The Role of GIS in Earth Sciences

(Final Paper)

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Abstract

GIS use has become widespread in the past two decades. GIS have been used in fields from Archeology to Zoology, and new applications of GIS are continuously emerging. The objective of this paper is to discuss its applications in Earth Sciences. Although it is hard to discuss all the applications of GIS in Earth Sciences, yet it has been tried to mention most of them. In this regard, previous published work has been reviewed and synthesized. Geological mapping has been utilized to show how with the help of GIS, a new combined map containing various information is prepared within no time and with more accuracy. Examples from exploration industry have been reviewed to show the use of GIS as data storage and how it is useful in analyzing the data spatially. We also tried to show GIS as an aid to hazard zonation mapping and mapping earthquakes/Landslides disasters (Human deaths, property damage and injuries etc.) in Earthquakes and Landslides studies. Examples from Groundwater studies have also been discussed to show the significance of GIS. It has been shown that GIS can improve project management, quality control and efficiency.

1 Introduction

Although geologists have been using computers to analyze spatial data for over 30 years, developments in hardware and software in the 1980s resulted in the emergence of a type of spatial analysis software known as Geographic information systems (GIS) (Bonham-Carter, 2000). The market of GIS grew rapidly in the late 1980s and early 1990s because it quickly became apparent that such systems could handle virtually any type of geographical data and could provide a range of functionality for spatial data handling and analysis that previously had required a combination of software to achieve.

In the initial years of GIS, the systems were visualized as a little more than a graphic tool with very limited spatial analysis capabilities. It was essentially addressing the needs of the geographical community. Therefore, the traditional geological community was skeptical about its usage in solving serious geological problems and it still preferred specialized mining software or geostatistical packages for their applications. However, the GIS developers soon realized the need for incorporating multivariate, geostatistical modules and powerful 3-D analysis and these components work often considered as advanced components and became the selling point of GIS packages. Another advantage was the low cost of the GIS packages as compared to the expense on specialized mining packages. Now it is understood that many of the geological applications can be conducted without such specialized packages. This resulted in the popularity of GIS in geological community.

Geographic Information Systems (GIS), used by municipalities and planners for quite a long time, are now being adopted as another tool in exploration because they can efficiently store different types of information which, in turn, leads to better interpretation/ understanding of the data i.e. satellite imagery, land ownership, location of seismic lines and wells etc (Mickellson, 2000).

2 Objective of the study

The objective of this paper is to discuss the significance/role of GIS in Earth Sciences i.e. how GIS is benefiting the mankind in different aspects within Earth Sciences. GIS has many applications in Geosciences some of which are: Geological Mapping, mineral exploration and mining, Groundwater, seismic acquisition, Hazard analysis etc. Although it is hard to discuss all the applications of GIS, yet have been tried very best to mention most of them in this study. We'll discuss one by one the applications of GIS in all the above mentioned fields.

3 Literature Review

Different studies have been carried out to investigate and demonstrate the applications of GIS in Earth Sciences. Stigant (2000) discusses the international aspects of GPS and GIS and also provides an introduction to the geodetic sciences, the foundation for any spatial data. The term spatial is used because it refers to located data for objects positioned in space and, as he points out, a location may be defined in many different ways. Hence latitude and longitude are not absolute. Quinlivan (2000) presents a different view of spatial information. Brew et.al (2000) show how integration of various sources and the use of GIS can map a regions' geologic and tectonic history. They described their use of GIS to facilitate regional tectonic mapping in Syria. Pawlowski (2000) demonstrates how GIS was vital in the acquisition and planning phases of an exploration project in Italy. Xu et al. (2000) describe research that integrates GIS and GPS in mapping geologic features of varying scale and complexity. Returning to seismic, Porter (2000) shows how a powerful database integrated with GIS can facilitate many aspects of seismic acquisition. Elkington et. al (1997) showed how GIS is useful in 3D seismic survey designs and acquisitions. Coburn (2000) discussed different issues and perspectives on the implementation of GIS for petroleum exploration and development. Porter (1997) discussed the role of GIS in optimizing 3D land operations. Jasmi (1997) used the remotely sensed data and GIS techniques for slope instability assessment and prediction in the Cameron Highlands area, northwest of Pahang state, Peninsular Malaysia.

4 Data Sources/ Nature of the Data

All the data used in this study have been taken either from the internet or from the published books. Since this is a synthesis of the past studies, that’s why no data was required to work on the GIS software.

5 Applications of GIS

GIS has so many applications that it will be hard to mention all of them in this study, yet I have tried to mention most of its applications in Earth Sciences. These have been discussed in detail as following:

5.1 Geological Mapping

One of the most fundamental applications in the field of geology is the geological mapping. In geological mapping it is often required to bring on to one scale various existing geological maps often in different scales. Traditionally, it was done through graph sheet or reflecting projector, which is extremely time consuming as it needs re-tracing of the map itself in the required scale often compromising a lot on quality. With the help of GIS, maps of any scale can be scanned, georeferenced and reproduced in any desired scale thereby bringing all old maps to one scale, at which more information can be collected either by field investigation or by remote sensing techniques to prepare a final updated geological map. In one such attempt at IIRS, the published geological maps on 1:250,000 and 1:50,000 from different sources were brought on to one scale of

1:25,000. Then all maps could be compared and the final map was prepared on 1:25,000 scale, which was later updated using merged IRS-LISS-III and PAN imagery on 1:25,000 scale and supported by ground investigation (Ray, 2002).

