

GIS-based strategic approach for land suitability analysis to beekeeping of *Apis cerana* and *A. mellifera* in China

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ABSTRACT

The importance of honeybees in honey production and environmental services is undeniable. Beekeeping plays a vital role in supporting these services. To improve honeybee performance and address the declining populations of *Apis cerana* and *A. mellifera*, it is essential to conduct land suitability analyses for beekeeping in China, the world's largest beekeeping country. Our strategic fuzzy logic approach integrated within a GIS (Geographical Information Systems) framework provides guidance on reducing colony loss risks and ultimately enhancing honey production by identifying the most suitable lands for beekeepers. In this study, the most influential environmental and ecological factors affecting beekeeping were incorporated to develop land suitability maps. Our approach revealed that 37% and 32% of China's land area is highly suitable for *A. cerana* and *A. mellifera*, respectively. Approximately 24% of the area was found to be commonly suitable for both species. Most of the highly suitable areas for *A. mellifera* were concentrated in specific parts of southern, central, and eastern China. In contrast, *A. cerana* suitability was widespread across China, excluding the Tibetan Plateau. The reliability of this approach was further confirmed through validation using actual beekeeping locality data. Overall, our findings indicate that while apicultural practices can be expanded across a large portion of China, the most favorable conditions are limited to specific regions. Identifying these optimal zones can help enhance colony productivity and reduce the risk of colony losses.

Keywords: GIS, *Apis mellifera*, *Apis cerana*, Fuzzy logic, China, Land suitability.

INTRODUCTION

Honeybees are not only providing pollination services of 22 billions of dollars but also provide other human health ingredients such as honey, royal jelly, propolis and pollens (Viuda-Martos et al. 2008, Gallai et al. 2009). However, the losses of colonies were observed

since 2010 (Zhou et al. 2013, Liu et al. 2016) with mortality rate reported from 3.3 – 12.6% within China (Chen et al. 2017). The consequences of honeybee losses are notorious (Moritz et al. 2010, vanEngelsdorp and Meixner 2010) for both crop production and human health. Multiple factors might be responsible for such losses. (Becher et al. 2013).

These factors might be epidemiological factors, the fragmentation or degradation of highly managed agricultural landscapes, loss of high rich flower plants and use of pesticides (Cox-Foster et al. 2007, Rollin et al. 2016).

To overcome the losses several tools have been evaluated (Chen et al. 2010) including flower strips introduction and early blooming shrubs spots (Canale et al. 2014, Benelli et al. 2014). Similarly, the introduction of hedges around the marginal areas of fields and other buffer zones can be helpful to

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overcome the declining population of the bees (Decourtye et al. 2010). Beekeeping is providing a platform to the honeybees for performing different ecological services (Klein et al. 2007, Gallai et al. 2009, Jeff et al. 2011, Wratten et al. 2012) either in agricultural or marginal areas due to its flexibility (Zoccali et al. 2016). China is the largest beekeeping country with the suitable geographical land and climatic conditions (Liu et al. 2016). Chinese honey has different varieties and could be potentially preferable for European market (Zhou et al. 2013). So, it is very important to keep its high production with the good quality. The prompt identification of land suitability for the beekeeping within China can maximize the efficiency and reduce the risk of colony losses. Thus, suitability analysis is extremely important where unrelated information will be merged and areas will be ranked according to their suitability for beekeeping.

Formation of single index of evaluation with the help of multi-criteria decision-making (MCDM) can easily deal with the large number of attributes and various criteria (Joerin et al. 2001). For such types of evaluation, Geographical Information Systems (GIS) was used to analyse and transform the data (Domingo-Santos et al. 2011). The GIS limitations in dealing with large data sets can be overcome with the help of MCDM and can also be helpful in assigning the values into suitability classes (Carver 1991). Analytical Hierarchy Process (AHP) is helping for combining the MCDM with GIS approach. This approach also helpful in order to classify and assign the values to each attributes in suitability classes (Chen et al. 2010).

