GIS System as a Decision Support Tool for Agricultural Planning in Arid Zones of Spain

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ABSTRACT

The main objective of this work was to analyze the factors involved in rural planning to enable the identification of the important agricultural possibilities and risks related to the province of Almeria, Spain. The most relevant result of this project was the development of a decision support system for agricultural planning. Main stages in the creation of this system were: *(a) Information preparation, (b) Data integration, (c) Construction of GIS tool* (*ESTIARA*SIG*), and *(d) Exploitation of the information stored at the Ministry of Agriculture of the Regional Government of Andalusia, Spain, and its updating at the University of Almeria*

Some examples of the use of the tool concern the determination of the zones with least agricultural resources, identification of optimum areas for the development of intensive agriculture and determination of fire danger areas. Finally, we are developing simulation models and incorporating them into the system. This will enable the modeling of several evolution processes (forest repopulating), resources use (alternatives of water utilization) and diffusion (pollution processes).

Keywords: Geographic Information Systems, Decision Support Systems, Rural Planning, Agricultural Planning

1. INTRODUCTION

The province of Almeria, located in eastern Andalusia, Spain, presents a great diversity and particularity. It contains one of a few European dessert areas.

Water plays the most important role in both natural and economic resources in the province of Almeria. Characterized by typical Mediterranean climate, with high temperatures, very low rainfall records, with few rainy days, but torrential, and a great number of sun hours per year, Almería has one of the topmost aridity levels in Europe. Rivers do not flow along a great period of the year. The drought problem restricts the irrigation in a good part of the province, limiting the cultivation with high hydric needs.

The introduction of forced cultivation has transformed unproductive coastal plains into greenhouses, where early products are obtained. This has introduced a new development model into our zone, causing the abandonment of the mean mountain zones. The underground aquifers are suffering an increasing overexploitation, presenting in some instances salinization problems, with a negative influence on the agricultural production. The control of the exploited underground aquifers is difficult, increasing the difficulties in obtaining accurate information.

This situation, also present in other arid regions, justifies the need of an adequate planning, which requires correctly updated information. Geographic Information Systems (GIS) provide suitable support to manage all the information required for land-use and agricultural planning, (Bosque, 1992 and Yialouris et al., 1995).

A GIS was carried out in the framework of the ESTIARA project, funded by the Ministry of Agriculture and Fishing of the Regional Government of Andalusia. Its objective is to make a detailed and exhaustive analysis of the situation, which allows detecting the main problems that can affect to the province of Almeria. Its final goal is to offer a support tool for decision-making, based on the duly updated objective data (Ayala et al., 1996).

Some research projects related to GIS used in rural planning were previously analyzed and evaluated (Chennamaneni, 1996, Engel et al., 1996, Tiilikkala et al, 1996, Yialouris et al., 1995), helping to design this agricultural planning decision support tool.

2. MATERIAL AND METHODS

2.1 DEVELOPMENT STAGES

This project was divided into several stages, each using a collection of techniques and tools. Quality control was introduced at different critical points of the process, in order to verify the correctness of the information. The different stages were:

(1) Information preparation. It consisted of multiple tasks of socioeconomic and agrarian data collection:

- Determination and collection (in the field over all the territory) of the socioeconomic data (see Table 3). The quality control procedures consisted in checking the correctness of all data.
- Development of the digital cartography, including *thematic layers* (Moldes, 1995) (rivers, underground water resources, water quality, soil types, etc.). In this phase the quality control procedures were complicated, requiring an exhaustive review of some digitized coverages to determine the error introduced.
- Analysis and classification of satellite images, by using thematic layers in vectorial format (Anderson et al., 1972). This process was focused on determining the territorial areas with great influence in water resources management (e.g. areas with plastic covered greenhouses). In this phase, the quality control procedures were simple. We took randomly some zones where the classification indicated the existence of greenhouses, among others, and then we checked their existence.

The main objective of this stage was summarizing and updating all the input information for the decision-making support system. The most important results of this stage were:

* A set of tables relating all the socioeconomic and agrarian information relevant for the decision-making support tool.

- Spatial description of an exhaustive collection of thematic layers within the agronomic environment (see Figure 1). These thematic layers were digitized from topographic maps (scale 1:10,000).
- A collection of maps showing the greenhouses growth evolution, as well as water resources for vegetation zones and urban sites.

2. Data integration. A georelational data model to establish spatial relationships between the graphic entities and the database supporting the thematic layers was built according to Laurini (1992) and Scholl and Voisard (1997). This model links all the agronomic information with the rest of the spatial information, so that detailed queries could be accomplished. We have obtained a schema for information representation, which guarantees its integrity and consistency.

