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Development and Implementation of a Web-based GIS for Registering and Monitoring the Livestock and Poultry Genetic Resources

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HIGHLIGHTS

- The designed system contributes towards increased efficiency in the managing and monitoring the livestock and poultry genetic resources.
- The system users are able to easily query, visualize, manage, reuse, map and store FAnGR-related data.
- The system has the potential to be utilized as a location-based database for domestic livestock and poultry genetic resources.

Abstract: Animal genetic resources (AnGR), which are a component of biodiversity in agriculture, has an essential role in sustainable agricultural development. Given the significance of AnGR for each nation, all communities need to maintain genetic diversity by preserving indigenous livestock and poultry populations as well as implementing the national plans and policies. This study aims at developing a web-based GIS to collect and monitor information on livestock and poultry genetic resources across the country for typical decision-making activities in the organizational and managerial sectors, where resource managers and policymakers with various ideas can put their conservation best practices into action. The suggested system integrates and organizes the concepts and tools from three distinct study areas, including AnGR, GIS, and web technologies into a unified framework. Data on the different breeds of six species including cattle, sheep, poultry, goat, horse and camel are currently being entered into the system. System implementation consists a four-step process that includes identification and data collection, data entry, querying, and planning and decision-making. The system as a whole contributes towards increased efficiency in the managing and monitoring the farm AnGR (FAnGR) by allowing users to query, visualize, manage, reuse, map and store FAnGR-related data.

Keywords: genetic resources; GIS; registration and monitoring; system.

INTRODUCTION

Animal genetic resources, which include all animal species, breeds, and strains [1], play an important role in agriculture's sustainable development and provide the foundation for the efficiency of local agricultural systems. The primary benefit of raising domestic animals is their services in food production, which is associated with the widespread participation of commercial breeds in the industrial production systems of developed and emerging countries [2]. Furthermore, these breeds provide a source of genetic diversity contributing to improve adaptation and productivity over time [1]. Farmers can use genetic diversity to select herds or produce new breeds in response to changing conditions such as climate change, new or renewable disease threats, new knowledge of human nutritional needs, and changing market conditions or social needs [3].

Given the importance of farm animal genetic resources to each nation, it is critical for all communities to preserve their own diversity by implementing effective conservation programs and strategies. FAnGR conservation, according to the FAO, refers to all human activities, such as plans, programs, policies, and actions, aimed at preserving the current and future diversity of FAnGR that contribute to food and agricultural production and productivity [4]. In 2007, at the international technical conference on animal genetic resources in Switzerland, the global action plan on animal genetic resources was endorsed by 109 delegates of different countries. The goal of this global program was to provide an integrated and comprehensive framework for strengthening management activities related to AnGR [5]. In some countries such as China, Germany, Slovenia and South Africa there are explicit regulations for evaluating and monitoring the genetic resources [6]. Also in Iran, the ministry of Agriculture Jihad is responsible for identifying, registering, and monitoring the genetic resources of farm animals, according to the law on conservation and exploitation of the country's genetic resources.

Current biodiversity conservation methods are mainly focused on geographical areas, ecosystems, ecological communities and species [7]. Geography is regarded as a critical component in the conservation of AnGR. According to FAO, AnGR should be monitored and conserved locally, regionally and globally [5]. For example, in a study on the risk status of Polish local breeds under conservation programmes, researchers used the geographical concentration as one of the model elements to assess the degree of extinction risk among 30 breeds of cattle, horse, pig, sheep and goat [8].

Emerging technologies that have the potential to assist managerial and organizational decision makers in the sustainable use of AnGR by providing and analyzing data will be advantageous. Lack of information as a commonly noted barrier has been considered one of the main reasons to prevent decision-making. On the other hand, when information is dispersed and disorganized, it cannot be effectively used in decision-making processes [5].

Various information and computer tools are now widely used in agriculture for the management, decision-making, and planning processes. One of these tools is Geographic Information System (GIS). GIS is a system that uses both tools and technologies facilitating the decision-making process. As the name implies, it is an information technology system containing some geographic characteristics [9]. As a result of its widespread use, the definition of GIS has evolved over time. Its current definition is based on and in response to the definition proposed from the end user's perspective [10]. GIS is a well-organized collection of computer hardware, software, geographic data, and people designed to collect, store, manipulate, update, analyze, and display geographical spatial information [11]. GIS applications have grown significantly during recent years in various agricultural sectors, such as agronomy [12], horticulture [13], irrigation [14], soli science [15], plant protection [16], fishery [17] and veterinary [18].

Animal farming, as one of the most important agricultural sub-sectors with a key role in ensuring the food security has not been an exception to this debate. In this subject, several studies have been conducted. For example, in a previous effort, a GIS-based poultry litter management system called PLDSS was developed. PLDSS is a comprehensive user-friendly system that aids reduce the overuse of poultry litter. The litters can be properly transferred to locations with nutritional deficits using transportation analysis in this system [19]. A GIS model was constructed in another study to identify the dairy manure transmission pathways in Louisiana (USA) [20].

