

# Introducing an Efficient System for Assessing Solutions for Damage Reduction From Dam Construction on Semi-Arid Forest Areas

Hossein Safaei (✉ [hossein.safaei59@gmail.com](mailto:hossein.safaei59@gmail.com))

Kimiagaran Khak Samen engineering consulting company, Tehran, Iran

**Mohadeseh Ghanbari Motlagh**

Ph.D. of Forestry, Department of R&D, Kimiagaran Khaksamen Consulting Engineers Company, Tehran, Iran.

**Mahmoudreza Khorshidian**

Ms.C of Agricultural Economics, Department of R&D, Kimiagaran Khaksamen Consulting Engineers Company, Tehran, Iran.

**Saeed Malmasi**

Department of Environment, Faculty of Environment and Energy, North Tehran Branch, Islamic Azad University, Tehran, Iran.

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## Research

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# Abstract

**Background:** Today, the environmental damages of dams are enormous and undeniable, and it is very difficult to reduce these losses. However, environmental damages from dam construction projects may be reduced in intensity and scope through remedial proceedings in the realm of engineering and management operations. The aim of this study was to provide a framework for reducing the destructive effects of dam construction in western Iran in the heart of the Oak forests of the Zagros.

**Methods:** To explore policymaking options and provide technical solutions to reduce damages from the dams and restoration the forests in the region, the scenario examination approach was used in a dynamic model due to the complexity of human-forest relationship interaction and the presence of many actors in this realm. In order to conduct this study, the value of forest ecosystem services in the dam reservoir area in the current situation was estimated. The model of forest growth in the region was prepared in the form of a dynamic system model. Then, the proposed scenarios of reducing the damage caused by the construction of the dam and repairing the damaged vegetation were prepared

**Results and Conclusion:** The dynamic model prepared by variations of forest growth over time and the evaluation of the value of forest ecosystem services made it possible to implement predefined scenarios in forest management. Four different scenarios were designed to develop policies for reducing damages caused by the dam construction. According to estimations, the largest share of Oak forest ecosystem services has been in wood and soil production. The value of damage to forest resources due to the Dam reservoir was estimated at \$ 16237819.4 and Finally, the appropriate scenario (S4) is one in which conservation, restoration and reduction of pressure on forest resources in the region is proposed as the final solution to reduce the damages to forest resources caused by dam construction and restoration of vegetation. Also, the afforestation in the area is not a suitable option for remediation of vegetation in this area.

## Introduction

In developing countries, dam construction has always been considered as an engineering method for supplying irrigation water in farms, storing drinking water, energy production, flood control and other applications (Ayeni and Ojifo 2018; Heydari et al. 2013; McCartney 2009; Sönmez and Kılıç 2014; Zare and Kalantari 2018; Divine et al. 2017; Qicai 2011; Caspary 2009; Yang et al. 2019). Dam construction has a historical background in Iran, with its dry and semi-arid climate, especially in order to prevent water wastage, deal with water shortage crisis, and regulate river water flow (Tajziehchi et al. 2012). There are different views on the dam construction in the world, which have their own pros and cons among the experts.

Although dam construction has many benefits for human beings, it has also causes damages that have been irreparable in some cases, because in most cases and in practice, dam construction does not take into account environmental considerations or the necessary forecasts to reduce the environmental,

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economic and social harms (Brown et al. 2009; Beck et al. 2012; Divine et al. 2017; McCartney 2009; Paul et al. 2013; Biswas and Tortajada 2001; Wiejaczka et al. 2020). This has come to a point that some international organizations have conducted studies and proposals to stop the dam constructions, especially in developing countries (Caspary 2009; World Commission on Dams 2000).

Among the effects of dam construction, mentioned in many studies, their effects on the energy and hydrological cycles of the region, changes in river flow, changes in hydrological and geomorphological system of the region, changes in frequency, peak and duration of floods in the region, reduction of river water flow and changing in the riverbed, increased evaporation from the dam water level that causes changes in the chemical properties of water, increased environmental pollution, spread of waterborne diseases, forced migration of residents of surrounding villages, changes in land use from rangeland and forest lands to agricultural lands and factories, disconnection of path roads from existing roads, reduction of land fertility, increased soil salinity, negative effects especially on the survival of riparian ecosystems, biomass production and survival of plant ecosystems adjacent to the dam, reduction of water table levels in the downstream areas of the dam, drowning or threatening historical monuments and cultural heritage, and so on (McCartney 2009; Heydari et al. 2013; Sönmez and Kılıç 2014; Ayeni and Ojifo 2018; Brown et al. 2009; Qicai 2011; Paul et al. 2013; Caspary 2009; Wiejaczka et al. 2020). On the other hand, the existence of dam resources increases the possibility of developing new water uses such as fish farming, fishing and tourism and creates more opportunities for the development of aquaculture with its effects on the local climate. Also, the effect of climate change and increased air humidity due to dams causes higher yield of dryland farming (Moradi et al. 2010).

Dam construction, like other forms of industrial development, has short-term and long-term positive and negative effects on natural ecosystems around the project areas (Zare and Kalantari 2018; Tajziehchi et al. 2012; Divine et al. 2017; McCartney 2009). But perhaps the most important effects of building large dams are their adverse effects on the region's natural ecosystems, including the destruction of forests in the dam reservoir, habitat fragmentation, food chain breakage, and increased pressure on forest resources around the dam (Ayeni and Ojifo 2018; Brown et al. 2009; Tajziehchi et al. 2012; Vale et al. 2015; Chen et al. 2015; Paul et al. 2013; Caspary 2009).

Additionally, there is no doubt that the presence of vegetation on the surface of the basin is one of the factors that reduce flooding due to the effects it has on the components of the hydrological cycle (Rezaian et al. 2016; Yang et al. 2019). Therefore, the conservation, restoration and creation of vegetation are very important due to their great impacts on increasing the permeability and duration of concentration and control of surface runoff and other services. Deforestation and destruction of vegetation around dams will reduce the penetrability of the soil or increase the drainage capacity of the basin, which in turn will lead to an increase in flood discharge (Qicai 2011; Chen et al. 2015). Therefore, the environmental impact assessment of dam construction should be considered in a comprehensive manner.

In developing countries, it is usually assumed that the economic benefits of building dams outweigh its costs, thus providing a logical reason for building dams. But this should not be taken as a loophole to

ignore its social and cultural, and especially ecological, damages (Beck et al. 2012; Biswas and Tortajada 2001; Wiejaczka et al. 2020). Although in most parts of Iran, dam construction may be economical in some respects, it is not compatible with the sustainable and comprehensive development plan (Moradi et al. 2010; Zare and Kalantari 2018). In the triangle of sustainable development, striking a balance among economic, social and environmental components at any time and place requires spending money obtained from other sectors in the less developed sector. On the other hand, the emphasis is on meeting the needs of the current and future generations. Therefore, the only way to achieve sustainable development is to pay enough attention to all the ecosystems downstream and upstream of the dams (Heydari et al. 2013; McCartney 2009).

Dam construction causes damage to the natural ecosystems and it is not possible to compensate for the damages, but its damages can be reduced (Moradi et al. 2010). When the decision is made on the construction of the dam, an attempt should be made to adopt a policy that minimizes the threat. A wide range of technical and non-technical operations have been proposed to improve the negative effects of dams (McCartney 2009). Given the inevitable damages from dam construction on the surrounding natural resources, especially forests, methods that can provide solutions to reduce or compensate for the damage in the form of applied policies, can be useful to take utmost care and adopt the right policy in order to refrain from any unconsidered actions (Moradi et al. 2010; Loncar et al. 2006).

Forests are among the natural ecosystems threatened by dam reservoirs. Forest ecosystems have undeniable advantages that are of great interest to policymakers, and in many cases the advantages have not been valued or are difficult to measure (Jahanifar et al. 2017; Musi et al. 2017; Amirnejad et al. 2006). With the construction of dams, many of these services provided by the forest ecosystem will be destroyed or the composition and biodiversity of forest communities will be changed (Vale et al. 2015; Chen et al. 2015; Beck et al. 2012). Numerous studies have been conducted on the valuation of forest resources (Amirnejad et al. 2006; Jahanifar et al. 2017; Ninan and Inoue 2013; Xue and Tisdell 2001). It is important to note that the numerical calculation of these values does not mean that these values are tradable, but is only a good way for calculating the compensation for damages (Amirnejad et al. 2006; Ninan and Inoue 2013).

