Applications of GIS in Geology
(Final Paper)

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Abstract

As our understanding grows of how the Earth functions as a complex system of huge number of interrelated mechanisms, it becomes clear that a revolutionary approach is needed to study and understand it. In order to take advantage of an ever-growing number of observations and large data sets and to use them efficiently in geological studies aimed at solving earth science problems, GIS technique must be applied. The complex nature of the earth sciences raises serious challenges for geologists in their need to understand the nature and the dynamic mechanisms at work in the planet. This paper has discussed several case studies in areas where GIS approach has been used and applied to solve different geological problem from different parts of the world. Problems presented in this paper are: oil exploration, structural geology, engineering geology, environmental geology, geological and subsurface mapping, and geo-hazards.
**Introduction**

One of the major and greatest challenges facing geologists and earth scientists is the assimilation, dissemination, and management of the ever growing quantity of digital information. The power of having at one’s finger tips all available relevant data has great potential for improving the quality of scientific research and education. In order to solve these challenging problems we must change the way information, data, and knowledge are preserved, utilized, and disseminated. The earth science community is in need of systems that not only provide digital data, but as importantly, provide tools that allow users to manipulate, query, select, and cross-reference any part of data sets with efficiency and speed. One of the most promising systems for use by earth scientists is the Geographical Information Systems (GIS). GIS is an organized collection of hardware, software, and data designed to store, manipulate, analyze, query, and display information for decision-making and accurate analysis of any spatial data.

One of the misconceptions about GIS is that it is only a map-making tool. In fact, GIS does much more than simply make maps. It enables a user to analyze, study, search and select databases for a specific purpose. For example, a person studying the seismotectonics of a region can display all active faults in a region, select earthquakes within a certain distance from these faults, and calculate the density of seismic events. Similarly, a user can select a geologic unit and determine its area, its topography, or the number of faults within it. These are simple tasks that can be completed in a few seconds. What GIS provides is a convenient way to expand our abilities to do better research in much less time and to bring interdisciplinary approaches to scientific studies by allowing efficient ways to cross-reference multiple data sets.

Using GIS software allows storage of the data in a spatially registered structure and permits cross-referencing for heterogeneous, multidisciplinary data sets. It manages data sets as layers of information. Geographic features such as rivers and lakes or geological features like faults, sample locations, and ages of rocks are all examples of layers. Each layer is independent from the others, yet all have a common geographic
registration and they can be linked with each other using specific identification tags. This provides a convenient way of selecting necessary information from the database and making it ready for further analysis and decision-making.

The objective of this term paper is to do a comprehensive literature review and show the different applications of Geographic Information Systems (GIS) in the field of geosciences and to show the important role as a data integration and manipulation tool that GIS can play.

**Review of Literature:**

Many previous studies have utilized GIS to integrate different geological data collected from the field to come up with more accurate interpretation with a new approach. (Aiken et al, 1997) have used GIS to map the gravity and magnetic field readings in Mexico. (Orange et al, 1999) have used GIS in identifying and predicting geo-hazardous areas in California, USA. GIS has been also used in to study the geologic evolution of Syria (Brew et al, 2000). The role of GIS in oil exploration has been identified in a study done by (Pawlowski, 2000). (Seber et al, 2000) study has shown the different applications of GIS in Middle East geology. GIS has been used extensively in mapping in 2D and 3D as in the studies conducted by (Kirkham et al, 2003) and (Belt et al, 2005). GIS has been applied in the field of environmental geology to study the environmental impact of mining heavy metals such as Cu, Zn, and Fe in Turkey (Akcay, 2004). Engineering geology is another field where GIS was applied to overcome geo-environmental problems in urban development (Aly et al, 2005).
This section will basically show a case study for each field of geology where GIS technology has been applied.

a. Oil exploration:

Examples from a recent land geophysical field program in the Central Apennines of southern Italy have shown several uses of GIS as applied to exploration. The examples illustrate the application of inexpensive, field portable GIS tools to exploration survey planning, management, and QC. (Pawlowski, 2000)

The Apennine Mountains, which run the length of and form the spine of the Italian peninsula, are characterized by rugged terrain, folded, and faulted rocks of the so-called Apennine platform carbonate series. The difficult terrain obstructs mobility of personnel and equipment, resulting in high seismic acquisition costs. In addition, the regional stratigraphy is highly calcareous, consisting of some thick and monotonous platform carbonate, flysch, and molasse sequences. These factors create a considerable challenge to acquisition of high quality data. Because of these challenges, a company was contracted to help design and manage a comprehensive nonseismic exploration field program in Forest’s onshore Caserta Block (Figure 1). The nonseismic program was designed to provide permit-wide exploration reconnaissance at a cost comparable to that of a single 15-km seismic line. The goals of the nonseismic reconnaissance program were to identify prospective structural leads and optimize the locations of new seismic lines to be acquired later.