A major effort was made in prior studies of GIS applications for the management of AnGR by Duruz and coauthors [21]. They presented a Web-GIS-based platform called GENMON, to monitor FAnGR and to evaluate the degree of endangerment of livestock breeds. In recent study on strategies for gene bank collection based on environmental and geographic indicators for beef breeds in the United States, researchers used GIS technology to document the geographical location of specimens as well as livestock production environment [22]. Based on the same researcher's previous work on the geographical distribution of sheep breeds in Brazil and their link to climatic and environmental factors as a risk categorization for conservation using GIS technology, the researchers found that since breeds' geographical distribution was significantly connected with environmental controls; understanding their spatial distribution can aid in the development of production descriptors and breed categorization for conservation [23]. In a recent research, McManus and coauthors [24] focused on merging spatial and genetic data to manage biodiversity in sheep genetic resources in Brazil. The goal of this work was to validate a proof of concept combining geographical and genetic data on the spatial origin of DNA samples from different breeds or genetic groups of sheep in Brazilian germplasm bank. According to spatialisation analysis, not all genetic groups have samples in the bank.

Considering the vast diversity of AnGR breeds as well as their extensive geographical distribution in Iran, managing and monitoring AnGR information using just traditional techniques and conventional monitoring systems is sometimes challenging and complex. As a result, this highlights the importance of putting greater effort into developing effective information and monitoring systems. In this context, GIS has the potential to be an excellent tool for collecting, monitoring, and managing AnGR information. By merging geographical data with AnGR data and using GIS tools, an integrated GIS-based platform will be established that will allow for better and more functional decision-making.

This study was undertaken to develop and implement a nationwide system for registering and monitoring FAnGR by combining the capabilities of GIS and web technologies.

MATERIAL AND METHODS

The proposed system integrates and organizes the concepts and methods of three distinct areas of research including AnGR, GIS and web technologies into a unified platform for monitoring and managing the FAnGR data. To gather, store, retrieve, and display data in a location-based manner, some GIS capabilities and network technologies were adopted in developing the system. Figure 1 presents a schematic of combining three research areas with a variety of system design and implementation features. While GIS is used as a powerful and integrated technology with unique capabilities for analyzing, manipulating, storing, and visualizing geographically referenced data, web technology provides an open, extensive and active environment through which GIS related data and tools can be accessed anywhere (any place with internet connection), anytime (on a 24-hour basis), and through any PC or handheld device and network connections [25].

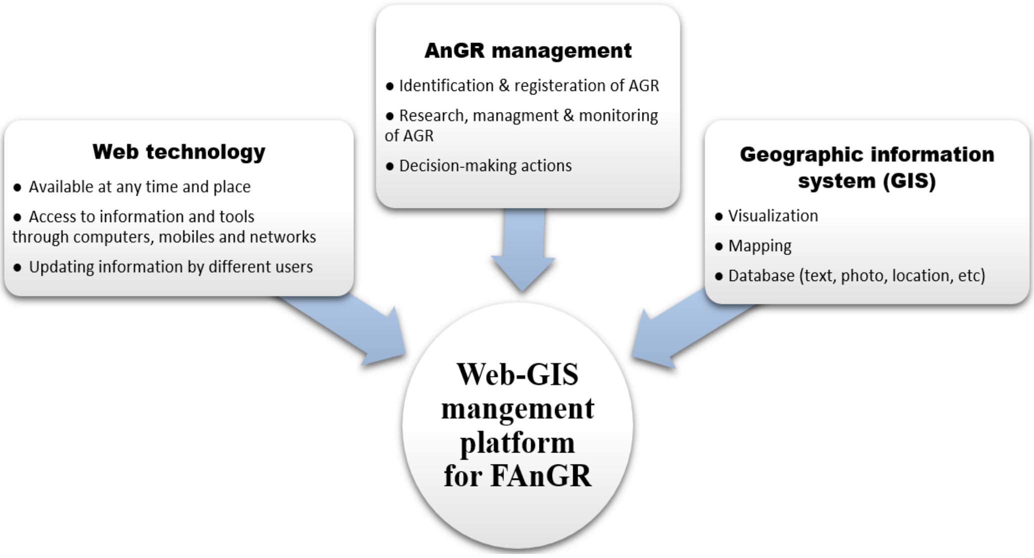


Figure 1. Using concepts and methodologies from three study domains (GIS, AnGR, and web technology) in system development

System architecture

The system architecture is made up of three major components including database management system, geospatial server, and base map (Bing and OSM). The system was built on a client/server web environment with multiuser access. The GeoServer as a most popular open source geospatial server was used in developing the system. GeoServer follow the Web Feature Service (WFS) and Web Coverage Service (WCS) standards and allows the sharing and editing of data used to generate the maps [26]. The running database management system was PostgreSQL with the spatial database extension PostGIS. PostgreSQL is a powerful open source object-relational database system that uses and extends the SQL language in combination with many features [27]. PostGIS adds support for geographic objects allowing spatial querying in SQL [28]. The Geospatial Data Abstraction Library (GDAL), a popular open source GIS library, was used as a translator library for raster and vector geospatial data formats [29]. Figure 2 illustrates the web technology components used in the system architecture.

