Review paper

GEOGRAPHICAL INFORMATION SYSTEM FOR BEEKEEPING DEVELOPMENT

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Received: 23 April 2018; accepted 19 November 2018

Abstract

Geographical Information System (GIS) is a computer-based system that can perform analysis for various datasets in relation to specific geographical locations and has been widely applied in agriculture. So far, GIS has been used in relatively few studies related to honey bees and beekeeping, but this article aims to review those previously performed and to present trends to apply GIS in beekeeping and then to help and guide researchers to perform more studies utilizing it. GIS can clearly be utilized to select suitable locations for apiaries, to map bee plants, to study bee behavior, diseases and pests, and to predict the effects of climate change on honey bees beside other benefits for beekeeping. Many obstacles and problems facing beekeeping can be mapped and analyzed using GIS, and other techniques can be used with it to perform the required tasks as presented in this review.

Keywords: apiaries, bee colonies, GIS, honey bees, RS

INTRODUCTION

Beekeeping as an agricultural activity constitutes many aspects that can be impacted by environmental and geographical factors. For example, the place of keeping an apiary should be selected carefully to ensure the safety and high productivity of the colonies (Estoque & Murayama, 2010; Amiri, Shariff, & Arekhi, 2011; Triantomo, Widiatmaka, & Fuah, 2016) because otherwise diseases between colonies can be prevalent and passively impact their survival and productivity. Honey bees are not only important for the agricultural sector but can also be utilized in research to study environmental issues, including environmental contamination with heavy metals and other chemicals (Celli & Maccagnani, 2003; Bratu & Georgescu, 2005; Skorbiłowicz et al., 2018). Recently, geographical information system (GIS), which manipulates, stores and analyses various datasets in connection with a geographical reference, has been used in many agricultural aspects. Climate, land cover, biological and geographical data are inserted into the GIS to be arranged as layers and analyzed, and then the results are as maps (e.g. Amiri, Shariff, & Arekhi, 2011; Abou-Shaara, Al-Ghamdi, & Mohamed, 2013; Pantoja et al., 2017). This system can be applied in beekeeping to solve issues related to the environmental and geographical factors, which would be beneficial for beekeepers and researchers. Fortunately, a full technical guide to use GIS in honey bee research is available (Rogers & Staub, 2013). GIS can be used alone or in combination with other technologies including remote sensing (RS) to perform the required analysis. RS acquires information from satellite or aerial images to the object (e.g. study area) without physical contact. These images are incorporated into the GIS analysis to provide more information about the study area (Jo, Kim, & Baek, 2001; Triantomo, Widiatmaka, & Fuah, 2016). The data collected from different locations are analyzed either statistically (i.e. spatial data analysis) or using GIS after linking the data to maps of the study area. In this article, previous investigations on GIS and honey bees, beekeeping and bee products are reviewed. Also, potential trends for GIS application in beekeeping are presented to help researchers to incorporate it into their studies.

GIS and apiary locations

One of the most common uses of GIS is to identify the best locations to establish new apiaries within a given geographical location. Specific datasets used to realize this include availability of flowering plants, land slope, distance from water resources and roads, distance between apiaries and such climatic factors as temperature, relative humidity and rainfall (Amiri, Shariff, & Arekhi, 2011; Amiri & Shariff, 2012; Abou-Shaara, Al-Ghamdi, & Mohamed, 2013; Yari, Heshmati, & Rafiei, 2016). During the winter season, it is possible to use GIS to select the most suitable areas to keep hives away from harsh conditions and hence minimize the death rate of bee colonies (Abou-Shaara, 2013a), when it especially rises (Genersch et al., 2010; vanEngelsdorp et al., 2012; Spleen et al., 2013). Selecting the correct locations for apiaries in a given area is essential to ensure that bee colonies have been distributed according to the flowering area without overcrowding the hives in one place. This in turn helps in preventing bee colonies from competing for flowering plants. Moreover, the suitable number of hives per each apiary can be determined according to the plant cover, as shown later.