3. Building the ESTIARA*SIG exploitation tool, as an open, dynamical and consistent query system, that could be applied to other arid zones. The most important feature of this tool is that the user can easily generate his reports that help to make appropriate agronomic decisions. The structure of the reports can be predefined or user made. In this phase, the quality control procedures consisted in a test set to verify its correct operation, and its ability to meet the user's requirements.

4. Exploitation of the information at the Ministry of Agriculture and Fishing of the Regional Government of Andalusia, and its updating at the University of Almeria.

2.2. METHODOLOGY AND TOOLS

The techniques used at each stage are shown in Table 1:

Table 1. Techniques used in the development stages

Stage	***Used Techniques***
1. Information preparation:	
➢ Collection of the socioeconomic data	Field data collecting and bibliographic work. These data were introduced in a database using a database management system to control the quality of the supplied information.
➢ Development of the digital cartography	This process was accomplished by means of point-to-point digitizing.
➢ Classification of satellite images	The classification process was carried out by using the rule of the minimal distance, which permits to obtain very good results, especially in arid zones.
2. Data integration	The technique used for generating this model consisted in defining virtual tables, which permits to both the agronomic and spatial information.
3. Building of exploitation tool (ESTIARA*SIG)	Templates were used to develop exploitation functions in a rapid and simple way.

Table 2 shows the set of tools used at each stage, justifying its use by comparing with other alternative tools.

Table 2. Tools used in the development stages.

Stage	Used tools	Justification	Alternative Tools
1. Information preparation:			
• Collection of socioeconomic data	dBase IV /Excel 97	DBase IV is a relational database system that permits to organize all the thematic layers according to a conventional data model. It can be imported by ESTIARA*SIG.	Microsoft Access 97
• Development of digital cartography	AutoCAD Ver.13	AutoCAD is the world most used computer-aided design system. It permits to accomplish a point-to-point digitizing. It generates an easily exportable cartography.	MicroStation
• Classification of satellite images	Erdas Ver. 8.3	Erdas allows importing directly the spatial coverages coming from ArcInfo to superpose them with the satellite images. It allows to classify the greater interest zones that cover the project objectives.	EASI/PACE
• Data integration	ArcView Ver. 3.0	ArcView permits to manage the interrelated information from various formats by creating of virtual tables.	IDL Soft Vision
• Building of ESTIARA*SIG tool	Avenue Ver. 3.0	Avenue is an object-oriented programming language, incorporated in ArcView, which allows the development of the predetermined functions of the application.	Borland C++ 5

2.3. MANAGED INFORMATION

All the collected and processed information is stored in a database, allowing to establish relationships among the different data formats. The information can be classified into several groups:

(a) *Alphanumeric Information*

The agrarian socioeconomic information is summarized in Table 3.

Table 3. Socioeconomic and agrarian information support the system of development

• *Soil attributes*	Representation of all the characteristics of the different types of soils existing in the province of Almeria.
• *Agrarian census*	Number of farms, terrain distribution, and cultivable area.
• *Marketing centers*	Information of the most relevant marketing centers, specifying infrastructures and other information (products, prices, and other).
• *Regions*	Limits and municipalities of the different agrarian regions.
• *Bioclimatic conditions*	Monthly weather information (temperature, rain, humidity) by month, for the different municipalities.

• *Economy: Agricultural expenses*	Structure of the expenses accomplished on the farms (transformation, plants, and installation expenses).
• *Economy: Agricultural investments*	Structure of the investments made on farms (land purchase, irrigation, wind shields, greenhouses construction and other).
• *Economy: Agricultural revenues*	Structure of the revenues obtained on farms, classified by production and modality.
• *Dams*	Location of dams, including capacity and surface specification.
• *Cattle exploitations*	Description of the type of cattle, censuses, wages, expenses in food and veterinary.
• *Water springs*	Spatial location of the most relevant water springs, specifying its description and wealth.
• *Greenhouses: Typologies*	Concrete analysis of the typologies and uses of the existing greenhouses.
• *Greenhouses: Technological levels*	Information of the most relevant aspects related to the technological advances in the design and construction of automated greenhouses.
• *Municipalities*	Data from the 103 municipalities of the province of Almeria (limits, agrarian region, description, spatial location)
• *Unemployment: Distribution by age*	Analysis of the existing unemployment rate by municipality and its distribution by age.
• *Unemployment: Distribution by groups*	Analysis of the existing unemployment rate by municipality and its distribution among the different work groups in the area of the agronomic planning.
• *Population*	Structure of the population and agrarian occupation.
• *Wells*	Spatial location of the province wells, including the wealth, depth and an exhaustive analysis of all the indexes that control the of water quality.
• *Irrigation systems*	Description of the different pipeline networks for irrigation of different cultivation, classified by capacity.
• *Subsidies*	Information of subsidies to the local agricultural field: olive oil, cereals, dry fruits, sheep and goats, agrarian structures, trellis.
• *Subsidies: Regional Government Employment*	Information of subsidies coming from the outstanding plan for rural employment.
• *Subsidies: Reforestation*	Description of the helps received for the reforestation process of zones that suffer forest fires, among other.
• *Surfaces: Cultivation*	Distribution of the province agrarian surface according to the different types of existing cultivation.
• *Surfaces: Mountains*	Surface property of the Board of Andalusia; mountain surface (public, private or commonwealth).
• *Technology of the exploitations*	Technological level of the exploitations, emphasizing the number of hectares and the irrigation surface located with and without automatic fertirrigation
• *Abandoned lands*	Lands not cultivated in the last 20 years. Economic uses of rural space