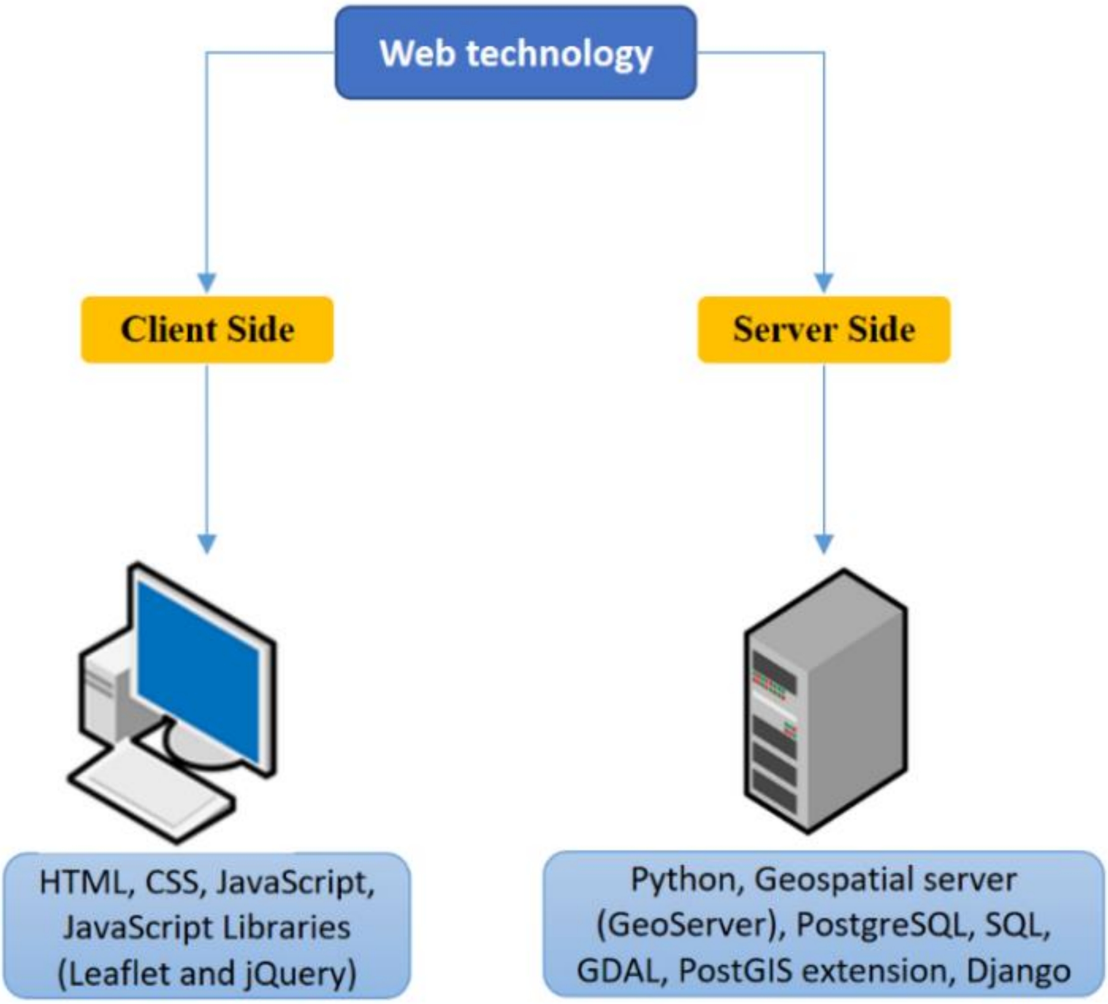


Figure 2. Client/server architecture of Web-GIS system

System implementation

System implementation involves a four-step process of identification & data collection, data registration, data querying and management & decision-making. Following the identifying FAnGR and collecting related data, in order to access the Web-GIS system, a username and password with a specific access level is needed for eligible users across the country. After logging in, users are able to register data in the system. Each user must specify the location (latitude and longitude) of genetic resources on the map and register the relevant descriptive data including biometric traits along with the image in the system. All FAnGR data can then be stored in a MySQL database. In the next step, based on the data stored in the system, various types of querying can be done. Subsequently, by using the different queries and further data analysis in other desktop softwares, valuable information will be generated for management activities, decision-making processes and other conservation efforts. The workflow diagram of the system is illustrated in Figure 3. The system includes the following main web pages: "data entry", "visualization", "statistics of registered data", "download the registered data", "querying" and "calculating the distance and area of distribution".

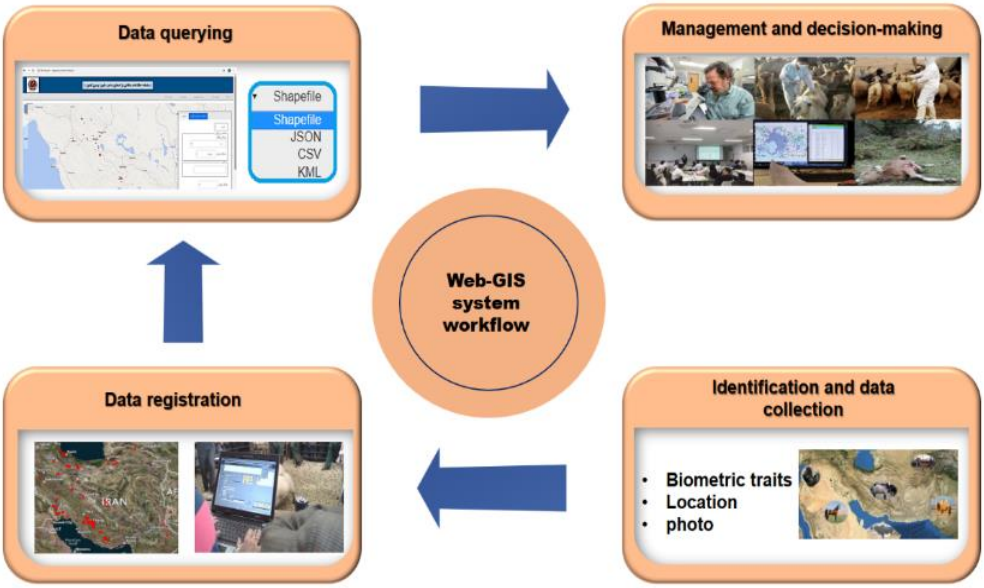


Figure 3. A schematic diagram outlining the implementation process of designed system