Beside GIS, remote sensing (RS) with help of global positioning system (GPS) is useful especially for the classification of plant species in a study area (Jo, Kim, & Baek, 2001; Abou-Shaara, 2013b). The maps resulting from such an analysis can be presented to beekeepers via beekeeping associations to help them to select the most appropriate locations for their apiaries. The techniques of GIS and Multi-Criteria Evaluation (MCE) were used to evaluate the suitability of the Province of La Union, Philippines for beekeeping (Estoque & Murayama, 2010). Suitable areas for apiaries at Montesinho Natural Park (Portugal) were identified using a GIS multicriteria approach (Fernandez, Roque, & Anjos, 2016). Suitable areas for beekeeping were recommended based on RS, GIS and Analytic Hierarchy Process (AHP) in Sukabumi regency (Triantomo, Widiatmaka, & Fuah, 2016), and the land suitability for beekeeping in Calabria (Southern Italy) was assessed using GIS and AHP (Zoccali et al., 2017). Details about GIS and MCE can be found in Eastman (1999) and about AHP in Saaty (1990 and 2008). The suitable beekeeping areas close to forests in Indonesia were identified using GIS utilizing temperature, rainfall, distance from water sources and altitude, distance from the roads and distance from the markets, land use and distance from settlements (Ambarwulan, Sjamsudin, & Syaufina, 2017). These studies have shown the efficacy of GIS to classify a study area according to suitability for beekeeping. It is expected that placing hives at suitable locations can greatly enhance the productivity bee colonies.

GIS, plants, and productivity of colonies

Bee-plant interaction is very important to the productivity of colonies. The unavailability of nectar and pollen sources and a shortened flowering period limit the suitability of lands for beekeeping (Amiri & Shariff, 2012). Other limiting factors are poor soil conditions and lack of roads in the vegetation areas (Fadaie et al., 2014). Identification of the flowering time per day, flowering period, nectar amount, sugar concentration in nectar and an average number of flowers per given plant is essential to calculate the suitable number of hives per area of this plant species to obtain the highest productivity. In this regard, an approach to determine the honey bee colony's optimum carrying capacity was developed based on the productivity of colonies and nectar secretion potential from bee forage species in the study area (Al-Ghamdi et al., 2016).

Satellite images for the study area can be analyzed using GIS to identify the distribution of a given plant species and to determine the suitable number of hives and their locations. Moreover, using satellite images, GPS and GIS for a given area can help in mapping bee plants. Changes in land cover in regard to vegetation can be studied using GIS and RS to understand impacts on honey production (Abou-Shaara, 2013b). In the Al-Baha region of Saudi Arabia, spatiotemporal distributions of the bee forages were mapped using GIS (Adgaba et al., 2017), and the resulting maps clearly show the distribution of the flowering plants and their area in the study location.

Also, the seasonal maps can be prepared to exactly show the flowering plants and their area per each season and help beekeepers to obtain the highest productivity from their colonies especially if predicted with GIS (Janssens, Bruneau, & Lebrun, 2006). In New Zealand, a spatial model for mapping nectar and pollen production on a monthly basis from maps of land cover has been developed using GIS to help understand and manage floral resources for bees (Ausseil, Dymond, & Newstrom, 2018). The mapping of bee plants helps when a specific product as propolis from a plant species is required for the colonies. Mapping also helps to avoid areas with toxic plant species, especially toxic honey produced by honey bees from some plant species (Sütlüpmar, Mat & Satganoglu, 1993).

GIS and beekeeping activities

There are two type of beekeeping (e.g. Sharma & Bhatia, 2001; Pirk et al., 2014); in stationary beekeeping beekeepers do not move their hives from the apiary location but in migratory beekeeping they move their hive from one location to another according to the flowering season. The migratory beekeeping may cause such problems as hybridization between bee colonies, overcrowded hives in a given area and prevalence of diseases. Especially, some diseases can be transported from bee to another by contact and during foraging activity (Abou-Shaara, 2014) and due to colony abundance (Forfert et al., 2016). Thus, responsible authorities by utilizing GIS can determine the suitable locations and the number of hives per location to track migratory beekeeping and prevent hive crowdedness and disease prevalence in a given area. The establishment of a database for beekeepers using questionnaires can be further used in GIS analysis according to geographical locations to identify the density of bee colonies and to detect the occurrence of certain diseases in a given area (Dippel et al., 1998). Also, maps would guide beekeepers to place their colonies away from the conservation areas of specific bee subspecies, as well as prevent the potential hybridization between conserved bee colonies and other managed bee colonies.

