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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 Boyar 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.

Introduction:

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

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

Land use changes occur due to a multitude of reasons, including economic, social, and ecological factors (Lambin & Meyfroidt, 2010). Economic drivers are influenced by factors such as per capita income, income inequality, land prices, and other economic variables (Lambin *et al*., 2001). Social factors, influenced by education level, population density, migration rate, and other demographic factors, drive changes in land use patterns over time (Briassoulis, 2009). Ecological triggers are driven by natural factors like atmospheric conditions, precipitation, vegetation, soil type, and land slope. These factors play a critical role in shaping land use patterns and can have significant ecological and environmental consequences (Lambin & Meyfroidt, 2010). Identifying drivers of land use changes is vital for managing natural resources and creating effective strategies for sustainable land use practices (Sonter *et al*., 2014). By identifying these drivers and understanding their impact on land use patterns, policymakers, land managers, and other stakeholders can develop more effective strategies for managing natural resources and ensuring sustainable land use practices.

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

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

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

All of the studies reviewed here support the hypothesis that the SD models are proficient in detecting the variables that influence transformations in land use. Although several studies have successfully created sustainable development models to address issues of land use changes, there are still certain limitations that need to be addressed. Despite the progress made in this field, the existing models are not completely free from deficiencies. Therefore, it is important to continue the research and development of new models that can overcome these limitations and ensure a more holistic approach to sustainable land use management. In general, the modeling of the pasture subsystem has received relatively less attention in terms of theoretical foundations. The present study aims to address this gap by exploring the impact of various variables, including live livestock price, fodder price, and climate change, on the modeling of the pasture level. Additionally, in the population subsystem, previous studies (Qian *et al*., 2014; Shen *et al*., 2009) have not adequately considered population change as an endogenous variable. Our study seeks to fill this gap by investigating the effects of population change as an endogenous variable. As well as, based on an extensive analysis of previous research, it has come to light that the utilization of a system dynamic approach to simulate land use in Iran has been limited. Therefore, the present study employs an SD approach to design a system for land use in Kohgiluyeh and Boyer Ahmad Province in southwest Iran. In this study, we aimed to develop a comprehensive mental model that considers various dimensions of land use as different subsystems. By integrating these subsystems, we created a basic model that can simulate land use changes effectively. This model provides decision-makers with a holistic view of the land use system, allowing them to identify the high-leverage and low-leverage points in the system and avoid policy resistance.

Materials and Methods

Study area description

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

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

Underlying Concept and Structure

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

Building System Dynamics Model for Land Use System Performance

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

A. Population subsystem

Population is one of the factors that affect the land use changes. The population subsystem focuses on analyzing the demographic trends and their impact on water and food demand, residential requirements, as well as, the environment (Wang *et al*., 2022). As the population grows, the demand for food increases, leading to changes in the demand for agricultural land and the extraction of surface and underground water sources. These changes have significant implications for water resource management and the sustainability of water supply systems. The relationship between population growth, land use changes, and water demand highlights the need for careful planning and management of water resources to meet the needs of growing populations while ensuring the preservation of natural resources. The population variable embodies the entire population of the case study, with one component being the "Population" stock which varies with the birth rate, death rate, and immigration rate (Haghani *et al*., 2003). The population at time *t* is mathematically represented by equation 1 as follows:

$$Population_t = Population_0 + \int_{t0}^{t} (birth\ rate - death\ rate - immigration\ rate)dt \quad (1)$$

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

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

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

At each time step, the birth rate, death rate, and immigration rate are taken from a per capita income and income to expenditure ratio which are represented as a LOOKUP[1] Table (Equation 2-4).

B. Agricultural subsystem

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

[1] 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).

