

1 **Simulating Carbon Sequestration using Cellular Automata and land use assessment; Case**
2 **of: Karaj City, Iran**

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1 Simulating Carbon Sequestration using Cellular Automata and land use assessment; Case 2 of: Karaj City, Iran

3 4 **Abstract**



5 In this study, in the city of Karaj five classes of land use-cover including residential, agriculture,
6 rangeland, forest and barren areas were considered and randomly in each class a total of 20
7 points were selected and vegetation and soil samples were taken. In plant samples, the amount of
8 carbon sequestration was determined by calculating the amount of organic carbon by dry weight
9 and in soil samples, the amount of carbon sequestration was determined by using Walleky and
10 Black method, too. For each area, the average value of carbon sequestration of samples was
11 introduced as 'carbon sequestration index' of that class. Average values for each category were
12 determined as an indicator of carbon sequestration of that class and then by using the
13 DINAMICA EGO software a simulation was conducted using cellular automata approach to
14 simulate changes in the classes of land use-cover in the city of Karaj. Finally, by using carbon
15 sequestration index and the results of the simulation, changes in carbon sequestration in each
16 class were calculated. On this basis, it was found that in the 15-year period from 2014 to 2029,
17 not considering the residential class as the effective use of carbon sequestration, the greatest
18 amount of carbon sequestration was found in the agricultural class and the lowest carbon
19 sequestration was found in barren area. Also, agriculture class will be faced with the huge
20 reduction of carbon sequestration, because of expansion of the residential area.

21 **Keywords:** Carbon Sequestration, Land use-cover Changes, Cellular Automata, City of Karaj

22 23 **Introduction**

24 Carbon sequestration can be defined as the process of removing carbon from the atmosphere and
25 depositing it in a reservoir (UNFCCC, 2015). Carbon sequestration describes long-term storage
26 of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid
27 danger climate change. It has been proposed as a way to slow the atmospheric and marine
28 accumulation of greenhouse gases, which are released by burning fossil fuels (Hodrien, 2008).
29 Terrestrial carbon sequestration is the result of a balance between the different stages of the
30 carbon cycle in the biosphere and pedosphere, such as photosynthesis, plant growth, congestion
31 and carbon accumulation in soils and carbon emissions from breathing organisms, microbial
32 decomposition of leaf litter, and oxidation of organic carbon in soil and land degradation. Several
33 factors are involved in this process, which are classified in two categories of physical and
34 managerial factors. Physical factors are divided into three categories of factors: soil, climate and
35 terrain geometry. These factors are difficult and sometimes impossible to control. Therefore, in
36 the management of carbon sequestration, only managerial factors are in the control of humans
37 (Ferreiro *et al.*, 2010).

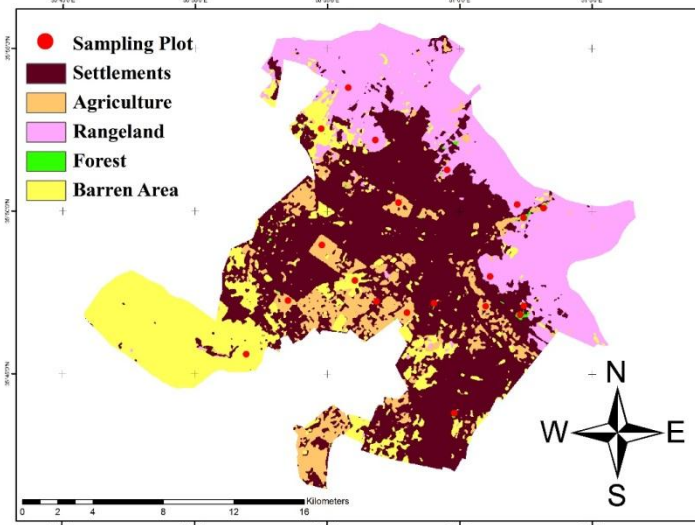
38 Because the majority of carbon sequestration is in the soil, organic carbon of the soil plays an
39 important role in the process of carbon sequestration. The amount of carbon in the soil
40 significantly changes according to location, topography, bedrock or vegetation type and previous
41 management approaches. Also time-wise, in the growing season and the time of decomposition
42 processes, the amount of carbon found in the roots, litter and biomass of microorganisms in the
43 soil can vary. The main processes of carbon sequestration in soil includes humus organic
44 material, transformation of humus into organic-inorganic compounds in soil, placing these
45 compounds deep in the soil in areas that are plowed, **deep root plants and calcareous soil.**
46 Instead, processes that reduce the amount of organic matter in soil include erosion, compaction