Brew et.al (2002) generated new structural maps and tectonic models for the whole Syria. Their research area comprised of the northern Arabian platform, especially Syria and immediately surrounding areas (Figure 1). Previous attempts were made to correlate the findings; however, these past syntheses relied on fewer data than currently available, and a full integration of all available data and results was never attempted. In the current work of Brew et.al, they took a truly regional approach, focusing simultaneously on all parts of the country, notwithstanding non-uniform data distribution. To achieve a fully regional and comprehensive tectonic analysis of Syria, they constructed data "coverages" or "layers" within a GIS. They used ESRI (Environmental Systems Research Institute) products, namely Arc Info and Arc View, for most of their work. Levant Lambert projection has been used in this study. Figure 2 is a simple demonstration of how selected coverages can be visualized.

GIS is particularly useful when interpreting remote sensing imagery, as the image can be viewed on screen and co-registered coverages overlain to aid interpretation. For example, known faults and folds mapped in the field can be overlain along with surface geology to establish the spectral and spatial characteristics of the various features and hence guide the interpretation. Figure 3 is a preview image of some Middle East Landsat TM images stored at Cornell GIS.

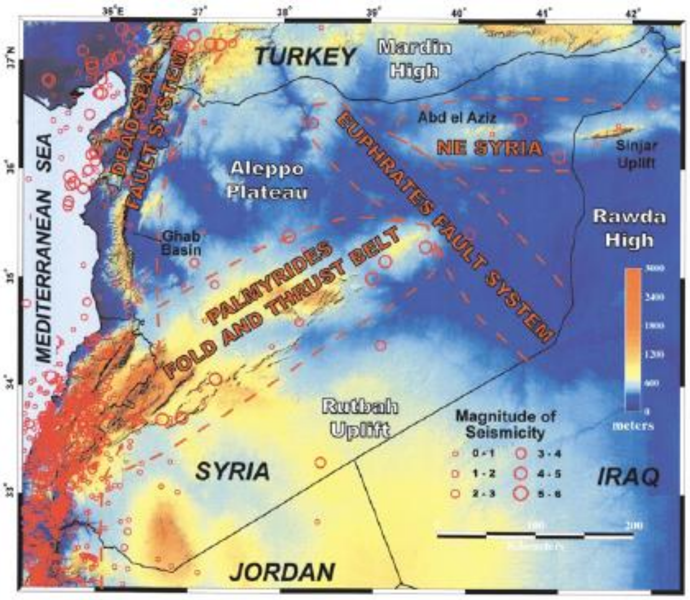

Figure 1: Topographic Image of the Northern Arabian Platform (Brew et.al, 2000)

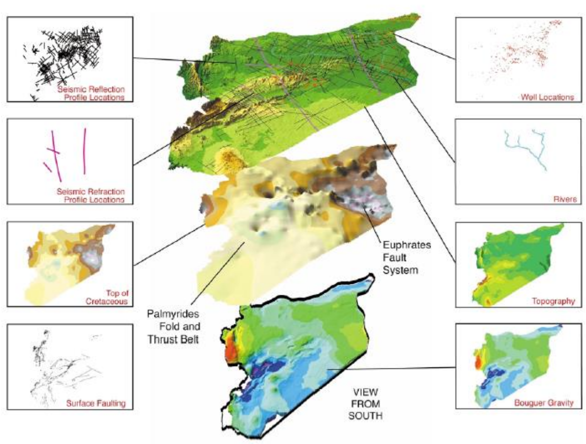

Figure 2: Composite image of selected coverages available at Cornell from within the GIS including a 3D perspective view of Syria showing data locations (Brew et.al, 2000)

A preliminary example of structure map construction is shown in Figure 4. The contours of depth to Lower Cretaceous are based on well data, together with digitized, depth-satellite imagery, and geology maps can facilitate mapping of features. The construction of a tectonic model for the Phanerozoic evolution of the northern Arabian Platform is the final goal of their interpretation and a preliminary version of such a model is shown in Figure 5. GIS played an essential role in this tectonic mapping of the northern Arabian Platform. Data manipulation, visualizations, and integrated interpretations, previously prohibited time-consuming or impossible, were quick and easy using this technology. This allowed faster, more accurate analysis, and better- quality, highly accessible, end products.

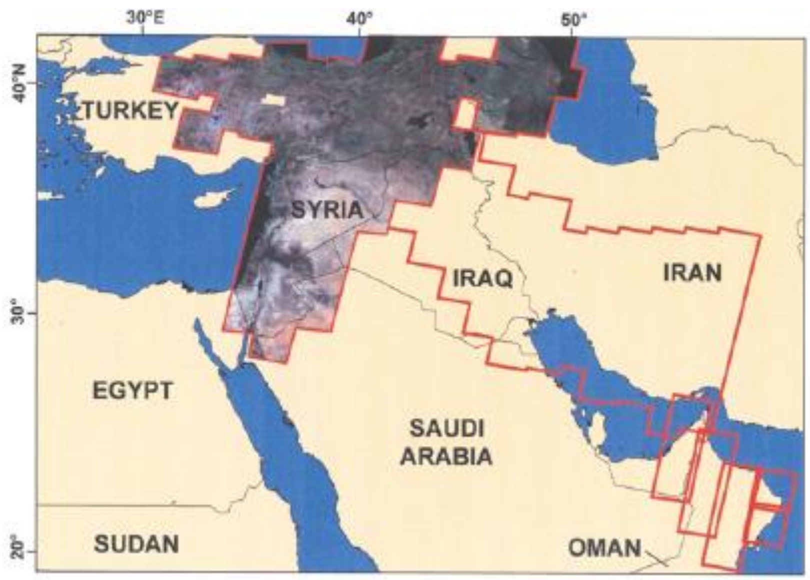

Figure 3: A preview image of some Middle East Landsat TM images (Brew et.al, 2000)

A preliminary example of structure map construction is shown in Figure 5. The contours of depth to Lower Cretaceous are based on well data, together with digitized, depth-satellite imagery, and geology maps can facilitate mapping of features. The construction of a tectonic model for the Phanerozoic evolution of the northern Arabian Platform is the final goal of their interpretation and a preliminary version of such a model is shown in Figure 6. GIS played an essential role in this tectonic mapping of the northern Arabian Platform. Data manipulation, visualizations, and integrated interpretations, reviously proibited time-consuming or impossible, are quick and easy using this technology. This allows faster, more accurate analysis, and better- quality, highly accessible, end products. The maps and models we are creating are important for continued hydrocarbon exploration within Syria and surrounding areas.