Dam construction and the resulting consequences on forest resources is a complex phenomenon with different aspects, including various stakeholders, many components and parameters involved, and various goals. It includes a variety of ecological, economic, and social variables that have interrelated, complex relationships and interdependencies between their components. Today, the description of interrelations and the evaluation of their effects, especially the environmental and social effects of dam development, has become an important issue that plays a role in the sustainable development of communities and natural resources. Therefore, its inclusion in a systematic and integrated approach to a project based on sustainable development is important (Tundisi et al. 2015).

Based on the systems perspective, the dynamic system approach first developed by Forrester (1961) is an idea developed by system modeling methods (Forrester 1961). It consists of a series of cause and effect

links through which the interaction between the elements of the system is shown (Olabisi 2010; Collins et al. 2013; Purnomo and Mendoza 2011; Hossain et al. 2020). This technique is used as a tool in the analysis and modeling of systems with various aspects, complex, reciprocal and nonlinear relations, and with feedback and delays (Tao et al. 2017; Machado et al. 2015). This model has been used in an interesting way in various scientific researches to model complex and dynamic natural and social systems such as natural resource system and forest, whose patterns are a function of time and need long-term planning (Collins et al. 2013; Hossain et al. 2020; Purnomo and Mendoza 2011; Olabisi 2010). The dynamic system method provides a demonstrative framework of the forest's natural environment, which responds to direct and indirect interferences, and its natural and unnatural disturbances (Blanco et al. 2017; Machado et al. 2015; Tao et al. 2017).

The power of simplification of complex natural phenomena such as problems of natural resources with different types of interconnected variables and having internal interrelationships, high speed and flexibility of the model in providing results, the ability to clarify interrelations, interactions and especially feedbacks, success in illustrating future changes and developments based on recognizing the structures and relations of variables in the past and present, are the special features of this model that prove its potential to solve management problems, especially in natural resource areas that we face, thus making it attractive for researchers to be used in studies (Olabisi 2010; Collins et al. 2013; Loncar et al. 2006; Tao et al. 2017; Sterman 2000; Musi et al. 2017). In fact, the purpose of systemic thinking and modeling using the dynamic system is to identify the causes, structures and relationships that have led to past changes and developments, in order to lead the developments and policies in the favorable direction (Collins et al. 2013; Musi et al. 2017; Sterman 2000; Olabisi 2010; Tao et al. 2017; Loncar et al. 2006).

The performance of the dynamics and scenario modeling system and the formulation of management policies and strategies in the forest based on its simulations has been tested in a series of studies with different criteria. In the oldest study, a dynamic system was used to simulate the dynamics of forest development (Bossel 1994). Also, modeling the dynamic system has been performed for forest fire management (Collins et al. 2013), planning for forest management (Loncar et al. 2006), simulating the dynamics of socio-ecological systems of forestry in adapting to climate change (Blanco et al. 2017), evaluating forest ecosystems (Tao et al. 2017), evaluating forest participatory management (Purnomo and Mendoza 2011), monitoring and evaluating forest growth and amount of carbon deposits (Machado et al. 2015), planting and reforestation planning in destroyed forest lands (Musi et al. 2017), and comparisons of forest management perspectives (Olabisi 2010).

The construction of Liro Dam in the Zagros Mountains, dominated by the ecosystem of unique forests of the Iranian Oak, is under consideration. Damage to the vegetative coverage of the dam will cause a lot of damage to the region's ecosystem if it is not compensated. In this study, the method of determining the amount of damage and the methods of restoration and reducing damage to the vegetation caused by dam construction in the region have been discussed. To conduct this study, first a dynamic system model was prepared for Oak forests in the region. Then, the value of ecosystem services of the existing

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estimated in the dynamic system model. In the next step,

different options for reducing damage and restoring vegetation under different scenarios and their impacts on damage compensation are examined. In the end, the optimal policies were introduced based on the best scenarios. The results of this study have the potential to provide solutions to reduce the adverse environmental impacts of dam construction by planning to restore the vegetation in the area and to prevent the continuation of forest degradation along the dam.

## Materials And Methods

### Study area

In this study, the construction of Liro hydroelectric dam on the common border of three provinces of Lorestan, Chaharmahal and Bakhtiari and Khuzestan in the Oak forests of Zagros, western Iran, was investigated. The annual storage capacity of the dam is 500 million cubic meters. With the construction of the Dam in the most pristine areas of the Zagros Oak forests, a vast part of the forests will be destroyed in one of the most inaccessible and natural areas and tens of thousands of trees in the virgin habitats of the endangered species in Zagros will be submerged. The area is located at the longitude of 50°20' to 49°15' E and the latitude of 32°35' to 20°33' N. The region's precipitation regime is predominantly Mediterranean, ranging from 300 to 1,400 millimeters per year. The average temperature in the region is 18 °C and the average annual evaporation is estimated at 1720 mm.

The dominant ecosystem of the region at the dam's wall consists of the Persian Oak forests and at the bed of the forest reservoir, it is riparian. The schematic of the Iranian Oak forests and the river ecosystem adjacent to the dam can be observed in Fig. 1. The Oak forests of the Zagros in the foothills of the Zagros Mountains are classified as semi-arid forests, covering an area of about 5 million hectares, or about 40% of Iran's forests. In general, this region has the greatest impact on water supply, soil protection, climate change and socio-economic balance. Currently, these forests have been damaged in many places due to the harvest of wood and livestock grazing and land use changes (Valipour et al. 2014). The Quantitative characteristics of the existing Oak stands in the reservoir area are as follows (Table 1).

**Table 1. Quantitative characteristics of forest stand in the study area**

Origin	coppice
Density per hectare	105/ha
Average number of sprouts	340/ha
Average percentage of crown cover	17 %
Average diameter of the crown	4.06 m±2.06
Average diameter of breast height	18.2 cm±15.9
Stand volume	60 m <sup>3</sup> /ha±5.0
Volumetric growth	0.6 m <sup>3</sup> /ha/year

To conduct this study, first, the value of Iranian Oak forest ecosystem services was measured/estimated in the current conditions and priced through conventional methods (alternative goods or costs, opportunity cost method, Willingness to pay for participatory, etc.) (Amirnejad et al. 2006; Jahanifar et al. 2017; Ninan and Inoue 2013; Xue and Tisdell 2001).

Then, the vegetation growth model of the region's forests was prepared in the form of a stand-scale dynamic system model, so that the value of forest ecosystem services would be estimated over time. In the next step, the proposed scenarios for the reduction of vegetation damage caused by the construction of the Dam were prepared and evaluated in the constructed model. Figure 2 shows the process of this study.

The forest growth model used in this study, which is based on data obtained from existing local study records, was implemented in the Vensim Dss software, which has the following characteristics.

- Model type: Whole-stand
- Simulator environment: Vensim DSS
- Simulator facilities: coppice forest natural stand growth, afforested high forest stand growth, calculating the value of ecosystem services (wood production, carbon sequestration, oxygen production, soil erosion reduction, habitat, tourism, pest control, dust reduction, socio-economic), the impact of internal and external factors on forest growth
- Time validity: 60 years
- Estimation error: 10

To investigate the quantitative accuracy of the model, the thresholds for the characteristics of Iranian Oak forest stands in Zagros habitat, including stand volume, annual growth, basal area, density, etc. were examined and the problems of the initial model were resolved. To investigate the quality of the model, the relationship between the components of the model was examined, so as not to violate the basic assumptions of forest dynamics.

In this study, a standard approach has been used to devise the scenario (Johansen 2018). In short, for devising the scenario, first the elements and drivers are identified, and then, the variants are formed. Scenarios are designed and finally the selected scenarios are introduced. The scenario building process of this study is shown in Fig. 3.

### **Estimation of the value of forest ecosystem services in the dam reservoir under current conditions**

The most important of direct services are soil resources, forage production, wood, charcoal, medicinal plants, tannins, syrup, Oak tree extract, Oak fruit for human and livestock feed, thin skin on Oak fruit skin used in medicine. Most of these values indicate the potentials of Oak forests, and more time is needed to commercialize them and their current valuation may not reflect their true value. Therefore, in this study, wood production and available soil values were calculated, which is the most important element for the indirect values, carbon sequestration, oxygen production,

soil erosion reduction, soil elements preserving, habitat protection, water production, runoff regulation, dust reduction, tourism services, pest reduction and socio-economic benefits were selected and evaluated (Table 2).

