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Prediction of land use changes in Hyrcanian forests using an Artificial Neural Network model

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ABSTRACT

BACKGROUND AND OBJECTIVES: Land use change is a pressing global environmental crisis requiring scientific study for sustainable regional decisions. This study analyzes the spatial-temporal dynamics of land use in the Hyrcanian forests of western Mazandaran province from 2013-2023 using remote sensing data. Image classification was based on six land use classes: vegetation, built-up, agriculture, water bodies, forest, and bare land.

METHODS: An Artificial Neural Network was employed to predict land use changes over ten years. The model was validated by comparing the simulated 2023 map with the actual map, resulting in a Kappa coefficient of 92%.

FINDINGS: Land use change maps from 2013-2023 show that built-up areas increased by 26.5517 km2, while forest and other vegetation decreased by 43.6353 km2 and 85.1967 km2, respectively. Projections for 2023-2033 indicate similar trends: an increase in built-up areas by 31.3106 km2 and a decrease in forest and other natural areas by 8.875 km2 and 16.6104 km2, respectively.

CONCLUSION: This research offers a valuable tool for the sustainable management of Hyrcanian forests, aiding informed decision-making for environmental improvement, identifying threats, optimal resource management, and predicting the effects of climate change. It offers valuable insights for sustainable planning, management, and improved environmental outcomes.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
30	2	3