1 and reduction of soil permeability, loss of soil structure, mineralization and oxidation of humic
2 substances (Bruce *et al.*, 1999).
3 Nowadays, with the development of vegetation covers of hard wood trees and shrubs, 
4 **method** is now used more effectively than other hods to reduce carbon dioxide in the air.
5 Although the amount and rate of carbon sequestration is higher in mild and humid tropical forest
6 ecosystems however, the speed of the chemical analysis and biological processes that cause the
7 release of carbon dioxide, due to high humidity and high ambient temperature is also very high.
8 Therefore, arid and semi-arid regions **are the best options** for carbon sequestration. The increase
9 in biomass of hard wood plants in these regions has many advantages due to the reduction of
10 carbon sequestration (Lal, 2008). That is why international organizations such as FAO and
11 UNDP have chosen these regions to implement programs of carbon sequestration to reduce
12 greenhouse gases (Ghanbari, 2014).
13 Through photosynthesis, plants absorb carbon and then return some of it to the atmosphere
14 through respiration. The carbon that remains in plant tissue either gets consumed by the animals
15 or gets added to the soil as litter (when the plants decompose and die). In the first way, the
16 carbon gets stored in the soil and is considered as soil organic matter. Soil organic matter is a
17 complex mixture of carbon syntheses including decomposing plant and animal tissues, microbes
18 (protozoa, nematodes, fungi and bacteria) and carbon minerals in the soil. Carbon can remain
19 stored in the soil for thousands of years. Factors such as climate, natural vegetation, soil texture
20 and drainage can influence the amount and duration of carbon storage in soil (Schlesinger, 1984).
21 The land use-cover is divided into multiple classes. This classification includes sorting the
22 objects in groups or collections of objects based on the relationships that exist between them
23 (Sokal, 1974; Anderson *et al.*, 1976; Gregorio & Jansen, 2005; Şatır & Berberoğlu, 2012). The
24 changes in land use-cover can be caused by natural factors or human's actions. Although people
25 have always changed the land for their basic needs in life, the speed of these changes is already
26 much higher than in the past, which led to many changes in the environment and ecological
27 processes at the local, regional and global spectrum. These changes in land, causes some changes
28 in the climate, the amount of pollution and biodiversity. Monitoring and modeling historical
29 situation of the region can be used to anticipate the negative effects of these changes in land use-
30 cover, in order to protect resources, effectively. As a result, finding appropriate methods for
31 modeling the land use-cover changes is a global goal for researchers and politicians (Ellis &
32 Pontius, 2010).
33 One of the most popular method to simulate spatial changes is cellular automata. A cellular
34 automata is a system of a finite number of cells that are located next to each other in terms of
35 location and continuity and are stored together in a regular grid of cells in the form of a raster
36 image. This model is well suited to simulate phenomenon of spatial landscape (Al-ghamdi, 2012;
37 Guan & Clarke, 2010; Jantz *et al.*, 2010; KwadwoNti, 2013).

38 39 **Materials and Methods**

40 After selection of city of Karaj as the study area and **characterization of sampling points** (Fig. 1),
41 plant and soil samples were taken from each and every point. Sampling at any point was usually
42 done in a season when plant growth in that area had been completed. Which means, depending
43 on the coverage of **each class**, and depending on the type of plant species in each class their
44 sampling time was determined (Karimian, 2009). For samples of grass and shrub cover, it was
45 **sure** to sample the **aerial** and underground biomasses separately. For measuring and sampling the
46 aerial biomass **direct measurement method** was used. For this purpose, the aerial biomass to the

1 ground was cut (completely cutting the aerial parts) and after drying them in the laboratory,
2 weighed, and then by including plant basis weight per unit area, weight of aerial biomass and
3 total biomass per hectare were estimated (Mesdaghi, 2001).



4
5 Figure 1 Map of Karaj city with locations of sampling points in 2014
6

7 In the sampling points, plots with specific measures (1×1 square m) had been placed. Litter in
8 each plot was harvested as part of the aerial biomass. Litter samples were transported to the
9 laboratory and after getting fully dried, the dry weight of each sample was recorded separately
10 and then the total weight of litter per square meter was determined. Also, belowground biomass
11 of the sampled species were extracted. Usually these profiles had the dimensions of $30 \times 30 \times 30$
12 cubic cm. In each plot, the roots were collected and after drying, weighted, and then by
13 calculating the root weight per unit area the amount of studied factors were determined. In forest
14 cover, usually a number of pure species with an average age of 20 years were selected. In order
15 to determine the weight of biomass of standing trees, depending on forest density and
16 homogeneity of mass, plots of different sizes were used. To do this, Plots were randomly located
17 in forest stand and the number of bases of the tree in each were counted and then we attempted to
18 measure the height and diameter at breast to determine the volume of the tree. To determine the
19 bulk density of the tree, we took samples from a tree branch in each stand. For this purpose, a
20 piece of tree branches with specified dimensions were cut and then their dry weight and volume
21 were measured. By dividing weight by volume, bulk density of the tree was determined. Then,
22 by multiplying the volume of trees in bulk density, biomass weight per unit area was determined.
23 The method was used for sampling the litter of forest stands was similar to the method used for
24 herbaceous and shrubs (Karimian, 2009; Ghanbari, 2014).

25 To study soil characteristics in grass and shrub cover, profile sampling point had been drilled in
26 the area under the canopy. Because microorganisms in the depth of 30 cm of the soil have the
27 highest deployment, and also the development of studied plant roots were mainly in this depth
28 too, therefore sampling carried out in each profile in the depth of 0-30 cm, and finally a sample
29 which weights around 1 kg was sent to the laboratory. Sampling in forest cover profiles, based
30 on the depth of soil, was usually done in the depth of 0-30 cm. Usually the dimensions of each
31 profile on the surface was 30×30 square cm and its depth was about 30 cm (or where the
32 bedrock was encountered). In forest covers, both from under the trees and the space between the

1 trees, soil sampling was done (Mahdavi *et al.*, 2007). Also in other land use-cover classes where
2 the structure did not include any plants, **due to the presence of microorganisms** in the soil, soil
3 sampling was done.