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

$$Food\ demand_t = per\ capita\ food\ consumption \times Population_t \tag{5}$$

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

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

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

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

$$Crop\ yield_t = \alpha + \beta \times rainfall_t \tag{8}$$

C. Water subsystem

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

$$Domestic\ water\ demand_t = per\ capita\ water\ use \times Population_t \tag{9}$$

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

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

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

$$water\ inflow_t = Surface\ water\ inflow_t + Runoff_t \tag{12}$$

$$water\ outflow_t = Evaporation_t + water\ demand_t \quad (13)$$

$$Evaporation_t = Evaporation\ rate_t \times water\ storage_t \quad (14)$$

$$Runoff_t = Surface\ area_t \times rainfall_t \times runoff\ rate \quad (15)$$

$$Surface\ area_t = look\ up\ function(water\ storage_t) \quad (16)$$

$$Evaporation\ rate_t = \alpha + \beta \times termprature_t \quad (17)$$

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

D. Forest and Pasture subsystem

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

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

$$Forest\ area_t = Forest\ area_0 + \int_{t=0}^{t} (increase_t - decrease_t)\, dt \quad (18)$$

$$increase_t = expected\ forest\ area_t - forest\ area_t \quad (19)$$

$$Expected\ forest\ area_t = \alpha + \beta_1 \times rainfall_t + \beta_2 \times investment_t \quad (20)$$

$$investment_t = rate\ of\ investment \times Income_t \quad (21)$$

$$decrease_t = forest\ area_t \times deforestation\ rate \quad (22)$$

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

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

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

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

E. Residential subsystem

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

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

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

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

Model Testing

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

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

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

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

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

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

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 https://www.maj.ir/
Population	658.62	1000 Person	The Statistical Center of Iran 2020
Forest area	873604	Hectare	The Ministry of Agriculture – Jahad 2020 https://www.maj.ir/
Pasture area	485080	Hectare	The Ministry of Agriculture – Jahad 2020 https://www.maj.ir/
Residential area	29×10^6	M^2	The Statistical Center of Iran 2020