Table 2

Calculation the services of Oak forest ecosystems in study area and their value in the present situation

<b>Ecosystem services</b>	<b>Estimated value</b>	<b>Valuation Method / Source</b>
Wood production	60 $m^3$ of standing wood per hectare.	Forest inventory based on aerial photographs
Value of the available soil	3000 ton soil	Soil profiles
Carbon sequestration	0.18 tons of carbon sequestration per hectare per year	Allometric equations
Oxygen production	0.13 tons per hectare per year	Physiological equations
Soil conservation value (reduction of soil erosion)	4.8 tons of erosion reduction which is equivalent to 3.2 $m^3$ of soil protection per hectare per year.	Global model of soil erosion
The value of preserving soil elements	Each hectare of Oak forest in Iran prevents the loss of 357 kg of NPK elements compared to non-forest lands.	Soil analysis
Habitat protection	The most valuable species in the Persian Oak forests include 34 species, including 8 woody species, 25 herbaceous species and one rodent species (Iranian squirrel).	Environmental studies
Water production	The water storage capacity of Iranian oak forests is very low.	Characteristic of the Mediterranean forests (EEA, 2015; Filoso et.al., 2017)
Runoff regulation	Due to the low water holding capacity of Persian Oak forests, as well as the significant effect of the dam on the regulation of local runoff, this value is negligible.	Characteristic of the Mediterranean forest EEA, 2015; Filoso et.al. 2017
Tourism services	Travel cost	Willingness to pay method
Dust reduction	Each hectare of Persian Oak forests absorbs a range of 4.6 $mg/m^3$ PM10 in 24 hours.	Powe and Willis (2004) method
Pest reduction	Despite the devastating effects of pesticides in nature, because the price of pesticides in Iran is very low, the value of pest reduction by Persian Oak forests in this way is estimated to be very low.	Relationship between the forest cover and pesticide usage in different watersheds
Socio-economic value	The average consumption of wood per household in the forest is estimated at 15 $m^3$ per year.	Questionnaire

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Ecosystem services	Estimated value	Valuation Method / Source
	The grasses under story of the Persian Oak forests are limited to 150 kg per hectare.	Direct measurement
	The cultivation in under story forest area is mainly in the form of rain fed with a yield of about 1 ton per hectare (low yield).	Questionnaire

### Devising the scenario of reduction and restoration of damages to vegetation due to the construction of the dam

The four main elements of damage reduction and vegetation restoration for this project include conservation, restoration, afforestation and reduction of pressure on forest resources. These elements are summarized below:

- Conservation: No land use change
- Restoration: Planting trees in existing forest stands with the aim of improving forest quality
- Afforestation: Afforestation in non-forested areas with the aim of quantitative improvement (increase in forest area)
- Reduction of pressure on forest resources: Lack or reduction of forest harvestation by forest dwellers

Based on strengths and weaknesses, these elements can be converted into the 7 elements described in Table 3.

Table 3  
List of total elements presented in the study

Element number	Element name	Description
1	100% conservation	Elimination of forest land use change
2	100% restoration	Annual planting of 200 seedlings per hectare in the land
3	50% restoration	Annual planting of 100 seedlings per hectare in forest lands
4	50% afforestation	Afforestation at 50% of the dam reservoir area
5	25% afforestation	Afforestation at 25% of the dam reservoir area
6	Reduce pressure on resources by 100%	Elimination of forest harvesting by forest dwellers
7	Reduce pressure on resources by 50%	50% reduction in forest harvesting by forest dwellers

The elements are arranged on a Wilson matrix according to the impact score and certainty about their implementation (Fig. 4). Finally, the appropriate (effective and certain) elements or drivers were introduced, with which the scenario was created. As shown in Fig. 4, elements 1, 2, and 6 are effective and reliable, and were introduced as project drivers. Development or afforestation elements (elements No. 4 and 5) in semi-arid regions are not reliable and are not recommended, because of the weak habitats and limited water resources, and are not effectively cared for in the long-term. On the other hand, in semi-arid areas, including the study area, due to the socio-economic problems of forest dwellers, the forest harvestation rate is much higher than forest growth. Therefore, in order to reduce the destruction of existing resources, the elements of restoration and reduction of pressure on resources must be fully implemented (elements No. 2 and 7) to be effective.

In the next step, possible scenarios of drivers and variants were defined using morphological analysis. The scenarios considered in the morphological analysis method are as shown in Fig. 5. Variant A is related to the non-implementation of the drivers and variant B is the complete implementation of the drivers. A list of possible scenarios is given in the results section (Table 4).

## Examining The Scenarios Using The Dynamic Model

The dynamic system model was used to examine the final scenarios and simulate them over time. The results of simulation using this model show the analysis of the behavior of problem variables over time in order to present policies and decisions. Part of the causal loop diagram of the flow state of the dynamic system is given in Fig. 6. The main parts of the model include coppice forest growth model, afforestation growth model, calculation of forest ecosystem services, evaluation of forest ecosystem services, effect of external degradation factors on forest growth and finally, the effect of damage reduction and vegetation restoration (conservation, restoration, afforestation and reduction of pressure on forest resources).

## Results

### Results of estimating the value of forest ecosystem services in the dam reservoir under current conditions

According to the calculations in Table 2, in total, the highest shares of ecosystem services in Oak forests are related to wood production (37%), soil available value (35%) and soil nutrient preserving (21%), respectively (Fig. 7). If the dam is built, 640 ha of Oak forests will be submerged. The value of damages incurred to forest resources from the Dam reservoir is given in Table 4.

It should be noted that the calculation of damages caused by the construction of the dam in the riparian forests is a large problem addressed in the main report of on environmental impact assessment of Liro dam and power plant (2019) and does not fit in this article. However, due to the importance and value of riparian forests, the amount of damage has been included in Table 4. Based on the above calculations, the value of the lost forest resources due to the dam construction and the proposed roads (excluding the operation of these forest resources in the future) was estimated at about \$16,237,819.4.

Table 4  
The value of damage to forest resources in the area of Liro Dam

Land use	Area (hectare)	Unit price (\$USD)	Total price (\$USD)
Oak Forests	640	24151.6	15457073.9
Riparian forests	238	3250	773500
Road area	0.3	24151.6	7245.5
Total	878.3		16237819.4

### Model simulation, reviewing the scenarios and formulating the desired policies

The list of suggested scenarios is given in Table 5. There is complete internal compatibility in all scenarios S1, S2, S3 and S4, because each has completely distinguished drivers.

Table 5  
List of possible scenarios proposed in the study

Scenario number	Scenario name	Specifications
S1	A1A2A6	Continue the current trend (forest degradation)
S2	A1B2B6	Pressure reduction + 100% restoration
S3	B1A2B6	Pressure reduction + conservation
S4	B1B2B6	Pressure reduction + 100% restoration + conservation

Figure 8 is a simulation of the stand under current conditions or in S1 scenario. As it turns out, over time, the soil depth and the stand density and the stand volume decrease, so that the soil gradually disappears in 29 years and the trees of the area, in 35 years. So the volume of the stand reduces to zero. Based on the severity of the destruction under current conditions, in the next 50 years, almost all forested lands within the dam area will be converted to other uses, including garden and agricultural lands, roads, settlements, and so on.

As can be seen from Table 4, the current value of a one-hectare stand of Iranian Oak is estimated at \$ 24,151.6. Now, if we add the current value of the stand (\$ 24,151.6) to its expected annual value in the next 50 years, with the 7% rate (annual net present value or NPV), the total value of the stand will be obtained (Saeed 2009).

Figure 9 estimates annual net present value (NPV) and the annual net value (ANV) of the stand in different years as the current destruction process continues. Also, the base in this study area is the average age of the existing stands of Iranian Oak coppices (40 years old). As can be seen in Fig. 9, although the current annual non-present value (ANV) of the stand reaches zero from \$1128.5 in the 50<sup>th</sup> year, its annual present value (ANV) in the 50<sup>th</sup> year is \$ 8050, which is significant, showing the value of

NPV calculations. Therefore, with the continuation of the current destruction trend, the total value of one hectare of Oak forest in the next 50 years is estimated at the sum of two numbers of \$24241.6 and \$8050, i.e. \$32951.67.

To compensate for this damage, four scenarios of S1 to S4 have been implemented, and their annual present cumulative values (ACV) are shown in Fig. 10.

