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# Impact of Land Cover Changes on Reducing Greenhouse Emissions: Site Selection, Baseline Modeling, and Strategic Environmental Assessment of REDD+ Projects

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## Abstract

Reducing emissions from deforestation and forest degradation (REDD+) is way key to reduce the emission of greenhouse gases (GHGs) while also protecting vulnerable forest ecosystems. The purpose of this study was to recognize suitable areas for REDD+ Programme projects and calculate the reduction in $CO_2$ emissions through the prevention of forest cover degradation in the Central Hyrcanian forests. For this purpose, the cover changes of the Central Hyrcanian forests were assessed using LANDSAT satellite images. Applying the voluntary carbon standard (VCS) methodology and the calibration period 1984–2014 (30 years), forest cover changes were predicted. The results showed that under the business-as-usual scenario, 155,698 ha of Central Hyrcanian forests will be declined by 2044. In general, the REDD+ Programme project implementation will prevent the release of 1,209,231 $tCO_2e$. Based on the social cost of carbon (SCC) approach, the REDD+ Programme project implementation can save 12,092,310 US$. In addition, this approach can be used for the project design document (PDD) of the forest development mechanism.

KEYWORDS

carbon stock, environmental assessment, forest cover change, multi-criteria evaluation, REDD+ Programme

## 1 | INTRODUCTION

Deforestation and forest degradation are recognized as critical environmental issues that contribute significantly to global greenhouse gases (GHGs) emissions (Fujisaki et al., 2020; Mattsson et al., 2012; Sheng et al., 2016). The United Nations Framework Convention on Climate Change (UNFCCC) introduced an international management mechanism to confront climate change, namely Reducing Emissions from Deforestation and Forest Degradation (REDD+) (Maraseni et al., 2020; Sheng, 2020; Srinivasarao et al., 2022). In recent years, REDD+ projects have been considered as a worldwide policy to avoid deforestation in developing countries (Atela et al., 2014; Lin et al., 2014; Maraseni et al., 2014; Wei et al., 2020). REDD+ projects are planned to increase carbon sequestration and forest conservation (Ji & Ranjan, 2019; Kassi et al., 2021) in areas facing extreme land use changes (Atela et al., 2014; Han et al., 2020). Furthermore, REDD+ initiatives would prohibit activities such as forest conversion to agricultural areas, indiscriminate tree removal, and any other human involvement in the environment.

To identify suitable regions for REDD+ projects, the most important criteria are substantial carbon stocks in the forest ecosystem, high deforestation rates, and the ability of the region to conserve the ecosystems (Salvini et al., 2016). Thus, choosing a method for site selection for REDD+ is very challenging because the economic and social issues and some activities of the governmental and nongovernmental sectors are affected by the projects (Satyal et al., 2020).

  

There are concerns about the success of REDD+ projects: how they would prevent forest degradation and deforestation, the impact of REDD+ projects on biodiversity protection and ecosystem services, and the effect of REDD+ projects on local people's living circumstances (Githiru & Njambuya, 2019). The strategic environmental assessment (SEA) can be applied to assess the environmental impacts of REDD+ policies. For strategic environmental evaluation, the rapid impact assessment matrix (RIAM) might be employed. RIAM is a technique for determining the possible effect of environmental initiatives and has been used in similar previous studies (Brandolini et al., 2018; El Gohary & Armanious, 2017; Mao et al., 2018). So far, RIAM has not been used for the SEA of the REDD+ projects. In this study, the SEA of REDD+ projects was considered as an innovative way to support decision-makers.

Forest cover change modelling has been investigated in many research studies with the aim of identifying areas facing deforestation. For instance, forest cover change was examined by Ty et al. (2011) in the Oddar Meanchey Province of Cambodia. The results showed that REDD+ projects will prevent 8,592,501.7 tons of $CO_2$ emissions between 2008 and 2038. A study in the Mantadia conducted by Eastman (2015a) showed that a REDD+ project can successfully reduce carbon emissions. Implementation of a REDD+ project in the Juma's protected area in Brazil indicated that the REDD+ project is effective in avoiding carbon emissions in the future (Yanai et al., 2012). Lin et al. (2014) identified the suitable regions for REDD+ projects by the weighted linear combination (WLC) procedure. They used five criteria: forest carbon, biodiversity, poverty alleviation, deforestation threat, and opportunity cost. Although many studies have been conducted on deforestation modelling, only Lin et al. (2014) applied the multi-criteria evaluation (MCE) approach to identifying suitable areas for REDD+. Most of these studies provide a brief overview of each project, and a series of process and experience-oriented 'lessons learned'. However, considering the enormous number of developing REDD+ initiatives in forest zones, data remains relatively scarce. Therefore, this study tried to fill these gaps and examined the ordered weighted average (OWA) procedure for the identification of suitable areas for REDD+ projects. The purpose of this study is to identify suitable areas for REDD+ projects and calculate the reduction in $CO_2$ emissions through the prevention of forest cover degradation in the Central Hyrcanian forests. Then a technique is suggested that considers locals' involvement in all phases of measuring, reporting, and verification. Locals can really learn how to assess carbon stocks or emissions in the context of REDD+. When locals' contribution to the REDD+ monitoring and validation components, as well as any resulting benefits, are taken into consideration, more difficulties appear. As a result, policy-makers, planners, and researchers should emphasize the use of interdisciplinary research to solve the many complicated difficulties associated with the implementation of REDD+ programmes. The subject of this study is important for climate change analysis. Using results and methodologies from the literature, this analysis indicates that REDD+ programmes can cut carbon emissions. In fact, the calibration period of 1984–2000, applied to predict forest cover change in 2014, showed that deforestation modelling had high accuracy and also, the scenario with equal weight for all criteria has the best result for identifying suitable areas for REDD+ projects. Iran has a high biodiversity of plant and animal species due to diverse climatic conditions. Many of these species are endangered, so forest and rangeland conservation projects aimed at controlling the risk of extinction of rare species are on the agenda of the Iranian Government, and various projects are underway to this end (Roudgarmi & Mahdiraji, 2020). For instance, the natural environment conservation project on Qeshm Island and Anzali wetland ecological management project in Gilan Province are examples of such projects.

In fact, achieving the goals and effective and successful results of REDD+ projects in Iran requires effective policy-making, accurate and transparent project design, and step-by-step monitoring during project implementation. Factors such as sovereignty, capacity, and rights to occupy land, justice, transparency, indigenous people's rights and knowledge, and increasing local and institutional capacities have been some of the most important reasons for the failure of these projects in Iran (Parsamehr et al., 2019; Shooshtari & Gholamalifard, 2015). In addition, initiatives like REDD+ may improve the standard of living for people who depend on forests by reducing poverty, increasing income through payments made in exchange for carbon credits, and providing extra advantages like better land tenure or carbon ownership (Bayrak & Marafa, 2016). The extent of central Hyrcanian forest has significantly decreased as a result of major land use changes in the Province of Mazandaran in recent decades. The forest cover decreased by about 4008 ha and 3635 ha during 1984–2000 and 2000–2014, respectively. With reference to rising deforestation in Central Hyrcanian forests and their critical role in climate change mitigation, land cover changes and the impact of REDD+ projects on lowering greenhouse gases (GHG) emissions may be evaluated and projected using the methods presented. Furthermore, the REDD+ data can be utilized to complete the Country's Project Design Document (PDD) for the Clean Development Mechanism (CDM). REDD+ projects are mainly handed over to the public and semi-private sectors. Therefore, some of these projects are research-based projects supported by research institutions, and some others are governmental-based and no private sector is involved in the implementation of these projects (Parsamehr et al., 2019).

The Central Hyrcanian forests of northern Iran, located near the Caspian Sea, are part of Iran's natural resources under the protection and supervision of the Iranian Forests and Natural Resources Organization. Some of these forests have been used by the villagers due to their proximity to their villages. Some of these resources have changed their land use to agricultural purposes. For this reason, in order to protect this national heritage, REDD+ projects have been started in this area.

One of the factors contributing to GHG emissions in emerging nations is land cover change. Iran is one of the countries facing the challenge of land use changes, especially deforestation. The Central Hyrcanian forests serve as a good case for the implementation of the REDD+ projects. They are one of the important resources for carbon sequestration in the world. In recent decades, they were faced with excessive deforestation and forest degradation, the decline in the extension of these forests has been mentioned. For example, the Central Hyrcanian forests lost 162,867 ha of their forest cover from 1984 to 2010. In the coastal areas, 33,487 ha of the Central Hyrcanian forests were reduced between 1988 and 2010 (Gholamalifard et al., 2012). The REDD+ project can be a good solution to deal with deforestation in the Central Hyrcanian forests. The primary objectives of this study are to select appropriate sites for REDD+ projects and to estimate the amount of carbon that REDD+ would save at each of the selected sites.

This study demonstrates how to apply a spatial targeting technique for REDD+ initiatives in Iran that accounts for land opportunity cost, deforestation risk, and variation in Central Hyrcanian forest carbon. This study identifies suitable areas for REDD+ projects that focus on reducing deforestation, rather than the original motivation for REDD+. Furthermore, by identifying locations with the potential for biodiversity conservation, poverty alleviation, and carbon emission reduction, the goal reflects the growing expectation. LANDSAT satellite images were used for this purpose to analyze changes in the Central Hyrcanian forest cover. Future deforestation patterns are created using historical data on land cover changes from a land change modeller (LCM). Future deforestation trends are combined using multi-criteria evaluation modules. We define the regions designated as suitable REDD+ landscapes under one targeted method. As a result, the unique combination of methods used in this study is the work's innovation. Finally, we compare the locations of REDD+ projects in Iran and other Central Hyrcanian forests around the world with our spatial targeting maps.

This research suggests a methodology that considers the involvement of local people in all phases of measuring, reporting, and verification. Locals can really learn how to assess carbon stocks or emissions in the context of REDD+. When locals' contribution to the REDD+ report and validation components, as well as any resulting benefits, are taken into consideration, more difficulties appear. Thus, policymakers, planners, and academics should favour the use of multidisciplinary research to address the various and complex issues connected with the execution of REDD+ projects.

## 2 | MATERIALS AND METHODS

Developing countries can achieve financial advantages through REDD+ projects. In this study, the GeOSIRIS modeller in the TERRSET software and RIAM were used as tools for modelling the impacts of the REDD+ policy. The TERRSET software combines the Idrisi geographic information system (GIS) and image processing tools and suggests vertical applications for modelling the Earth system. The policy set for GeOSIRIS modeler uses a carbon payment system to motivate emission reductions and it can be implemented at various legal levels, such as the region or county (Nahib, Turmudi, Munajati, & Windiastuti, 2018).

Land-use/land-cover (LULC) change models are used for the simulation of future forest cover change (Mas et al., 2014; Sahoo et al., 2018). The efficiency of LULC models depends on their transition potential modelling (Streck, 2020). LCM is one of the most important procedures for baseline modelling of REDD+ (Kim, 2010) and has been used in many studies for land change modelling (Heidarlou et al., 2019; Nahib, Turmudi, Windiastuti, et al., 2018; Reddy et al., 2017; Roy et al., 2014).

The GIS software provides tools that can help decision-makers in spatial analyses. These tools are very useful in modelling, predicting, and site selection (Lin et al., 2014). MCE consists of three approaches: Boolean, WLC, and OWA. WLC was used by Lin et al. (2014) for identifying suitable areas for REDD+ in Tanzania. The impact ofdecision strategy space (DSS) and its scenarios have not been examined for site selection of suitable areas for REDD+. In this study, we examined the OWA procedure for site selection of suitable areas for REDD+ projects. As shown in Figure 1, this research consists of four stages as follows: (1) forest cover change modeling by LCM, (2) MCE and site selection, (3) REDD+ baseline modeling based on the voluntary carbon standard (VCS) method, and (4) SEA of REDD+ projects using the GeOSIRIS model and RIAM.