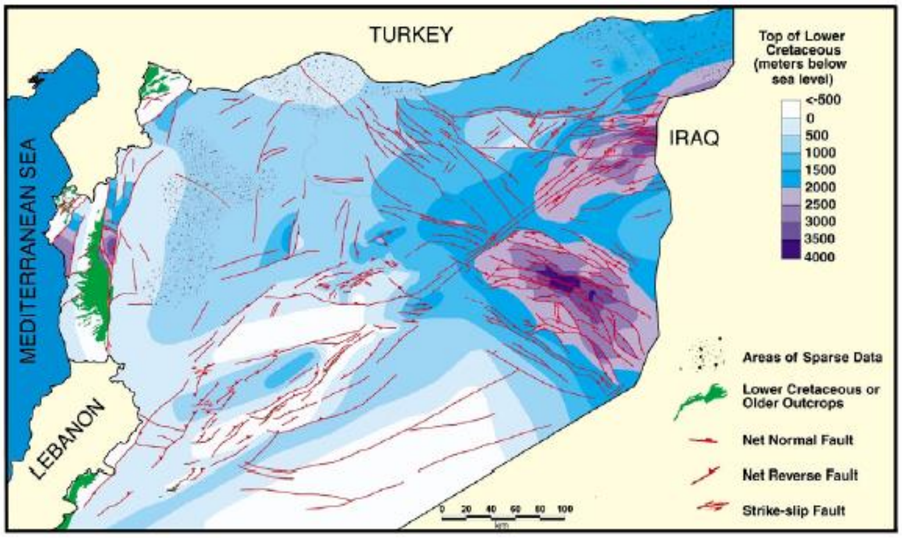

Figure 4: Preliminary structural map showing the top of lower Cretaceous Horizon (Brew et.al, 2000)

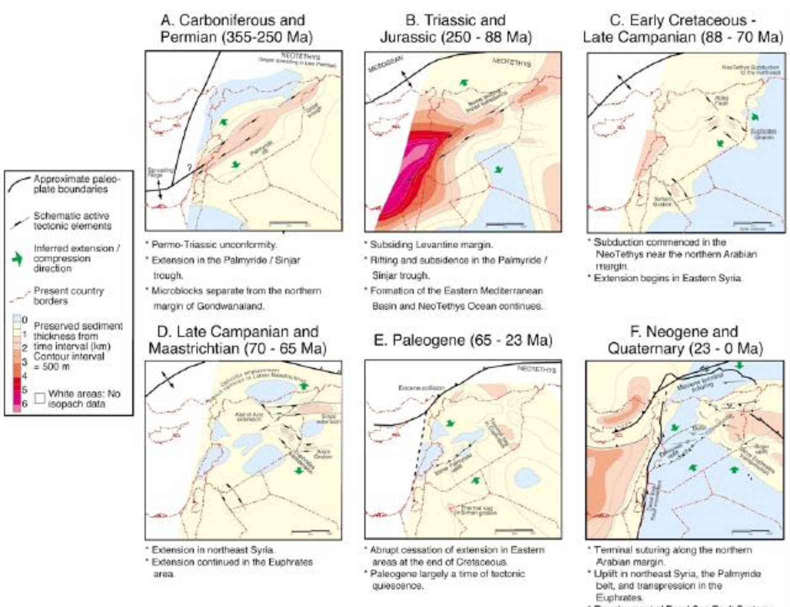

Figure 5 : Preliminary maps showing tectonic evolution of Syria (Brew et. al, 2000)

Table 1: All coveraged included, or planned for this study (Brew et.al, 2000)