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INTRODUCTION

In recent years, rapid economic development and urban sprawl, often driven by the conversion of large amounts of agricultural land to construction and other types of urban land, have significantly altered regional land use patterns and natural landscapes, and have compromised the health of terrestrial and aquatic environments (Luo *et al.,* 2020). This is particularly evident in the vicinity of urban areas (Munksgaard *et al.,* 2019). Land use change is one of the environmental hazards and ecological crises that humanity faces today. Land use is a term used to describe human use of land that results in changes in the natural characteristics of an area, including vegetation, water resources, soil, rocks, and other natural resources. (EPA, 2024). In response to rapid population growth, industrial activities, development, and urbanization have also grown rapidly, and the negative result of this growth is the serious water crisis and its pollution in today's world, which leads to various diseases and threatens human health. Understanding the extent of the adverse effects of human activities on ecosystems can help humanity comprehend the impact of ecosystem health on the human living environment, which is reflected in social, population, and economic responses (Costanza *et al.,* 2014). Land use patterns reflect the interaction between human activities and the natural environment. Land use change, which is often influenced by policies, is the result of a complex interaction between social-ecological feedbacks and socio-economic developments (Wang *et al.,* 2022). Land use change refers to temporal changes in the form and type of land use that are driven by social and economic changes (Zhang and Li, 2022a). Land use morphology represents the quantity and spatial structure of land use in a specific area over a given period of time. Improving land use morphology leads to sustainable use of land resources. In the current context, the conversion of natural areas to developed or agricultural areas is considered to be one of the major factors driving significant changes in land use, especially in developing countries (Baig *et al.,* 2022). Socioeconomic changes, including population growth, increasing globalization, urbanization, changes in supply, demand, and trade patterns, technological advances, dietary habits, or public opinion, are considered to be major factors in land use changes and agricultural practices (Beyer *et al.,* 2022; Subedi *et al.,* 2022). According to the Food and Agriculture Organization (FAO), agricultural development is responsible for about 90% of global deforestation (DeValue *et al.,* 2022). More than half of global forest loss occurs due to conversion to agricultural land. Deforestation in developing countries, such as Iran, is mainly due to the expansion of cultivated land and the production of charcoal and timber. The intensification and expansion of agriculture around the world have placed significant pressure on the environment and climate, threatening the health, security, and survival of people and the planet (EEA, 2021). However, land use changes cannot usually be attributed to a single factor, but are the result of a complex interaction of climate, politics, and socio-economic conditions (Ustaoglu and Williams, 2017). In addition to significant impacts on our planet's current and future climate (Tattoni *et al.,* 2017), these changes have major implications for biodiversity (Powers and Jetz, 2019) and human well-being through changes in key ecosystem services (Gomes *et al.,* 2021). Given that land use change is the main driver of environmental change (Islami *et al.,* 2022) and the main challenge is to preserve the environment while increasing economic and social benefits, understanding the patterns and trends of land use change at different scales is of great importance (Salehi *et al.,* 2018). Knowing the ratio of land uses and how they change over time is one of the most important issues in management planning. Command and control in land use also refers to a set of activities and processes used to manage and monitor land use, which requires an accurate and timely prediction of future land use changes. Geographic Information Systems (GIS) and Remote Sensing (RS) have been key tools for identifying and monitoring land use changes for many years. Landsat satellite images, especially at large scales, play an important role in classifying different land use types (Zhang & Li, 2022b). Access to multi-temporal remotely sensed data is essential for examining past changes and analyzing land use trends. QGIS is an efficient tool for quantifying these changes. In recent years, various methods such as supervised classification, unsupervised classification, Principal Component Analysis (PCA), neural networks, and fuzzy classification have been developed to identify land use changes using remote sensing data (Butt *et al.,* 2015). Also, in the past two decades, regression methods have been widely used for modeling land use predictions (Huu *et al.,* 2022). In the past half-century, the watersheds of the Hyrcanian forests of Mazandaran province have faced serious threats from land use change, including clearing forests for agricultural development and expansion of construction due to increasing land values. Analyzing and monitoring land use changes is of great importance for understanding the depth and extent of these changes, as well as for integrated watershed management (Malede *et al.,* 2023). The most important problem of these ecosystems is the lack of compliance with carrying capacity, meaning the imbalance between existing resources and the amount and manner in which humans use them. The carrying capacity of resources is defined as the size of the population that can be maintained by using local resources and other natural resources, intelligence, technology and other conditions to ensure a material standard of living in accordance with local socio-cultural norms in a predictable period (Wang *et al.,* 2018; Sun *et al.,* 2020). The most obvious feature of this type of imbalance is the reduction of environmental quality and also the reduction of quality of life. Therefore, finding a solution to maintain the integrity of the interaction between environmental protection and development has become an important practical concern for planners. In recent years, numerous studies have been conducted at home and abroad in the field of analyzing land use changes in different watersheds. Karimzadeh Motlagh *et al.,* (2022) conducted a study to assess and predict land use changes using the Markov_CA model in the Zayandeh Rood River Basin. They examined the rate of land use changes from 1996 to 2018 and then predicted future changes for the years 2030 and 2050. Also, Jahdi (2023) conducted a study on modeling land use changes and future predictions using ANN-CA simulation in the 25th watershed of Shenrud Siahkal in Gilan Province. She evaluated land use changes over a 21-year period from 2001 to 2022. She also used modeling to predict the amount of increase in man-made areas and the decrease in forests and other natural areas in the next 21 years. Schirpke *et al.* (2023) assessed the past and future impacts of land use change on ecosystem services in Austria. Their findings showed that socio-economic drivers had the greatest impact on land use change in the past. Atef *et al.* (2024) conducted a simulation study of future land use cover changes in the Al-Fayoum Governorate, Greece, using satellite data and a CA-Markov model. They used the IDRISI-TerrSet software and found that the modeled future scenarios in LULC indicate a significant change in LULC classes over time, especially for the year 2030. Using Land-N2N, an effective and efficient model for simulating demand-driven changes in mixed-use lands, Gao *et al.* (2025) investigated the CLUMondo model through four strategies, resulting in an improved version called "Land-N2N." They stated that the Land-N2N model has the ability to provide scientific solutions for land management by predicting land changes. The aim of this research is to model land use changes and predict the future using Artificial Neural Network (ANN) technique in the western basin of Hyrcanian forests for optimal and sustainable development in 2024. Modeling temporal and spatial changes in land use is important for investigating the dynamic processes of land use in the western basin of Mazandaran province, which is the hub of Iranian tourism. The identification of driving forces is done by utilizing a combination of remote sensing and geographic information systems in the preparation of land use maps and physical, social, and economic data. Physical and socio-economic factors were identified as potential drivers of land use changes. Land use class changes are analyzed using Landsat satellite images in 2003, 2013, and 2023. Also, the prediction of land use changes in the next ten years in the study area is studied using an ANN. Finally, suggestions for management measures for sustainable use and land use management in the future, such as managing the development process and protecting the valuable Hyrcanian forests, are presented.