### 2.1 | Study area and data

The study area is Mazandaran Province located in northern Iran. The Central Hyrcanian forests are located in Northern Iran. Mazandaran Province is approximately 24,000 $km^2$ and lies between 35° 47 and 38° 5 Northern latitudes and 50° 34 and 56° 14 Eastern longitudes (Figure 2) (Ghorbani et al., 2015). The spatial data sources used are presented in Table 1. The protected areas and agricultural land cover about 20.58% and 25% of the Mazandaran Province (Mehri et al., 2014; Mirzayi et al., 2013). All map layers were converted to raster data according to spatial coordinates (WGS 1984/UTM zone 39 N). The pixel size for layers was considered as 30 m × 30 m. In this study, the forest layer map of 1984 was derived from a study by Mirzayi et al. (2013). Furthermore, the forest layer maps of 2000 and 2014 were gathered from a study by Parsamehr et al. (2019). LANDSAT images - TM and ETM+ were used for generating forest cover maps in 1984 and 2000 (Mirzayi et al., 2013; Parsamehr et al., 2019). In addition, for the year 2014, forest images were digitized from LANDSAT images in Google Earth (Parsamehr et al., 2019). Forest cover maps for the three time periods are presented in Figure 3.

The data used in the research project was produced in Iran. To evaluate the accuracy, the control points were produced on the satellite image of the date in question and were visually checked. For the date of 2014, field visits were also made and then the necessary corrections were made. The data used have the necessary accuracy to continue the analysis.

In general, the GeOSIRIS model was applied to evaluate the impact of the REDD+ project on reducing emissions within each county. In this study, the GeOSIRIS showed which county could benefit from more carbon credits due to the prevention of deforestation (see Supplementary Information, Table S11). In fact, the GeOSIRIS model helps create a rewards and penalties system for each administrative level. Administrative levels that perform better will be

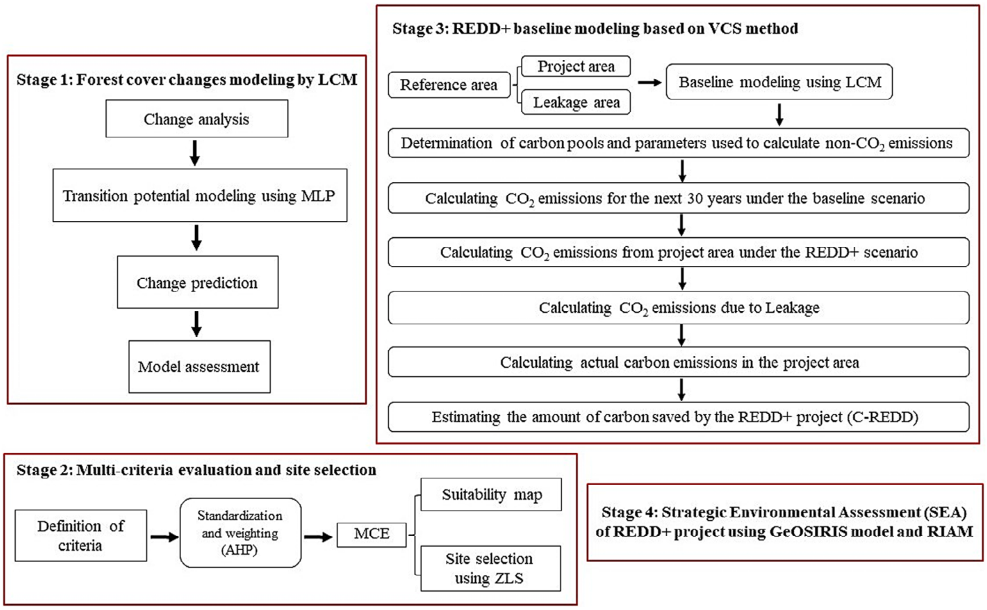


**FIGURE 1** Flowchart of the procedure used in this research. [Colour figure can be viewed at wileyonlinelibrary.com]

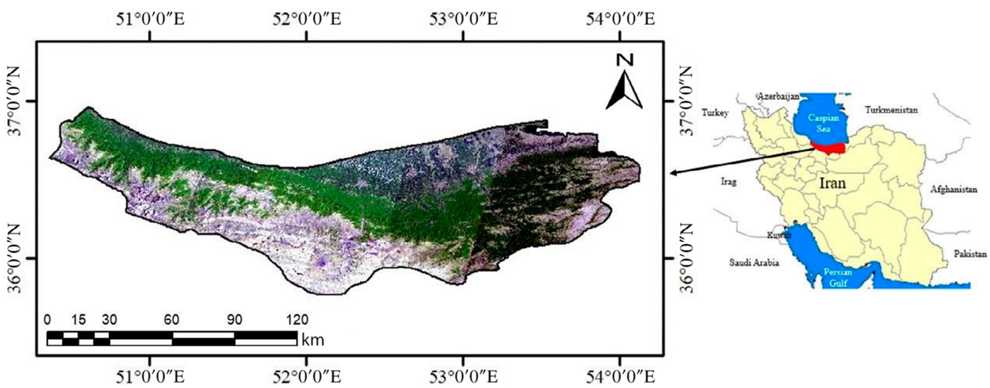


**FIGURE 2** Study area (Central Hyrcanian forests). [Colour figure can be viewed at wileyonlinelibrary.com]

encouraged by carbon credits and will have a greater incentive to reduce carbon emissions.

## 2.2 | Forest cover changes modelling by LCM

The change analysis tab in LCM was used for change detection. We examined forest cover changes during 1984, 2000, and 2014. In addition, the spatial trend maps of deforestation for 1984–2000 and 2000–2014 were evaluated (Eastman, 2015b). The multi-layer perceptron (MLP) neural network method was used for transition potential modelling from forest to nonforest conversion (Eastman et al., 2005). MLP can model a nonlinear relationship between the variables (Kim, 2010). The driver variables used in the MLP model were prepared by Parsamehr et al. (2019) (Figure S1). The relationship between forest cover changes as the dependent variable and the driver variables was tested by Cramer's V (see Supplementary Information, Table S1) (Kim, 2010). The test shows a statistical relationship between the dependent variable and driving variables. If it is closer to one, there is a stronger relationship (Kumar et al., 2014).

The accuracy rate and skill statistic were considered for validation testing of the MLP model. The accuracy rate demonstrates that the MLP, after iterations of training the network with appropriate accuracy, is capable of correctly predicting validation pixels. There are chance predictions in the validation test. For example, if one transition is modelled, then there are two answers to predict each pixel: change or persistence. There will be a 50% chance of a correct answer for a change. By increasing the number of transitions, the possibility of a chance response will be reduced. The skill statistic was introduced to solve this problem. It ranges from $-1.0$ to $+1.0$. The model with a skill of 0 indicates a random chance. A skill of $+1.0$ indicates a perfect prediction. A model with a negative skill indicates that it is performing worse than chance (for more information refer to Eastman, 2015b).

The calibration period of 1984–2000 was applied to predict forest cover change in 2014. The likelihood of forest cover transition to non-forest cover was calculated using the Markov chain (Eastman, 2015a). For model assessment, statistics of relative operating characteristic (ROC), hit/false alarm rate (Eastman, 2015b), and figure of merit (FOM) (Kim, 2010) were used. The ROC can compare a transition potential image with an actual change image. If the ROC value is 1, it indicates perfect agreement, and if it is 0.5, it indicates a chance agreement (Eastman, 2015a). FOM has a value from 0 to 100 percent (closer values to 100 indicate perfect prediction). FOM was calculated from Equation (1) (Kim, 2010) where A refers to pixels

TABLE 1 Spatial data sources

| Data | Source |
|---|---|
| Updated global map of terrestrial carbon stocks | Kapos et al. (2008) |
| Global above and below-ground living biomass carbon density | Ruesch & Gibbs (2008) |
| Global soil organic carbon | |
| Global map of opportunity cost | Naidoo & Iwamura (2007) |
| Land cover map of 1984 | Mirzayi et al. (2013) |
| Forest cover maps of 2000 and 2014 | Parsamehr et al. (2019) |
| Digital elevation model (DEM) | NASA's Earth Observation System Data and Information System (EOSDIS) |
| Village points | National Cartographic Center of Iran (http://www.ncc.org.ir) |
| Village boundaries | National Cartographic Center of Iran (http://www.ncc.org.ir) |
| Roads | National Cartographic Center of Iran (http://www.ncc.org.ir) |
| Rivers | National Cartographic Center of Iran (http://www.ncc.org.ir) |
| Protected areas | Environmental Protection Agency of Iran (2015) |
| Residential areas of 1984 | Mirzayi et al. (2013) |

whose persistence has been predicted by the model, but they did not persist (losses); B refers to pixels whose change has been predicted by the model, and they did change (hits); and C refers to pixels whose change has been predicted by the model, but they did persist (false alarms) (Kim, 2010; Kiourtis et al., 2018). In addition, if the Hit/False alarms rate is about 25%, the model has good performance (Eastman, 2015b). After verifying the accuracy of the model, the forest cover change prediction was done using the calibration period of 1984–2014 (30 years). The transition potential map for the year 2044 was considered as an input for MCE. A ROC equal to 0.975, hits/false alarms rate equal to 77%, and a FOM equal to 26.8% were obtained for the MLP model. FOM was calculated as follows:

$$\mathrm{FOM} = \left(\frac{395.351}{567.033 + 395.351 + 510.412}\right) = 0.268 \times 100 = 26.8\% \tag{1}$$

## 2.3 | Multi-criteria evaluation

Multi-criteria evaluation (MCE) is utilized as a method to compare different scenarios and help decision-makers choose the best alternative (Lin et al., 2014). To select a suitable area for a REDD+ project, a WLC and an OWA were applied to the multi-criteria evaluation embedded in TerrSet (Lin, 2012). The International Union for the Conservation of Nature's *Red List* and the biodiversity hotspot concept are two methods for quantifying biodiversity richness. We should choose the distance to the protected area since, according to some research (such as Lin et al., 2014), it indicates both the presence of biodiversity and the desire to preserve it. Information related to protected areas is obtained from the Department of Environment of Iran. It is assumed that protected areas have high biodiversity (the larger the area of these areas, the greater the biodiversity) because the habitat of different species of animals and plants is diverse and not limited. Accordingly, and given the previous studies (e.g., Carter et al., 2017; Matheus, 2018), it is assumed that distance from protected areas can be considered as a criterion in locating REDD+ projects. In this study, the multi-criteria evaluation (MCE) approach has been defined based on the studies by Lin et al. (2014) and Parsamehr et al. (2019). The criteria used in MCE included carbon stocks map defined by Kapos et al. (2008), distance from the protected areas, deforestation threat (output of the MLP model), and opportunity cost map defined by Naidoo and Iwamura (2007). The carbon layer refers to the terrestrial carbon stocks (tC/ha). The distance from the protected areas relates to biodiversity protection. The opportunity cost represents that the agricultural land has neglected economic benefits once forest conservation is implemented. In order to compare the criteria, they were standardized by the fuzzy membership functions (Table S2) (Eastman, 2015a). This study used the pair-wise comparison function to set up the multi-criteria evaluation module to weigh the criteria (Saaty, 1990). To assess the suitability of areas for REDD+, three scenarios have been defined (Table S3). Then, the zonal land suitability (ZLS) method was used to select the REDD+ project site [Equation (2)] (Eastman, 2015b). In Equation (2), zonal land suitability is Sz[1], local appropriateness of the pixels *i* related to the zone *z* is $(\mathrm{Li})_z$, and the number of pixels in zones of z is $n_z$.

