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Research Article

SOME ASPECTS OF GIS MAPPING AND GEOVISUALIZATION TECHNIQUES IN HYDROGEOLOGY

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ABSTRACT
This paper describes a methodical approach to hydrogeologic mapping and outlines principles of data management using Geographic Information Systems (GIS). Using groundwater maps based on a cartographic reasoning approach is an excellent way to support a comprehensive, integrated geospatial analysis and visualizations that contribute to a balanced, sustainable evaluation, protection, management, and governance of water resources.

Keywords: *GIS, Database, Mapping, Hydrogeology, Geovisualization, Groundwater, Digital Maps, Information, Data*

INTRODUCTION

Hydrogeology is a field of science that studies groundwater, its origin, movement, and interaction with the environment. Effective management of groundwater resources requires modern methods of data analysis and visualization. One such method is geographic information mapping and geovisualization. These tools allow not only to collect and process information, but also to present it in a visual and accessible form.

Hydrogeological mapping, intensively developed in Uzbekistan over the last several years, is an essential tool for conducting hydrogeological and environmental analysis of the conditions of groundwater occurrence, undertaken for designing new projects and hydrogeological investigation, hydrogeological studies to looking for areas with particularly favorable conditions for the recognition of groundwater, hydrogeological regionalization for economic needs, planning groundwater monitoring locations, assessing quantitative and chemical status of groundwater, planning and developing programs for the protection of groundwater.

Digital hydrogeologic maps and their databases are well suited for water resources planning. A GIS serves as a platform of integration for digital maps around which available data are centered. The application of a GIS and a subsequent georelational database allows data capture, processing, analysis, and visualization in support of decision making (Djumanov *et al.,* 2021).

MATERIALS AND METHODS

GIS is a tool for storing, manipulating, retrieving and presenting both spatial and non-spatial data in a quick, efficient and organised way. Since most land information elelments have a geographic connotation, geographically referenced data with GIS techniques come to the fore in such and application. The term 'geographic' in GIS refers to the locational attributes which define the spatial positioning of the piece of information on the face of the earth. Preparation and maintenance of data in the form of maps and referenced tabular files itself can be considered as a primitive form of GIS.

However, with the advent of digital computers, with high data processing speed and the development of analytical tools thereon to handle geographically referenced data with ease and flexibility, computer aided GIS has become a reality of late. (Figure 1). Such systems generally deal with data classified/segregated into the spatial type (locationally referenced), attribute type (without locational connotation) and the time variant or repetitive types of data. The three components-location, attributes and time-represent the content of most GIS (Das, 2009).

