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Potential of Geographic Information Systems to Create a Municipal Environmental Model

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ABSTRACT

Geographic information systems are used internationally to acquire information about the characteristics of the global surface and digitalize it to facilitate georeferencing, statistical analysis, virtual scenarios and mitigation of disasters. In Cuba, they are inserted in the design of Environmental Models, along with other applications. The aim of this paper was to demonstrate the potential offered by Geographic Information Systems to establish an Environmental Model in the municipality of Camaguey, based on previous studies made in other municipalities of Cuba. Moreover, the main elements supporting this study were defined. This paper also deals with the different stages of Environmental Modeling, and how the Geographic Information Systems are included, based on the views from different researchers and specialists.

KEY WORDS: geographic information system, environmental modeling, georeferencing

INTRODUCTION

Since long ago, humanity has expressed concerns about the environment. Then, people began to make the first cartographic designs on the walls of caves, based on rough and sometimes incoherent representations of how to locate the surrounding resources, like water, prey animals, and fruits. Also, their sizes and ways to exploit them, as well as the occurrence of natural events in their territories.

Overtime, the methods and cartographic means that represented natural resources and their use also changed. The goal was to make a more practical understanding, efficient use, and conditions of resources. Consequently, the idea of drawing on cave walls was abandoned, and new platforms, like wood, paper, and more recently, computers, were used.

Today, setting up new structures that help understand the very complex dynamics existing among nature´s elements in a particular territory, and their coexistence with human development, is a relevant endeavor. Accordingly, Territorial Organization and Environmental Models have appeared as a need to quantify natural resources, assess their existence and use potential, without affecting the resource´s recovery speed or altering the natural balance. Also, production and social sectors must be in concert with preservation and

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sustainable use of the existing raw materials, or the services offered by the ecosystem (Domínguez and Madrigal, 2008; Cárdenas, 2014; Primelles, 2014).
In the digital era, model analyses have gained remarkable efficiency. State of the art technology, like computers, satellites, GPS, and field work, are invaluable tools to perform more accurate and reliable studies. All of it is integrated in the Geographic Information System (GIS), which complements Teledetection.
Integration of GIS in different methodological aspects that contain local and environmental models in Cuba, have contributed to studies of this kind both at the national and municipal levels, with high accuracy.
The aim of this paper is to demonstrate the advantages and significance of Geographic information Systems to design the Environmental Model of the municipality of Camaguey, by submitting solid evidence and preceding models, to implement modern technologies in environmental studies.
Accordingly, the theory and previous practice about this topic have been used in this study (e.g. model design in the municipality of Jimaguayu) (Primelles 2013).

DEVELOPMENT

Definition and components of the Geographic Information Systems (GIS).

Authors like Pineda and Franco (2008) have defined GIS as a system of hardware, software and procedures designed to support capture, handling, manipulation, analysis, modeling and deployment of specially referred data (georeferenced), to address complex management and local planning issues.
The main purpose is to gather information and store georeferenced data, using Teledetection of the land surface to produce geographic information that can be used in consultations, analyses, theme cartography, and decision making.
The origin and evolution of GIS is closely related to the history of Cartography. Approximately 15 000 years ago, the primitive men made graphic representations of the animals they hunted, on the walls of their caves, drawing lines telling the possible trajectories of herd migrations.
Another example was presented in 1854, when Dr. John Snow represented on a map the incidence of cholera cases in the Soho district, London (Cerda and Valdivia, 2007), perhaps the first cartographic analysis of the extension of an event that was affecting the population.
In the 1960s of the Twentieth Century, cartographic applications made for different purposes gained extraordinary momentum. The Canadian Geographic Information System was developed by Roger Tomlison, and was used to store, analyze, and manipulate data gathered for the Canadian Inventory of Lands. It contained cartographic information related to soil types and uses, agriculture, recreational areas, wildlife, aquatic birds, and forestry (scale 1:50). The novelty of the system was a classification factor to allow for information analysis.
During the second half of the last century, space satellites contributed to remote teledetection, making a huge advance globally. The instruments of several ground observatories and weather platforms, like Landsat, Nimbus, RADARSAT and UARS offered the world all kinds of information (civilian,

