

# **A system dynamics model for the land use planning and development: A case study of Kohgiluyeh and Boyer-Ahmad Province**

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## **Abstract**

The impact of human activities on the environment is mainly reflected in changes to land use and land cover. Land use changes are complex and dynamic processes that can be influenced by many factors. This study aims to present an integrated land use change model for Kohgiluyeh and Boyer Ahmad Province in the southwest of Iran. The model uses the system dynamic approach, incorporating different subsystems such as agriculture, water, population, forest, and pasture. The main objective of this model is to analyze and simulate the behavior of key variables over time (2010-2040), to provide a deep insight into land use dynamics in the region. The validity of the model was tested and proved to be acceptable, and it was used to simulate the key variables of the land-use system. The results indicated that water demand, population growth, and agricultural development are directly related, leading to an increase in the withdrawal from water storage over time. Based on the findings, the average annual change in cultivated land and water demand was +1.79% and +1.82%, respectively. If no policy changes are implemented, the forest and cropland areas will continue to expand while pasture will decrease. The water body has reduced at an average rate of -4.43% annually due to increased surface water extraction as a result of high demand for water, decreased surface water inflow, and higher evaporation as a result of climate change. These results indicate the need for careful management of land use and water resources to ensure sustainable development. Reducing water resources calls for water demand management policies in agriculture and domestic sectors. Modifying cultivation patterns according to the province's potential can help reduce resource harvesting. This study offers valuable insights for experts interested in land use management and sustainable development.

**Keywords:** Environment, Feedback, Simulation, Complexity, Land use changes.

## 38 **Introduction:**

39 The preservation of natural resources is crucial to ensure their sustainable utilization in the long  
40 term, considering their finite nature (Rudel, 2021). However, threats have reduced the quality  
41 and extent of these resources, causing irreparable damage to natural ecosystems (Siregar *et al.*,  
42 2018). The change in land use is a significant peril to natural and agricultural resources, which  
43 has consequential social, political, and environmental implications (Zhao *et al.*, 2016). Land  
44 use changes refer to the transformation of natural landscapes due to human activities, with an  
45 emphasis on the functional role of land for economic purposes (Rudel, 2021). This process  
46 involves modifying land cover and is influenced by both social and natural factors (Paul &  
47 Rashid, 2017). Land use changes can have significant impacts on ecosystems, biodiversity, and  
48 climate patterns, and understanding past changes is crucial for predicting future dynamics and  
49 ensuring sustainable conditions (Prokopová *et al.*, 2019).

50 Land use changes can have a range of impacts on society, including demographic shifts,  
51 changing income levels, development opportunities, human migration, and ecological  
52 imbalances. Understanding these effects is crucial for ensuring sustainable growth and  
53 development and making informed decisions about land use policies (Noszczyk, 2019). Land  
54 use changes have the potential to significantly impact the economic growth, trade, and  
55 competitiveness of regions and countries (Verburg *et al.*, 2019). Human migration is another  
56 significant effect of land use changes, as people may move to or from areas that are experiencing  
57 new development. Demographic shifts resulting from such changes can affect housing needs  
58 and employment opportunities (McConnel, 2015). This movement can result in changes in  
59 population density, the demand for resources, and the availability of services (Wang *et al.*,  
60 2022). As well as, land use changes can also lead to ecological imbalances, as natural habitats  
61 are disrupted and biodiversity is impacted. As such, it is essential to understand and evaluate  
62 the effects of land use changes to ensure sustainable growth and development (Sonter *et al.*,  
63 2014).

64 Land use changes occur due to a multitude of reasons, including economic, social, and  
65 ecological factors (Lambin & Meyfroidt, 2010). Economic drivers are influenced by factors  
66 such as per capita income, income inequality, land prices, and other economic variables  
67 (Lambin *et al.*, 2001). Social factors, influenced by education level, population density,  
68 migration rate, and other demographic factors, drive changes in land use patterns over time  
69 (Briassoulis, 2009). Ecological triggers are driven by natural factors like atmospheric  
70 conditions, precipitation, vegetation, soil type, and land slope. These factors play a critical role  
71 in shaping land use patterns and can have significant ecological and environmental

72 consequences (Lambin & Meyfroidt, 2010). Identifying drivers of land use changes is vital for  
73 managing natural resources and creating effective strategies for sustainable land use practices  
74 (Sonter *et al.*, 2014). By identifying these drivers and understanding their impact on land use  
75 patterns, policymakers, land managers, and other stakeholders can develop more effective  
76 strategies for managing natural resources and ensuring sustainable land use practices.

77 Land use changes are complex and dynamic processes. The complexities of land use changes  
78 require interdisciplinary approaches to study and manage its environmental and societal  
79 impacts. System dynamics (SD) can help policy-makers design effective strategies to address  
80 land use changes by taking into account the intricate interactions and dynamics of land use  
81 systems. By utilizing SD models, decision-makers can integrate economic, social, and  
82 environmental factors to achieve sustainable land use management (Turner *et al.*, 2013). SD is  
83 a powerful tool for modeling land use changes. The integration of SD modelling into land use  
84 and landscape pattern analysis enables researchers to simulate and study changes over time  
85 (Noszczyk, 2019).

86 SD is a widely used method in land use change studies that enables investigation of the impact  
87 of various policies. Several studies have employed this approach to analyze the outcomes of  
88 different land use scenarios and evaluate the effectiveness of policy interventions. Qian *et al.*  
89 (2014) used remote sensing, landscape indices, and system dynamics modelling to analyze land  
90 use changes in a nature reserve in Anhui Province, China. In this study wetlands loss has been  
91 observed in several lakes, which have been transformed into tidal-flat areas, cultivated land, or  
92 fish ponds. McConnell (2015) discussed land change models that aim to explain past land  
93 changes and project future dynamics. These studies demonstrate the utility of system dynamics  
94 modeling in analyzing and predicting land use changes, which can enable more effective land  
95 use planning and management. Zhao *et al.* (2016) developed coupling models to understand the  
96 driving factors of spatial multi-scale land use changes and their interactions. Results indicated  
97 that land-use change is influenced by policy, topography, accessibility, and potential  
98 productivity. Policy factors are mandatory, topography determines human activities,  
99 accessibility affects convenience, and potential productivity determines output. Socioeconomic  
100 factors have a stronger and more direct influence than environmental factors. Siregar *et al.*  
101 (2018) analyzed land use changes in West Kalimantan, Indonesia, using field observation,  
102 interviews, focus group discussions, and system dynamics modeling, to predict future changes.  
103 Results indicated that the primary leverage factors in the land use changes system of West  
104 Kalimantan were the pursuit of anticipated economic growth and the globally increased per  
105 capita consumption of edible oil. Liu *et al.* (2020) proposed a Land-use Simulation and

106 Decision-Support system to explore the impact of environment, choice, and policies on land  
107 use. Results showed migrant workers in Beijing caused ecological and land supply pressure due  
108 to resource concentration such as educational resources and medical resources. Azarm *et al.*  
109 (2022) conducted a study on Iran's Kishlak pastoralist settlements to predict the potential land  
110 use changes in the area. The study also employed the fuzzy analytic hierarchy process to  
111 determine the environmental stresses over multiple years and assess the vulnerability of the  
112 region. The results showed that the current land use trends would exacerbate environmental  
113 vulnerability and lead to a decline in rangeland, forest, and water body areas. Recently, Zhang  
114 *et al.* (2023) have used an SD model to predict the spatiotemporal distribution of land use under  
115 different scenarios (natural population growth, economic development, and ecological  
116 conservation) in Xi'an, China, in 2030. The research findings indicate that the most prominent  
117 changes in land use between 2000 and 2015 were a result of urban expansion, alteration of  
118 arable land into construction land, and the transformation of grassland into arable land. The  
119 analysis of land use changes under various scenarios revealed that the ecosystem service value  
120 was positively impacted by natural increase and ecological protection scenarios, while it  
121 experienced a negative influence due to land use transformations under the economic  
122 development scenario.

