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STUDYING DEFORESTATION AND CHANGES IN FOREST LAND COVER USING AGENT-BASED MODELLING. CASE STUDY: TONKABON, IRAN

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Abstract

Deforestation and changes in forest cover are subject to the effects of many factors: economic, social, cultural, political, and environmental and their interactions. To assess these factors, one should necessarily know their nature and then model them. Nowadays many models have been introduced to explore deforestation, however most of them are based on past events and do not pay enough attention to socioeconomic factors. Moreover, considering the future is sometimes absent in those models. The present study develops an agent-based model for studying deforestation and changes in forest land cover using a case study. The model assesses deforestation in the past and then concentrates on the future of forest land cover. The study area is located in the north of Iran. The socioeconomic factors considered in this research as agents are farmers, ranchers and lumberjacks. The information and statistics of the agents were gathered over 10 years and so their manner in the forest was simulated. To validate the model, satellite imagery was used. The comparison between the simulated forest and the real one shows the power of the model as being 76% correct considering the Kappa coefficient. The results of forecasting reveal that the forest land cover will be reduced by 189 ha in 10 years' time. Also the results show that in the study area the ranchers have more severe effects on deforestation than the beneficiaries.

Key words: agent-based modelling, deforestation, forest destruction, Iran, simulation

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1. Introduction

Forest resources are vitally important to human life and survival on the earth. The formation and revival of forests are a long-term phenomenon and this doubles the importance of protecting them. Nowadays, for various reasons, natural and manmade, forests are being destroyed. In forest destruction, two issues- one quantitative and one qualitative- are encountered. Qualitative forest destruction happens when the ecosystemic function of the forest is reduced while the structure of the forest still remains (FAO, 2010). Good examples of this kind of destruction include: the erosion and cranking of the soil due to livestock movement, the reduction of stand wood because of irregular and wasteful harvesting, long term and over- grazing, forest fires, the reduction of plant density and so on.

Quantitative destruction of forest (deforestation) is diverting forest land cover to alternative uses such as residential, industrial, agricultural etc. (Van Kooten and Bulte, 2000). In other words, quantitative destruction means losing a portion of forest and this research focuses on this type of destruction. The basic definition of quantitative destruction is the FAO's definition of deforestation:

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"change from forest land cover to the others in a specific time" (FAO, 2010).

By determining the factors which affect deforestation and then studying the functionality of each one, it is possible to understand the changes in forest land use during various periods of time. The results of such studies may help planners to better manage forests. In the past, many studies on deforestation, its trends and causes, have been carried out (Khuc et al., 2018; Rusu et al., 2017; Sahana et al., 2018; Gayen and Saha, 2018). Those models facilitate the recognition of land use/cover change as being a complex phenomenon and provide useful information for land administration. For instance Tanaka and Nishii proposed the relationship between forest land cover and the population in the corresponding area by a mathematical relation (Tanaka and Nishii, 1997) (Eq. (1)):

$$\log F = -\frac{r}{2} N^2 + C \tag{1}$$

where: F denote forest proportion in an area (0<F<1), N is human population size in the same area (N>0), r is a positive deforestation coefficient and constant C should represent forest and woodland coverage rate without human pressure and perturbation (N=0).

However, most of these studies focused on environmental and demographic factors such as the distance to roads, the elevation, types of trees, population size and so on. The social factors and the human decisions which impact severely on deforestation have not been considered so widely. In other words, in the past, existing modelling tools were not able to simulate human activities in the environment. Thus there is a need to develop new contextual models which are able to consider and simulate interactions between humans and the environment (Hsu et al., 2018; Sharif and Alesheikh, 2017; Tashayo et al., 2017).

Agent-based modelling is mostly applicable in simulating the behaviour of actors in complex systems. This model has various capabilities such as independence, a learning capability, flexibility and an ability to analyse. Therefore, it is a suitable tool for modelling varieties of complex spatial phenomena such as urban development (Jokar Arsanjani et al., 2013), natural disasters (Dawson et al., 2011) and animal movements (Tang and Bennett, 2010). In deforestation phenomenon, an agent-based model is able to take many affecting factors (e.g. social, economic or environmental) into account, enabling simulation of their inter-relations. Consequently, in this research, using a newly developed agent-based model, changes in the forests are simulated and the future situation is forecasted. Forecasting enables planners to attempt to reduce or stop deforestation.

The main *goals* of this research are to determine the trend of forest land cover, simulating this trend, evaluating its variations and forecasting the future situation under several possible scenarios. In particular, scientific *contributions* of this research are: (1) the identification of factors affecting deforestation and the development of a new agent-based model that considers these factors and (2) the study of the future trends of deforestation using the developed model and the suggestion of some approaches to reduce or stop it.

In the following sub-sections, theoretical bases are defined and some related literature is reviewed. In Section 2, the developed agent-based model is introduced. Then in Section 3, the model is validated and results of implementation of it are discussed. Finally, Section 4 summarizes the article and provides recommendations for future studies.

1.1. Literature Review

Studying forest cover changes and their conversion into other land uses has been investigated from different aspects at continental (Armenteras et al., 2017), national (Khuc et al., 2018), provincial (Sudhakar Reddy et al., 2015) and regional (Sahana et al., 2018) levels. Following the objectives of this research, this sub-section explores the main drivers that affect deforestation as well as forest degradation modelling methods.