military and research purposes) to scientists and specialists. Space probes sent to other planets have also offered the opportunity to conduct remote teledetection studies in outer space environments.
GIS generalization was slow in third world countries for many years, because it was associated with technological development. It was introduced in the late eighties, thanks to lower computer prices and the recent appearance of powerful software with different features and goals.
In the late 1980s and early 1990s, works started in Cuba to digitalize large volumes of information related to the environment and the resources. In the second half of the 1990s, it was introduced in Camaguey, particularly associated with the protection of natural resources and local cartography.
Today, many sciences and branches from the economy benefit directly from that technology.
Accurate agriculture: It provides a detailed study of croplands or potential croplands, mapping of distribution and impact of pests and diseases, levels of production and crop destination.
Meteorology: it offers atmospheric temperature profiles, pressure maps, water vapor contents, wind velocity, prediction of hurricanes.
Oceanography: it helps with studies of surface ocean temperatures, oceanic streams, wave speed and height, tides, detection of tsunamis.
Geology and Geomorphology: identification of geotechnical profiles, fault location and tectonic displacements, determination of minerals, springs, ground water, etc.
Topography and Cartography: Generation of detailed maps of the earth´s surface.
Zoology: It facilitates animal inventories, migrations and distribution.
Forestry Engineering: The study of plant coverage types and sanitary state, pest identification, soil usage maps, fire vulnerability.
Environment and control of catastrophic natural phenomena: It is closely related to some of the above mentioned disciplines, like storm advice, seismic activity, avalanches, floods, and contamination control.

Environmental Organization (EO) and Environmental Modeling (EM).

Local Environmental Organization is an environmental policy tool, that may be characterized as a mechanism of command and control, as it is enforced by direct binding regulations from the government, whose goal is to structure activities spatially in a given location.
The Environmental Organization is also a planning process and a tool for environmental management, expressed in a model that includes zoning of a territory into environmental units, environmental guidelines (defined as goals or desirable state of each area and its natural resources), and environmental strategies, that must be considered in the local organization plans.
The Cuban environmental law (No. 81) specifies that environmental organization must ensure sustainable environmental development of the location, based on whole analysis of biotic and abiotic resources and the

socioeconomic factors, providing environmental standards, regulations and guidelines for management.

The models rely on transformation of basic variables into dynamic variables, allowing for joint global control. Used in concert with other variables, they will offer explanations of different process that take place in the location, depending on the structuring topic dealt with.

Interactions characterizing the conformation of geosystems and their behavior This part is presented through critical paths and concept models of analyses introduced in GIS, making possible the system´s (or ecosystem´s) entry, correlation and exit stages. It also generates concepts integrated dynamically in a cause-effect relationship.

EMs can contribute largely to local sustainable development, relying on their physical, biotic and social and economic features, and the participation of representatives from every economic sector, the people, and governments. It helps identify use limitations; potential for development; existing conflicts; and environmental issues, in order to submit policies, environmentally recommended uses, guidelines, regulations and environmental standards. Certainly, it is a contribution to the local government and other decision makers, as they could plan development on solid and sound grounds (Martínez *et al.*, 2013).

To many researchers, environmental models have been conceived as a projection within local environmental policies (Primelles, 2014). It ensures the relationship between the availability of resources in a location and the establishment of policies or actions that condition their sustainable exploitation or preservation.

Common stages of EMs

Usually, an EM is developed through four stages, according to Primelles Fariñas (2014).

Labor organization: It deals with setting up working teams, defining the legal and theoretical framework, demarcating the area in the study and determination of work scale, the starting workshop and the definition of tasks and work schedule.

Characterization: Inventory of local resources is made, they are characterized, and their level of preservation is evaluated.

Diagnostic: The local resource potential is determined, along with possible conflicts, limitations for resource management, and identification of environmental issues.

Propositional: Where the model is placed, policies and guidelines are established, planned actions are implemented.

Other authors claim the establishment of a last stage: interaction with Local Organization, in which the working results are approved by the corresponding Administration Council. There is integration to Local Organization and proper monitoring and corrections are made (Cárdenas, 2014).

Integration potential of GIS and the municipal EMs

Based on previous studies (Pineda and Franco, 2008; Cárdenas, 2014; and Cánovas, 2015) that integrate GIS with construction, planning, and later implementation and evaluation of EMs in Jimaguayu, Camaguey, assessment was made to determine the feasibility of technology application in similar studies in Camaguey.

The possible goals of EM for the municipality of Camaguey are,

- Make sound proposals for location and identification of social and economic activities associated to several sectors of production, emphasizing on the services sector, taking into account the natural resources and limitations of the region; as well as adaptation to climatic change and risks of disasters.
- Integration of the model results to the local organization process, and social and economic projection of development based on sustainable grounds, with the application of environmental policies and guidelines.
- Decrease or elimination of the negative environmental impact produced by social and economic activities. Recommend relocation to more suitable places, and incorporate new environmentally friendly actions to make optimum use of natural resources and services, preserving the ecological balance.
- Minimization or eradication of vulnerabilities against natural disasters, and prevention the appearance of new weaknesses.
- Protection and restoration of the natural values and the material and immaterial heritage.