123 All of the studies reviewed here support the hypothesis that the SD models are proficient in  
124 detecting the variables that influence transformations in land use. Although several studies have  
125 successfully created sustainable development models to address issues of land use changes,  
126 there are still certain limitations that need to be addressed. Despite the progress made in this  
127 field, the existing models are not completely free from deficiencies. Therefore, it is important  
128 to continue the research and development of new models that can overcome these limitations  
129 and ensure a more holistic approach to sustainable land use management. In general, the  
130 modeling of the pasture subsystem has received relatively less attention in terms of theoretical  
131 foundations. The present study aims to address this gap by exploring the impact of various  
132 variables, including live livestock price, fodder price, and climate change, on the modeling of  
133 the pasture level. Additionally, in the population subsystem, previous studies (Qian *et al.*, 2014;  
134 Shen *et al.*, 2009) have not adequately considered population change as an endogenous variable.  
135 Our study seeks to fill this gap by investigating the effects of population change as an  
136 endogenous variable. As well as, based on an extensive analysis of previous research, it has  
137 come to light that the utilization of a system dynamic approach to simulate land use in Iran has  
138 been limited. Therefore, **the present** study employs **an SD** approach to design a system for land  
139 use in Kohgiluyeh and Boyer Ahmad Province in southwest Iran. In this study, we aimed to

140 develop a comprehensive mental model that considers various dimensions of land use as  
141 different subsystems. By integrating these subsystems, we created a basic model that can  
142 simulate land use changes effectively. This model provides decision-makers with a holistic  
143 view of the land use system, allowing them to identify the high-leverage and low-leverage  
144 points in the system and avoid policy resistance.

145

## 146 **Materials and Methods**

### 147 **Study area description**

148 Kohgiluyeh and Boyer-Ahmad Province is situated in the southwest region of Iran and share  
149 borders with five neighboring provinces namely Isfahan and Fars Provinces to the east, Bushehr  
150 Province to the south, Khuzestan to the west and Chaharmahal and Bakhtiari to the north. The  
151 province is mostly mountainous in terrain, forming a part of the Zagros Range (Akbari, 2022).  
152 The highest peak in this region is the Dena summit, which stands at an impressive height of  
153 5,109 meters above sea level. The province can be divided into two regions, which are  
154 characterized by distinct climates. The first region, known as Boyer-Ahmad, experiences cold  
155 weather, while the second region, Kohgiluyeh, is known for its hot climate. The climate in  
156 Boyer-Ahmad can be classified as semi-arid, with cold winters and mild summers. Conversely,  
157 the climate in Kohgiluyeh is also semi-arid but characterized by hot summers and mild winters.  
158 The province experiences an average annual temperature ranging from 10 to 25°C and an  
159 average annual precipitation ranging from 300 mm to 800 mm (Hashemi Ana, 2023). According  
160 to the latest census in 2016, the population of Kohgiluyeh and Boyer-Ahmad Province was  
161 713,052 inhabitants in 186,320 households. Agriculture is one of the main economic activities  
162 in Kohgiluyeh and Boyer-Ahmad Province, as it provides employment and income for many  
163 rural households (Mousavizadeh et al., 2018).

164



Fig. 2: Geographical location of Kohgiluyeh and Boyer-Ahmad Province.

165

## 166 Underlying Concept and Structure

167 **System Dynamics (SD)** is a quantitative modeling approach for analyzing complex systems,  
 168 which incorporates feedback loops and time delays to capture the system's behavior and identify  
 169 ways **to improve** its performance. SD is a methodology that aims to understand the complex  
 170 behavior of systems by analyzing the relationships between their components and identifying  
 171 feedback loops. This approach is particularly useful in academic and business environments,  
 172 where it can provide valuable insights into the dynamics of complex systems and support  
 173 decision-making and policy development (Walters *et al.* 2016). This study follows a four-step  
 174 SD modeling process introduced by Sterman (2001) and Ford and Ford (1999): (1) Problem  
 175 articulation; (2) Model formulation; (3) Model testing; (4) Simulation. The first step is to  
 176 identify the problem and key variables related to it, such as stocks, exogenous and endogenous  
 177 variables, and time and space scales. Model formulation aims to represent the problem's  
 178 structure and formulate an SD simulation model of the causal theory using diagram tools such  
 179 as causal loop (CLD) and stock and flow (SFD) diagrams. CLDs capture the feedback structure  
 180 of the system, while stock and flow diagrams provide more detailed information on the system's  
 181 structure. The stock variable is an accumulator variable. The system dynamics approach  
 182 represents all systems using three types of variables: level, rate, and auxiliary. Level variables  
 183 accumulate a flow over consecutive periods while rate variables represent a flow during a given  
 184 period. Auxiliary variables are used to identify or clarify other variables. Each variable is  
 185 associated with an equation: level equations are expressed as difference equations, while other  
 186 equations are general algebraic ones (Haghani *et al.*, 2003).

187

## 188 **Building System Dynamics Model for Land Use System Performance**

189 The model developed in this study comprises five subsystems, namely, population, agriculture,  
190 water, forest and pasture, and residential. These subsystems are designed to analyze and predict  
191 the impact of various factors on the environment and the ecosystem.

192

### 193 **A. Population subsystem**

194 Population is one of the factors that affect the land use changes. The population subsystem  
195 focuses on analyzing the demographic trends and their impact on water and food demand,  
196 residential requirements, as well as, the environment (Wang *et al.*, 2022). As the population  
197 grows, the demand for food increases, leading to changes in the demand for agricultural land  
198 and the extraction of surface and underground water sources. These changes have significant  
199 implications for water resource management and the sustainability of water supply systems.  
200 The relationship between population growth, land use changes, and water demand highlights  
201 the need for careful planning and management of water resources to meet the needs of growing  
202 populations while ensuring the preservation of natural resources. The population variable  
203 embodies the entire population of the case study, with one component being the "Population"  
204 **stock which varies** with the birth rate, death rate, and immigration rate (Haghani *et al.*, 2003).

205 The population at time  $t$  is mathematically represented by equation 1 as follows:

$$Population_t = Population_0 + \int_{t_0}^t (birth\ rate - death\ rate - immigration\ rate) dt \quad (1)$$

$$birth\ rate_t = lookup\ function\ (Per\ capita\ income_t) \quad (2)$$

$$death\ rate_t = lookup\ function\ (Per\ capita\ income_t) \quad (3)$$

$$immigration\ rate_t = lookup\ function\ (Income\ to\ expenditure\ ratio_t) \quad (4)$$

206 At each time step, the birth rate, death rate, and immigration rate are taken from a per capita  
207 income and income to expenditure ratio which are represented as a LOOKUP<sup>1</sup> Table (Equation  
208 2-4).