4 Samples of shoots, underground and litter plants were dried in the open air for a few weeks and
5 then their dry weight were determined using the scale (Karimian, 2009). Also, the wet samples
6 were placed in the oven at 72 ° C for 48 hours to completely dry, then dry weight of each sample
7 was calculated (Gholami, 2008). For determination of organic carbon of samples the combustion
8 in the furnace method was used (McDicken, 1997). On this basis, samples were grounded and 2
9 grams of each sample were separated. The samples were placed in the electric furnace for 24
10 hours at 375 ° C (Karimian, 2009) or 550 ° C for five hours (Ghanbari, 2014). After weighing the
11 ashes we took out of the electric furnace, the difference between initial weight and weight of the
12 ashes showed the amount of organic matter in the sample. With having the amount of organic
13 matter and by using the number 1 equation (Birdsey *et al.*, 2000), the amount of organic carbon
14 in each of the samples was calculated separately.

15 Equation 1
$$OC = \frac{1}{2} OM$$

16 Whereas, *OC* is amount of organic carbon in gram and *OM* is amount of organic matter in gram.
17 According to Equation 1, half of the organic matter of the plants consists of organic carbon.

18 Soil samples, were then dried in the open air, crushed and sieved by 2 mm sieve and then some
19 experiments were conducted to determine the amount of organic matter and organic carbon
20 according to Walleky and Black method (Allison, 1965) and based on soil analysis methods. The
21 amount of soil organic matter was determined by measuring the amount of oxide-able organic
22 matter in the soil, therefore, after determining the percentage of organic carbon, the amount of
23 soil organic matter and soil organic carbon were calculated. Following the Walleky and Black
24 method, we poured one gram of soil in the Erlenmeyer flask, and then we poured 10 cc of normal
25 potassium dichromate and 20 cc of sulfuric acid into the Erlenmeyer flask and gently shake the
26 mix. After cooling the contents of the Erlenmeyer flask, we poured it into the volumetric flask
27 and then we brought the volume to 200 cc with distilled water. Then we added 10 drops of
28 orthophenanithroline to the solution and continued the titration by ferrous ammonium sulfate,
29 and we continued until the mixture became puce. At this time we read the volume of consumed
30 orthophenanithroline. The amount of soil organic matter was determined by measuring the
31 amount of oxide-able organic matter in the soil. Percentage of soil organic matter can be
32 calculated by equation number 2 (Haghighi, 2003; Gholami, 2008).

33 Equation 2
$$\%OM = \frac{(V_2 - V_1) \times N \times 0.39}{S}$$

34 Whereas, V_1 is amount of used ferrous ammonium sulfate for control sample in mL, V_2 is amount
35 of used ferrous ammonium sulfate for sample in mL, N is Normality of ferrous ammonium
36 sulfate, S is weight of dried soil sample in the open air and *OM* is amount of organic material of
37 soil sample. Then by using equation 3, the percentage of organic matter was converted into the
38 percentage of organic carbon (Haghighi, 2003).

39 Equation 3
$$\%OC = \frac{\%OM}{1.724}$$

40 Whereas, *OC* shows organic carbon content. Finally, by using the Equation 4, amount of organic
41 carbon content of the soil was determined in kilograms per hectare (Haghighi, 2003).

42 Equation 4
$$OC = 10000 \times \%OC \times Bd \times E$$

43 Whereas, *Bd* is density of soil sample in gram per cubic centimeter and *E* is depth of sampling
44 point in cm.

1 For simulating the land use-cover changes, the DINAMICA EGO software was used. All data
2 used, before entering the simulation, were preprocessed in other applications such as ArcGIS,
3 ENVI, IDRISI and all the images were studied in respect to their number of rows and columns,
4 geographic coordinate system and overlapping border area and in different images were
5 reviewed and modified (Makhdoom *et al.*, 2001).

6 In the simulation method used which was based on cellular automata method, the main rule
7 amongst the cells was the possibility of any of the uses changing to another. To calculate the
8 probability values, the Markov chain method was used (Soares-filho *et al.*, 2012). Then all the
9 predictable variables were introduced to the model in form of auxiliary data. Before running the
10 simulation based on the proposed model, all the proposed variables were examined in terms of
11 their effectiveness on the model. First, for all of the modes of transition, the proposed variables
12 were introduced as effective variables. After running the model and calculating effective
13 variables coefficients matrix, the results were reviewed and for any transition, the variables that
14 have been identified as ineffective and correlated were removed from the transition (Soares-filho
15 *et al.*, 2009; KwadwoNti, 2013).

16 In the DINAMICA EGO software, land use-cover changes model was executed for a specified
17 time period by using transition matrix, the effective variables coefficients matrix, effective
18 variables values and the initial land use-cover status. The output of this model was simulated
19 results of the area from t_1 timestamp to the specified time as the number of repetitions of the
20 process. The time unit in the model was proportional to the purpose of the research which in
21 most studies of land use-cover changes, yearly time unit is considered (KwadwoNti, 2013;
22 Soares-filho *et al.*, 2009).


23 To validate the results of simulation, there are some tools in the DINAMICA EGO software
24 which opens up a window with odd dimensions and moves it on the same position of both maps,
25 and proportional to the size of each window, the minimum similarity is calculated on the basis of
26 the fuzzy reciprocal similarity. After identifying the final simulation models of land use-cover
27 changes, and using the final model, data on the current time entered into the model and the
28 simulation process for the future was conducted (Soares-filho *et al.*, 2009; Soares-filho *et al.*,
29 2012; KwadwoNti, 2013).

