu and Bhagyanathan, 2022). It means the reduction of quality lands and biodiversity (Mani et al. 2021). When viewed indirectly, the damage to the ecological cycle progresses to the threat to food security, the increase in air pollution values, and the consequences that threaten human health (Ghoma et al. 2022; Isinkaralar et al. 2022; Kumar et al. 2021). It is essential to monitor land losses, which affect many levels, from a single living thing living in the city to the global system,

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and conduct comprehensive research (Sandifer 2015). The United Nations Conference on Environment and Development (UNCED, 1992) emphasizes the need for an extensive investigation of LULCC.

LULC studies can be considered a prerequisite for better-planned land use (de Mello et al. 2020). It has been involved in many research topics such as urban planning (Liu et al. 2020; Wang and Maduako 2018), watershed management (Sun, 2013; Rajaei et al. 2021), urban heat island (Hassan et al. 2021; Zhang et al. 2013), sustainability (Bindajam 2021; Rodríguez-Rodríguez 2017), and urban landscape (Sharma and Joshi 2015). In studies investigating urban growth forecasts, the land classification approach is prominent.

This study aims to predict the growth of residential areas at the building level in the city center as a form of land use, with the effects of two different scenarios. Housing areas meet the need for shelter, which is one of the most basic needs of the citizens and is the function with the most significant spatial size in urban land use. It reflects the primary morphology of the city together with the planned urban services. In this context, the growth of the Kastamonu city center, located in the northern region of Türkiye, was modeled via an integrated methodology. The study includes simulations for two different target years. The usability of the modeling for residential area growth was being investigated by following interconnected steps.

## Simulation methodology

Making growth forecasts consists of four consecutive steps. First, the data required for the temporal-spatial change of residential areas were obtained and organized to be used in forecast maps. After the collection of data, the statistical similarity of these maps was measured with the Kappa statistic values. In the fourth step, estimations were produced for the target years within the scope of two different scenarios (Fig. 1).

### Study area and database

The main material of this study is the residential area of Kastamonu city center (Fig. 2). The city is defined as a medium-sized city among Turkish cities. The urban center was built in the valley between the sloping areas in the east–west

