Mapping the Relative Pollination Potential of Iran Using Multi-Criteria Evaluation and The Lonsdorf Model

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Research Article

Keywords: Iran, Pollination service, Multi-criteria evaluation, The Lonsdorf model, Wild bees

Posted Date: August 9th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-344096/v1>

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Abstract

Since very little attention has been paid to pollination service in Iran, especially its mapping, there is little information about the areas where wild bees are present. Therefore, in this study, we used two models based on expert opinion that does not need the presence points of pollinating bees to estimate pollinating service. The Lonsdorf (Lonsdorf et al., 2009) model, simply considers the potential of land covers in providing nesting habitat and floral resources for mapping pollination services in different landscapes. In addition to considering the potential of land covers in providing pollination service, the multi-criteria evaluation model uses additional factors such as altitude, climate, roads, and rivers network. The results of the Lonsdorf model showed that the majority of Iran have a low potential for providing pollination service and only three percent of the northern and western parts of Iran have high potential. However, the results of the multi-criteria evaluation model showed that 23% of Iran has a high potential to provide pollination services that cover most of the northern and southern parts of the country. The difference in the results of the models was due to their attention to the factors affecting the probability of the presence of pollinators in Iran because the Lonsdorf model does not pay attention to factors such as altitude and climate in modeling, while these factors significantly affect the activity of bees. Therefore, the present study acknowledges the results of the multi-criteria evaluation model for pollination service mapping in Iran and emphasizes that the approach adopted in the Lonsdorf model for accurate estimation of pollination service is not complete and needs correction.

Highlights

- In general, land covers with moderate potential for pollinating services cover most on Iran.
- Because the Lonsdorf model only emphasizes the potential of land use users to provide pollination services, the results of this model are inconsistent with reality.
- The present study considers the multi-criteria evaluation model to be more appropriate for estimating pollination service because it takes into account factors such as climate and altitude in modeling.

1. Introduction

In recent years, there has been global concern about the decline of pollinators around the world (Viana et al., 2012). This concern has led to further studies identifying pollinator threats and quantifying the effects of pollinator reduction on pollinator service in agricultural and natural systems. Approximately 75% of the world's agricultural products, known as human food, benefit from the presence of pollinator insects (Klein et al., 2007). Several studies have estimated the global economic value of pollination (Gallai et al., 2009), but these estimates are uncertain because the dependence of crops on pollinator insects is not fully understood, these studies indicate that ecosystem services such as pollination are critical to humans. In Europe, agricultural production is said to be highly dependent on pollinating insects, at about 84%. (Williams, 1994). The notion of the dependence of agricultural products in Europe on pollinators and the associated high economic value has led to the determination of the relative potential of land uses in

Europe, especially in natural and semi-natural areas of Europe to provide pollination services. (Zulian et al., 2013).

Recent studies have shown that bees are more efficient pollinators than other pollinators because they both visit more flowers and place more pollen on the flower's stigmas. (Willmer et al., 2017) Thus, the most important pollinators are bees, which are directly responsible for maintaining the diversity of native vegetation, and many plants are dependent on these plants for their reproduction (Ollerton et al., 2011). Although farmers typically use honey bees to pollinate their crops, the recent decline in their activity and population (Potts et al., 2010) has led to a focus on wild bees and how they function in nature. Some studies have shown that in the absence of bees, wild bees have increased agricultural production, especially in orchards (Garibaldi et al., 2013). Thus, wild bees are vital components of ecosystems that provide essential services to wild plants and farms (Kennedy et al., 2013 250). In some cases, wild bees can pollinate the fields alone (Winfrey et al., 2007 251). In organic farms near natural habitats, all pollination may be done by wild bees (Kremen et al., 2002).

The two drivers that affect wild bee populations on farms are 1- Local management practices in the fields and 2- Quality and structure of the surrounding landscape (Klein et al., 2007). Various management practices such as organic farming, in-farm heterogeneity, improve bee populations even if the amount of natural habitat in the surrounding landscape is small (Batary et al., 2011). Research on the effects of landscape on pollinators focuses mainly on the participation of natural and semi-natural areas around farms, which provide foraging habitats and nesting sites for pollinators (Williams and Kremen, 2007).

Pollination depends on the movement of native pollinators from non-agricultural areas such as forests to farms (Ricketts et al., 2008). Therefore, the amount of habitat that bees visit during the day depends on the distance between foraging and nesting habitats and the configuration of these habitats (Kremen et al., 2004; Westrich, 1996). Large patches provide more biodiversity for pollinators (Tschamtker and Brandl, 2004) and as the size of these patches decreases, the abundance of pollinators also decreases (Aguirre and Dirzo, 2008). Pollinator abundance also decreases with increasing distance from large patches (Donaldson et al., 2002) (Mitchell et al., 2014; Ricketts et al., 2008) (Joshi et al., 2016). For example, for the coffee plant at distances of 0 to 500 m, it has been shown that the size effect of forest patches on the coffee plant is directly related to the visitor rate of pollinators (Krishnan et al., 2012). Decreased pollination has also been acknowledged by increasing the distance from forest patches for the coffee plant (Boreux et al., 2013; Klein et al., 2003; Ricketts, 2004; Saturni et al., 2016). Several studies have shown that pollination decreases with increasing distance from natural and semi-natural tree spots within agricultural fields, and the decrease is reported exponentially with increasing distance from forest patches (Keitt, 2009; Martins et al., 2015; Mitchell et al., 2015; Ricketts et al., 2008). Ricketts et al. (2008) reviewed 23 studies related to the effects of landscape structure on pollination and acknowledged that in most of these articles, the results show that the abundance and visiting rate decrease exponentially with distance from natural habitats.