The destruction of forest cover and deforestation can be seen as occurring due to social, political, economic, demographic, cultural and environmental factors and highly complex interactions between them (Kissinger et al., 2012). Recent research highlights that there are variations in forest degradation rates in different countries (Armenteras et al., 2017). Therefore, it is necessary to examine the dependent and independent deforestation variables for each geographic region separately. With this in mind, Pir Bavaghar (2015) investigated the changes of regional forest cover in northern Iran from two physiographic (i.e., elevation, slope, landscape) and socio-economic (i.e., distance to road and residential areas) aspects and used the results to predict deforestation patterns. The results of this study showed that factors relating to accessibility: having a slope, main roads and residential areas, correlated highly with deforestation in that region. Armenteras et al. (2017) investigated the destruction of forest types in Latin America over the last three decades. They divided the major deforestation drivers into two direct and indirect sets. The former includes geographical variables, infrastructure, agricultural expansion, cattle grazing, forestry, aquaculture, natural disasters, fire and mining. The latter contains population, economy and politics. Khuc et al. (2018) selected seven groups of factors that can affect forest loss and forest degradation in Vietnam: agricultural production, income, poverty, population, food and provincial-scale governance. Sahana et al. (2018) investigated two categories of deforestation drivers namely anthropogenic (population distribution, distance from road, distance from settlement, proximity to agricultural land) and site-specific physical (slope angle, slope aspect, elevation, annual average rainfall, soil texture, soil depth) in order to analyse the deforestation sensitivity of the Himalayan area in India. In a different study, Castilho et al. (2018) studied the attitudes and behaviours of individuals along with demographic factors in the phenomenon of deforestation in a protected area in Brazil. The results of this study showed the effects of demographic factors, values held for protected areas and location-influenced respondents' attitudes, descriptive norms, and perceived behaviour in preserving these resources. Two conclusions can be drawn from studying the results of the abovementioned and similar studies. First, although similar agents play a role in deforestation, the importance of each agent varies from region to region and does not necessarily always have the same impact. Second, interactions between natural (environmental) and unnatural (human) factors are very important in assessing and predicting forests degradation rates.

Various forest degradation models have been developed and used individually or collaboratively. Primary research normally uses logistic, multi-line, geographic weighted and ordinary least squares regression as the common models for estimating the correlation between dependent and independent variables (Gayen and Saha, 2018; Ugon, 2004). However, the use of these models requires the existence of certain assumptions and conditions in the dataset (Stock and Watson, 2003). Cellular automata models were also used to analyse the spatial patterns of deforestation and their expansion trends (Naghdizadegan et al., 2013; Walsh et al., 2002). The limitation of cellular automata model is related to the transmission rules that are inferred from adjacent cells and are limited only to changes in the type of land cover and land use (He et al., 2013).

With regards to the spatiotemporal nature of deforestation, the use of Geographic Information System (GIS) tools can play an important role in applying different layers of information and analysing them properly (Linkie et al., 2004; Habibi et al., 2017). Mas et al. (2004) simulated forest degradation by combining GIS methods and the artificial neural network model. Amini et al. (2008); Arekhi (2011); Gayen and Saha (2018) used GIS and logistic regression model to analyse spatial patterns of deforestation. Exploiting the frequency ratio model in the GIS environment, Sahana et al. (2018) developed a spatial model to analyse deforestation in mountainous forest ecosystems.

Agent-based models, because of their ability to simulate entities or independent agents which are influenced by their surroundings, can be used for modelling land use changes and deforestation. Unlike previous modelling methods that integrate several indices, agent-based models examine the role of each factor separately (Parker et al., 2003). Manson and Evans (2007) exploited heuristic methods and integrated modelling to estimate households' decisions on land use changes in Mexico. In particular, agent-based modelling was used to determine the relationship between household decisions and social and environmental factors in deforestation. In another attempt, a coupled modelling system, including an agent-based model of subsistence farming, an individual-based model of forest dynamics and a spatially explicit hydrological model which predicts distributed soil moisture and basin scale water fluxes was developed (Bithell and Brasington, 2009). This modelling system is able to investigate demographic changes in deforestation.

1.2. Conceptual framework

Agent-based modelling is the implemented method in this research. Thus, it is necessary to first review some basic definitions and concepts about this method. Many definitions have been suggested for "Agent" in scientific literature. Each of the definitions is related to a specific scientific background. This shows the spread area of agent usage. In general, the agent may be known as a discrete autonomous entity with especial goals and behaviours, which is able to establish relationships, is adaptable and also able to change its behaviour (Siebers and Aickelin, 2008). A definition that is generally accepted and is applied in most research is (Ferber, 1999):

"*An agent is a physical or virtual entity, which is capable of acting in an environment, which can communicate directly with other agents, which is driven by a set of tendencies (in the form of individual objectives or of a satisfaction/survival function which it tries to optimize), which possesses resources of its own, which is capable of perceiving its environment (but to a limited extent), which has only a partial representation of this environment (and perhaps none at all), which possesses skills and can offer services, which may be able to reproduce itself, whose behavior tends towards satisfying its objectives, taking account of the resources and skills available to it and depending on its perception, its representations and the communications it receives.*"

Agent-based modelling is constructed based on the assumption that the behaviour of interconnected agents encountering an event, or a decision-making situation can be simulated using a set of laws. In other word, the agents are governed by a set of laws which determine their interactions between each other and the environment. In agent-based modelling, usually the agents with the simplest laws act in the environment but complex behaviour from their interactions is achieved. Therefore, agent-based modelling is known as a bottom-up method. In this method each individual entity, human or animal, is defined by a set of parameters and behavioural laws (Bomblies, 2014; Iwamura et al., 2014). Using simulator software for agent-based modelling is very popular. There are several programs available in this area such as AgentSheets, NetLogo, Repast, SWARM and Anylogic. These programs have different powers in different fields of study.