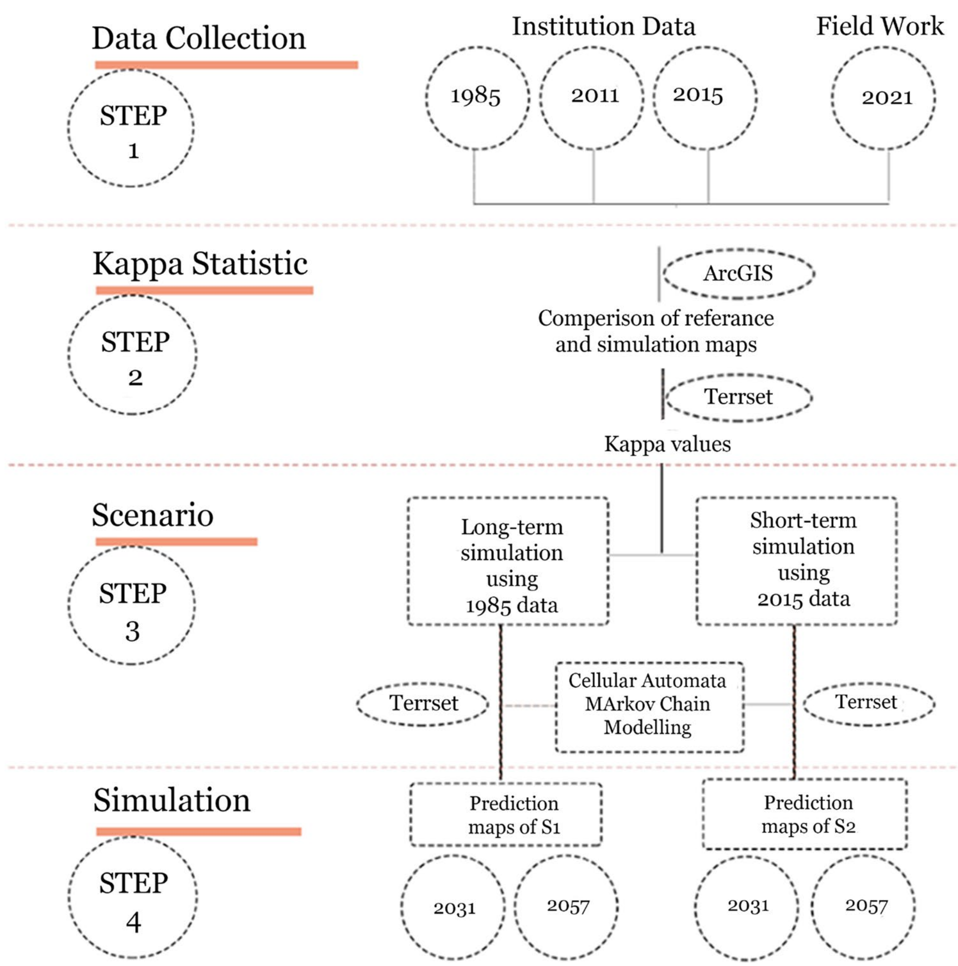


**Fig. 1** Workflow of the research procedure

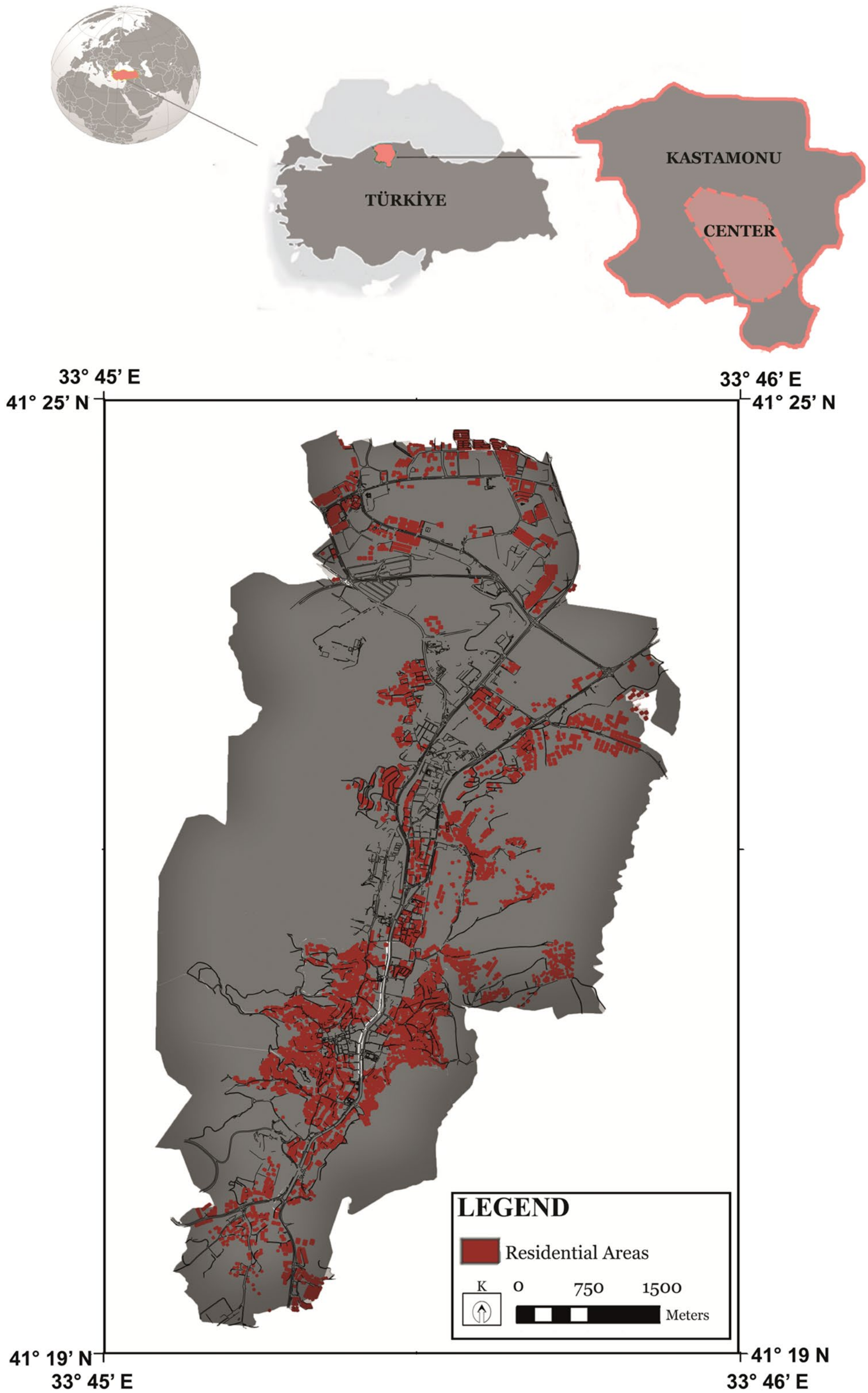


**Fig. 2** Location of the Kastamonu city center

direction. For this reason, it shows a linear development in the north–south direction. It can be said that the university located in the north of the city is one of the factors that affect the change of the morphological structure.

The northern development area, where the campus is located, has developed rapidly as a result of the housing demands of the students and university staff, and high-rise buildings and commercial uses have quickly chosen this area in the last period. Accordingly, the rate of spatial increase in the housing stock gains momentum in Fig. 3.

The transportation connection and housing proposal opened on the northeastern axis of the city turned the development in this direction. Due to the limited areas suitable for settlement in the city's south, the southward action has been limited to a large extent, and the city has tended to grow in one direction towards north.

A high historical data is required in the study carried out to reveal the temporal changes of residential areas and to realize their estimations depending on the purpose of the study. The data for 1985, 2004, 2011, and 2015 have been partially compiled using the archieves of local government and planning institutions. The data of 2021, which reveals the current land use, was carried out with the control of the remote sensing technique through fieldwork. During the fieldwork, the residential parcels in the field were processed and compared with the satellite image. The data set was created by bringing all the data together in the ArcGIS 10.0 software. The northeastward growth behavior of residential areas is clearly seenincluded in Fig. 4.

## Interpretation of Kappa

It is necessary to statistically analyze the compatibility of the maps obtained with each other before including them in the estimation process. Kappa simulation has the logic of estimating a period when we know the land use, using data from two different time zones, and checking its compatibility with the reference map (Aburas et al. 2021). It can be expressed as a kind of verification or calibration approach.

In this study, an estimate of the 2021 map, which we know how it is today, was made using data from 1985 and 2011. The compatibility of the obtained prediction map (Fig. 5d) with the comparison map (Fig. 5c) as a reference was analyzed.