	COVERAGE TYPE	COVERAGE	SOURCE/ REFERENCE	ORIGINAL SCALE	QUANTITY/ EXTENT	FEATURE TYPE	SPECIAL NOTES
NON-DATA BEARING	Seismic Data Locations	Seismic Reflection	Industry Basemaps	1:200 000	~17 000 km	Arcs and Points	–
		Seismic Refraction	Basemap	1:500 000	~875 km	Arcs	–
	Cultural Data	International Borders	DCW www.esri.com	1:1 000 000	Global	Arcs	–
		Urban Areas	DCW www.esri.com	1:1 000 000	Global	Polygons	–
		Roads	DCW www.esri.com	1:1 000 000	Global	Arcs	–
		Rail Roads	DCW www.esri.com	1:1 000 000	Global	Arcs	–
		Lakes	DCW www.esri.com	1:1 000 000	Global	Polygons	–
		Rivers	DCW www.esri.com	1:1 000 000	Global	Arcs	–
	Hydrocarb. Production	Field Locations	Various	1:500 000	Syria	Polygons	Production, Pay Zone etc.
		Pipelines	Various	1:500 000	Syria	Arcs	–
DATA BEARINGS	Well Data	Well Locations and Formation Tops	Various	Various	Nearly 400 Wells	Points	Selected Log Data to be included
		Facies Information	Well Logs	–	Selected Wells from Syria	–	From Well Logs
	Potential Field Data	Bouguer Gravity Anomalies	BEICIP (1975)	Various	Syria, Lebanon	Grid and Arcs	2 mGal Resolution
		Aeromagnetic Anomalies	Filatov (1958)	1:500 000	Syria	Grid and Arcs	25 nT Resolution
	Imagery	Landsat Thematic Maper	Eros Data Center edcwww.cr.usgs.gov	~30 m Ground Resolution	See Figure 4	Grid	Seven Spectral Bands
		Topography	GTOPO30 Gesch et al. (1999)	~1 km Ground Resolution	Global	Grid	Bathymetry also Available
	Geology / Tectonics	Geologic Map	Field Mapping Ponikarov (1966)	1:500 000	Syria, Turkey, Lebanon	Polygons	–
		Seismicity	ISC Dataset www.isc.ac.uk	–	~22 000 events for study Area	Points	–
		Earthquake Focal Mechanisms	Harvard CMT www.seismology.harvard.edu	–	–	Points	For Magnitudes >~5
		Volcano Locations	Ponikarov (1966) and Others	1:500 000	Syria, Turkey	Points	Ages also Available
		Detailed Field Observations	Various	1:1000	Palmyrides/ Coastal ranges	–	Detailed Surface Sections
		Tectonic Domain Boundaries	Cornell Interpretation	–	Northern Arabian Platform	Polygons	–
		Surface Folding	Ponikarov (1966) and Image Interpretations	1:500 000	Syria	Arcs	–
		Surface Faulting	Ponikarov (1966) and Image Interpretations	1:500 000	Syria	Arcs	–
INTERPRETATIONS	Structural Maps	Top Paleogene	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Fault Activity, throw etc.
		Top Cretaceous	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Fault Activity, throw etc.
		Top Lower Cretaceous	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Fault Activity, throw etc.
		Top Triassic	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Fault Activity, throw etc.
		Top Paleozoic	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Fault Activity, throw etc.
		Top Mid-Cambrian	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Prominent Seismic Reflector
		Top Metamorphic Basement	Cornell Interpretations	1:500 000	Syria	Grid and Arcs	Predominantly from Refraction Analysis
	Sed./Strat. Analysis	Isopachs	Interpreted	1:500 000	Syrian Mesozoic Section	Arcs	Future Project
		Facies Variation	Interpreted	1:500 000	Syrian Mesozoic Section	Arcs	Future Project
		Paleogeography	Interpreted	1:500 000	Syrian Mesozoic Section	Arcs	Future Project
		Source Rock Potential etc.	Interpreted	1:500 000	Syrian Mesozoic Section	Arcs	Future Project

5.2 Ground Water

GIS is playing a rapidly increasing role in the field of hydrology and water resources development. GIS can be used for a multiplicity of applications related to occurrence and movement of groundwater. In order to obtain long-term groundwater level change maps, GIS was used by (Napoli and Latin, 2003) to visually and spatially analyze water level data obtained from the U. S. Geological Survey (USGS) and Department of Water Resources (DWR). Change maps (Figures 6 and 7) were only constructed for areas of overlapping data from associated time periods. This limited the overall coverage; however, based on an assumption of homogeneity, an overall average change per year was calculated for the main portion of the Lucerne Valley groundwater basin (Napoli and Latin, 2003).

One of the main benefits of using GIS with groundwater modeling programs is that simulation results can be displayed geo-referenced, allowing further analysis and display of topological relationship between the model and other spatial features. In recent years various hydrological modeling options have become available in commercial GIS packages. Additionally, some hydrological packages have a live link with GIS packages and to perform specific hydrological operations. The most notable amongst them are:

- ModelGIS – pre-processor for the MODFLOW (USGS software for GW modeling) groundwater code that allows model input and output to be created, stored and displayed within ARC/INFO GIS on UNIX workstations.
- SiteGIS – Windows based software package for analyzing and presenting environmental data for soil and groundwater remedial investigations. SiteGIS is an application for a desktop mapping package MapInfo.

- Visual MODFLOW- is a commercial program developed by Waterloo Hydrogeologic. Its main advantage over MODFLOW is that it allows the user to design the finite difference grid and input the boundary conditions of the model in a graphical environment. Coupling Visual MODFLOW with ArcView, the most popular GIS software, promises increased accuracy in data input and opportunity to further process modeling output in GIS environment, as well as visually appealing presentation of results.

GIS can be used for almost all application related to groundwater management such as hydrogeological database management, groundwater targeting, resource estimation, groundwater recharge estimation, evaluation of ground water exploitation impact on environment (runoff, soil moisture, vegetation growth conditions etc.), evaluation and re-evaluation of groundwater resources for urban and rural fresh water supplies (Figure 8). Groundwater risk assessment can also be carried out using GIS such as studies related to removal, localization and remediation of contaminant plumes (including oil and radioactive pollution), ground water vulnerability assessment, environmental impact evaluation for civil engineering and human activity affecting ground water etc. Attempts have been made to develop Groundwater GIS using ArcView and ARC/INFO software in South Australia. This GIS contributes significantly to the assessment, development and management of the groundwater resources (Ray, 2002).

