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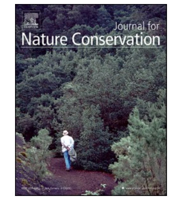

Environmental and socioeconomic assessment of agroforestry implementation in Iran

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ABSTRACT

Agroforestry has been recognized as a sustainable strategy over conventional agriculture that can mitigate environmental impacts, enhance ecosystem services, maintain natural resources, and simultaneously improve smallholders' livelihoods in rural areas. Agroforestry will be most effective in agricultural lands that are more vulnerable in terms of environmental and socioeconomic aspects. Therefore, it is necessary to identify the priority areas that are more susceptible to agroforestry. The objective of this study was to evaluate where and to what extent Iran's farmlands were subjected to increased environmental and socioeconomic pressures that can be alleviated through the implementation of agroforestry practices. To do so, two climatic, four soil, and four socioeconomic indicators were selected, and their maps were generated as well. Then, pressure maps of these indicators were created by applying the critical threshold of each indicator to the corresponding map. Finally, all the pressure maps were accumulated on a map called the Agroforestry Suitability Map (ASM). The locations that have more than five pressures on the current map were designated as priority areas for the development of agroforestry. The main findings showed that rise in temperature and soil organic carbon (SOC) deficit were the dominant pressures that affected the study area. Furthermore, about 17% of the total farmlands were recognized as the priority areas. The priority areas were mostly located in arid and semi-arid regions, which indicates the greater vulnerability of these regions to climatic and socioeconomic conditions. Our results highlighted that the farmlands of Kermanshah, Khuzestan, and Lorestan provinces, located adjacent to the Zagros Mountains, are the most suited areas for agroforestry implementation, respectively. The study findings could assist decision makers in mitigating the negative effects of environmental pressures and in providing a wide range of other beneficial services through the establishment of agroforestry systems in the recognized priority areas.

1. Introduction

Nowadays, climate change is known as the most important threat that humanity must face and the greatest challenge of the 21st century due to its negative impacts on economy, agricultural production, social communities, and natural resources (Sabbaghi et al., 2020). Agricultural activities such as deforestation and increase in the use of fossil fuels, pesticides, agrochemicals, monoculture, and livestock are recognized as the major causes of global warming, which have local, national, and global consequences (Wang et al., 2021). However, the agriculture sector is inherently most sensitive to changing climate conditions and is directly affected by the alterations of precipitation level and pattern, as well as temperature changes (Bhattacharjee et al., 2018). The negative effects of climate change on the agriculture sector would be exacerbated by the integration of natural resources destruction, land use change, and exceeded water draining (Cui, 2020). By the end of 2050, it is anticipated that climate change will have reduced agricultural production by 25 % (IPCC, 2018). Moreover, it is predicted that by the year 2050, there will be an additional 2.3 billion people on the planet, which would result in a 70 % increase in food consumption (Hunt et al., 2018). Therefore, agricultural land uses and practices should be significantly improved to meet the needs of future generations without putting more pressure on

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global ecosystems. The need to feed the growing population, reduce the problems of agricultural lands, and mitigate global warming led to the appearance of concepts such as sustainable intensification (SI) and climate-smart agriculture (CSA) (Manes et al., 2021). The basis of these two concepts is to increase the efficiency as well as the resilience of the agricultural lands against the loss of natural resources, biodiversity, and habitat through safe and sustainable strategies, which leads to the conservation and improvement of ecosystem services (Thomson et al., 2019).

Agroforestry is known as the paradigmatic example of SI and CSA in which woody elements (trees/shrubs) are deliberately integrated with crop and/or animal production systems (Amadu et al., 2020). It is often considered as the most efficient and sustainable land-use management of agricultural systems that simultaneously provides multiple environmental and socioeconomic benefits (Thomas et al., 2021). Agroforestry has been identified as a promising nature-based solution to climate change that creates synergies between both adaptation and mitigation strategies (Rosenstock et al., 2019). Agroforestry implementation can generate a wide range of ecosystem services including nutrient and water cycling, erosion control, carbon sequestration, environmental hazards risk reduction, increase in recreational, aesthetic, and cultural heritage values, production of timber, coal, fiber and food, and enhancement of pollination, pest control, and biodiversity (Fu et al., 2021). Sustainable agroforestry implementation can mitigate global warming (Zhang et al., 2022), affect daily mean temperature (Merle et al., 2022), and also modify regional precipitation, particularly in arid and dry areas (Branch & Wulfmeyer, 2019). Adoption of agroforestry systems enhances householders' income through selling the produced fruits and timber every year (Escribano et al., 2018). It also generates new employment opportunities and unique subsidiary markets (e.g. nursery raising, mat weaving, basket making, and honey collection) for landless farmers and unemployed rural communities, which also reduces rural-to-urban migration (Brown et al., 2018). Lack of education and specialized skills prevents farmers from finding jobs other than agriculture (Luo et al., 2022). Therefore, enhancing their livelihood will be possible only through improving agricultural activities and adopting sustainable practices such as agroforestry. Accordingly, a number of international agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, encouraged the governments to put agroforestry on their agenda. In addition, the REDD (Reducing Emissions from Deforestation and Forest Degradation) program was started by the United Nations in 2005 with the aims of rewarding developing countries for employing sustainable agroforestry strategies and preventing forest degradation (Ickowitz et al., 2017).

As a developing country, Iran ranks first in the Middle East and seventh in the world in terms of total greenhouse gas (GHG) emissions (nearly 41 million tons of CO_2 per year) (Daneshvar et al., 2019). Different areas of Iran have experienced an increase in air temperature during the past few decades. By the end of 2050, it is expected that the mean temperature will have risen by 2.6° C. The study of precipitation variations also shows a decreasing trend over the last few decades, and it is estimated that the amount of precipitation will decrease by an average of 35 % in the next decades (Daneshvar et al., 2019). The efficiency of agricultural systems has significantly decreased in Iran, which has led to a decline in the share of this sector in the gross domestic product (GDP) of the country over the past decades (FAO, 2020). It is reported that in order to increase the productivity of Iranian farmlands, water and wind erosion, soils salinity and alkalinity, and absence or inadequacy of soil organic matter must be resolved (FAO, 1964). These issues haven't been addressed in recent decades, though. They have also become more critical. Roozitalab et al. (2018) stated that soil resources of the country are now facing crucial challenges such as erosion, salinity, fertility, organic matter, and pollution, which need to be seriously included in the country's sustainable development programs. Several studies have reported the yield loss of various crops in different regions of the country due to climate change (Oliveira et al., 2018), depletion of water resources (Gohari et al., 2013), land degradation (Mesgaran et al., 2021), and climate-induced shocks such as droughts (Bhattacharjee et al., 2018). Additionally, it is anticipated that future climate change will negatively impact agricultural products in various Iranian regions (Bannayan & Rezaei, 2014). Even so, agriculture is the source of livelihood for more than 15 million people in Iran, many of whom are smallholders and belong to low-income rural communities (FAO, 2020). However, agricultural systems must be more efficient and productive while preserving natural resources in order to promote sustainability and decrease these people' vulnerability to climate change.

These challenges call for the implementation of programs, such as agroforestry, that reduce the risk of food insecurity, strengthen the resilience of rural communities and their livelihoods, and reinforce the contribution of the agricultural sector to the country's economy (Coulibaly et al., 2017). However, there has not been yet an organized agenda about the extent of agroforestry in Iran, and the use of various types of agroforestry systems that play an important role in achieving sustainable agriculture has been neglected and not welcomed by the government. Consequently, the purpose of this research is to look into the viability of implementing agroforestry systems in Iranian farmlands. Farmlands in Iran will be evaluated for this purpose using environmental and socioeconomic pressures to create an Agroforestry Suitability Map (ASM). Indeed, this research aimed to identify the priority areas that are more vulnerable from an environmental and socioeconomic point of view. The most important hypothesis of this study is that "most of Iran's farmlands are under environmental and socioeconomic pressures and, therefore, there is a high potential for implementing agroforestry in these areas." It is assumed that the implementation of agroforestry systems leads to increasing adaptive capacity and decreasing vulnerability in the priority areas. As de Mendonça et al. (2022) stated, the identification of priority areas is a crucial step for the implementation of agroforestry systems as a sustainable way for the recovery of degraded lands and as a socioeconomic alternative for local stakeholders. There are two general approaches to determine the priority areas for agroforestry implementation. In the first approach, the areas with the best environmental conditions are prioritized for the agroforestry implementation (Ahmad et al., 2019), while in the second approach, the areas with the most environmental pressures (the worst environmental conditions) are considered as priority areas for agroforestry implementation (Kay et al., 2019; Mendonça et al., 2022). The second approach was chosen according to the goal of this study, which is the restoration of degraded agricultural lands. Therefore, the ASM demonstrates the number of pressures in the farmlands of Iran, and the regions with the most pressures are the priority areas for agroforestry implementation. Agroforestry systems have the highest efficiency among the degraded lands in terms of various environmental and socioeconomic problems (Gupta et al., 2020). Additionally, agroforestry systems are being used at different scales to restore and revitalize lands that have been damaged by intensive agriculture, soil erosion, deforestation, rangeland degradation, and over-extraction (Dagar et al., 2020). Production systems can be made more profitable by implementing appropriate agroforestry technologies. To the best of our knowledge, the ASM approach was never applied earlier in Iran. Based on the above-mentioned objective, this study seeks, for the first time, to answer the following fundamental question: To what extent Iran's farmlands are most suited for the implementation of agroforestry? This study also attempts to answer two major questions:

(i) What environmental and/or socioeconomic pressure has the greatest impact on farmlands of Iran?
(ii) What are the climate types of Iran's priority areas for agroforestry implementation?

2. Materials and methods

2.1. Study area

This research was performed in the total farmlands of Iran (Fig. 1). Iran is located between 25 and 40 °N latitudes and 44 to 63 °E longitudes with a total area of about 1.75 million km^2 and is bordered by the Caspian Sea to the north and the Oman and Persian Gulfs to the south. Iran is composed of 31 provinces, enjoys a relatively heterogeneous climate, and covers different types of climates including arid (60 %), semi-arid (28 %), Mediterranean (4 %), semi-humid (1 %), humid (2 %), very humid (3 %), and extremely humid (2 %) areas (Tabari et al., 2014). Iran's temperature sometimes varies from − 20 to + 50 °C while the annual precipitation varies from less than 50 mm over the eastern deserts to more than 1000 mm over the western Caspian Sea coast and the western highlands (Madani et al., 2016). Iran is a predominantly agricultural country, and about 37 million ha of the total surface of this country is arable. Of this area, 15.4 million ha are farmlands and are mostly cultivated by field crops such as wheat, barley, corn, and rice throughout all 31 provinces of the country. Furthermore, about 56 % of the farmlands are irrigated, while the other 44 % are rainfed (Fig. 1; Karimi et al., 2018).

2.2. Selection of indicators

It was also implied that the forthcoming climate change will drastically affect the environmental, social, and economic dimensions of the agricultural sector in Iran with an adverse tendency that is more severe than what will occur in the Middle East (Daneshvar et al., 2019). Therefore, in this study, the annual mean temperature and the annual accumulative precipitation were selected as the climatic indicators. As the dominant climatic variables for land evaluations, these two indicators were widely recommended for the ASM investigation (Ahmad et al., 2019; Kay et al., 2019).

In this study, soil erosion, salinity, pH, and soil organic carbon (SOC) were selected as the main components of soil properties in Iran to form the soil indicators in this study. Soil erosion is considered a serious environmental issue due to its damaging effects on agricultural ecosystems and food production (Panagos et al., 2015). Soil salinity induces destructive environmental pressure on agricultural systems including shrinking of cultivated land area and reduction of agricultural productivity (Shahbaz & Ashraf, 2013). Soil pH measures the alkalinity or acidity of soils and influences numerous biological, chemical, and physical properties. Alkalinity or acidity of soils exacerbates the soil biodegradation and negatively affects crop growth and biomass production through disruption of nutrient cycling (Neina, 2019). SOC is essential for sustainable food production and improves many functions of soil, enhances the ecosystem services, and upgrades the adaptation to climate change of agricultural systems (Aguilera et al., 2020). It has been widely discussed that adoption of agroforestry could significantly prevent soil erosion (Fu et al., 2021), modify soil salinity (Lefroy & Stirzaker, 1999; Umrani, 2010), neutralize soil pH (Hong et al., 2018), and enhance SOC (Mosquera-Losada et al., 2018).

Sustainable agricultural projects, such as agroforestry, should consider environmental and socioeconomic effects simultaneously in order to ameliorate the livelihoods and environment. Many studies (e.g., Escribano et al., 2018; Apuri et al., 2018) have supported the positive socioeconomic impacts of agroforestry systems. Therefore, in this study, income, land ownership, and education level of farmers, as well as the unemployment rate in rural communities, were selected as the main four

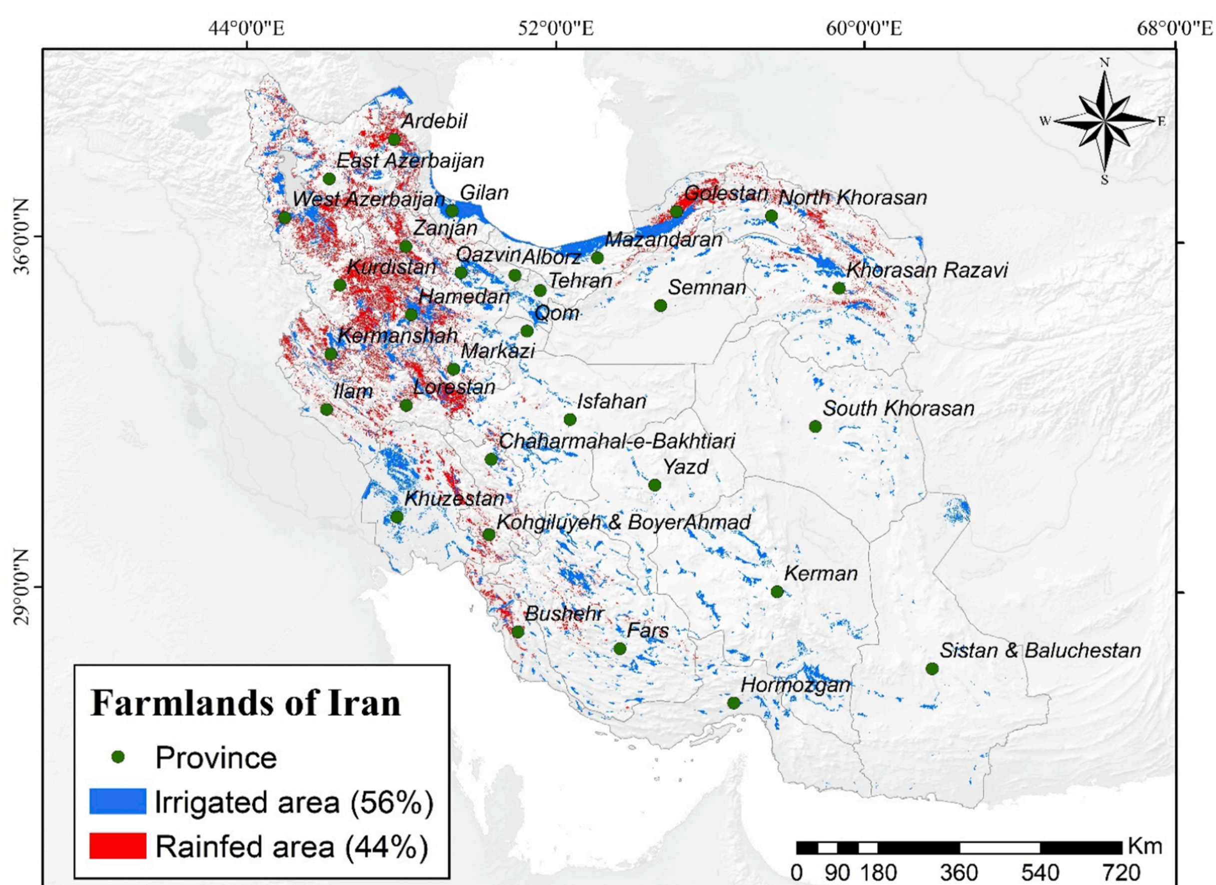

Fig. 1. The geographical distribution of farmlands (rainfed and irrigated areas) of Iran.

indicators to investigate the socioeconomic status of the study area for agroforestry implementation.