Kappa values ($K_{standart}$: 0.93; $K_{location}$: 0.98; $K_{no}$: 0.98; and $K_{locationStrata}$: 0.95) are presented in Fig. 6. The overall accuracy of the agreement was above 93%, which indicates the "excellent" performance of the model proposed in this study.

## Scenario design

Creating a scenario approach according to different possibilities makes it easier for us to interpret the options that may come up. In this study, prediction maps were modeled according to other initial conditions. Accordingly, two different scenarios were developed. First, the initial time frame was accepted as 1985, and the $S_1$ estimate was added to the 2021 map. Accordingly, the city's development reaches its current state in the longer term.

In the other scenario, the changes that have occured since 2015 are considered. For a short period, $S_2$ forecast maps were produced depending on the speed of change. Thus, it was possible to compare the current growth rate with the past growth rate.

## CA-MC process for urban growth simulation

Today, the rapid development of remote sensing and computer-based mapping methods has enriched model approaches (Cetin et al. 2021; Kilicoglu et al. 2021; Onac et al. 2021). Cellular automata (CA) have been the most widely used method in making predictions since the 1990s. CA is a discrete dynamic system in which the state of each cell at time $t+1$ is determined by the states of its neighboring cells at a time according to the pre-defined transition

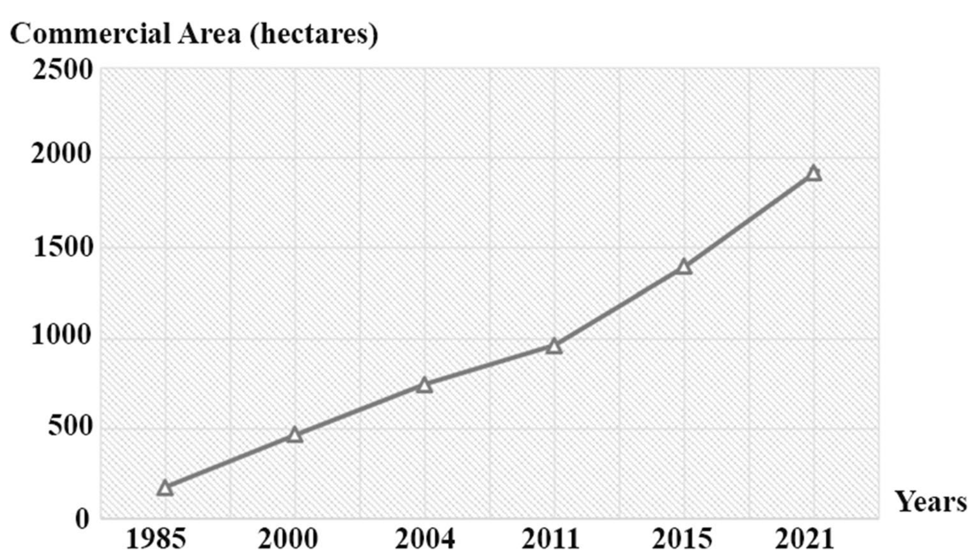


**Fig. 3** Development of residential areas (ha)

**Fig. 4** Spatio-temporal change of residential areas

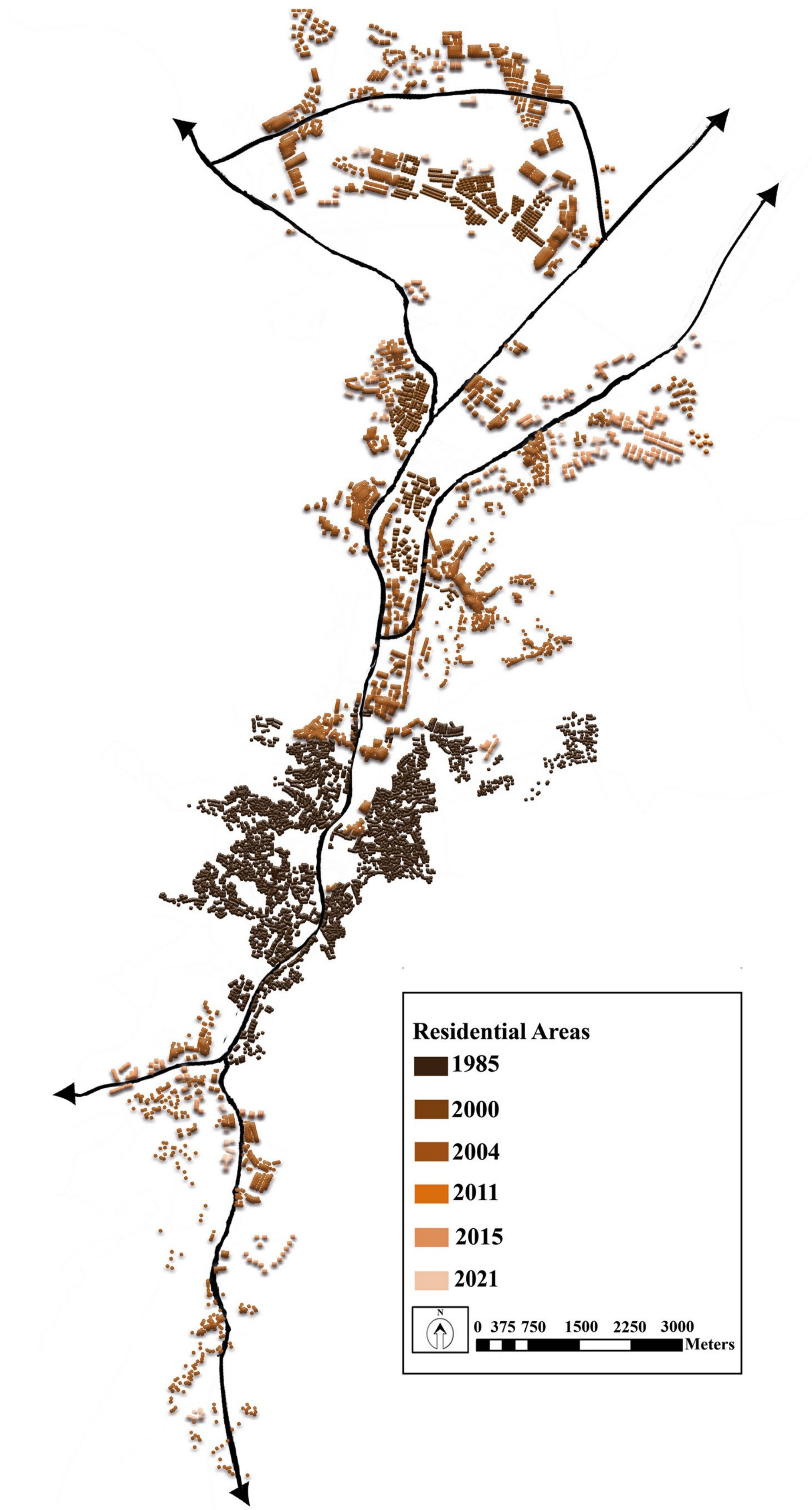


**Fig. 5** Visual comparison of reference and predicted land use for 2021 (**a**: 1985, **b**: 2011, **c**: reference map of 2021, **d**: predicted map of 2021)

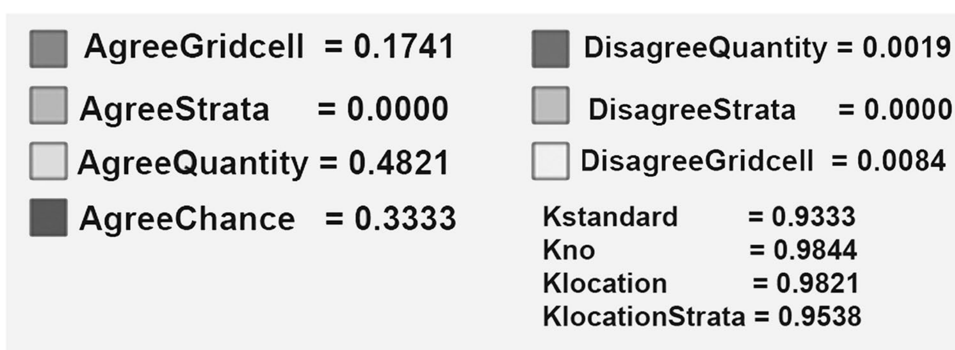


**Fig. 6** Agreement values

rules (Mondal et al. 2016). However, CA has been mainly criticized for failing to predict a leap beyond neighborhood-based limitations and producing growth predictions in the form of oil stains.

The use of some methods integrated into CA can overcome this obstacle. Some of them are artificial neural networks (Saha et al. 2021; Babu et al. 2021), fractal-based modeling (Sadeghi, 2021), and Markov chain (Kundu et al. 2021; Kushwaha et al. 2021; Rahnama 2021). Thus, the advantages of the integrated methods are combined, and the model is strengthened.