MATERIALS AND METHODS

Study area

The western region of Mazandaran, which, in addition to being homogeneous, has undergone many changes in the landscape due to being the most tourist-friendly part of this basin, was selected as the study area. This region includes the cities of Ramsar, Tonekabon, and Abbasabad, which are selected based on the sub-basins corresponding to the country or political-administrative divisions of the selected cities. The area of this region is 2887.79 square kilometers. Fig. 1 shows the study

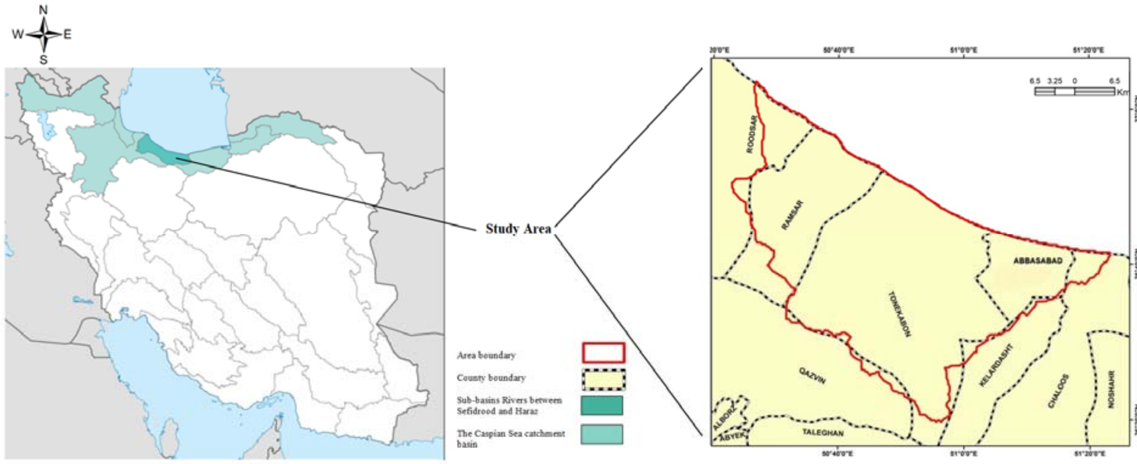

Fig. 1: Location of the study area, including the watershed, sub-watershed, and counties (Source: Authors)

area. These areas are hot and humid in summer and temperate in winter. Also, due to their proximity to the Caspian Sea, the Alborz Mountain wall, and the short distance between the mountains and the sea, they have moderate temperatures and high humidity, so that the annual rainfall reaches 1300 mm, and the seasonal distribution of rain is proportional and the dry period is very short (Mazandaran Province Natural Resources and Watershed Management Department, 2023).

Research method

In order to investigate land use changes, according to the country's official population censuses and also the latest Landsat satellite images, ten-year time nodes, i.e., 2003, 2013, and 2023, were selected to select the relevant satellite images. For this purpose, all satellite images in this study were used from the US Geological Survey website (http://earthexplorer.usgs.gov/) and Landsat 5 and 9 images from Collection 2 and Level 1 with a resolution of 30x30. Table 1 shows the characteristics of the satellite images used in this study.

Considering the division of land cover into six categories, including Bare-land, Forest, Rice, Build-up, Vegetation, and Water body (Table 2), based on the biological cycle of rice growth (after planting and before harvesting) and cloud cover, the best time to select images was during the summer period. As a problem, due to the humid subtropical climate, images without clouds or with cloud cover less than 10% were not available on a specific date. Therefore, images with cloud cover less than 10% from July 15 to August 15 were selected and downloaded.