The outcomes of agent-based models need to be evaluated. In order to assess the accuracy of the results, the Kappa coefficient and overall accuracy are used by Eqs. (2-3). These two indexes are calculated using the confusion matrix (Table 1).

$$kappa\ index = \frac{\sum_{i=l}^{c} p_{ii} - \sum_{i=l}^{c} p_{iT}\, p_{Ti}}{1 - \sum_{i=l}^{c} p_{iT}\, p_{Ti}} \quad (2)$$

$$Overal\ accuracy = \sum_{i=l}^{c} p_{ii} \sum_{i=l}^{c} p_{ii} \quad (3)$$

where $i=1,\ldots,c$ are the existing classes, P_{ii} are the true classified pixels, P_{iT} is the sum of the pixels of class i in realty and P_{Ti} is the sum of the pixels of class i in the simulation.

Table 1. Confusion matrix

		Simulated model/Classified Image		
		Forest	***Non-forest***	***Total***
Reality	**Forest**	P_{11}	P_{12}	P_{1T}
	Non-forest	P_{21}	P_{22}	P_{2T}
	Total	P_{T1}	P_{T2}	I

2. Material and methods

In this section, first the study area is introduced and then the causes of deforestation in the study area are discussed. Afterward, deforestation is modelled and its trend in the future is evaluated.

2.1. The study area

The northern forests of Iran have been vastly damaged in the recent years. United Nations' statistics regarding land use in the north of Iran between 1988 and 2004 illustrate that during this 16-year period, 12152 ha of forest vanished. The main reasons for this destruction are: heavy livestock grazing, wasteful commercial exploitation of forests, wood smuggling, tree-felling by the woodmen for firewood, forest fires and finally land-use change for residential, industrial and agricultural purposes (Pir Bavaghar, 2015; Miremadi, 2014).

The study area of this research is Liresar, a village on the south side of Tonkabon, Mazandaran, Iran. The study area is more than 14000 ha and is located at $36^0$40'28" of latitude and $50^0$53'49" of longitude (Fig. 1).

The study area already has a forestry plan. Thus, the exploitation of wood and other actions in the forest is under this plan. In the study area, the activities of villagers are controlled, reminding them that forest land use should not change. The reason for choosing this study area is to discover how far these control plans are successful in maintaining the forest land cover.

2.2. Factors affecting deforestation

In this part, the most important factors affecting deforestation in the study area are assessed and their characteristics and behaviours are described. The agents which should be modelled act independently but simultaneously the interactions among agents and between agents and the environment (forest) produce an emergent result which can be meaningfully complex. The types of agents are described in the following:

- **Farmer and villager agents**

Rural communities settled in or near forests are closely connected to their ecosystems. Thus, inappropriate use by them may harmfully affect and finally disrupt forests. Land use changes made to agricultural areas, especially the felling of forest trees on hillsides, gradually causes serious changes to the forest environment. Yet forests are the settlement areas for these villagers so their lives strongly depend on them.

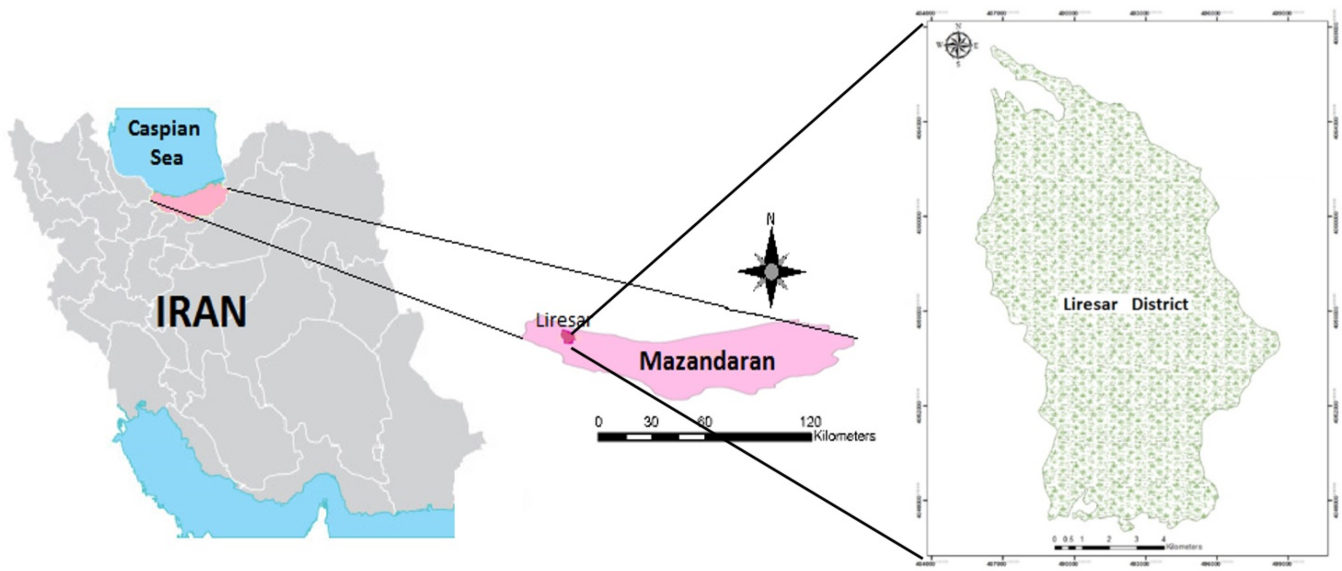


Fig. 1. Study area: Liresar Village

Farmers are a type of agent in the model. They expand agricultural and residential areas and have an important effect on deforestation. Another motivation of villagers for cutting down trees or their branches at least is using the wood for energy. Sometimes, villagers do not use the area captured from the forest themselves, but instead sell it to others who build recreational villas on it.