$$S_z = \frac{\sum (\mathrm{Li})_z}{n_z} \tag{2}$$

In this study, the weights justification is retrieved from Lin et al. (2014). The OWA is the same as the WLC method, but it considers two types of weight: (1) the factor weight regulates the relative share of the special criterion, and (2) the order weight regulates the aggregation of the weighted criteria (Gorsevski et al., 2012). The OWA procedure represents a range of risk situations between AND and OR operators (Malczewski, 2006). The risk situations in the DSS are defined by risk and trade-off (see Supplementary Information, Figure S2). The degree of the weights' dispersion controls the trade-off level which represents the compensation measurement. Risk and trade-off are calculated by Equations (2), (3), and (4) (Jiang & Eastman, 2000). The total number of criteria is *n*, the order of criteria is *i*, and the weight for the criteria of the *i*th order is *Wr*.

$$\mathrm{ANDness} = (1/(n-1)) \sum ((n-i) W_{order\,i})\; ORness = 1 - \mathrm{ANDness} \tag{3}$$

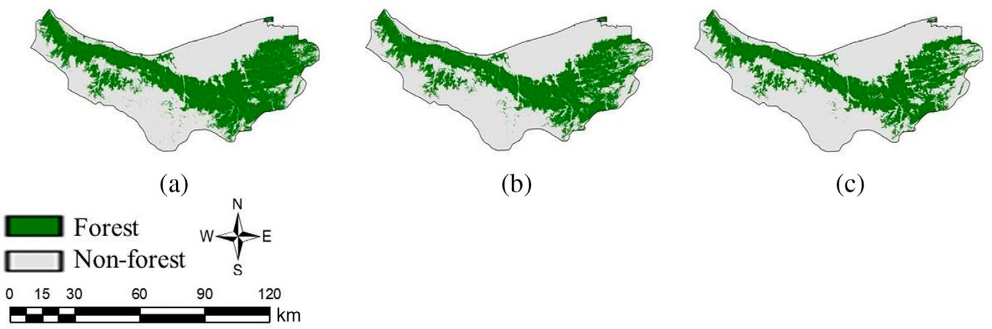


**FIGURE 3** Forest cover maps. (a) 1984, (b) 2000, (c) 2014. [Colour figure can be viewed at wileyonlinelibrary.com]

$$\text{Trade}-\text{off} = 1-\sqrt{\frac{n\sum\left(W_{\text{order}\,i}-1/n\right)^2}{n-1}} \tag{4}$$

ANDness is from 0 to 1, and values closer to 1 indicate that the risk is low. ORness is from 0 to 1, and values closer to 1 indicate that the risk is high (Jiang & Eastman, 2000). Order weights control the degree of trade-off. The trade-off closer to 1 indicates full compensation between the criteria (Gorsevski et al., 2012). After selecting the best option from defined scenarios in Table S3, the impact of order weight was examined for it (see Supplementary Information, Table S4).

## 2.4 | REDD+ baseline modelling based on the voluntary carbon standard (VCS) method

In this study, the VCS method offered by Bio Carbon Fund (BIOCF) was used for the implementation of a REDD+ project for each site (Pedroni et al., 2008). LCM module was used for a REDD+ implementation using the TerrSet software (Eastman, 2015a).

Each site as a reference area was divided into two geographical areas: project and leakage areas. Forest protection is considered in the project area. The leakage area is located around the project area and deforestation activities will probably be transferred to this area. In fact, the leakage area is likely to experience the consequences of the protection of the project area (Pedroni et al., 2008). For REDD+ baseline modelling, the calibration period of 1984–2014 (30 years) was considered, and forest cover change was predicted for 2044. The amount of carbon average in forest and nonforest areas for site selection was estimated using the global map of terrestrial carbon stocks by Kapos et al. (2008) (Table S9). The business-as-usual approach will not alter in the current circumstances; rather, the existing situation indicates developments without REDD+ (Pedroni et al., 2008). In this study, lowering tCO2e emissions over the next 30 years and 5 years was explored (Eastman, 2015a).

Six carbon resources provided in the VCS methodology include above-ground carbon, below-ground carbon, dead wood, harvested wood products, litter, and soil organic carbon. They are considered for the calculation of $CO_2$ emissions caused by deforestation. Furthermore, non-$CO_2$ emissions such as $CH_4$ and $N_2O$ caused by forest fires are calculated (Pedroni et al., 2008). In this study, these parameters were ignored because there was no suitable data for non-$CO_2$ emissions.

Based on the business-as-usual scenario, the reduction in forest area and carbon stocks was calculated for the next 30 years (for every 5 years) in the project and leakage area using the following equations (Pedroni et al., 2008):

$$\{\text{deforested area(ha)}\}\times\left\{\begin{array}{c}\text{average carbon density}\\ \text{in forest area}\left(\text{tCOe}^2/\text{ha}\right)\end{array}\right\} = \left\{\begin{array}{c}\text{CO}^2\text{ emissions from forest area}\\ \text{under business}-\text{as}-\text{usual scenario}\end{array}\right\} \tag{5}$$

$$\{\text{non\_forest area(ha)}\}\times\left\{\begin{array}{c}\text{average carbon density}\\ \text{in non\_forest area}\left(\text{tCOe}^2/\text{ha}\right)\end{array}\right\} = \left\{\begin{array}{c}\text{sequestrated carbon in the}\\ \text{non\_forest area under business}-\text{as}-\text{usual scenario}\end{array}\right\} \tag{6}$$

$$\left\{\begin{array}{c}\text{CO}^2\text{ emissions from forest area}\\ \text{under business}-\text{as}-\text{usual scenario}\end{array}\right\} - \left\{\begin{array}{c}\text{sequestrated carbon in the}\\ \text{non\_forest area under business}-\text{as}-\text{usual scenario}\end{array}\right\} = \left\{\begin{array}{c}\text{total CO}^2\text{ emissions}\\ \text{from project and leakage area}\\ (\text{C}-\text{Baseline})\end{array}\right\} \tag{7}$$

The expected outcomes of the REDD+ project were determined by leakage and success rates. These rates determine how much carbon emission is expected to be reduced during the project implementation (Pedroni et al., 2008). In this study, the REDD+ project information in the Mantadia National Park was used to determine the rates of leakage and success (Table S5) (Eastman, 2015a). The reduction of carbon stocks due to the implementation of the REDD+ project (relocation of deforestation activities) within the leakage region is defined as leakage. An increase in $CO_2$ emissions that occurs due to leakage was calculated using Equation (8). In Equation (9), the actual carbon saved within the project area can be calculated using the success rate. Then Equation (10) estimates actual $CO_2$ emissions under the REDD+ project (Pedroni et al., 2008).

$$\left\{\begin{array}{c}\text{total } CO_2 \text{ emissions from project area}\\ \text{under business}-\text{as}-\text{usual scenario}\end{array}\right\}\times\{\text{leakage rate}\} = \left\{\begin{array}{c}CO_2 \text{ emissions due to Leakage}\\ (\text{C}-\text{Leakage})\end{array}\right\} \quad (8)$$

$$\left\{\begin{array}{c}\text{total } CO_2 \text{ emissions from project area}\\ \text{under business}-\text{as}-\text{usual scenario}\end{array}\right\}\times\{\text{success rate}\} = \left\{\begin{array}{c}\text{actual carbon saved}\\ \text{within the project area by REDD+}\end{array}\right\} \quad (9)$$

$$\left\{\begin{array}{c}\text{total } CO_2 \text{ emissions from project area}\\ \text{under business}-\text{as}-\text{usual scenario}\end{array}\right\} - \left\{\begin{array}{c}\text{actual carbon saved}\\ \text{within the project area by REDD+}\end{array}\right\} = \left\{\begin{array}{c}\text{actual carbon emissions}\\ \text{under REDD+project}\\ (\text{C}-\text{Actual})\end{array}\right\} \quad (10)$$

The amount of carbon saved by the REDD+ project (C-REDD+) over the next 30 years was calculated using Equation 11. The output of REDD+ baseline modeling is a file named Project Design Document (PDD). It indicates carbon stocks change in the project and leakage area during the implementation of the project (Pedroni et al., 2008).

$$\{\text{C}-\text{baseline within project area}\}-\{\text{C}-\text{Actual}\}-\{\text{C}-\text{Leakage}\} = \{\text{CREDD+}\} \quad (11)$$

The reduction of $CO_2$ emissions has economic benefits. The current carbon market price per metric or an equal amount of $CO_2$ per ton leads to economic valuation (World Bank, 2017). Because of policies, subsidies, and other legislative influences, carbon prices often change. That is why the social carbon cost (SCC) may be a better carbon price estimate. The SCC estimates the benefit to society by eliminating the damage caused by each extra metric ton of $CO_2$ released into the atmosphere (Bell, 2011; Nordhaus, 2011). In this research, economic benefits from the reduction of $CO_2$ emissions were estimated using Equation (12):

$$\text{C}-\text{REDD}+\times \text{US\$10 per ton } CO_2 \text{ equivalent} \quad (12)$$

## 2.5 | Strategy environmental assessment of the REDD+ project

A SEA is a methodical procedure for assessing the environmental consequences of a proposed policy, strategy, or programme. It is appropriate for the early assessment of cumulative impacts, as well as economic and societal factors. A successful SEA also requires public participation. In comparison to an environmental impact assessment (EIA), a SEA provides strategic recommendations and allows for better control of interactions and cumulative effects (Tamasang & Ngwome, 2018). The environmental consequences of the REDD+ projects were investigated using the RIAM. Pastakia and Jensen (1998) introduced the RIAM matrix and its concepts (Table S6). The evaluation criteria of A and B were defined based on Pastakia and Jensen's (1998) study, which: (1) the criteria (A) are metrics relevant to the condition that the score obtained can be changed individually, and (2) the criteria (B) are metrics valuable to the situation, but incapable of changing the score acquired individually. The criteria (A) are impact (A1) and magnitude (A2). The criteria (B) are permanence (B1), reversibility (B2), and cumulatively (B3). Eventually, the final score or environmental score (ES) is calculated by the following equations (Table S7):

$$(A_1)\times(A_2)=A_T \quad (13)$$

$$(B_1)+(B_2)+(B_3)=B_T \quad (14)$$

$$(A_T)\times(B_T)=ES \quad (15)$$

In this research, the GeOSIRIS modeller was used for modelling the impact of the REDD+ policy in Mazandaran Province. The GeOSIRIS model predicts the changes in deforestation rate, carbon emissions, agricultural income, and carbon payments when a REDD+ paradigm has been implemented (Nahib, Turmudi, Munajati, & Windiastuti, 2018). The GeOSIRIS step flowchart is shown in the Supplementary Information (Figure S3). In GeOSIRIS, the relationship between deforestation and other spatial variables is calculated using a regression model (Nahib, Turmudi, Munajati, & Windiastuti, 2018). The deforestation image as one input should represent deforestation that has occurred in recent years (for further study about GeOSIRIS refer to Nahib, Turmudi, Munajati, & Windiastuti, 2018).