Wild bees are very sensitive to environmental changes such as the destructive activities of humans (Kennedy et al., 2013). Therefore, preserving the habitat of pollinators and their diversity in agricultural lands against human activities is necessary to ensure food production and security (Lonsdorf et al., 2009). It is well established that habitat loss and fragmentation have devastating effects on biodiversity and ecosystem functions (Haddad et al., 2015). Action 5 EU Biodiversity Strategy to 2020 requires its members to map and evaluate ecosystem services in their territories (Maes et al., 2013). The purpose of this evaluation is to provide information for complex decisions. The processes that lead to the production of ecosystem services originate from spatial nature and these processes change in time and place (Burkhard and Maes, 2017). Therefore, determining the environmental conditions that affect wild bees at the local and landscape levels is critical (Kennedy et al., 2013). An applied methodology adopted by Invest software was used to map the pollination ecosystem service across Europe, which in addition to the factors required to implement Invest, Zulian et al. (2013) added several other factors to the model. For example, they used a land parcel system based on the Common Agricultural Policy Regionalized Impact to estimate the participation of crops in floral resource availability and the benefit of crops. These models use an expert assessment of different land covers to determine the availability of floral resources, foraging areas, and nesting habitats. Kennedy et al. (2013) For 39 different regions of the world, modeled the effects of landscape composition and configuration and farm management on the abundance of wild bees. They found that landscape and local factors affect the bees. And at the landscape level, the bee population is higher if we have a lot of high-quality habitats around the farms. At the local level, organic management and crop diversity improve bee populations. Landscape configuration has little effect on bee populations and bees are more affected by the amount of habitat within their foraging range (Kennedy et al., 2013).

The present study aims to estimate pollination service in Iran based on two Lonsdorf and multi-criteria evaluation models. In the multi-criteria evaluation model, in addition to the potential of land covers in providing pollination services, factors such as climate, altitude, roads, and rivers network are also modeled. Therefore, the questions of the present study are as follows.

- 1- Which model is more suitable for estimating pollination service in Iran? And what are the strengths and weaknesses of each of these models?
- 2- What parts of Iran are habitats with a high potential to provide pollination services? And what percentage of Iran do these habitats cover?

2. Natural Geography Of Iran

Iran is divided into three phytogeographical regions ([Talebi et al., 2014 248](#)): the Euxino-Hyrcanian, Saharo-Sindian region, and Irano-Turanian. Ecologists have divided Iran's forests into three ecological zones: Caspian or Hyrcanian, the Khalijo- Omani, and Iranian-Turanian, which is divided into Zagros mountainous and central plateau zones. 5 ecological regions of Iran are briefly introduced below (Fig 1).

2.1 Hyrcanian or Caspian ecological zone

Hyrcanian ecological region is located in the south of the Caspian Sea and along the Alborz mountain range. The area of forests in this region is 2 million and 4 thousand hectares and 4 species of conifers, 50 species of shrubs and 80 species of broadleaf trees have been identified so far, which are mostly beech, hornbeam, oak, maple, alder (Anonymous, 2008). These forests belong to the third geological period, which is considered as a world natural heritage (Fig 1).

2.2 Irano-Turanian Ecological Zone

This region with an area of 4666941 hectares is divided into mountainous and desert areas that cover the central and western regions of Iran. 69% of the flora of Iran is located in this area and the main species of this region are pistachio, almond and wild pear (Anonymous, 2008). The oak forests of the Zagros region are estimated to be 5500 years old. This area with an area of 5440494 hectares is the most important area containing Iranian oak (Fig 1).

2.3 Arasbaran Ecological Area

More than 775 plant species have been identified in this region, 55 of which have been reported for the first time from Iran. Therefore, UNESCO has protected these forests with an area of 174838 hectares since 1976 as one of the biosphere reserves. (Anonymous, 2008) The main species of Arasbaran region are black oak, white oak, hornbeam, yew and maple (Fig 1).

2.4 Khalijs- Omani Ecological Region

The area of forests of the Persian Gulf-Omani ecological zone, which includes part of the southwest and all southern coasts, is 2039963 hectares. Iranian acacia varieties are the main plants of this region. Wetlands or mangroves, which consist of two species *Avicennia marina* and *Rhizophora mucronata*, are also seen in this area. The mangrove forest habitat is located between the tides of the seas (Anonymous, 2008).

Table 1 shows the area and proportion of Iran's natural resources. According to this table, forests deserts, Rangeland, and bushes have covered eighty-one percent of Iran, among which rangelands cover almost half of the country, most of which are poor rangelands. Deserts has covered twenty percent of Iran, which are mainly in the center, east, and southeast of Iran and fact in the Irano-Turanian ecological region.

Area and proportion of natural resources in Iran (Talebi et al., 2014)

Natural resources	Area (ha)	Proportion (%)
Natural forest	13,364,010	8.10
Man-made forest	946,546	0.57
Bush and woodland	2,723,756	1.65
Rangeland	84,960,321	51.60
Desert	32,863,972	19.94
Total	134,884,365	81.85

3. Agriculture In Iran

About 14.46% of Iran is occupied by agricultural lands. In 2016, the area of crops in Iran was about 11 million hectares, of which 54% of the land is irrigated and 46% is rainfed. The level of cereals was 69.55%, beans 7.27%, industrial products 5.02%, vegetables 4.71%, Cucurbits 2.7%, fodder crops 9.44%, and other products 1.31%. The highest levels in cereals were related to wheat (49.46%), barley (13.4%), alfalfa (5.91%), paddy (5.43%), chickpeas (4.57%), and fodder corn (1.81%). That is, about 80.58% of the crop harvest area belongs to these 6 crops. (Agriculture, 2016). In 2015, the area of orchards in the country was about 2.91 million hectares, of which about 86.8% was irrigated and the rest was rainfed. The fertile area of the country's orchards is estimated at 2.46 million hectares, which is equivalent to 84.6% of the total area of the country's orchards. The five products that have the highest production in Iran are oranges, grapes, apples, cucumbers, and dates, respectively (Agriculture, 2015). Figure 2 shows the spatial distribution of forest, rangeland, and agricultural covers in Iran. According to this figure, agricultural lands can be seen almost all over Iran, but the northeastern and western parts of Iran have a larger surface area, as shown in Fig. 2, the eastern and central regions of Iran are free of vegetation. All types of forest, rangeland, and agricultural covers are combined to get a better view of their location in Iran, the details of each cover are presented in Table 2.