Acquisition of new gravity data was planned to make use of the extensive network of roads in the area. This decision was made for logistical ease and because future seismic acquisition will likely maximize use of the same roads. The GIS tools used were valuable in (1) tracking and monitoring gravity data acquisition and (2) verifying that the gravity station data were acquired in the correct locations. Acquisition of
Magnetotelluric (MT) data is negatively affected by cultural sources of electromagnetic noise (e.g., electric railroads, pipeline cathodic protection, electric power switching equipment and transmission lines, cities, etc.). Thus GIS can help optimize MT data acquisition because it can provide a rapid first look at possible problem (electrically noisy) areas.

![Fig 1. Caserta Block](image)

![Fig 2. Surface geologic map is useful GIS backdrop](image)

Figure 2 illustrates the utility of the data-layering capability inherent to GIS. In Figure 2, surface geologic map information has been put as a base map and displayed with other data/information of interest. The geologic information serves as a GIS map backdrop, ensuring that all MT sites sample outcropping geologic units/features of interest. The four MT sites (dark blue triangles) of the initial noise-test program can be seen in Figure 2.

b. Structural Geology:

(Brew et al, 2000) generated new structural maps and tectonic models for the whole Sirya. Information on this region is relatively limited, despite the local importance of hydrocarbon production and abundant surface and subsurface data. The regional approach involved new interpretations of seismic reflection profiles, well data, remote sensing imagery, and potential-field data, merged with existing interpretations of similar
data sets (see figure 3). These interpretations, integrations, analyses, and map preparation were all performed within a GIS platform.

![Composite image of selected layers and coverages that have been imported into GIS and used for interpretation](image)

Figure 3. Composite image of selected layers and coverages that have been imported into GIS and used for interpretation

Figure 4 shows a preliminary and initial structural map example. The contours of depth to Lower Cretaceous are based on well data, together with digitized, depth-converted, converted, seismic-reflection interpretations that have been entered into the GIS. Faults are interpreted from seismic reflection profiles and other data and their digitized locations entered into the GIS. Both the depth contours and the faults can be edited on screen. In this way, coregistered topography, satellite imagery, and geology maps can facilitate mapping of features.
GIS is an essential component in tectonic mapping and structural interpretation. Data manipulation, visualizations, and integrated interpretations, previously prohibitively time-consuming or impossible, are quick and easy using GIS technology. This allows faster, more accurate analysis, and better quality, highly accessible, end products. The maps and models were created are important for continued hydrocarbon exploration.

c. Engineering Geology:

Urban development is a high priority in Egypt. New Minia City, located on the eastern bank of the Nile River, approximately 250 km south of Cairo, is one of 16 new development communities. Urban development in New Minia City may encounter several geo-environmental problems. Karst conditions and structural features in the local heterogeneous bedrock limit its suitability for constructional purposes. In this example, suitability of the area for urban development was assessed using a geographic information systems (GIS) based approach (Aly et al, 2005). A weighted GIS model that incorporated land use/cover, types of soil, karst feature distribution, fracture densities,
slopes, distances to major faults and streams, road network, and city boundaries was established to create a map of site suitability for the city (See table 1).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Potential Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Karst distributions</td>
<td>Large caves and/or sinkholes</td>
</tr>
<tr>
<td>Distances to major faults (m)</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Distances to major streams (m)</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Fracture densities (no./km²)</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Slopes (%)</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Soil types</td>
<td>Argillaceous sands</td>
</tr>
</tbody>
</table>

Table 1. Standardized potential scores (the higher the score, the better the suitability).

Current urban land use within New Minia City falls into four classes of suitability. Approximately 7 percent of the area built by 2002 is in the low suitability class, which suggests that the map of site suitability can serve as a reliable base for planning sustainable development in New Minia City. The developed map of site suitability is effective for assessing and revealing ratings of suitability for urban development. Furthermore, the map of suitability provides the foundation for informed decision making in the development of New Minia City (See figure 5).
d. Environmental Geology:

The Pontide metallocene is the major producing area in Turkey for base metals and has significant Au producing potential. Two major developments are currently at the feasibility stage and face opposition because of their potential environmental impact. Little information exists to substantiate past impacts. Figure 6 is showing the location of the area and the major mineral deposits.

A study conducted by (Akcay et al, 2004) describes reconnaissance water sampling and observations of the impact of some of the major current and disused operations. These are volcanic hosted massive sulphide (VMS) deposits at Murgul, Kutlular, Lahanos and Çayeli. Smaller vein mines at GümüEki Tepe and Midi Maden were also sampled. The VMS deposits have had considerable impact. At Kutlular and Lahanos acid mine drainage (AMD) is strongly developed and metals are transported into drainages.

One of the major parts of this study was to assemble a database in geographical information system (GIS) format to come up with a map showing the potential for AMD by utilizing the analytical ability in GIS (see figure 7). This presents a problem in Turkey as there has been a long tradition of governmental classification of map data as secret. As a result very little information is available in digital format and obtaining paper maps to
digitize is not easy. The layers that have been used are: rainfall map, topography map, Geology map, and mineral deposits map.