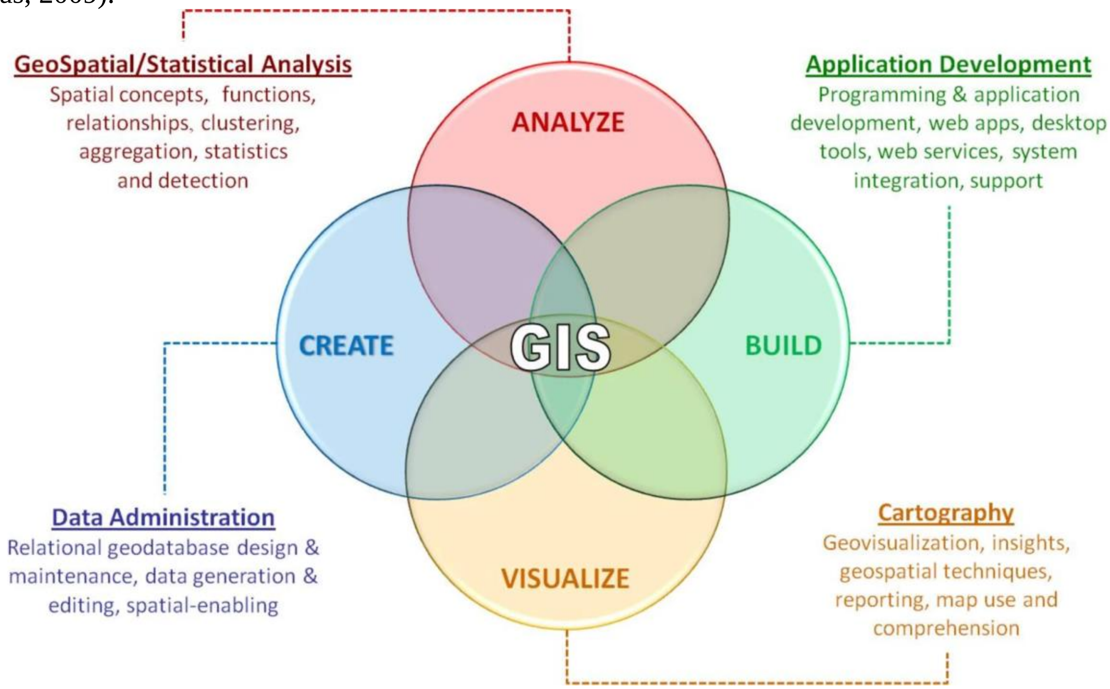

Figure 1: Objects and tasks of geographic information systems (GIS)

GIS-based mapping and geovisualization analysis constantly develop and incorporate various approaches from diverse fields. The use of visualization techniques, image analysis, information visualization, exploratory data analysis, and GIS-based tools can assist in a better understanding of geographical data. These advanced techniques offer limitless possibilities for exploring and analyzing data in new and innovative ways (Chaminé *et al.*, 2024).

Data and information required by hydrogeological studies are complex. Information concerning geology, hydrology, geomorphology, soil, climate, land use, topography, and man-made (anthropogenic) features needs to be analysed and combined. Data are collected from existing databases and maps as well as through new field measurements. All these data need to be managed, and this can be achieved using databases, particularly GIS databases (Gogu *et al.*, 2001).

Cartographic data produced using digital GIS techniques, are the primary resource for information about the conditions of groundwater occurrence, together with their quantitative and qualitative characteristics.

Information gathered in the database of hydrogeological map is necessary for preparing analyses, such as status assessments, forecasting changes in groundwater quantity and quality and identifying threats to groundwater resources.

Storing data in the GIS format allows data stored in different structures to be merged without interference with raw data. The functionality of the environment in which the GIS data are collected and presented allows also other data created in the same software to be used and data created in different software environments to be imported. The geographical information system allows also the incorporation of additional thematic layers into the master database (Herbich *et al.*, 2010).

Storing and manipulating data through spatial relationships can be achieved with the GIS packages using the "georelational" model or the "geodatabase" model. The first consists of linking a relational database to geometrical features. The modelled entities are organized into categories sharing common characteristics (points representing wells, piezometers, or gallery wells). A table represents each category. The different attributes occur as columns of the table, and the rows assure the data registration. Relationships "one to one" or "one to many" can be established between tables (Levene and Loizou, 1999).

In GIS, distinction between objects and fields is often associated with vector data models and raster data models. The vector model represents spatial phenomena through differences in the distribution of properties of points, lines, and areas. In this system, each layer is an adapted combination of one or more classes of geometrical features.

A raster model consists of a rectangular array of cells with values being assigned to each cell. In the raster model, each cell is usually restricted to a single value (Figure 2). Thus, representing the spatial distribution of a number of parameters or variables requires multiple layers.

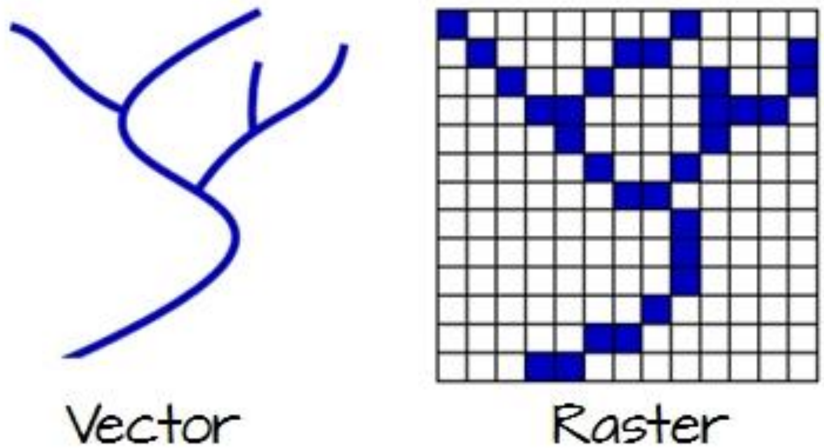

Figure 2: Difference between vector and raster data

Spatial objects in hydrogeology refer to specific features or entities that can be represented in a GIS and are relevant to the study and management of groundwater resources. Some common examples include:

