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Importance of GIS solutions for beekeepers: a review

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Abstract. In today's realities, beekeeping encounters a number of different challenges, including the lack of suitable areas, urbanisation, intensive farming methods etc. In order to meet the current needs, modern beekeeping uses various information technology solutions that support beekeepers in their activities. Among such solutions, the use of geographic information systems and spatial data is relevant. At the time of writing this work, its authors are developing software solution for beekeepers based on Geographic Information System (GIS) and an interactive map within the scientific project named Hiveopolis. To further develop this solution, it is necessary to investigate the current situation related to issues in modern beekeeping and the solutions already available. In this study, a detailed review of solutions was carried out, which, according to the authors, are the most similar in subject matter to their developed solution. During the review, the authors studied the actual problems of beekeeping solved with the help of the considered solutions, and also provided possible ways to improve existing solutions, presenting their developed system. As a result, the study confirmed the relevance of this direction, and also made it possible to identify challenges for beekeeping and possible improvements to existing solutions.

Key words: GIS, precision beekeeping, pollinators, decision making, data, Hiveopolis.

INTRODUCTION

Beekeeping is an important activity that provides economic and ecological benefits (Altunel & Olmez, 2019). However, the success of beekeeping is dependent on various factors such as weather, vegetation, and landscape features. Geographic Information System (GIS) provides a powerful tool for analyzing and mapping these factors, allowing beekeepers to make informed decisions about hive placement, honey production, and disease management. This paper discusses and reviews how GIS can be used in beekeeping. Beekeeping activities are closely related to the agriculture and land resources. Therefore, it is necessary to look for the most efficient and environmentally friendly ways to use the available resources (Andrijević et al., 2022). One of the problems is related to the efficient use of the land resources. This is especially important for agriculture, as this field of activity provides food for humans (Dai et al., 2022; Sadri et al., 2022). One of the agricultural subsystems is beekeeping, as bees as pollinators provide invaluable ecosystem services to agriculture and biodiversity. Beekeeping is an important component of agriculture since it maintains the diversity of the ecosystem, ensures the process of pollination of a wide variety of plants and provides valuable food resources (Thapa & Murayama, 2008; Gratzer et al., 2021). In recent years, the global decline in the number of pollinators and the lack of services for pollination of plants has become especially relevant (Cappa et al., 2021).

In modern (precision) beekeeping, there are many opportunities and technological solutions to help the beekeepers to maintain the bee colonies more efficiently (Catania & Vallone, 2020; Zacepins et al., 2015). Due to the close relationship between honey bees and their surrounding environment, there is a scope to exploit the value of geospatial information to improve beekeeping activities (Sponsler et al., 2017). Data provided by GIS can be widely used by beekeepers to improve apiary management decisions. This is confirmed by various cases of using GIS to solve various problems in beekeeping.

At the same time, in earlier studies related to the application of information technologies in beekeeping, there were mentions of the deficiency of solutions using GIS and that the application of GIS methodology for beekeeping development was used in relatively few studies related to honey bees and beekeeping (Mutinelli et al., 2021). To further develop such solutions, within the framework of this study, an analysis of examples of the use of GIS in beekeeping was carried out to assess the current situation. In the future, this information could be used to identify potentially important areas for the development of GIS-based software solutions to meet the needs of beekeeping.

The possibilities of GIS are especially important for the development of precision beekeeping, within which a combination of various digital solutions such as the Internet of Things and remote monitoring of bee colonies is possible (Sharma et al., 2018). Ultimately, these solutions can be widely used by beekeepers in decision making, planning their activities and supervision of the bee colonies (Komasilova et al., 2020). In this way, it is possible to improve the efficiency of the use of available resources for beekeeping, as well as contribute to the development and success of agriculture (Hadjur et al., 2022). Within this article GIS solutions for beekeeping needs are reviewed, as well as the authors provided solution based on GIS is presented. The main objective of the study was to understand how GIS solutions were used for solving various problems in beekeeping.

This study was necessary to be implemented since the authors at the time of writing this work, within the framework of a scientific project named Hiveopolis, are working on the development of a software solution based on GIS for the needs of beekeepers.

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MATERIALS AND METHODS

To conduct this study, scientific works related to the use of GIS in beekeeping were analysed. From the available studies, those articles were selected, that were most closely corresponded to the goals pursued by the authors of this article in their research - to improve beekeeping activities by implementation of digital solutions based on capabilities of GIS.

The authors of this study did not intend to limit the research to a specific region for study, instead focusing on the variety of issues addressed. Each of the reviewed studies has its own problems, goals and proposed solutions to a particular problem. Since this direction, according to the authors, is very relevant for further research and there are relatively few available studies, it was decided to study each of them in detail.