- **Rancher agent**

People who live in or around the forest, let livestock enter the forest and graze there. This endangers the regeneration of trees because livestock eat the planted seedlings and sprouts. Moreover, those who live in or around the forest often fell trees to use the wood as fuel or to conduct animal husbandry on the site. Destruction of the forest due to livestock grazing is severe around animal husbandry sites yet lessens as one moves further away. Field observations reveal that the most severe destruction due to livestock grazing occurs in the three kilometres around animal husbandry sites. In that area, 75% of seedlings often disappear. Table 2 illustrates the destruction around animal husbandry sites based on field observations. However, destruction due to livestock grazing occurs when the livestock stay in the forest (from the middle of autumn to spring). Livestock migrate to the countryside in the late spring and by the time they return to the forest (after around six months) the seedlings have had time to regenerate. During this six-month period, around 35% of seedlings are recreated.

Table 2. Amount of destruction around animal husbandries

Destruction (%)	***Buffer (m)***
35	500
15	1000
10	1500
5	3000

- **The beneficiary agent**

One of the most effective ways of protecting forests is planned crossing of the trees for industrial use. The forestry plan defines the time, duration and amount of wood harvesting permitted, the method that must be used and the subsequent revival operation which must be completed. The wood harvester is obliged to act within the limitations of this plan. For example, based on the forestry plan of Liresar forest (2004-2014), a wood harvester is only allowed to extract 89.985 m^3 of wood from the forest within 10 years.

As mentioned, the beneficiary is obliged to perform recreational actions such as planting seedlings. In Liresar the area of seeding planting is 823 ha and with respect to the area of the forest, which is 14500 ha, it can be calculated that 5.5% of forest is regenerated by this action. Seedlings are not appropriate to be used in industry until their circumference measures at least 30 centimetres. It is important to note that the planting of seedlings should occur away from animal husbandries because the movements of livestock destroy seedlings. In terms of exploiting the forest, the distance from existing roads is very important; areas near to the roads are exposed to more severe damage than areas that are further away. In terms of exploitation of the forests, slope is of vital importance. The ideal angle of the slope for exploitation is between zero and 30 degrees since in the case of exploiting steeper slopes, machines encounter fundamental problems in the movement or transfer of tree trunks.

2.3. Agent-based Modelling of Deforestation

In this research, agent-based modelling is used to evaluate the amount and spatial distribution of deforestation in the study area. The structure of the process is illustrated in Fig. 2. Initially, it is necessary to collect and prepare the data for modelling and simulation. These data include: maps of the forest, animal husbandries in the forest, elevation and slope. Because livestock is one of the most important causes of deforestation, the location of animal husbandries is important and the destruction around them should be determined. Another part of the data includes information about forestry exploitation, the number of recreational activities and the amount of destruction related to livestock grazing. This part of the data may change during the modelling and simulating process.

In this research, agents are divided into three categories, namely villager, rancher and beneficiary. Members of each of these categories act independently in the forest and their actions all cause problems. The beneficiary agent however, does destroy the forest but simultaneously tries to compensate at least in part, by planting seedlings.

Every agent-based model should pass three principle stages of calibration, verification, and validation. The calibration of the model (which means setting the parameters) is performed using information gathered from the forest. This information reveals that the beneficiary exploits 0.6% of the forest area every year yet tries to regenerate 0.5% by planting seedlings. On the other hand, expansion of villages and agricultural areas grew by 20% of their existing area for 10 years.

Observations focused on animal husbandries showed that the most severe damage caused by livestock grazing occurred in the 3000 metre area immediately surrounding the animal husbandry. Thus, the corresponding parameters related to these three categories of agents were set out based on this gathered information.

3. Results and discussion

In this section the results of implementation are expressed. In the next sub-section details of data and implementation are presented.