30 Considering the measured data about the amount of carbon sequestration for each land use-cover
31 class in the region which were measured by field studies and introduced laboratory experiments,
32 the rate of carbon sequestration and its variations in accordance with the land use-cover changes
33 was simulated for the future. For this purpose, if the region has n number of land use-cover
34 classes, and each class has C_i number of cells, each class has carbon sequestration of \overline{CS}_i , the
35 area of each cell on the ground is S , then the total amount of carbon sequestration in the region of
36 the study can be calculated using Equation 5.

37 Equation 5
$$CST = \sum_{i=1}^n (\overline{CS}_i \times C_i \times S)$$

38 In the above equation for each $i = 1, 2, \dots, n$, part of $(\overline{CS}_i \times C_i \times S)$ shows the amount of carbon
39 sequestration in the i^{th} class. The amount of carbon sequestration on each class can include
40 amount of carbon sequestration of the shoots of vegetation cover, underground organs, all of the
41 vegetation cover, soil and the amount of total average for the land use-cover class.

42 **Results**

43  After measuring the amount of the sequestered carbon in each hectare, the mean values for each
44 class were determined as an indicator of carbon sequestration of the soil in that class and the
45 results are shown in Table 1.
46

1
2

Table 1 Mean values of carbon sequestration of soil per land use-cover classes

Land use-cover class	Mean values of carbon sequestration of soil (ton per Hectare)
Agriculture	1178
Rangeland	686
Forest	675
Barren Area	92

3 After the calculation of soil tests, carbon sequestrations of plant samples were measured and
4 according to the average volume of plants in each plot, amount of carbon sequestration of plants
5 per plot and eventually per hectare were found. After the calculation for each sample in same the
6 class, mean values were calculated for each land use-cover class and were introduced as an
7 indicator of the average sequestration plant of that class (Table 2).

8 Table 2 Mean value of carbon sequestration in vegetation per land use-cover classes

Land use-cover class	Mean values of carbon sequestration in vegetation (ton per Hectare)
Agriculture	28
Rangeland	14
Forest	94

9

10 Finally, the average of values of the indicators of soil and plant for each land use-cover class
11 were calculated and were introduced as an indicator of total average for each class. The results
12 are shown in Table 3.

13 Table 3 Mean amount of total carbon sequestration per land use-cover classes

Land use-cover class	Mean values of total carbon sequestration (ton per Hectare)
Agriculture	122
Rangeland	700
Forest	769
Barren Area	92
Total	2767

14 In order to run simulation of changes in land use-cover classes, transition matrix between two
15 land use-cover maps between the years 1985 and 2000 was calculated based on Markov chain
16 method and for a 15-year period (Table. 4).

17 Table 4 Results of Markov Chain for the study area in 1985-2000

Class	The most probability of transition	
	Value	Class name
Residential	0.0094	Rangeland
Agriculture	0.0520	Rangeland
Rangeland	0.0307	Barren Area
Forest	0.1122	Agriculture
Barren Area	0.0604	Residential

18 Then, due to transitions and proposed variables, effective variables coefficients matrix were
19 calculated and the impact of variables was examined in each transition. Also, the correlation
20 between the coefficients by using Uncertainty Information Joint method was calculated and
21 finally one of two correlated variables or the variables which didn't have any impact in transition

- 1 were excluded from the model and final effective variables coefficients matrix were stored.
- 2 Some of final effective variables shows in Figure 4.

Transition_From*	Transition_To*	Variable*	Ra...	Ra...	Pos...	Ex...	Weight_C...	Contrast	Significant
1	2	Distance_to_Agriculture/distance_to_2	0	100	23731	2312	1.052150...	2.43332...	1
1	2	Distance_to_Agriculture/distance_to_2	100	200	17201	279	-0.826841...	-0.9792...	1
1	2	Distance_to_Agriculture/distance_to_2	200	300	11364	98	-1.466260...	-1.5942...	1
1	2	Distance_to_Agriculture/distance_to_2	300	400	7674	27	-2.367915...	-2.4662...	1
1	2	Distance_to_Agriculture/distance_to_2	400	1800	17585	101	-1.875604...	-2.1055...	1
1	2	Distance_to_Barrenarea/distance_to_5	0	100	7151	172	-0.424850...	-0.4598...	1
1	2	Distance_to_Barrenarea/distance_to_5	100	200	7795	249	-0.133003...	-0.1468...	1
1	2	Distance_to_Barrenarea/distance_to_5	200	300	7455	289	0.067639...	0.07508...	0
1	2	Distance_to_Barrenarea/distance_to_5	300	6900	55154	2107	0.052402...	0.19347...	1
1	2	Distance_to_Barrenarea/distance_to_5	0	100	4971	381	0.789480...	0.87141...	1
1	2	Distance_to_Forest/distance_to_4	100	200	8079	333	0.131526...	0.14791...	1
1	2	Distance_to_Forest/distance_to_4	200	700	34322	1171	-0.064898...	-0.1137...	1
1	2	Distance_to_Forest/distance_to_4	700	800	4800	83	-0.761771...	-0.7970...	1
1	2	Distance_to_Forest/distance_to_4	800	900	4113	123	-0.201045...	-0.2112...	1
1	2	Distance_to_Forest/distance_to_4	900	1000	3968	159	0.102098...	0.10788...	0
1	2	Distance_to_Forest/distance_to_4	1000	1100	3105	76	-0.406938...	-0.4209...	1
1	2	Distance_to_Forest/distance_to_4	1100	1600	10917	328	-0.196241...	-0.2252...	1
1	2	Distance_to_Forest/distance_to_4	1600	1700	876	22	-0.380572...	-0.3842...	0
1	2	Distance_to_Forest/distance_to_4	1700	1800	576	33	0.477714...	0.48220...	1
1	2	Distance_to_Forest/distance_to_4	1800	1900	372	34	0.981630...	0.98924...	1
1	2	Distance_to_Forest/distance_to_4	1900	2300	1084	72	0.635298...	0.64755...	1
1	2	Distance_to_Forest/distance_to_4	2300	2400	109	0	0	0	0
1	2	Distance_to_Forest/distance_to_4	2400	5600	263	2	-1.593057...	-1.5958...	1