As a result of a preliminary analysis of the available works, 7 scientific articles were selected, which describe in detail the use of GIS for solving various tasks and problems in beekeeping. The list of works are: 1) Estoque & Murayama, 2010; 2) Al-Khalaf, 2021; 3) Marnasidis et al., 2021; 4) Cappa et al., 2021; 5) Mutinelli et al., 2021; 6) Brodschneider et al., 2021; 7) Prestby et al., 2023. These publications were analysed and studied from the point of view of software engineering methods. The problems of each situation, the scale of the tasks set, the stages of solution, and in particular the role of GIS as a component of information technology are considered. A detailed overview of each of the articles is provided in the next chapter. All figures shown within review sub-chapters (see Fig 1–11) are taken from the corresponding research papers.

OVERVIEW OF GIS IN BEEKEEPING

The works reviewed in this study generally show the diversity of challenges in modern beekeeping. Although the problems described in the works have differences, in all cases one can see a common goal which is adaptation of the beekeeping to modern realities, considering close connection with agriculture and, in particular, with the food production.

Suitability analysis for beekeeping sites in La Union, Philippines, using GIS and multi-criteria evaluation techniques

The first reviewed study is related to the analysis of the suitability of a certain area for the development of beekeeping. The authors of the article emphasise the importance of the suitability of the land for beekeeping, since in this case it is possible to improve both the pollination process and financial profit.

In this case, a certain territory of the province of La Union in the Philippines was chosen for the study. Accordingly, by promoting beekeeping activities in this area, the current situation in the region can be improved.

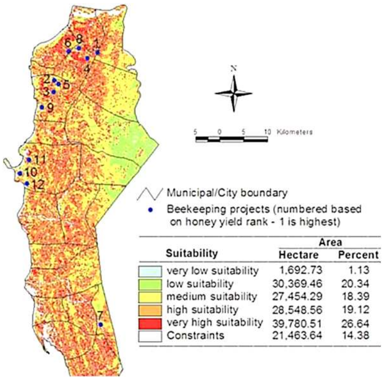
Practical research in this case can be divided into three main stages:

1. collection of necessary data about the territory;
2. data analysis and development of methodology for suitability assessment;
3. assessment of the suitability of the territory and development of a suitability map.

As a result, the authors provided a developed map of the suitability of the province of La Union for beekeeping activities, as well as a table of suitability testing results using 12 existing beekeeping projects (see Fig. 1).

The suitability map shows the territory of the province of La Union and the levels of suitability shown in different colours, as well as the area in hectares and the percentage of the total area. Using this map, beekeepers can determine the suitability of the area for beekeeping and evaluate the possibilities for the development of beekeeping activities in the selected area.

In addition to developing a suitability map, the authors conducted a validation using 12 real beekeeping projects. The results clearly show the dependence of colony productivity (kilograms per colony) in 2005 and the suitability index at the specific project site. In this case, the higher the fitness index, the higher the productivity of the colony. Thus, the authors were convinced of the effectiveness of the developed suitability map.



Rank based production rate[a]	Geographic coordinates UTM 51N) x	y	2005 Production rate (kg/colony)	(Suitability value where the project is located
1	229019	1862524	37.50	252.0000
2	220036	1856655	33.33	240.0000
3	219872	1854181	21.05	222.0000
4	226969	1861279	20.00	214.0000
5	220892	1855846	19.17	211.0000
6	223035	1862736	14.00	204.0000
7	229723	1804923	13.50	194.0000
8	225145	1863452	12.67	204.0000
9	217464	1850916	11.00	123.0000
10	212872	1836852	10.00	146.0000
11	214720	1839716	8.00	151.0000
12	214298	1834668	5.00	49.0000
Pearson product moment correlation coefficient, r between the production rate and suitability value				0.8010

Figure 1. The La Union suitability map for beekeeping and the result of the validation using the 12 existing beekeeping projects.

Modelling the potential distribution of the predator of honey bees, *Palarus latifrons*, in the Arabian deserts using Maxent and GIS

In this study, the authors consider the problem associated with the spread of predators *Palarus latifrons* in the Arabian deserts, which are dangerous for honey bees. The authors emphasise the importance of this study, since this type of predator is able to reduce the productivity of bees and destroy entire colonies. Predators of this species are also able to adapt well to conditions outside their natural habitat.

As material for the study, the authors used data on the distribution of predators in the Arabian deserts, the countries of the Persian Gulf, North Africa and Saudi Arabia. The authors noted the dependence of the distribution of predators on climatic conditions in the summer. In this regard, the minimum, average and maximum temperature values of the summer months (from June to August) were used, as well as data from two bioclimatic variables: Maximum temperature of the warmest month (MTWM), and mean temperature of the warmest quarter (MTWQ).