4. Pollinating Bees Of Iran

There are about 800 species of wild bees in Iran that belong to the families Colletidae, Halictidae, Andrenidae, Melittidae, Megachilidae, Anthophoridae, and Apidae. They are too interested in the temperate climate and we see the most in these cases (Mohammadian, 2003). A wide range of pollinating bees has been identified in different parts of Iran. Among these, two species of *Apis florea* and *Apis mellifera meda* are widely distributed (Sanjerehei, 2014). *A. florea* is widespread in the southern parts of Iran, but *Apis mellifera meda* is native to Iran and has the highest distribution among other bees in the country (Rahimi and Mirmoayedi, 2013). The economic value of pollination of Iranian agricultural products in 2005–2006 was estimated at \$ 6.59 billion (Sanjerehei, 2014). Of that, \$ 5.72 billion was allocated to honeybees and \$ 0.87 billion to wild bees. it is estimated that 25% of the total production of agricultural products related to pollination in Iran is done by pollinators. (Sanjerehei, 2014). In Iran, few

studies have focused on the distribution modelling of wild bees and most studies have focused on the identification of species, therefore, there is rarely a map of the distribution of these species in different parts of Iran and only there are reports of bee presence in different parts of Iran that do not cover all species and the whole of Iran. For example, in a study modeling the spatial distribution of *A. flora* species under the influence of climatic and topographic factors Parichehreh et al. (2020) showed that the *A. florea* is seen from southeast to south and southwest of Iran and identified the tropical climate with cold winters and hot summers as the most desirable areas for this species (Parichehreh et al., 2020).

In the present study, most of the studies that have studied wild bees in Iran have been reviewed and their results are as follows. Monfared et al. (2005) in a collective study on wild bees in Iran, acknowledged that 34 species of Iranian bumblebees are found in twenty provinces of Iran (Monfared et al., 2005). Khodaparast and Monfared (2012) in a comprehensive work on wild bees in Fars province (southern Iran), identified 177 species, of which 56 species belong to the Apoidea family, 49 species of Halictidae, 39 species of Megachilidae, 31 species of Andrenidae, one species of Melittidae and one species of Colletidae (Khodaparast and Monfared, 2012). Izadi et al. (1999) also recorded 35 species of Apoidea family in Fars province (southern Iran). Khodaparast and Monfared (2013) reported 47 species of the Eucerine bees in Iran, all of which are in Fars province (Khodaparast and Monfared, 2013). Keshtkar et al. (2012) Identified 25 species of wild bees in urban parks of Shiraz. Tavakoli Korqand et al. (2010) in Legume-crops pollinators in Gilan province (northern Iran) identified 46 species from 24 genera and 6 families. Khodarahmi Ghahnavieh and Monfared (2019) in the Isfahan province, identified 154 species, which registered 29 new species and 35 species of the family Andrenidae, 11 species of the family Apidae, 20 species of the family Colletidae, 50 species of the family Halictidae 36 species of the family Megachilidae and 2 species of the family Melittidae (Khodarahmi Ghahnavieh and Monfared, 2019). Salehi Sarbijan et al. (2012) Identified 34 species of bees in Sistan and Baluchestan province (southeastern Iran) that were of 17 genera and 5 families.

5. Measuring Pollination Of Iran

Pollination estimation in the present study is based on two models of Lonsdorf and multi-criteria evaluation. In the Lonsdorf method, only for each land cover, the availability of floral and nesting resources is determined and the pollination is estimated according to the foraging range of the desired species. In the process of mapping pollination services based on the multi-criteria evaluation, first, the factors that affect the presence of pollinators in Iran are identified based on the expert opinion and their effect degree on pollination is determined according to each other. The basis of this method is more on the distance so that increasing or decreasing changes in the distance of the influential factors, change the degree of habitat suitability for the species. multi-criteria evaluation is suitable for cases where insufficient information is available on the spatial distribution of the species in question and therefore a potential assessment of the species' habitats can be obtained.

5.1 Measuring pollination based on the Lonsdorf model

The Lonsdorf model examines the spatial arrangement of nesting and foraging habitats of wild bees, which can be disjointed in place or time. The bees return to the nest after collecting pollen and nectar, so the visiting rate in a patch with floral sources depends on the distance between the nesting habitat and that patch (Lonsdorf et al., 2009). This model logically predicts pollination service in a landscape (Kennedy et al., 2013) and is the first explicit spatial model in this field (Lonsdorf et al., 2009). The Lonsdorf model focuses on wild bees and estimates their relative abundance on farms. Initially, using pollinating species habitat needs and food sources and the distances the species can travel, it produces an indicator of the relative abundance of species in nesting habitats. In the next step, it predicts the abundance of each species in the agricultural fields. This model first measures the desirability or quality of patches that are suitable for the bee nesting habitat according to the floral resources around these patches (Equation 1). In the assessment of food resources around nests, near pixels weigh more than those around distant ones according to the expected flight distance of the bee. The result is a map showing the desirability of nests between 0 and 1. In the next step, the model predicts the relative abundance of visiting bees in agricultural fields according to the desirability of the nests (Equation 2).