In RIAM, four categories of environmental components are defined as physical/chemical (PC), biological/ecological (BE), sociological/cultural (SC), and economic/operational (EO). In this study, the components used in the creation of the RIAM matrix are listed in the Supplementary Information (Table S8). Furthermore, some GeOSIRIS outputs were applied as components in the RIAM matrix. The optimum location with the fewest negative consequences was chosen. Although there is widespread support for REDD+ at the moment, several concerns remain unsolved, including funding to maintain the process and providing adequate socioeconomic incentives to reduce deforestation. Other essential criteria in these initiatives include defining reliable deforestation baselines, the technical challenges of monitoring and approving changes in forest cover, and worries about inadequate governance and illicit logging (Samndong et al., 2018). The most crucial socioeconomic elements of REDD+ projects include respect for landowners' rights, land occupation, involvement of communities' dependent on forests, sustainable forest management, preservation of forests as intact ecosystems, preservation of biodiversity, and environmental services in carbon-rich ecosystems (Adekugbe et al., 2020).

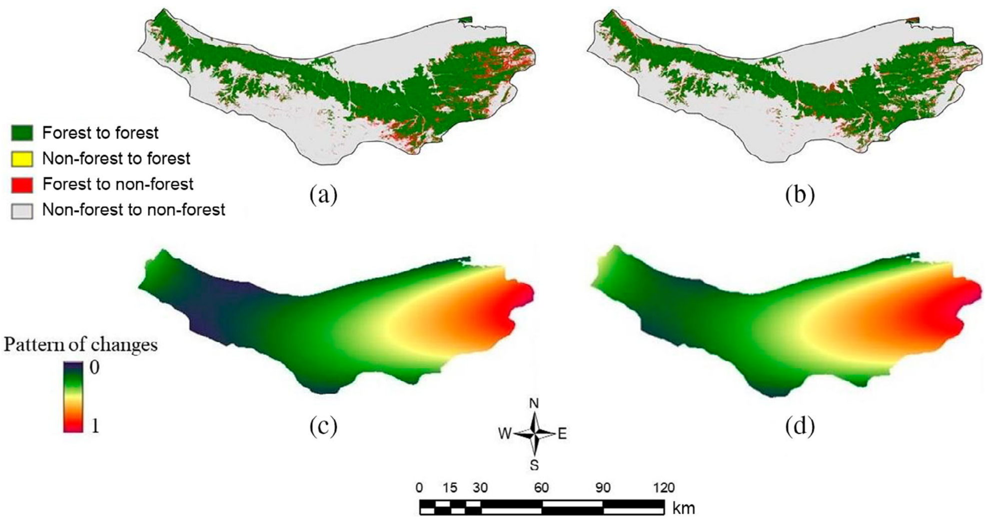


**FIGURE 4** Change analysis. (a) change analysis between 1984 and 2000, (b) change analysis between 2000 and 2014 [adapted from Parsamehr et al. (2019)], (c) spatial trend of 1984–2000, (d) spatial trend of 2000–2014. [Colour figure can be viewed at wileyonlinelibrary.com]

Considering the nature and priority of the site selection, our criteria have been selected based on a relevant study by Lin et al. (2014) to develop the study framework. In general, the purpose of this study was to determine and identify suitable areas for REDD+ projects. Other factors (such as socio-economic concerns) should be examined after finding appropriate regions through future studies. The first strategy, efficient targeting, focuses on regions with high forest carbon content, high deforestation risk, and low opportunity cost, according to Lin et al.'s study (Lin et al., 2014). In addition to criteria for efficient targeting, the second strategy (co-benefits targeting) targets regions with high biodiversity and high poverty rates. Based on the targeted strategies, the suitability maps show regions that are highly, moderately, and poorly suitable for the development of future REDD+ initiatives. Therefore, in this study, larger areas were selected as the main site, so that officials can also review smaller sites during the implementation phase. Another goal of this study was to identify the primary REDD+ project locations in the Hyrcanian forests. To assist policy-makers in making judgments, after selecting the areas, we decided to utilize the SEA tool to demonstrate what the good and negative benefits would be if these projects were executed.

## 3 | RESULTS AND DISCUSSION

### 3.1 | Forest cover changes modelling

According to the results, the reduction in forest cover in Mazandaran province was about 102,192 and 86,415 ha between 1984–2000 and 2000–2014, respectively (Figure 4), which is also confirmed by Parsamehr et al. (2019). In recent decades, due to severe land use changes in Mazandaran province, deforestation activities have increased. The spatial trends in Figure 4 indicate that the intensity of deforestation in the east of Mazandaran province was higher. In these areas, agricultural activities, residential development, rural populations, and mining have a considerable impact on the reduction of forests. This finding is also shown and confirmed by Joorabian Shooshtari et al. (2012).

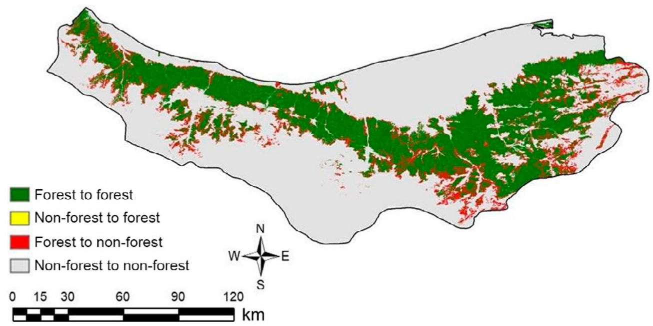


**FIGURE 5** Change analysis between 2014 and 2044. [Colour figure can be viewed at wileyonlinelibrary.com]

In this study, the elevation and distance from the roads have a maximum (Cramer's V value = 0.50) and minimum (Cramer's V value = 0.11) correlation in association with the changes in forest cover (Table S1). Pirbavaghar et al. (2003) concluded that the most deforestation in the Central Hyrcanian forests occurred at high altitudes. They stated that the rural populations in upper altitudes are responsible for deforestation. A few studies referred to a direct relationship between elevation and deforestation (Bagheri & Shataee, 2010; Mas et al., 2004). Deforestation at high altitudes has occurred in the Central Hyrcan forests due to a lack of control by land conservation organizations. Patterns of change in landscapes, heavily influenced by human activity, may be complicated, making them exceedingly challenging to understand. The ability to map trends with a best-fit polynomial trend surface to the patterns of change is provided by spatial trends.

The prediction map of 2014 is presented in Supplementary Information (Figure S4). Furthermore, the accuracy rate and skill measure for the transition potential modelling were obtained as 83.12% and 0.6624, respectively, which indicated that MLP had a good performance in the validation test. The FOM obtained in this study indicates the high accuracy of the model compared to other studies. The map of changes between 2014 and 2044 is presented in Figure 5. The

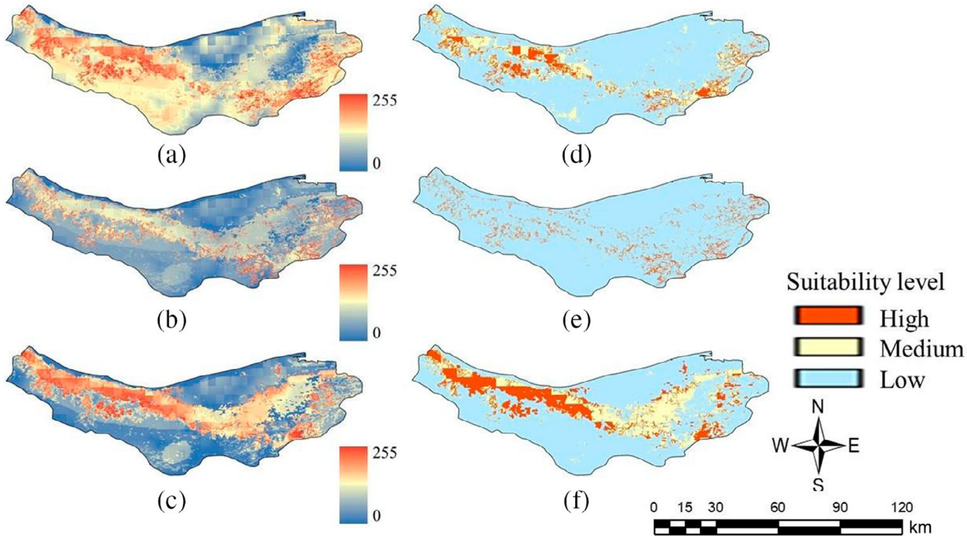


**FIGURE 6** Suitability images of WLC scenarios: (a) WLC-1, (b) WLC-2, (c) WLC-3, (d) suitability level for WLC-1, (e) suitability level for WLC-2, (f) suitability level for WLC-3. [Colour figure can be viewed at wileyonlinelibrary.com]

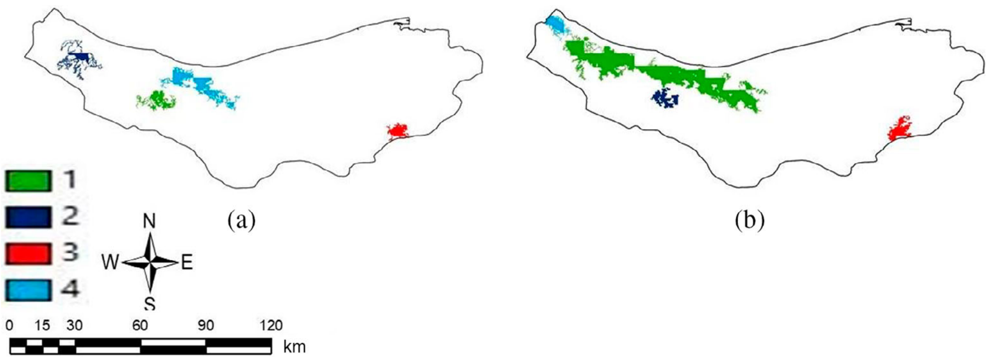


**FIGURE 7** Site selection using defined ZLS method for (a) WLC-1, (b) WLC-3, adapted from Parsamehr et al. (2019). [Colour figure can be viewed at wileyonlinelibrary.com]

change prediction for 2044 showed that based on a historical scenario, 155,698 ha of forest cover will be lost by 2044. Kim (2010) reported that the FOM was equivalent to 8% in analyzing the deforestation models for REDD+ projects. Vieilledent et al. (2013) reported that the FOM held a range of 10–23% in their case-study in Madagascar.

## 3.2 | Multi-criteria evaluation

The suitability of the region for REDD+ based on scenarios defined in the Supplementary Information (Table S3) is presented in Figure 6.

According to the pixel values, the suitability ranges from 0 to 255 where numbers closer to 255 indicate good conditions to implement the REDD+ project. Furthermore, the suitability value was classified into three categories: high, medium, and low (Figure 6). In our study, the defined ZLS was focused on the discovery of sites with a total area of 810 ha and minimum suitability of 180 (ha). The results of site selection and site priority based on higher suitability are shown in Figure 7.

The figure indicates that four sites were found for the WLC-1 scenario in which all the criteria had the same weight as the variable. In the WLC-2 scenario, maximum weight was given to the deforestation threat. The least weight was also given to the distance from protected areas and the opportunity cost. In this study, the opportunity cost means that areas with the potential for agricultural activities (high opportunity cost) can be ignored during REDD+ project implementation. They were hence considered undesirable for fuzzy operation and the rest of the regions (approximately 75% of Mazandaran Province) were desirable for the REDD+ project. One of the goals of REDD+ projects is to conserve biodiversity. In other words, the suitability for REDD+ projects is reduced by increasing the distance from protected areas.