- Wells: Structures used for extracting water from underground aquifers.
- Piezometers: Instruments used to measure the pressure head of groundwater, providing data on groundwater levels.
- Boreholes: Holes drilled into the ground to explore subsurface conditions, often for resource extraction or environmental assessment.
- Galleries: Underground passages designed for water collection or drainage.
- Protection Zones: Areas designated to safeguard water sources from contamination and over-extraction.
- Aquifers: Geological formations that can store and transmit water.
- Recharge Areas: Regions where water infiltrates the ground to replenish aquifers.

The main task in forming a database for a GIS is to establish links with the objects it characterizes on a cartographic basis, which allows integrating the cartographic and descriptive components of the database, making them part of one system. Such connections between the essence of the phenomenon and process and the corresponding objects of the terrain provide convenience for the user. This allows, on the one hand, to visually display and effectively perceive the requested information in cartographic form, and on the other hand, to clearly and promptly request the necessary tabular information, while using the map when forming the request. This approach corresponds to the dominant direction in the development of integrating spatial information on a raster and/or vector basis with attached factual and metadata bases (Kamara and Samuel, 2019).

Digital hydrogeologic maps fundamentally different from their conventionally elaborated counterparts. As soon as a GIS is part of a project, we are leaving the traditional way of storing, analyzing, accessing, and presenting data. A GIS is not exclusively applied for the task of map production and data visualization. It does not store maps - it holds a spatial database from which views can be derived to suit particular user requests (Figure 3). A GIS means creating and maintaining a digital information system with its internal geospatial and/or an external relational database as one interface of access to its information (Khabibullaev and Mamirov, 2021).

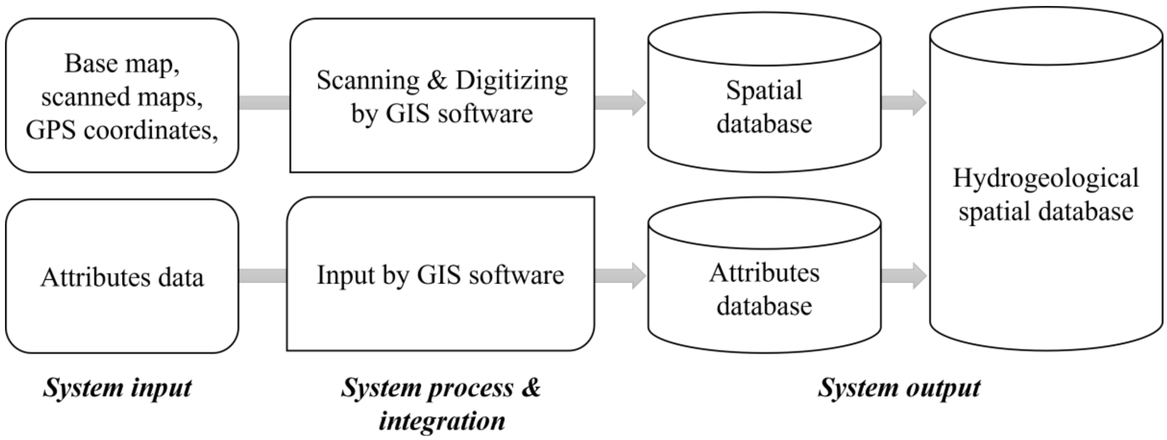

Figure 3: Establishment of the hydrogeological spatial database by GIS

The digital approach to hydrogeologic mapping demonstrates its flexibility by taking advantage of the GIS's analytical tools. The open data structure facilitates data updates and the automation of the process of map production (Oesterreich, 2000).

RESULTS AND DISCUSSION

In GIS, the real world is described using digital-map data, which define positions in space, and attribute data, which usually consist of alphanumeric lists of characteristics and, frequently, temporal information describing when the other data are valid in time. The various objects, such as rivers or wells, are represented on different layers using an appropriate geometry; the rivers are represented as lines, the wells as points. Attribute data may be converted to graphic symbols presented together with other data on a map. Simply moving a pointer to a symbol on a screen display and entering a command can retrieve the attribute data. Geometric data and attribute data are usually separated in the software hierarchy. Identical identifiers for the two kinds of data (geometric and attribute) facilitate matching for retrieval and processing.