Study area

Iran, with an area of more than 1,648,000 square kilometers (the 16th largest country in the world in terms of area) includes 31 provinces housing different breeds of livestock and poultry, so that each of them is adapted to different geographical regions in terms of environmental and climatic conditions. In the present study, in order to evaluate the suitability and effectiveness of Web-GIS system, FAnGR data of 12 provinces including Fars, Kurdistan, Kermanshah, Gilan, Tehran, Qazvin, Mazandaran, Sistan & Baluchestan, East Azerbaijan, Khuzestan, Kerman and Bushehr were studied (Figure 4A). As depicted in Figure 4, registered data of three, seven, three, two and four provinces were considered for the breeds of goats (B), horses (C), cattle (E), sheep (F), and poultry (D), respectively.

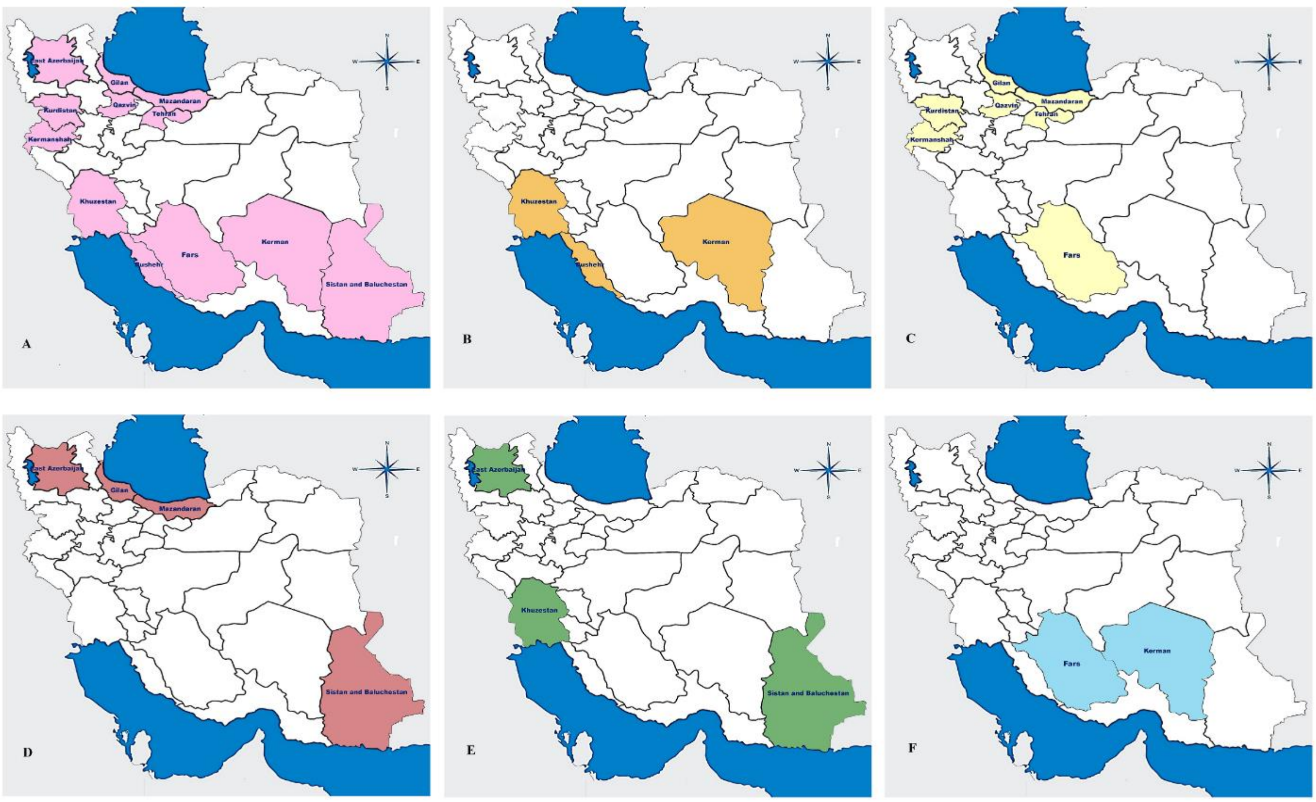


Figure 4. Study area maps for evaluation of system suitability

Data

The geographically referenced biometric data (biometric traits, location and photo) related to the domestic breeds of five species including horse, sheep, goat, cattle and poultry belonging to different provinces were entered in the system by eligible users across the country. In this study, data of 1014 FAnGRs were investigated. Table 1 gives general information on registered data, such as species, breed, province, and number of FAnGR.