3
4 **Figure 4** A summary of final effective variables

5 By using DINAMICA EGO software, the model ran starting from 1985 for a 15-years period to
6 get simulated result for year 2000. Then, minimum similarity between observed and simulated
7 result was determined by using fuzzy reciprocal similarity method for the same area regions to
8 validate the model (Table. 5).

9 **Table 5** the minimum similarity between observed and simulated result in year 2000

Area (square meters)	Minimum Similarity
900	0.30
4500	0.41
8100	0.50
15300	0.61
26100	0.70

10 Finally, the simulation process for the city of Karaj was carried out in a period of 15 years
11 starting from 2014, and the results obtained are presented in Table 6. Also, the results have been
12 presented in Figure 5-7.

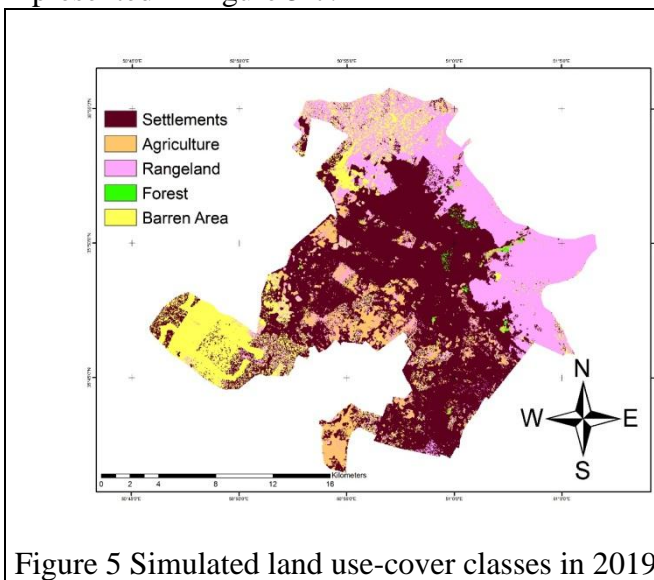


Figure 5 Simulated land use-cover classes in 2019

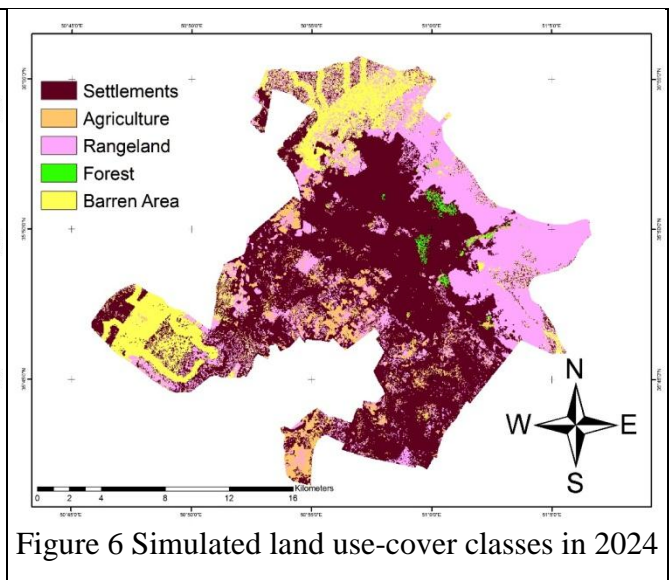


Figure 6 Simulated land use-cover classes in 2024

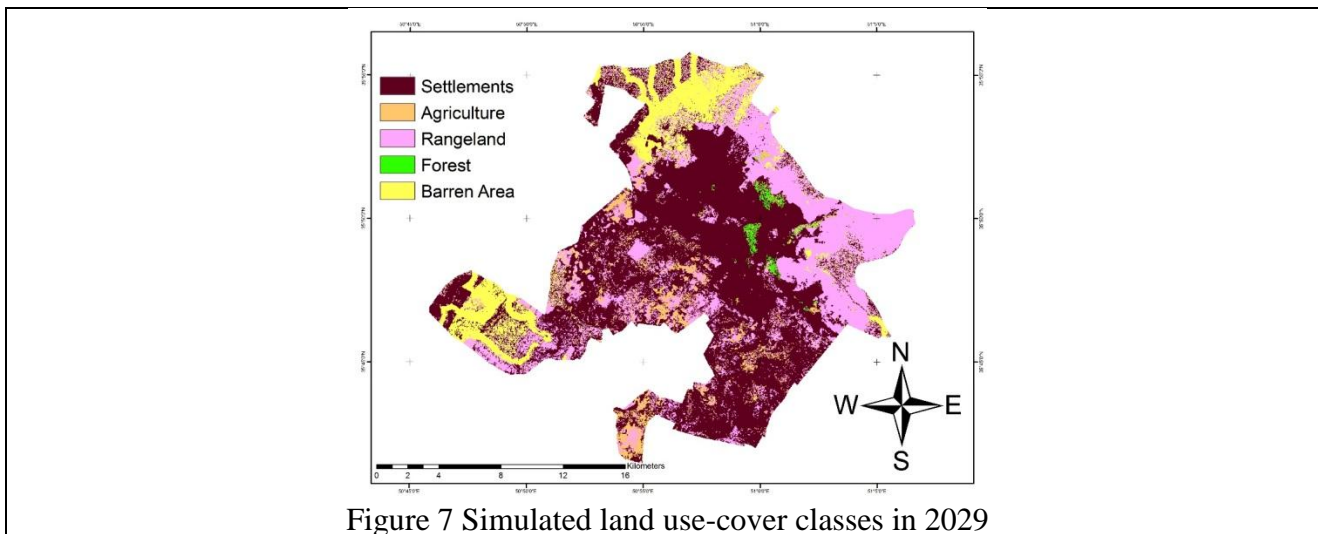


Figure 7 Simulated land use-cover classes in 2029

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Table 6 Changes of land use-cover in the city of Karaj from 2014 to 2029 (in hectare)

Year / Class	Residential	Agriculture	Rangeland	Forest	Barren Area
1985	7534.53	7289.37	17138.61	1412.37	2202.75
2000	9267.21	7201.98	13968.36	531.81	4608.27
2014	16002.54	3632.85	9433.98	89.37	6418.89
2019	18240.89	2659.06	9916.14	73.29	4459.79
2024	19141.89	1830.01	9851.92	166.24	4345.46
2029	19705.01	1407.71	9657.84	193.10	4373.93

3

4 By combining the obtained results, the results of the simulation of carbon sequestration using the