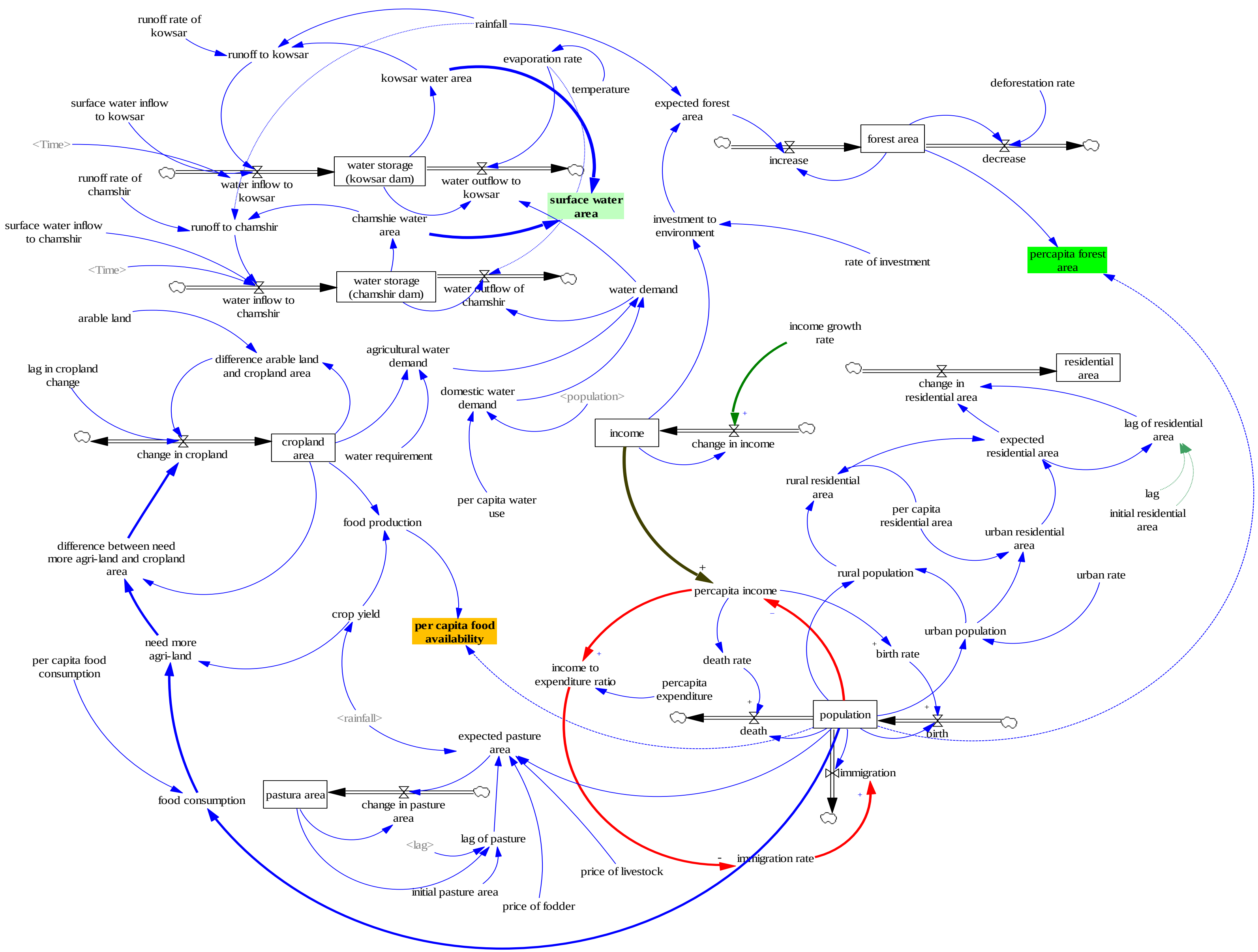

Fig 1: Land use changes stock and flow diagram.

Results

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

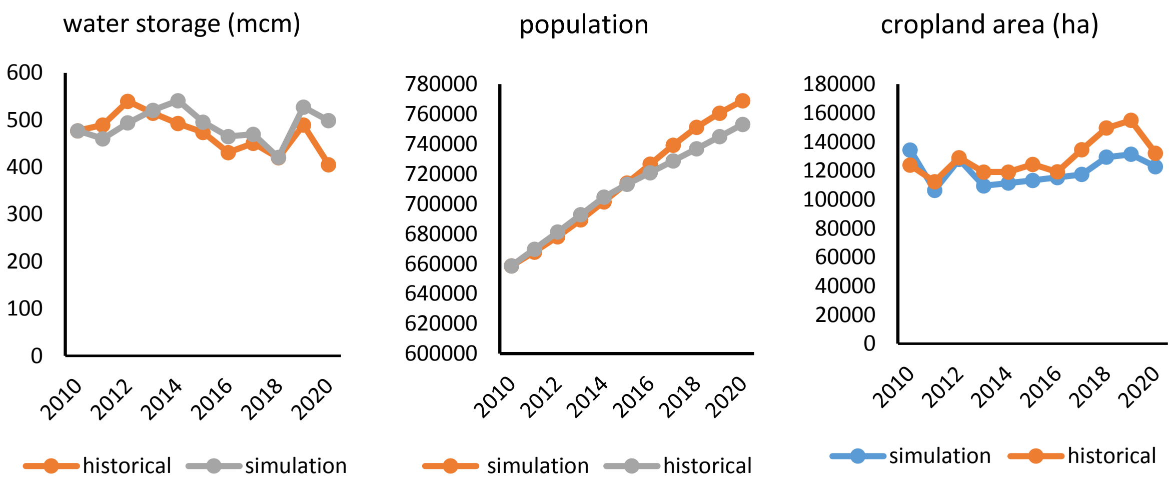

Fig. 3: The observed and simulated values of variables.

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

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

Source: Study results.

Baseline simulation

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

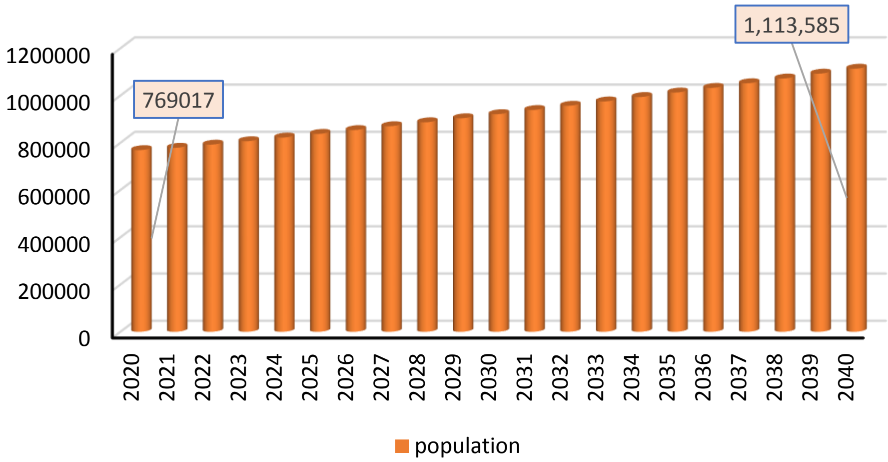

Fig. 4: Simulation of the population in the study area.