If the REDD+ project is planned to be located in low-opportunity areas (unqualified for agricultural development), fewer problems will be created for farmers and indigenous people. The protection of biodiversity in the Central Hyrcanian forests is critical and unfavourable. Alborz mountains are located in the province of Mazandaran and there are many endemic species of animals and plants in these areas. Special attention should therefore be given to the conservation of habitats in these regions. In the WLC-1 scenario, equal weights were given to all the criteria and four sites with the desired conditions were found. In this scenario, the impact of the criteria was considered to reduce the risk of the REDD+ project implementation. As shown by Akter et al. (2018), REDD+ is a beneficial project because it can prevent serious land use changes. The four sites offered in the WLC-1

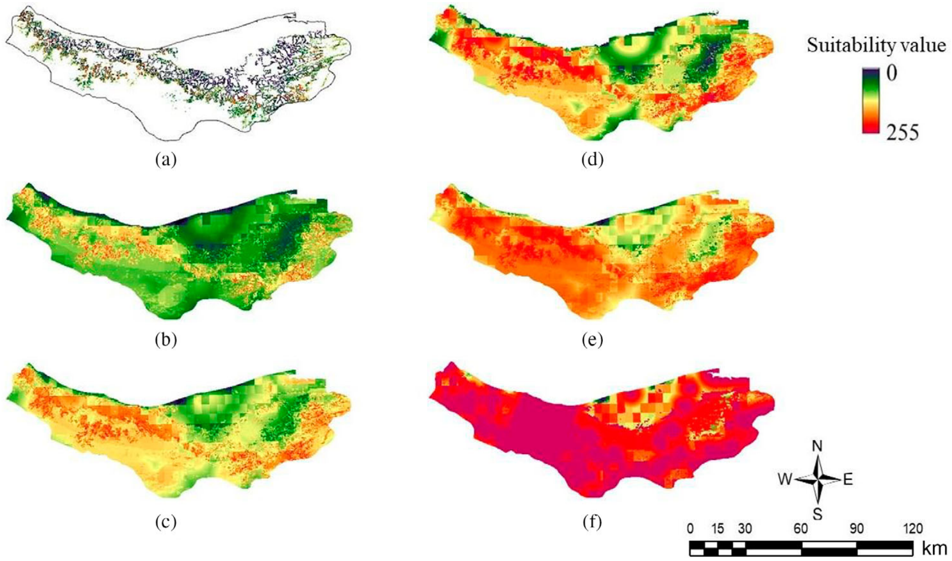


**FIGURE 8** Suitability images of OWA: (a) AND scenario, (b) MIDAND scenario, (c) AVG scenario, (d) MED scenario, (e) MIDOR scenario, (f) OR scenario. [Colour figure can be viewed at wileyonlinelibrary.com]

scenario were selected to conduct the REDD+ project, according to the items mentioned earlier. After selecting the WLC-1 scenario as the best choice, the OWA procedure was examined. This study investigated the effect of risk and trade-off in DSS. Images showing the suitability have been obtained based on order weights defined in the supplementary material (Table S4 and Figure 8).

Scenario (a) generates a risk-averse strategy. The ANDness value in scenario (a) is equal to 1 which means the solution corresponds to the AND logic while the ORness value is 0, indicating that the solution is not consistent with OR logic. The trade-off degree for scenario (a) was 0 which indicates no compensation between the criteria. Scenario (b) gains a low level of risk and increases suitable areas for REDD+ projects compared with scenario (a). There are some trade-offs in scenario (b) which is situated between scenarios (a) and (c). Scenarios (c) and (d) are situated in the middle of DSS. They have an average level of risk. In scenario (c), the order weights are equal and there is a full compensation between the criteria, while in scenario (d), some trade-offs are admissible. The comparisons of suitability images between scenarios (c) and (d) demonstrate that (d) generates great regions for REDD+ projects. Scenario (e) is situated between scenarios (c) and (f). There is a high level of risk and some trade-offs in scenario (e). Scenario (f) has the highest risk degree, and its trade-off is equal to 0. The ORness value in scenario (f) is equal to 1 which means the solution corresponds with the OR logic. Scenario (f) suggests almost the entire Mazandaran province for REDD+ projects. In this study, as in other studies (e.g., Malczewski, 2006; Valente & Vettorazzi, 2008; Ferretti & Pomarico, 2013; Junior & Rohm, 2014), there was a trend of increasing suitability from scenario AND to OR.

Using the ZLS method defined in this study, site selection was done for OWA scenarios. For scenarios (a) and (b), no site was found. The risk-averse scenarios demonstrate the minimum suitable regions because, for aggregation (final suitability), all the criteria must have a high value of suitability. For scenarios (e) and (f), the sites with a high spatial extent were achieved. Risk-taking scenarios suggest large suitable regions because the high value of suitability in one criterion determines a region as the best. Comparing scenarios (c) and (d), better sites were found for (c). The suitability maps for scenarios (c) and (WLC-1) are similar because in scenario (c), the trade-off degree is 1 which causes full compensation between the criteria. It should be noted that the WLC method is considered as one of the scenarios of the OWA if the order weights for all the criteria are equal.

The geographical situation of sites offered for REDD+ projects is demonstrated in Figure 9. Site #1 with an area of 38,247 ha is located in Nowshahr and Chalus Counties, Site #2 with an area of 52,263 ha is located in Tonekabon County, Site #3 with an area of 20,085 ha is located in Sari County, and Site #4 with an area of 56,972 ha is located in Nowshahr and Nur Counties. Based on a report released by the Environmental Protection Agency (EPA) of Iran, these sites are facing deforestation, construction of access roads, overgrazing, timber smuggling, and drastic land use changes. In addition, as shown by the EPA of Iran (2015), the sites of REDD+ have natural landscapes, dense forests, and areas with high biodiversity value.

## 3.3 | Consistency ratio

The chance that the ratings were chosen at random is shown by the CR value. Good consistency is shown by values lower than 0.10. A consistency index matrix will be shown when values are more than 0.10, at points where the weightings matrix should be reevaluated.

The consistency matrix depicts how the individual evaluations would have to be altered to be entirely consistent with the right fit weightings obtained. Thus, it is needed to examine this matrix to find the pairwise comparison with the greatest variance if the total consistency ratio is larger than 0.1. The most erratic rating is this one. However, there are several methods to compare each pair in the matrix. There are ratings like A to C and C to B that allow the same sort of comparison in addition to a straight evaluation of variable A to variable B. The deviation mentioned for this more erratic rating shows what would need to be adjusted for it to be in line with the weightings

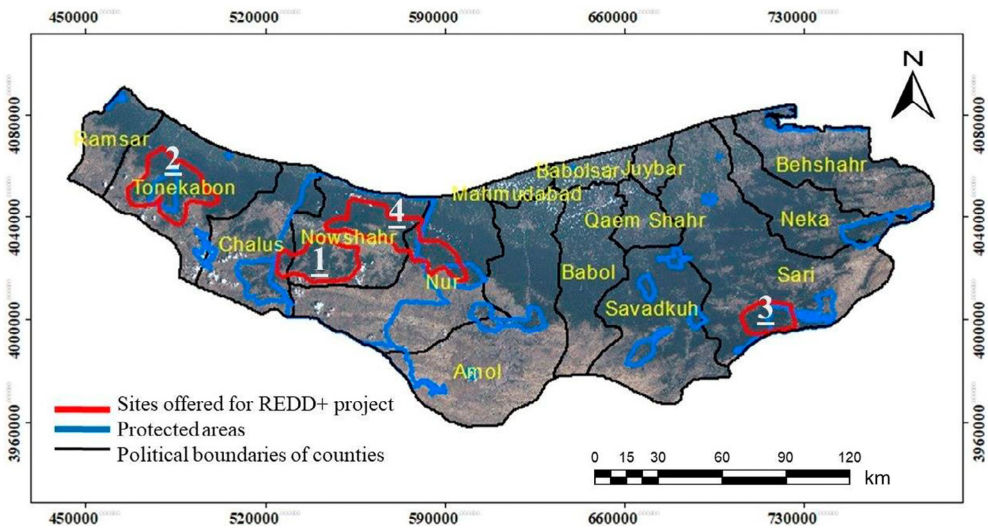


**FIGURE 9** Geographical situation of sites selected for REDD+ projects. [Colour figure can be viewed at wileyonlinelibrary.com]

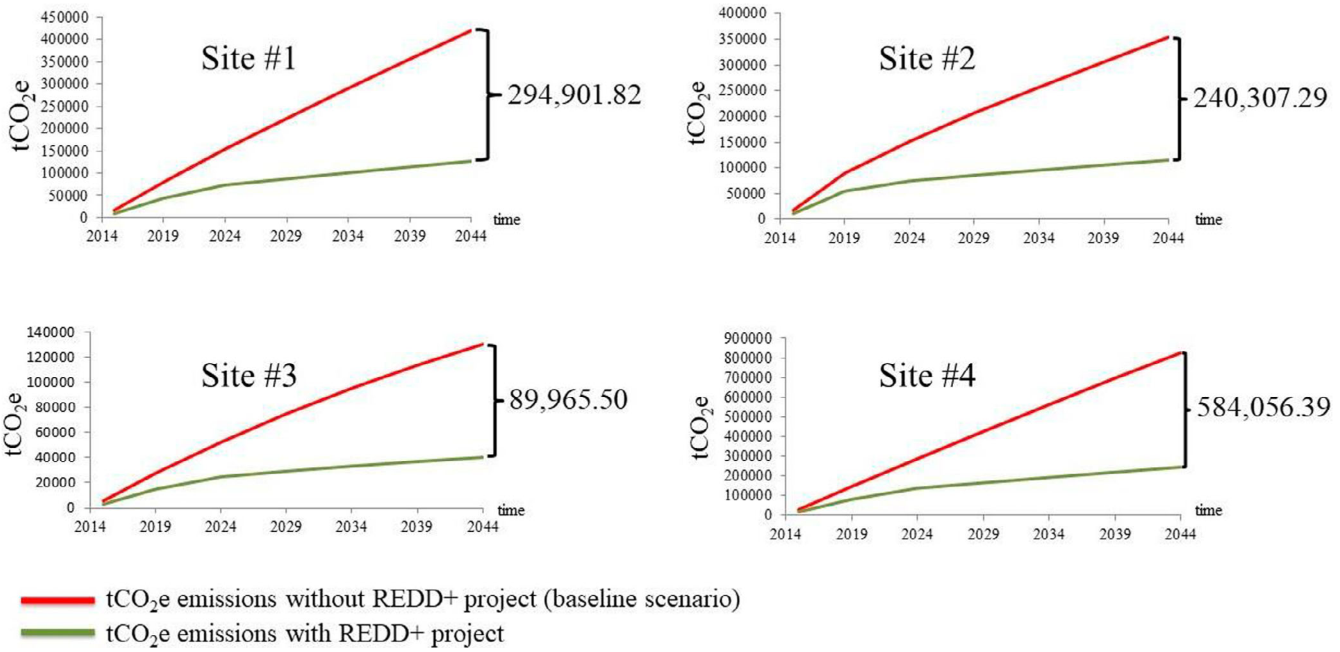


**FIGURE 10** Carbon saved by the REDD+ project in each site (C-REDD+). [Colour figure can be viewed at wileyonlinelibrary.com]

that provide the greatest match. We need to slide two points down the scale, for instance, if it displayed a −2. For instance, this would be the same as lowering the rating from 5 to 3, or similarly, from 1/3 to 1/5. As a result, the scale locations are where the variances are stated. Since fractional places are permitted, the new rating would need to be 1/(3.2), or 1.8 spots higher on the scale, if the deviation was +1.8 and the previous weighting was 1/5.

## 3.4 | Results of REDD+ baseline modelling

The outputs of the run of the REDD+ projects are reported in Supplementary Information (Table S10) which indicates that the most and least baseline deforestation in the project area will respectively occur in sites #4 and #3. Furthermore, the maximum $tCO_2e$ emissions from the project area (C-baseline) and the maximum C-leakage belong to site #4. The results of $tCO_2e$ emissions under REDD+ project implementation and business-as-usual scenario are presented in Supplementary Information (Table S10). Figure 10 shows the saved carbon (C-REDD+) by REDD+ projects for each site.