Table 1. General information about registered data

Species	Breed	Province	No.
Horse	Darehshori	Fars	203
Horse	Kord	Kurdistan	28
Horse	Kord	Kermanshah	4
Horse	Caspian	Gilan	120
Horse	Caspian	Tehran	26
Horse	Caspian	Qazvin	2
Horse	Caspian	Mazandaran	6
Cattle	Sistani	Sistan & Baluchestan	94
Cattle	Sarabi	East Azerbaijan	128
Cattle	Najdi	Khuzestan	106
Sheep	Kermani	Kerman	50
Sheep	Fars Grey (Kabodeh)	Fars	20
Goat	Najdi	Khuzestan	16
Goat	Adani	Bushehr	73
Goat	Raeini	Kerman	57
Native chicken	Khazak	Sistan & Baluchestan	32
Native chicken	Marandi	East Azerbaijan	10
Native chicken	Gardan lokht	Gilan	25
Native chicken	Gardan lokht	Mazandaran	14

System evaluation

The system's usability was assessed by the experts and researchers from several regions around the country, who are conversant with the subject of AnGR. A survey of these individuals was conducted to obtain their feedback and responses on the system's functionality. In this approach, the participants filled out a paper-based questionnaire form with evaluation items for various concerns such as: willingness to use the system, system complexity, ease of system use, need for technical support, integrity of system functions, system inconsistency, learning to work with the system, confident feeling when working with the system, and need for a lot of knowledge to work with the system.

RESULTS

Spatial and attribute data associated with various breeds and species (over 1000 data) were entered in the system to evaluate the system's performance. The findings revealed that employing a Web-GIS system contributes greatly to monitor FAnGR, making it a beneficial tool for authorities to manage and track livestock and poultry genetic resources in a given geographical region. To ensure the successful implementation of the Web-GIS system from different views, a total of 17 experts and researchers were invited to complete the system questionnaire. Table 2 highlights the system's evaluation outcomes from the perspectives of several evaluators. It consists of a 10-item questionnaire with five possible responses.

Table 2. Evaluation results of system

Question	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think that I would like to use this system frequently	1		3	12	1
I found the system unnecessarily complex	3	12	1	1	
I thought the system was easy to use			2	15	
I think that I would need the support of a technical person to be able to use this system	2	6	4	5	
I found the various functions in this system were well integrated		1	8	8	
I thought there was too much inconsistency in this system	3	11	2	1	
I would imagine that most people would learn to use this system very quickly		1	3	11	2
I found the system very cumbersome to use	2	14	1		
I felt very confident using the system		2	4	8	3
I needed to learn a lot of things before I could get going with this system	1	11	3	2	

According to the survey, the system is easy to use for the users following workflow procedure. The system, on the other hand, appears to be impacted by the lack of complexity that leads to its regular usage. Most of the respondents did not find the system cumbersome to use (83% disagree). 65% of them believed that they learn to use this system very quickly and 47% of them felt very confident using the system. Based on the 47% of users' feedbacks, various functions in this system were well integrated. Overall, the findings suggest that users tend to use this system, and that the development of such systems contributes to the effective administration and use of FAnGR information. The system developed in this study is presently being used to register FAnGR data across the country. At the same time, the system is being expanded to include more species and breeds, such as honeybees. The procedure of entering data into the system begins with selecting the relevant species in the data input area, followed by a data entry window. The image of the desired livestock or poultry is also input in this section, while following the standard specifications. Figure 5 depicts several examples of photos stored in the system.

Figure 5. Example images of animals that have already been registered in the system

The system's interface provide the users with two main distinct parts; spatial search and visualization. The users are able to use any of these sections depending on their needs. By selecting the spatial layer of the desired species in the visualization section (Figure 6), the geographical location of all livestock or poultry whose data is registered in the system will be presented on the map.

Figure 6. Page for visualization section

Spatial querying using the spatial search section is another feature of the system. This allows users to geographically search for a given livestock or poultry with specific characteristics based on the defined criteria. To do this, first the desired species layer is selected, and then a spatial search is conducted based on the data stored in the system. An example of a spatial querying is finding all Darehshori horses locating in Fars province (Figure 7). By exporting the query results, the system displays locations on the map housing requested horses. Consequently, all of the defined items listed in the item selection section can be used as search criteria. In other words, dynamic maps are generated from spatial searches based on the many items defined in the system for each species.