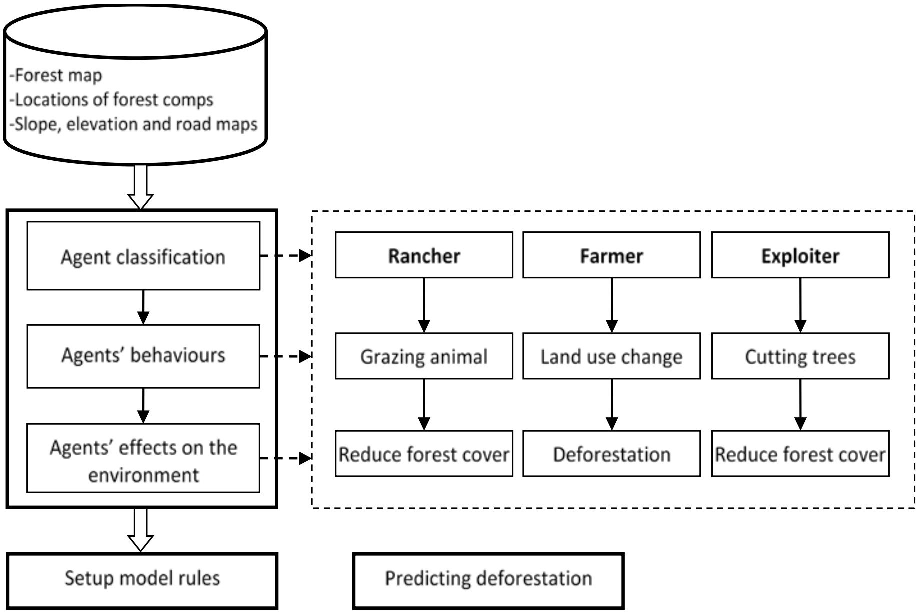


Fig. 2. Steps of implementation

3.1. Data and implementation materials

In this study NetLogo 5 which is a free agent-based modelling software was used due to its ability to model complex natural and social phenomena as well as an ability to support spatial data models. The behaviours of three types of agents as well as their interactions with the environment were implemented by coding in NetLogo. At the initialization step the data are loaded into the model. These data include the map of the area, the locations of animal husbandries, and digital elevation model as well as slope map. These data do not change during the implementation. The location of animal husbandries is vitally important because the amount of forest destruction around them is very high. Also, there are another input data involve amount of exploitation, amount of planting seedlings and the amount of destruction occurred by livestock grazing. These types of data may vary during the implementation of the model. It is worth noting that all data and statistics except the satellite images gathered from the hand-book of forestry originally prepared by Forest, Range and Watershed Management Organization of Iran. This hand-book contains information about forest exploitation over periods of 10 years, the number of dairies (animal husbandries) in the forest, and the number of cows in each. The used satellite images are free Landsat 5 and Landsat 7 images downloaded from the United States Geological Survey (USGS) website.

The input maps which are essentially in vector form have the scale of 1:25000. Before input, the some maps are converted into raster form with cell size of 10 meters. The locations of animal husbandries as well as the extents of the study area are vector maps in Shapefile format. The other input maps are raster in ascii format. On the other hand, the satellite images from Landsat 5 and Landsat 7 satellites have 30 meters resolution. To compare the results of the simulation with the classified maps extracted from the satellite images, the resolution of the result map is reduced to 30 meters.

3.2. Evaluating the results

The results of this study are validated by running the model with past data and comparing its results to the existing conditions of forests in the study area. With this aim in mind, Landsat 7 images in two time periods of 2002 and 2012 were used. First, atmospheric corrections using the "Dark Subtract" method were applied to the images and then the images were classified. The image classification method was maximum likelihood, which is a supervised method. Control samples involved forest without tree areas and villages introduced to ENVI software for supervised classification. The Kappa coefficient for classification calculated equalled 98% and 99% for 2002 and 2012 respectively. One reason for achieving good classification is that there are only two classes of forest and non-forest which is completely different. Satellite images reveal that the forest areas have reduced by 200 ha over 10 years (2002-2012) equal to 1.4% of the total area of study. In Fig. 3, a part of deforestation has been demonstrated.

The model was calibrated with the existing gathered field data. Then it was run with the 2002 data. Each epoch of run is equivalent to one year. After 10 epochs the results were compared with the real data of 2012. The overall accuracy of 95% was calculated in this comparison while the Kappa coefficient equals to 76%. These results indicate a good fit between the model and the reality.

One may argue that new seedlings planted by beneficiaries are smaller than the size that can be detectable and classifiable as forest in the satellite image of 10 years later. Although the growth of trees in a rain forest such as Liresar forest is almost fast, to be more confident the model was run for 20 epochs equivalent to 20 years. It is expected that after 20 years the planted seedlings are converted to the forest land cover. Fig. 4 shows Landsat 5 satellite image of 1992 alongside Landsat 7 satellite image of 2012. The zoomed sub-region shows a seedling area. This comparison reveals that in Liresar region new seedlings can confidently be assumed as forest after 20 years. Therefore, the model was run with data of 1992 for 20 epochs and the result was compared with the real data of 2012. The overall accuracy and Kappa coefficient were calculated equal to 89% and 70% respectively. Regarding the long simulation period, these results are also acceptable.

Most of the research on deforestation and modelling of deforestation is based on historical data and observations and such research is not appropriate for forestry policy making. This research does not consider each factor affecting deforestation individually; it instead gives an overall evaluation of it. This research, however, allows the function and effect of each factor to be monitored and tracked onward into the future. In the proposed model, various scenarios about future conditions can be implemented and the corresponding deforestation evaluated.

3.3. Current trend scenario

In this scenario, beneficiary and rancher continue their current actions in the forest. The beneficiary exploits 188.918 m^3 woods from the forest per year. The rancher also continues livestock grazing and the number of animal husbandries is constant. The villagers and farmers are not allowed to expand their farms and villages but they continue crossing trees to prepare firewood or supply other needs. Table 3 illustrates the amount of forest disruption for each of the factors per year. The results of this scenario are illustrated in Fig. 5.

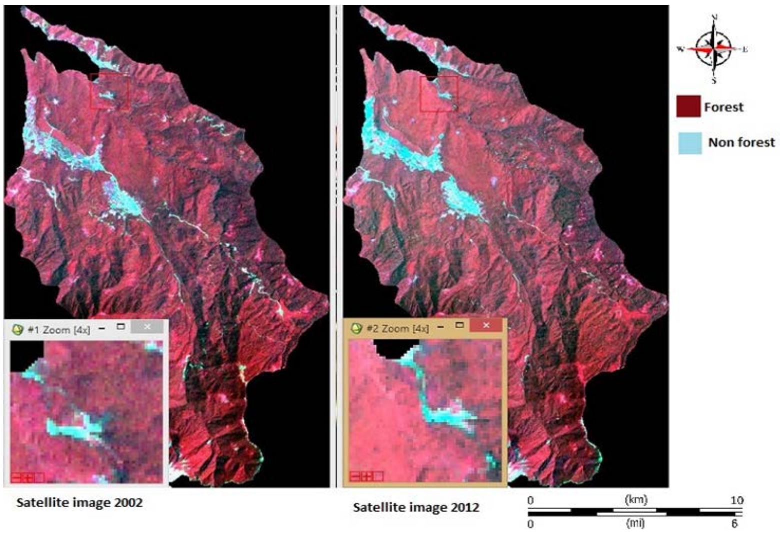


Fig. 3. Satellite imagery of deforestation (Forest areas are red and non-forest area are white)