Considering the necessity of pre-processing for analyzing satellite images to increase the visual interpretation and spectral resolution of the earth's surface features (Seyam *et al.,* 2023), the pre-processing of the downloaded images includes image integration, atmospheric corrections to remove and correct the atmospheric effects caused by the presence of gases, solid and liquid particles from the atmosphere, and geometric corrections using ENVI version 5.6 software with the classification method for tree images. It was done in 2003, 2013, and 2023. Although the current modeling framework primarily relies on remotely sensed data and land cover maps (2003, 2013, 2023) to simulate and predict land use dynamics, it is important to acknowledge that land use change is also strongly influenced by socio-economic factors. Variables such as population growth, accessibility to transportation networks, spatial planning policies, and local economic drivers can provide additional explanatory power for predictive models. Due to the limited availability of spatially explicit socio-economic datasets at the required resolution, these variables were not incorporated in the present analysis. However, the adopted ANN framework is flexible and can integrate such variables in future studies to further enhance prediction accuracy and better capture human-environment interactions.

Table 1: Characteristics of satellite images used in this study

Satellite	Sensor	Acquisition Date	Bands used	Spatial Resolution	Processing
Landsat 5	Thematic Mapper (TM)	2003	B1, B2, B3, B4, B5, B7	30 m	collection 2-level 1
Landsat 5	Thematic Mapper (TM)	2013	B1, B2, B3, B4, B5, B7	30 m	collection 2-level 1
Landsat 9	Thematic Mapper (TM)	2023	B2, B3, B4, B5, B6, B7	30 m	collection 2-level 1

Table 2: Land cover/use classification characteristics of this study

LU/LC category	LU/LC description
Bare-land	Areas covered by exposed soil and rocks, sandy soil, and beaches) and devoid of built-up structure and vegetation or plants.
Build-up	Areas covered by settlements (urban and rural areas), roads, commercial or industrial structures, and buildings.
Forest	Areas covered by trees.
Rice	Agricultural areas producing rice.
Vegetation	Areas covered by grass, tea garden, bush and shrub, and cropland.
Water body	Areas covered by river, wetland, dam water, seawater, fish breeding pond, Farm ponds and irrigation reservoirs for agriculture (especially for rice).

Analytical framework

In the present study, the initial analytical framework focused on quantifying land-use changes between 2003, 2013, and 2023 by comparing classified land-use maps of the western Hyrcanian forests (Ramsar, Tonekabon, and Abbasabad). The Artificial Neural Network (ANN) model in the MOLUSCE plugin of QGIS was used to simulate and project future land-use dynamics based on these time series data. For each pair of time points, the spatial relationship between input maps was examined, and a transition matrix was generated to feed the predictive model. The model was then validated by comparing the simulated 2023 map with the observed 2023 land-use map, yielding a Kappa coefficient of 92%.

Model validation metrics

Although the Kappa coefficient demonstrates a high level of agreement, additional accuracy measures were also considered. The Overall classification Accuracy (OA) reached 94%, while the mean Producer's Accuracy (PA) and User's Accuracy (UA) across all land-use classes were approximately 91% and 90%, respectively. A detailed confusion matrix was also generated to assess class-specific misclassifications, ensuring that no single class disproportionately influenced the overall performance. These complementary metrics further confirm the robustness of the ANN-based prediction framework. Beyond reporting changes in total area (km²) for each land-use class, a simple spatial-ecological assessment was also conducted to better capture the patterns of landscape transformation. Specifically, the Forest Fragmentation Index (FFI)—defined as the number of discrete forest patches per 100 km²—increased from 3.2 in 2013 to 4.7 in 2023, indicating a more fragmented forest structure. Likewise, the Connectivity Index (CI)—the percentage of forest patches located within 100 m of each other—declined from 68% in 2013 to 55% in 2023, suggesting that the remaining forest areas became more isolated over time. These additional spatial metrics highlight that land-use changes in the region are not only reducing forest extent but also disrupting ecosystem connectivity and habitat integrity, which are critical considerations for sustainable management.