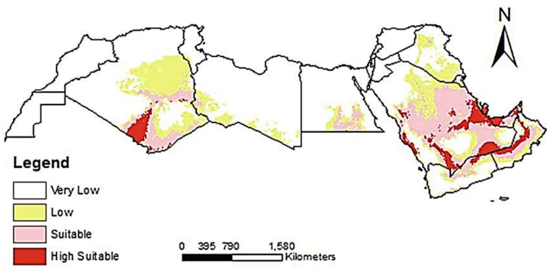


Figure 2. Potential distribution of *Palarus latifrons* under current conditions based on the average of three maps (minimum, average, maximum temperature) during summer months.

During the study, the authors developed maps showing the possible distribution of *Palarus latifrons* predators in the above areas. For this, the Maxent software version 3.4.1 was used for modelling the distribution of species based on machine learning methods, as well as geographic information system software ArcGIS 10.5. As a result, two types of maps were developed for the current situation and for a possible situation in the future. The first type of maps was developed on the basis of data on temperature values in the summer months, the second on the basis of bioclimatic variables.

As a result, the developed maps clearly show the possible distribution of predators of *Palarus latifrons*. The example below (see Fig. 2) shows a distribution map in the current situation based on the temperature values of the summer months.

The map shows areas of possible distribution as well as the level of suitability using a particular colour. Thus, beekeepers have the opportunity to assess the possible risks when placing bee apiaries in specific regions. This can be especially useful for migratory beekeepers who periodically change apiary locations. Analysing the results, the authors note that apiaries can be placed in desert areas for a short period of time, since these territories are areas of risk for attack by predators of *Palarus latifrons*. This may be due to the fact that predators of this species prefer a hotter and more desert climate. In conclusion, the authors argue about the need to develop a method for early detection of the distribution of this type of predator.

Mapping priority areas for apiculture development with the use of geographical information systems

The purpose of this study was to develop thematic maps of priority to support apiculture development. The authors of the study note the importance of support for decision makers regarding efficient land use and rational methods of pollination. In this case, the authors highlight the dual role of honey bees - as honey producers and as crop pollinators. Also noted are previous studies of similar issues, in which the needs of bees were considered to a greater extent, without taking into account the needs for pollination of crops.

The study was conducted in the Pella regional unit in Northern Greece, which includes several municipalities and about 89 municipal communities. The authors used a large amount of data, including the attractiveness of crops and plants for pollination, land cover data, and honey bee pollination services. During the analysis of information and spatial data, the authors introduced three indicators: Relative Attractiveness Index (RAI), Relative Dependence Index (RDI), and Relative Priority Index (RPI). Based on these indicators, the corresponding thematic heat maps were developed.

To implement the maps, the authors used QGIS, a free and open-source geographic information system software, and the Inverse Distance Weighted (IDW) interpolation method. Microsoft Excel was also used for data processing. As a result, three heat maps were developed, each of which displays a specific indicator (RAI, RDI and RPI). As an example, the Relative Priority (RPI) map for 2018 is shown below (see Fig. 3).

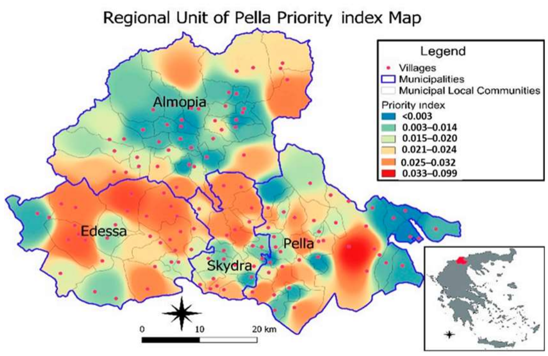


Figure 3. Relative Priority Map (RPIA) for 2018.

The map clearly shows a variety of zones depending on the priority index. Since the indices on the basis of heat maps are depicted at the local level, this can help to make more accurate decisions at the local level regarding the development of beekeeping and agriculture in general. According to the conclusions of the authors, the results displayed on the maps differ at the local level, as they depend on many parameters, in particular, on the land cover.

The authors noted the main drawback of the proposed method, which, in their opinion, is the relative value of the indicators. However, it should be noted that the methodology proposed by the authors in this study may be very useful for other studies with similar topics.

Analysis of bee population decline in Lombardy (Italy) during the period 2014–2016 and identification of high-risk areas

This study is dedicated to the analysis of bee population decline and identification of areas with high risk of depopulation. The authors studied the dependence of bee depopulation on the territories surrounding the apiary. The authors note a variety of possible causes of bee depopulation, including climate change and air pollution, the impact of pathogens, and changes in habitat availability associated with activities of modern agriculture.

In the course of the study, the authors used data on more than 14 thousand apiaries from 5,646 farms in Lombardy, which were obtained over a two-year period (from 2014 to 2016). When processing the data, the authors used a logistic regression model and the Kernel methodology - a spatial interpolation method that allows to determine areas with the highest risk of depopulation. As a software, the authors used R (programming language) version 3.6.1 for statistical analysis and QGIS for working with spatial data and creating maps.