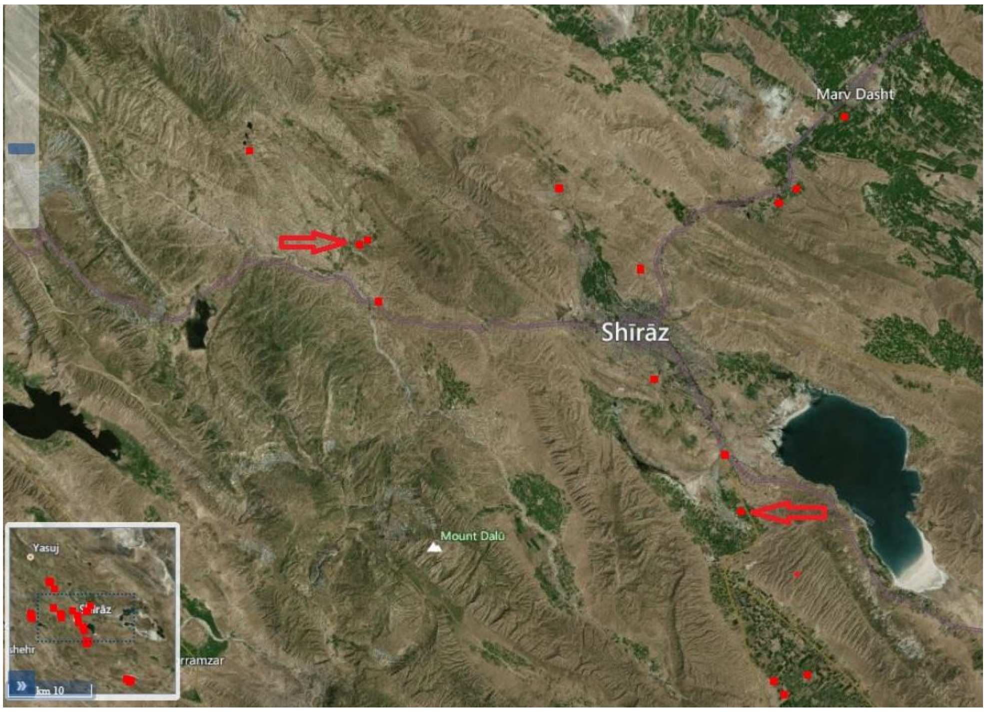
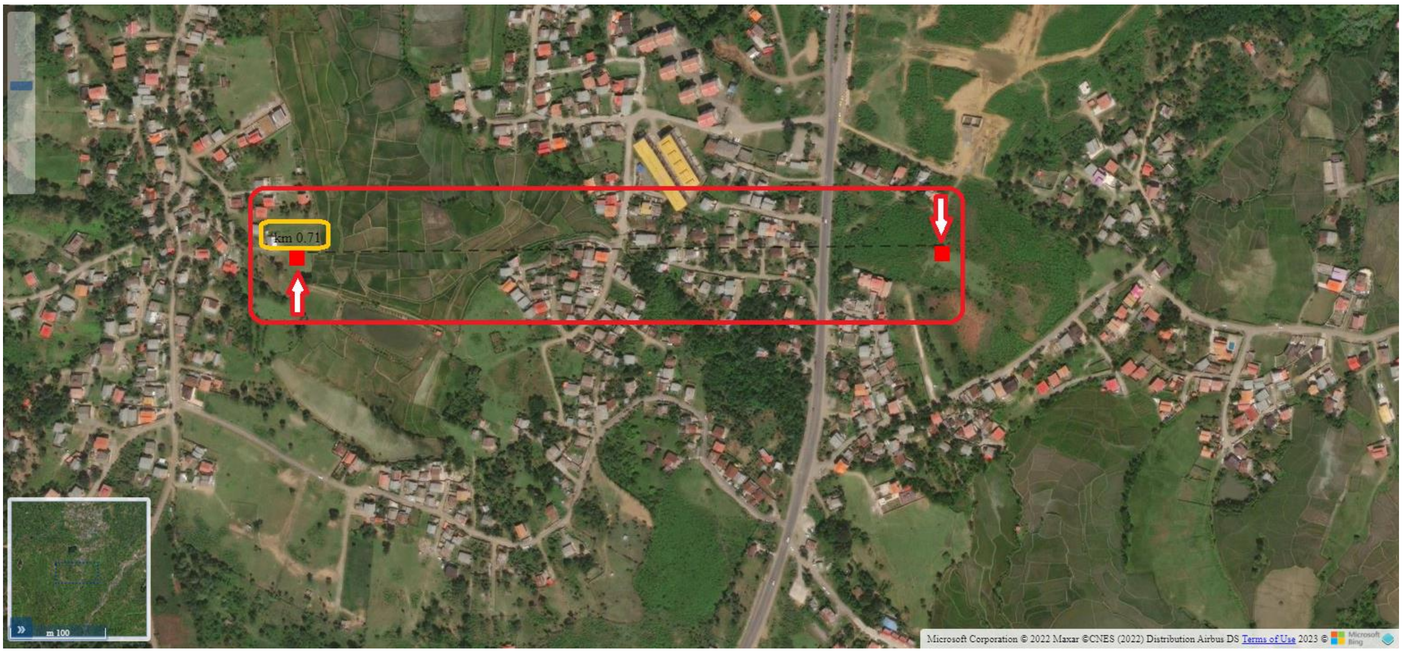


Figure 7. Using spatial search to generate dynamic maps

Another characteristic of the system is the calculation of the area and distance of the FAnGR distribution. In this manner, two measurement criteria on the map were defined. The first is the distance between two places of distribution (in kilometers), and the second is the distribution area (in square kilometers) of selected points on the map. Figure 8-A is an example of calculating the distance between two Caspian horses in the country's north. Figure 8-B displays calculating the distribution area of Caspian horses within a given location. As the findings show, employing these approaches can provide some insight into the distribution of FAnGR across the country.