GIS and organic beekeeping

Organic products from bee colonies require organic practices and foundations (Lodesani et al., 2008) without the application of any chemicals (Iancu, Oprean, & Codoi, 2012). Even though the production cost of organic honey from bee colonies is higher than that of the normal one (Güemes-Ricalde et al., 2006), but this approach can be accepted by beekeepers (Pocol et al., 2011). The locations of registered organic farms can be mapped using GIS and then determining the suitable farms for beekeeping based on the availability of the flowering plants. Also, the suitable number of hives per farm can be determined as previously mentioned.

GIS and apitourism

Implementing beekeeping with ecotourism, known as apitourism, is expected to enhance the beekeeping sector greatly, as involvement could provide beekeepers with in additional income. This type of ecotourism is practised in such European countries (Wos, 2014) as Slovenia (Šivic, 2013) and Bulgaria (Grigorova, Timareva, & Shopova, 2016). The most suitable beekeeping sites for apitourism can be identified using GIS, where it was done in Chile for this purpose with datasets of precipitation, vegetation, tourism, temperature, rivers, roads, genetically modified (GM) crops , highways, soil use and wild areas (Pantoja et al., 2017).

GIS, bee diseases and pests

The prevalence of bee diseases and pests is one of the obstacles facing beekeeping development. Adult and immature stages of honey bees can be infected with other bacterial, fungal and viral diseases beside mites (Spivak & Reuter, 2001; De Miranda & Genersch, 2010; Forsgren et al., 2013; Freiberg, De Jong, & Cox-Foster, 2013); Fries et al., 2013). Various pests that attack honey bee colonies include wax moths (Ellis, Graham, & Mortensen, 2013), *Vespa* hornets (Arca et al., 2014) and small hive beetles (Evans, Pettis, & Shimanuki, 2000). GIS can be used to map locations heavily infested with specific diseases or pests, which migratory beekeepers can avoid. Moreover, Google maps can be used together with GIS (Abou-Shaara, 2013b), and Halbich & Vostrovský (2012) described such a method to help solving problems related to the prevalence of American Foulbrood disease.

The reasons behind the high infestation at specific locations can be identified through the analysis of geographical and environmental factors, and GIS can help to predict other locations with high infestation. Presently, some pests including small hive beetles have been reported in Italy (Palmeri et al., 2015) and the Asian hornet (*Vespa velutina*) in some parts of Europe (Villemant et al., 2011; Budge et al., 2017; Garigliany et al., 2017; Keeling et al., 2017). GIS can track the movements of invasive species within the new environments, and then authorities will be able to make suitable decisions towards such pests. Moreover, the new locations invaded by the invasive species can be predicted using GIS.

GIS and CCD

The sudden disappearance of many colonies known as colony collapse disorder has been observed in various countries (CCD) (Oldroyd, 2007; Maini, Medrzycki, & Porrini, 2010; Neumann & Carreck, 2010). Research efforts have been employed to identify the exact reasons behind CCD, and a combination of factors has been suggested to be as potential reasons (e.g. vanEngelsdorp et al., 2009; Neumann & Carreck, 2010). An investigation of the hypothesis related to CCD using GIS is possible through an analysis of land use data to understand the link between increasing loss of foraging resources and CCD (Naug, 2009).