One of the main actions of GIS in relation to EM is the relationship set up between the analogue data gathered during the field work and their respective elements that make up the digital systems, either statistical, or graphic databases.

GIS contributes to new scenarios by measuring and choosing development alternatives, information management for risk mitigation, adaptation to climatic change, food safety indexes, human settlement and population system accounting. Furthermore, the integration of GIS and EM not only offers an enhanced approach of local and environmental organization, but also fosters improved analysis of integrated management of water basins, land sustainability and use, the ecological impact caused by production forms, like human actions to make use of certain resources or services from nature, and even, the transformation of the local ecological balance.

The geographic location, costs, geology, relieve, climate, hydrography, soils, flora, fauna, population, economy, environmental conditions, and landscape, are some of the areas for GIS and EM integration in the municipality of Camaguey. It must be assumed that each of those elements require digitalized maps that include the existence and use of resources, as well as vulnerabilities and risks. It is made in accordance to the previously recommended EM stages, in which GISs are integrated as a tool to make analyses more efficient and dynamic.

Camaguey is the third most inhabited municipality in Cuba, with a vast urban area and highly complex design, so the risk conditions and vulnerabilities are remarkably increased. There are large urban areas with risks of extreme floods.

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The city is settled in a relatively high area, vulnerable to droughts and adequate water supply, a high percentage of water access is through wells spread throughout the city. Therefore, the climatic conditions must be studied closely, in order to prevent negative impacts not only on the population and industry, but also on other natural elements located in the region.

In that sense, GIS facilitates the integration of maps with water basins, river and dam systems, availability of ground water, supply networks, and risk areas due to floods or droughts. It leads to the adoption of policies and actions to manage water and prevent disasters. That will also include climate maps that include the behavior of variables (temperatures and rainfall).

Another important element to consider is the distribution of municipal contaminating sources, and the quantification of the contaminating load deposited, such as, gas emissions and suspension particles from industries, untreated wastewater, solid wastes and their final destination. Also included is the emergence of pathologies associated to air and water quality, location and infestation degree of insects and rodents.

Camaguey is the most developed municipality in the province, but it is also the most complex territory, so the application of GIS is important to achieve proper EM planning, to carry out assessment of the economic potential and the need for resources for sustainable management. Moreover, it is important to consider the evolution or presence of climate change issues, decline of risks and vulnerabilities, sustainable development, and agriculture conservation and precision.

Hence, the integration of maps that can show the location of contaminating sources, the predominant direction of winds, direction of water drainage and infiltration speed, determination of existence or location of vectors that threat human health, and different types of contamination. It makes possible to relocate some contaminant sources, strategic construction of water treatment for human consumption and residual treatment, as well as to establish ways of action to manage all kinds of wastes, based on governmental policies.

Below are some examples of maps of the municipality, created through MapInfo software, showing GIS potential at different stages of local EM creation.

Relieve map (Figure 1): It helps with analysis of height and composition of local relieve, including slopes, erosion, sediment accumulation studies. It is useful to perform construction project of any kind.

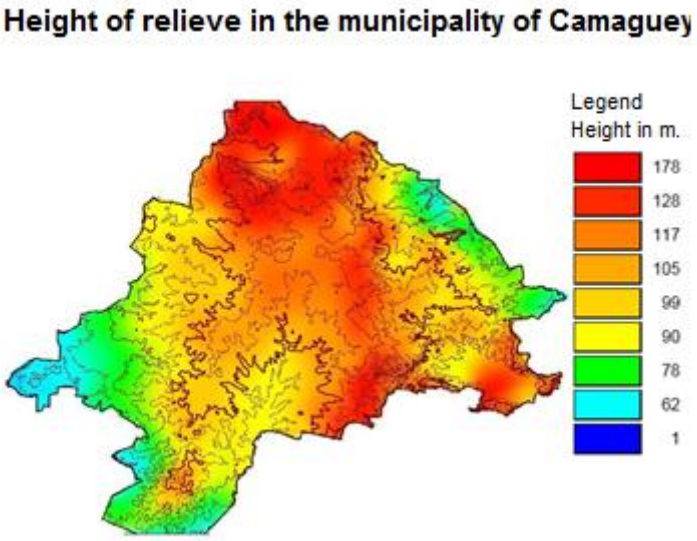

Figure 1: Relieve map of the municipality of Camaguey
Source: Self-made

Hydrographic map (Figure 2): It allows analysis of surface water availability, the areas containing it, population using it, direction of courses and volumes, and accumulated water according to seasons. It also helps with area analysis of the main basins, their volume, management and protection, plus the social and industrial sectors that they cover.