209

### 210 **B. Agricultural subsystem**

211 The agriculture subsystem is designed to evaluate the impact of agricultural practices on the  
212 environment. The agricultural subsystem stands in a direct nexus with the size of the population  
213 and the corresponding demand for food (Yu *et al.*, 2003). Food demand is also a crucial factor

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<sup>1</sup> Lookup Tables are typically used in SD modeling to represent nonlinear relationships between two variables. A table function can be defined as a list of numbers whereby input values to a function are positioned relative to the x-axis and output values are read from the y-axis (Ford & Ford 1999, Vensim Reference Manual 2011).

214 that is determined by population growth and per capita food consumption in the study area. As  
 215 the population increases, there is also an increase in the demand for food (Equation 5).

$$Food\ demand_t = per\ capita\ food\ consumption \times Population_t \quad (5)$$

216 The increasing demand for food is directly linked to the need for more agricultural land, which  
 217 in turn is influenced by the yield per hectare and the overall demand for food (Yu *et al.*, 2003).

$$need\ more\ agri - land_t = \frac{Food\ Demand_t}{Average\ crop\ yield} \quad (6)$$

$$Cropland\ area_t = Cropland\ area_0 + \int_{t=0}^t (change\ in\ cropland\ area_t) dt \quad (7)$$

218 Based on the findings of Le Houérou and Hoste (1977) and Stephenne and Lambin (2001), the  
 219 agricultural **sub-model** suggests that crop yield in the study area is solely influenced by rainfall.  
 220 The statistical correlation between the agricultural crop yield (in tons per hectare) and annual  
 221 rainfall serves as evidence to support this claim.

$$Crop\ yield_t = \alpha + \beta \times rainfall_t \quad (8)$$

### 222 C. Water subsystem

223 The water subsystem analyzes the availability and usage of water resources in the study area.  
 224 Water demand is impacted by various factors, including population (Sušnik *et al.*, 2012). The  
 225 water demand is primarily driven by two factors, namely, agricultural and residential purposes.  
 226 According to Davies and Simonovic (2011), the residential water demand is determined by the  
 227 product of the population and per capita water demand within the land use model (Equation 9).  
 228 On the other hand, the agricultural water demand is a function of the water requirement of  
 229 various agricultural products and the area under cultivation (Layani *et al.*, 2023).

$$Domestic\ water\ demand_t = per\ capita\ water\ use \times Population_t \quad (9)$$

$$Agricultural\ water\ demand_t = \sum_{i=1}^n (cropland\ area_i \times water\ requirement_i) \quad (10)$$

230 Water demand is a critical factor to consider in the management of water resources. Accurate  
 231 estimation of water demand is critical for the effective management and allocation of water  
 232 resources. The water sub-system's storage capacity in a dam is determined by the inflow of  
 233 surface water, outflows, evaporation, and rainfall. The evaporation is computed by multiplying  
 234 the evaporation rate with the surface water available for each time step. The decrease in the  
 235 volume of water in the dam will cause the surface water area to decline. The water storage in  
 236 the dam, represented as a LOOKUP Table, is used to obtain the reservoir surface area at each  
 237 time step (Layani *et al.*, 2020).

$$Water\ storage_t = water\ storage_0 + \int_{t=0}^t (water\ inflow_t - water\ outflow_t) dt \quad (11)$$

$$water\ inflow_t = Surface\ water\ inflow_t + Runoff_t \quad (12)$$



$$\text{water outflow}_t = \text{Evaporation}_t + \text{water demand}_t \quad (13)$$

$$\text{Evaporation}_t = \text{Evaporation rate}_t \times \text{water storage}_t \quad (14)$$

$$\text{Runoff}_t = \text{Surface area}_t \times \text{rainfall}_t \times \text{runoff rate} \quad (15)$$

$$\text{Surface area}_t = \text{look up function}(\text{water storage}_t) \quad (16)$$

$$\text{Evaporation rate}_t = \alpha + \beta \times \text{temperature}_t \quad (17)$$

238 The data about the reservoir's water storage capacity and the inflow of surface water into the  
 239 reservoir were extracted from the reports submitted by the Regional Water Organization of  
 240 Kohgiluyeh and Boyer-Ahmad Province (2020).

241

#### 242 **D. Forest and Pasture subsystem**

243 The forest and pasture subsystem evaluates the impact of land use, management practices, and  
 244 climate change on the forest and pasture ecosystems. By integrating these subsystems, the  
 245 model provides a comprehensive understanding of the environmental and ecological issues in  
 246 the study area (Wang *et al.*, 2022).

247 One important variable in the designed system is the forest area within the study area, which is  
 248 subject to changes caused by both afforestation (increase) and deforestation (decrease). The  
 249 reduction in forest area was determined by calculating the product of the deforestation rate and  
 250 the total forest area for different years. Moreover, the increase in forest area is influenced by  
 251 the amount of rainfall and the rate of investment in environmental conservation (Liu *et al.*,  
 252 2020).

$$\text{Forest area}_t = \text{Forest area}_0 + \int_{t=0}^t (\text{increase}_t - \text{decrease}_t) dt \quad (18)$$

$$\text{increase}_t = \text{expected forest area}_t - \text{forest area}_t \quad (19)$$

$$\text{Expected forest area}_t = \alpha + \beta_1 \times \text{rainfall}_t + \beta_2 \times \text{investment}_t \quad (20)$$

$$\text{investment}_t = \text{rate of investment} \times \text{Income}_t \quad (21)$$

$$\text{decrease}_t = \text{forest area}_t \times \text{deforestation rate} \quad (22)$$

253 In this research, the pasture area is regarded as a function of the live livestock price, fodder  
 254 price, population, the lag of the pasture area, and rainfall. The study is conducted to determine  
 255 the relationship between these factors and the pasture area (Wang *et al.*, 2022). As the  
 256 population grows and the demand for food rises, the pressure on pastures is anticipated to  
 257 intensify. This is likely to have significant implications for the management of livestock  
 258 production, particularly in regions where pasturelands are already under stress (Azarm *et al.*,  
 259 2022). The findings of the research could potentially provide valuable insights into the  
 260 management of pasture areas, which could ultimately lead to improved livestock production  
 261 and profitability.

$$Pasture_t = Pasture_0 + \int_{t=0}^t (change\ in\ pasture_t) dt \quad (23)$$

$$change\ in\ pasture_t = expected\ pasture\ rate_t - pasture_t \quad (24)$$

$$expected\ pasture\ rate_t = \alpha + \beta_1 rainfall_t + \beta_2 price\ of\ livestock_t + \beta_3 fodder\ price_t + \beta_4 population_t + \beta_5 lag\ of\ pasture_t \quad (25)$$

## 262 E. Residential subsystem

263 Residential usage is closely linked to the population subsystem, as it directly influences the  
 264 demand for construction. As the population grows, the demand for construction increases,  
 265 leading to a rise in residential usage. This highlights the positive impact of the population  
 266 subsystem on residential areas. In more detail, the residential area is dependent on the  
 267 population and the standard per capita of the residential locality (Wang *et al.*, 2022).

$$residential\ area_t = residential\ area_0 + \int_{t=0}^t (change\ in\ residential\ area_t) dt \quad (26)$$

$$change\ in\ residential_t = expected\ residential\ area_t - residential\ area_t \quad (27)$$

$$expected\ residential\ area_t = percapita\ residential\ area \times population_t \quad (28)$$

## 268 Model Testing

269 Testing the model is crucial in system dynamics modeling (Ford & Ford, 1999). There are two  
 270 types of tests: structure tests and behavior tests. Structure tests compare the model structure  
 271 with the real system's historical data. Behavior tests run the model and compare the results with  
 272 observed data. The mean absolute percentage error (MAPE) and coefficient of determination  
 273 ( $R^2$ ) are commonly used to evaluate the model's performance. MAPE measures the maximum  
 274 divergence between observed and simulated data, while  $R^2$  describes the proportion of variance  
 275 in measured data explained by the model (Moriassi *et al.* 2007, Wu *et al.* 2013, Kotir *et al.* 2016).

$$MAPE = \frac{100}{N} \times \sum_{i=1}^N \left| \frac{Y_i - \hat{Y}_i}{Y_i} \right| \quad (29)$$

$$R^2 = 1 - \frac{\sum (Y_i - \hat{Y}_i)^2}{\sum (Y_i - \bar{Y})^2} \quad (30)$$

276 To validate a model, we compared the observed and simulated values of the variable being  
 277 tested.  $Y_i$  represents the observed value,  $\hat{Y}_i$  represents the simulated value, and  $\bar{Y}$  is the average  
 278 of all observed values of the variable (Zhuang, 2014).