GIS, bee products and environmental contamination

Honey bees as bio-indicators may be used to determine whether pesticides or heavy metals cause environmental pollution (Celli & Maccagnani, 2003; Bratu & Georgescu, 2005; Mullin et al., 2010; Skorbiłowicz et al., 2018). Samples of honey bee or bee products (e.g. honey or pollen) can be analyzed to identify the level of heavy metals or type of pesticides used in an apiary region. Moreover, diesel exhaust is considered a pollution factor and passively impacts both the identification of floral odours by bees and the bee-plant interactions (Girling et al., 2013). The exact contaminated areas can be mapped using GIS, and chemical analysis of nectar and pollen from flowering plants helps in locating safe areas for apiaries. Antibiotics and pesticides were detected in the collected honey samples from different apiaries and the health status of colonies were recorded in combination with GIS to monitor the status of beekeeping in the Marche region of Italy (Cordoni & Spagnuolo, 2007). Recently, Berg et al. (2018) detected residues of glyphosate, a common herbicide, in honey samples collected from different locations on the Hawaiian island of Kaua`I and with the aid of GIS identified the percentages of contaminated areas according to land use type. Moreover, it is possible to predict the contaminated areas by identifying time and type of pesticides used by farmers in a given area.

Studies have shown that some physical factors impact honey bees. Electromagnetic radiation is among these factors and impact honey bees under certain conditions (Kumar, 2012; Kumar et al., 2013; Vilić et al., 2017). Towers used to strengthen cell phone signals of or transmit electricity cause pollution with electromagnetic radiations at an apiary location in a given area. GIS can be employed by engineering companies to avoid regions with beekeeping activities during the establishment of new towers and by responsible authorities to guide migratory beekeepers to safe areas away from those with such towers.

Additionally, GIS helps to identify the origin of bee products. For example, the analysis of pollens in a honey sample determines the plant species (e.g. Fagúndez & Caccavari, 2006; Silici & Gökceoglu, 2007; Oliveira, van den Berg, & Santos, 2010) and with the use of GIS locates where this species is cultivated and where it originates. GIS was used to characterize and manage honey produced in Sierra Morena (Andalusia, Southern Spain) with application that utilized such aspects as climatic conditions and nectar sources (Serrano et al., 2008). Origin and distribution patterns of multifloral honey based on mineral composition, sugar content and basic physicochemical properties were studied using GIS in Serbia (Radović et al., 2014). The collected honey samples were chemically analyzed and then GIS was used to classify the honey according to the geographical origin (Kaur, Mishra, & Lal, 2016).

GIS and bee behaviors

Some behaviors of honey bees that can be analyzed and tracked using GIS are foraging activity, swarming and absconding. Foraging is mostly performed by bees older than 21 days to gather nectar, pollen or resin from plants and water (Abou-Shaara, 2014). GIS aids in identifying available floral resources of nectar, pollen and resin as well as water sources for bee colonies to forage. Colonies' productivity of honey, pollen or propolis can be then predicted. A production map was created through GIS using a map of apiary distribution within a 1 km forage area, hive density map and a map of honey forest types (Berardinelli & Vedova, 2004). Henry et al. (2012) developed a modeling tool to evaluate floral scheme efficiency with respect to landscape context based on honey bee foraging activity. Camargo et al. (2014) used datasets about flora, land use, and honey productivity to investigate a three-kilometer radius around apiaries. This model would help land managers to avoid low-efficiency landscape areas, and hence optimize their financial investment.

Water is essential to bee colonies to dilute honey and to regulate the internal microclimate (Doull, 1976; Human, Nicolson, & Dietemann, 2006). Especially, bees at immature stages require specific relative humidity percentage to be able to hatch and complete their development (Doull, 1976; Al-Ghamdi, Abou-Shaara, & Mohamed, 2014). Typically, honey bees gather water from many resources including salty and unclean ones (Butler, 1940; Abou-Shaara, 2012) and those located a long distance away (Visscher, Crailsheim, & Sherman, 1996). If there are no clean water resources around an apiary location, one must be provided for bees. The availability of water sources and their type either clean or not can be identified and mapped using GIS.

