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Advanced spatial analysis and visualization using GIS and digital mapping technologies

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Abstract: Maps have always been essential for representing diverse places and phenomena, evolving from paper to digital formats with technological advancements. Geographic Information Systems (GIS) enhance this by offering precise, digitized spatial data analysis, crucial for solving environmental and social challenges. Integrating surveys, computation, mathematics, and statistics, GIS converts geographic data into digital formats, facilitating accurate, efficient data management and analysis. This technology is invaluable for public services and infrastructure development, providing easy-to-use tools with quick outputs, addressing economic and environmental concerns. The science of cartographic modeling simplifies complex phenomena, aiding in the creation of accurate, testable hypotheses and spatial analyses. Modern GIS applications, like ArcGIS, enable thematic mapping and data manipulation, crucial for visualizing spatial patterns and relationships. This integration of GIS and information technology results in high-quality, realistic simulations, significantly impacting spatial studies and practical problem-solving.

Keywords: Digital Mapping, GIS, Cartography, Sample.

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1. Introduction

The information revolution has significantly transformed the methods used by geographers and specialists in producing geographical maps across various topics. This revolution introduced the concept of digital or computer-based maps, which rely on high-precision, user-friendly programs that are relatively easy to learn. However, users need a strong scientific foundation, particularly in surveying sciences and statistical mathematical operations, to handle these programs accurately.

Digital maps contain natural and human phenomena that need to be captured such that they closely model real life without any deviation. These applications rely on input from recorded data in terms of images, satellite visual aids, or existing maps used by service departments for their work. Very often, different images will vary noticeably. As such the sources need to be correctly geographically using certain computer steps, and program modules for the geographical correction process to be conducted. This way, a model corresponding to the coordinates of the extent of the study area can be done so that required corrections FILE on the model.

2. Method

Digital Cartography and Geographic Information Systems

Geographic information systems, on the other hand, can be defined as computer systems that are problem-solving, information storage, answering questions, analyzing phenomena, and the presentation of oriented information systems through GIS, through geographical information or those carrying information that is geographically integrated. This means GIS can exist as a container or store of data and/or a device for the treatment of geographical data. GIS helps in converting geographic data into digital format. This digitized data is considerably challenging to be brought out using conventional manual methods of a high degree of effort, resources, and time. Environmental Research and Systems Institute, in its uniqueness, defines them as "systems that form a coherent complex, including computer components, programs, databases, and trained individuals who utilize computer equipment and software to process and analyze spatial information in digital form." This is a complex with accurate inventories of information-spatial and non-spatial-with capabilities for storage, updating, processing, analysis, and presentation. This concept is as illustrated in Figure 1 below.

Benefits of GIS

GIS stands for Geographic Information Systems; it helps a lot in organizing whatever surrounds us. It has significantly impacted public service projects and service infrastructure development. Some important advantages among many of GIS are:

Figure 1. Elements of Geographic Information Systems.

1. Easy to use and with quick outputs for all.
2. Possible economic and environmental concerns, and service infrastructure solutions.
3. Very accurate output.
4. The capability to design programs using technology and culturally evolving tools.
5. Cartographic, testing, and monitoring environmental and social change improve mapping and modeling.

Other than the other advantages, this technology is also referred to as 'critical' in science as well as human studies. The electronic devices are reasonably affordable to obtain, accessible at a minimized cost. Additionally, GIS techniques along with their applications are quickly accessible. In the same way, the spatial data is readily obtainable via the Internet or by accessing the high specification and accurate satellite images and videos.

Applications of GIS

All these high-level methods and technologies of discovery and invention, therefore, are oriented to the utmost precision in arriving at solutions and proposals that can reduce the problems humans and their existence, therefore, are directed towards improvement of life in the universe through environmental and social change minimization and reduction of negative effects." The confluence can be seen in GIS methods and tools through practical solutions derived since the essential requirements for the application of GIS are mapping and data collection as follows:

- Data availability: preferably current and accurate.
- Representing Data in Maps.
- Making changes and adding updates.
- Finding solutions based on output results.