Data analysis is an important consideration in database construction. In order to identify the data needs and to provide the optimal data representation, accurate assessments of all types of data and data formats are extremely important before designing a database.

Hydrogeological mapping requires the regionalization of hydrogeologic conditions. The data that have to be processed fall into one of the following three categories, all of which can principally be described in either the raster or vector data model of hybrid GIS software:

1. Point data: data belonging to objects that can be pin-pointed on the earth's surface. Wells, well galleries, groundwater monitoring wells, and springs, for instance, fall into this category. Data related to point objects are, among others, borehole logs, groundwater level registrations, or hydrochemical analyses.

2. Line data: data referring to linear objects. Faults, cross-sections, hydroisohyps and border of water bearing horizon may serve as examples of this group.

3. Polygonal data: polygonal data can be either polygonal objects or the spatial distribution of hydrogeological parameters and/or properties. Polygonal objects are homogeneous areas defined by the same

propertiesl. In hydrogeologic maps these data are separated by closed polygons indicated by a certain signature or color. Spatial distributions and their according variations are, for instance, distribution of groundwater potential, groundwater depth, hydrochemical characteristics, or top and base levels of aquifers. They are commonly displayed by contour lines or related methods of visualization (Figure 4).

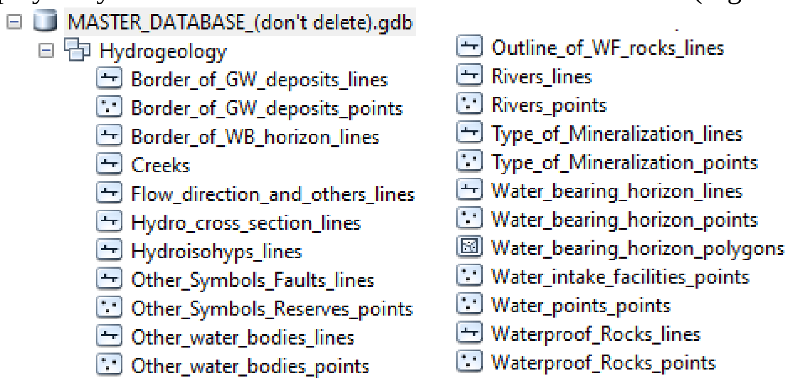

Figure 4: A structure of the database of hydrogeological objects

If the georelational model uses points, lines, polygons, and related attribute tables to define various properties in the geodatabase model, entities are represented as objects with properties, behaviour, and relationships. For example, a well object can be found within a library of objects with the entire attribute scheme attached. The user can simply take it, place it on the map, and enter the data in the attached tables.

Storing data implies data analysis, conceptual design of data models, and data representation. In hydrogeology, because of a limited number of sample locations, point-attribute data also need to be processed by applying adequate kinds of interpolation or modelling algorithms (Figure 5).