However, AHP-MCDM approach still have constraints that can result into uncertainty. This uncertainty may be due to multiple factors including original data set consistency, biased data set analysis or biased in the selection criteria. Personal preferences in given the values to a particular factor may also influence the result in AHP-MCDM (Chen et al. 2010). Similarly, some concerns also aroused during standardization or aggregation methods (Jiang and Eastman 2000). To overcome these problems, fuzzy logic approach has been implemented here for solving complex tasks with high degree uncertainty. This approach is much more similar to human reasoning approach in dealing with such types of problems (Kahraman et al. 2003). This approach has already been used for land suitability analysis to beekeeping in Southern Italy (Zoccali et al. 2016). Our current strategic approach might be helpful to meet such demands in order to providing the information about the beekeeping suitability. Our main objective is to identify the high and very high suitable lands for *A. cerana* and *A. mellifera* as well as commonly shared suitable land for both species.

METHODOLOGY

Study Site and Types of Data

For our analysis of land suitability, whole China country was selected for this study (Fig. 1). The total area is approximately 960000 km². China has various types of topography and different types of climatic conditions and landcovers with elevation varies from < 0 to > 8000 m a. s. l. We selected main environmental factors that can acts as important derivatives for the suitability of land for beekeeping. We followed the same criteria for the selection of data and the development of map, as did by Zoccali et al. (2016) because of low cost and easily reproduced.



Figure 1. Study site with highlighter grey boundary for China and grey boundary for provinces.

According to expert views, we also selected only those factors which directly influence the hive, honeybee biology as well as their managements. These factors are: temperature, roads, water streams, elevation and landcover types. Average temperature layers from April to October months of 30 years from www.worldclim.org were download. Temperature has pivotal influence on the poikilothermic activities of organisms (Campolo et al. 2014). The average range of temperature for this period was from -7 to 27°C (Fig. S1) Here we considered the very high suitable

temperature from 15-27°C in case of both honeybee species and as suitable from 10-15 °C for *B. mellifera* and -1 to 9°C as suitable for the beekeeping of *A. cerana*. However, <10°C for the former and < 0°C for the latter were considered as unsuitable temperatures. We downloaded the road and water stream data from www.diva-gis.org (Fig. 2 & 3). The area close to water steams and roads were considered as suitable for the beekeeping. Euclidean distance was performed for both raster layers within ArcGIS.

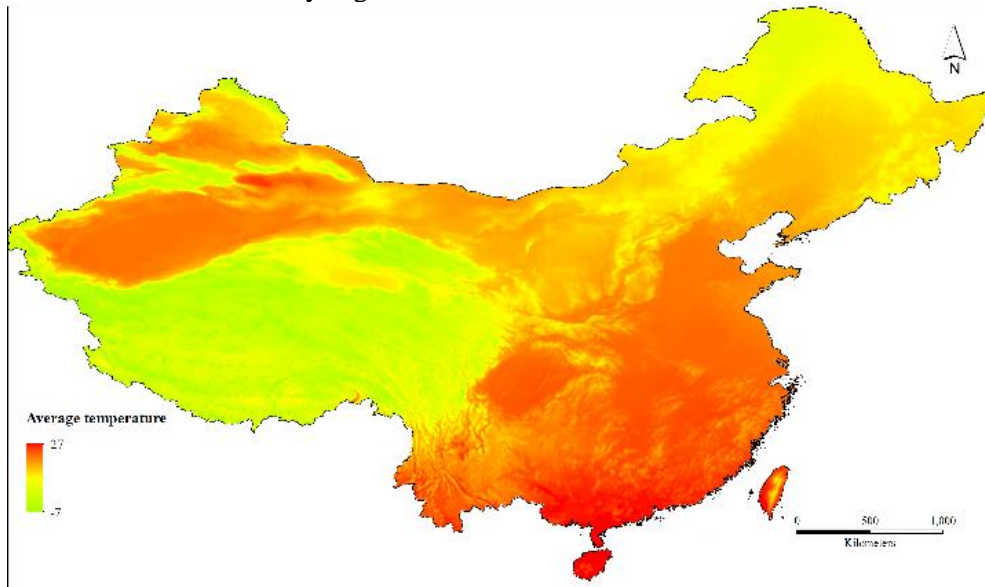


Figure 2. Average temperature within China.