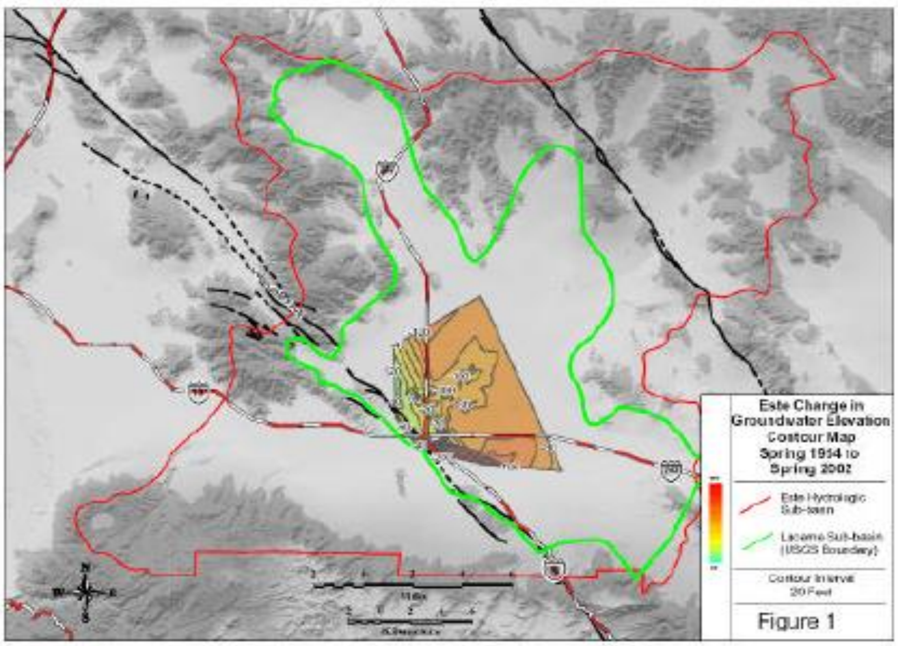

Figure 6: Changes in Groundwater elevation from spring 1954 to spring 2002

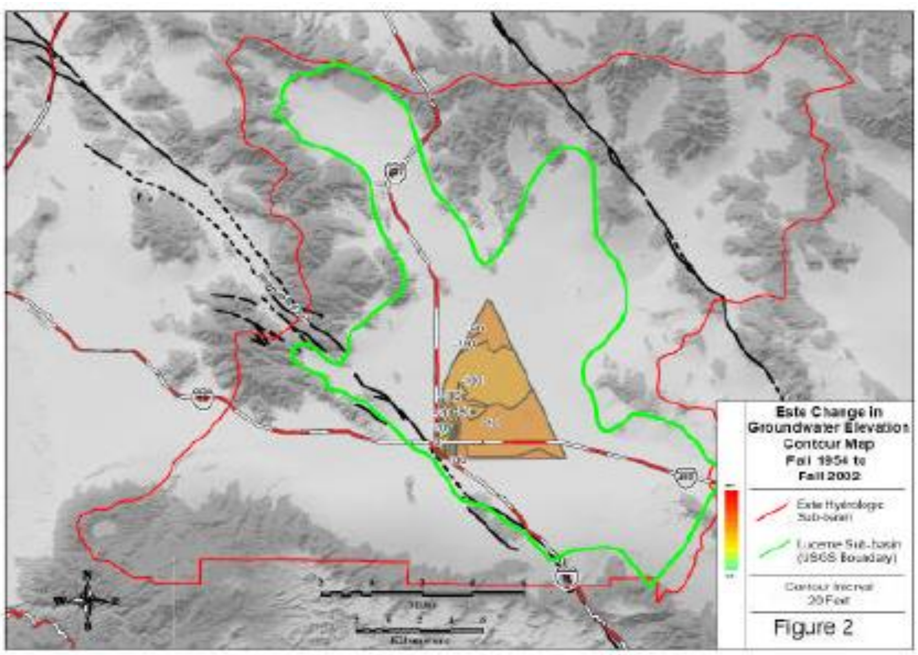

Figure 7:Changes in Groundwater elevation from fall 1954 to fall 2002

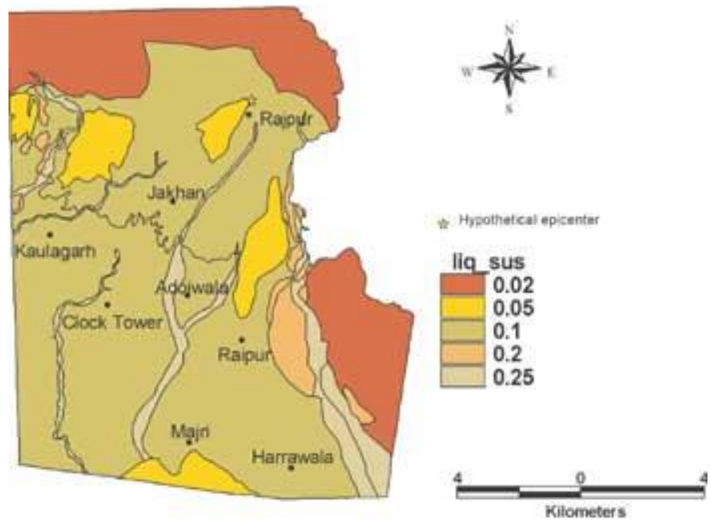

Figure 8:Liquefaction susceptibility in parts of Doon valley (Ray, 2002)

5.3 Mining and Mineral Exploration

The use of GIS in mineral exploration is now widespread, allowing the integration of disparate digital datasets into a single, unified database. The recommended approach is to compile all of the available geoscientific data within the GIS in the context of an exploration model in order to produce a mineral potential map. Careful consideration must be given in developing the model so that all of the relevant, important aspects of the deposit being sought are represented. The model is also very important in deciding what weightages to apply to each of these aspects. In the final analysis, these weightages may be arbitrarily applied by a geologist, with an intimate knowledge of the model and the deposit. He also decides which factors related to the deposit are most important, ranging down to those of least importance (a knowledge based approach). Another approach, which is not applicable in all situations, is to use a statistical method in order to decide upon weightages. The final result is a combination of all of the weighted values, producing a map which ranks the study area by degrees of perceived prospects. One of the widely used statistical data integration technique is the Weights of Evidence Method suggested by Bonham-Carter (1994) in which the quantitative relationships between data sets representing the deposit recognition criteria and known mineral occurrences is analyzed using Bayesian weights of evidence probability analysis. In this method the predictor maps are used as input maps and the end product is an output map showing the probability of occurrence and the associated uncertainty of the probability estimates of mineral deposits. In ample number of case examples, this approach has been applied using various GIS packages.