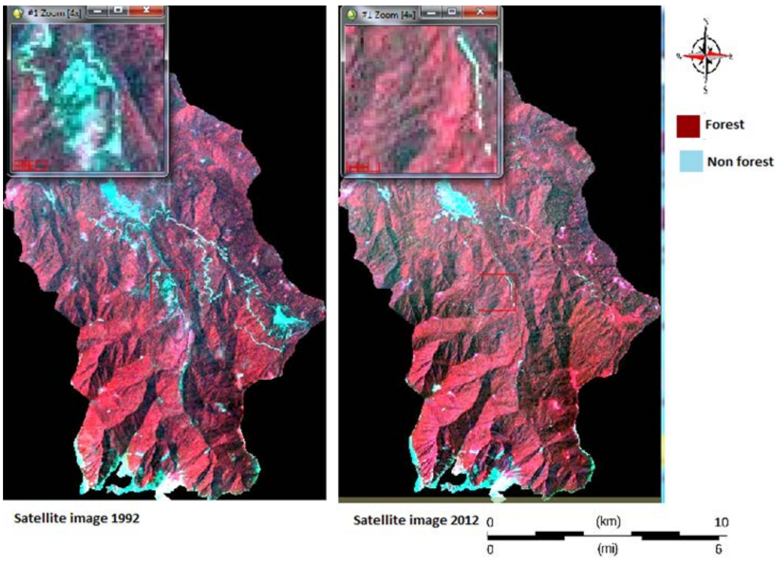
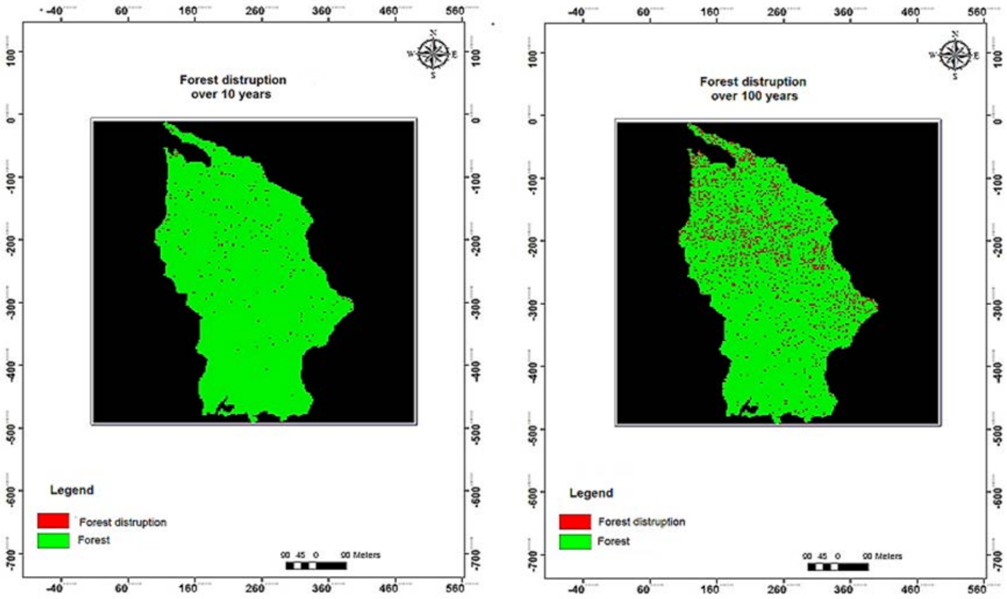


Fig. 4. Satellite Imagery of forest regenerating by seedlings (Forest areas are red and non-forest area are white)

Table 3. The changes in forest land cover (ha) in current Trend Scenario

Factor / Time	*Destruction of Beneficiaries*	*Destruction of Livestock Grazing*	*Destruction of Farmers*
10 Years	61.6	127.12	0
100 Years	587.44	949.2	0



(a) (b)

Fig. 5. Current trend scenario: (a) after 10 years (b) after 100 years

3.4. Critical trend scenario

This scenario assumes that the exploitation of the forest increases without recreational actions. In this scenario, animal husbandries still exist. Moreover, forest exploitation increases by 2.5 times- a value equal to the amount of exploitation in the previous forest plan between 1992 and 2002. Even more, in this scenario, no limitation is placed on villagers and farmers regarding expansion of their villages and farms. Simulation of this scenario shows that if this trajectory is followed, the forest will be ruined and in 10 years' time, 295 ha of forest will have vanished completely. In addition, in the coming 100 years, 17.35% of forest will be destroyed. Table 4 shows the quantity of forest destruction and Fig. 6 illustrates the simulated map.

Table 4. The changes in forest land cover (ha) in critical trend scenario

Factor / Time	*Destruction of Beneficiaries*	*Destruction of Livestock Grazing*	*Destruction of Farmers*
10 Years	168.98	125.16	1.988
100 Years	1516.2	910	1.988