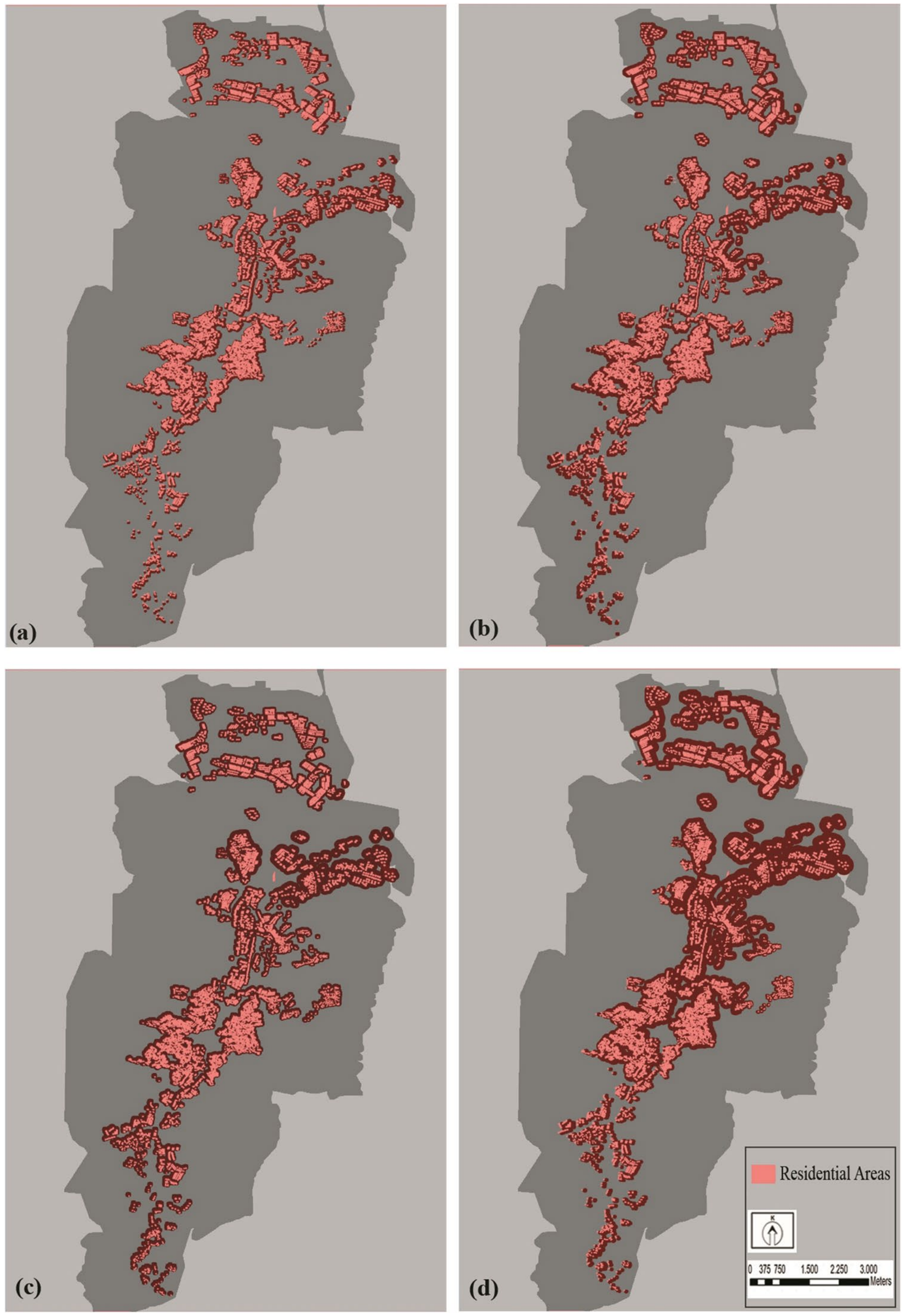


**Fig. 7** 2031 simulations (**a**) $S_1$ and (**b**) $S_2$, and 2057 simulations (**c**) $S_1$ and (d) $S_2$

This study uses a prediction technique based on CA controlling spatial interactions and a Markov chain algorithm managing temporal dynamics. Based on the nature of the MC process (Guan et al. 2011) and the definition of conditional probability, the prediction of land-use change is as follows:

$$S(t+1) = Pij \times S(t) \tag{1}$$

where $S(t)$ and $S(t+1)$ denote the row vectors at time step $t$ and time step $t+1$; $P$ refers to the transition probability matrix for a prior time interval, which is calculated as follows:

$$\| Pij \| = \begin{Vmatrix} P_{11} & P_{12} & P_{1n} \\ P_{21} & P_{22} & P_{2n} \\ P_{n1} & P_{n2} & P_{nn} \end{Vmatrix} \quad (0 \leq P_{ij} < 1 \; ve \; \textstyle\sum_1^n P_{ij} = 1) \tag{2}$$


**Fig. 8** Prediction of residential growth (ha)

where $P_{ij}$ indicates the transition probability from land-use type *i* to *j*.

This study produced predictions with Terrset software based on the CA-MC modeling principle. First , a 10-year development process was investigated. Then, the simulation was carried out for 2057 by trying to predict the time between 1985 and 2021.

## Results

### Spatio-temporal mapping

CA-MC modeling, maps are exhibited in Fig. 7. The city center is a protected area, and the slope values in its immediate vicinity support the growth in the northern axis. The growth between $S_1$ and $S_2$ can be observed from the given maps. This situation reveals the recent acceleration in the development of residential areas in the city.

It has been determined that the growth rate, which is 15% in the long-term forecasts according to $S_1$ in the predictions made for 2031, takes 2015 as the starting year in $S_2$, and since it produced a growth approach for the last period, this rate has nearly doubled and reached 29%. In the simulations made with the target of 2057, these growth values were measured as 50% growth in $S_1$ and 72% in $S_2$ compared to 2021 (Fig. 8).

## Discussion and future work

Studying the growth possibilities based on scenarios allows us to think about alternatives. Thus, we can examine different conditions. In another study, where the current trend is discussed as short term and long term, the growth of the city of Erbil (Iraq) is modeled, and landscape changes are examined (Mitsova et al. 2011). Feng and Liu (2012) selected the SLEUTH model to predict urban growth under different scenarios. In addition, chaotic processes such as disasters and large investments can be included in the scenarios in future studies.

While growth models focus on established areas, Irwin et al. (2003) discussed housing growth at the parcel scale with a microeconomic growth model. It evaluated the policies of different scenarios regarding rural and open space growth. Agyemang et al. (2022) used a CA-based model to simulate housing growth within the framework of informal urbanization. In studies on the change in some housing areas, there are perspectives such as consumer preferences (Beghestani 2021) and housing typology (Xu et al. 2020).

In future studies, within the scope of estimations for the growth of residential areas, the number of residences can be enriched with criteria such as building order and parcel layout. Consumer behaviors can also be analyzed and integrated into the process through research to be carried out locally. It can be enriched by identifying areas suitable for development by analyzing natural features.