Figure 10 shows that the maximum and minimum C-REDD+ belong to site #4 and site #3. Under the business-as-usual scenario, 1,733,610.1 $tCO_2e$ will be emitted within four sites offered during 2014–2044, while with REDD+ project implementation, the emissions will reach about 524,379.1 $tCO_2e$. Therefore, REDD+ projects can prevent the release of 1,209,231 $tCO_2e$ over the next 30 years (2014–2044). It should be noted that the amount of C-REDD+ is different in other studies and is related to the geographical extent and carbon stocks. In this study, C-REDD+ results indicate that REDD+ projects can earn $US12,092,310 based on the social cost of carbon (SCC). The economic benefits of reducing carbon emissions will be effective for government decisions on climate change policies. Thus, decision-makers should focus in particular on reducing carbon emissions. They can use carbon credits as a tool for political motivations in connection with the implementation of Clean Development Mechanism projects, as shown by Busch et al. (2012).

The VCS method was used for the implementation of the REDD+ project in Mantadia National Park. The results showed that under the REDD+ scenario, the release of 44,355,616 $tCO_2e$ will be prevented. Using the VCS method, the amount of C-REDD+ was estimated for a case study in Nigeria. Under the business-as-usual scenario, 354,408.26 $tCO_2e$ would be stored in this area, while REDD+ projects are able to save 1,606,147.09 $tCO_2e$ by 2040. Furthermore, in a case study in Indonesia, a REDD+ project was implemented using the VCS method and the results indicate that the REDD+ project will prevent the emission of 18,868,706 $tCO_2e$ into the atmosphere by 2045. The results of various studies indicated that the REDD+ projects successfully had significant effects on the reduction of carbon emissions in developing countries. The present study confirmed the performance of REDD+ as a strategy to reduce deforestation and carbon emissions. These findings are in line with the findings of, Bununu et al. (2016), and Nahib and Suwarno (2018), and are confirmed by them.

## 3.5 | Strategic environmental assessment of the REDD+ project

This study examined some of the policy implications of the REDD+ framework, based on an assessment with GeOSIRIS model for the counties where the four selected sites are located. The GeOSIRIS results are presented in the Supplementary Information (Table S11). Output 1 in Supplementary material (Table S11) indicates how much forest cover was reduced between 2010 and 2014. Most deforestation has occurred in Sari County, which has a high potential for REDD + implementation. Output 2 in Supplementary Material (Table S11) shows the modelled deforestation under the REDD+ scenario during the period 2010–2014, which demonstrates a significant potential impact of REDD+ in Sari County and the highest absolute reduction in deforestation. Based on the simulation of deforestation by the GeOSIRIS model, Tonekabon County has the largest relative change in the deforestation rate under the REDD+ scenario (see output 3 in Supplementary Material, Table S11). Output 4 in Supplementary Information (Table S11) shows emissions under the business-as-usual scenario between 2010 and 2014 in each county, and output 5 shows the predicted emissions by REDD+. For example, the emission without REDD+ in Sari County was 844,229 $tCO_2e$ from 2010 to 2014, while the emissions with REDD+ were estimated at about 551,752 $tCO_2e$. In fact, the REDD+ project could have saved 292,477 $tCO_2e$ in Sari County from 2010 to 2014 (see output 6 in Supplementary Material, Table S11). Output 7 in Supplementary material (Table S11) indicates the gross carbon benefit from choosing a REDD+ project.

RIAM analysis matrices for the four sites offered are presented in Supplementary Material (Table S12, S13, S14, and S15). The REDD+ project has a very positive impact on all aspects of physical/chemical (PC) and biological/ecological (BE) components mentioned in the Supplementary Material (Table S8). REDD+ projects are appropriate for emissions reduction, protection of forest lands, reforestation, preventing deforestation, and soil conservation. In addition, the implementation of a REDD+ project will improve the status of biodiversity conservation in the region. The REDD+ project has positive and negative effects on the sociological/cultural (SC) components mentioned in Supplementary Material (Table S8). The protection of forests has impacts on the livelihoods of the rural community. On the one hand, this protection can affect the livelihood of rural communities by limiting activities such as animal husbandry and agriculture. On the other hand, the implementation of the REDD+ project helps create jobs in connection with the implementation of these projects and thus can reduce poverty. In other words, by carrying out the project, the villagers can be hired for project-related businesses such as forestry, and the project's profits can be shared among them. This is in line with Corbera and Schroeder's findings in 2010. In addition, small-scale local activities like the gathering of fuelwood, the manufacturing of charcoal, and the grazing of animals have a significant impact on the local forest degradation in Iran and are among its main drivers. As a result, the REDD+ project's implementers may see reducing poverty as one of their objectives. More REDD+ initiatives are situated in high or medium-suitable regions, which consider the co-benefits of biodiversity and poverty reduction.

REDD+ projects will improve the level of socio-cultural development in Mazandaran Province. In fact, some of the counties in Mazandaran Province are less developed and should benefit from the rewards of REDD+ projects. REDD+ project has positive and negative impacts on the economic/operational (EO) components mentioned in Supplementary Information (Table S8). In general, international financial incentives can be fairly distributed between local people but require an appropriate turnover system. It must be determined to what extent the profits obtained by REDD+ are able to provide the needs of indigenous people. It should be noted that the implementation of REDD+ will prevent cutting down trees, wood smuggling, the development of agricultural lands, and firewood harvesting. Finally, REDD+ has a negative impact on the economically active population because it will prevent many of the common activities in rural areas. Furthermore, governmental, and international organizations related to climate change mitigation are considered as a sponsor for REDD+ because there are costs associated with field research and project implementation.

Based on the SEA results, the priorities of the sites for the REDD+ projects are demonstrated in Table 2. The SEA results showed that site #1 obtained the highest final environmental score (ES) which was equal to 515 and was considered as the first priority for REDD+ projects and site #3 obtained the least ES (Table 2). In addition, the scores obtained for the sites in each environmental category are represented in Table 2. Finally, a summary of RIAM analysis is shown in Figure 11.

Site #1 is located in the Central Alborz Protected Area and includes natural landscapes and dense forests. In this site, forest cover decreased by about 4069 ha from 1984 to 2014. There are many villages within site #1, and animal husbandry and agriculture are the most important activities of the villagers. Table 2 shows that site #1 obtained a good score in the PC category and REDD+ will help preserve biodiversity on this site. In total, site #1, compared to other sites, has the lowest negative impact on SC and EO components (Table 2).

The second priority for the REDD+ project was obtained for site #2 with an ES of 513. This site is located in Tonekabon County. The Bleskouh Protected Area is located in the centre of this site and there are indicator species in this region; therefore, REDD+ will have positive impacts on the biodiversity of the region (EPA of Iran, 2015). Site #2 obtained the highest score in the PC category (Table 2). This site lost 4261 ha of its forest cover from 1984 to 2014. Many villagers live in this site; therefore, there will be some problems linked to protection policies. For site #2 compared with site #1 more negative impacts are obtained in SC and EO categories (Table 2).

The third priority for the REDD+ project was obtained for site #4 with an ES score of 390. This site is located in the Central Alborz Protected Area. At this site, there were 3168 (ha) of forest cover, which decreased during the years 1984–2014. This site is located in the political boundaries of Nowshahr County and Nur County. In these counties, rural and farmer populations are over 143,213 and 14,600, respectively. Then, before implementing the REDD+ project, attention should be paid to the needs of farmers and rural people. In site #4, compared to sites #1 and #2, more negative impacts could be obtained in SC and EO categories (Table 2).

Finally, the last priority for REDD+ projects was obtained for site #3 with an ES of 263. Site #3 is located in Sari County. In addition, parts of the Dodangeh and the Chahardangeh Wildlife Refuges, the Kyasar National Park, and the Boola Protected Area are situated in this site. This site has the lowest amount of deforestation (equal to 1126 ha) compared to other sites (it should be noted that this site has the smallest area among others). Based on the global biodiversity map by Pimm et al. (2014), site #3 has mammal and bird species richness. Table 2 shows that the highest negative score in SC and EO categories was obtained for site #3. Sari County has the highest rural population, and over 32,000 farmers are active in this county; for this reason, in all the forest areas, the negative effect of rural communities is clearly visible. Therefore, the REDD+ project can have a negative effect on the rural people's needs in this county.

Figure 11 shows the greatest difference between the sites in relation to the sociological/cultural and economic/operational sectors. Studies related to REDD+ projects are focused on the socio-economic issues of the indigenous communities. The SEA results indicated that REDD+ projects will have positive impacts on the protection of forests and biodiversity. In the economic and social sectors, the REDD+ projects will be faced with problems. Protecting forest resources will have costs. Long-term profits from projects for local people are unreasonable because their livelihoods depend on the utilization of natural resources. However, REDD+ project benefits, such as forest conservation, increasing carbon sequestration, reduction in greenhouse gas emissions, protection of biodiversity, and distribution of profits from carbon credits between local people, can support the decision-making process. These findings are in line with the findings of Jagger et al. (2010), and Mwayafu and Kisekka (2012).

**TABLE 2** Summary of scores (ES was computed from Tables S12, S13, S14, and S15)

| | PC | BE | SC | EO | Final ES |
|---|---|---|---|---|---|
| Site 1 | 462 | 133 | −39 | −41 | 515 |
| Site 2 | 483 | 161 | −45 | −86 | 513 |
| Site 4 | 413 | 182 | −90 | −115 | 390 |
| Site 3 | 385 | 182 | −101 | −203 | 263 |

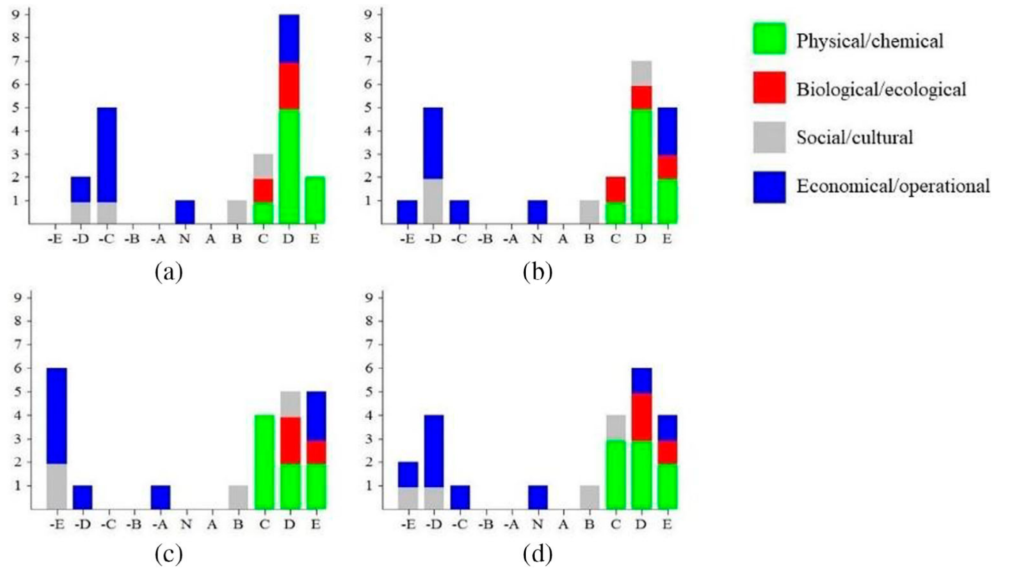


**FIGURE 11** Summary of RIAM analysis: (a) site #1, (b) site #2, (c) site #3, (d) site #4 (X: range bands of environmental score; Y: number of components (Table S7). [Colour figure can be viewed at wileyonlinelibrary.com]

## 4 | CONCLUSIONS

Given the extensive literature on REDD+ and the growing volume of analyses, it is clear that our current understanding of the benefits and drawbacks of REDD+ will be rethought within the next few years. This review is merely the first step in the yet-to-be-written history of a hugely promising but also dangerous approach to reorganizing the structure of interests and stakes in forests and forest governance.