A



B

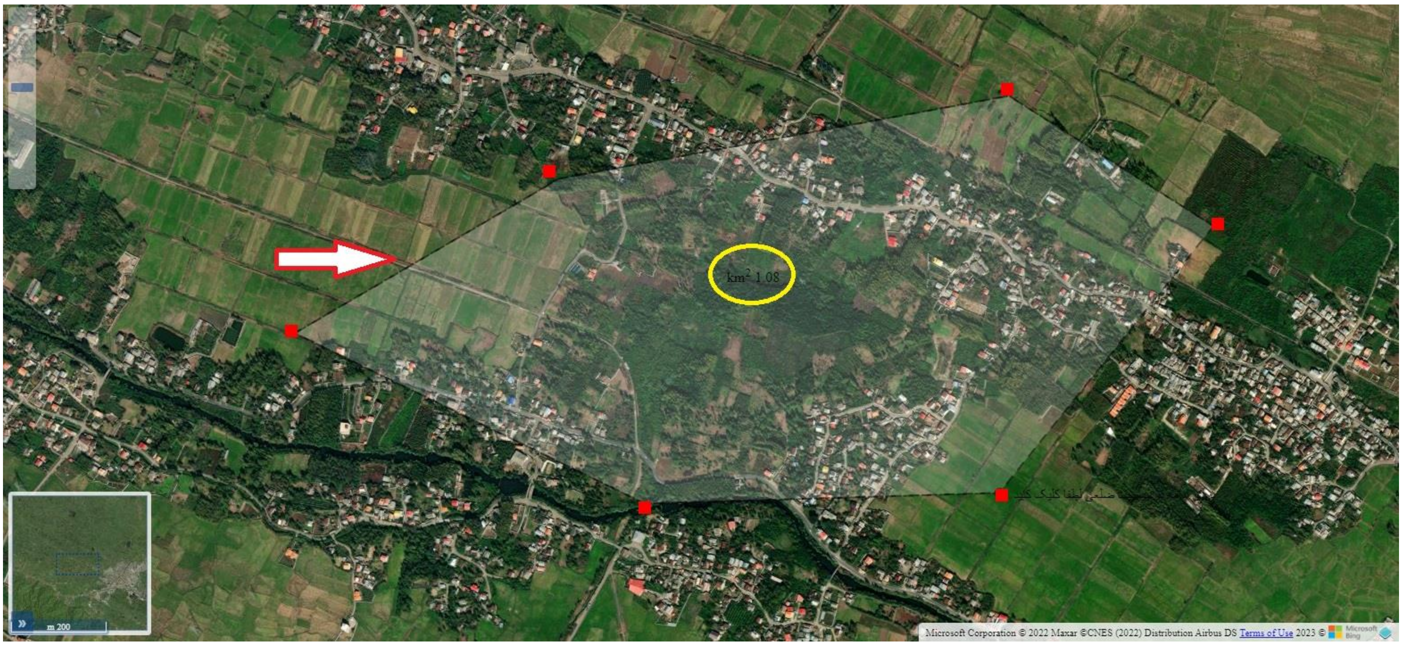


Figure 8. Measuring the distance between genetic resources and their distribution area

Receiving data in geographical formats is required for further analysis in GIS tools. In this respect, the system allows users to download data in multiple formats, including shapefile, JSON, CSV, and KML (Figure 9). Shapefile (.shp) is the most widely used and popular spatial data format, and it contains nontopological geometry and attribute information for the spatial features in a data collection. The geometry for each feature is stored in this format as a shape with a set of vector coordinates. Area, line, and point features are all supported by the shapefile format [30]. By selecting the relevant species layer and shapefile format in the system, the data set for the species in question is exported as a zip file. After that, the extracted file can be opened in GIS software.