One of the significant results of this study are maps that show the location of apiaries where depopulation was ascertained, as well as areas of risk of population decline (see Figs 4–5). The map at Fig. 4 also shows the type of territory depending on the use of land.

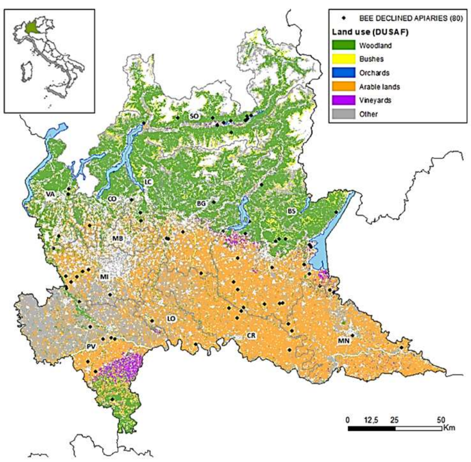


Figure 4. Map of land use (DUSAF 2015) and apiaries with population decline events.

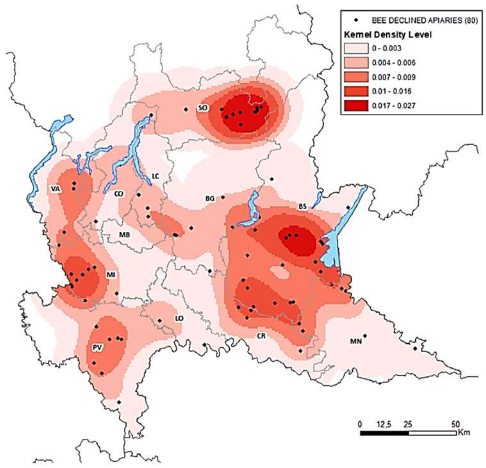


Figure 5. Lombardy with areas at risk of population decline.

During the analysis of the results, the authors identify the use of insecticides as the main reason for the reduction in the number of bees, which is also associated with the cultivation of arable land and other areas. According to the authors, other studies also prove this. The risk of bee depopulation was assessed quantitatively, considering the area and type of a particular area near apiaries, and the results showed an obvious relationship between a particular type of area and the reduction in the number of bees.

In conclusion, the authors note that the results obtained in this study point to plant protection products as the presumed cause of the extinction of bees in Lombardy. Thus, bees can be considered as an indicator of environmental friendliness and 'health' of the environment. Pollution of their habitat with toxic substances can lead to a significant reduction in bee colonies.

The Italian national beekeeping registry (BDNA) as a tool to identify areas suitable for controlled mating of honey bees in Italy

The authors of this study from Italy focused on the issue of mating control of honey bees. The reason for the need for this study is an increase in the importation into Italy of queen bees and swarms belonging to other subspecies (as a result of interracial crossing) and not being native species. In this case, a problem is the uncontrolled mating of different species and the possible violation of local biological diversity. To solve this problem, the authors highlighted the need to create territories suitable for controlled mating stations and the ability to use the Italian National Beekeeping Registry (BDNA), which acts as a database to control the position of apiaries and the movement of hives.

To establish suitable locations for stations, the authors relied on the criteria proposed in the BDNA, among which the height is below 1,500 metres above sea level, the distance from the apiary is at least 6,000 metres, etc. During the implementation, the authors collected the necessary data, including the location of apiaries, spatial data on soil types, elevation, etc. Next, the necessary calculations were made to exclude unsuitable territories and determine suitable territories, based on the criteria put forward. During implementation, the authors used ESRI ArcMap 10.5.1 software.

In the course of the study, the authors used data on 143,788 apiaries. A very large area that did not meet the criteria put forward, which amounted to 300,088 square kilometres, was considered as unsuitable and was excluded. As a result, 136 sites with a total area of 1,977.59 km^2 were identified as suitable for mating stations. This area is approximately only 0.65% of the total national surface of Italy. Eligible areas are shown in red on the map below (see Fig. 6).

Figure 6. Comprehensive distribution and location of the possible suitable areas for establishment of mating stations in the Italian territory.

In conclusion, the authors note that the available 136 suitable areas have a low surface value based on the results of the study. According to the authors, BDNA data, combined with the use of GIS methods, can serve as a useful solution in choosing areas for the establishment of bee mating stations at the country level, despite the limitations of this study. The authors emphasise that based on a preliminary review, the application of GIS methodology to beekeeping needs has been used in a relatively small number of studies related to beekeeping and bees.