279 The study considered a period of 30 years (2010-2040) as the model time boundary. A literature  
 280 review revealed that different studies use varying periods, ranging from 10 years to 100 years.  
 281 Longer intervals are commonly used to assess the effects of long-term management options.  
 282 The study used 10-year observational data (2010-2020) to validate the system dynamics model.

283 Annual time steps were chosen based on available data from the land use system. The model  
 284 was designed to compare the results with the observational data and understand the behavior of  
 285 the system in the future. The development and execution of the land use system is facilitated  
 286 by Vensim Professional 5 software, which is one of the many software packages available for  
 287 SD modeling. Ventana Systems released this software in 2009. Figure 1 depicts the stock and  
 288 flow diagram that tracks the land use changes in the study area. Some stock variables used in  
 289 the model and their corresponding values are described in Table 1.

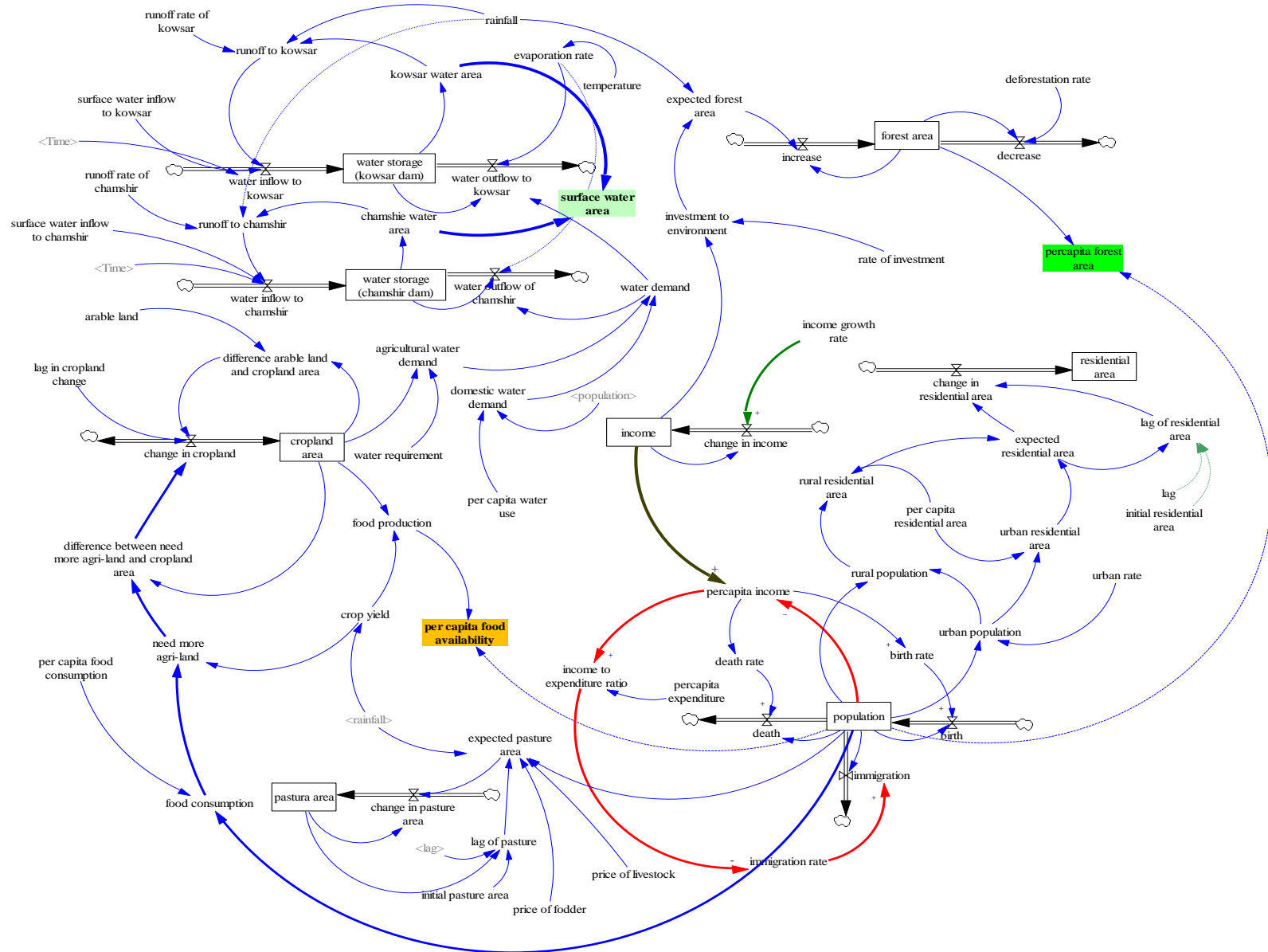
290

291

**Table 1.** The stock variables of land use system.

Variable Name	Initial value	Unit	Source
Water storage (Kowsar Dam)	477	MCM	Regional Water Organization of Kohgiluyeh and Boyer-Ahmad Province 2018
Water storage (Chamshir Dam)	759	MCM	Regional Water Organization of Kohgiluyeh and Boyer-Ahmad Province 2018
Cropland area	134.4	1000 Hectare	The Ministry of Agriculture – Jahad 2020 <a href="https://www.maj.ir/">https://www.maj.ir/</a>
Population	658.62	1000 Person	The Statistical Center of Iran 2020
Forest area	873604	Hectare	The Ministry of Agriculture – Jahad 2020 <a href="https://www.maj.ir/">https://www.maj.ir/</a>
Pasture area	485080	Hectare	The Ministry of Agriculture – Jahad 2020 <a href="https://www.maj.ir/">https://www.maj.ir/</a>
Residential area	$29 \times 10^6$	M <sup>2</sup>	The Statistical Center of Iran 2020