$$G_i = N_i \frac{\sum_{j=1}^M F_j e^{-D_{ij}/\alpha}}{\sum_{j=1}^M e^{-D_{ij}/\alpha}} \quad (1)$$

In this Equation, if the habitat is suitable for nesting the desired species, N_i is equal to 1 and otherwise equal to 0. D_{ij} is the Euclidean distance between nesting cells (i) and floral resource cells (j). The numerator is the total weight of the distance between all the cells of the floral resources adjacent to the nest patches that the quality of these cells (F_j) is between 0 and 1. α determines the average distance that the bee can travel. The result of this Equation is a map that shows the fitness of the patches for bees to nest between the numbers 0 to 1.

$$P_j = \frac{\sum_{i=1}^M G_i e^{-D_{ij}/\alpha}}{\sum_{i=1}^M e^{-D_{ij}/\alpha}} \quad (2)$$

To determine the abundance of bees on farms, Lonsdorf, based on the concept of Equation 1, assumes that cells from farms that are closer to the nesting habitats are more qualified and therefore have more bee abundance. Therefore, the abundance index of P in j cells is calculated according to (Equation 2), in which G_i shows the fitness of nesting patches, which was calculated in the previous step.

The distance that bees can fly affects their ability to pollinate. This ability varies according to the species and size of the bee (Everaars et al., 2018). For example, *A. mellifera* can fly up to 1100 meters (Gary et al., 1981). But most bees fly at distances below their maximum capacity, in fact, something between 100 and 300 meters (Greenleaf et al., 2007) (Zurbuchen et al., 2010). This distance is considered as a local scale.

In many landscapes of agriculture, the abundance and diversity of bees are reduced at distances of 50 to 500 meters from forest spots (Bailey et al., 2014). The average foraging distance for pollination service mapping in Europe was considered to be 200 meters (Zulian et al., 2013), in the present study, according to experts' opinions, 1000 meters was considered as foraging distance. Scoring for different land cover In the Lonsdorf model, the numbers are between zero and one (Table 2), which 0.5 means that 50% of the desired habitat provides floral or nesting habitat (Lonsdorf et al., 2009).

Table 2. Floral availability and nesting suitability scores for the Iran land covers.

Land use/cover	Nesting suitability	Floral availability
Irrigated Agriculture	0.2	0.5
Rainfed agriculture	0.2	0.2
Orchard	0.2	0.8
Abandoned orchard	0.4	0.2
Fallow	0.3	0.3
Broad-leaved forest	0.8	0.7
Aleppo oak	0.6	0.6
Low density forest	0.4	0.3
Woodland	0.5	0.4
Natural grasslands	0.7	0.9
High quality range	0.6	0.8
Poor range	0.3	0.4
Bare soil	0.2	0
Rocky lands	0	0
Desert	0	0
Urban	0.2	0.1
wetlands	0.3	0.5
Lakes	0	0
Shoreline	0	0
Sand dune	0.1	0
Salt land	0	0

5.2 Mesuring pollination based on multi-criteria evaluation

Multi-criteria evaluation is usually achieved by one of the following three methods. The first method is based on Boolean integration, which is based on the logic of zero and one, and the final output of the model is completely suitable (one) and completely inappropriate (zero). This model is the simplest and without flexibility. The second method is weighted linear composition (WLC) which is based on the concept of weighted average. Factors are not only converted to zero and one values but also scaled to specific ranges based on specific functions (Eastman, 2012 27). The most common method for multi-criteria evaluation and multi-objective evaluation (MOE) in the GIS to analyze land suitability is the weighted linear composition approach. The WLC method allows a complete exchange between all factors and is more flexible than the Boolean method. The third method for multi-criteria evaluation is the ordered weighted average (OWA) (Eastman and Jiang, 1996). In this study, a weighted linear combination (Equation 3) was used to combine the criteria. In superimposing layers by weighted linear combination method, criteria are categorized into both factors and constraints (Eastman, 2012). The factor is a measure that increases or decreases the appropriateness of an option for the intended purpose. Constraints are criteria that limit the decision option and some places are removed by them. Factors affecting the presence of pollinators in the present study are presented in several components and each component has also sub-components that how they affect pollination service and their weight is given in Table 3.

$$S = \sum (w_i x_i) \prod C_j \quad (3)$$

where, S , X_i , W_i , and C_j are the suitability value, the score of criterion i , the weight of criterion i , and the score of constraint j , respectively.

5.2.1 The anthropogenic component

The anthropogenic component includes all man-made non-natural phenomenon, and these factors usually negatively affect biodiversity. In the present study, according to experts, opinions, cities, roads, airports, and railways were identified as influential factors in the presence of pollinators in Iran. The extent and impact of the factors of this component are included in Table 3. The most important ones are briefly described below.

5.2.2 Urban

Pollination is a vital ecosystem service not only in natural ecosystems but also in cities (Theodorou et al., 2020). In urban areas, wild bees are more abundant than bees (Lowenstein et al., 2014). Pollination in agricultural systems and natural habitats has been well studied (Baldock et al., 2015) but the ability of urban ecosystems and inland pollinators to provide ecosystem services has been less studied. (Wenzel et al., 2020). Many studies have reported declining pollinators in the city (Matteson et al., 2013), and others have reported the positive effects of urbanization, for example, from 141 studies related to urban impacts on pollination 74 of these studies showed the negative effects of urbanization and 37% of its positive

effects on pollination ([Theodorou et al., 2016](#)). The positive effects of urbanization on biodiversity at the intermediate levels of urban development are reported ([Theodorou et al., 2016](#)), in fact, in areas where the density of buildings is low and there is a lot of space between houses (less impermeable levels between 20 and 30%). In the present study, experts emphasized the negative role of cities in attracting pollinators, and hence in the mapping process of pollination service in Iran, pollinators increase with distance from cities (Table 3).