Csi pollen: Diversity of honey bee collected pollen studied by citizen scientists

This study, titled COLOSS 'CSI Pollen', analysed the diversity of pollen collected by honey bee colonies. Authors of the study highlighted pollen diversity as an important factor for the health of honey bees. At the same time, there is a significant lack of information on the availability of various pollen for bee colonies on a landscape scale. Authors of this study conducted a study with beekeepers to determine pollen diversity at the European level.

To conduct the study, the authors involved beekeepers, who for two years (2014 and 2015) as citizen scientists analysed the pollen collected from their bee colonies. Following general guidelines, beekeepers from different countries collected the required amount of pollen and sorted individual grains into colours and groups: a very rare colour, a rare colour and the most common. Next, using the European Environment Agency (EEA) Corine land cover map, the surrounding land cover within a 2 km radius around each participating apiary was studied (see Fig. 7). Data analysis was performed using ESRI ArcGIS 10.0.

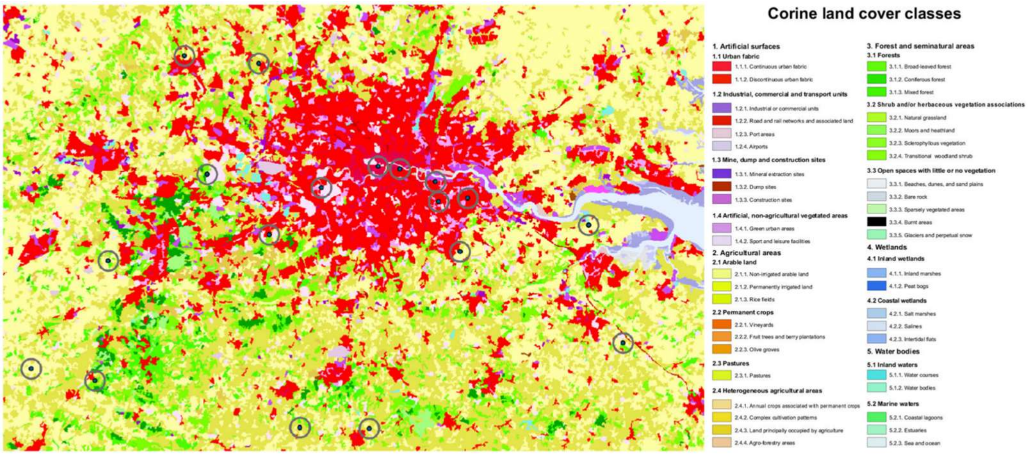


Figure 7. Exact location (point) and 2 km buffers (circles) around sampling sites in the area of greater London, UK. Map shows CORINE land cover classes.

In continuation, the authors also conducted a study on the influence of several variables on the amount of observed pollen colours, such as apiary coordinates including altitude, number of habitat types (surrounding the apiary), presence of cities, arable land, meadows, etc. During the implementation, the authors fitted generalised linear mixed models with Poisson distribution and using log link function. The authors used R 3.3.1 as software, in particular the lme4 and MASS packages.

According to the authors, approximately 18 thousand pollen samples revealed an average of six pollen colours, of which four were the most common and one colour was rare. The authors emphasise that the participating beekeepers did not place the hives in specially selected landscapes, thus the study is more realistic, not subject to artificial intervention and control. Also, very important was the fact that all participating beekeepers used the same standardised amount of pollen, which also had a positive effect on the accuracy of the species diversity results.

Characterizing user needs for Beescape: A spatial decision support tool focused on pollinator health

The research described in this article is related to the development of a software solution called Beescape. This software has been developed to provide beekeepers with a useful tool to help them make bee management decisions, as well as to visualise resources and environmental risks. The main component of Beescape is an interactive map (see Fig. 8), which, according to the authors, can be used as a very powerful tool for meeting various needs of beekeeping, in particular, for decision support. To fully implement this solution, the authors conducted a study to determine the needs of end users.