(b) *Vectorial Information*

The digital cartography developed for this project includes the thematic layers shown in Table 4.

Table 4. Digital entities of the geographical information system

• *Municipalities*	• *District roads*	• *Roads*
• *Population groups*	• *Local roads*	• *River basins*
• *Highways*	• *Tracks*	• *Contour lines*
• *National roads*	• *Paths*	• *Soil classification*

Figure 1 shows the representation in thematic layers of all the vectorial information. These levels, when introduced in this decision-making support system are converted into *thematic layers*, representing a specific type of elements of the real world (Moldes, 1995).

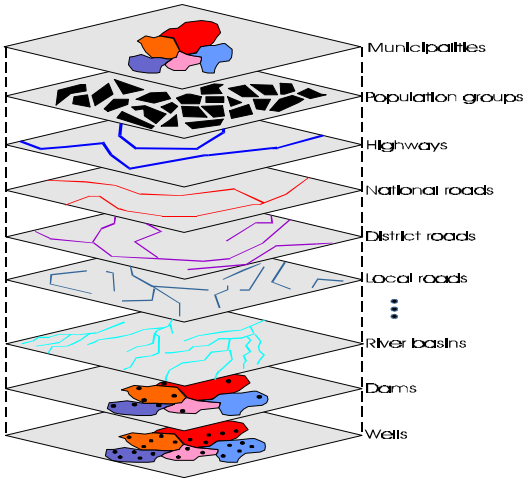

Figure 1. Thematic layers in ESTIARA*GIS

(c) *Raster information*

The system allows to establish spatial relationships with entities in GRID format. The results of the treatment of two Landsat images were incorporated with a spatial resolution of 20x20 meters for all bands (the thermal one that has a spatial resolution of 120x120 meters).

The most important results generated by the analysis of these images incorporated to the system are the classification of vegetation zones, burnt-out zones, populated spaces and cultivation under plastic.

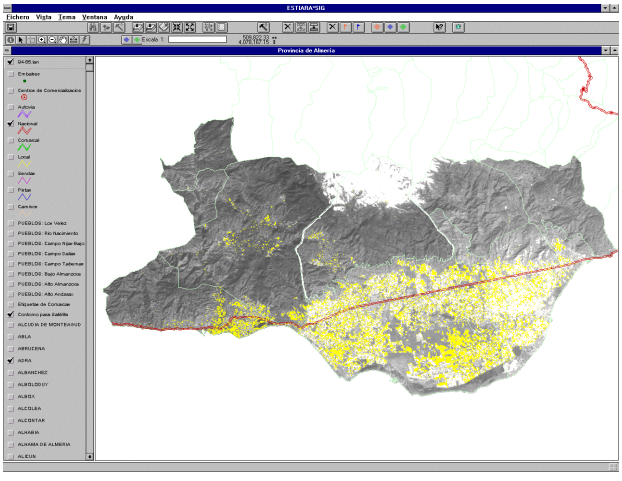

Figure 2. Greenhouses classification

This process focuses on the zones related to the control of the water resources. Figure 2 shows an example of one of the accomplished classifications (greenhouse surface in one of the agrarian regions).

(d) *Photographs*

This information is incorporated in the GIS as a complement associated with any spatial element.