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

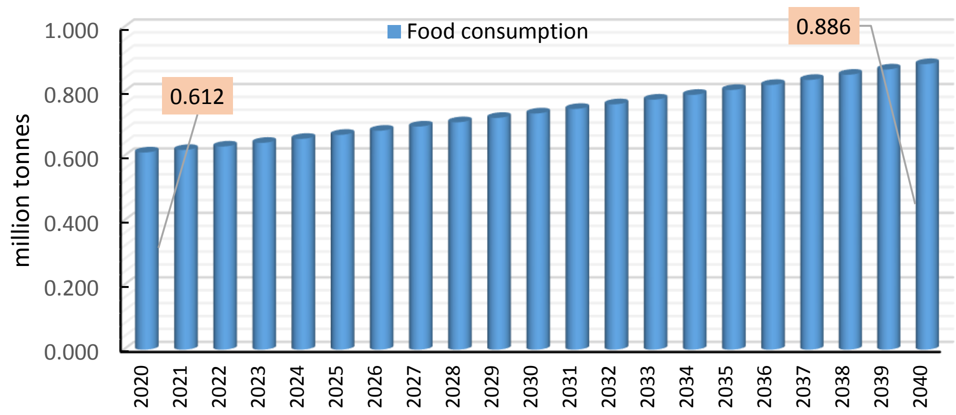

Fig. 5: Simulation of the food consumption in the study area.

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

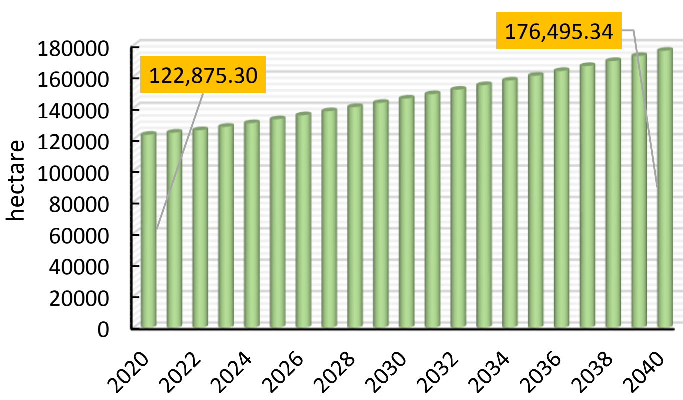

Fig. 6: Simulation of the cropland area at the study area.

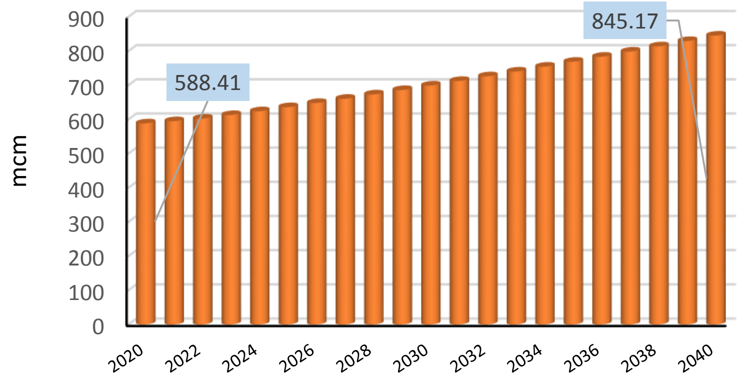

Fig. 7: Simulation of the agricultural water demand in the study area.

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.