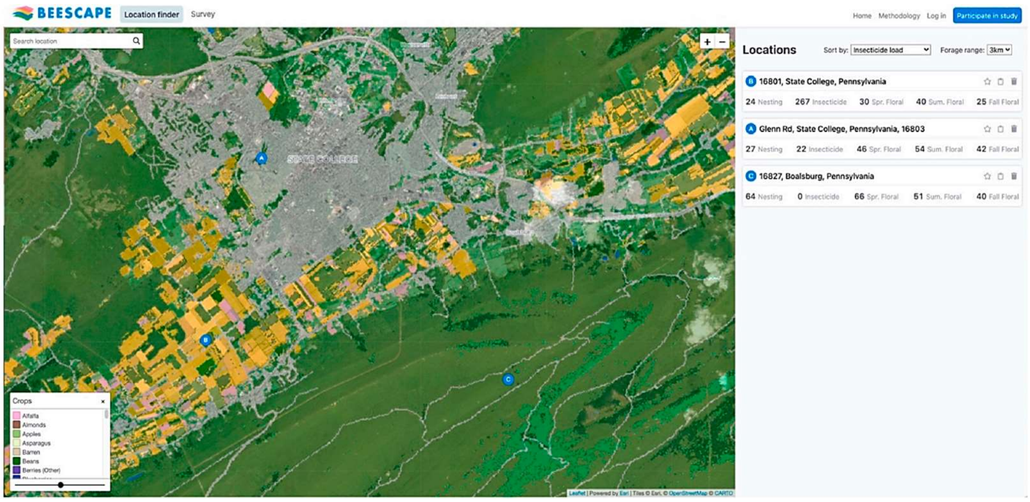


Figure 8. The initial Beescape prototype comparing the nesting, insecticide, and foraging scores of three locations in State College, Pennsylvania.

To implement this idea, the authors involved four groups of stakeholders in the study: beekeepers, growers, conservationists and scientists. These groups participated in the study as focus groups and answered a series of questions to assess the needs of potential users.

The research methodology was based on the principles of user-centred design (UCD), in which the needs and opinions of users are given extensive attention at every stage of the software product design process.

Each of the focus groups participated in three different sessions of 45 minutes each. At the same time, each session was accompanied by a discussion of all groups. During the analysis of the results, the summaries of each group for each stage were compared. As a result, the researchers were provided with very valuable material from the focus groups to determine the possible development of Beescape, which was presented in detail in the appendix of the article. Of particular importance is the outline of the graphical user interface that was developed by each focus group. As an example, the image below (see Fig. 9) shows a sketch created by the scientist group.

In conclusion, the authors note the value of this study for similar situations where the environmental field can be associated with several groups of interested users. The authors emphasize the importance of documenting the difficulties associated with the use of focus group methods, as this information can be used as a guide in further research with focus groups. The authors highlighted the need to conduct a structured evaluation of the usefulness and usability of the solution with target users upon completion of development.

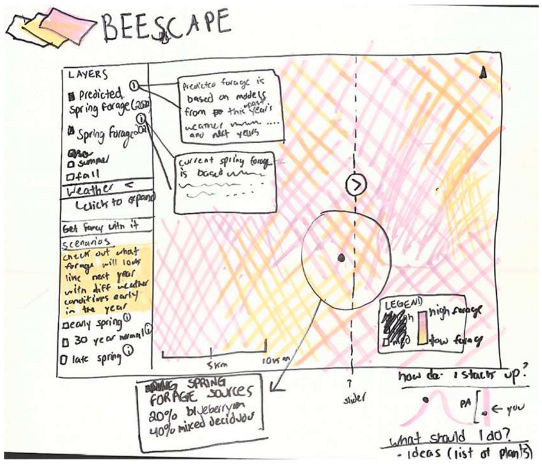


Figure 9. Sketched interface by scientist pair visualising and predicting forage quality based on different scenarios.

RESULTS AND DISCUSSION

A detailed study of each of the presented works shows the importance of information and communication technology in the development of beekeeping. In each of the works, the authors encounter the consequences of modern problems, which was repeatedly emphasised in the works. At the same time, reviewed studies confirmed the lack of research related to the use of GIS capabilities to solve the problems of modern beekeeping.

One of the most noticeable problem of modern beekeeping is the lack of suitable areas for bee colony foraging. There can be many reasons for this. One of the most important is modern farming approaches where it is important to increase production from a limited area. This is associated with the processes of urbanisation and industrialization, in which the area of suburban and rural areas is shrinking. It is also important to note another one problem related to the conditions of modern agriculture where various chemicals are used that can be dangerous for bees. In this regard, beekeepers, especially migratory ones, may not have information about the fields on which certain chemicals, for example pesticides, have been applied (Cappa et al., 2021). The authors describe in great detail each of the stages of their work, which allows them to delve into the method of solving the problem. In drawing conclusions, the authors highlight the potential benefits for further research, as well as the limitations and need for future research.

The reviewed studies have both similar characteristics and specific differences. In most cases, the results of studies are presented in the form of a heatmap (articles from 1 to 4). This approach allows to display a different degree of data diversity, making maps informative. However, in cases where it is important to display the presence of single type of data or the fact of their presence, a monochrome color was used, as was presented in article 5.

Studies also have different scales, which is also visible on the resulting maps. In this case, the resolution of the displayed data also differs. However, it is important to consider the level of assessment of the area of the studied territories. In some cases, high accuracy at the regional scale is important (studies 1, 3, 4, 6) and it is necessary to assess the situation at a lower level. However, to assess the situation on a more global scale (studies 2, 5), there is no need for high detail at a low level, which allows displaying data at the country level or entire groups of countries.