RESULTS AND DISCUSSION

Investigating land use changes in Hyrcanian forests and predicting the trend of these changes has several benefits, which in summary are:

• *Identify threats:* By examining land use changes, it is possible to identify patterns of degradation and major threats. For example, the uncontrolled expansion of man-made, agricultural, or industrial areas on the edge of the forest can lead to habitat destruction, increased pollution, and reduced

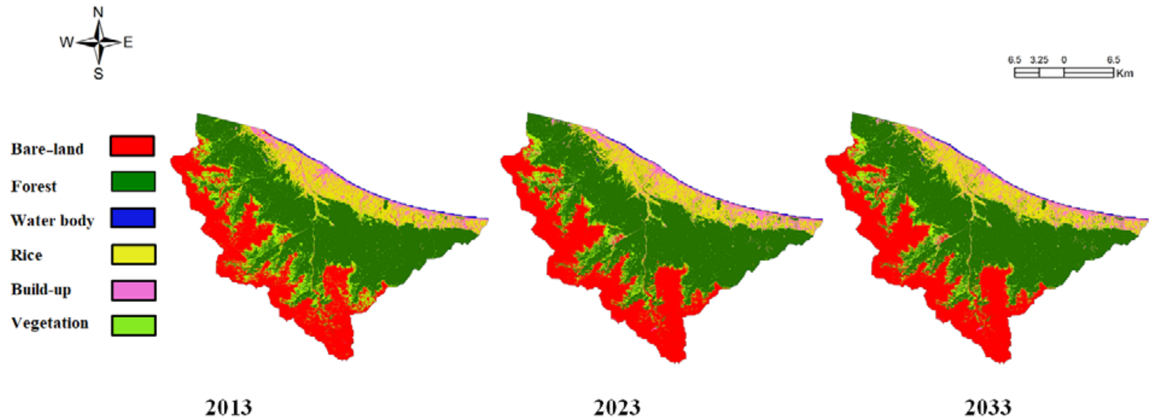

Fig. 2: Map of temporal-spatial changes in land use classes (Source: Authors)

biodiversity.

• *Optimal resource management:* With accurate information on the status of vegetation and land use, better management plans can be developed to preserve and restore forests. These plans can include designating protected areas, implement afforestation projects, and control human activities.

• *Predicting the impacts of climate change:* Land use changes can exacerbate the impacts of climate change. By modeling and predicting the course of change, we can assess potential impacts and plan for their mitigation. For example, converting forests to agricultural land can increase greenhouse gas emissions and reduce the forest's ability to absorb carbon.

• *Economic and social assessment:* Land use changes can have significant impacts on local economies and communities. By examining these impacts, policies can be adopted that both help conserve forests and benefit local communities. For example, developing sustainable tourism can provide an alternative source of income for local communities and reduce their dependence on forest resources.

• *Informed decision-making:* With accurate information and reliable predictions, decision-makers can adopt policies and programs that help maintain the ecological integrity of the Hyrcanian forests. This information can be effective in allocating funds, setting research priorities, and implementing conservation projects.

Fig. 2 shows a map of the temporal-spatial changes in the western region of Mazandaran province in the six land use classes explained in the previous section, for the years 2013, 2023, and the forecast for 2033, respectively. While the main projections shown in Fig. 2 follow a business-as-usual pathway, additional scenario analyses were performed to explore potential alternatives. In a conservation intervention scenario, where stricter land-use controls and afforestation programs are assumed, the projected loss of forest cover from 2023 to 2033 would be reduced from 8.9 km^2 to approximately 4.0 km^2, and the expansion of built-up areas would slow from 31.3 km^2 to 20.0 km^2. Conversely, in a policy-driven urban expansion scenario, where fewer restrictions on construction are assumed, built-up areas could increase by as much as 40.0 km^2, with a corresponding forest loss of around 12.0 km^2. These exploratory scenarios highlight that land-use dynamics are not strictly deterministic and can vary significantly depending on management strategies and policy directions.

To better understand Fig. 2 and analyze the changes in the six land use classes in three-time nodes, Table 3 is presented. Based on this table, the rate of change in the classes between 2013 and 2023 can be calculated, and the changes in 2033 can be predicted.