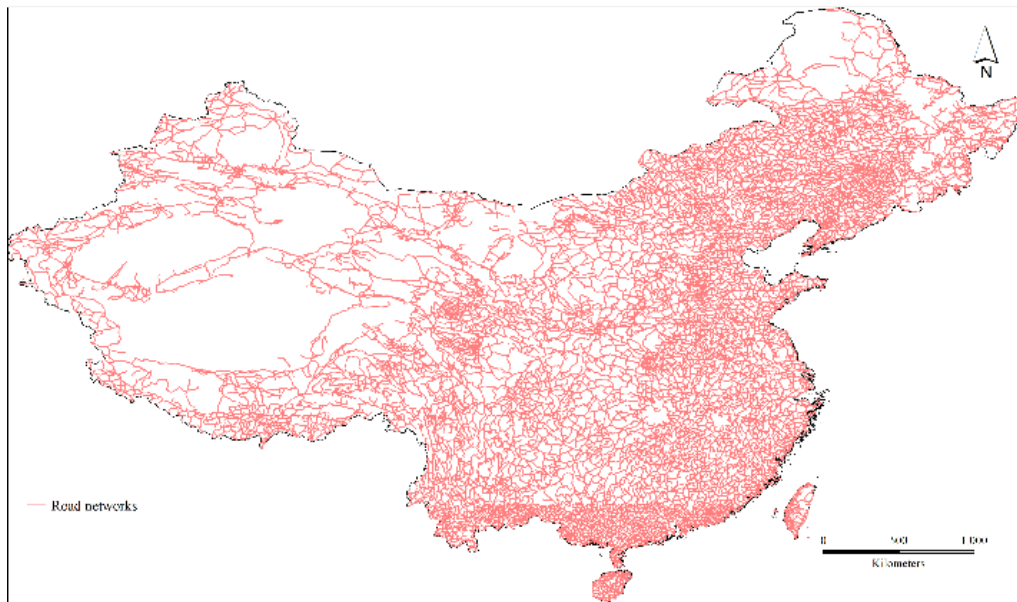


Figure 3. Road networks in China.

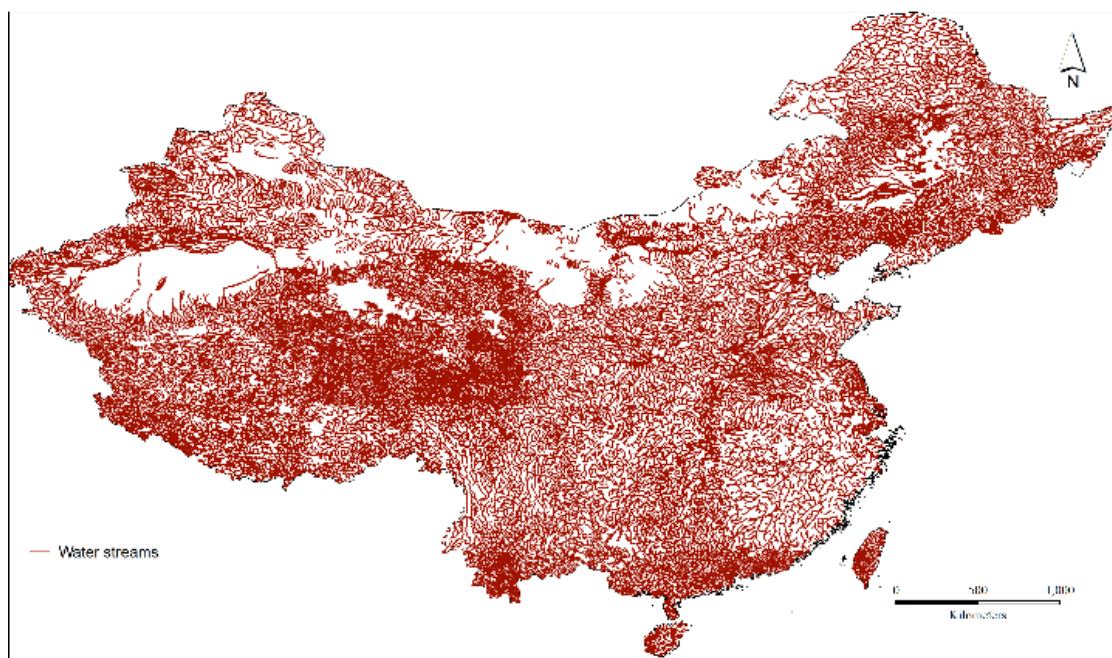


Figure 4. Water streams network distributed in China.