## Conclusion

Urban growth models spatialize the possibilities of the future. This research model the growth of residential areas in cities , emphasizing the problem of land degradation from a global perspective. The CA-MC model has been used in many studies in urban growth estimations, which are frequently discussed in the related literature. In this study, the model's applicability was investigated in residential areas, which constitute a function of urban land use. Kappa values revealed that the model statistically showed a high predictive performance (> 0.93). An increase in residential areas gaining momentum has been remarked in the short-term scenario.

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**Data availability** The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The authors declare no competing interests. All co-authors have seen and agreed with the contents of the manuscript, and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

## References

Aburas MM, Ho YM, Pradhan B, Salleh AH, Alazaiza MY (2021) Spatio-temporal simulation of future urban growth trends using an integrated CA-Markov model. Arabian Journal of Geosciences, 14(2), 1–12. https://link.springer.com/article/10.1007/s12517-021-06487-8

Agyemang FS, Silva E, Fox S (2022) Modelling and simulating 'informal urbanization': an integrated agent-based and cellular automata model of urban residential growth in Ghana. Environment and Planning B: Urban Analytics and City Science, 23998083211068843. https://doi.org/10.1177%2F23998083211068843

Ahmed N, Wang G, Lü H, Booij MJ, Marhaento H, Prodhan FA, Ali Imran M (2022) Attribution of changes in streamflow to climate change and land cover change in Yangtze River Source Region China Water 14 2 259. https://doi.org/10.3390/w14020259

Aksoy T, Dabanli A, Cetin M, Senyel Kurkcuoglu MA, Cengiz AE, Cabuk SN, Cabuk A (2022) Evaluation of comparing urban area land use change with Urban Atlas and CORINE data Environ Sci Pollut Res 29 19 28995 29015. https://doi.org/10.1007/s11356-021-17766-y

Amir Siddique M, Wang Y, Xu N, Ullah N, Zeng P (2021) The spatiotemporal implications of urbanization for urban heat islands in Beijing: a predictive approach based on CA–Markov modeling (2004–2050). Remote Sensing 13(22):4697. https://doi.org/10.3390/rs13224697

Babu KA, Prithiv TS, Gupta A, Mandal S (2021) Modeling and simulation of dynamic recrystallization in super austenitic stainless steel employing combined cellular automaton, artificial neural network and finite element method. Comput Mater Sci 195:110482. https://doi.org/10.1016/j.commatsci.2021.110482

Baghestani H (2021) Forecasts of growth in US residential investment: accuracy gains from consumer home-buying attitudes and expectations. Appl Econ 53(32):3744–3758. https://doi.org/10.1080/00036846.2021.1885613

Bindajam AA, Mallick J, Talukdar S, Islam ARM, Alqadhi S (2021) Integration of artificial intelligence–based LULC mapping and prediction for estimating ecosystem services for urban sustainability: past to future perspective. Arab J Geosci 14(18):1–23. https://doi.org/10.1007/s12517-021-08251-4

Booth DB, Karr JR, Schauman S, Konrad CP, Morley SA, Larson MG, Burges SJ (2004) Reviving urban streams: land use, hydrology, biology, and human behavior 1. JAWRA J Am Water Resources Association 40(5):1351–1364. https://doi.org/10.1111/j.1752-1688.2004.tb01591.x

Cetin M, Aksoy T, Cabuk SN, Kurkcuoglu MAS, Cabuk A (2021) Employing remote sensing technique to monitor the influence of newly established universities in creating an urban development process on the respective cities. Land Use Policy 109:105705. https://doi.org/10.1016/j.landusepol.2021.105705

Chaplot V (2021) Evidences of plants' impact on land degradation and climate change an urgent call for new multidisciplinary research. Geoderma 392:114984. https://doi.org/10.1016/j.geoderma.2021.114984

de Mello K, Taniwaki RH, de Paula FR, Valente RA, Randhir TO, Macedo DR, Hughes RM (2020) Multiscale land use impacts on water quality: assessment, planning, and future perspectives in Brazil J Environ Manage 270 110879. https://doi.org/10.1016/j.jenvman.2020.110879

Dullinger I, Essl F, Moser D, Erb K, Haberl H, Dullinger S (2021) Biodiversity models need to represent land-use intensity more comprehensively. Glob Ecol Biogeogr 30(5):924–932. https://doi.org/10.1111/geb.13289

Esbah H (2007) Land use trends during rapid urbanization of the city of Aydin. Turkey Environ Management 39(4):443–459. https://doi.org/10.1007/s00267-005-0331-y

Feng H, Liu H (2012) Scenario prediction of urban growth based on the SLEUTH model. In Advanced Technology in Teaching-Proceedings of the 2009 3rd International Conference on Teaching and Computational Science (WTCS 2009) (pp. 945–952). Springer, Berlin, Heidelberg. https://link.springer.com/chapter/10.1007/978-3-642-25437-6_126

Garg V, Nikam BR, Thakur PK, Aggarwal SP, Gupta PK, Srivastav SK (2019) Human-induced land use land cover change and its impact on hydrology. HydroResearch 1:48–56. https://doi.org/10.1016/j.hydres.2019.06.001

Genet A (2020) Population growth and land use land cover change scenario in Ethiopia. International J Environmental Protection and Policy 8(4):77–85. https://doi.org/10.11648/j.ijepp.20200804.12

Ghoma WEO, Sevik H, Isinkaralar K (2022) Using indoor plants as biomonitors for detection of toxic metals by tobacco smoke. Air Qual Atmos Health 15(3):415–424. https://doi.org/10.1007/s11869-021-01146-z