As shown in Fig. 10, only scenarios S3 and S4 can compensate for the calculated vegetation damage in the future, and the difference is in the duration of the vegetation restoration. Under S3 and S4 scenarios, the duration of recovering the lost capital of \$32,951.67 is estimated at 33 years and 23 years, respectively. This means that if the S4 and S3 scenarios are implemented, at a surface area equivalent to that of the dam reservoir (640 ha), the damage to the destroyed Oak forest caused by the dam construction will be compensated for over a period of 23 and 33 years. It is clear that with increasing surface area in s3 and s4 scenarios, the damage recovery time can be reduced. The domain proposed for the selection of this 640-hectare area is determined under the name of the effective domain of vegetation destruction due to the construction of Liro Dam according to ecological principles in ecosystem and landscape scale, on which the conservation, restoration and reduction of pressure on forest resources must be implemented. In addition to the Iranian Oak forests that submerge in the dam area, 238 hectares of riparian forest will also be destroyed, so that the same amount of riparian forest should also be protected, restored, resource pressures of which should be reduced elsewhere.

## Discussion

This study aims to determine the optimal solutions to compensate for the damages caused by the construction of the Liro Dam and to achieve the goals of sustainable development through simulating different scenarios within the dynamic system model and calculating ecological and socio-economic values of Iranian Oak forests in semi-arid areas of western Iran.

Based on the combination of the four options of conservation, restoration, development and reduction of pressure on forest resources, four scenarios S1 to S4 were designed. The results of model simulation in the present study showed that the continuation of the current situation (scenario S1) will cause the complete destruction of forest areas and erosion and destruction of soil. Therefore, the value of the forest stand under this scenario decreases over time. In two scenarios of S3 (reduction of pressure on forest resources along with conservation) and S4 (reduction of pressure on forest resources along with conservation and 100% restoration), the destroyed Oak forest will be recovered in 33 and 23 years, respectively. Therefore, the optimal policy should be such that, first of all, it guarantees the preservation and conservation of existing forests and reduces the pressure on forest resources. Along with these two, efforts should be made to restore and enrich the forest in order to minimize the damage caused by the dam construction to the forests of the region.

Unfortunately, the existing forest lands face changes in their use every year, especially toward agriculture  
Loading [MathJax]/jax/output/CommonHTML/jax.js tting down trees and soil erosion. With the construction of the

dam, the largest share of damages is related to wood (biomass), soil and elements lost in the soil, which is due to the destruction of a forest ecosystem and its conversion into a dam reservoir. Compensating damage to the trees and especially lost soils takes a long time or may not be really compensable.

In order to compensate for the lost trees, considering the low fertility of the habitat and the slow growth of trees and compensation for damages in a short time, extensive afforestation (much more than the area of the dam reservoir) is required. However, large-scale afforestation in arid and semi-arid regions has its own problems, which reduces the possibility of its successful implementation. The main reasons for this uncertainty include the lack of adequate land with sufficient area and access to sufficient water and the high cost of maintaining afforestation. Also, in many cases, especially in developing countries, afforestation is abandoned after a few years. Therefore, afforestation is not a recommended solution to reduce damage to vegetation due to dam construction in this research. But it is possible to maintain the value of existing forest ecosystem services at a lower cost conservation, restoration and reduction of pressure on forest resource, instead of large-scale afforestation. In the case of compensation for lost soil, reversing the use of low-yield agricultural land to forest may be a good way to compensate for lost soil.

The precondition for sustainable development is that the planning, construction and operation of future dams in the future should be part of an integrated management effort that will lead to the conservation of the environment (McCartney 2009). This is especially challenging in a country like Iran, which is facing both a water shortage crisis and has a very small area of renewable natural resources, including forests. However, with some operations, the adverse environmental effects of these projects can be reduced, which is generally in the form of remedial operations and reduction of damages caused by adverse environmental consequences through feasible methods (Tundisi et al. 2015; Rezaian et al. 2016; Zare and Kalantari 2018; Biswas and Tortajada 2001; Moradi et al., 2010).

Investigation of spatial-temporal patterns of deforestation and tropical forest destruction in response to the operation of the Tucuruí Dam in the Amazon Basin using remote sensing and GIS and statistical tests over a period of 25 years 1988 to 2013 by Chen et al. (2015) showed that dam construction can cause disturbances on small and large scales in the forest. But the disturbances caused by the relocation and settlement of human communities (due to its conversion into agricultural lands, exploitation and expansion of roads) has played a major role in deforestation. The destruction caused by humans has increased the vulnerability of the forest to disturbances caused by dam construction in water and soil. The results also showed that forests that were closer to the dam did not necessarily experience further destruction. Such a problem exists in the forests of the Liro Dam reservoir. In fact, deforestation and the associated social problems are complex issues in developing countries, and this complexity of forest management is a serious obstacle to determining optimal management policies (Musil et al. 2017).

Providing a model which is not only comprehensible but also help policymakers address all of these complex problems is itself a challenge. Therefore, in the proposed approaches, the dimensions of the problem and the method of interacting with them to reduce the damages of the dam construction have been clearly considered from the point of view of stakeholders, including local communities. In a political

system for sustainable development of forest resources, in addition to considering different perspectives, government mechanisms to support these resources and finance projects must be redefined. By introducing the results of scientific and modern studies, as with the present study, in the decision making on sustainable forest management, we can take steps on comprehensive and coordinated development of ecological and socio-economic factors in the direction of sustainable development policies and implement methods of adaptation to change, and strike a balance in providing the various ecosystem services expected (Olabisi 2010; Beck et al. 2012; Loncar et al. 2006; Blanco et al. 2017; Purnomo and Mendoza 2011; Musi et al. 2017).

This study emphasizes the role of conservation and reduction of damages in existing forests instead of new afforestation. Attempts have also been made to use the construction of the dam as an opportunity to support and conserve the forests around the dam. In a way, part of the revenue from the sale of water can be spent on the forests around the dam. Finally, with the implementation of scenarios 3 and 4, the possibility of land use change for agricultural development and cutting tree by the regional natives will be limited. Therefore, to solve this problem and to empower local communities under the new conditions, it is better to change the livelihood of forest dwellers, instead of agriculture and animal husbandry, towards forestry and to provide a new opportunity that is brought about along with dam construction, i.e. tourism.

In the end, the fact should be noted that the construction of the dam, in addition to damaging the reservoir, causes a lot of damage to the surrounding environment in different phases and even after operation, which has not been evaluated and calculated. This could confirm that damages to dam reservoirs can only be reduced, and that these damages cannot be compensated.

## Conclusion

The construction of dams on rivers causes many changes in the region's ecosystem. In arid and semi-arid area, in addition to increased water loss through evaporation, it also causes more vegetation to be destroyed, mainly due to the creation of a sustainable water resource to further change land use. The damages caused by the dam construction on the coppice Oak forests of the study area were estimated at about \$24,151.6 per hectare.

Dynamic modeling system was used in this study as a flexible and effective way to simulate different scenarios of vegetative damage reduction. The proposed approach in this study is to **“reduce the damage to natural forest resources resulting from the construction of the Liro Dam by emphasizing conservation, restoration and reduction of pressure on forest resources in the region in the long run with the participation of natives and government funds”**. Through the conservation of existing forests, we may reduce these negative effects and partially restore the destroyed natural landscape surrounding the dam. The scenarios presented in this study are based only on legal requirements and the scope of applicable solutions in Iran, but they may be possible to be used in other areas with similar climates and forests.

It should be noted that the estimated amount of damage is the only guideline for predicting damages. It Loading [MathJax]/jax/output/CommonHTML/jax.js mean the reproduction of lost resources. Any type of damage

can only be compensated by the same commodity. For example, wood with wood and oxygen with oxygen etc. Also, the costs of reducing or restoring the damage will not be necessarily equal to the amount of damage. In this study, to compensate for the damage to the vegetation around the dam, the costs of conservation, restoration and reduction of pressure on the forest resources around the dam for more than 20 years should be taken into account. At last the process used in this study to determine the appropriate solutions to reduce the damaging effects of dam construction can be used for other similar studies because it is flexible and it has used new analytical tools for ecological analysis, including scenario building and dynamic modeling.

## Abbreviations

SV

Stand volume, SD:Stand density, SoD:Soil depth per hectare, NPV:annual net present value, ANV:annual net value of stand per hectare, ACV:annual cumulative value.

## Declarations

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### Authors' contributions

Hossein Safaei has participated in designing and conceptualization the subject of the study, performing analyzes and models, and reviewing information and data. Mohadeseh Ghanbari Motlagh was a major contributor in writing the manuscript, editing and analyzing results. Mahmoudreza Khorshidian has been involved in field working, gathering information, searching for resources and performed calculations. Saeed Malmasi has participated in reviewing the article and editing it, collecting data, analyzing the results and editing article. All the authors read and approved the final manuscript.

### Availability of data and materials

The datasets used and/or analyzed during this study are available from the corresponding author. The datasets supporting the conclusions of this article are included within the article. All data is available on request.

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

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Not applicable.