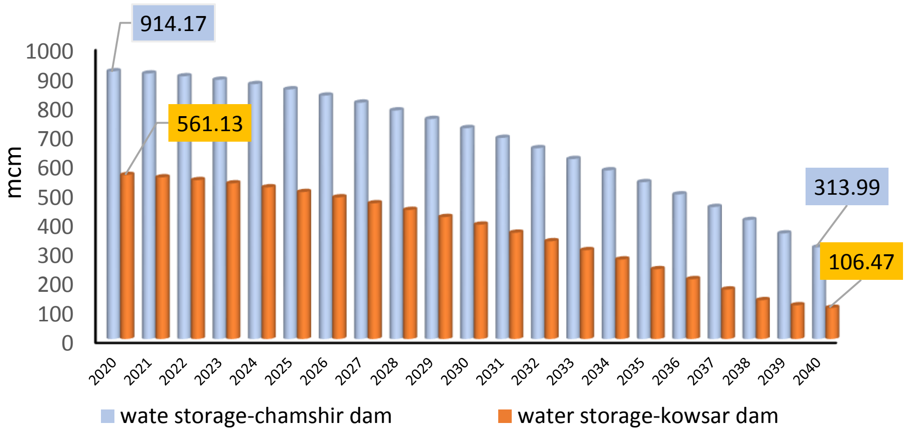

Fig. 8: Simulation of the water storage in the study area.

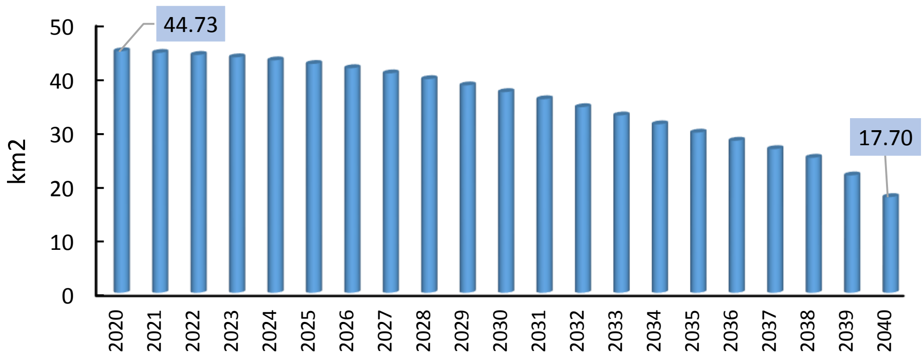

Fig. 9: Simulation of the surface water area in the study area.

Based on the findings, the average annual rate of change of forest and pasture area in the research area between 2020 and 2040 was determined to be +0.68% and -9.86%, respectively. Specifically, the forest area in 2020 was measured at 877 thousand hectares, which is projected to increase to 1005 thousand hectares at the end of the simulation period (Fig. 10). As shown in Fig. 11, the province's pasture area was 456 thousand hectares in 2020, and it is anticipated to decrease to less than 100 thousand hectares by 2040. The growth in population and demand for food has led to an increase in livestock numbers, creating pressure on pastures to meet this demand. Conversely, alterations in weather patterns and occurrences of drought can have damaging effects on pastures. During the simulation period, pasture cover has undergone significant changes in response to the increased demand for both agricultural and residential use. Gholami *et al*. (2015) revealed that the area of pasture land has decreased proportionately to the rise in population. Similarly, Dakhani and Karimzadeh (2007) of *Fereydounshahr* city highlight that the growth of the farmers and herdsman population, coupled with a lack of agricultural land, has led to the conversion of pasture land into agricultural land, resulting in significant changes to the chemical, hydrological, and physical characteristics of the soil. Wassie (2022) also attributed the destruction of vegetation to the conversion of natural resource lands into agricultural lands. In light of these findings, comprehensive and effective programs must be developed by environmental officials to continuously monitor the environment and natural resources. This is essential to ensure sustainable land use and safeguard the environment for future generations.

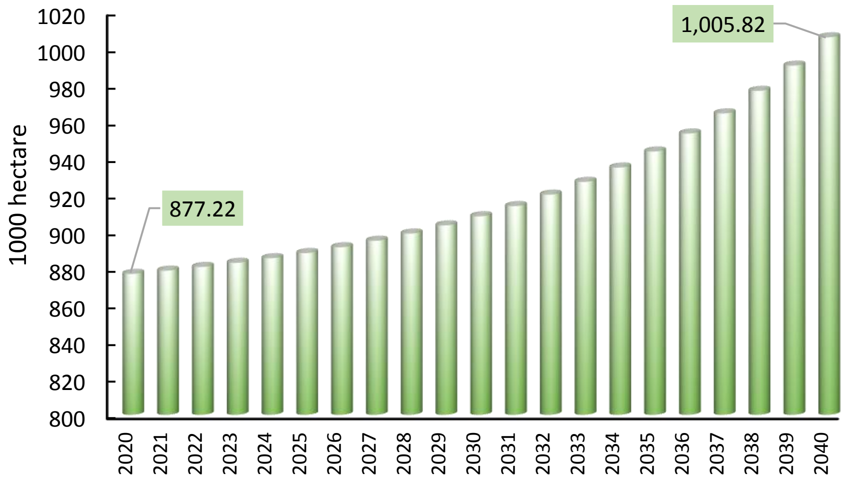

Fig. 10: Simulation of the forest area in the study area.