GIS is increasingly important in customizing and integrating a broad range of exploration data consisting of information on drill holes with summary stratigraphic logs, rock sample and drill hole sample geochemistry, mineral occurrences, magnetic and gravity images, digital geology, current and historic exploration details, roads and railways, localities, parks and reserve forests, restricted areas and integrated bibliography. IIRS has attempted to develop such a system i.e. Mineral Resource Information System, which is a database on mineral deposits, mainly iron and manganese ore deposits of the Iron Ore belt of Keonjhar and Singhbhum regions of Orissa and Jharkhand, India (see box). Similar type of database also exits with much more capabilities and information content like CBMap which is a two-part GIS database that assembles and displays information related to mineral exploration in Central America and the Caribbean Basin. Part 1, The Prospect Database locates and describes over 1000 base and precious metal mines and prospects and the second Part 2, The Land Status Database locates and describes over 2000 mineral concessions, national parks, forest reserves, reservations, and other areas of restricted mineral entry. The data from both the Prospect and the Land Status Databases can be overlaid on a series of detailed base maps including geology, geography, and shaded relief.

5.4 Seismic Designs and Acquisition

The industry has numerous powerful geological and geophysical planning, evaluation, processing, and analysis tools. To date, limited operational tools exist to effectively manage today's complex 3D projects. This initiative addresses these requirements with an effective implementation of GIS technology. The net gains are improved efficiency through effective information management and dissemination (Porter, 2000).

In land, TZ, and OBC seismic projects, significant effort and expense is invested in designing and securing an exploration prospect. Seismic operations are becoming more difficult to conduct due to culture, permits, restrictions, and divided interests. Valuable information is gathered and compiled for feasibility and evaluation in the design stages. Minerals, permitting, and pre-survey/hazard mapping information is provided prior to, and during the advance, survey, and drilling operations. These subsequent operations report incrementally on their respective progress as well. As these inter-dependant operations usually run concurrent, coordination is extremely challenging to achieve production quality, and safety objectives. Therefore, a system for managing, analyzing, and presenting information from initial inception to completion would provide benefit to a wide variety of user groups involved on the project. Utilizing GIS technology and open database design, user's can enter, access, query data spatially and /or on a time basis (temporal), and perform analysis to support decision making (Porter, 1997) as shown in Figure 9. The use of GIS data, along with the classical sampling and data processing considerations, can help the geophysicist to achieve the difficult task of recommending an “all things considered” 3D design. The examples will show 3D prospects from several areas in Latin America, where the design stage was greatly aided by the GIS data provided by our clients and/or other service companies (Figure 10,11). In all cases the design data base was transferred to the acquisition crew, to be used in operation assistance and monitoring (Elkington et. al, 1997).

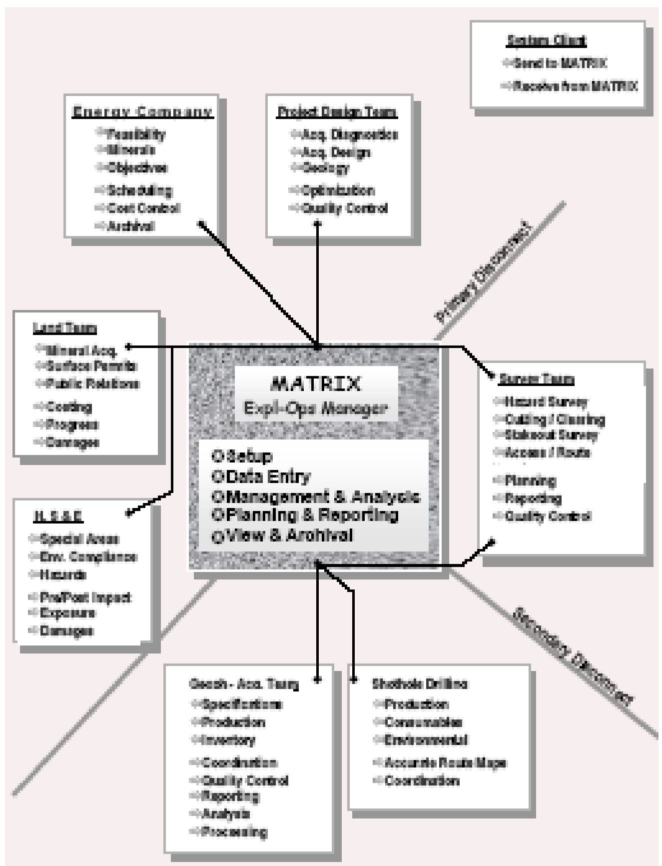

Figure 9: Open database design and using GIS technology (Porter, 1997).