In this study, deforestation modelling had high accuracy; thus, WLC results indicated that the scenario with equal weight for all criteria had the best result for identifying suitable areas for REDD+ projects. Finally, based on the site selection results, four sites were found. REDD+ baseline modelling showed that in the selected sites, 1,733,610.1 $tCO_2e$ will be released during 2014–2044, while the REDD+ project implementation will prevent the release of 1,209,231 $tCO_2e$. In addition, based on SEA results, site #1, with an environmental score of 515, has the first priority for the REDD+ project, and the next priorities are for site #2, site #4, and site #3.

In general, this research shows deforestation hotspots and solutions for climate changes mitigation in the Central Hyrcanian forests. Furthermore, in this study, the implementation of the REDD+ projects via the OWA procedure, the application of RIAM in REDD+ projects, the application of GeOSIRIS in relation to REDD+ projects, and the integration of MCE and RIAM in REDD+ projects for SEA are discussed. This study also suggested the decision rule to support the complexity of decision-making in REDD+ projects. This decision rule can be improved in environmental assessment methods and using other multiple-criteria decision analyses such as outranking (ELECTRE, PROMETHEE) and non-additive (TOPSIS, pareto set) methods. Evidently, the ability to achieve these goals is contingent on a variety of factors, including the proponent's geographic expertise and local governance conditions. However, poverty, forest carbon emissions, and biodiversity are its three main pillars. Overall, it is highly desired to locate in areas with a high potential for biodiversity co-benefits. Projects under the REDD+ programme are more frequently found in nations with high biodiversity indices. Last but not least, our study of REDD+ initiatives and the areas around them indicates that they are largely agricultural in nature and that small-scale farms are seen as one of the biggest dangers to deforestation and degradation. Although there are few outliers, the majority of communities do not rely heavily on the sale of forest products for their revenue. This indicates that slowing local deforestation without endangering agricultural livelihoods would be a major issue for REDD+ on the ground.

In addition, small-scale local activities like the gathering of fuelwood, the manufacturing of charcoal, and the grazing of livestock have a significant impact on the local forest degradation in Iran and are one of its main drivers. As a result, the REDD+ project's implementers may see reducing poverty as one of their objectives. Thus, more REDD+ initiatives are situated in high or medium suitable regions, which consider the co-benefits of biodiversity and poverty reduction. Finally, this study shows how to locate and map the ideal landscapes for REDD+ initiatives. Overall, the focus of the current study is on deforestation. The main reason is the lack of high-resolution satellite images for accurate extraction of forest degradation in the study area. Therefore, based on LANDSAT satellite images, deforestation images were extracted and analyzed in this study. Nevertheless, in order to investigate degradation trends, changes in NDVI were considered and added as one of the indicators of forest degradation.


## AUTHOR CONTRIBUTIONS

All authors made the same contribution to this study.

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## CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## DATA AVAILABILITY STATEMENT

Research data are not shared.

## ENDNOTE

[1] The main focus of land suitability is on land development and planning and aims to promote scientific and rational use of land resources.

## REFERENCES


Adekugbe, O. A., Oyerinde, O. V., Oluwajuwon, T. V., Abisoye, T. R., & Atanda, T. A. (2020). Socio-economic characteristics and level of awareness and perception on reducing emissions from deforestation and forest degradation programme (REDD+) by rural communities in Akure Forest Reserve, Nigeria. *Journal of Applied Sciences and Environmental Management*, *24*(11), 1909–1915. https://doi.org/10.4314/jasem.v24i11.10

Akter, T., Quevauviller, P., Eisenreich, S. J., & Vaes, G. (2018). Impacts of climate and land use changes on flood risk management for the Schijn River, Belgium. *Environmental Science & Policy*, *89*, 163–175. https://doi.org/10.1016/j.envsci.2018.07.002

Atela, J. O., Quinn, C. H., & Minang, P. A. (2014). Are REDD projects pro-poor in their spatial targeting? Evidence from Kenya. *Applied Geography*, *52*, 14–24. https://doi.org/10.1016/j.apgeog.2014.04.009

Bagheri, R., & Shataee, S. (2010). Modeling forest areas decreases, using logistic regression (case study: Chehl-chay catchment, Golestan Province). *Iranian Journal of Science and Technology*, *2*(3), 243–252 (In Persian). https://www.cabdirect.org/cabdirect/abstract/20123184396

Bayrak, M. M., & Marafa, L. M. (2016). Ten years of REDD+: A critical review of the impact of REDD+ on Forest-dependent communities. *Sustainability*, *8*, 620. https://doi.org/10.3390/su8070620

Bell, R. G. (2011). *The social cost of carbon and climate change policy*. World Resources Institute.

Brandolini, P., Pepe, G., Capolongo, D., Cappadonia, C., Cevasco, A., Conoscenti, C., Marsico, A., Vergari, F., & Del Monte, M. (2018). Hillslope degradation in representative Italian areas: Just soil erosion risk or opportunity for development? *Land Degradation & Development*, *29*(9), 3050–3068. https://doi.org/10.1002/ldr.2999

Bununu, Y., Ludin, A. N. M., & Hosni, N. (2016). *Modeling vegetation loss and greenhouse gas emissions in Kaduna, Nigeria, conference: 10th SEATUC symposium*. Shibaura Institute of Technology.

Busch, J., Lubowski, R. N., Godoy, F., Steininger, M., Yusuf, A. A., Austin, K., Hewson, J., Juhn, D., Farid, M., & Boltz, F. (2012). Structuring economic incentives to reduce emissions from deforestation within Indonesia. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(4), 1062–1067. https://doi.org/10.1073/pnas.1109034109

Carter, S., Manceur, A. M., Seppelt, R., Hermans-Neumann, K., Herold, M., & Verchot, L. (2017). Large scale land acquisitions and REDD+: A synthesis of conflicts and opportunities. *Environmental Research Letters*, *12*(3), 035010. https://doi.org/10.1088/1748-9326/aa6056

Eastman, J. R. (2015a). *TerrSet Manual* (p. 392). Clark University.

Eastman, J. R. (2015b). *TerrSet help system. Accessed in TerrSet 18.31*. Clark University.

Eastman, J. R., Van Fossen, M. E., & Solorzano, L. A. (2005). Transition potential modeling for land-cover change. In D. Maguire, M. Batty, & M. Goodchild (Eds.), *GIS, spatial analysis and modeling* (pp. 357–385). ESRI Press.

El Gohary, R. I., & Armanious, S. (2017). Environmental impact assessment for projects in the Nile basin countries. *European Journal of Scientific Research*, *13*(5), 134. http://doi.org/10.19044/esj.2017.v13n5p134

Ferretti, V., & Pomarico, S. (2013). Ecological land suitability analysis through spatial indicators an application of the analytic network process technique and ordered weighted average approach. *Ecological Indicators*, *34*, 507–519. https://doi.org/10.1016/j.ecolind.2013.06.005

Fujisaki, K., Perrin, A. S., Garric, B., Balesdent, J., & Brossard, M. (2020). Soil organic carbon changes after deforestation and agrosystem establishment in Amazonia: An assessment by diachronic approach. *Agriculture, Ecosystems & Environment*, *245*, 63–73. https://doi.org/10.1016/j.agee.2017.05.011

Gholamalifard, M., ZareMaivan, H., JoorabianShooshtari, S., & Mirzaei, M. (2012). Monitoring land cover changes of forests and coastal areas of northern Iran (1988-2010), a remote sensing approach. *Journal of the Persian Gulf*, *3*(10), 47–56. http://jpg.inio.ac.ir/article-1-142-en.html

Ghorbani, H., Kashi, H., Hafezi Moghadas, N., & Emamgholizadeh, S. (2015). Estimation of soil cation exchange capacity using multiple regression, artificial neural networks, and adaptive neuro-fuzzy inference system models in Golestan Province. *Communications in Soil Science and Plant Analysis*, *46*(6), 763–780. https://doi.org/10.1080/00103624.2015.1006367

Han, G., Tang, Y., Liu, M., Van Zwieten, L., Yang, X., Yu, C., Wang, H., & Song, Z. (2020). Carbon-nitrogen isotope coupling of soil organic matter in a karst region under land use change, Southwest China. *Agriculture, Ecosystems & Environment*, *301*, e107027. https://doi.org/10.1016/j.agee.2020.107027

Heidarlou, H. B., Shafiei, A. B., Erfanian, M., Tayyebi, A., & Alijanpour, A. (2019). Effects of preservation policy on land use changes in Iranian Northern Zagros forests. *Land Use Policy*, *81*, 76–90. https://doi.org/10.1016/j.landusepol.2018.10.036

Jagger, P., Sills, E. O., Lawlor, K., & Sunderlin, W. D. (2010). *A guide to learning about livelihood impacts of REDD+ projects, occasional paper 56*. CIFOR.

Ji, Y., & Ranjan, R. (2019). A global climate-economy model including the REDD option. *Journal of Environmental Management*, *247*, 342–355. https://doi.org/10.1016/j.jenvman.2019.06.052

Jiang, H., & Eastman, J. R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information Science*, *14*(2), 173–184. https://doi.org/10.1080/136588100240903

Joorabian Shooshtari, S., Hosseini, S. M., Esmaili-Sari, A., & Gholamalifard, M. (2012). Monitoring land cover change, degradation, and restoration of the hyrcanian forests in northern Iran (1977–2010). *International Journal of Environmental Science*, *3*(3), 1038–1056. https://doi.org/10.6088/ijes.2012030133012

Junior, A. C., & Rohm, S. A. (2014). Analysis of environmental fragility using multi-criteria analysis (MCE) for integrated landscape assessment. *Journal of Urban and Environmental Engineering*, *8*(1), 28–37. https://doi.org/10.4090/juee.2014.v8n1.028037

Kapos, V., Ravilious, C., Campbell, A., Dickson, B., Gibbs, H., Hansen, M., Lysenko, I., Miles, L., Price, J., Scharlemann, J. P. W., & Trumper, K. (2008). *Carbon and biodiversity*. UNEP-WCMC.