For the creation of maps in most studies, two leading geographic information systems were used: ESRI ArcGIS/ArcMap (studies 2, 5, 6) and QGIS (studies 3 and 4). Both solutions are among the leading in the field of geoinformatics and represent a wide range of functions for working with spatial and geographic data. The difference is that ESRI's solution is proprietary commercial software, while QGIS is a free and open-source cross-platform software.

According to the authors of this study, one of the most important limitations that can be seen in the considered solutions and which can be improved is the static and relativity of the results. This means that if the result of the study is a suitability map, then the information displayed on the map is relative and relevant at the time of development. Another one important limitation is the lack of interconnection with other areas of agriculture, in particular with crop farming. Since beekeeping is a part of agriculture and is closely related to the pollination of crops, it is very important to ensure the cooperation of beekeepers and farmers.

The authors of the reviewed articles in the conclusions also mention the limitations of their research and highlight the need for further research. However, despite the limitations, the reviewed studies have positive results in general and allow assessing the situation in each specific case.

PROPOSED SOLUTION

Considering the relevance of this direction and the approach of the majority of available solutions, the authors of this work are aimed at further research and implementation of a new generation solution based on geographic information system. A key feature of this system is real-time data exchange in combination with interactive maps. Thus, the data within the system will be up-to-date over time, which can reduce the risk of incorrect decisions and inaccurate actions on the part of beekeepers who use this solution. A particularly important factor for improving beekeeping, according to the authors, is the exchange of data between beekeepers and farmers. Thus, it is possible to organize a mutually beneficial system of services for the development of all agriculture, given the importance of the pollination process.

To implement a system of this level, the authors developed an experimental prototype, which is being actively improved at the time of writing this work. The purpose of this prototype is to use it as a 'sandbox' for implementing and testing various solutions that could be useful for beekeepers. With the help of this method, it is possible to conduct research on possible approaches to implementation and create a conceptual model of a working solution. Proposed solution is called BeeLand. For the end user, this solution is presented as an interactive WEB application. The earlier version of this application is described in details in the corresponding article (Kotovs & Zacepins, 2023). The overall design of the solution is shown in the Fig. 10.

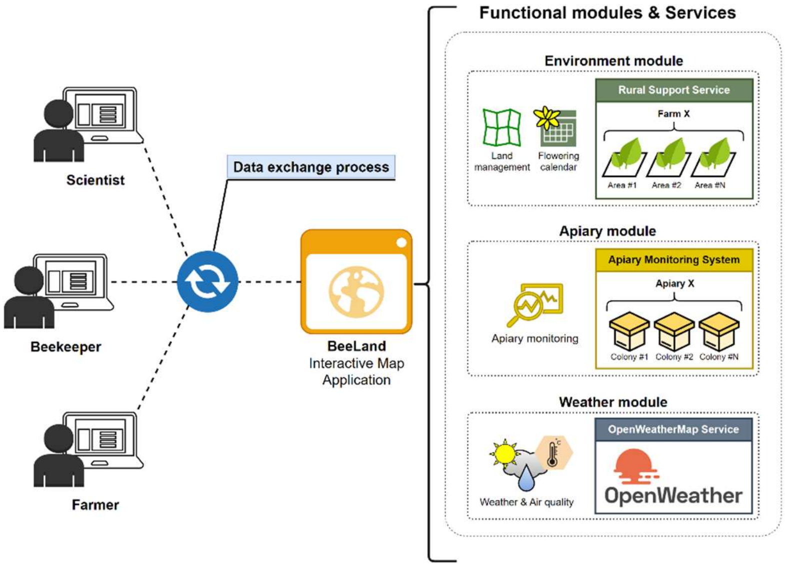


Figure 10. The overall design of the BeeLand.

The solution is being developed using R programming language and environment for statistical computing and graphics (R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org). The basis of this solution is an interactive map showing bee apiaries as well as the agricultural fields. The key feature of the system is a real time data exchange between users of the system, that is possible through the WEB application. For the full implementation of this system, it is necessary to conduct additional studies of the needs of beekeeping, explore available data, as well as the possible scale of application of this kind of system.

Application functionality is provided by the functional modules that are connected with the corresponding systems and services. In the current version, there are three functional modules: Environment module, Apiary module and Weather module.

Environment module. Environment module is focused on the agricultural fields surrounded the apiaries. The module uses the GIS data provided by the Rural Support Service of Latvia, that includes important data about the area of the fields, cultivated plants etc. that can be used within the whole system. Based on GIS data provided, agricultural fields are represented on an interactive map. The land manager of the module allows to store very important information for beekeepers such as presence of pesticides and state of use of each field. In this case, farmers play an important role, providing information about their fields in real time. The important prerequisite for complete functionality of this module is the data crowdsourcing.