5.2.3 Road network

While roads have a wide range of negative ecological effects on insects ([Muñoz et al., 2015](#) 278), some believe that marginal habitats, roadside, and railways have a positive effect on pollinators due to providing nesting and floral habitats ([Brondizio et al., 2019](#); [Henriksen and Langer, 2013](#)). In some cases, the effects of roads on insects such as bumblebees have been reported negatively, and roads have acted as a barrier for them ([Keller and Largiader, 2003](#)). The negative effects of roads on wildlife depend on vehicle speed, traffic volume, road width, time, and habitat density around roads ([Forman et al., 2003](#)). One study examined 141 studies related to the effects of roads on pollinating insects ([Phillips et al., 2020](#)). The results generally showed that roadside roads are often hotspots for flowers and pollinators, and 2. Traffic and pollution caused by them have negative effects on pollinators, but the advantages of Roads outweigh the damage to pollinators ([Phillips et al., 2020](#)). In a review, [Muñoz et al. \(2015\)](#) examined the effects of roads on insects, and reviewed 50 studies that reported these effects and stated; in general, roads negatively affect the diversity and abundance of insects due to their impact on obstacles, fragmentation, pollution, accidents, and traffic ([Muñoz et al., 2015](#)). In the present study, the effect of roads on the attraction of pollinators in Iran was considered negative according to expert's opinions, and therefore, with increasing distance from roads, the abundance of pollinators increases. The same is true of airports and railways (Table 3).

5.2.4 Forest component

The highest habitat suitability is assigned to natural and semi-natural areas (forests, wooden wetlands, meadows, and shrubs), followed by some farms and then to low-density developed areas ([Kennedy et al., 2013](#)). The most important factor that affects the population of bees in the fields is the number of quality habitats around the fields, and with the increase in the level of single-field farms, the amount and variety of habitats for wild bees in the landscape are more important ([Kennedy et al., 2013](#)). Habitats such as forest edges, flower-rich meadows, and riverbanks are suitable areas for the presence of pollinators such as honey bees, solitary bees, bumblebees, and butterflies ([Kells and Goulson, 2003](#); [Svensson et al., 2000](#); [Westphal et al., 2003](#)). Woodlands and forests provide good nesting habitats and floral resources for pollinators, In particular, the forest edge has a higher value ([Svensson et al., 2000](#)). In the Estimap model ([Zulian et al., 2013](#)), the edge of the forest was considered fixed, but the score decreased with increasing distance to the forest. The forest component in the present study includes dense broad-leaved forests, Zagros oak, low-density forests, and woodlands, which with the distance of these natural areas, the presence of pollinators also decreases (Table 3).

5.2.5 Agricultural component

Farms mostly serve as floral resources for bees, and bees use natural areas around farms, such as forests, as nesting habitats. Some crops, such as cereals, do not require pollination but are necessary for fruits, vegetables, nuts, spices, and olives (Klein et al., 2007). The majority of crops grown in Iran are cereals, but the place of cultivation of these crops changes every year, so it was not possible to prepare a map showing the location of each crop in Iran. The agricultural component in the present study includes irrigation fields, rainfed fields, fallow lands, and orchards, which increasing the distance from these factors result in decreasing the abundance of pollinators (Table 3).

5.2.6 Rangeland component

Rangelands are home to a variety of herbaceous plants and are therefore the preferred habitat for pollinators (Öckinger and Smith, 2007). About 50% of Iran consists of rangelands, which mostly include low-density and poor rangelands. Rangelands are very important for both floral and nesting habitats for pollinators. In the northern and western regions of Iran, which there are high-quality rangelands, we may see an abundance of high pollinators. The present study includes natural grasslands, high-quality rangelands, and low-quality rangelands, which with increasing distance from these factors, the abundance of pollinators decreases (Table 3).

5.2.7 Water component

The water component in the present study includes rivers, wetlands, and lakes that the vegetation around these factors provides a good resource of food and nesting habitats for pollinators. Therefore, with increasing distance from these factors, the frequency of pollinators decreases (Table 3).

5.2.8 River network

Vegetation around rivers and wetlands contains more pollinators than on drylands and single-crop farms (Kuglerová et al., 2014 283). Noting that the rivers have placed valuable floral resources and nests in their margins, Santos et al. (2018) in the rivers understudy, stated that the vegetation cover around 300 m of the rivers are supports more pollinators than farms. In mapping the pollination service in Europe, rivers were also included in the model as one of the parameters influencing the presence of pollinators (Zulian et al., 2013).

5.2.9 Wetlands

Wetlands play an important role in pollination by providing diverse nesting and foraging habitats for pollinators (McInnes, 2018). For example, there are more than 920 species of pollinating birds (Whelan et al., 2008), many of which depend on wetlands for part of their cycle (McInnes, 2018). Ponds are also a potential source of insects (Stewart et al., 2017). More abundance of syrphids and bees has been reported in ponds than in other habitats due to the high heterogeneity of the pond landscape (Vickruck et al., 2019). Wetlands surrounded by farms also have a high potential for pollination service and with

increasing distance from the wetland (75 m) in canola and cereal farms pollinators abundance decreases (Vickruck et al., 2019).