Guan DJ, Li HF, Inohae T, Su WC, Nagaie T, Hokao K (2011) Modeling urban land use change by the integration of cellular automaton and Markov model. Ecological Modelling 222:3761–3772. https://doi.org/10.1016/j.ecolmodel.2011.09.009

Hassan T, Zhang J, Prodhan FA, Pangali Sharma TP, Bashir B (2021) Surface urban heat islands dynamics in response to lulc and vegetation across south Asia (2000–2019). Remote Sensing 13(16):3177. https://doi.org/10.3390/rs13163177

Hussein MS (2021) An "out-of-the-depression" drainage solution to the land degradation problem in Siwa Oasis. Egypt Arabian J of Geosciences 14(9):1–15. https://doi.org/10.1007/s12517-021-07100-8

Irwin EG, Bell KP, Geoghegan J (2003) Modeling and managing urban growth at the rural-urban fringe: a parcel-level model of residential land use change. Agricultural and Resource Economics Review 32(1):83–102. https://doi.org/10.1017/S1068280500002525

Ishtiaque A, Shrestha M, Chhetri N (2017) Rapid urban growth in the Kathmandu Valley, Nepal: monitoring land use land cover

dynamics of a Himalayan city with Landsat imageries. Environments 4(4):72. https://doi.org/10.3390/environments4040072
Isinkaralar K (2022a) Atmospheric deposition of Pb and Cd in the Cedrus atlantica for environmental biomonitoring Landscape Ecol Eng 1–10. https://doi.org/10.1007/s11355-022-00503-z
Isinkaralar, K (2022b) Temporal Variability of Trace Metal Evidence in Cupressus arizonica Platanus orientalis and Robinia pseudoacacia as Pollution-Resistant Species at an Industrial Site. Water Air & Soil Pollution 233(7) 250 10.1007/s11270-022-05743-1
Isinkaralar K, Koc I, Erdem R, Sevik H (2022) Atmospheric Cd, Cr, and Zn deposition in several landscape plants in Mersin, Türkiye. Water Air Soil Pollut 233(4):1–10. https://doi.org/10.1007/s11270-022-05607-8
Onac AK, Cetin M, Sevik H, Orman P, Karci A, Gonullu Sutcuoglu G (2021) Rethinking the campus transportation network in the scope of ecological design principles: case study of Izmir Katip Çelebi University Çiğli Campus. Environ Sci Pollut Res 28(36):50847–50866. https://doi.org/10.1007/s11356-021-14299-2
Kapović Solomun M, Ferreira CS, Barger NN, Tošić R, Eremija S (2021) Understanding the role of policy frameworks in developing land degradation in stakeholders perception from a post-conflict perspective in Bosnia and Herzegovina. Land Degrad Dev 32(12):3393–3402. https://doi.org/10.1002/ldr.3744
Kilicoglu C, Cetin M, Aricak B, Sevik H (2021) Integrating multicriteria decision-making analysis for a GIS-based settlement area in the district of Atakum, Samsun. Turkey Theoretical and Applied Climatology 143(1):379–388. https://doi.org/10.1007/s00704-020-03439-2
Kindu M, Schneider T, Döllerer M, Teketay D, Knoke T (2018) Scenario modelling of land use/land cover changes in Munessa-Shashemene landscape of the Ethiopian highlands. Sci Total Environ 622:534–546. https://doi.org/10.1016/j.scitotenv.2017.11.338
Kumar A, Pinto MC, Candeias C, Dinis PA (2021) Baseline maps of potentially toxic elements in the soils of Garhwal Himalayas, India: assessment of their eco-environmental and human health risks. Land Degrad Dev 32(14):3856–3869. https://doi.org/10.1002/ldr.3984
Kundu K, Halder P, Mandal JK (2021) Detection and prediction of Sundarban reserve forest using the CA-Markov chain model and remote sensing data. Earth Sci Inf 14(3):1503–1520. https://doi.org/10.1007/s12145-021-00648-9
Kushwaha K, Singh MM, Singh SK, Patel A (2021) Urban growth modeling using earth observation datasets, cellular automata-Markov chain model and urban metrics to measure urban footprints. Remote Sensing Applications: Society and Environment 22:100479. https://doi.org/10.1016/j.rsase.2021.100479
Liu B, Pan L, Qi Y, Guan X, Li J (2021) Land use and land cover change in the Yellow River Basin from 1980 to 2015 and its impact on the ecosystem services. Land 10(10):1080. https://doi.org/10.3390/land10101080
Liu P, Jia S, Han R, Liu Y, Lu X, Zhang H (2020) RS and GIS supported urban LULC and UHI change simulation and assessment J of Sensors 2020. https://doi.org/10.1155/2020/5863164
Liu Y (2018) Introduction to land use and rural sustainability in China. Land Use Policy 74:1–4. https://doi.org/10.1016/j.landusepol.2018.01.032