2.3. Data collection

In this study, a land-use map of Iran with a scale of 1:250,000 was obtained from the Iranian Forests, Range, and Watershed management organization (FRW). Then, the farmland categories (rainfed and irrigated areas) were extracted from the current land-use map and were further merged into one category for our analysis.

2.3.1. Climatic indicators

The maps of the annual mean temperature (°C) and the annual accumulative precipitation (mm) were downloaded from the WorldClim-Global data website for the current (1970–2000) and the future (the 2050 s) periods. In this study, the processed data of the SSP3-7.0 scenario, one of the most recent emission scenarios of the Shared Socioeconomic Pathways (SSPs) from the sixth phase of the Coupled Model Comparison Program (CMIP6), were used to create a projection map of the selected climatic indicators under the future global warming. The current and the future maps have a spatial resolution of one km (30 arc-seconds) and five kms (2.5 arc-minutes), respectively. In the next step, the variations of these two indicators were calculated, as follows:

$$T_V = T_{Future} - T_{Current} \quad (1)$$

$$P_V = \frac{P_{Future} - P_{Current}}{P_{Current}} \times 100 \quad (2)$$

where T_V and PV, which were used in the study that followed, stand for differences in annual mean temperature (°C) and yearly accumulative precipitation (%) by the 2050 s, respectively.

In this study, the de Martonne aridity index was calculated using the spatial maps of the annual mean temperature (°C) and the annual accumulative precipitation (mm) for the current time period (1970–2000) to classify the climate of the study area, as follows:

$$I_{DM} = \frac{P}{T+10}\left\{\begin{array}{c} humid\ if\ 28\leqslant AI < 35 \\ semi-humid\ if\ 24\leqslant AI < 28 \\ Mediterranean\ if\ 20\leqslant AI < 24 \\ semi-arid\ if\ 10\leqslant AI < 20 \\ arid\ if\ AI < 10 \end{array}\right\} \quad (3)$$

where I_{DM}, P, and T are the de Martonne aridity index, the annual accumulative precipitation (mm), and the annual mean temperature (°C), respectively. Furthermore, the climatic classifications illustrated in Eq. (3) are based on Croitoru et al. (2013). In this study, we used the I_{DM} classification to determine the type of climate in the areas that are suitable for agroforestry implementation.

2.3.2. Soil indicators

The maps of soil erosion and soil salinity with the scale of 1:250,000 and 1:100,000, respectively, were obtained from the land suitability assessment reports of the Iranian Soil and Water Research Institute (SWRI). Moreover, the maps of SOC and pH were downloaded from the open global database of SoilGrids which shares the soil properties data at 250 m spatial resolutions.

2.3.3. Socioeconomic indicators

We used the general agricultural census report of the Statistics Center of Iran (SCI, 2014) which reports the results at the provincial level to map the socioeconomic indicators in the study area. This report provides the percentage of farmers who are classified into very low, low, moderate, high, and very high classes based on their annual income. It also shows the percentage of farmers who are classified into illiterate, elementary or non-formal, high school, and associate or higher classes based on their education level. Based on the objectives of this study, the classes of "very low income" and "illiterate" were considered for mapping the income and education level indicators, respectively. Furthermore, the report indicated the percentage of landless farmers as well as the percentage of the "unemployed in rural communities" of each province, which were employed for mapping the land ownership and unemployment indicators, respectively. Table 1 shows the socioeconomic and demographic characteristics of the farmers at the country level.

2.4. Pressure area analysis

2.4.1. Climatic pressures

Hart et al. (2012) mentioned that agroforestry systems maintain their effectiveness under different climate scenarios when appropriately designed. They also explained that these systems provide different ecological services in a medium scenario with an increase temperature of 2 °C, and depending on the location and design, these systems even remain robust under extreme climate scenarios with an increase temperature of greater than 4 °C. Moreover, Kay et al. (2019) indicated that agroforestry might be helpful in areas with a forecasted temperature increase of more than 2 °C but less than 4 °C. As a result, in this study, all places with 2 °C TV 4 °C were designated as the pressure zones where agroforestry development may be beneficial. Ellison et al. (2019) demonstrated that the effects of trees on microclimate precipitation may involve a 10–20 % shift in many areas relevant to agricultural production. They noted that upwind deforestation can result in a drop in microclimate precipitation, whereas upwind tree cover can result in an increase. In this study, based on the meetings held with experts of the Meteorological Organization of Iran and consultations and discussions, we selected the regions with $P_V < -10$ % as the pressure areas which are more suited for agroforestry implementation.

2.4.2. Soil pressures

Soils with erosion greater than 50 t ha^{-1} a^{-1} are classified as the "highly erodible soils" (FAO, 1980). Based on this classification, a critical threshold is reached if the soil loss is greater than 50 t ha^{-1} a^{-1}. The soils with electrical conductivity (EC) greater than 4 dS m^{-1} were considered as the saline soils (Artiola et al., 2019), and the areas with more than 4 dS m^{-1} were considered as the pressure areas. The generally accepted pH for a wide range of crops in which most nutrients become

Table 1
Socioeconomic and demographic characteristics of the farmers in Iran.

Variable	Group	Frequency	Percent
Age	≤ 20	3,287	0.13
	21–30	133,400	5.4
	31–40	409,785	16.5
	41–50	585,967	23.6
	51–60	599,800	24.2
	61–70	407,382	16.4
	≥ 70	343,270	13.8
	Total	2,482,891	100
Annual income	Very low (≤75 mill IRR)	197,769	8.0
	Low (76–120 mill IRR)	277,254	11.2
	Moderate (121–195 mill IRR)	605,836	24.4
	High (196–360 mill IRR)	890,634	35.9
	Very high (≥360 mill IRR)	511,397	20.6
	Total	2,482,891	100
Education level	Illiterate	852,822	34.4
	Elementary/non-formal	871,839	35.1
	High school	628,481	25.3
	Academic Degree	129,748	5.2
	Total	2,482,891	100
Land Ownership	Landowner	2,076,960	83.7
	Landless	405,931	16.3
	Total	2,482,891	100
Employment*	Employed	19,745,846	91.6
	Unemployed	1,810,754	8.4
	Total	21,556,600	100

* refers to the employment in rural communities of Iran. Source: SCI, 2014.

available is between 6 and 7.5 (Wingeyer et al., 2015). Iranian farmlands' soils are mainly alkaline (Qadir et al., 2008). Therefore, the regions with a pH greater than 7.5 were included as the pressure areas. Oldfield et al. (2019) provided the threshold for SOC and stated that acceptable SOC for the sustainable soils is more than 2 %. Hence, the areas with less than 2 % of SOC were identified as the pressure areas.

2.4.3. Socioeconomic pressures

In order to identify the socioeconomic pressure areas and determine the reliable threshold for the socioeconomic indicators, meetings were held with experts of the Iranian Ministry of Agriculture-Jahad (MAJ), which led to consider the upper quarter of the range of income, land ownership, education level, and unemployment maps as socioeconomic pressure areas. Table 2 shows that the respective characteristics and the threshold of the datasets were used in this study for the identification of the ASM.

2.5. Identification of priority areas

After determining the thresholds for the selected indicators, the ASM was performed using the ArcGIS10.8 software. For this purpose, all of the obtained maps were converted into raster format. The maps of T_V, PV, SOC, and pH were already in raster format, so they were directly transferred into the software. In the next step, the maps were resampled using the nearest neighbor assignment resampling technique, which is an appropriate method for both discrete and continuous data and for forward processing. Then, the maps were reclassified to assign new values to them according to the determined thresholds (Table 2). Accordingly, in each map, the pressure areas and non-pressure areas were separated by assigning new values of 1 and 0, respectively. Finally, inspired by the methodological approach of Kay et al. (2019), all the ten pressure maps were simply accumulated using raster calculator tools to create the ASM. The number of pressures was added together considering the equal weight for each indicator in each spatial unit. The ASM displays the areas where one or several pressures occur. In the current map, the areas with more than five pressures were identified as the priority areas for agroforestry implementation.

2.6. Tree/Shrubs allocation

The frost and heat resistance of woody plants are two of the most important factors to consider when recommending a woody element in a specific area (Zhang et al., 2021). These two factors have been used to determine which woody plants are most likely to thrive in an area. In this regard, many studies (e.g., Gloning et al., 2013; Ouyang et al., 2019), inspired by the United States Department of Agriculture (USDA) cold hardiness zone map and the American Horticultural Society (AHS) heat zone map, geographically zoned their study regions to determine the frost and heat stresses of corresponding regions for woody plants allocation. The USDA cold hardiness zone and the AHS heat zone maps were generated based on the average annual minimum winter temperature and the number of days per year above 30 °C, respectively. The implications, advantages, and disadvantages of the USDA and AHS methods are discussed in detail in a study by Widrlechner et al. (2012). The USDA cold hardiness and AHS heat classifications is shown in Table s1.