Elevation, was considered here as a negatively associated with the beekeeping suitability lands (Fig. 5). However, here we categorized the elevation into three classes: elevation < 0 m and > 4000 m a. s. l. were unsuitable and between 0 to 4000 m was considered as suitable and highly suitable lands for the

beekeeping (Fig. 5). Food plant resources and other landcovers data were obtained from www.fao.org. Where 11 types of landcovers were identified. Among all landcovers, cropland, tree covered area and shrubs were considered as highly suitable landcovers for the bee pollination and other floral resources (Fig. 5).

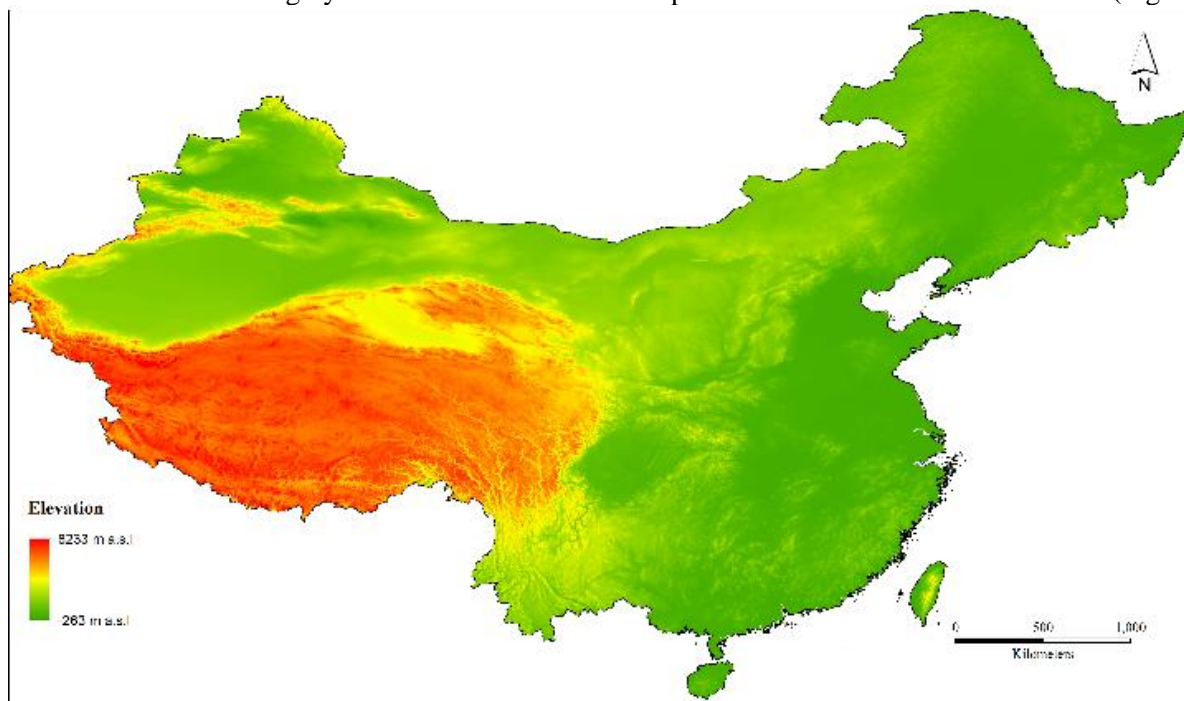


Figure 5. Map showing elevation of China.