Local governments use this technology to address economic, environmental, and urban challenges as well as to provide services related to housing, health, security, commerce, and transportation.

Cartographic modeling

A model can be defined as "a simplification of reality that puts forward a testable and examinable hypothesis" [1]. It is an "approximate representation of the structure of the relationships and interactions present in the environment of the studied phenomena" [2]. In other words, a model is a simplified view of reality with minimal complication, taking into account all relevant natural and human-related phenomena and describing them in an easily comprehensive manner.

From the above, it's apparent that the geographer depicts all realities, cherry-ripe on paper, in a miniature, simplified form, which is an adjustment and processing of all the rest to emerge as visually and intelligibly, arbitrary results and proposals. The map is presented in two dimensions but can be rendered in three dimensions for more clarity and realism using the following model:

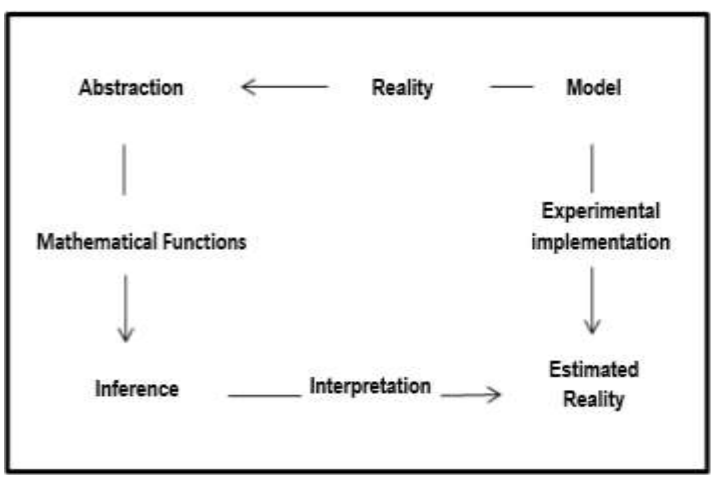

Figure 2. Construction and Utilization of the Cartographic Model (Al-Mousawi, 1993, p.8)

From the above, the use of a model provides an easy way of representation, monitoring, control, and understanding phenomena sans the complexity. It empowers students to solve problems using the formulation of proposals and derivation of results that are accurate. The model does not attempt to provide a representation of all characteristics of a phenomenon but the key characteristics that define the phenomenon, thus helping to abridge understanding [3].

Reasons for Creating a Model and Key Principles for Its Development

There is a clear difference among thinkers regarding the foundations, constants, and reasons for creating a model. However, they agree on identifying the main, non-negotiable causes necessary for model development. The participant initially creates a preliminary prototype and tests it to determine its acceptability. Following this, corrections and adjustments are made before finalizing the model.

Principles of building the model

It is one of the essential features of a good model to represent its extremely high degree of accuracy, consistency, and correctness. No matter how much preciseness the predictions for the future solutions hold for the model, it presents with no margins of error [4]. It is simply necessary to account for the basic steps in the application. As the problems and expectations appearing while using the mathematical equations and its scientific–practical application will usually bring the outcomes in a more accurate manner, it would mean the complete conceptualization of the model should be accounted for before finalization, as vision may vary from one researcher to another. Each case has its specificity and reasons, which must be deeply accounted for, clearly and understandably defined. Model simplifies the phenomenon in a clear and acceptable way, but sometimes this simplification may distort the phenomenon, which is hidden behind the model and is unclear from it. This issue needs to be accounted for to avoid the wrong diagnostic of the problems for which the solutions are made on the model. Accurate measurements must be found and applied to the phenomenon as represented in the model to prevent a mismatch between the two and avoid misconceptions in the formulation of spatial functions between the variables.

Map and model

It is important to clarify here the actual relation between the basic and common concepts of the map and model. The most important reason for presenting these models is the guide and accrue benefits for all the specialists of spatial studies all over the world since they represent an integrated overlap between the two layers, one of them about existing reality and the second one of the mathematical procedures which will be used together for the final results. This approach will help fully understand the interaction of layers of geography along with a precise spatial analysis of the data. The establishment of a model for any of the maps clearly and simply ensures the actual correct steps and methods represented in the spatial data through the correct technique of the GIS applications; these applications are mainly based upon the data, the application procedures, and the work steps.