5.2.10 Topography

Topographic microclimate changes contribute to the plant-pollinator relationship because they affect flowering time (Olliff-Yang and Ackerly, 2020). Slope and aspect also have significant ecological effects on vegetation patterns and consequently pollinators by changing temperature and humidity (Bennie et al., 2008). In the northern hemisphere, for example, the southern slopes receive more sunlight and therefore higher temperatures (Bennie et al., 2006). As altitude increases, the population of many pollinators decreases (Devoto et al., 2005 293; Hodkinson, 2005 294; Kimball, 2008; Totland, 2001 296). Someone reported that with increasing altitude from 60 meters to 2000 meters, the abundance of wild bees decreases linearly (Gottlieb et al., 2005 297). In areas with an altitude of more than 1000 m, the probability of the presence of A.flora in Iran decreased (Parichehreh et al., 2020). In the present study, according to experts' opinion, increasing altitude was considered as a factor with a negative impact, and therefore with increasing altitude, the abundance of pollinators in the present study decreased (Table 3).

5.2.11 Climate component

The results of Parichehreh et al. (2020) on A.flora in Iran showed that the southern, southeastern, and western regions of Iran, dominated by the tropical climate, cold winters, and hot summers are the most desirable areas for A.flora (Parichehreh et al., 2020). The minimum temperature of the coldest month and altitude were the most influential factors on the distribution of this species. The probability of the presence of this species increased with the increase of the maximum temperature of the warmest month and it is distributed in areas with an annual rainfall of 50 to 300 mm (Parichehreh et al., 2020). With increasing air temperature, the activity of this species increases (more than 15 degrees), and the temperature below 5 degrees decreases its activity. The best average annual temperature for it is 25 to 27 degrees Celsius (Parichehreh et al., 2020). For Halictus smaragdulus species, the average annual temperature was identified as the most important parameter affecting the distribution of this species (Ashcroft et al., 2012). Gill and Sangermano (2016) for Apis mellifera scutellata considered the minimum air temperature as the determining parameter (Gill and Sangermano, 2016). Bees become inactive when the combination of temperature and sunlight reaches below a threshold (Corbet et al., 1993). Habitat may be suitable for nesting and foraging, but if the ambient temperature is below a certain threshold, the pollination potential is zero (Zulian et al., 2013). Corbet et al. (1993) developed a model for pollinator activity based on the proportion of active bees. They developed the pollinator activity index based on temperature and solar irradiance, which estimates the activity of solitary bees on average between 0 and 100% per year (Zulian et al., 2013). In the present study, we used the bee activity index as a representative of the climate component (Equation 4). The activity index is calculated as follows.

$$A (\%) = -39.3 + 4.01 T_{\text{blackglobe}} \quad (4)$$

In this equation, $T_{\text{blackglobe}}$ represents the temperature in a spherical, black model that mimics the body temperature of an insect. This temperature is based on a function of ambient temperature T (°C) and solar irradiance (Equation 5) (Corbet et al., 1993).

$$T_{\text{blackglobe}} = -0.62 + 1.027 T + 0.006 R \quad (5)$$

5.2.12 Analytical hierarchical process (AHP)

The multi-criteria evaluation process is done by taking criteria with different importance according to the decision-makers and information about the relative importance of the criteria. This is usually done by assigning a weight to each factor. Different factors have different effects on choosing the right place for pollinators. The Analytic Hierarchy Process (AHP) is a tool for weighting that is done through pairwise comparisons and the judgment of weighting experts. The weight of factors is from 1 (extremely insignificant) to 9 (extremely important) (Saaty, 2008). Assignment of weight to different layers was done based on the literature and the experts' opinion (Table 3).

Table 3. Descriptions of data used in multi-criteria evaluation and weights of the criteria

Component	Criteria	Function*	Component Weight	Sub-Component Weight
Anthropogenic			0.03	
	Distance from urban	S ~ X		0.44
	Distance from road	S ~ X		0.23
	Distance from airport	S ~ X		0.10
	Distance from railway	S ~ X		0.13
Climate			0.15	
	Bee activity index	S ~ -X		
Water				1
	Distance from river	S ~ -X		
	Distance from wetlands	S ~ -X		0.52
	Distance from lakes	S ~ -X		0.38
Topography			0.09	0.10
	Elevation	S ~ -X		1
Forest			0.31	
	Distance from broad-leaved forest	S ~ -X		0.48
	Distance from Aleppo oak	S ~ -X		0.28
	Distance from low-density forest	S ~ -X		0.10
	Distance from woodland	S ~ -X		0.14
Agriculture			0.18	
	Distance from irrigated agricultural lands	S ~ -X		0.27
	Distance from rainfed agricultural lands	S ~ -X		0.13
	Distance from orchards	S ~ -X		0.42
	Distance from an abandoned orchard	S ~ -X		0.08
	Distance from fallow lands	S ~ -X	0.24	0.10
Range				
	Distance from natural	S ~ -X		0.61

grasslands		
Distance from high-quality ranges	$S \sim -X$	0.29
Distance from poor ranges	$S \sim -X$	0.10
$-X$, lower values result in higher suitability. $\sim X$, larger values result in higher suitability; $S \sim *S$		

6. Results

Figure 3 shows a map of the potential of Iran's land covers in providing pollination services based on the Lonsdorf model. In this figure, areas with high potential have the number one and are marked in a light color. An overview of this map shows that the majority of Iran is covered by areas with low potential for pollination service and areas with high potential for this service are distributed sparsely in Iran. The northern regions in the south of the Caspian Sea and along the Alborz mountain range with quality forests and rangelands are one of the areas that have a high potential for pollination in Iran. The western and southwestern regions along the Zagros Mountains also have a high potential for pollination because in these areas the forests are not very dense and the distance between the trees is covered by quality rangeland that provides good habitat for pollinators. Figure 4 shows a classified map of pollination potential in Iran based on the Jenks natural breaks method (Jenks, 1977) that minimizes intra-class variance while maximizes inter-class variance. As can be seen, this map is divided into five classes, two classes of very low and medium, occupying a higher surface of Iran than the other classes (Table 4). According to the table, about 77% of Iran has very low to low potential in providing pollination that covers most of the arid and desert areas of Iran, which includes the center, east, and southeast, and the Iranio-Turanian ecological area in general.