5 simulation approach for land use-cover changes in the city of Karaj and equation number 5 get
6 calculated and results are shown in Table 7 and Figures 8 and 9. Residential class due to lack of
7 impact on the process of carbon sequestration were removed from the results.

8 Table 7 the results of the simulation of carbon sequestration of the study area from 2014 to 2029
9 (in ton)

Year / Class	Agriculture	Rangeland	Forest	Barren Area	Total
1985	43950039	6003740	54329	202719	50210827
2000	43423135	4893186	204570	424099	48944990
2014	21903662	3304770	34377	590730	25833539
2019	16032358	3473673	28192	410434	19944657
2024	11033739	3451176	63947	399912	14948774
2029	8487552	3383189	74279	402532	12347552

10

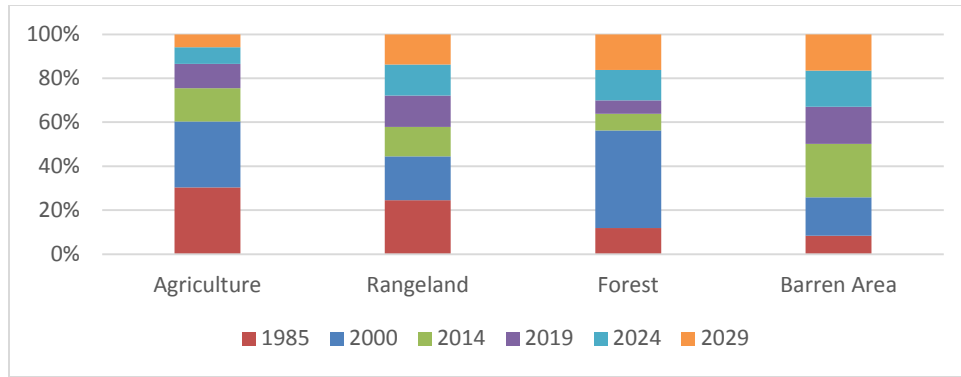


Figure 8 Status of carbon sequestration amount in the land use-cover classes of the study area in 1985-2029

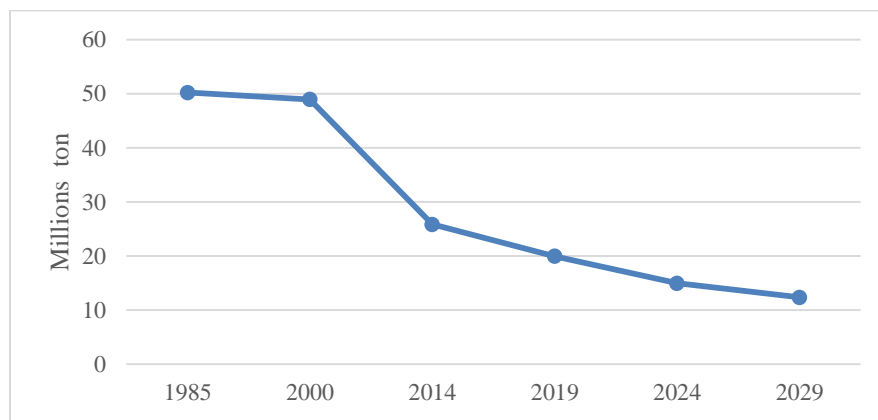


Figure 9 Changes of total amount of carbon sequestration of the study area in 1985-2029

Conclusion

The results of this study corresponded with the findings of Soares-filho *et al.* (2012) that used DINAMICA EGO software to study carbon sequestration in the agricultural land and low-yielding forests of Brazil. White and Engelen (1993), Deadman *et al.* (1993), Itami (1994, 1988), White and Engelen (1997), White (1998), Li and Yeh (2002), Barredo *et al.* (2003, 2004), Al-Ahmadi *et al.* (2008), Al-Ghamdi (2012) and KwadwoNti (2013) also used the cellular automata approach in studying the land use-cover changes and their results confirms the suitability of this approach in the studies such as this.