In this study, in order to map the cold hardiness and heat zones of the priority areas, we used the USDA and AHS methods. Hence, the required weather data including daily minimum and mean temperatures for 41 synoptic weather stations with less than 5 % of missing values, as well as good distribution over the country, were gathered from the Meteorological Organization of Iran over the period 1966–2015 (50 years) to map the cold hardiness and heat zones. According to Tabari et al. (2014) the maps were made using the Kriging interpolation method, the best linear unbiased estimator, for this purpose. The spatial distributions of the 41 selected weather stations are shown in Fig. s1.

3. Results

3.1. Evaluation of pressure areas

Fig. 2 shows an overview of the proportion of farmlands of Iran affected by each of the individual ten pressures. In this regard, the regions with temperatures rising between 2 °C and 4 °C by 2050 s were identified in 92.7 % of the study area. Furthermore, 27.2 % of the study area has more than a 10 % decrease in precipitation. In terms of the soil indicators, 43.3 % of the farmlands are located in regions where soil erosion was more than 50 t ha^{-1} a^{-1}. In total, the regions suffering a soil salinity of more than 4 dS m^{-1} were detected in 13.9 % of the farmlands. Furthermore, 83.9 % of the farmlands have pH levels higher than 7.5. However, the regions with an SOC lower than 2 % were provided in 90.5 % of the study area (Fig. 2). As mentioned earlier, we considered the upper quarter of the range of each socioeconomic indicator map for the identification of the socioeconomic pressure regions. Accordingly, the maps of the socioeconomic indicators show the ranges of 0.2 to 50 %, 30 to 68 %, 11 to 56 %, and 7 to 25 % for income, education level, land

Table 2
The studied ten indicators along with their spatial resolution/scales and their thresholds which used for ASM in farmlands of Iran.

Indicators		Resolution/ scale	Thresholds	Source
Farmlands of Iran	1: 250,000		–	http://www.frw.ir
Climate	Temperature	1 km (current) 5 km (future)	$2°C < T_{Future} - T_{Current} < 4°C$(Kay et al., 2019)	http://worldclim.org
	Precipitation	1 km (current) 5 km (future)	$(\frac{P_{Future} - P_{Current}}{P_{Current}} \times 100) < 10\%$(Consultation of experts of the Meteorological Organization of Iran)	
Soil	Salinity	1:100000	EC greater than 4 dS m^{-1} (Artiola et al., 2019)	http://www.swri.ir
	Erosion	1:250000	greater than 50 t ha^{-1} a^{-1} (FAO, 1980)	http://www.swri.ir
	pH	250 *m*	greater than 7.5 (Wingeyer et al., 2015)	https://www.soilgrids.org
	SOC	250 *m*	less than 2 % (Oldfield et al., 2019)	https://www.soilgrids.org
Socioeconomic	Income	–	The upper quarter of the range (consultation of experts of the Ministry of Agriculture-Jahad of Iran)	SCI, 2014
	Education level	–		
	Land ownership	–		
	Unemployment	–		

SOC: soil organic carbon; T and P refer to the annual mean temperature (°C) and annual accumulative precipitation (mm), respectively; Current and future refer to the baseline (1970–2000) and 2050 s, respectively.

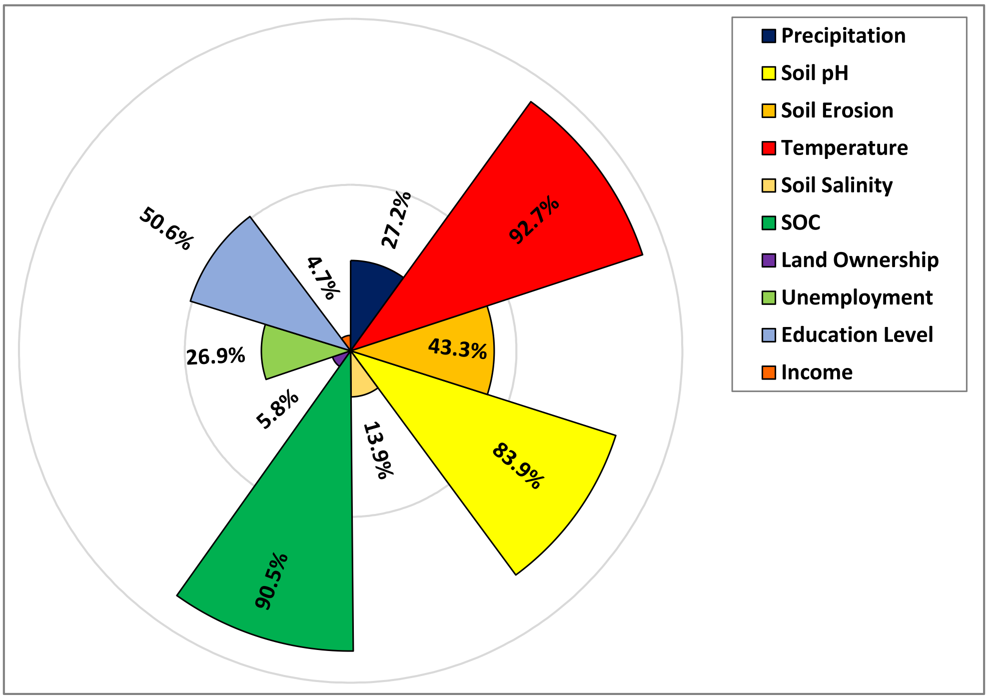

Fig. 2. The proportion (%) of the farmlands of Iran affected by each of the climatic (precipitation and temperature), soil (salinity, pH, erosion, and SOC), and socioeconomic (income, unemployment, education level, and land ownership) pressures. SOC: soil organic carbon.

ownership, and unemployment, respectively (data not shown). However, a relatively small part (4.7 %) of the farmlands was recognized as the income pressure regions (Fig. 2). In addition, 50.6 % of the farmlands were identified as the education level pressure regions. The unemployment pressure regions account for 26.9 % of the study area. Finally, the land ownership pressure regions cover 5.8 % of the study area.

Fig. 3a illustrates the climate classes of the study area based on the de Martonne aridity index (see Eq. (3)). To put it more clearly, the farmlands of Iran cover six types of climates consisting of arid (29.7 %), semi-arid (55.1 %), Mediterranean (8.1 %), semi-humid (2.6 %), humid (1.9 %), and very-humid (2.6 %) areas (Fig. 3a). Additionally, the climatic, soil, and socioeconomic pressure maps are created separately by combining corresponding individual indicators (see Table 2). In this regard, only 0.6 % of the study area has no climatic pressures, while 72.2 % of the study area shows one climatic pressure. However, the remaining 27.2 % shows two climatic pressures (Fig. 3b). The soil pressures map indicates that approximately 4.1 % of the study area has no pressure, while 8.2 %, 42.6 %, 43 %, and 2.1 % of the study area experience one, two, three, and four pressures, respectively (Fig. 3c). In terms of the socioeconomic pressures, 43.2 % of the study area has no pressure. Moreover, 41.2 % of the study area indicates one pressure, while 14.3 % of this area shows two pressures. Furthermore, four socioeconomic pressures are detected in the remaining 1.3 % of the study area. However, there is no area with three socioeconomic pressures (Fig. 3d).

3.2. Assessment of agroforestry suitability and priority areas

The ASM of the farmlands of Iran is generated by combining all the climatic, soil, and socioeconomic pressures (Fig. 4a). Accordingly, the negligible 0.01 % (1,540 ha) of the study area has no pressure. Furthermore, 82.59 % of the study area (~12.7 million ha) has less than five pressures (except for the no pressure regions), while the remaining 17.4 % (~2.7 million ha) suffers more than five pressures (six to ten pressures) (Fig. 4a).