Mani S, Osborne CP, Cleaver F (2021) Land degradation in South Africa: justice and climate change in tension. People and Nature 3(5):978–989. https://doi.org/10.1002/pan3.10260
Mitsova D, Shuster W, Wang X (2011) A cellular automata model of land cover change to integrate urban growth with open space conservation. Landsc Urban Plan 99(2):141–153. https://doi.org/10.1016/j.landurbplan.2010.10.001
Mondal, M. S., Sharma, N., Garg, P. K., & Kappas, M. (2016). Statistical independence test and validation of CA Markov land use land cover (LULC) prediction results. The Egyp J Remote Sensing and Space Science 19(2), 259–272. https://doi.org/10.1016/j.ejrs.2016.08.001
Rahnama MR (2021) Forecasting land-use changes in Mashhad Metropolitan area using cellular automata and Markov chain model for 2016–2030. Sustain Cities Soc 64:102548. https://doi.org/10.1016/j.scs.2020.102548
Rajaei F, Dahmardeh Behrooz R, Ahmadisharaf E, Galalizadeh S, Dudic B, Spalevic V, Novicevic R (2021) Application of integrated watershed management measures to minimize the land use change impacts. Water 13(15):2039. https://doi.org/10.3390/w13152039
Rimal B, Sharma R, Kunwar R, Keshtkar H, Stork NE, Rijal S, Baral H (2019) Effects of land use and land cover change on ecosystem services in the Koshi River Basin Eastern Nepal Ecosystem Services 38 100963 https://doi.org/10.1016/j.ecoser.2019.100963
Rodríguez-Rodríguez D, Martínez-Vega J (2017) Assessing recent environmental sustainability in the Spanish network of National Parks and their statutory perip heral areas. Appl Geogr 89:22–31. https://doi.org/10.1016/j.apgeog.2017.09.008
Roy PS, Ramachandran RM, Paul O et al (2022) Anthropogenic land use and land cover changes—a review on its environmental consequences and climate change. J Indian Soc Remote Sens. https://doi.org/10.1007/s12524-022-01569-w
Sadeghi B (2021) Concentration-concentration fractal modelling: a novel insight for correlation between variables in response to changes in the underlying controlling geological-geochemical processes. Ore Geol Rev 128:103875. https://doi.org/10.1016/j.oregeorev.2020.103875
Saha TK, Pal S, Sarkar R (2021) Prediction of wetland area and depth using linear regression model and artificial neural network based cellular automata. Eco Inform 62:101272. https://doi.org/10.1016/j.ecoinf.2021.101272
Samie A, Abbas A, Azeem MM, Hamid S, Iqbal MA, Hasan SS, Deng X (2020) Examining the impacts of future land use/land cover changes on climate in Punjab province, Pakistan: implications for environmental sustainability and economic growth. Environ Sci Pollut Res 27(20):25415–25433. https://doi.org/10.1007/s11356-020-08984-x
Sandifer PA, Sutton-Grier AE, Ward BP (2015) Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: opportunities to enhance health and biodiversity conservation. Ecosyst Serv 12:1–15. https://doi.org/10.1016/j.ecoser.2014.12.007
Seto KC, Shepherd JM (2009) Global urban land-use trends and climate impacts. Current Opinion in Environmental Sustainability 1(1):89–95. https://doi.org/10.1016/j.cosust.2009.07.012
Sharma R, Joshi PK (2015) The changing urban landscape and its impact on local environment in an Indian megacity: the case of Delhi. In Urban Development Challenges, Risks and Resilience in Asian Mega Cities (pp. 61–81). Springer, Tokyo. https://doi.org/10.1007/978-4-431-55043-3_4
Sonu TS, Bhagyanathan A (2022) The impact of upstream land use land cover change on downstream flooding: a case of Kuttanad and Meenachil River Basin, Kerala. India Urban Climate 41:101089. https://doi.org/10.1016/j.uclim.2022.101089
Spruce J, Bolten JD (2018 December) Using MODIS and Landsat data to produce land use land cover maps for the lower Mekong Basin: implications for regional water and disaster management. In AGU Fall Meeting Abstracts (Vol. 2018, pp. GC23C-03).
Sun A (2013) Enabling collaborative decision-making in watershed management using cloud-computing services. Environ Model Softw 41:93–97. https://doi.org/10.1016/j.envsoft.2012.11.008
UN Prospects (2019) Highlights (ST/ESA/SER. A/423): United Nations, Department of Economic and Social Affairs, Population