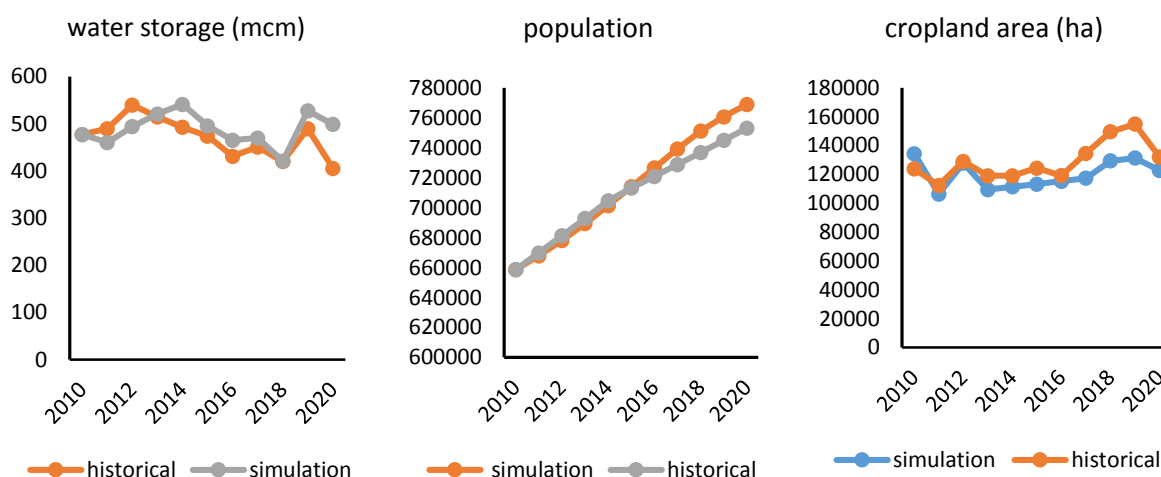
292



**Fig 1: Land use changes stock and flow diagram.**

293 **Results**

294 After mapping the structure of the land use system, the simulation of water storage, cropland  
 295 area, and population behavior was compared to their historical data to validate the model. Model  
 296 validation is a fundamental aspect of the system dynamics methodology. To validate the model,  
 297 data from 2010 to 2020 was used. Structure verification involves comparing the model's  
 298 assumptions to descriptions of decision-making and organizational relationships in the relevant  
 299 literature. It also involves analyzing behavior generated by the structure to evaluate the  
 300 adequacy of the model structure. To pass the structure-verification test, the model structure was  
 301 directly compared to the structure of the actual system that it represents. The results of the  
 302 behavioral test showed a significant correlation between the observed and predicted trends of  
 303 population, cropland area, and water storage for a complex land use model, suggesting that the  
 304 model has been well-calibrated to reconstruct the behavior of various parameters within the  
 305 system.



306 **Fig. 3: The observed and simulated values of variables.**

307 The  $R^2$  for the desired variables was also calculated. For the population variable, the  $R^2$  was  
 308 0.86, while for the volume of water storage and cropland area, it was 0.67 and 0.75,  
 309 respectively. These values confirm the good ability of the designed model in the reconstruction  
 310 of the behavior of key variables in the system. The MAPE for the three variables of population,  
 311 cropland area, and water storage has been calculated as 1.75%, 4.90%, and 6.64%, respectively  
 312 (Table 2). Therefore, the developed system can be used to simulate the behavior of the land use  
 313 system in the future.

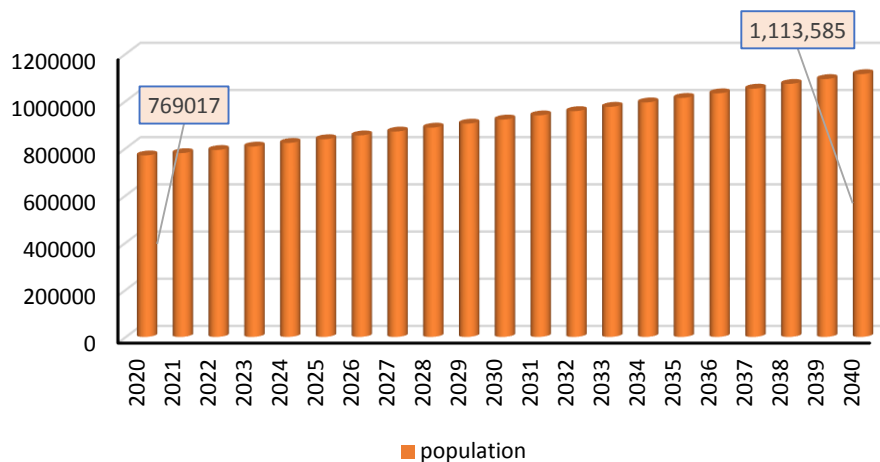
314 **Table 2: Result of behavior test in system dynamic process.**

Variable	$R^2$	MAPE (%)
Population	0.86	%1.75
Cropland area	0.75	%4.90
Water storage (Kowsar Dam)	0.67	%6.64

315 Source: Study results.

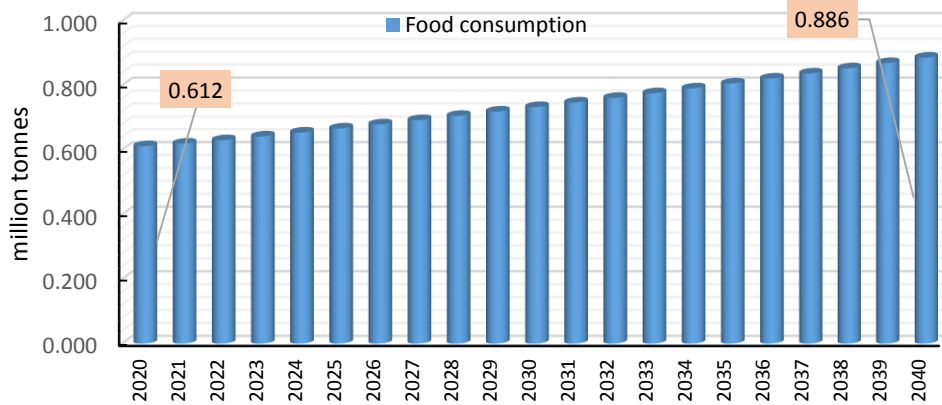
316 **Baseline simulation**

317 Upon completion of reliability testing, the SD model was employed to analyze the behavior of  
318 critical variables. In Fig. 4, we present a graphical representation of the population's behavior  
319 over the simulation period. The population variable, as described by the stock and flow diagram,  
320 is influenced by three primary factors: population growth rate, death rate, and migration rate.  
321 Our findings suggest that the population grew at an average annual rate of 1.86 percent between  
322 the years 2020 and 2040. At the beginning of the simulation period, the population in the study  
323 area was 778 thousand individuals. However, by the end of the simulation period, it had risen  
324 to 1.113 million individuals. This demonstrates a notable increase in the population of the study  
325 area over the simulation period.



326 **Fig. 4: Simulation of the population in the study area.**

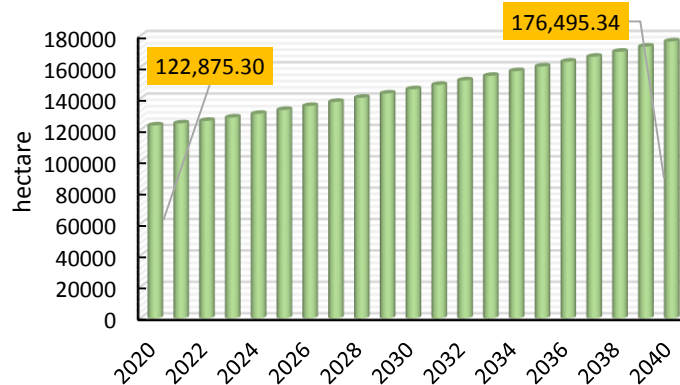
327 Changing the population variable has a direct and indirect impact on the behavior of all the  
328 crucial variables within the system. The demand for food variable behavior is exhibited in Fig.  
329 5. According to the results, the variable of food consumption in the year 2020 amounted to  
330 0.612 million tons, which is expected to experience a marginal increase of 1.26% to 0.620  
331 million tons in the year 2021. By the time we reach the years 2025 and 2030, this variable is  
332 expected to rise to 0.667 million tons and 0.733 million tons, respectively. At the end of the  
333 simulation period, it is projected that this variable will increase to 0.886 million tons. The rise  
334 in demand for food can be fulfilled through domestic production and imports. By the principles  
335 of microeconomics, an increase in demand, provided other conditions remain constant, leads to  
336 the rightward shift of the demand curve, ultimately leading to an increase in the market price.  
337 This results in an incentive for producers to engage in production. Thus, with the increase of  
338 this variable, the demand for agricultural land is likely to increase.