The Khalijo- Omaniian Ecological Zone (southern Iran) also has low to moderate potential for pollination service as shown in Fig. 4. About 20% of Iran consists of land uses that have a moderate potential to provide pollination services, which includes the Hyrcanian ecological areas in the north, Arasbaran in the northwest, and the Zagros part of the Iranio- Turanian region. As mentioned in natural geography in the section of Iran, these areas include the forest cover of Iran and the highest biodiversity of Iran is observed in these areas. About 3% of Iran is allocated to areas that have been obtained as hotspots serving Iranian pollination in this study. These three percents are located in the middle of areas that have a moderate potential to provide pollination services, with the difference that they are located in the highest quality rangelands and grasslands of Iran and are surrounded by pristine and natural forest habitats.

Figure 5 shows the map of pollination potential in Iran based on the multi-criteria evaluation. According to this figure, a large part of Iran is covered by areas with low to medium potential, which is located mainly in the eastern and central regions of Iran, where relatively weak vegetation can be seen in these areas. Areas with high potential are seen in the north and southwest of Iran, which are drawn in the color of the method. Figure 6 shows a classified map of pollination potential in Iran based on the Jenks natural

breaks method in five classes. In this figure, the two classes of low and moderate have the highest part and the very high class has the lowest percent of Iran (Table 5). The southern regions of the country (Khalijo- Omani) are covered by almost two moderate and high classes, which can be seen in the central and northern parts. According to the multi-criteria evaluation model (Table 5), about 76% of Iran has very low to moderate pollination potential, which covers most of the arid and desert areas of Iran in the center and east, and the ecological areas of Irano-Turanian and the Khalijo- Omani. Land uses that have a high potential for pollination services cover about twenty-three percent of Iran, locating in the Hyrcanian ecological areas in the north, Arasbaran in the northwest, and the southern part of the Zagros region in the Irano- Turani region.

Table 4
The area and proportions of pollination supply classes for the Lonsdorf model

Pollination supply classes	Area (Ha)	Proportion (%)
Very High	3034680	1.86
High	2055016	1.26
Moderate	32986632	20.28
Low	23156164	14.24
Very Low	101378856	62.34

Table 5
The area and proportions of pollination supply classes for multi-criteria evaluation model

Pollination supply classes	Area (Ha)	Proportion (%)
Very High	8856447	5.4
High	29949291	18.36
Moderate	49910990	30.60
Low	53237883	32.63
Very Low	21361874	13.1

7. Discussion

The present study mapped the potential of pollination service in Iran based on two models of multi-criteria evaluation and the Lonsdorf models. An important part of the results of these two models is influenced by experts' opinions because both models to determine the factors needed to estimate pollination service benefits the opinions of experts. Therefore, the results of such models may have uncertainty because the opinions of experts may also differ. One of the objectives of the present study was to investigate the efficiency of these two models in a more accurate estimation of pollination service in Iran. The results of these models show that there is a significant difference in the approaches adopted by these two models in evaluating ecosystem service. There is pollination and it seems that each of these models has strengths and weaknesses that the present study deals with the performance of these two models and determines a more appropriate model for future studies.

The results of the Lonsdorf model showed that most of Iran (77%) are regions with low potential for pollination service and these regions are mainly located in the southeast, east, and center of the country. About 20% of Iran based on this model have moderate potential in providing pollination services and about 3% have high potential. The results obtained from this model are close to reality as expected and previous conjectures, because any cover that should have high potential, high numbers of this potential are given in advance. Therefore, since this model relies solely on the potential of the uses and the bee's ability to fly for food, it is not difficult to guess which areas are likely to have the highest potential for pollination service. To understand how the different land uses affect, this explicit spatial model has been developed that predicts the presence of pollinators at the landscape level concerning nesting and foraging habitats. It is not based on farm management practices and does not take into account the landscape configuration (Kennedy et al., 2013). The Lonsdorf model is not influenced by the spatial arrangement of nesting and foraging patches, which means that it does not explicitly take into account the landscape configuration. However, implicitly, larger patches score higher on this model because the first step in estimating pollination service based on this model is to determine the quality of the patches according to the surrounding floral resources. Thus, the central cells of the patches receive a higher score than the marginal cells. Therefore, the larger the patch, the less it is affected by the marginal cells. Also, the proximity of high-quality nesting patches next to each other will increase their score, therefore, continuity will have a positive effect on the output results. Several studies have criticized the Lonsdorf model (Groff et al., 2016; Olsson et al., 2015) and listed some of the weaknesses of this model. In the present study, based on the comparison of the results of this model and the multi-criteria evaluation model, some of these other weaknesses are pointed out.