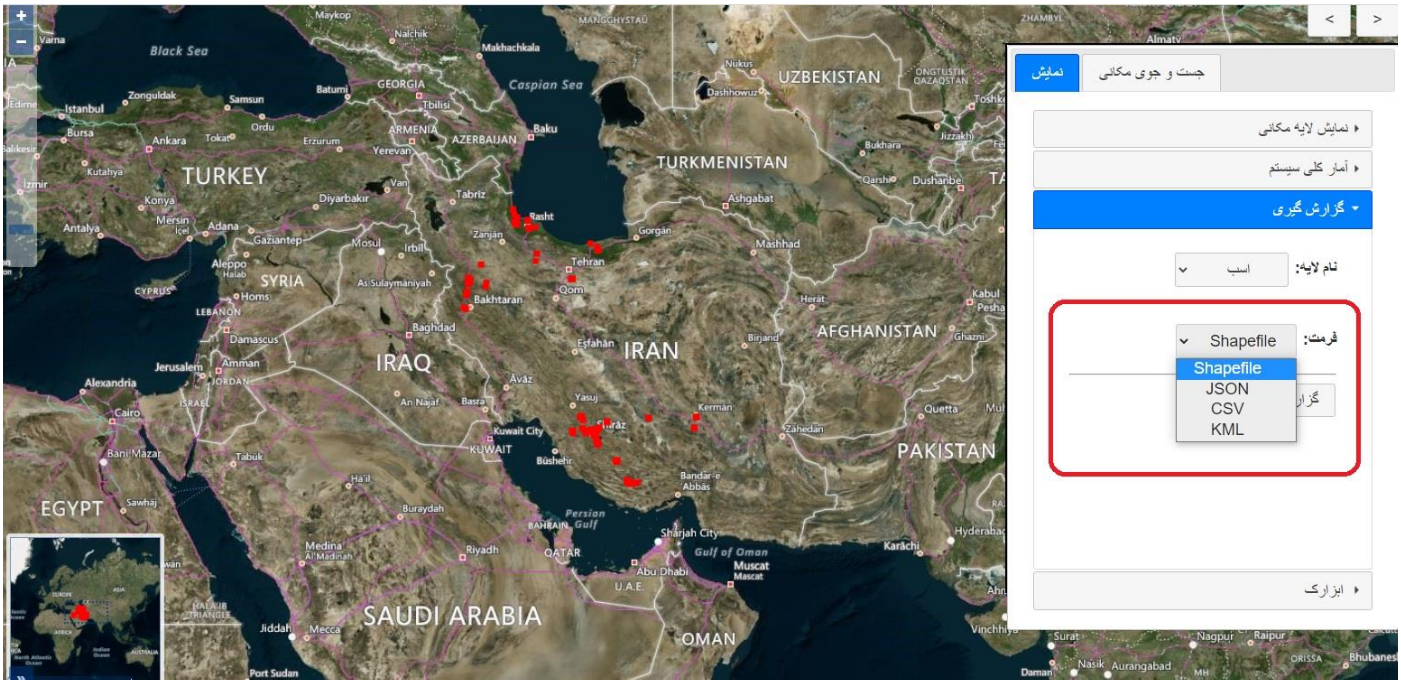


Figure 9. An illustrative screen of data download window

DISCUSSION

Due to the importance of FAnGR, all communities find it necessary to maintain genetic diversity by supporting the indigenous livestock and poultry populations as well as implementing nationally agreed actions and strategies. Despite recent advancements in information technology, Iran still lacks a suitable platform for registering, monitoring, and managing FAnGR-related information. In this work, given the wide diversity of Iranian breeds, an integrated system for managing and monitoring the FAnGR was designed and deployed for the first time in the country. In general, limited studies have been conducted on the application of information systems as well as GIS to manage the FAnGR, which makes it difficult to compare the results of the present study with others. According to the evaluation results, one of the most important advantages of the system is the ease with which it can be used, which encourages system users to use it. The systems should be designed with a user-friendly graphical user interface that can meet all of the users' demands and expectations [25]. It is believed that a good participatory GIS provides tools that enable non-specialist users to execute analytical tasks on par with specialists [31].

In a previous study, a Web-GIS based system was developed to monitor the FAnGR. In this system known as GENMON, users may also evaluate the degree of endangerment of livestock breeds [21]. In agreement with GENMON, our system was developed to meet some requirements of the "FAO Global Program on Genetic Resources for Farm Animals". Compared to the GENMON, which considers the pedigree and socio-economic variables, our developed system contains a variety of biometric and performance variables from various livestock and poultry breeds. In addition, each genetic resource's image, as well as its relevant data, is stored in the system, and the system can export data as a shapfile for additional geographical analysis. One of the most well-known examples of information systems in the field of AnGR management is FAO's Domestic Animal Diversity Information System (DAD-IS). DAD-IS is used as an information and communication tool to implement the strategies for managing the AnGR. Through it, users can access searchable databases of breed-related information and photos and links to other online resources [32]. Although DAD-IS has been considered to be a comprehensive system that provides valuable information and tools, but it does have its limitations when compared to our system offering the feature of storing and managing spatial data. To put it another way, it lacks the ability to geographically query the collections and create dynamic maps for AnGR distribution. The project "Innovative Genetic Resources Management (IMAGE)," which is funded by the European Union's Horizon 2020 Research and Innovation Programme, is an example of a coordinated effort for the management of AnGR. This project intends to provide a European web site that brings together data from animal gene banks and collections around Europe, as well as genomic and geographical data and other associated information. By georeferencing the samples, the initiative uses GIS technology to define the origin of the preserved material [33]. As can be seen, the IMAGE project has some characteristics in common with our system. Technically, both projects employ GIS to manage spatial data on the network, allowing specialists and decision-makers to monitor animal genetic resources on a local level. Another common aspect refers to phenotype data stored on the system including anything from metric performance data. The DAGRIS system is another example of how information technology is being used to manage animal genetic resources. The goal of DAGRIS is to make it easier to collect, organize, and disseminate information about the origin, distribution, diversity, current use, and status of indigenous FAnGR based on historical and current research [34]. In comparison to the system presented in this work, as with DAD-IS, the DAGRIS lacks GIS capabilities for storing and displaying data, and thus does not allow for spatial monitoring.

As previously stated, the findings show that GIS technology plays a critical role in achieving sustainable FAnGR management since it enables well-organized decision-making based on different climates and geographical areas across the country by integrating spatial data with genetic resource data and location-based FAnGR monitoring. Despite the many possibilities of the designed system, there are several limitations in the current study. One of these limitations comes from the unavailability of positioning technology like animal tracking devices (e.g. GPS), which makes tracing the geographical location of FAnGR on the system impossible. The spatial analysis is another source of limitation. To perform spatial analysis, spatial analysis functions need to be specified in the system for managerial and analytical purposes. The system's inability to provide data in the form of breed and demographic graphs is further restriction. An additional issue with the system is its incapability of assisting users with complex queries for the data collections. To overcome some of the system's fundamental constraints, it is necessary to transfer the data in defined formats, particularly shapfile, to GIS software, and a variety of software tools must be used to analyze genetic resource data for various uses.

Regardless of shortcomings discussed here, this GIS-based system has the potential to play an essential role in the monitoring and management of FAnGR information. Although the system does not directly contribute to the conservation of genetic resources, it enables managers and decision makers to monitor the status of livestock and poultry genetic resources in various geographical areas, allowing management strategies (including conservation or management options) to be implemented.

CONCLUSION

The findings of this study demonstrated that FAnGR's geographic information system, which was developed and implemented for the first time in the country, has the potential to be used as an effective tool for managing and monitoring the FAnGR data. The FAnGR may be traced and monitored in a specific geographical location using the system's tools and capabilities, such as spatial querying. The system may also be utilized as a location-based database for domestic livestock and poultry genetic resources.

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Conflicts of Interest: The authors declare no conflict of interest

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