Another one function of the Environment module is an interactive Flowering calendar that allows to show the fields whose plants bloom at the specific period of time. Flowering calendar also provides the calculated parameters such as diversity index, equitability index and meliferousness of specific area.

Apiary module. For beekeepers, the Apiary module can become especially important. Module provides real-time monitoring of apiaries and individual hives and ensures access to historical data. Currently, monitoring data includes information about the temperature inside and outside the hive, as well as the weight of the hive and the technical parameters of the equipment. Since this module is one of the most important for beekeepers, the functional architecture of the monitoring system is shown below, in the Fig. 11.

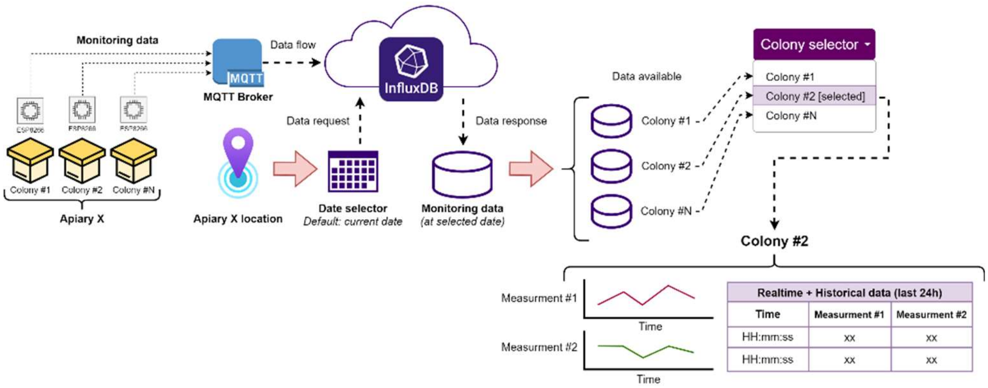


Figure 11. Functional architecture of the apiary monitoring system of BeeLand.

For the operation of the apiary monitoring system, it is necessary to equip the hives with a special set of sensors and microcomputers based on ESP8266. At the moment, this module is being adapted for use in real conditions and it is expected that the hives will be equipped with the necessary equipment in accordance with the beekeeping season. The monitoring data through the MQTT broker are being sent to the InfluxDB data base that are connected to the Apiary module of the application.

To get the monitoring data, it is need to select apiary (perform a click on the marker) on the map. As a result, function of requesting data about a selected apiary will be triggered and will send the corresponding query to the InfluxDB. By default application will set the current date to get last monitoring data including historical data (last 24 h with step of 3 h). In addition, it is possible to select a specific date from the past to get the historical monitoring data at the specific date.

The function automatically determines which data of which colonies are available on a specific date and performs the integrity check of the data. The list of apiary colonies (hives), whose data is available at the selected date becomes visible on the application, so each colony can be selected and explored separately. As a result, the data will be displayed in a table as well as in the form of graphs to better represent the change in measurements over time.

Weather module. The Weather module allows to obtain detailed information about meteorological conditions at the location of the apiary. This would be especially useful for beekeepers in the case of remote monitoring of bee colonies, as weather information can provide additional information about external factors that can influence the climate inside the bee hive.

Weather module is connected to Weather API of OpenWeatherMap service. Module has a separate and independent interactive map and provides different kind of current weather parameters such as temperature, air pressure, humidity, cloudiness and wind speed. Also, a forecast of temperature and humidity + cloudiness is available (presented as plots). Additionally, to meteorological parameters, module provides air quality parameters, that shows the concentrations of different air quality parameters such as CO, NO, NO_2, O_3, SO_2, PM2.5, PM10 and NH_3 as well as index of air pollution.

CONCLUSIONS

With the help of a study of works on similar topics, the authors of this work became convinced of the importance of this area, realising the main problems of beekeeping and possible improvements in existing solutions. It is especially important to note the role of end users in solution development, as the Beescape solution development study (Prestby et al., 2023) confirmed. Thus, it is important for the authors of this paper to follow suit and provide beekeepers with access to a prototype of proposed solution to ensure closer collaboration and feedback.

The review and study of the developed solutions based on GIS for beekeeping shows a variety of tasks and methods for solving them. With different problems in each situation, research is entirely aimed at the promotion and development of beekeeping. At the same time, a study of the available literature and a relatively small number of works on the use of GIS in beekeeping indicate the need for additional research and development in this area. This is especially true for the availability of interactive GIS-based solutions for beekeepers.

Despite the small number of considered works, which, according to the authors, were the most appropriate in terms of their developed prototype of proposed solution, the results of the study indicated the main areas of problems in beekeeping. Also, the possibilities for improving the current solutions were identified, the main of which is the static and relativity of the data. In addition, it is important to note the collaboration between beekeepers and farmers. Such a collaboration can give a very positive impact on the development beekeeping and improvement of agriculture in general.

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