The main motivation in building the model is to assist in the simple, precise, and more realistic re-combination of layers for any map through the application of GIS methods and specialized tools for spatial analysis of natural or human procedures. The outputs are further valuable products for use in other studies and as a foundation in other or related fields. From a more general perspective, cartographic modeling refers to the summarizing and representation of information in a GIS-based on a given model. The information model itself forms the core of the system, and it involves a bundle of processes that model the goals and activities in the real world in a digital manner (Juma'a, 2014).

Modeling a map, in its simplest form, is a general method to express and organize the selection and use of spatial variables and processes to develop an analytical solution using GIS. This method relies on layers of data, processes, and procedures. Sequential operations in computational procedures may be used to create new map layers from existing ones [6]. According to Tomlin (1991), "the basic norms of mapping modeling are not specific to GIS. Instead, they are general agreements intended to relate to as many systems as possible" [7]. This demonstrates the critical role that system technologies play: the application's data is analyzed using a descriptive spatial approach using geographic information, complete with all of its requirements. Furthermore, tools facilitate the creation of models utilizing algebraic equations and mathematical processes.

Access Geographic Information System (GIS) Data using ArcGIS

The actual need for the GIS programs of ArcGIS has just become obvious, not only for correctly representing any piece of land and its features for any particular purpose but also concerning the ability of researchers to make maps with different themes and add and process them by using the available tools. The application of these tools within the respective programs targets several needs, according to Lena [8]:

1. Data availability to model the phenomenon using technical programs and tools with visual diversity by variables such as position, shape, direction, color, texture, silhouette value, and size.

2. Ability to create thematic maps on various themes to be generated when required, thus allowing spatial patterns to be perceived or relationships that are hidden or non-obvious to be brought to light.

3. These technologies demand that their users are highly educated and experienced to avoid mistakes that can be misleading to the true nature of the information in the visual image, especially when using data in absolute quantitative terms or using mathematical algorithms.

4. Databases would then allow this most significant role in the combination of technically produced maps with a graphical representation of the same geographic model to be conducted so the spatial comparison using the statistical methods provided by the program could be carried out and layers that represent the nature of the area can be created.

5. Such tools can implement the usual GIS functions for layering, querying, distance measuring, and area measurement over geographic data and databases.

6. They provide very necessary generalization and smoothing operations to avoid deformation at the large scale, yet give feature clarity in operations such as simplification, exaggeration, and displacement in scale change.

7. The correctness of the information is ensured through the provision of statistics for the features of the image or visual used, as well as metadata.

8. Programs help in creating the data for developing virtual models of geographical phenomena and in visual comparison with other available maps—or they are imported from computer memory.

In such sources and their drawing tools, the output is not only limited to the digital fixation of the map but extends to the provision of the result in a picture or paper. Applications extend to the manipulation of the map by changing layers, deleting, and adding elements, moving in all directions, zooming, and the control of size. The key interaction that occurs between a map and the database is the user-database interface in the drawing tools. Even though current programs differ in their variety and types, they do not ensure satisfaction of all the requirements for exploration of large-scale applicability and mapping. The greater part of the programs supports the creation of thematic maps of various types, dynamic maps, dynamically bound maps, and interactive diagrams. Most of the programs also allow for transforming geographical and tabular data for visual analysis of spatial and temporal data. Such possibilities are based on high computer devices and high-precision, high-quality information technologies. As shown in Figure 3.