Fig 7. Potential for AMD based on rainfall and deposits type. Darker spots indicate higher potential.

e. Geological and subsurface Mapping:
(Kirkham et al, 2003) have created a three-dimensional computer model of the Con and Giant gold mines in the Yellowknife Greenstone Belt. The Yellowknife Mining Camp has produced a great deal of gold (over 400,000 kg) in the past sixty years and the assumption was that the mines were at the end of their lives. However, the potential for discovering additional resources using new ideas and technology, and maximizing use of existing data, offered an opportunity to sustain the old mining operations and maintain their contribution to the community.

The objectives of that study included the compilation and creation of a three-dimensional Geographic Information System model (combining 3D subsurface data with surface information) to provide a framework for concurrent structural and alteration studies, and to encourage new exploration in the area. A secondary objective was to retain the data in digital format as a historical reference for future remediation efforts, and to document a portion of Canada’s rich mining history.
The end result was a database and set of models that have been instrumental in facilitating further exploration in the area, as well as in developing targets for future exploration and mining activities. In addition, the 3D GIS model has made a valuable contribution toward the understanding of the arsenic remediation issues at the Giant mine, and has served as a tool in support of a variety of highly technical engineering studies and for communicating information and problems to the layman and community as a whole (See figure 8).

![Fig 8. The West Bay and Negus faults viewed at an oblique angle in combination with the underground development and mined-out stopes, and an isopach thickness map of the Campbell shear. The isopach map is color-coded to show areas that have relatively low thickness values to high thickness values, in the sequence: yellow, light green, dark green, blue, and red. On the south (right) side of the fault, the potential equivalent ore zone is shown as a relative high 200 m down dip within the dotted circle.](image)

f. Geo-hazards

*Earthquakes:* (seber et al, 2000) have shown that having the historical earthquake events data managed in GIS platform can help in avoiding urban development in areas with high risk records and it also helps in knowing high risk areas for better emergency planning and management (see figure 9). This layer can be also overlaid on top of a geological map and/or fault map for regional tectonic interpretations.
Volcanoes: GIS can be used in building database for active volcanoes (Seber et al, 2000). The attributes associated with each volcano may include: location, last eruption date, type of eruption, height, lava composition, eruption duration… Etc. (See figure 10)

GIS is also useful in predicting the lava flow direction, and managing the development and emergency evacuations. The United States Geological Survey has applied GIS in analyzing the volcanic hazards associated with Lassen Volcanic National Park area, California. The volcano scientists utilized the available data to develop a volcano hazard zones (USGS fact sheet fs022-00, 2000). (See figure 11)
Fig 10. Map showing distribution of volcanic activity in the Middle East. Only Neogene/Quaternary and Paleogene volcanic fields are shown. Holocene volcanoes obtained from the Smithsonian Institution are also shown colored based on their age groups. The majority of the Neogene/Quaternary fields are in western Arabia and Turkey, whereas the majority of Paleogene volcanics are in Iran.

Fig 11. The areas of highest hazard in the region of Lassen Volcanic National Park are those that could potentially be affected by pyroclastic flows and mudflows. These areas are those in the immediate vicinity and downhill from likely eruption sites. Fallout of ash will affect areas downwind at the time of an eruption. Within the hazard zones, relative hazard is gradational, decreasing away from the location of potential vents.
Flooding: Muzaffarabad city is one the most severely flood affected area in northern Pakistan. It is situated at the confluence of River Neelum and Jhelum. High-class residential area and commercial activities are situated along riverbanks, which are severely vulnerable to flooding. Due to rugged topography and lack of further land for extension, the people are imposed to construct either double-storey buildings or multi-storeys buildings. (Nawaz and Shafique, 2003)

For a number of reasons the most frequent choice should be protection from the flooding by means of physical control of the river, but there is also a need for a broader and comprehensive program for managing flood hazard in the study area. Flood protection has been helpful and must be continued. Side by side other preventive tools like effective planning for the growth of the city, creation of a computerized GIS database for the flood prone areas and a detail flood risk assessment mapping and zonation are required to minimize the harmful effects of flood hazard. Therefore, an attempt has been made to apply modern techniques like Geographical Information System and Remote Sensing for the assessment of flood hazard. The presence of risk assessment mapping will help the concerned authorities to formulate their development strategies according to the available risk to the area. (See figure 12)
GIS applications in managing the geo-hazards are not limited to these three hazards. It is heavily used in other areas such as: drought, fire, cyclone, landslide and soil erosion. (GIS Development website)
Conclusion

The need for comprehensive geoscience information systems in research and education is overwhelming. Examples shown in this paper provided detailed explanations about geographic information system that will lead to better and more efficient research studies in many parts of the world. The success of future geoscience research relies on how efficiently and effectively researchers can access multidisciplinary data sets in their analysis. As our understanding of the Earth increases, it is becoming clearer that cross-disciplinary techniques must be utilized to achieve a higher level of understanding.

Acknowledgment

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List of References