## Competing interests

The authors declare that they have no competing interests.

## Author details

<sup>1,2,3</sup> Experts of Department of R&D, Kimiagaran Khaksamen Consulting Engineers Company, Iran, Tehran Province, District 13, Tehran City, Central Part, Tehran, North Salsabil, Shahid Abdullah Bagheri Alley, Ghasroldasht St., No. 859, second floor. [Tel:+982166365092](tel:+982166365092). <sup>4</sup>Assistant Professor, Department of Environment, Faculty of Environment and Energy, Shahid Babaei Highway, Hakimiyeh Exit, Shahid Sadoughi St., Shahid Abbaspour Blvd., Islamic Azad University, North Tehran Branch, Tehran, Iran. [Tel: +982177009800-77009847](tel:+982177009800-77009847).

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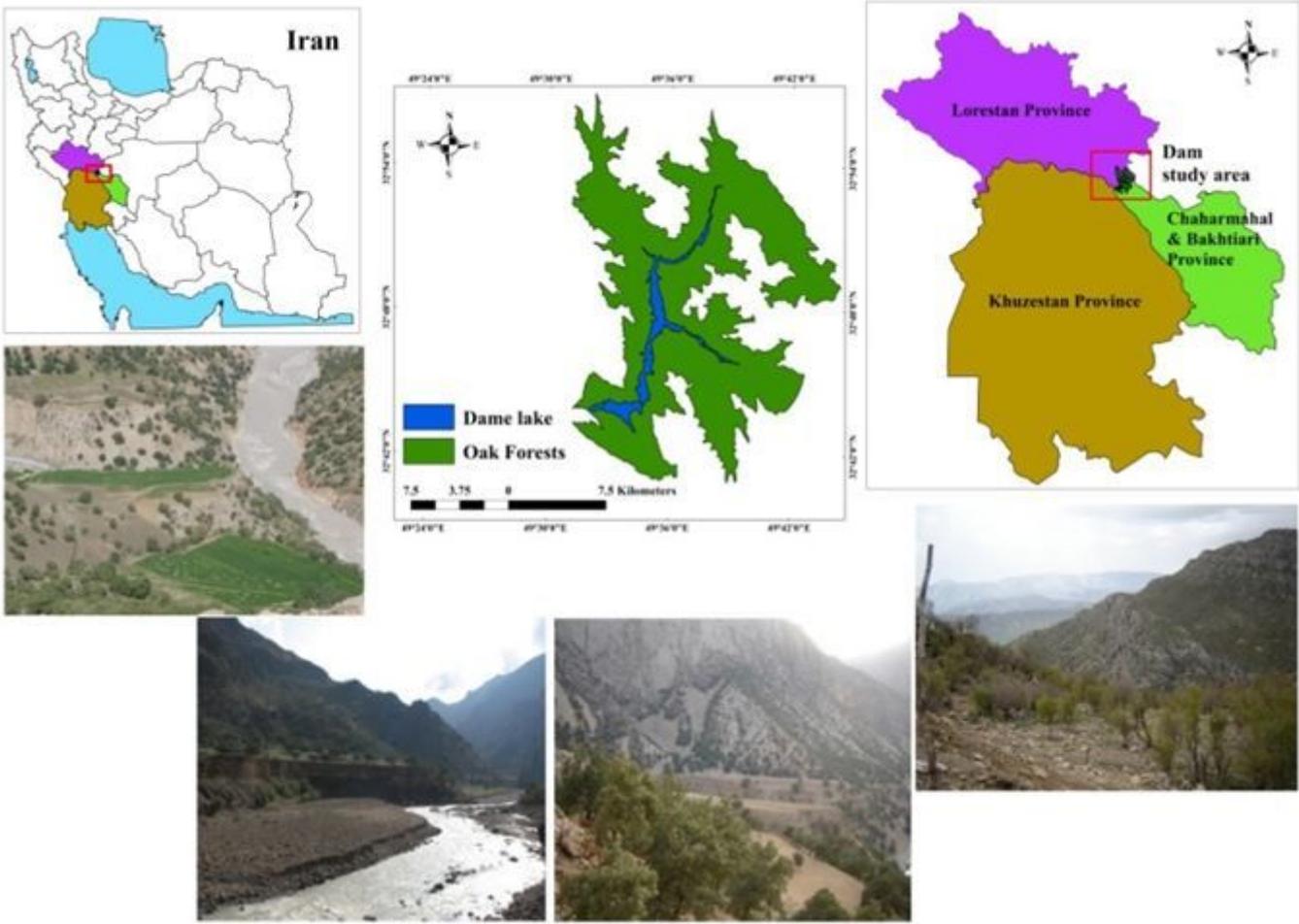
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## Figures



**Figure 1**

The location and photos of the Dam Lake and Oak forests in the study area.

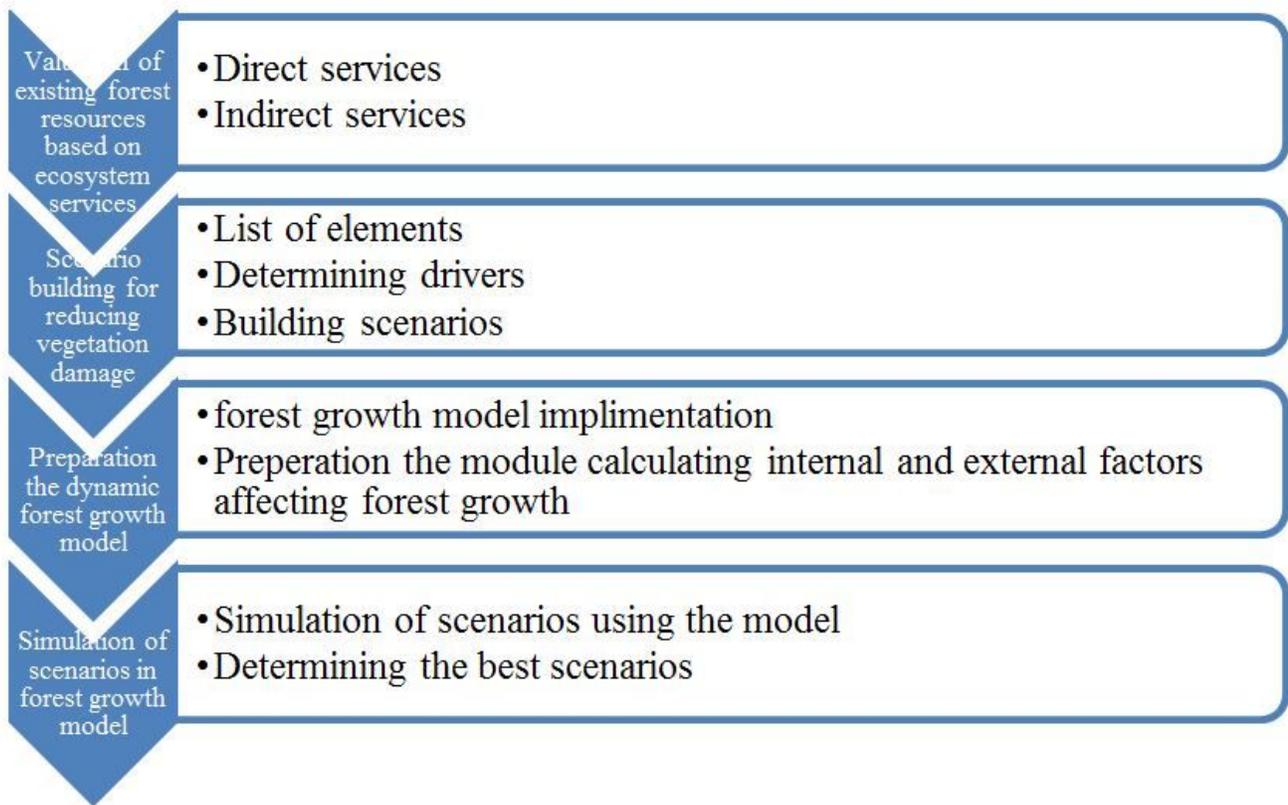
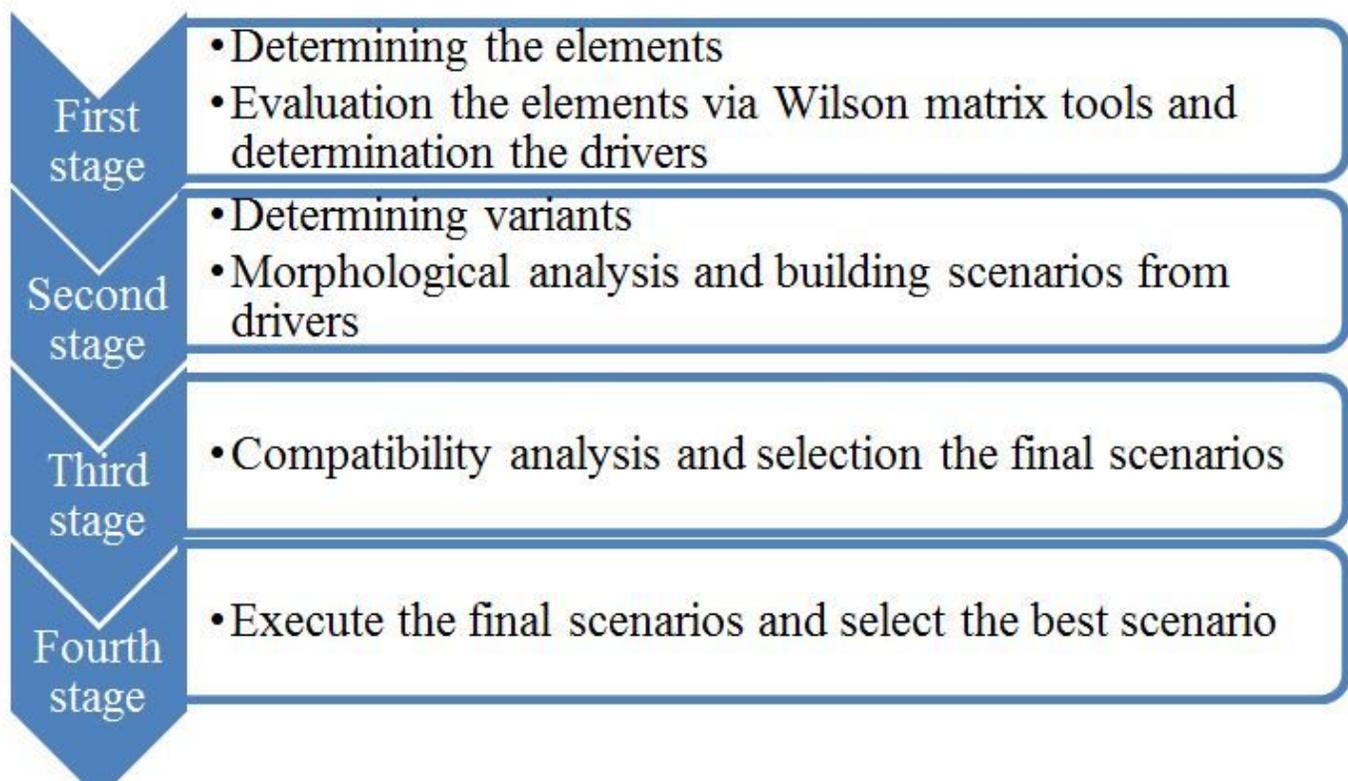