**Fig. 5: Simulation of the food consumption in the study area.**

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340 Fig. 6 illustrates an upward trend in the area under cultivation of agricultural products between  
 341 2020 and 2040. At the beginning of the simulation period, this variable was 122 thousand  
 342 hectares, and it experienced an average annual growth rate of 1.79% to reach 176 thousand  
 343 hectares by the end of the period. These findings suggest that the production of agricultural  
 344 products is likely to expand steadily in the coming years. During the simulation period, it was  
 345 observed that the increase in the cultivated area led to a corresponding increase in the demand  
 346 for water in the agricultural sector. The predicted average annual growth rate for this variable  
 347 was 1.82%. As shown in Fig. 7, the volume of water demanded in the agricultural sector in the  
 348 province at the beginning of the simulation period was 594 million cubic meters, but this value  
 349 increased to 845 million cubic meters (MCM) at the end of the simulation period. The study  
 350 area experienced an increase in water demand due to the growth of the cultivated area in the  
 351 agricultural sector and population growth in the province, leading to an increase in the  
 352 withdrawal from water resources and a change in the volume of available water.



**Fig. 6: Simulation of the cropland area at the study area.**

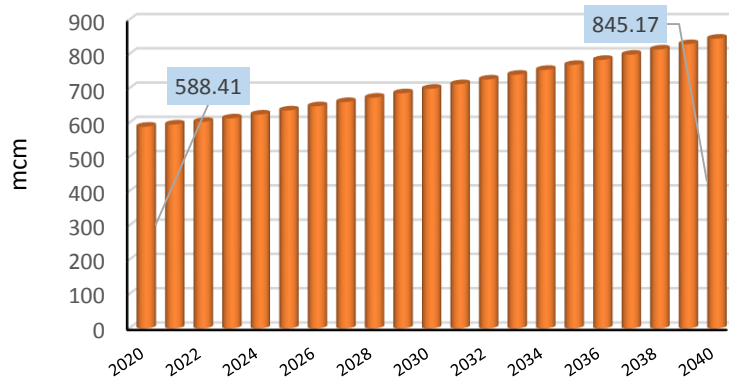
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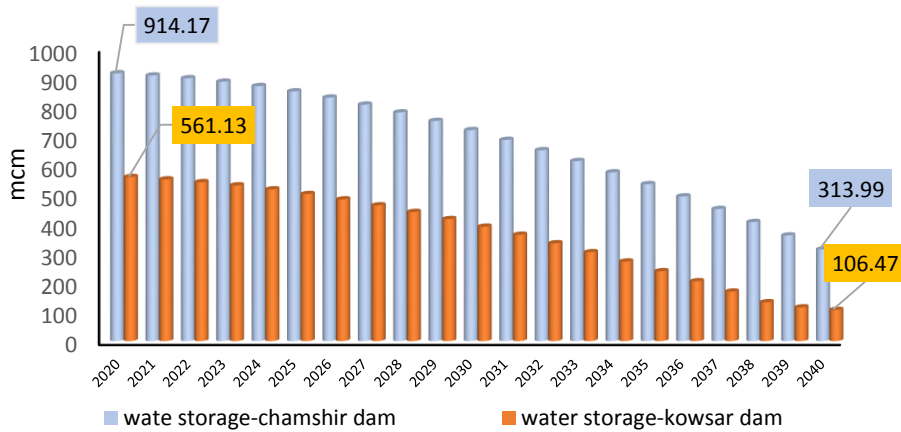


**Fig. 7: Simulation of the agricultural water demand in the study area.**

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The study shows that an increase in demand for agricultural water, combined with population growth, has led to a decrease in surface water availability in the study area. The simulation revealed that the volume of water stored in *Chamshir Dam* has significantly reduced from 906 MCM in 2020 to 313 MCM, with an average annual decrease of 5.13% projected from 2020 to 2040 (Fig. 8). Similarly, *Kowsar Dam's* water storage capacity has decreased from 553 MCM in 2020 to 106 MCM by the end of the simulation period (Fig. 9), with an average annual decrease of 7.80%. In our study on land use changes, we found that there is a direct relationship between water storage and surface water area. Our analysis showed that the water body area in the study area was 44.73 square kilometers in 2020, but it is projected to decrease to 17.69 square kilometers by the end of the simulation period (Fig. 9). The average annual change rate for this variable is expected to be -4.43%. At the beginning of the simulation period, the changes in this variable were insignificant, but they became more significant as the end of the studied period approached. The water demand is increasing rapidly and the supply is not keeping up. This will make the water system more vulnerable in the future. The amount of water stored in a dam increases when more water flows into it from surface water inflow, precipitation, and runoff. However, the amount of stored water decreases when it evaporates or is withdrawn from the surface. The amount of surface water withdrawal depends on the surface water level, which means that if the volume of stored water falls below a certain level, water withdrawal decreases. This leads to an increase in the volume of water in the dam, which in turn causes an increase in the surface water area and evaporation making the volume of water drop again. Based on current trends, it is expected that the amount of stored water will not be sufficient to meet future water demands.

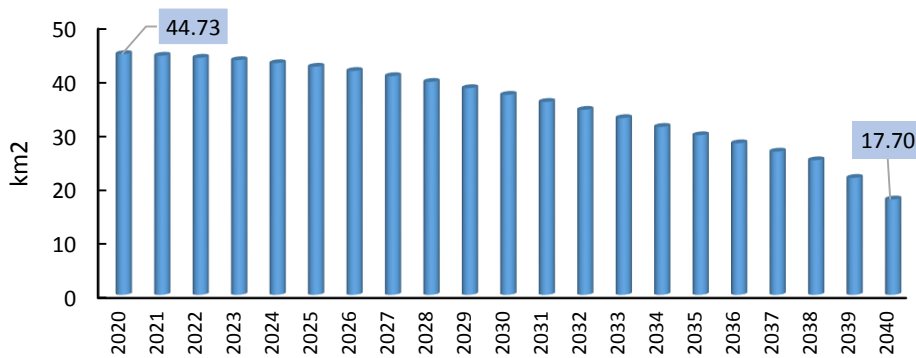




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**Fig. 8: Simulation of the water storage in the study area.**