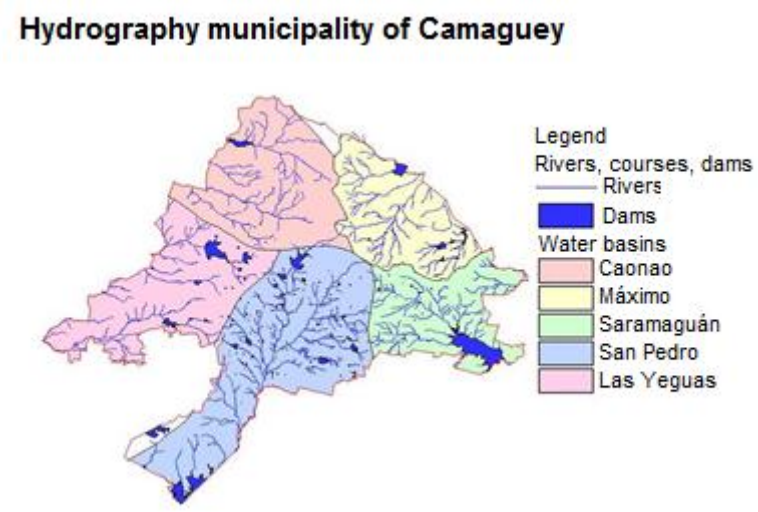

Figure 2: Hydrography map of the municipality of Camaguey
Source: Self-made

Soil map (Figure 3): The information provides knowledge about soils. Once completed, this map can help determine the fertility degree, depth, compression, acidity, salinity, and minerals in it.

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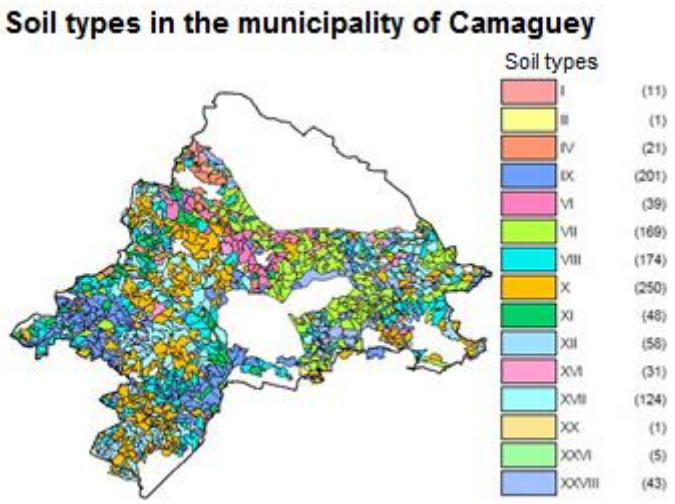

Figure 3: Soil map of the municipality of Camaguey
Source: Self-made

Map of vegetation (Figure 4): It helps gather information about the types of local plants. It can be highly specialized, because it contains data about the species, features and distribution. In some cases, crops are included. It is useful to determinee the ecological impact caused by natural or events, or humans.

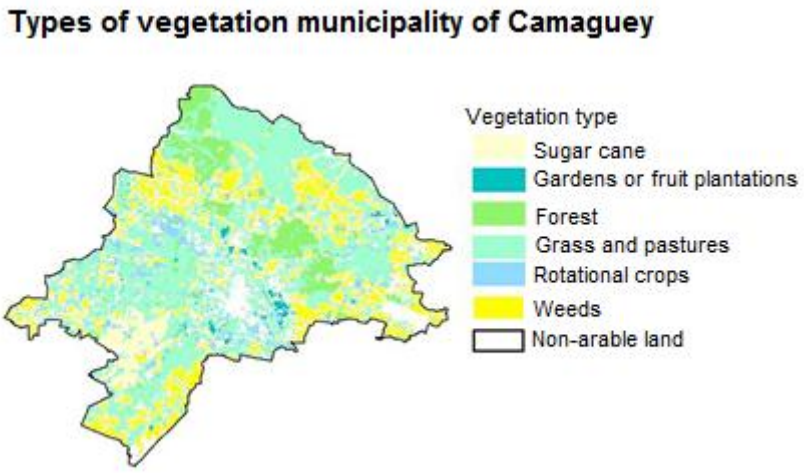

Figure 4: Map of vegetation of the municipality of Camaguey
Source: Self-made

Map of communication ways (Figure 5): It facilitates the study of goods and people transportation, strategic or economic accesses, and connected infrastructure. Additionally, strategies can be designed to connect areas where no road communication exists.