Bee colonies reproduce naturally by swarming (Grozinger, Richards, & Mattila, 2014), while in case of absconding the whole colony moves to inhabit another location. The occurrence of swarming and absconding is considered as a problem for beekeepers as well as for honey bees in conservation areas bees exhibiting these behaviours can invade mate with the conserved bees. GIS helps to track the movements of bee swarms and absconded bees, and to predict whether they will invade conservation areas or not. Also, GIS helps responsible authorities to take the appropriate actions against absconded bees.

GIS and honey bee mating

Honey bees mate in the air (Gary, 1963; Neumann & Moritz, 2000) and at drone congregation areas (DCA) (Zmarlicki & Morse, 1963). The exact reasons why bees select these areas are not fully known, but magnetic fields may have a role (Loper, 1992). GIS can be used to analyze the geographical and environmental factors in a DCA and then predict potential ones in different locations. Identifying DCAs greatly helps beekeepers, especially those producing mated honey bee queens. Some factors are known to passively impact the mating of virgin queens including bee pests and the unsuitable environmental conditions (Szabo, Mills, & Heikel, 1987; Cobey, 2007; Heidinger et al., 2014; El-Niweiri & Moritz, 2011). Thus, placing mating nuclei in DCAs greatly ensures the successful mating of queens. Additionally, queen rearing stations (apiaries specialized in queen rearing) can be distributed according to the locations of DCA. Harmonic radar (Osborne et al., 1996) is another technology that can be used with GIS to locate DCAs.

GIS and honey bee morphology and genetics

The genetic boundaries of various plant and animal species can be geographically located (Leempoel et al., 2017), and a large number of honey bee subspecies can be separated using morphological and genetic characteristics (Meixner et al., 2013). Almost each country has regions for native bees and other regions for hybrid bees (native bees mixed with other bee subspecies). Honey bee subspecies or hybrids can also invade new environments; for example Africanized honey bees (Taylor Jr, 1977; Winston, 1992) moved from South America to North America. The areas occupied by subspecies or hybrid bees are mapped and tracked using GIS. Also, after the morphological and genetic characteristics of managed honey bees are measured, a morphometry map using GIS can be established (Abou-Shaara, 2013c). These characteristics are measured at different time points, and then changes can be geographically linked with GIS by establishing maps for each study time. The changes in areas occupied by each subspecies or hybrid are then identified and beekeeping activities in regions with high changes are analyzed to understand the reasons for such changes. Also, it is possible to use GIS to track the movements of the invasive bees in the new regions. GIS can clearly have a role in conserving the genetic and morphological characteristics of honey bees in a given area.

GIS and climate change

Climate change, one of the current challenges facing beekeeping worldwide, impacts directly productivity and survival of honey bee colonies and indirectly the floral sources and diseases of honey bees (Le Conte & Navajas, 2008), and may increase the risk of invasion by such pests as hornets, *Vespa velutina nigrithorax* (Barbet-Massin et al., 2013). Temperature increase is the major phenomena related to the change in the climate during the next years (e.g. Walther et al., 2002). GIS can help to identify the potential changes in a climate in an area and to predict the most suitable locations for apiaries through the utilization of available datasets about future climatic factors. In Egypt, changes in land suitability to beekeeping under current and expected future environmental conditions were studied using GIS (Abou-Shaara, 2015). Also, GIS was used to present expectations about the potential impacts of climate change on honey bees in Egypt (Abou-Shaara, 2016). Castellanos-Potenciano et al. (2017) studied spatio-temporal mobility of beekeeping in the Gulf of Mexico over the short, medium and long term based on temperature changes due to climate change and so found a potential loss of citrus area suitable for beekeeping. Also, mapping current beekeeping conditions (e.g. colonies productivity and disease prevalence) and comparing them at different time points could help to understand the effects of climate change on beekeeping.

CONCLUSION

According to the review above, geographical information system (GIS) can be applied in many aspects related to beekeeping. Implementing GIS during honey bee research is worth to be considered by researchers since few GIS studies have been done on honey bees. There are many technologies that can be used in line with GIS to develop beekeeping.

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