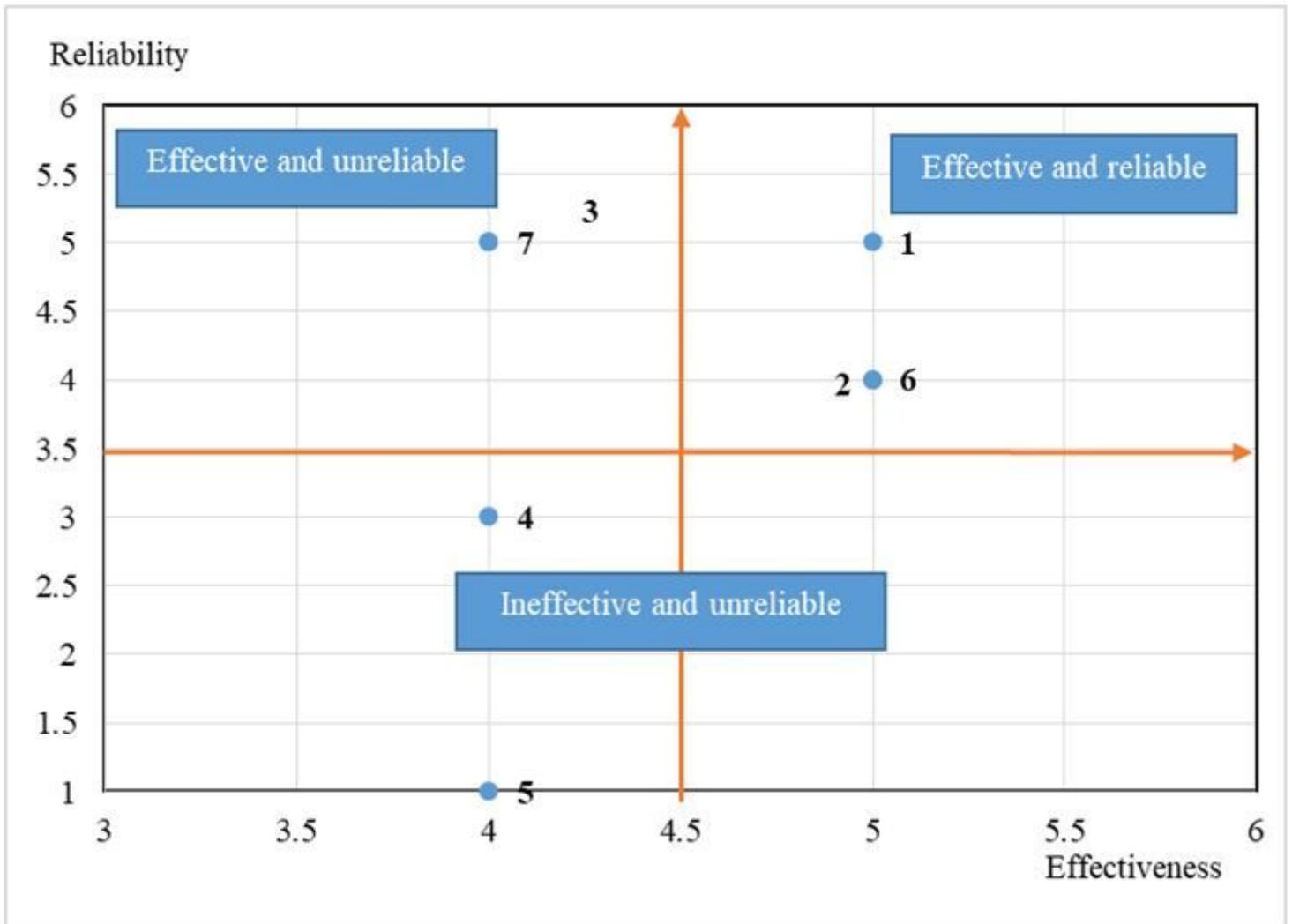
Figure 2

Conceptual model of research method.



**Figure 3**

The process of creating scenarios



**Figure 4**

Wilson's matrix of study elements.

	Drivers			
Variants	1	2	6	
A	A1	A2	A6	A1A2A6
B	B1	B2	B6	A1B2B6
				B1B2B6
				B1A2B6

Figure 5

Morphological analysis diagram to determine possible scenarios.