Based on the data in Table 3, significant changes can be observed in the land cover of the western basin of Mazandaran from 2013 to 2023 and the predictions for 2033. From 2013 to 2023, respectively, bare land increased by 54.1539 km2, water bodies by 3.9176 km2, man-made land by 26.5517 km2,

Table 3: Changes in land use classes at three time points (Source: Authors)

Classes	Area (km^2)		
	2013	2023	2033
Bare-land	742.5288	796.6827	795.689
Forest	1391.1453	1347.51	1338.635
Water body	20.9709	24.8885	26.665
Rice	286.0263	304.2354	315.3519
Build-up	135.4917	162.0434	193.354
Vegetation	296.8993	211.7026	195.0922

and agricultural land by 18.2091 km2, while forests decreased by 43.6353 km2 and vegetation by 85.1967 km2. The projections also show that from 2023 to 2033, the trend of changes will be somewhat moderated. Thus, bare land will decrease by 0.9937 km2, forest by 8.875 km2, and vegetation by 16.6104 km2. It is also expected that agricultural land, which is mostly rice in this region, will increase by 11.1165 km2, water bodies by 1.7765 km2, and man-made land by 31.3106 km2. The projected slight decrease in barren land between 2023 and 2033 should not be taken as a sign of improvement. This change is very small and cannot compensate for the losses caused by past degradation. The continuous increase in man-made land reflects urban, industrial, and infrastructure development in the region and will continue to be an important factor in land cover changes in the region. Urbanization and industrial development lead to increased production of urban and industrial waste and wastewater. Failure to properly treat these wastewaters can cause pollution of water and soil resources. The increasing trend of rice planting also indicates increased market demand, farmers' interest in cultivating this crop, and the consolidation of Mazandaran's position as the country's rice production hub. The conversion of natural lands to agriculture is usually accompanied by increased use of fertilizers and pesticides. These substances enter the soil and groundwater and cause pollution. The loss of forests and vegetation has been largely due to logging for commercial exploitation, agricultural development, and construction. In addition, climate change and drought have also contributed to the loss of vegetation in the region. This change leads to increased soil erosion, reduced biodiversity, increased flood risk, and reduced water resources. It should be noted that the increase in water bodies is not due to an increase in water resources, but rather due to the expansion of rice agricultural lands. The loss of Hyrcanian forests not only destroys the habitat of unique plant and animal species, but also disrupts their vital function in regulating the water cycle, preventing soil erosion, and absorbing carbon dioxide. The reduction in vegetation also indicates the destruction of the region's orchards, pastures, and grasslands. These ecosystems play an important role in feeding livestock, conserving soil, and regulating water flow, and their destruction leads to increased runoff, soil erosion, and reduced land fertility. Reduced vegetation cover reduces the soil's ability to absorb water, leading to increased runoff and the risk of flooding. This can cause significant loss of life and property, especially in areas with high rainfall, such as Mazandaran. To prevent this trend from continuing, serious measures need to be taken to protect existing forests and rangelands, restore degraded forests, and promote sustainable agriculture.