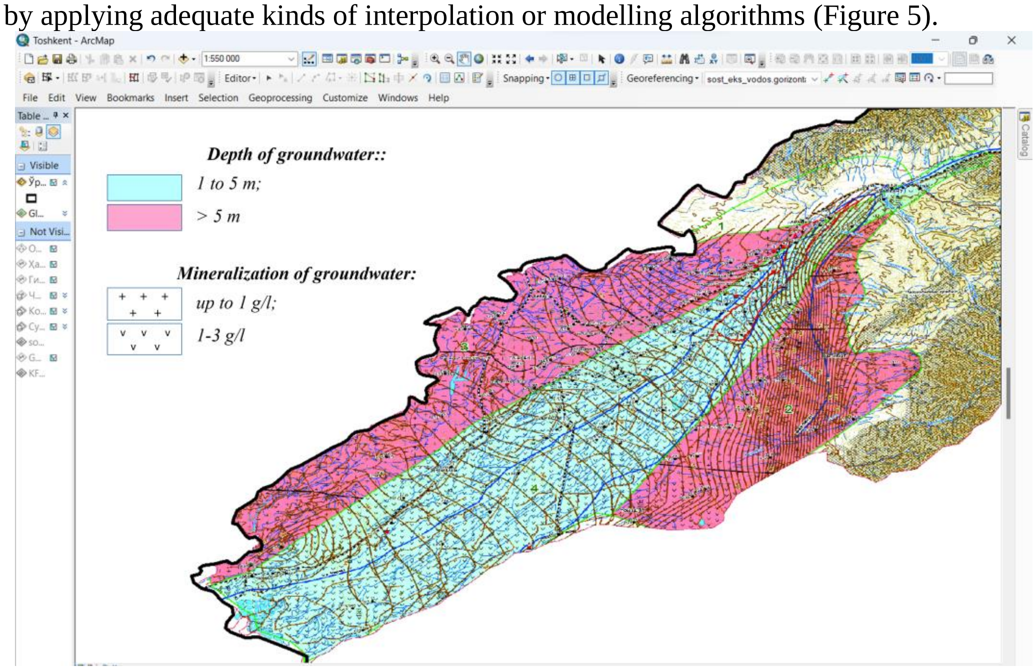

Figure 5: Digital map showing the depth and mineralization levels of groundwater in the Chirchik Basin

Interpolation of point-attribute data is a vital tool in groundwater studies. By estimating values between sampled points, researchers and practitioners can gain a better understanding of spatial patterns, inform management decisions, and effectively communicate findings to stakeholders .

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The techniques, procedures, design, and conceptualization used for map-making have improved significantly over time. In contrast to showing abstract data, geovisualization deals with geospatial data and visual analytics, i.e., georeferenced data in a robust and versatile geographic database that permits conceptual and numerical modeling.

Geovisualization techniques play a crucial role in groundwater practice by enhancing the understanding, management, and communication of groundwater data.

The use of visualization techniques, image analysis, information visualization, exploratory data analysis, and GIS-based tools can assist in a better understanding of geographical data. These advanced techniques offer limitless possibilities for exploring and analyzing data in new and innovative ways (Figure 6).

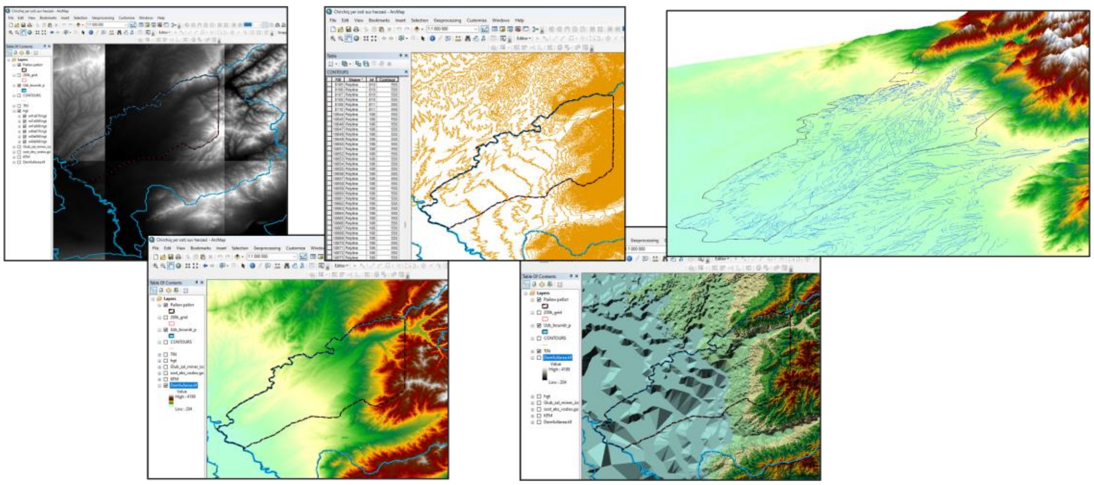

Figure 6: Geovisualization methods for spatial data

Geovisualization methods for spatial data are essential for effectively analyzing, interpreting, and communicating geographic information. These methods transform complex spatial datasets into visual formats that enhance understanding and decision-making.

Conclusion

GIS mapping and geovisualization play a key role in modern groundwater management. These methods allow complex data to be effectively analyzed and presented, which contributes to more informed decision-making. In the context of climate change and increasing pressure on water resources, their importance is only increasing. The future of hydrogeology is certainly associated with further developments in GIS and geovisualization technologies, which will open up new horizons for the study and management of groundwater.

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