As mentioned earlier, in the ASM, the regions with more than five pressures are defined as the priority areas (Fig. 4b). It is shown that 44.1 % of the priority areas are located in the irrigated regions, while the remaining 55.9 % are located in the rainfed regions of the study area. In other words, the priority areas in the irrigated and rainfed regions amount to ~ 1.2 million ha and ~ 1.5 million ha, which include about 14 % and 21 % of the total irrigated and the total rainfed farmlands of Iran, respectively (Table 3). In terms of climate types, the majority of the priority areas are located in the arid and semi-arid regions, which together include 74.8 % (~2 million ha) of the priority areas (Fig. 4c). Accordingly, 18.9 % (~0.51 million ha), 5.7 % (~0.15 million ha), and 0.6 % (~0.02 million ha) of the priority areas are located in the Mediterranean, semi-humid, and humid regions, respectively. However, there are no regions with a very humid climate among the priority areas (Fig. 4c).

Table 3 separately indicates an overview of the priority areas in the farmlands of different provinces of Iran for the rainfed and irrigated regions. There is a large variability in the proportion of farmlands classified as the priority areas in each of the provinces. Hereof, among the 31 provinces of the country, Sistan and Balouchestan, Kermanshah, Hormozgan, Khuzestan, and Lorestan provinces are ranked first to fifth with 92.2 %, 87.3 %, 53.2 %, 51.1 %, and 49.7 % of the priority areas in their total farmlands, respectively. However, the five provinces of Gilan, Golestan, Mazandaran, Qazvin, and Tehran, located in the southeast to the southwest of the Caspian Sea, are not among the priority areas (Table 3).

3.3. Assessment of tree/shrubs allocation

According to the USDA cold hardiness zone map, the study area is classified into 9a to 13a zones (Fig. 5a). It means that the average annual minimum winter temperature of the farmlands varies between − 6.7 °C and + 18.3 °C over the studied 50 years (1966–2015). It is indicated that the majority of regions of the study area (23.98 %) are located in zone 10a during the studied 50 years (Fig. 5a). Based on the AHS heat zone map, the study area is classified into two to nine zones (Fig. 5b). In other words, the number of days per year with a temperature above 30 °C varies between 1 and 7 days and 120–150 days in the farmlands over the

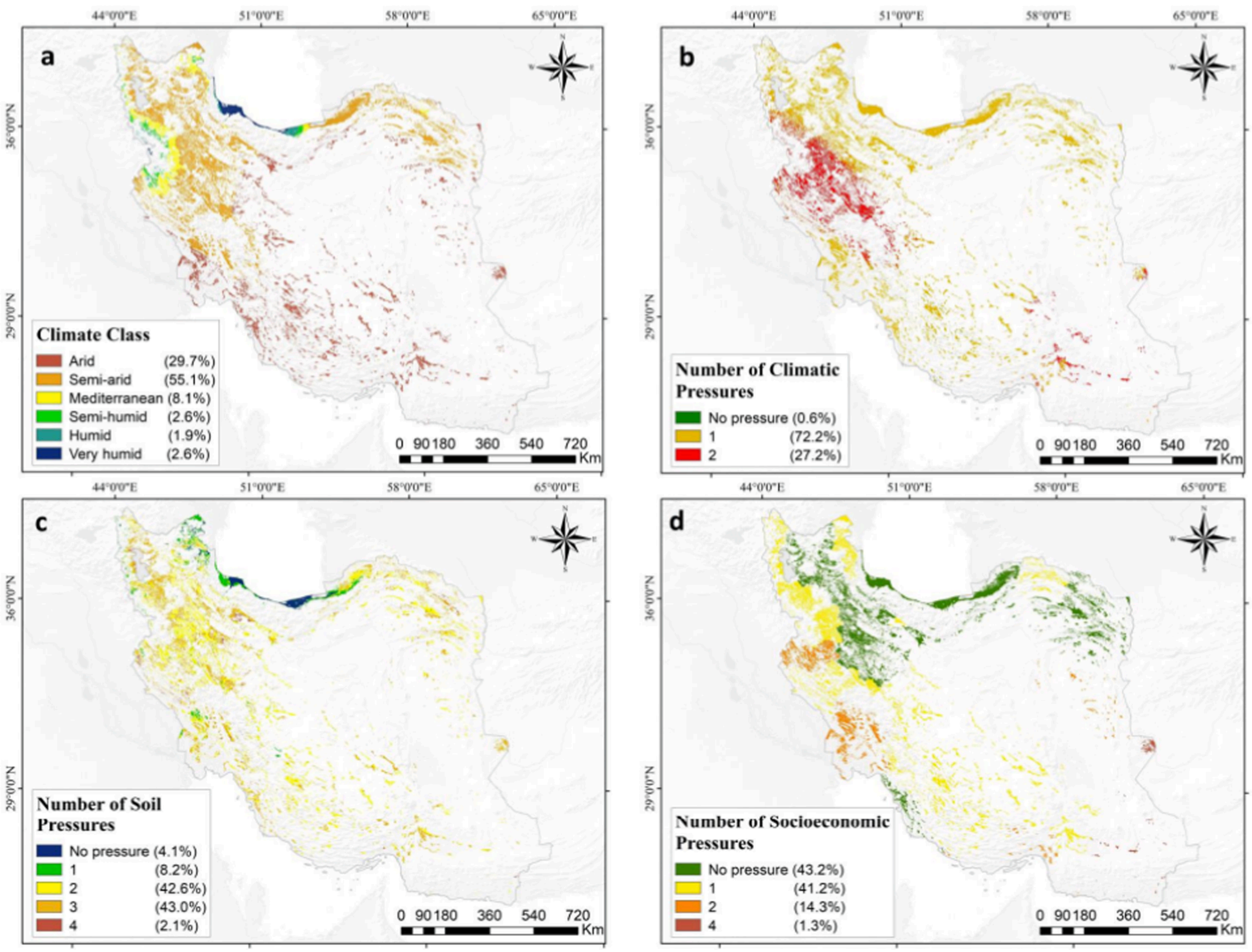

Fig. 3. Map shows the a) climate classes, b) the number of climatic pressures, c) the number of soil pressures, and d) the number of socioeconomic pressures across the farmlands of Iran. The proportion (%) of each class is represented in the corresponding legends. Source: Study findings.

studied 50 years (1966–2015). The zone 2 covers most regions of the study area (29.1 %) during the studied 50 years (Fig. 5b). Table 3 shows the cold hardiness and heat zones for the priority areas of each province of Iran in detail.

4. Discussions

4.1. Pressure areas of Iran's farmlands

This research assessed the most suited areas for agroforestry implementation in the farmlands of Iran. In order to answer our fundamental question, i.e., "To what extent Iran's farmlands are most suited for the implementation of agroforestry," two climatic, four soil, and four socioeconomic pressures were selected. The agroforestry implementation mapping was mostly investigated by considering only the environmental aspects (Kay et al., 2019; Ahmad et al., 2019), and to the best of our knowledge, the socioeconomic sector, as one of the key aspects of the agricultural systems, has often been ignored and not welcomed in such studies.

In this study, the pressure maps were generated by applying a critical threshold for the map of the corresponding indicator. The critical thresholds for delimiting the pressure areas were obtained from the literature review or experts' consultations (see Table 2). Adopting the thresholds is always arbitrary because of the existence of different thresholds and different methods which affect the extent and the location of the Pressure Areas (Kay et al., 2019). For example, in terms of soil erosion, Panagos et al. (2015) defined 5 t ha^{-1} a^{-1} as a threshold for the soil erosion in Europe, whereas FAO (1980) recommended the soil erosion of more than 50 t ha^{-1} a^{-1} as a "high" soil erosion class. According to the nature of Iran, where the average soil loss is approximately 20 times more than the world average (Sadeghi, 2017), 50 t ha^{-1} a^{-1} was considered as the more reasonable threshold for the whole farmlands of Iran. Consequently, determination of the thresholds was done only due to obtaining a reasonable proportion of the study areas as the most suited areas for agroforestry implementation. However, in terms of the socioeconomic pressures, for example, if the farmers with "very low" income were considered to determine the priority areas, it would not mean that agroforestry cannot be beneficial for the farmers with "low" or "moderate" income. Our findings showed that the rising temperature was the dominant pressure that affected the study area. This finding is in line with that of Kay et al. (2019) who investigated nine environmental pressures for the identification of pressure regions for agroforestry implementation in the arable lands of Europe and revealed that the pressure of rising temperatures between 2 °C and 4 °C by 2050 was the high pressure that affected around 63 % of arable lands. It was expected that the rising temperature leads to higher evapotranspiration as well as higher water requirement in agricultural systems and, consequently, results in the shortened crop growth period, reduced production, and lower water productivity of all crops in Iran (Gohari et al., 2013; Kheiri et al., 2022). Iran's farmlands were often characterized by dry and semi-arid climates, which made up around 85 % of the studied area.. Tabari et al. (2014) surveyed the climate of Iran based on the de Martonne aridity index and illustrated that about 88 % of the country is located in the arid and semi-arid areas. The primary