Analysis of Data

All factors were reclassified into three categories in reclassify tool of ArcGIS 10.3 *ver.* Where 0 = unsuitable for the beekeeping, 1= suitable land for beekeeping and 2= highly suitable for beekeeping. Fuzzy overlay with Gamma function was performed to get the final suitable maps for both species (Zoccali et al. 2016). For the assessing of accuracy of our analysis, we get the current location data for the beekeepers and natural distribution data of *A. cerana* and *A. mellifera* from all over the China and compare the result with our suitability maps. All the analysis was carried out in ArcGIS 10.3 and Excel 2016.

RESULTS AND DISCUSSION

Due to the most important products: honey, pollen, propolis and royal jelly, beekeeping is rapidly growing. The minor difference in land suitability of both *A. cerana* and *A. mellifera* is found (Fig. 7). Although, both have similar characteristics, *A. cerana* have minimum foraging temperature comparatively (Tan et al. 2012). China is the one of the largest beekeeping country in the world (Liu et al. 2016). The average estimated colony mortality was varied from 2.5 to 19% depending upon the province (Liu et al. 2016). However, this approach is cheap and strategic and accurately identify the beekeeping areas within China. This approach is without the relying on AHP because of uncertainties in the decision makers.

This approach has already successfully employed in order to identify the highly suitable land for beekeeping (Zoccali et al. 2016). Our

approach is contradicting with the previous land suitability analysis studies in different parts of the world. Because they involved AHP-MCDM approach which is having uncertainty level (Chen et al. 2010, Saremi et al. 2011, Abou-Shaara 2013, Abou-Shaara et al. 2013, Abou-shaara 2015, Ullah and Mansourian 2016).

The result of our study is presented in Figure 1. However, all the other layers which were used for the analysis are also reported in supplementary figures S1-S4. The continuous data on land suitability was categories into three classes from unsuitable, suitable and suitable (Fig. 1). Among all suitable landcovers, trees cover maximum area (25%) followed by croplands (18%) and shrubs (<1%) (Fig. S5). China is the important country with a great potential for the beekeeping areas for Eastern and Western honeybees. For *A. cerana*, the suitable and high suitable surface lands are 22% and 37% respectively. However, for *A. mellifera*, the suitable and high suitable surface lands are 23% and 32% respectively (Table 1). Similarly, both species shared 17% area as suitable and 24% area as high suitable within country (Table 1). At province level, Henan, Shandong, Yunnan provinces showed high suitable lands for the beekeeping of both species. However, Ningxia, Shaanxi and Neimenggu showed high suitable land for *A. cerana* only (Fig. 1). All those areas which showed suitable and high suitable lands have good networks of roads and water streams. These areas also have optimum temperature 1-25°C.