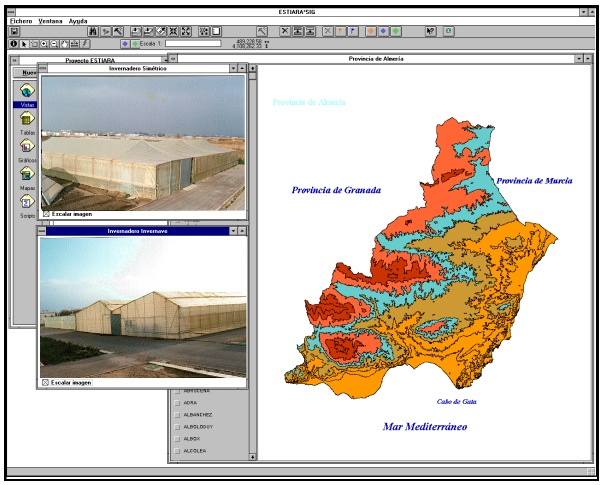

Figure 3. Example of greenhouses types

Photographs of some greenhouses are included. Some examples of the use of the photographic images are: displaying the trace of an interesting highway; aerial photograph sequence of a city, photographs of the types of greenhouses built in a given zone, or their type of cultivation.

Figure 3 shows an example of the most important greenhouses types in the province.

3. RESULTS

The system permits to generate some reports to support decision-making in agronomic planning in a rapid and simple way. One of the principal features of the tool is a flexible user interface to generate new queries linking socioeconomic and agrarian information.

The tool allows generating a wide range of results that eases the process of the decision-making in a strongly changing environment. This system has a set of utilities that link all the socioeconomic and geographical information included in the database. A very summarized description of the different utilities, emphasized on the results that generate, is the following:

- *Views:* Interactive maps that permit to visualize, explore, consult and analyze geographical data and the associated thematic information. This utility permits to display all the (agrarian) information related to the province of Almeria and their relationship with the digitized information.
- *Predefined queries:* They allow to select and show (as sets of tables) both economic and agrarian information related to a determined spatial entity or group of entities.
- *Maps:* This utility permits to include views, report results generated by the user, graphic results of a query, as well as the selected agrarian information of all the alphanumeric data.
- *Graphs:* Dynamic representations with several graphic formats of the results obtained with a query. This information is interrelated with all the thematic layers of the system, and it permits to design a set of templates for information representation.

These utilities allow to generate a very wide set of reports that ease the process of decision-making in rural planning in a simple way. The results can be generated from a wide combination of the different features the tool presents; for example, views can be combined with predefined queries to generate graphics showing unforeseen correlations. On the other hand, all the reports generated from document combinations can be easily printed in detailed maps.

It is quite difficult to estimate the whole volume of output reports the tool allows to generate, taking into account the great range of possible combinations that can be made with the system information and features. Nevertheless, an approximate estimation based on the

reports for agricultural planning which are now being made in the province of Almeria can be given. This volume makes possible to determine fundamentally:

- Plastic covered cultivation surfaces
- Territorial zones with technological delay
- Territorial spaces with greater water deficit
- Zones with water resources with greater quality for irrigation and human consumption
- Control of the production management
- Control of the number of farms
- Natural hazard forecasts
- Others

Four examples of the results generated by this tool are shown. The first one is a view of the man population distribution by age and the chart of monthly temperature for a certain municipality (Figure 4). The second example shows a map with bioclimatic conditions information (table format), monthly rainfalls (charts) and the vectorial representation with the selected municipality highlighted (Figure 5). The third example shows the influence area affected by works on a street of an urban zone in the province of Almeria (Figure 6). This result is of great importance to evaluate the expropriation process of territorial zones in the building of this road. The last example shows the spatial location of the set of wells of a district selected with a predefined query (Figure 7).