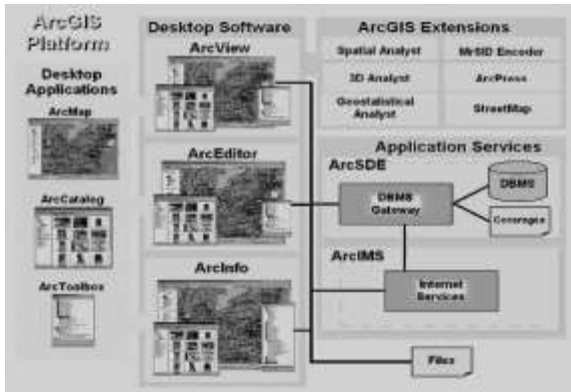

Figure 3. Arcgis (screenshot from ArcGIS Online)

3. Results and Discussion

Principles of Cartographic Modeling

Four rules must be adhered to to generate various models of geographical maps [9]:
1. Design of map layers or description of spatial data for the area.
2. Use logic and natural language to develop the process of how to transition from available information into the solution.
3. Draw a flowchart from the logical stages that graphically represents the entire process. It is a set of algorithms that the researcher must follow through to the solution; it also contains a fallacy.
4. Annotate with the help of the planner all the sequences of operations that are performed in the GIS program.

Building up the map with the application of these principles to identify a single point on the map requires four layering:
- Land utilization.
- Phenomenon site
- Map of rivers
- Roadmap

For the ideas to be implemented, the right logic has to be set and the right language that goes with the language of the program. This program makes it possible for all the spatial information to flow the right way, and the adopted simulation will be a true picture of the form and application of reality. After this, statistical equations will be set in for the processing of information and getting back of results, as shown in Figures (4) and (5).

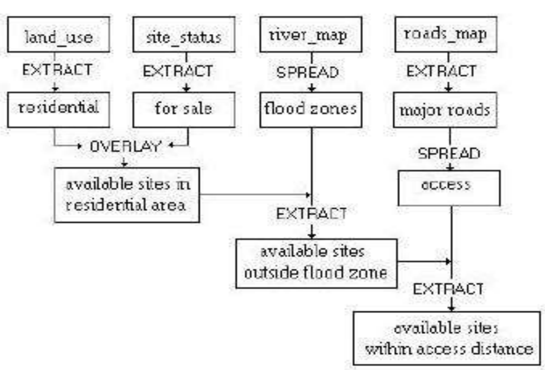

Figure 4. Flowchart of how to find a particular phenomenon on a map (GeoMedia)

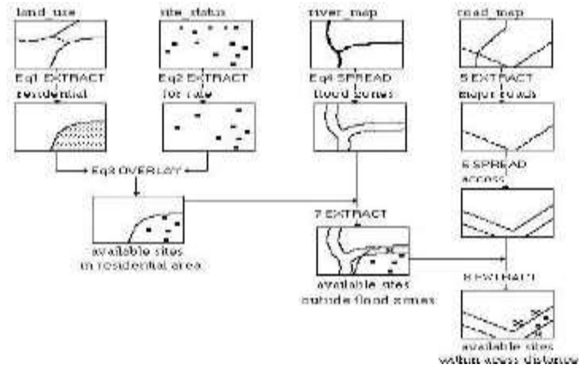

Figure 5. Data-based flow chart by (MapInfo)

he strength of the analytical power of mapping remains in the possibility of laying down a stack of equations. Now, with these findings, we can move to the final step and apply these algebraic equations with modern information system technologies to obtain necessary outputs from the Geo-GIS an mapping model.

4. Conclussion

Cartographic modeling can be conceived of as a structured way of developing geographical information system designs with the possible development of technical steps that allow for the implementation of all mathematical operations in an integrated way. The modeling allows for a high level of precision in the production of cartography. Using natural language and proper logic for all applied steps allows the mapping model to be highly developed. To integrate the operations using such programs, updated data and experienced users of information system technology programs are required. The user handling these programs needs to be highly capable through a range of statistical methods and algebraic equations to secure high-quality analysis and descriptions in detail of the outputs produced by the cartographic models from a range of geographical and non-geographical domains. The integration of information technology with geographical information systems also influences development in the direction of more effective and precise tools that can nullify the limitations of existing programs. The results obtained are of high quality and accuracy and use natural and human phenomena to provide a more realistic simulation of these.

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