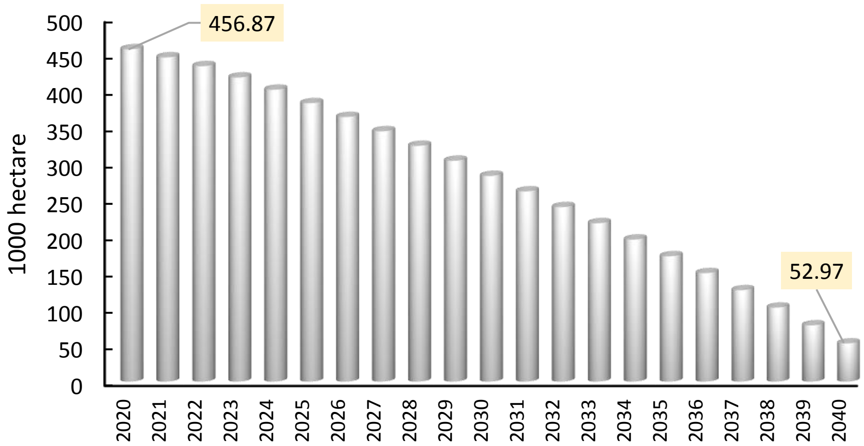

Fig. 11: Simulation of the pasture area in the study area.

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

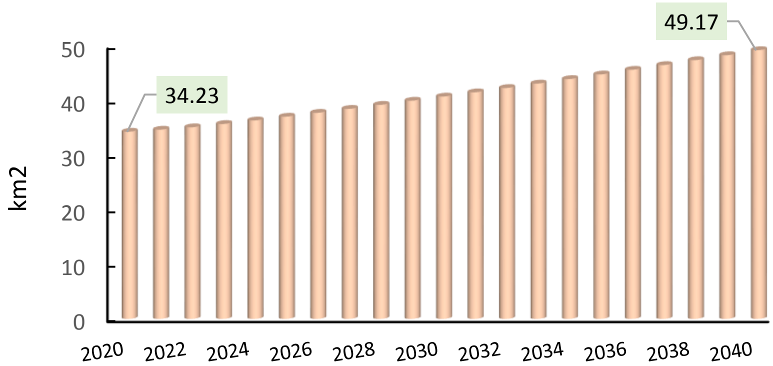

Fig. 12: Simulation of the residential area in the study area.