CONCLUSION

Hyrcanian forests, with their ancient history and unique biodiversity, play a key role in the ecological sustainability of the region. In addition to providing a valuable genetic resource, these forests directly impact the quality of life of local communities and beyond by regulating climate cycles, protecting soil and reducing erosion, and sequestering carbon dioxide. Maintaining the ecological integrity of these forests requires a comprehensive approach that, in addition to sustainable resource management, pays special attention to reducing threats from land-use change, pollution, and invasive species. Continuous monitoring of ecosystem health, careful assessment of the ecological services provided, and active participation of stakeholders in the decision-making process are essential measures to ensure the long-term sustainability of this valuable natural heritage. Furthermore, the effective implementation of any land-use management strategy depends heavily on the active involvement of local stakeholders, including community members, farmers, municipal authorities, and regional planners. In the context of the Hyrcanian forests, the perceptions, knowledge, and participation of local actors are crucial for designing practical and socially acceptable policies. Integrating stakeholder feedback can enhance policy relevance, improve compliance with conservation measures, and ensure that development plans align with local needs and values. Therefore, future management efforts and policy frameworks derived from this study should prioritize stakeholder engagement and participatory decision-making processes. Considering that this area is called the natural and green tourism hub of Iran and is the most touristic province in the country due to its short distance and proximity to the capital province, as well as its beautiful nature and diverse landscapes, its assessment in the region is essential. Investigating land use changes and predicting their trends is a powerful tool for sustainable management of Hyrcanian forests that helps identify threats, optimally manage resources, predict the effects of climate change, assess economic and social factors, and make informed decisions. Therefore, this study provides valuable findings that can play a role in future sustainable planning and management and help managers make informed decisions to improve the environment. The ANN model is an effective tool in predicting land use and cover by successfully simulating different land use classes in the western region of Mazandaran province, which includes the Hyrcanian forests. Therefore, the use of a fixed base of land use and cover maps is recommended for future studies in similar areas. Comparison of satellite images from different years shows that in the past these forests were denser and had a greater northern expansion, but due to population growth, agricultural development and increased exploitation, the forest area has decreased and its northern limit has been limited to the Alborz foothills. This study showed how the proposed ANN model can be used to better simulate complex and dynamic land use changes over time. Of all the changes, the most worrying situation in the region is the reduction of forest land and vegetation cover and the increase in built-up land. The destruction of forests and pastures reduces the capacity to absorb Carbon Dioxide (CO_2) and contributes to the intensification of climate change. Green covers are natural carbon sinks and their destruction leads to the release of CO_2 into the atmosphere. Land use change can cause changes in the species composition of the region, and species that are more resistant to human conditions replace native and sensitive species. If current land use trends continue, it is predicted that by 2033, forest area will decrease by 8,875 km^2 and man-made land will increase by 31,3106 km^2, which will undoubtedly change other ecosystems in the region. It should be noted that the intensification of agricultural land use and urban expansion will primarily lead to a decrease in ecosystem services in the regions. Given the precious heritage of the Hyrcanian forests, which are remnants of the Tertiary geological period and date back to the Tertiary period, and the role of ecotourism in the socio-economic development of this region, it is essential to preserve the quality of its environment. In fact, ecotourism can act as an alternative source of income for local communities and reduce their dependence on forest resources. However, the development of ecotourism should be in a way that helps preserve the environment of the region. Therefore, management and planning of the study area are emphasized. According to previous studies, socio-economic factors such as economic growth, political systems and technological developments have played a major role in land use change in the past. This is also true for the Hyrcanian forests. The expansion of agriculture and the development of cities on the edges of forests, which are a result of economic growth and technological developments, have led to the destruction and conversion of part of these forests to agricultural and residential lands. Ineffective policies and lack of proper management of resources related to political systems have also played a role in the destruction of forests. To better manage this situation, the following strategies can be considered:

- *Protecting forest areas:* Designating protected areas and implementing conservation programs to prevent forest destruction
- *Controlling land use change:* Enforcing strict laws to control land use change and prevent the conversion of forests to urban and agricultural areas
- *Restoration of degraded areas:* Implementation of afforestation projects and restoration of degraded areas
- *Promotion of sustainable agriculture:* Promotion of sustainable agricultural methods that help

conserve soil and water and avoid the use of chemical fertilizers and pesticides.

- *Development of sustainable ecotourism:* Development of sustainable ecotourism that helps preserve the environment of the region and provides benefits to local communities.
- *Raising public awareness:* Raising public awareness about the importance of forests and the need to preserve them
- *Stakeholder participation:* Participation of local stakeholders in the decision-making and planning process

AUTHOR CONTRIBUTIONS

M. Jadidi designed the study, collected and analyzed the data, and drafted the manuscript. M. J. Amiri contributed to the data analysis and manuscript revision. All authors reviewed and approved the final version of the manuscript.

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CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

ABBREVIATIONS (NOMENCLATURE)

There are no abbreviations.

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