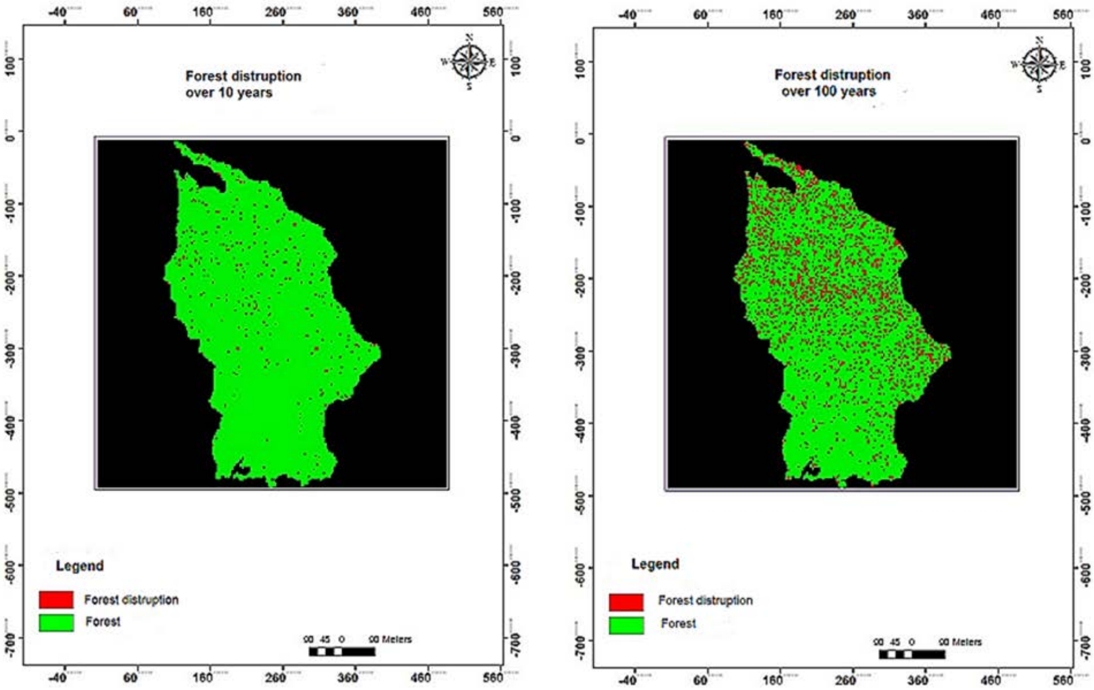
3.5. Scenario of exiting livestock from the forest

In this scenario the expansion of villages and farms is forbidden. In addition, animal husbandries are obliged to leave the forest so the destruction caused by cattle grazing is removed. However, the beneficiary continues its determined actions of exploitation and regeneration. Simulating this scenario shows that in following this trajectory, the amount of destruction reduces to 75.5 ha in 10 years which actually belongs to the beneficiary. Table 5 shows the amount and Fig. 7 illustrates the dispersion of deforestation based on this scenario. Assessment of the simulations reveals that forest land cover will be reduced by a predicted amount of about 188 ha in the next 10 years. However, the expansion of farms or residential areas is not too significant. In addition, the beneficiary must regenerate a portion of its exploitation, thus mitigating any destruction.

Table 5. The changes in forest land cover (ha) in the scenario of exiting livestock from the forest

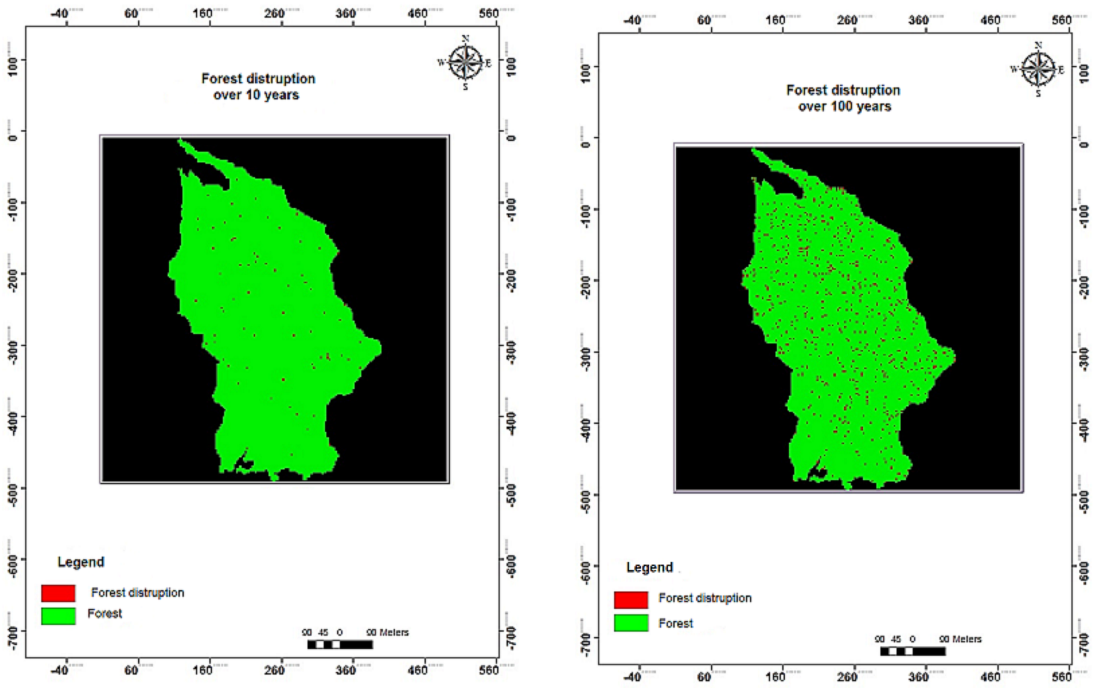
Factor / Time	*Destruction of Beneficiaries*	*Destruction of Livestock Grazing*	*Destruction of Farmers*
10 Years	75.544	0	0
100 Years	641.06	0	0

The simulation also clarified that even if the beneficiary does not perform these regeneration activities, its destruction is less than that which livestock grazing accounts for. Consequently, it becomes obvious that livestock grazing has a huge impact on deforestation and the natural recreation of the forest. The bold role of livestock grazing in deforestation is twice as important in forests that have no forestry plan, because in these forests, the number of animal husbandries is not controlled. The damage caused by livestock grazing to the forest is severe; livestock grazing limits the evolution of the forest and endangers its future. Fig. 8 shows the trend of deforestation in the coming 10 years and Fig. 9 illustrates the amount of deforestation in the future by each factor.