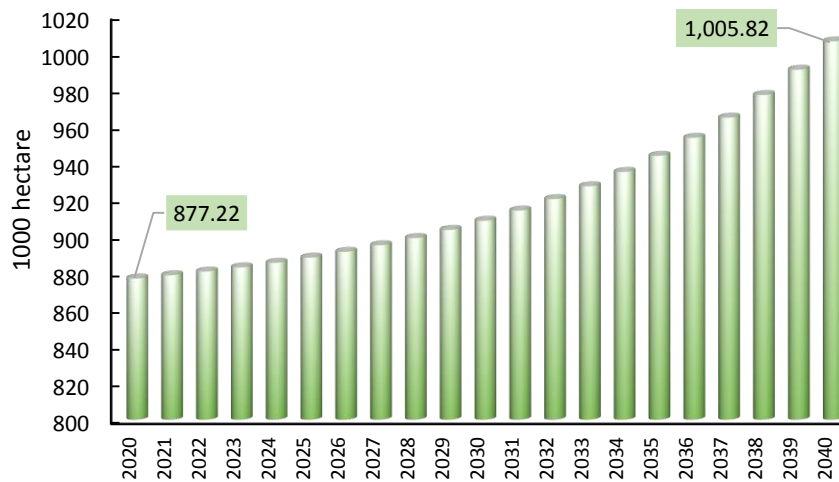
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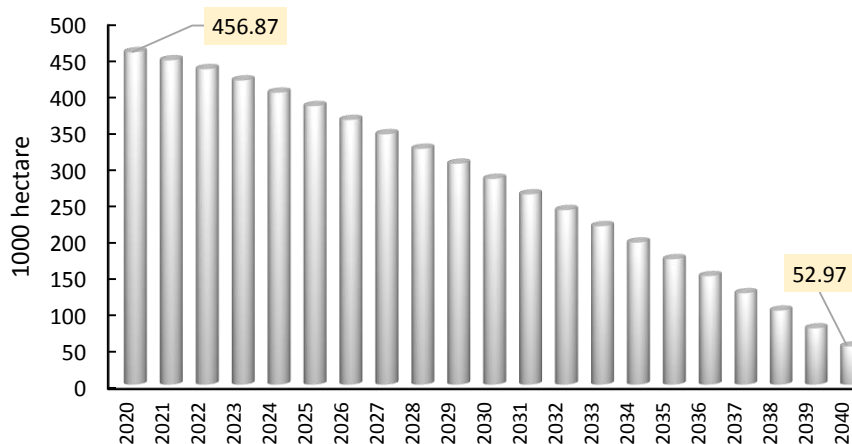
**Fig. 9: Simulation of the surface water area in the study area.**

389 Based on the findings, the average annual rate of change of forest and pasture area in the  
 390 research area between 2020 and 2040 was determined to be +0.68% and -9.86%, respectively.  
 391 Specifically, the forest area in 2020 was measured at 877 thousand hectares, which is projected  
 392 to increase to 1005 thousand hectares at the end of the simulation period (Fig. 10). As shown  
 393 in Fig. 11, the province's pasture area was 456 thousand hectares in 2020, and it is anticipated  
 394 to decrease to less than 100 thousand hectares by 2040. The growth in population and demand  
 395 for food has led to an increase in livestock numbers, creating pressure on pastures to meet this  
 396 demand. Conversely, alterations in weather patterns and occurrences of drought can have  
 397 damaging effects on pastures. During the simulation period, pasture cover has undergone  
 398 significant changes in response to the increased demand for both agricultural and residential  
 399 use. Gholami *et al.* (2015) revealed that the area of pasture land has decreased proportionately  
 400 to the rise in population. Similarly, Dakhani and Karimzadeh (2007) of *Fereydounshahr* city  
 401 highlight that the growth of the farmers and herdsman population, coupled with a lack of  
 402 agricultural land, has led to the conversion of pasture land into agricultural land, resulting in  
 403 significant changes to the chemical, hydrological, and physical characteristics of the soil.  
 404 Wassie (2022) also attributed the destruction of vegetation to the conversion of natural resource

405 lands into agricultural lands. In light of these findings, comprehensive and effective programs  
 406 must be developed by environmental officials to continuously monitor the environment and  
 407 natural resources. This is essential to ensure sustainable land use and safeguard the environment  
 408 for future generations.



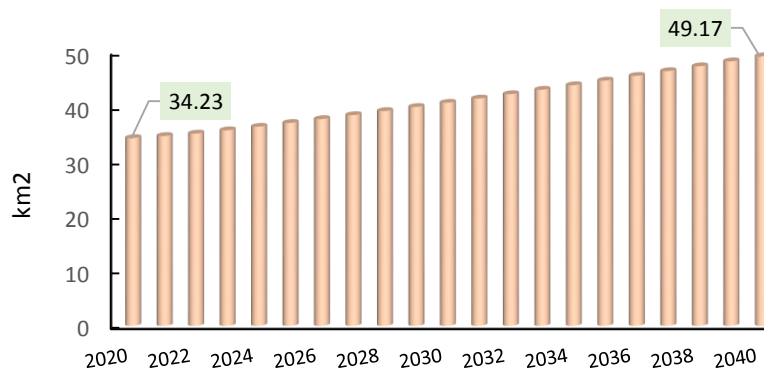
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 410 **Fig. 10: Simulation of the forest area in the study area.**



411  
 412 **Fig. 11: Simulation of the pasture area in the study area.**

413 As demonstrated in Fig. 12, the demand for residential properties has been on an upward  
 414 trajectory. The results indicate that the average population growth rate during the period of  
 415 2040-2020 is expected to be 1.86 percent. As a consequence, the demand for construction in  
 416 this province is predicted to increase accordingly. Specifically, the area of residential properties  
 417 in this province is projected to expand from 34.23 square kilometers in 2020 to 49.17 square  
 418 kilometers in 2040. Mahesh *et al.* (2008) and Dewan and Yamaguchi (2009) showed a  
 419 correlation between population growth and urban expansion. As the population increases, so

420 does the area of the residential in the city, indicating that the population growth rate is a crucial  
421 factor in controlling urban expansion and development.



**Fig. 12: Simulation of the residential area in the study area.**

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## 423 Discussion and Conclusions

424 Land use changes are the process of converting land from one use to another, such as from non-  
425 urban to urban or from agriculture to urban uses. As a multidisciplinary field of study, it  
426 examines the impacts of human activities on the land surface and the biophysical characteristics  
427 of the land. Given the significant implications of land use changes for social, economic, and  
428 ecological needs, it is crucial to monitor and understand these changes. Various factors drive  
429 land use changes, including urbanization, market forces, and agricultural expansion. Therefore,  
430 it is imperative to develop effective strategies and policies to manage and mitigate the impacts  
431 of land use changes. Over the years, numerous models and scenarios have been employed to  
432 study the simulation of land use changes in various regions. These studies have provided  
433 valuable insights into the dynamics of land use changes and their implications for different  
434 sectors. The results have helped policymakers and stakeholders make informed decisions on  
435 land use planning and management. Simulation of land use changes is a significant research  
436 area that requires a thorough understanding of system dynamics. Several papers have discussed  
437 the use of system dynamics models to simulate land use performance and evaluate the causes  
438 and consequences of land use changes (Siregar *et al.*, 2018; Zhao *et al.*, 2016). Such models are  
439 particularly important for analyzing land use patterns and their impact on the environment,  
440 economy, and society. By using these models, researchers can simulate different scenarios and  
441 develop policies that can help mitigate the negative effects of land use changes. Therefore, it is  
442 essential to continue exploring this field to develop more accurate models that can better predict  
443 land use changes and their impacts. This study builds upon previous research and proposes an  
444 integrated land-use model for Kohgiluyeh and Boyer-Ahmad Province in southwest Iran. The  
445 objective of this model is to analyze the behavior of key variables over time. Through this study,