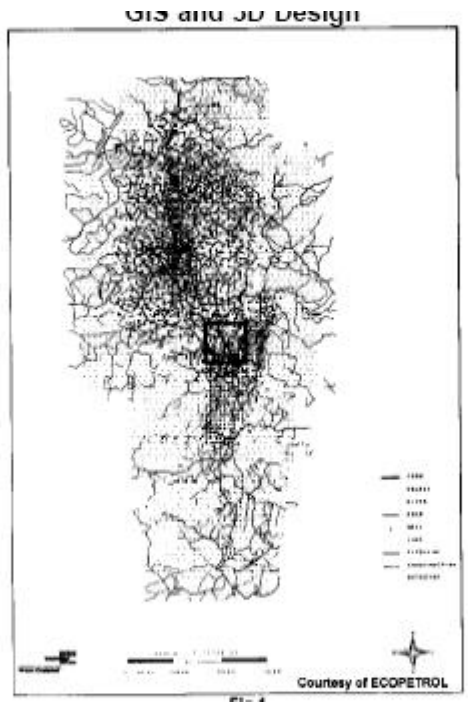

Figure 10: Relevant themes along with shot and receiver grids for the total survey area (Elkington et.al, 1997)

5.5 Petroleum Exploration and Development

GIS have been applied by the petroleum industry to manage, display, and analyze map based data since the mid 1980s. Data and information are clearly crucial to the success of any petroleum exploration and development effort. People who have been around the oil business for any length of time recognize that most companies are virtually swimming in data that they have paid large sums of money to obtain. Yet the industry have been plagued with the enigma of how to get at these data, and how to package and deliver them in the forms that are most easily and efficiently used by geoscientists. Over the past decade, GIS have come to the forefront of industry-wide attempts to transform the way that petroleum exploration and development information is obtained, processed, managed, and delivered (Coburn, 2000).

Bartagne et. al (2000) showed the importance of data and information to the success of any petroleum exploration and development effort. They also showed how GIS helps a new company in deciding to enter a new basin, selecting focus area, l;icensing geophysical/geologic data, acreage acquisition, partnering , exploration, drilling and facility planning, and reservoir management.

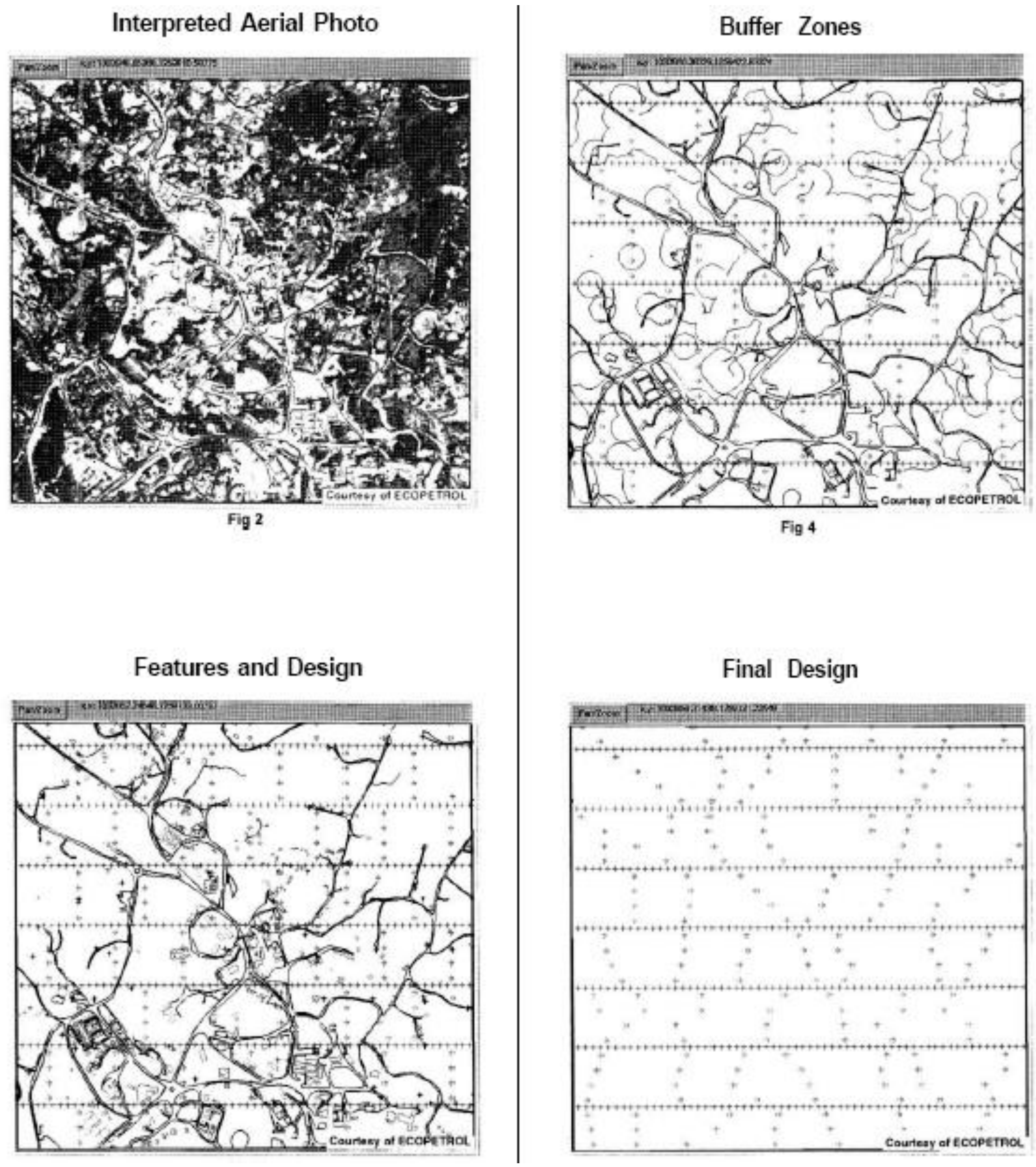

Figure 11: Zoom around the box drawn in center of Figure 10 (Elkington et. al, 1997).