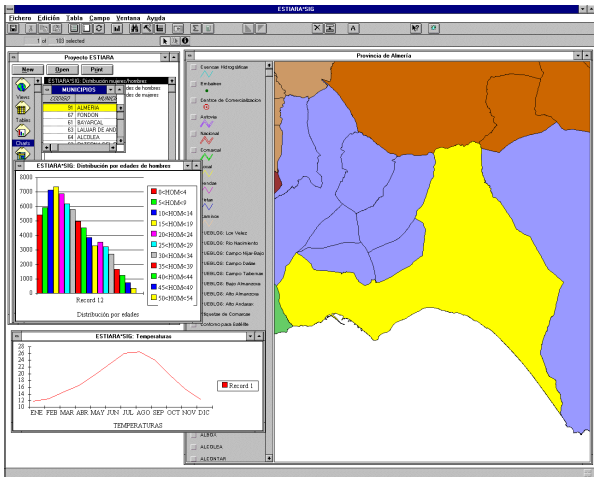

Figure 4. Example of tables for a municipality selected in ESTIARA*SIG

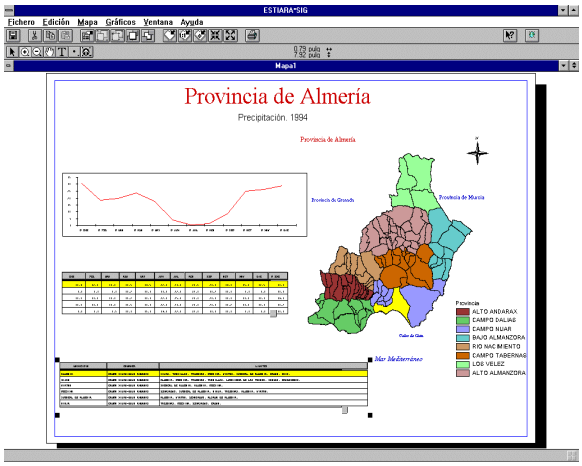

Figure 5. Example of map in ESTIARA*SIG

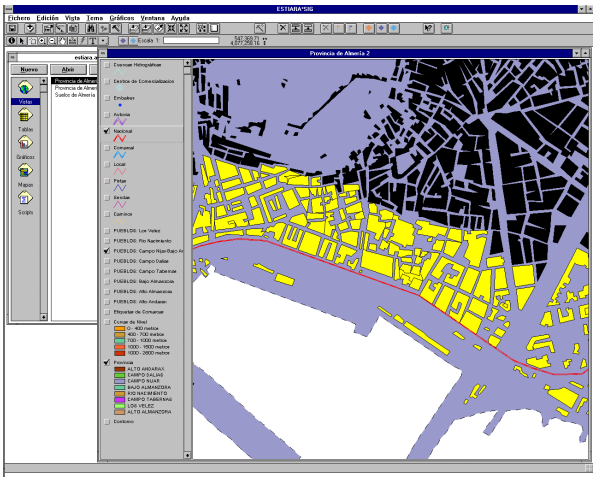

Figure 6. Example of influence analysis

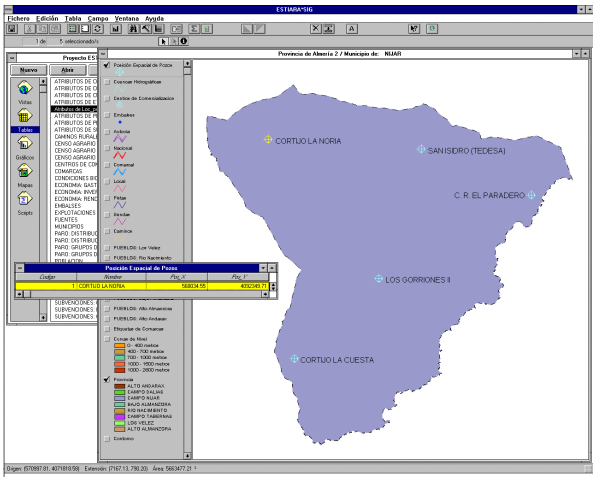

Figure 7. Spatial location of wells

Finally, we show the results of the analyzed satellite images. We have used two Landsat images to evaluate the greenhouse evolution from 1985 to 1994, incorporated into ESTIARA*SIG and shown in Figures 8 and 9. Comparing Figures 8 and 9, there is a significant increase of the greenhouse area. In 1985, there were 13,000 hectares and in 1994, there were about 20,000 hectares for the studied area (only a part of the province).

Figures 8 and 9. Satellite images of the southwest coast of Almeria.
The greenhouse covered areas are highlighted in blue (1985 - 1994).

4. CONCLUSIONS

The following conclusions can be drawn:

- The use of decision support tools based on Geographical Information Systems is of great interest in the field of rural planning. This is specially important in regions where the main wealth source is agriculture. These tools can facilitate to take advantage of the development opportunities and foresee the risks.

- It is possible to develop a specific tool for arid and semi-arid regions taking into account their specific characteristics. ESTIARA*SIG has been implemented in the province of Almeria as a flexible tool in rural development. The tool has certain characteristics (interrelate agrarian and spatial information, predefined queries, easy use of data) that allow exhaustive analysis. These analyses include the location of depressed zones in economic and agricultural development, or the classification of zones in danger of forest fires, or the evaluation of the surface for new crops in this province.

- The tool, ESTIARA*SIG, allows to obtain a wide set of reports, which can be obtained by the users directly from a set of predefined options. In addition, the users can elaborate new reports combining simple items with fully different relationships and formats. This feature provides an enhanced flexibility.

- The structure of ESTIARA*SIG is general. It can be applied on any other arid or semiarid region, loading the data and easily adapting parameters and tables.

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