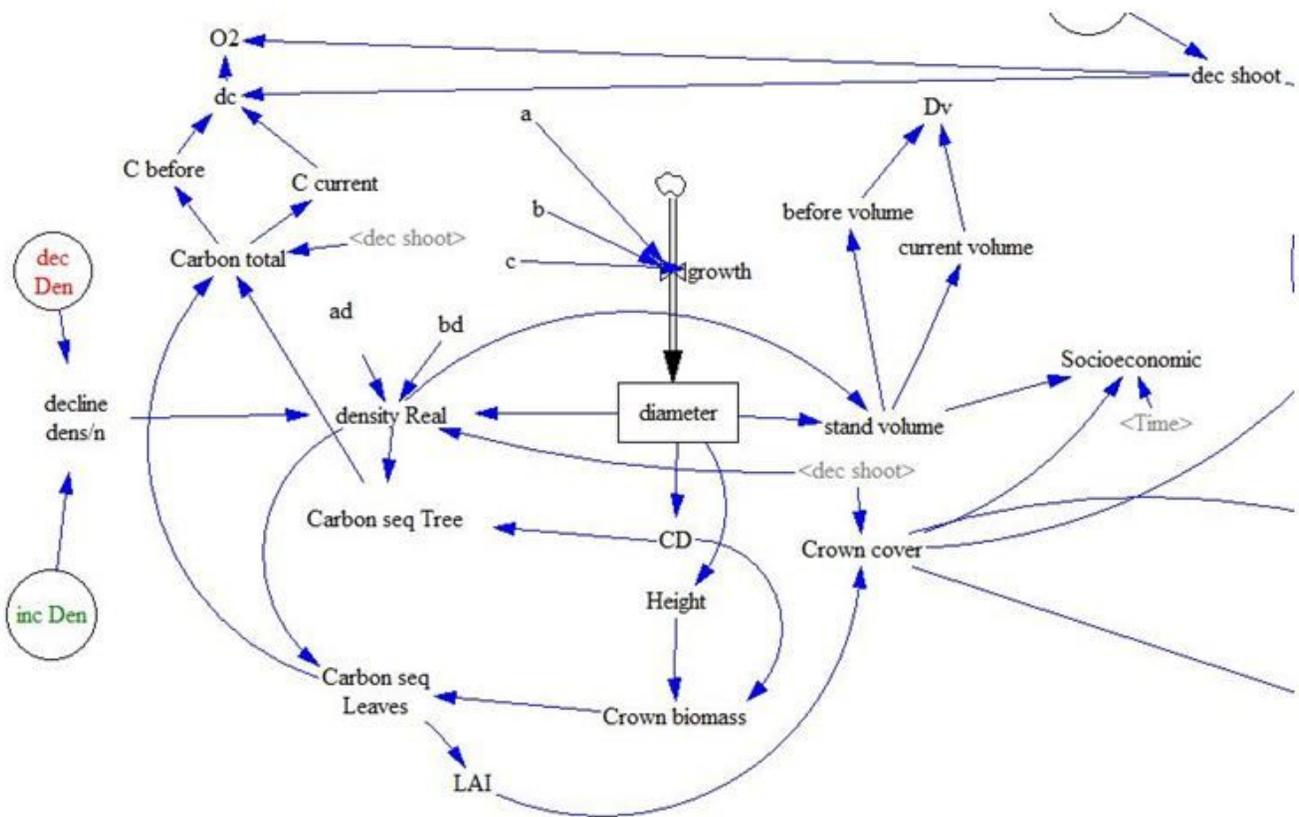
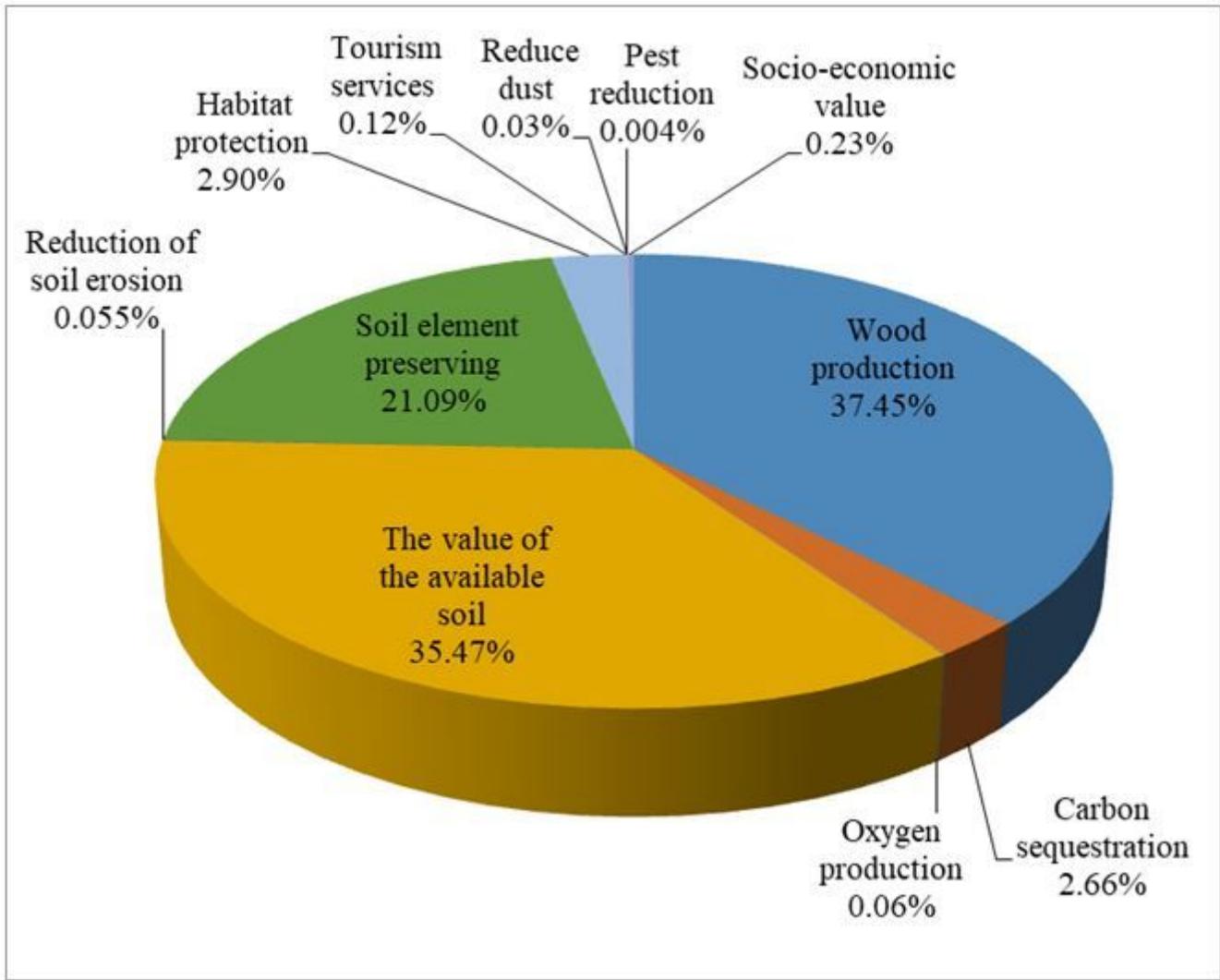


Figure 6

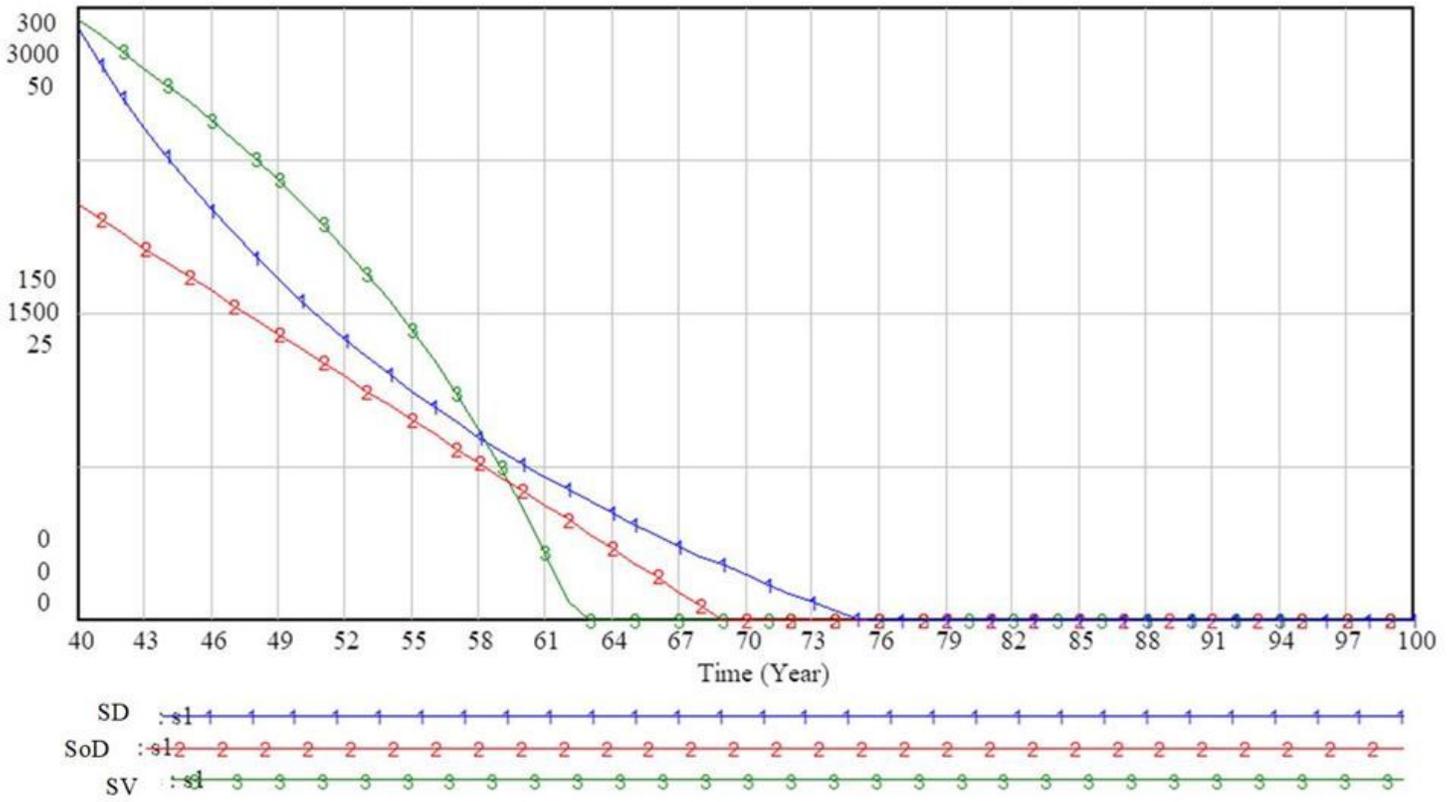
Part of the Casual loop diagram of the dynamic system of Oak forests in the region.