In this study, by using fuzzy reciprocal similarity method, structural similarities between the obtained data and observed data, in regions with an area of 900 to 26100 square meters, were examined. The results show that the similarity between the observed and simulated results in a 15-year period increases with an increase in the size of compared area. Also, we can claim results of simulation will catch up with reality for regions with an area of 900 square meters with the probability of at least 30% and for regions with an area of 26100 square meters with a probability of at least 70%. Sheng *et al.* (2012), Soares-fihlo *et al.* (2012, 2013) and KwadwoNti (2013) also used fuzzy analysis method in validation of simulation results for examining land use-cover changes and the results obtained by them validates the efficiency of methods based on fuzzy analysis in the validation of the results of the simulation.

According to the simulations carried out in the city of Karaj it was determined that in the 15-year period from 2014 to 2029, In terms of the extent of land use-cover classes, residential areas with

1 growth of about 10%, agriculture with 5% reduction, forests with a slight increase of about 0.3%,
2 barren area with a reduction of about 6% and rangeland is also faced with a little fluctuation are
3 almost stable. Considering the results of carbon sequestration in each land use-cover class and
4 combining them with the results of land use-cover changes in the studied area it was observed
5 that generally during 2014 and 2029 we will face a reduction in the amount of carbon
6 sequestration, especially in agriculture class. The reason for this is the increase of residential
7 areas and their expansion into other classes and given that residential areas have no measurable
8 impact on carbon sequestration therefore development of these areas increase the ineffective
9 classes in carbon sequestration of the region. According to the results of this research it is
10 recommended to city managers to take effective measures to increase residential green spaces
11 with appropriate plant species in the study area in such a way that in the future the increasing
12 carbon emissions don't cause a sharp drop in air quality.
13

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19 **References**

- 20 Al-Ahmadi, K., See, L., Heppenstall, A., Hogg, J. 2008. Calibration of a fuzzy cellular
21 automata model of residential dynamics in Saudi Arabia, *Ecological Complexity*, pp. 80-101.
- 22 Al-Ghamdi, K. A. 2012. *Modeling Spatial Dynamics Changes with Cellular Automata*.
23 The 7th National GIS Symposium April 29 – May 1, pp. 1-7.
- 24 Allison, L. E., 1965. Organic Carbon. In: C. A. Black, et al. eds. *Methods of Soil*
25 *Analysis, Part 2, Chemical and Microbiological Properties*. Madison: American Society of
26 Agronomy, p. 1367.
- 27 Anderson, R. J., Hardy, E. E., Roach, J. T, Witmer, R. E. 1976. *A Land Use and Land*
28 *Cover Classification System for Use with Remote Sensor Data*. Washington, 964 p.
- 29 Barredo, J. I., Demicheli, L., Lavallo, C., Kasanko, M., McCormick, N. 2004. Modelling
30 future residential scenarios in developing countries: an application case study in Lagos, Nigeria,
31 *Environment and Planning B: Planning and Design*, Volume 31(1), pp. 65-84.
- 32 Barredo, J. I., Kasanko, N., McCormick, M., Lavallo, C. 2003. Modelling dynamic
33 spatial process: simulation of residential future scenarios through cellular automata, *Landscape*
34 *and Residential Planning*, Volume 64, pp. 145-160.
- 35 Birdsey, R., Heath, I. & Williams, D., 2000. *Estimation of Carbon Budget Model of the*
36 *United State Forest Sector. North Carolina, Advances in Terrestrial Ecosystem Carbon*
37 *Inventory*. Measurement, and Monitoring Conference in Raleigh, pp. 3-5.
- 38 Bruce, J. P. et al., 1999. Carbon Sequestration in Soil, *Journal of Soil and Water*
39 *Conservation*, Volume First quarter.
- 40 Deadman, P., Brown, R. D., Gimblett, H. R. 1993. Modelling Rural Residential
41 Settlement Patterns with Cellular Automata, *Journal of Environmental Management*, Volume
42 37(2), pp. 147–160.
- 43 Ellis, E., Pontius, R. 2010. Land-use and land-cover change. In: *Encyclopedia of Earth*.
44 [Online] Available at: <http://www.eoearth.org/view/article/154143/> [Accessed 7 1 2015].
- 45 Ferreiro, J. P. et al., 2010. Effect of Management and Climate on Biochemical Properties
46 of Grassland Soils from Galicia (NW Spain), *Journal of Soil biology*, Volume 46, pp. 136-143.

1 Ghanbari, N., 2014. *Investigating of Impacts of Land use Change from Rangeland to*
2 *Forest on Soil Carbon Sequestration (Case Study: Sanandaj city)*. MSc thesis, faculty of natural
3 resources, University of Tehran, Iran, 105 p.

4 Gholami, H., 2008. *Investigating and Comprising of Carbon Sequestration between*
5 *Atriplex canescence and Hulthemia persica*. MSc thesis, faculty of natural resources, University
6 of Tehran, Iran, 82 p.

7 Gregorio, A. D., Jansen, L. J. 2005. *Land Cover Classification System: Classification*
8 *concepts and use manual*. [Online] Available at: [http://www.fao.org/gtos/doc/ECVs/T09/ECV-](http://www.fao.org/gtos/doc/ECVs/T09/ECV-T9-landcover-ref25-LCCS.pdf)
9 [T9-landcover-ref25-LCCS.pdf](http://www.fao.org/gtos/doc/ECVs/T09/ECV-T9-landcover-ref25-LCCS.pdf) [Accessed 7 1 2015].