446 we aimed to provide a comprehensive understanding of land-use dynamics in the region. The  
447 system dynamic approach was used to design the land use system in the study area, which  
448 involved various subsystems such as agriculture, water, population, forest, and pasture. The  
449 model was tested, and the results showed an acceptable level of validity. Subsequently, the  
450 designed land use system was utilized to simulate the key variables of the system. Based on our  
451 research, we have found that there is a direct correlation between water demand and population  
452 growth as well as agricultural development. The study suggests that, over time, the withdrawal  
453 of water from the water storage will increase under such circumstances. Our findings are  
454 consistent with the results of Gohari *et al.* (2017) for the Zayandehrud River basin and Layani  
455 *et al.* (2020) for the *Kheirabad* River basin. During the simulation period, it was observed that  
456 the increase in population growth resulted in an annual rise of 1.82% in water demand,  
457 accompanied by a concurrent annual decline of 5.13% and 7.80% in water storage in the  
458 *Chamshir* and *Kowsar* dams, respectively. These findings highlight the impact of population  
459 growth on water resources and the need for effective management strategies to ensure  
460 sustainable usage of this precious resource. Policymakers and stakeholders must prioritize the  
461 development of innovative solutions to mitigate these effects and maintain a healthy balance  
462 between water supply and demand for water. Based on the simulation results, it was observed  
463 that if no policy changes were implemented, the forest and cropland areas would continue to  
464 expand while pasture would decrease within the province, under the current environmental and  
465 socioeconomic conditions. Wang *et al.* (2023) conducted a study on land use prediction in  
466 Bortala, China, and reported their findings. The results of their study indicate that the area of  
467 cultivation is on the rise, while the area of pastures is decreasing. The policies implemented by  
468 the government, which primarily focus on "pasture inspection and issuance of livestock grazing  
469 permits," "preparation and enactment of pasture management plans," and "livestock control in  
470 pastures," have proven to be ineffective in promoting sustainable pasture ecosystem  
471 management. Despite governmental efforts, these policies have not contributed to the long-term  
472 sustainability of pasture ecosystems. Policymakers must prioritize the task of amending laws  
473 and closely monitoring their implementation. This is a crucial step towards ensuring that laws  
474 are effective and serve their intended purpose. **The present** study provides valuable insights into  
475 the trends in land use in the region and highlights the need for effective management strategies  
476 to balance land use and conservation efforts. The study found that population growth is a critical  
477 factor influencing land use changes. The increase in population has led to a surge in the demand  
478 for construction, resulting in an expansion of residential land in the province. Moreover, the  
479 escalation in the demand for food and water has led to an increase in resource extraction, leading

480 to a decline in the province's water body area. The research indicates a direct correlation  
481 between population growth and the expansion of agricultural land. However, to prevent the  
482 depletion of national resources such as forests and pastures to meet the increasing food demand,  
483 it is recommended to adopt efficient production strategies. The results of the land use simulation  
484 indicate that the water body area of the province will face a significant decrease due to the  
485 increase in agricultural and residential use. This decrease will be exacerbated by the growth of  
486 the population and the impacts of climate change. The scarcity of water resources and the  
487 consequential reduction in the water body are a growing concern. The decline in rainfall,  
488 coupled with the rise in temperature, population growth, and rapid expansion of residential  
489 areas, presents an urgent need for proper management and precise planning. It is imperative to  
490 employ appropriate methods to exploit water resources while avoiding the arbitrary conversion  
491 of natural resource lands, especially agricultural lands, and industrial and residential units.  
492 Effective management and planning can address these challenges and ensure the sustainable  
493 use of water resources. To reduce the impact of population increase on drinking water, multi-  
494 price water policies and tiered prices for higher consumption can be used. The agricultural  
495 sector can adopt adaptive strategies such as changing cultivation patterns to crops with lower  
496 water needs. Finally, it is recommended that the model developed to simulate the impacts of  
497 climate change and various management strategies in the province be utilized in future research  
498 endeavors to ensure that their findings can be employed in effective resource management  
499 policies. Last but not least, it is recommended that individual studies be conducted to analyze  
500 land management strategies for each province and region. This is because a single pattern or  
501 strategy cannot be applied to all areas due to their distinct characteristics. There are, however,  
502 some limitations of our study that could be addressed to add more precision to our results. This  
503 research has mainly concentrated on predicting future land use patterns without taking into  
504 account any socio-economic and environmental policy changes. Further research can be  
505 conducted by incorporating variables such as climate change, population growth, and other  
506 socioeconomic policy changes into the SD model. Future research can also study the effect of  
507 different resource management scenarios to define policy packages for environmental  
508 protection.

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631

632 **مدل سازی پویایی شناسی سیستم در راستای برنامه ریزی و توسعه کاربری اراضی: مطالعه موردی استان**  
633 **کهگیلویه و بویراحمد**

634

635

**چکیده**

636 تأثیر فعالیت‌های انسانی بر محیط‌زیست عمدتاً در تغییر کاربری و پوشش زمین منعکس می‌شود. تغییرات کاربری اراضی  
637 فرآیندهای پیچیده و پویایی هستند که می‌توانند تحت تأثیر عوامل زیادی قرار گیرند. این مطالعه باهدف ارائه یک مدل تغییر  
638 کاربری یکپارچه برای استان کهگیلویه و بویر احمد در جنوب غربی ایران انجام شده است. این مدل از رویکرد پویایی شناسی  
639 سیستم‌ها استفاده می‌کند که زیرسیستم‌های مختلفی مانند کشاورزی، آب، جمعیت، جنگل و مرتع را در بر می‌گیرد. هدف  
640 اصلی این مدل تجزیه و تحلیل و شبیه‌سازی رفتار متغیرهای کلیدی در طول زمان (2010-2040)، برای ارائه بینشی عمیق  
641 نسبت به پویایی کاربری اراضی در منطقه است. در ابتدا پس از مدل‌سازی اعتبار مدل مورد آزمون قرار گرفت و بر اساس نتایج  
642 آزمون ساختاری و رفتاری می‌توان از سیستم طراحی شده به‌منظور شبیه‌سازی رفتار متغیرهای کلیدی سیستم استفاده نمود.  
643 نتایج نشان داد که تقاضای آب، رشد جمعیت و توسعه کشاورزی باهم ارتباط مستقیمی دارند که منجر به افزایش برداشت از  
644 ذخیره آب در طول زمان می‌شود. بر اساس یافته‌ها، میانگین تغییر سالانه سطح زیر کشت محصولات کشاورزی و تقاضای آب به  
645 ترتیب  $+1/79$  و  $+1/82$  درصد بود. اگر هیچ تغییری در سیاست‌ها اعمال نشود، سطح جنگل و زمین‌های زراعی به تغییرات  
646 مثبتی را از خود نشان می‌دهند درحالی‌که مراتع کاهش می‌یابد. پیکره آبی در استان به‌طور متوسط سالانه  $4/43$  درصد  
647 کاهش یافته است که دلیل آن افزایش استحصال آب سطحی در نتیجه تقاضای زیاد برای آب، کاهش جریان آب سطحی و تبخیر  
648 بیشتر در نتیجه تغییرات آب و هوایی است. این نتایج بیانگر نیاز به مدیریت دقیق کاربری اراضی و منابع آب برای تضمین توسعه  
649 پایدار در منطقه مورد مطالعه است. کاهش منابع آب مستلزم سیاست‌های مدیریت تقاضای آب در بخش کشاورزی و خانگی است.  
650 اصلاح الگوی کشت با توجه به پتانسیل استان می‌تواند به کاهش برداشت منابع کمک کند. این مطالعه بینش‌های ارزشمندی را  
651 برای کارشناسان علاقه‌مند به مدیریت کاربری زمین و توسعه پایدار ارائه می‌دهد.

652 **کلید واژه:** محیط زیست، بازخورد، شبیه‌سازی، پیچیدگی، تغییرات کاربری اراضی.

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