**Figure 7**

The share of different ecosystem services of Oak forests in the study area.

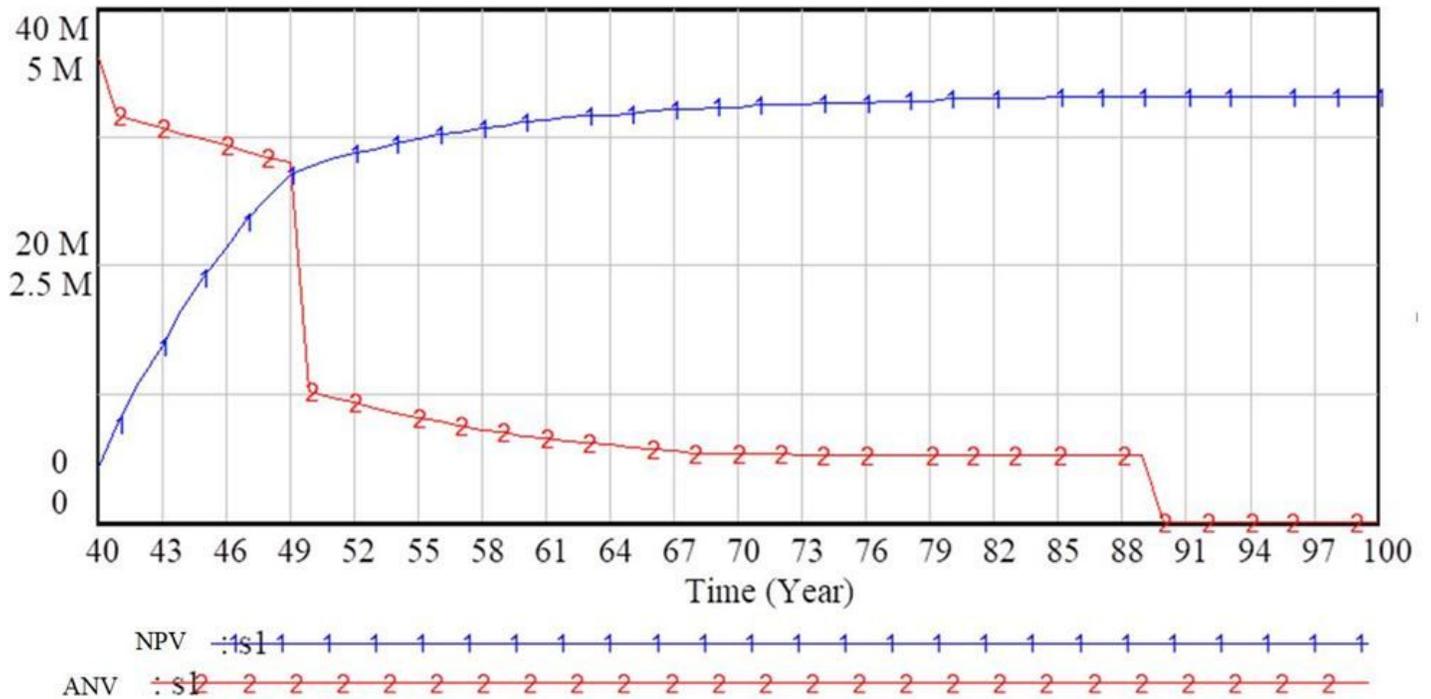
### Selected Variables



**Figure 8**

Stand volume (SV), stand density (SD) and soil depth (SoD) changes per hectare in Persian Oak forest.

### Selected Variables



Changes the annual net present value (NPV) and the annual net value (ANV) of stand per hectare in Persian Oak forest.

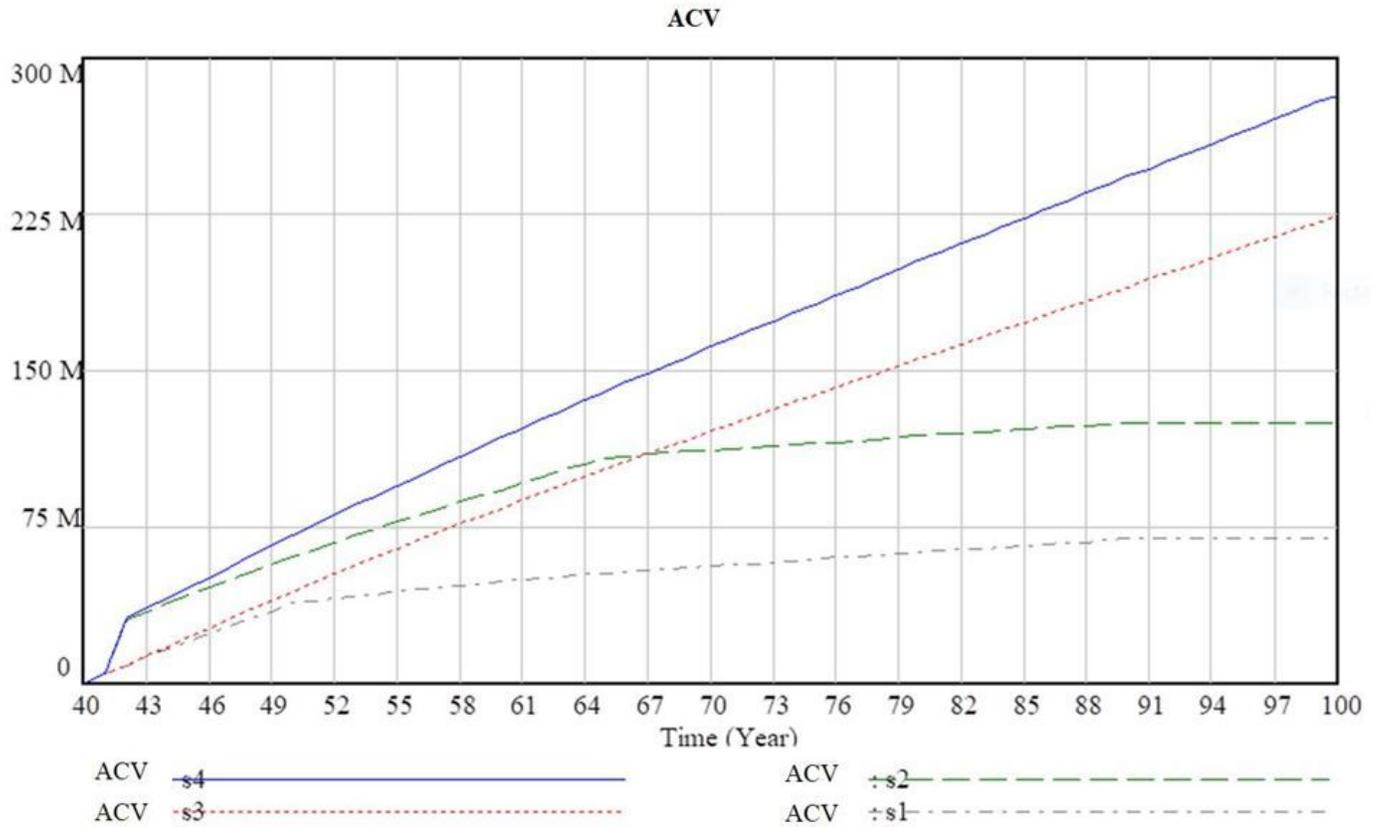


Figure 10

The annual cumulative value (ACV) changes through implementation of the four scenarios S1, S2, S3 and S4.