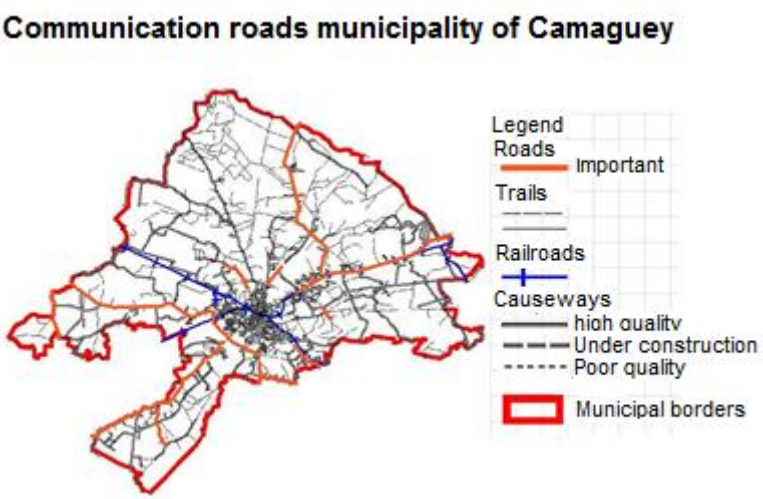

Figure 5: Map of the main communication ways
Source: Self-made

Map of cartographic sheets, scale 1:25 000 (Figure 6): It provides a thorough and detailed surface study (relieve, crops, hydrography, population, infrastructure of different kinds, etc.). All the information is georeferenced, so the maps are very accurate, and the scale type favors little generalizations.

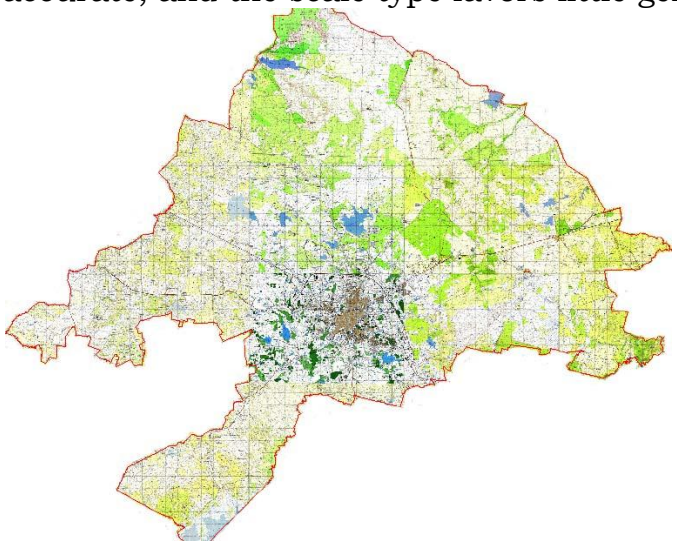

Figure 6: Map based on cartographic sheet, scale 1:25000.
Source: Self-made

As mentioned above, overlapping of the information found in GIS maps offers several possibilities related to the EM stages. The information can be used as a way to input data and produce outputs. Moreover, they also allow for modeling of virtual environments, by changing some patterns and checking the possible results theoretically, almost immediately. Consequently, errors produced due to adverse effects caused by certain actions on the land can be reduced.

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CONCLUSIONS

The Environmental Model for the municipality of Camaguey is a process that increases knowledge of the local environmental potential, and alerts on possible vulnerabilities, socially and in terms of ecosystem stability. It encourages the establishment of policies and guidelines to achieve sustainable development, as well as preservation and restoration of environmental values, and the material and immaterial heritage of the municipality.

GIS and Teledetection guarantee georeferenced data gathering that permits evaluation of resources, local processes and events. It also contributes to risk prevention of any kind, through modeling of virtual scenarios that might occur, actually. Furthermore, the most detailed and updated information about every factor and variable can be accessed, with a direct repercussion on the efficacy of Environmental Modeling.

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