Division (2019). World Population; 2019. https://www.un.org/development/desa/publications/world-population-prospects-2019-highlights.html

Wang J, Maduako IN (2018) Spatio-temporal urban growth dynamics of Lagos Metropolitan Region of Nigeria based on hybrid methods for LULC modeling and prediction. European Journal of Remote Sensing 51(1):251–265. https://doi.org/10.1080/22797254.2017.1419831

Weng L, Qian M, Xia M, Xu Y, Li C (2020) Land use/land cover recognition in arid zone using a multi-dimensional multi-grained residual Forest☆. Comput Geosci 144:104557. https://doi.org/10.1016/j.cageo.2020.104557

Xu C, Rahman M, Haase D, Wu Y, Su M, Pauleit S (2020) Surface runoff in urban areas: the role of residential cover and urban growth form. J Clean Prod 262:121421. https://doi.org/10.1016/j.jclepro.2020.121421

Yilmaz, D., & Isinkaralar, Ö. (2021). Climate action plans under climate-resilient urban policies. Kastamonu University Journal of Engineering and Sciences, 7(2): 140–147.

Zhang H, Qi ZF, Ye XY, Cai YB, Ma WC, Chen MN (2013) Analysis of land use/land cover change, population shift, and their effects on spatiotemporal patterns of urban heat islands in metropolitan Shanghai, China. Appl Geogr 44:121–133. https://doi.org/10.1016/j.apgeog.2013.07.021