Kassi, S. A. Y., Koné, A. W., Tondoh, J. E., & Koffi, B. Y. (2021). Corrigendum to "*Chromoleana odorata* fallow-cropping cycles maintain soil carbon stocks and yam yields 40 years after conversion of native- to farmland, implications for forest conservation". *Agriculture, Ecosystems & Environment*, *47* (September) (2017), 298–307. https://doi.org/10.1016/j.agee.2017.06.044

Kim, O. S. (2010). An assessment of deforestation models for reducing emissions from deforestation and forest degradation (REDD). *GIS Transport*, *14*(5), 631–654. https://doi.org/10.1111/j.1467-9671.2010.01227.x

Kumar, R., Nandy, S., Agarwal, R., & Kushwaha, S. P. S. (2014). Forest cover dynamics analysis and prediction modeling using logistic regression model. *Ecological Indicators*, *45*, 444–455. https://doi.org/10.1016/j.ecolind.2014.05.003

Lin, L. (2012). *Geography of REDD+ at multiple scales: Country participation and project location*. North Carolina State University Retrieved from http://www.lib.ncsu.Edu/resolver/1840.16/8200

Lin, L., Sills, E., & Cheshire, H. (2014). Targeting areas for reducing emissions from deforestation and forest degradation (REDD+) projects in Tanzania. *Global Environmental Change*, *24*, 277–286. https://doi.org/10.1016/j.gloenvcha.2013.12.003

Malczewski, J. (2006). Ordered weighted averaging with fuzzy quantifiers GIS-based multicriteria evaluation for land-use suitability analysis. *International Journal of Applied Earth Observation and Geoinformation*, *8*(4), 270–277. https://doi.org/10.1016/j.jag.2006.01.003

Mao, D., Wang, Z., Wu, B., Zeng, Y., Luo, L., & Zhang, B. (2018). Land degradation and restoration in the arid and semiarid zones of China: Quantified evidence and implications from satellites. *Land Degradation & Development*, *29*(11), 3841–3851. https://doi.org/10.1002/ldr.3135

Maraseni, T. N., Neupane, P. R., Lopez-Casero, F., & Cadman, F. (2014). An assessment of the impacts of the REDD+ Pilot Project on community forests user groups (CFUGs) and their community forests in Nepal. *Journal of Environmental Management*, *136*, 37–46. https://doi.org/10.1016/j.jenvman.2014.01.011

Maraseni, T. N., Poudyal, B. H., Rana, E., Khanal, S. C., Ghimire, P. L., & Subedi, B. P. (2020). Mapping national REDD+ initiatives in the Asia-Pacific region. *Journal of Environmental Management*, *269*, e110763. https://doi.org/10.1016/j.jenvman.2020.110763

Mas, J. F., Kolb, M., Paegelow, M., Camacho Olmedo, M. T., & Houet, T. (2014). Inductive pattern-based land use/cover change models: A comparison of four software packages. *Environmental Modelling & Software*, *51*, 94–111. https://doi.org/10.1016/j.envsoft.2013.09.010

Mas, J. F., Puing, H., Palacio, J. L., & Sosa-Lopez, A. (2004). Modeling deforestation using GIS and artificial neural networks. *Environmental Modelling & Software*, *19*, 461–471. https://doi.org/10.1016/S1364-8152(03)00161-0

Matheus, F. S. (2018). The role of forests and protected areas in climate change mitigation: A review and critique of the ecosystem services and REDD+ approaches. *Desenvolvimento e Meio Ambiente*, *46*, 23–36. https://doi.org/10.5380/dma.v46i0.54187

Mattsson, E., Persson, U. M., Ostwald, M., & Nissanka, S. P. (2012). REDD+ readiness implications for Sri Lanka in terms of reducing deforestation. *Journal of Environmental Management*, *100*, 29–40. https://doi.org/10.1016/j.jenvman.2012.01.018

Mehri, A., Salman Mahiny, A., Mirkarimi, S. H., & Rezaei, H. R. (2014). Use of optimization algorithms to priorities protected areas in Mazandaran

Province of Iran. *Journal for Nature Conservation*, *22*(5), 462–470. https://doi.org/10.1016/j.jnc.2014.05.002

Mirzayi, M., RiyahiBakhtiyari, A., Salman Mahini, A., & Gholamalifard, M. (2013). Investigating the land cover changes in Mazandaran Province using landscape ecology's metrics between 1984-2010. *Iranian Journal of Applied Ecology*, *2*(4), 37–55 (In Persian). http://ijae.iut.ac.ir/article-1-325-en.html

Mwayafu, D. M., & Kisekka, J. W. (2012). Promoting and implementing REDD+ safeguards at national level in East Africa, REDD-net programme.

Nahib, I., & Suwarno, Y. (2018). Modeling deforestation and greenhouses gas emissions in Morowali Utara District, Central Sulawesi Province Indonesia. *IOP Conference Series. Journal of Earth and Environmental Sciences*, (Vol. 165, pp. 012030). IOP Publishing. https://doi.org/10.1088/1755-1315/165/1/012030.

Nahib, I., Turmudi, T., Munajati, S., & Windiastuti, R. (2018). Simulation impact of REDD policy: Case study of forest area in Indonesia. *International Journal of Environment, Agriculture and Biotechnology*, *3*(3), 776–786. http://dx.doi.org/10.22161/ijeab/3.3.9

Nahib, I., Turmudi, T., Windiastuti, R., Suryanta, J., Dewi, R. S., & Lestari, S. (2018). Comparing of land change modeler and Geomod modeling for the assessment of deforestation (case study: Forest area at Poso Regency, Central Sulawesi Province). *International Journal of Advanced Engineering, Management and Science*, *4*(8), 597–607. https://dx.doi.org/10.22161/ijaems.4.8.4

Naidoo, R., & Iwamura, T. (2007). Global-scale mapping of economic benefits from agricultural lands: Implications for conservation priorities. *Biological Conservation*, *140*(1), 40–49. https://doi.org/10.1016/j.biocon.2007.07.025

Nordhaus, W. (2011). *Estimates of the social cost of carbon: Background and results from the RICE-2011 model*. Cowles Foundation discussion paper No. 1826. Yale University. https://doi.org/10.2139/ssrn.1945844

Parsamehr, K., Gholamalifard, M., & Kooch, Y. (2019). Comparing three transition potential modeling for identifying suitable sites for REDD+ projects. *Spatial Information Research*, *28*, 159–171. https://doi.org/10.1007/s41324-019-00273-1

Pastakia, C. M. R., & Jensen, A. (1998). The rapid impact assessment matrix (RIAM) for EIA. *Environmental Impact Assessment Review*, *18*(5), 461–482. https://doi.org/10.1016/S0195-9255(98)00018-3

Pedroni, L., Garcia, A., De jong, B., Schlamadinger, B., Steiniger, M., Brown, S., Pearson, T., Andrasko, K., & Scholz, S. (2008). BioCF RED Mosaic Methodology-Version1 of the BioCarbon Fund's proposed methodology for estimating reductions of GHG emissions from mosaic deforestation. Published date: 2009/10/14. Retrieved from http://wbcarbonfi nance.org/Router.cfm?Page=Doclib&CatalogID=49189

Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., Raven, P. H., Roberts, C. M., & Sexton, J. O. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Sci-Hub*, *344*(6187), 1246752. https://doi.org/10.1126/science.1246752

Pirbavaghar, M., Darvishsefat, A., & Namiranian, M. (2003). *The study of spatial distribution of changes in the northern forests of Iran, Proceedings of Map Asia*.

Reddy, C. S., Singh, S., Dadhwal, V. K., Jha, C. S., Rao, N. R., & Diwakar, P. G. (2017). Predictive modelling of the spatial pattern of past and future forest cover changes in India. *Journal of Earth System Science*, *126*(1), 1–16. https://doi.org/10.1007/s12040-016-0786-7

Roudgarmi, P., & Mahdiraji, M. T. A. (2020). Current challenges of Laws for preservation of forest and rangeland, Iran. *Land Use Policy*, *99*, 105002. https://doi.org/10.1016/j.landusepol.2020.105002

Roy, H. G., Fox, D. M., & Emsellem, K. (2014). Predicting land cover change in a Mediterranean catchment at different time scales. *Computer Science Admission Category*, *8582*, 315–330. https://doi.org/10.1007/978-3-319-09147-1_23

Ruesch, A., & Gibbs, H. K. (2008). *New IPCC Tier-1 global biomass carbon map for the year 2000. Available online from the Carbon Dioxide Information Analysis Center* [http://cdiac.ornl.gov]. Oak Ridge National Laboratory, USA.

Saaty, T. L. (1990). The analytic hierarchy process in conflict management. *International Journal of Conflict Management*, *1*(1), 47–68. https://doi.org/10.1108/eb022672

Sahoo, S., Sil, I., Dhar, A., Debsarkar, A., Das, P., & Kar, A. (2018). Future scenarios of land-use suitability modeling for agricultural sustainability in a river basin. *Journal of Cleaner Production*, *205*, 313–328. https://doi.org/10.1016/j.jclepro.2018.09.099

Salvini, G., Ligtenberg, A., van Paassen, A., Bregt, A. K., Avitabile, V., & Herold, M. (2016). REDD+ and climate smart agriculture in landscapes: A case study in Vietnam using companion modelling. *Journal of Environmental Management*, *172*, 58–70. https://doi.org/10.1016/j.jenvman.2015.11.060

Samndong, R. A., Bush, G., Vatn, A., & Chapman, M. (2018). Institutional analysis of causes of deforestation in REDD+ pilot sites in the Equateur Province: Implication for REDD+ in the Democratic Republic of Congo. *Land Use Policy*, *76*, 664–674. https://doi.org/10.1016/j.landusepol.2018.02.048

Sheng, J. (2020). Private sector participation and incentive coordination of actors in REDD+. *Forest Policy and Economics*, *118*, e102262. https://doi.org/10.1016/j.forpol.2020.102262

Sheng, J., Ozturk, U. A., & Zhang, S. (2016). Effects of asymmetric information and reference emission levels on the emissions from deforestation and degradation. *Journal of Cleaner Production*, *133*, 1118–1127. https://doi.org/10.1016/j.jclepro.2016.05.186

Shooshtari, S. J., & Gholamalifard, M. (2015). Scenario-based land cover change modeling and its implications for landscape pattern analysis in the Neka watershed, Iran. *Remote Sensing Applications: Society and Environment*, *1*, 1–19. https://doi.org/10.1016/j.rsase.2015.05.001

Srinivasarao, C., Jasti, V. N. S. P., Kondru, V. R., Bathineni, V. S. K., Mudigiri, R., Venati, G. V., Priyadarshini, P., Abhilash, P. C., & Chaudhari, S. K. (2022). Land and water conservation technologies for building carbon positive villages in India. *Land Degradation & Development*, *33*(3), 395–412. https://doi.org/10.1002/ldr.4160

Tamasang, C. F., & Ngwome, G. F. (2018). In K. Yogo (Ed.), *REDD+ implementation in Cameroon's environmental law: The role of indigenous peoples and local communities*. https://www.jstor.org/stable/pdf/j.ctv941sr6.48.pdf

Ty, S., Sasaki, N., Ahmad, A. H., & Zainal, A. Z. (2011). REDD development in Cambodia–potential carbon emission reductions in a REDD project. *FORMATH Research Society*, *10*, 1–23. https://doi.org/10.15684/formath.10.1

Valente, R. D. O. A., & Vettorazzi, C. A. (2008). Definition of priority areas for forest conservation through the ordered weighted averaging method. *Forest Ecology and Management*, *256*(6), 1408–1417. https://doi.org/10.1016/j.foreco.2008.07.006

Vieilledent, G., Grinand, C., & Vaudry, R. (2013). Forecasting deforestation and carbon emissions in tropical developing countries facing demographic expansion: A case study in Madagascar. *Ecology and Evolution*, *3*(6), 1702–1716. https://doi.org/10.1002/ece3.550

Wei, W., Gao, Y., Huang, J., & Gao, J. (2020). Exploring the effect of basin land degradation on lake and reservoir water quality in China. *Journal of Cleaner Production*, *268*, e122249. https://doi.org/10.1016/j.jclepro.2020.122249

World Bank., Ecofys., & Vivid Economics. (2017). *State and trends of carbon pricing 2017*. World Bank. Retrieved from https://openknowledge.worldbank

Yanai, A. M., Fearnside, P. M., Graca, P. M. L. D. A., & Nogueira, E. M. (2012). Avoided deforestation in Brazilian Amazonia: Simulating the effect of the Juma Sustainable Development Reserve. *Forest Ecology and Management*, *282*, 78–91. https://doi.org/10.1016/j.foreco.2012.06.029

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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