The results of the multi-criteria evaluation model showed that 35% of Iran's land uses have little potential in providing pollination services and are more common in the central and northwestern desert regions of Iran. 30% of Iran has a moderate potential to provide pollination, which is mainly located in the southern and eastern regions of Iran. 23% of Iran is covered by areas with high potential for pollination services, which are found in the broad-leaved forests of northern Iran and the warm southwestern regions of the country. A comparison of the results of this model and the Lonsdorf model shows that there is a

significant difference in how to estimate these two models of pollination service in Iran. The most important differences in determining the areas with high potential for pollination are that in the Lonsdorf model these areas constitute 3% of Iran but in the multi-criteria evaluation model 23%. On the very low and low classes, there is a 22% difference, with the Lonsdorf model identifying about 77% of Iran and the multi-criteria evaluation model identifying about 34% of Iran as areas with little potential for pollinating services. One reason for this difference is that the multi-criteria evaluation model also included additional factors such as road and rail network, altitude, and climate in its modeling, but the Lonsdorf model does not pay attention to these important factors and is based solely on land covers potential in providing nesting and foraging habitat, this model estimate pollination and do not pay attention to the altitude and climate of these land uses, which can affect the results of this model. For example, the bee activity index in Fig. 7 shows that areas with low altitude and high temperatures have a higher rate of bee activity, and these areas are seen in the center and the entire southern strip of Iran, which in the model Lonsdorf was estimated as a low-potential area. Therefore, the two factors of altitude and the level of bee activity due to climate caused a difference in the output results of the two models used in the present study.

In the multi-criteria evaluation model, it is assumed that service pollination service is distance-based and decreases exponentially with distance from important habitats (Mitchell et al., 2015). Therefore, near habitat patches, due to the foraging range of bees, the level of pollination increases and therefore, at the border of two covers such as forest and rangeland, we are most likely to have more pollinators in these areas, but in the Lonsdorf model, the exact opposite of this process occurs, and in the margins of land uses, the probability of presence decreases, and at the intersection of two covers, such as forest and Rangeland, we have the least probability of presence. At the forest-rangeland boundary, a high probability of pollination service is estimated (Zulian et al., 2013). Therefore, because of the above, the present study considers the multi-criteria evaluation model to be more appropriate for estimating pollination service and considers the weaknesses of the Lonsdorf model to be important and inevitable. Lack of attention to important parameters such as climate and altitude and have a significant effect on the presence of pollinators in different habitats, so that in the present study, attention to these two factors in the multi-criteria evaluation model caused a significant difference in the final results.

One of the important factors in estimating pollination service is the marginal effect of influencing factors on the presence of pollinators. For example, in the Lonsdorf model, for water bodies, the score of nesting and foraging habitat is usually considered to be zero, but according to what was stated in the water component section, around wetlands and water zones, some vegetation provides a suitable habitat for pollinators, which usually have a positive effect up to 300 meters away (Santos et al., 2018). The Lonsdorf model also ignores linear phenomena such as river and road networks and the effect of distance between phenomena because these phenomena are usually not included in land use maps and, in general, the intersection of several important factors resulting from the proximity of forests, rangeland and rivers or wetlands that increase the habitat suitability for pollinators in these areas is ignored in this model and as a result of the results of this the models do not have high accuracy. Disadvantages of the multi-criteria evaluation model include the sensitivity of the results of this model to the opinions of experts, which in particular in the process of weighing the factors to determine the impact of each of

them on the probability of the presence of pollinators. In this study, the weights of the factors were determined by experts related to the field of pollination, which was determined for these weights according to the general conditions of Iran, and changing the weight of each of the factors can significantly change the final results.

8. Conclusion

In general, various studies have claimed that pollination service depends on nesting habitats and floral resources, and consider the existence of these two factors necessary for the presence of pollinators. Therefore, given the potential of the land uses that provide these two habitats, a pollination service map can be achieved. Currently, the most common model for estimating pollination service is the Lonsdorf model, which is embedded in Invest software and, based on the potential of each cover in providing pollination service, estimates the pollination service in the entire landscape of the country. The present study showed that it is not enough to rely solely on covers in which the presence of pollinators is high and important factors such as altitude and climate that have a significant impact on the presence of pollinators in different parts of the world should be included in the modeling. This is because some covers are sometimes given a lot of weight in the Lonsdorf model, but the cover may be in a very cold climate or at a high altitude where pollinators are less likely to be present in such areas. The result is seen in the final map of these areas as pollinating hotspots that can mislead management plans. Another weakness of the Lonsdorf model is that it gives low value to ecotones in providing pollination service while the boundary between forest and rangeland cover is highly desirable for pollinators because according to the theory Central Forge Theory. Bees try to reduce energy to obtain food, and on the border between forest and rangeland, bees have easy access to nesting and foraging habitat and spend less energy flying longer distances. Therefore, the present study proposes the multi-criteria evaluation model as an alternative to the Lonsdorf model, which has much more flexibility than this model.

To improve the pollination service in Iran, solutions in two scales of farms and landscapes are suggested. 1- Practices that should be done to benefit wild bees in farms, such as 1- Reducing the use of pesticides and insecticides. 2- Planting crops with diverse flowers and 3- Increasing the use of mass flowering crops periodically (Brosi et al., 2008). One of the mechanisms that help to improve the pollination service in a landscape is the increase of natural and semi-natural areas in the landscape (Kremen et al., 2004 255). For every ten percent increase in the amount of natural habitat, the bee population increases by 37 percent (Kennedy et al., 2013).

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Funding

There are no financial conflicts of interest to disclose.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Figures

Figure 1

Phytogeographical regions of Iran (Euxino-Hyrcanian: 1 Caspian (Hyrcanian), 2 Arasbaran; Irano-Turanian: 3 Zagros, 4 Steppic central plateau, 5 Saharo-Sindian)

Figure 2

Overview of the location of forest, rangeland, and agricultural covers in Iran

Figure 3

The map of relative pollination potential based on the Lonsdorf model.

Figure 4

The classified map of relative pollination potential based on the Lonsdorf model.

Figure 5

The map of relative pollination potential based on the multi-criteria evaluation model.

Figure 6

The classified map of relative pollination potential based on multi-criteria evaluation model.

Figure 7
the bee activity index calculated with temperature and solar irradiance in Iran