Discussion and Conclusions

Land use changes are the process of converting land from one use to another, such as from non-urban to urban or from agriculture to urban uses. As a multidisciplinary field of study, it examines the impacts of human activities on the land surface and the biophysical characteristics of the land. Given the significant implications of land use changes for social, economic, and ecological needs, it is crucial to monitor and understand these changes. Various factors drive land use changes, including urbanization, market forces, and agricultural expansion. Therefore, it is imperative to develop effective strategies and policies to manage and mitigate the impacts of land use changes. Over the years, numerous models and scenarios have been employed to study the simulation of land use changes in various regions. These studies have provided valuable insights into the dynamics of land use changes and their implications for different sectors. The results have helped policymakers and stakeholders make informed decisions on land use planning and management. Simulation of land use changes is a significant research area that requires a thorough understanding of system dynamics. Several papers have discussed the use of system dynamics models to simulate land use performance and evaluate the causes and consequences of land use changes (Siregar *et al*., 2018; Zhao *et al*., 2016). Such models are particularly important for analyzing land use patterns and their impact on the environment, economy, and society. By using these models, researchers can simulate different scenarios and develop policies that can help mitigate the negative effects of land use changes. Therefore, it is essential to continue exploring this field to develop more accurate models that can better predict land use changes and their impacts. This study builds upon previous research and proposes an integrated land-use model for Kohgiluyeh and Boyar-Ahmad Province in southwest Iran. The objective of this model is to analyze the behavior of key variables over time. Through this study, we aimed to provide a comprehensive understanding of land-use dynamics in the region. The system dynamic approach was used to design the land use system in the study area, which involved various subsystems such as agriculture, water, population, forest, and pasture. The model was tested, and the results showed an acceptable level of validity. Subsequently, the designed land use system was utilized to simulate the key variables of the system. Based on our research, we have found that there is a direct correlation between water demand and population growth as well as agricultural development. The study suggests that, over time, the withdrawal of water from the water storage will increase under such circumstances. Our findings are consistent with the results of Gohari *et al*. (2017) for the Zayandehrud River basin and Layani *et al*. (2020) for the *Kheirabad* River basin. During the simulation period, it was observed that the increase in population growth resulted in an annual rise of 1.82% in water demand, accompanied by a concurrent annual decline of 5.13% and 7.80% in water storage in the *Chamshir* and *Kowsar* dams, respectively. These findings highlight the impact of population growth on water resources and the need for effective management strategies to ensure sustainable usage of this precious resource. Policymakers and stakeholders must prioritize the development of innovative solutions to mitigate these effects and maintain a healthy balance between water supply and demand for water. Based on the simulation results, it was observed that if no policy changes were implemented, the forest and cropland areas would continue to expand while pasture would decrease within the province, under the current environmental and socioeconomic conditions. Wang *et al*. (2023) conducted a study on land use prediction in Bortala, China, and reported their findings. The results of their study indicate that the area of cultivation is on the rise, while the area of pastures is decreasing. The policies implemented by the government, which primarily focus on "pasture inspection and issuance of livestock grazing permits," "preparation and enactment of pasture management plans," and "livestock control in pastures," have proven to be ineffective in promoting sustainable pasture ecosystem management. Despite governmental efforts, these policies have not contributed to the long-term sustainability of pasture ecosystems. Policymakers must prioritize the task of amending laws and closely monitoring their implementation. This is a crucial step towards ensuring that laws are effective and serve their intended purpose. The present study provides valuable insights into the trends in land use in the region and highlights the need for effective management strategies to balance land use and conservation efforts. The study found that population growth is a critical factor influencing land use changes. The increase in population has led to a surge in the demand for construction, resulting in an expansion of residential land in the province. Moreover, the escalation in the demand for food and water has led to an increase in resource extraction, leading to a decline in the province's water body area. The research indicates a direct correlation between population growth and the expansion of agricultural land. However, to prevent the depletion of national resources such as forests and pastures to meet the increasing food demand, it is recommended to adopt efficient production strategies. The results of the land use simulation indicate that the water body area of the province will face a significant decrease due to the increase in agricultural and residential use. This decrease will be exacerbated by the growth of the population and the impacts of climate change. The scarcity of water resources and the consequential reduction in the water body are a growing concern. The decline in rainfall, coupled with the rise in temperature, population growth, and rapid expansion of residential areas, presents an urgent need for proper management and precise planning. It is imperative to employ appropriate methods to exploit water resources while avoiding the arbitrary conversion of natural resource lands, especially agricultural lands, and industrial and residential units. Effective management and planning can address these challenges and ensure the sustainable use of water resources. To reduce the impact of population increase on drinking water, multi-price water policies and tiered prices for higher consumption can be used. The agricultural sector can adopt adaptive strategies such as changing cultivation patterns to crops with lower water needs. Finally, it is recommended that the model developed to simulate the impacts of climate change and various management strategies in the province be utilized in future research endeavors to ensure that their findings can be employed in effective resource management policies. Last but not least, it is recommended that individual studies be conducted to analyze land management strategies for each province and region. This is because a single pattern or strategy cannot be applied to all areas due to their distinct characteristics. There are, however, some limitations of our study that could be addressed to add more precision to our results. This research has mainly concentrated on predicting future land use patterns without taking into account any socio-economic and environmental policy changes. Further research can be conducted by incorporating variables such as climate change, population growth, and other socioeconomic policy changes into the SD model. Future research can also study the effect of different resource management scenarios to define policy packages for environmental protection.

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مدل‌سازی پویایی شناسی سیستم در راستای برنامه ریزی و توسعه کاربری اراضی: مطالعه موردی استان کهگیلویه و بویراحمد

چکیده

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

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