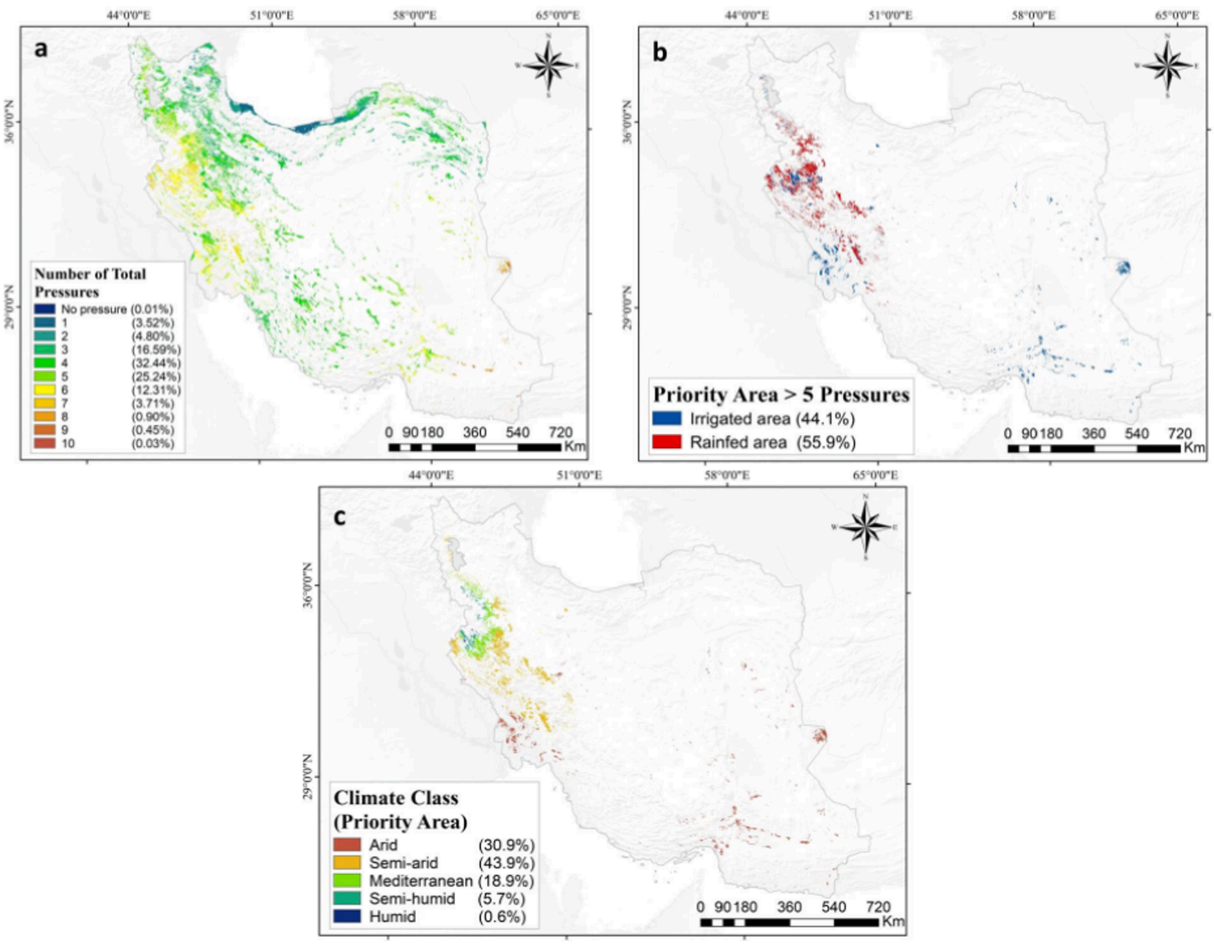

Fig. 4. Map shows the a) the number of total pressures (more number of pressures are much more suited for agroforestry), b) Priority Areas (regions with more than five pressures), and c) climate classes of the Priority Areas across the farmlands of Iran. The proportion (%) of each class is represented in the corresponding legends. Source: Study findings.

difference in geographical scope between the two studies, where they looked at the entire nation, including the middle deserts with their naturally hot and dry environment while we just looked at farmlands, appears to be the primary cause of the 3 % variation in the results.

4.2. *Agroforestry suitability map and priority areas of Iran's farmlands*

To give a spatial overview of the climatic, soil, and socioeconomic conditions of the country's farmlands, we simply accumulated their corresponding individual pressures separately, and to identify the priority areas, we simply put them all together on a map called ASM. Simply, accumulation refers to assigning the same weight to all pressures without considering the importance of each pressure. We believed that this simple method could prevent a further level of arbitrariness about assuming different weights for pressures based on their magnitudes. Furthermore, interpreting its output is easier and more understandable for decision makers (Mouchet et al., 2017). However, the ASM (Fig. 4) showed that the farmlands located in the western and south-eastern areas of the country had the highest number of pressures, while the least number of pressures were observed in the north of the country. Mesgaran et al. (2017) assessed the capability of Iran's lands for sustainable agriculture development and divided the lands into six classes of "very good" to "unsuitable" based on the soil, topography, and climate indicators. Similar to our findings, they illustrated that the southern strip of the Caspian Sea experiences the least pressures and is, therefore, classified as the "very good" class. They also included the southeastern and some parts of the southwestern areas of Iran in the classes of "very low" to "unsuitable" for agricultural cropping.

In this research, the priority areas were mostly located in the arid and semi-arid climates, which indicates the greater vulnerability of these two climates compared to other climates in terms of the studied indicators. This finding is consistent with Segnon et al. (2020) who reported that the arid and semi-arid regions, particularly in developing countries, are most vulnerable to environmental and socioeconomic conditions. Similarly, Farrokhzadeh et al. (2020) found that the arid and semi-arid regions of developing countries are seriously vulnerable to ecological, economic, and social impacts. Agriculture in the arid and semi-arid regions is exposed to several challenges including water restriction, extreme heat, frequent drought, degraded and erosive soil, and unfavorable topography for natural hazards (Kheiri et al., 2021; Karimi et al., 2018). Accordingly, numerous practices such as changing planting schedule, adopting improved varieties, minimizing tillage, and changing cropping pattern have been continuously recommended to reduce the vulnerability and enhance the sustainability of the agriculture sector. However, among the practices, agroforestry is one of the most important and sustainable approaches in these regions (Wang et al., 2022; Krishnamurthy et al., 2019; Marone et al., 2017). Agroforestry systems potentially enhance the system productivity and profitability, income, and ecosystem sustainability with a limited water supply in these regions (Fan et al., 2018). In this regard, Zhao et al. (2022) evaluated the response of young apple tree-based agroforestry to extreme droughts in semi-arid regions and reported that agroforestry has clear ecohydrological advantages such as increased soil water storage, improved root biomass development, and promoted growth to monoculture in these

Table 3

Summary of priority areas of each province in Iran, provided separately for irrigated and rainfed regions, along with their cold hardiness and heat zones. See the supplementary material for the complete list of cold hardiness and heat zones.