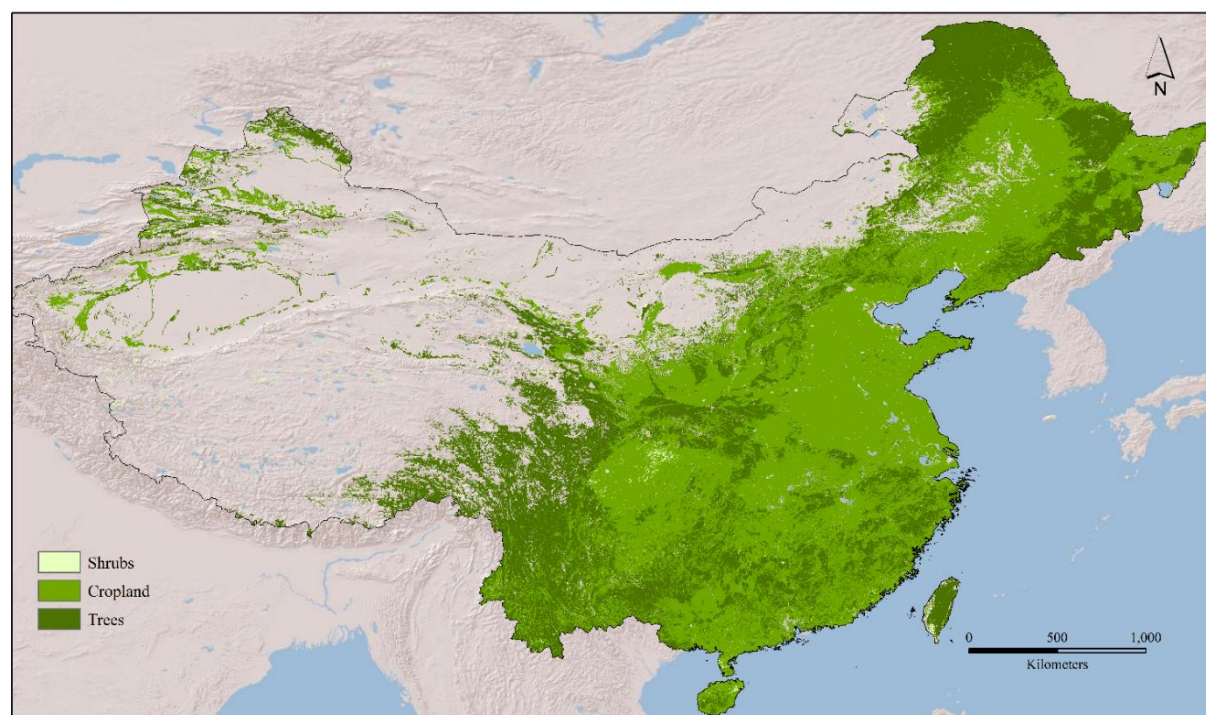


Figure 6. Distribution of different vegetation landcovers in China.

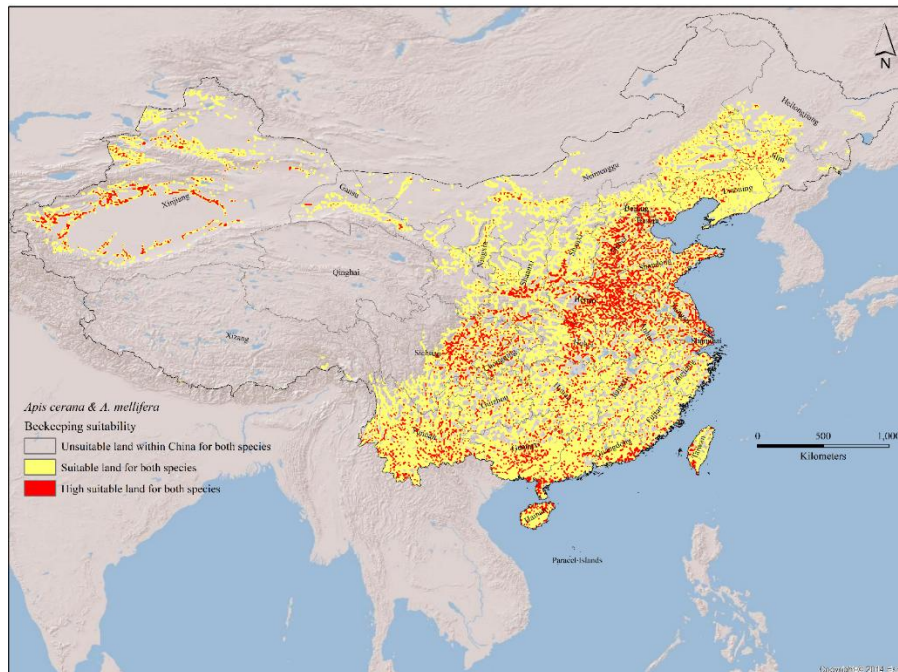


Figure 7. Beekeeping suitability areas in China.