(a) (b)

Fig. 6. Critical trend scenario (a) after 10 years (b) after 100 years



a) b)

Fig. 7. The scenario of exiting livestock from the forest (a) after 10 years (b) after 100 years)

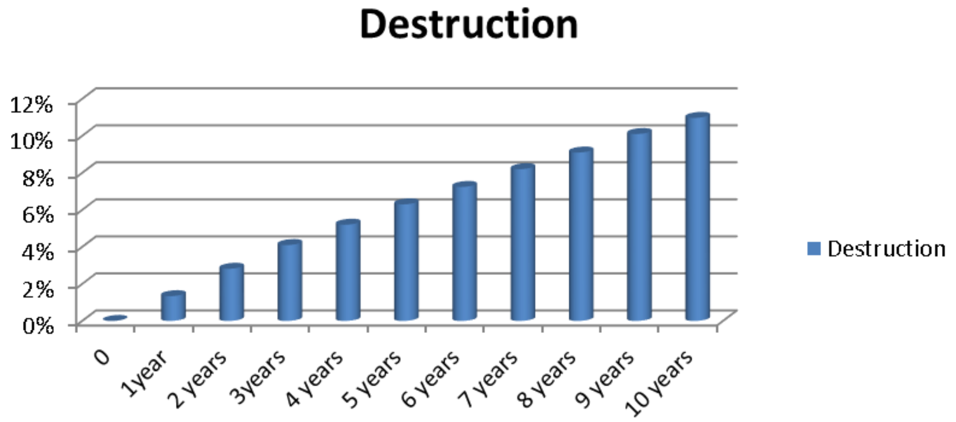


Fig. 8. Percent of forest destruction in the current trend

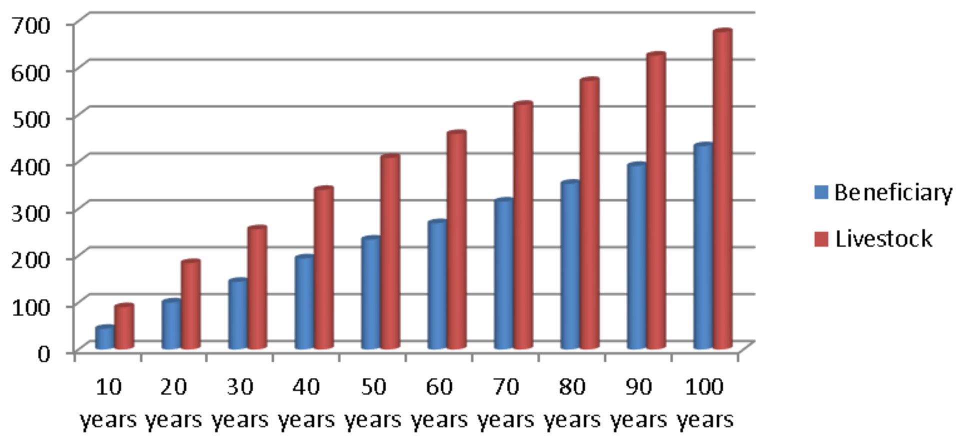


Fig. 9. Amount of the destruction of forest (ha) in the next 100 years by animal husbandries and beneficiaries separately

4. Conclusions

Most studies about deforestation do not pay much attention to the social and economic origins of land use/cover changes. However, due to the important role of these factors, this research tried to take human drivers and factors and their interactions with the environment into account. The aim of this research was to achieve a more realistic analysis, able to precisely simulate the factors affecting forest destruction. To achieve this goal, an agent-based model following an almost new approach, was used to study the complexity of actions and interactions in the forest. By simulating the behaviour of the affecting factors, the trend of changes in forest land use emerged. In this research, three types of affective actors in the forest were determined, the farmer, rancher and beneficiary-each of whom has independent behaviour that impacts on it.

According to the results, the rancher agent causes destruction of the forest equal to 0.9% (126 ha) over 10 years. This agent has been identified as being the most effective in the forest and the amount of destruction caused by him/her is more severe around the areas of animal husbandry. The amount of destruction caused by the beneficiary is 0.5%-equivalent to 70ha over 10 years. Of course, the beneficiary is obliged to undertake recreational activities which reduce the amount of destruction. The villagers and farmers who live in the forest are under intense monitoring, thus, the destruction caused by them is very low, close in fact to zero. Satellites images show that the number of changes made to the forests around villages are very low, proving that monitoring plans have been correctly implemented.

It is an ancient and routine discussion between beneficiaries and ranchers regarding who has a more important role in deforestation with each believing that the other is worse. This study, however, revealed that ranchers cause more deforestation than beneficiaries. Thus, it is recommended that more comprehensive plans be implemented to remove livestock from the forest. Upgrading traditional animal husbandry to using modern methods may be one of the effective factors to improve this, a conversion that would not only prevent deforestation but would also allow the forest to regenerate naturally.

Regarding the amount of deforestation in Liresar forest, it can be said that in general, forestry plans do achieve success but not to the levels expected or hoped for. In fact, the current trend scenario suggests that forest land cover will reduce in the future by 188 ha in the 10 years following 2012. This is a tragic figure for a forest that is under the forestry plan.

The proposed model neglects the effects of natural phenomena such as forest fires, floods and drought on deforestation. Moreover, knowing and entering the exact location where trees are cut down by beneficiaries may strengthen the effectiveness of the model in terms of simulation.

Beyond that, a combination of agent-based modelling with cellular automata is recommended for future studies. Such a combination can consider both socioeconomic as well as natural and physiographic factors affecting deforestation.

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