10 Guan, Q., Clarke, K. C. 2010. A general-purpose parallel raster processing programming
11 library test application using a geographic cellular automata model, *International Journal of*
12 *Geographical Information Science*, Volume 24(5), pp. 695–722.

13 Haghghi, M. J., 2003. *Methods of Soil Analysis*. Nedaye Zoha Publication, Tehran, Iran,
14 450 p.

15 Hodrien, C., 2008. Squaring the Circle on Coal -Carbon Capture and Storage (CCS).
16 *Calverton Energy Conference*, Bath.

17 Itami, R. M. 1988. Cellular worlds: models for dynamic conceptions of landscape,
18 *Landscape Architecture*, Volume July/August, pp. 52–57.

19 Itami, R. M. 1994. Simulating spatial dynamics: cellular automata theory, *Landscape and*
20 *Residential Planning*, Volume 30, pp. 27-47.

21 Jantz, C., Goetz, S. J., Donato, D., Claggett, P. 2010. Designing and implementing a
22 regional residential modeling system using the SLEUTH cellular residential model, *Computers,*
23 *Environment and Residential Systems*, Volume 34(1), pp. 1–16.

24 Karimian, Z. R., 2009. *Comparison of Carbon Sequestration in Grassland and Shrubbery*
25 *Area (Case Study: Shahriar)*. MSc thesis, faculty of natural resources, University of Tehran,
26 Iran, 89 p.

27 KwadwoNti, I. 2013. *Geospatial Process Modelling for Land Use Cover Change*. PhD
28 thesis, Auckland University of Technology, Aukland, 216 p.

29 Lal, R., 2008. The Role of Soil Organic Matter in the Global Carbon Cycle, *Journal of*
30 *Soil and Environmental Pollution*, Volume 116, pp. 353-360.

31 Li, X. & Yeh, A. G., 2002. Neural-network-based cellular automata for simulating
32 multiple land use changes using GIS, *International Journal of Geographical Information*
33 *Science*, Volume 16, pp. 323-343.

34 Makhdoom, M., Darvishsefat, A.A., Jafarzadeh, H., Makhdoom, A. 2001. *Environmental*
35 *assessment and planning by using GIS*. University of Tehran press, Tehran, Iran, 304 p.

36 Mahdavi, S. K., Mokhtari Asl, A. & Mahdavi, F., 2007. Role of rangeland in Carbon
37 Sequestration, *Journal of Forest and Rangeland*, Volume 79-80, pp. 24-31.

38 McDicken, K. G., 1997. *A Guide to monitoring Carbon Storage in Afforestation and*
39 *Agro-afforestation Projects*. Winrock International Arlington, VA, USA, 90 p.

40 Mesdaghi, M., 2001. *Rangeland Management in Iran*. 4 ed. Astan Ghods Razavi Press,
41 Mashhad, Iran, 760 p.

42 Şatır, O., Berberoğlu, S. 2012. Land Use / Cover Classification Techniques Using Optical
43 Remotely Sensed Data in Landscape Planning. In: *Landscape Planning*. InTech, Shanghai,
44 China, pp. 21-55.

1 Schlesinger, W. H., 1984. Soil Organic Matter a Source of Atmospheric CO₂. In: *GM*
2 *Woodwell (Ed.), the role of terrestrial vegetation in the global carbon cycle*. John Wiley & Sons,
3 New York, USA, pp. 11-127.

4 Sheng, J., Qing, G., Chun-yu, W., Bei, L., Xiao-dong, L., Guang-ming, Z., Zhong-xing,
5 Y., Jie, L. 2012. Ecological suitability evaluation for residential growth boundary in red soil hilly
6 areas based on fuzzy theory, *Journal of Central South University*, Springer, Volume 19, pp.
7 1364-1369.

8 Soares-filho, B., Rodrigues, H., Costa, W., Schlesinger, P. 2009. *Modeling*
9 *Environmental Dynamics with DINAMICA EGO*. Belo Horizonte, Brazil, 116 p.

10 Soares-filho, B., Lima, L., Bowman, M., Viana, L. 2012. *Challenges for Low- Carbon*
11 *Agriculture and Forest Conservation in Challenges for Low-Carbon Agriculture and Forest*
12 *Conservation in Brazil*. Inter-American Development Bank, 40 p.

13 Soares-Filho, B., Rodrigues, H., Follador, M. 2013. A hybrid analytical-heuristic method
14 for calibrating land-use change models, *Environmental Modelling & Software*, Volume 43, pp.
15 80–87.

16 Sokal, R. R. 1974. Classification: Purposes, Principles, Progress, Prospects, *Science*,
17 Volume 185(4157), pp. 1115-1123.

18 UNFCCC, 2015. [Online] Available at:
19 http://unfccc.int/essential_background/glossary/items/3666.php#C [Accessed 5 1 2015].

20 White, R. 1998. Cities and cellular automata, *Discrete Dynamics in Nature and Society*,
21 Volume 2, pp. 111-125.

22 White, R., Engelen, G. 1993. Cellular automata and fractal residential form: a cellular
23 modeling approach to the evolution of residential land use patterns, *Environment and Planning*,
24 Volume 25, pp. 1175-1199.

25 White, R., Engelen, G. 1997. Cellular automata as the basis of integrated dynamic
26 regional modelling, *Environment and Planning B*, Volume 24, pp. 235-246.