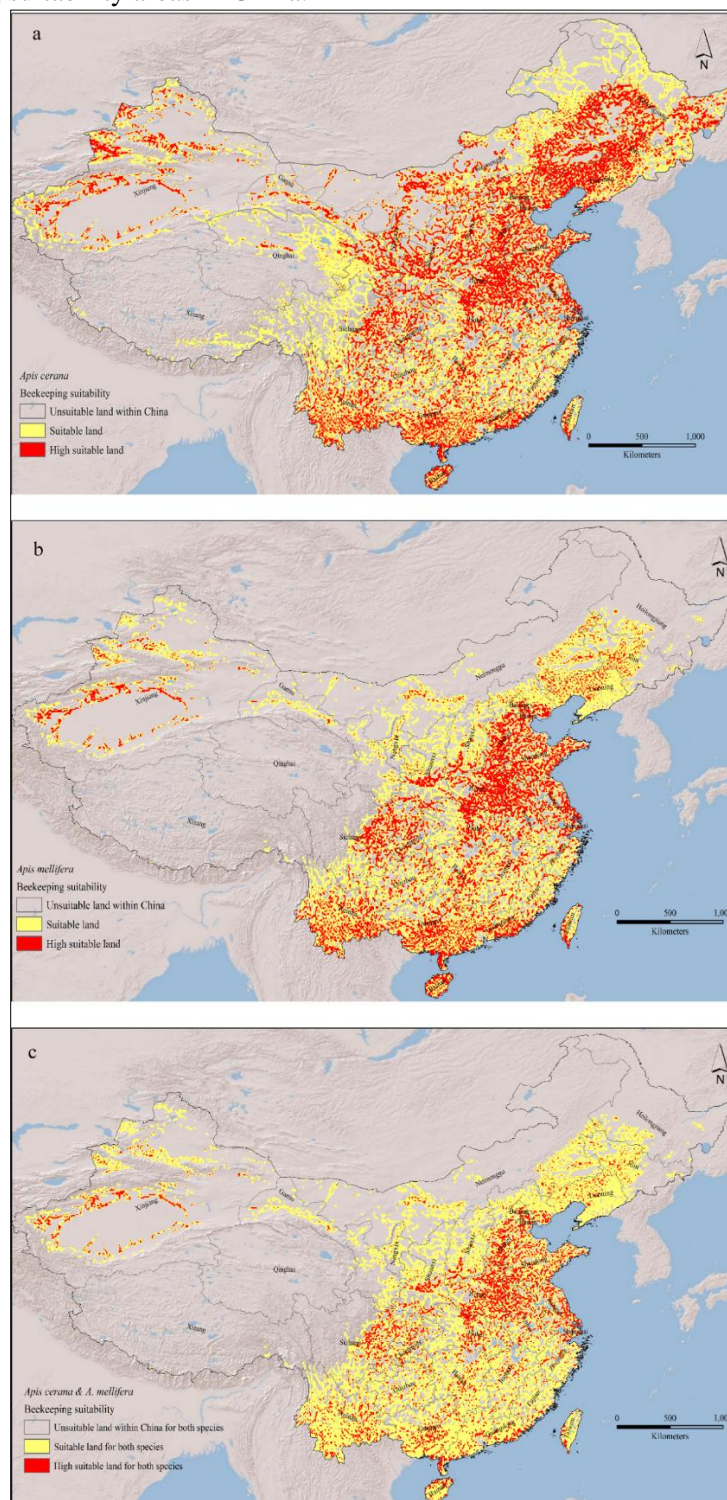


Figure 8: Land suitability analysis for *Apis cerana* (a) and *A. mellifera* (b) and overlapped regions for the beekeeping of both species (c) within China.

Table 1. Land suitability analysis for *Apis cerana* and *Apis mellifera* and overlapped areas shared by both species for beekeeping within China

Species	Unsuitable land		Suitable land		High suitable land	
	km ²	%	km ²	%	km ²	%
<i>Apis cerana</i>	3957924	41	2122543	22	3519533	37
<i>Apis mellifera</i>	7414674	77	2185326	23	3084599	32
Overlapped area	5611598	58	1653906	17	2334496	24

The accuracy of our result is found with the actual beekeeping locations compared with our final map. This approach is in the agreement with the evaluation of the experts views which performed for the evaluation of land suitability (Zoccali et al. 2016).

CONCLUSION

Overall, this approach prove that it is highly replaceable (Zoccali et al. 2016) and also it is consistent with the actual location of beekeeping within China. This approach is applicable for the beekeepers in order to provide the information either for the beekeeping of *A. cerana* or *A. mellifera*.

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