Numbers	Provinces	Irrigated (ha)	Rainfed (ha)	Total (ha)	Total farmlands (ha)	% of total farmlands	Cold Hardiness Zone	Heat Zone
1	Alborz	9,516	–	9,516	59,351	16.0	10a	4
2	Ardebil	–	130	130	576,351	0.0	9b to 10a	2
3	Bushehr	–	39	39	295,410	0.0	11a to 11b	7
4	Chaharmahal-e-Bakhtiari	8,428	22,395	30,823	155,619	19.8	9a to 10a	5 to 7
5	East Azerbaijan	39,372	4	39,376	936,928	4.2	9a to 9b	2
6	Fars	2,337	8,679	11,017	1,031,662	1.1	10b to 12a	5 to 8
7	Hamedan	161	1,039	1,199	813,182	0.1	9a to 9b	2 to 4
8	**Hormozgan**	**84,757**	**779**	**85,535**	**160,922**	**53.2**	**11b to 13a**	**8 to 9**
9	Ilam	11,681	62,044	73,726	188,219	39.2	10a to 11b	6 to 7
10	Isfahan	23,747	29,439	53,185	398,270	13.4	9b to 10b	5 to 6
11	Kerman	171,263	–	171,263	779,385	22.0	10a to 12b	5 to 9
12	**Kermanshah**	**221,699**	**489,186**	**710,886**	**813,840**	**87.3**	**9a to 10a**	**3 to 4**
13	Khorasan Razavi	–	51	51	1,253,695	0.0	10a	4 to 5
14	**Khuzestan**	**318,166**	**221,407**	**539,572**	**1,055,438**	**51.1**	**10a to 11b**	**7 to 9**
15	Kohgiluyeh & BoyerAhmad	25	5,475	5,500	151,468	3.6	10a to 11a	6 to 7
16	Kurdistan	12,494	286,790	299,284	897,201	33.4	9a to 9b	2
17	**Lorestan**	**20,433**	**298,957**	**319,390**	**643,124**	**49.7**	**9b to 11a**	**4 to 7**
18	Markazi	2,438	1,549	3,987	534,363	0.7	9a to 10a	4 to 6
19	North Khorasan	933	–	933	334,981	0.3	10a	6
20	Qom	8	–	8	67,096	0.0	10a	5
21	Semnan	182	–	182	161,636	0.1	10a	5 to 6
22	**Sistan & Baluchestan**	**188,426**	**–**	**188,426**	**204,354**	**92.2**	**10b to 13a**	**7 to 9**
23	South Khorasan	64,234	–	64,234	166,675	38.5	10a to 10b	4 to 7
24	West Azerbaijan	39	68,667	68,706	955,276	7.2	9a to 9b	2
25	Yazd	1,996	–	1,996	140,525	1.4	10a to 10b	5 to 6
26	Zanjan	–	15	15	618,377	0.0	9a	2
	Total country farmlands	1,182,335	1,496,647	2,678,982	15,402,525	17.4		

The five provinces of Gilan, Golestan, Mazandaran, Qazvin and Tehran were not among the priority areas, therefore, they were not located in this table. Bold inputs show the provinces with the highest amount of the priority areas in their total farmlands.

regions. In another study, Rathore et al. (2022) indicated that agroforestry systems improve soil carbon storage, water productivity, and economic returns in marginal lands of semi-arid climates. Also, Zhang et al. (2018) revealed that agroforestry systems enable more efficient light capture and photosynthesis, and higher dry matter production in these climates. Telwala (2023) introduced the agroforestry as a nature-based solution for achieving sustainable development goals in the drought-prone drylands. Generally, the findings of this study revealed ~ 2.7 million ha (17.4 %) of the country's farmlands as the priority areas for agroforestry implementation. In line with this finding, Kay et al. (2019) evaluated the priority of agricultural landscapes for agroforestry implementation in Europe and reported about 8.9 % of the European agricultural lands as priority areas where the agroforestry implementation could be particularly effective. Chuma et al. (2021) assessed the suitability of agroforestry using environmental indicators in eastern districts of Congo and reported that about 29.2 % of their study area was very suitable for agroforestry implementation. In the two mentioned cases, the priority areas have been identified only by considering the environmental indicators, while in this study, the social and economic indicators were also involved in determining the priority areas. Identifying the priority areas for the implementation of agroforestry will be more reliable if it is done by simultaneously considering the environmental and socioeconomic aspects (Mukhlis et al., 2022). The three western Iranian provinces of Kermanshah, Khuzestan, and Lorestan, which are all close to the Zagros Mountains, were also placed first through third with corresponding shares of 26.5 %, 20.1 %, and 11.9 % of the overall priority areas. On the other hand, according to the reports of the Ministry of Agriculture-Jahad, the three mentioned provinces are responsible for producing about 22.5 % of the total agricultural products of Iran (MAJ, 2019). The main agricultural products produced in these areas include wheat, corn and barley. These three provinces produce 19.5 %, 22.5 % and 57.9 % of the total wheat, barley and corn productions in Iran, respectively (MAJ, 2019). As a result, given the importance of these three provinces in Iran's agricultural sector and their undeniable role in ensuring Iran's food security, agroforestry systems, as the most sustainable approach, must be implemented in these regions. To sum up the points, there were some limitations to the current study. Considering the approach of this study regarding the determination of priority areas for agroforestry implementation, it was not possible to spatially identify different crop types in whole farmlands and to examine the interactions between crops-trees/shrubs. Nonetheless, given that selecting the type of agroforestry system components (crops and trees) is the most important issue for achieving an efficient system (Lehmann et al., 2020), some aspects such as nutrient retention, water availability, ecophysiological aspects of allelopathy, biodiversity, and susceptibility to pests and diseases should be addressed for agroforestry implementation. As a result, agroforestry systems not only do not interfere with agricultural systems, but also improve their function by creating synergies. In this regard, it has been demonstrated that integrating trees with cereals, the primary products in priority areas, in agroforestry systems has resulted in increased sustainability and productivity (Liu et al., 2020; Rivest et al., 2013). For example, Arenas-Corraliza et al. (2022) compared the phenological, morphological and physiological reactions of winter wheat and barley in the agroforestry and monoculture systems. Their results showed that agroforestry has the advantages of buffering extreme temperatures at the crop canopy level, increasing ambient humidity, and enhancing advanced crop development compared to monoculture. Sida et al. (2018) assessed the growth and development of wheat in an agroforestry system and indicated that the agroforestry system significantly increased soil mineral N, water use efficiency and grain yield of wheat while it decreased heat stress. Amadu et al. (2020) analyzed the maize-based agroforestry systems in the climate-smart agriculture projects of southern Malawi and found that the agroforestry systems could increase maize yield by 20 % in a drought year. Given the forthcoming climate change, population growth, and the need to feed the growing population, the current results call on the policy makers to put the agroforestry systems on their agenda.

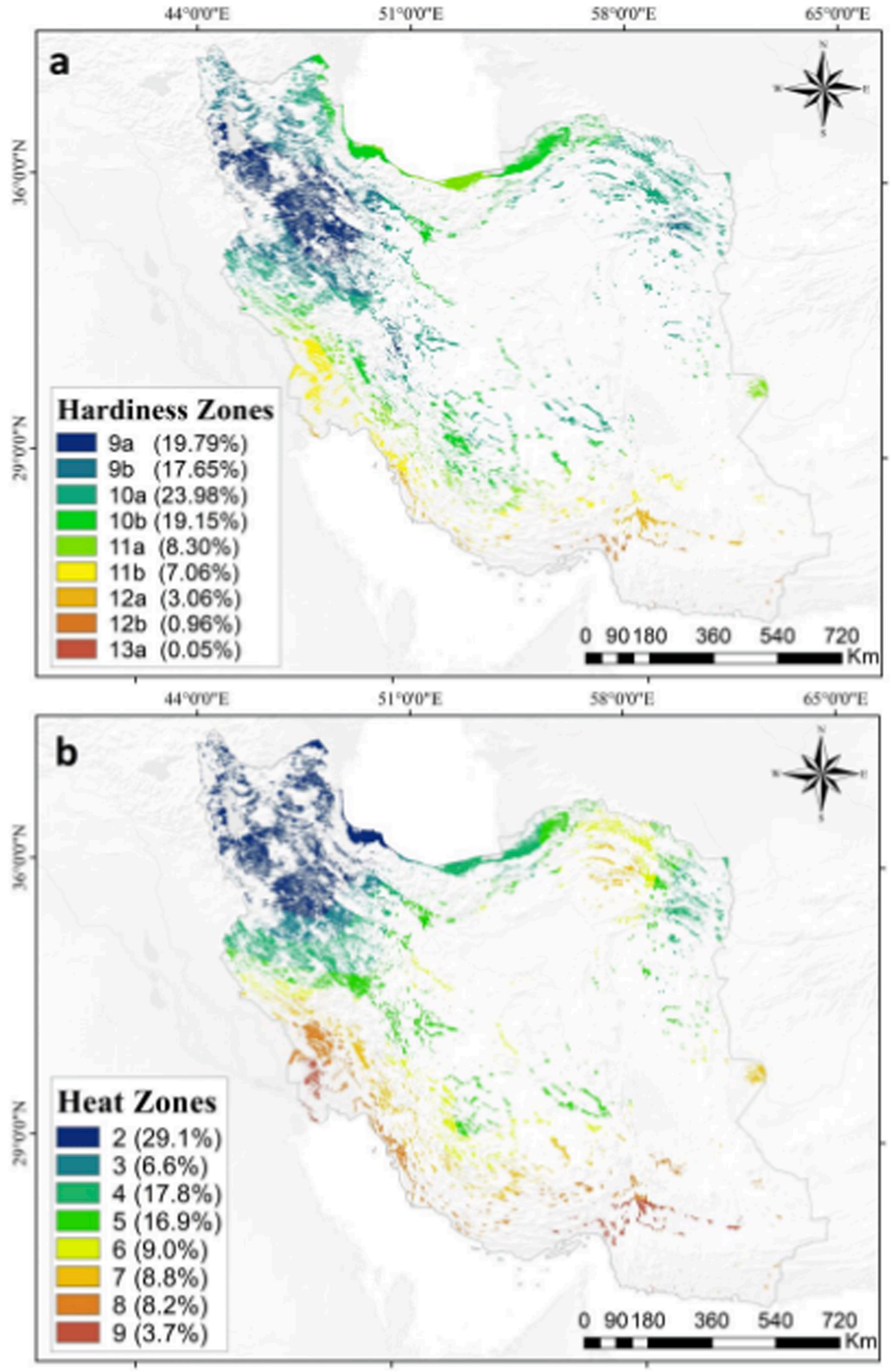

Fig. 5. Map of the a) USDA cold hardiness zones and b) AHS heat zones for the farmlands of Iran. The proportion (%) of each class is represented in the corresponding legends. Source: Study findings.

4.3. Allocation of tree/shrubs for the priority areas

In this research, the study area was zoned in terms of the two key factors of cold hardiness and heat tolerance of tree/shrubs according to USDA and AHS classifications. Our findings showed that Kermanshah, Khuzestan, and Lorestan, as the most important provinces in terms of the proportion of the priority areas, were located in the cold hardiness zones of 9a to 10a, 10a to 11b, and 9b to 11a, respectively. These provinces were also located in the heat zones of 3 to 4, 7 to 9, and 4 to 7, respectively. According to the purposes and the types of agroforestry systems, different woody elements could be adopted in the above-mentioned zones, although it is suggested to use the native woody species of the country that are adapted to the soil and topographic conditions of Iran and are also welcomed from the socioeconomic point of view. Generally, according to Table 3, all native woody plants which are hardy to the annual minimum winter temperature ≤ -6.7 °C (cold hardiness zone 9a) and the number of days per year above 30 °C $\geq$ 150 days (heat zone 9) can be planted with more confidence in these three provinces. The identified hardy ranges of woody elements to cold hardiness and heat zones allow us to suggest that the native hardy plants of Iran, such as oak, almond, hazelnut, and berries, be planted in these provinces. However, it should be noted that the allocation of woody elements in an area needs comprehensive knowledge about the different aspects of regional conditions, such as soil properties, topography, water availability, insect and disease susceptibility, and environmental hazards. On the other hand, although agroforestry systems create a wide range of environmental and socioeconomic benefits, there is still an undeniable lack of acceptance by farmers (Rois-Díaz et al., 2018). Therefore, the farmers' preferences in choosing the type of agroforestry systems and woody elements should be considered (Kay et al., 2019). In this regard, the poor and non-educated farmers, as the most vulnerable social communities, are willing to earn profits in the short time, and this is the main reason why they were inclined to unsustainable practices such as intensive monocultures (Azadi et al., 2021); however, this does not mean that sustainable approaches such as agroforestry are not efficient. It is worth mentioning that these farmers need to be supported more by the government agencies in different ways among which agroforestry is the most sustainable method. In this regard, the government could encourage this group of farmers to implement agroforestry by creating financial support and granting government credits (Karimi et al., 2018). However, it should be mentioned that although these financial supports are necessary, they are not enough for acceptance of an approach, such as agroforestry, by farmers. Thus, there is a need for a strong education plan to change the farmers' attitudes and behaviors to agroforestry. If the government or organizations are not planning an education initiative, the agroforestry systems could not be successful. Jha et al. (2022) explained that the perception and acceptance of agricultural innovations is an important adaptation mechanism for smallholder farmers to prepare and deal with potential shocks and uncertainty. In addition, Sanou et al. (2019) showed a positive relationship between education and adoption of agroforestry. They also stated that to have an effective adoption, the farmer must percept the problem and this requires a comprehensive education to be able to understand the information about the benefits of the agroforestry. In another study, Paudel et al. (2022) reported that education programs such as training, farmer field schools, door-to- door visits, etc., should be intensified to sensitize farmers about climate change and encourage them to adopt agroforestry practices.

5. Conclusion

The findings of this study indicated that the rise in temperature was the dominant pressure that affected the farmlands of Iran. The ASM showed that the farmlands located in the western and southeastern areas of Iran had the highest number of pressures, while the least number of pressures were observed in the north of the country, especially in the areas located around the Caspian Sea. Generally, the findings of this study revealed about one-fifth of the farmlands as the priority areas for agroforestry implementation. Moreover, the priority areas were mostly located in the regions with arid and semi-arid climates, which indicates the greater vulnerability of these two climates compared to other climates in terms of the studied pressures. Accordingly, Kermanshah, Khuzestan, and Lorestan provinces, all located in western Iran and adjacent to the Zagros Mountains, ranked first to third with a total share of about 58.5 % of the total priority areas, respectively. Furthermore, using the USDA cold hardiness and AHS heat zoning maps, the findings revealed that all native woody plants tolerant of minimum annual winter temperature $\leq -6.7\,^{\circ}$C and to the number of days per year above 30 $^{\circ}$C $\geq$ 150 days can be planted as the woody elements of agroforestry systems with more confidence in the priority areas. Agroforestry is a multi-functional agricultural land management approach that has the potential to simultaneously improve the total environment and socio-economic dimensions. Agroforestry plays a significant role in conserving and improving biodiversity in four ways: (i) It offers habitat to species that can resistant to a certain amount of disturbance; (ii) It enhances the preservation of sensitive species' germplasm; (iii) It reduces the rates of habitat change by providing a more efficient and sustainable alternative to conventional agriculture practices, which may necessitate the destruction of natural ecosystems; and (iv) It protects biological diversity by providing additional ecosystem services, such as erosion control and water recharge, to reduce habitat degradation and loss. From the environmental and socioeconomic point of view, this study identified the most vulnerable farmlands as the areas that are more suitable for the implementation of agroforestry. Given the forthcoming climate change, population growth, and the need to feed the growing population, the findings of this study help policy makers to put the agroforestry systems on their agenda to move towards sustainable development goals. However, the implementation of agroforestry systems will be successful if farmers' preferences and acceptance be taken into consideration. It is also necessary to consider some other aspects such as soil properties, topography, water availability, insect and disease susceptibility, environmental hazards, and competition over resources in the implementation of agroforestry in the future studies. It should be noted that choosing the compatible species, their spatial and temporal arrangement, and the management practices are critical to optimize the overall production of any specific agroforestry system. Overall, the approach used in this study could be transferrable to other countries, particularly in arid and semi-arid developing countries that are experiencing similar problems. Relying on the approach used in this paper, researchers will be able to confidently identify susceptible areas for agroforestry implementation. In addition, with the help of the approach applied in this study, it can be postulated that the agricultural challenges of each region are mainly affected by climatic, soil, and socioeconomic factors. In addition, the findings of this research can be used in other regions with conditions similar to Iran. The researchers in the Middle East countries and those in arid and semi-arid regions, where agriculture is fragile and whose farmers are often smallholders, can potentially be the audience of this research. One of the most important challenges of this study was selecting the number and type of indicators as well as determining the critical threshold for each indicator. Although the lack of a database is an unavoidable and inherent limitation in Iran, this study investigated the areas suitable for agroforestry for the first time using the most recent available data. It should also be noted that this study cannot address all the existing farmland problems. For example, the nutrient retention, biodiversity aspects (quality and quantity), greenhouse gasses emissions (e.g., CO_2 and Methane), and the natural hazards (e.g., floods, storm, and landslides) were not considered in the current study, and all could be addressed in future studies.

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Declaration of Competing Interest

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

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jnc.2023.126358.

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