5.6 Earthquake Studies

Potential earth science hazards due to earthquakes include ground motion, ground failure (i.e., liquefaction, landslide and surface fault rupture) and tsunamis. Ground motion is characterized by: (1) spectral response, based on a standard spectrum shape, (2) peak ground acceleration and (3) peak ground velocity. The spatial distribution of ground motion can be determined using one of the following methods such as, deterministic ground motion analysis (methodology calculation), probabilistic ground motion maps and other probabilistic or deterministic ground motion user-supplied maps. Deterministic seismic ground motion demands are calculated for user-specified scenario earthquakes. For a given event magnitude, attenuation relationships are used to calculate ground shaking demand for rock sites which is then amplified by factors based on local soil conditions when a soil map is supplied by the user. IIRS has done such studies for Bhuj with respect to recent earthquake and for Dehradun region with respect to a hypothetical event using ARCVIEW (Ray, 2002). Peak ground acceleration, liquefaction probability and lateral spreading are calculated and cross-checked with actual liquefaction in Bhuj region. For Dehradun region, different scenarios were built for assessing seismic hazard. Although these studies are very much generalized with respect to data variability, at least one point is highlighted that the role of GIS is obvious in creating such maps. Such maps can be used for calculating intensity and damage in different scenarios using damage assessment methodology such as RADIUS in GIS environment. GIS in conjunction with remote sensing and photogrammetry, can be used to identify hazards. Seismic faults and flood prone areas can be identified by scientists using GIS to analyse satellite image, aerial photos and field survey data (Lavakre, 1997).

Seismicity induced landslides can also be assessed in GIS using parameters such as Intensity; slope steep-ness; strength and engineering properties of geologic materials; water saturation existing landslide areas; and vegetative cover. Various integration techniques for seismic induced landslides like the one given in HAZUS methodology, can be implemented using simple matrix overlay in any GIS package.

5.7 Landslide Hazard Zonation

Landslide Hazard is defined as the probability of occurrence of a landslide with a specified period of time and within a given area, whereas the Landslide Hazard Zonation is defined as the division of the land in classes with equal landslide hazard (Varnes, 1984). A landslide hazard zonation provides information on the susceptibility of the terrain to slope failures and can be used for the estimation of the loss of fertile soil due to slope failures (in agriculture areas), the selection of new construction sites and road alignments (in urban or rural areas) and the preparation of landslide prevention, evacuation and mitigation plans (Jasmi, 1997). In the recent past various direct and indirect methods and techniques have been proposed to analyze causative factors and produce maps portraying the probability of occurrences of similar phenomena in future. The direct method consists of geomorphological mapping in which past and present landslides are identified and assumptions are made on the factors leading to instability, after which a zonation is made of those sites where failures are most likely to occur. The indirect method includes two different approaches, namely the heuristic (knowledge driven) and statistical (data driven) techniques. In the heuristic approach, landslide-influencing factors such as slope, rock type, landform and land-use are ranked and weighted according to their assumed or expected importance in causing mass movements.

In the statistical approach, the role of each factor is determined based on the relationship with the past/present landslide distribution. With the advancement of computing technology, it has become feasible to apply various statistical methods to analyze landslide phenomena and derive at reproducible hazard zonation maps. This is further facilitated by the rapid progress in the field of remote sensing, which provides most authentic information on earth surface features and processes involved. Moreover, information from remotely sensed data can be digitally processed and integrated with other ancillary information using GIS.

Recently IIRS has contributed towards a national mission launched at the behest of Cabinet Secretary for landslide hazard mitigation in most critical areas of H.P. and Uttaranchal Himalayas, subsequent to Malpa and Okhimath landslides killing over 300 people in 1998. This project was a joint effort of 11 government departments coordinated by NRSA. The database was generated on 1:25,000 using IRS-LISS-III and PAN merged data products and data integration was carried out in ARC/INFO GIS using customized add-on software modules on Analytical Hierarchy Process (AHP). The hazard degree can be expressed by the Safety Factor, which is the ratio between the forces that make the slope fail and those that prevent the slope from failing. Using one of the simplest models, the so-called infinite slope mode Factor of Safety can be calculated on a pixel basis. For example, the following formula can be easily implemented in any raster based GIS.

Lanzhou city is located in the area covered by big thickness loess. The three main type of the seismic hazard of loess are subsidence, liquefaction and landslide. Geographical map, micro zonation map of seismic acceleration, loess thickness map, geomorphologic map, ground water depth map, slope type map and geotechnical data were collected and digitalized to build GIS database. Subsidence and liquefaction prediction zonation has been described by Wang et al (2001). The data related with landslide were mainly seismic acceleration, contour, slope distribution and geotechnical data.

Microzonation result of seismic acceleration (Sun and Chen, 1991) was shown in Figure 12a. Figure 12b describes the slope distribution within the Lanzhou city. Figure 12c describe the seismic stability zonation in the city. Figure 12 d describes

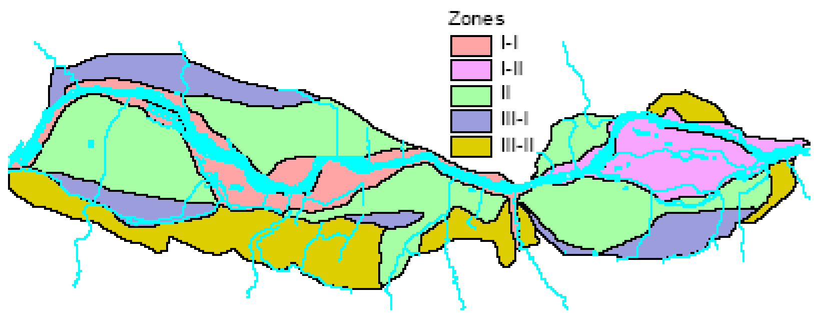

Figure 12a:Microzonation map of seismic acceleration at Lanzhou city (Sun and Chen, 1991).

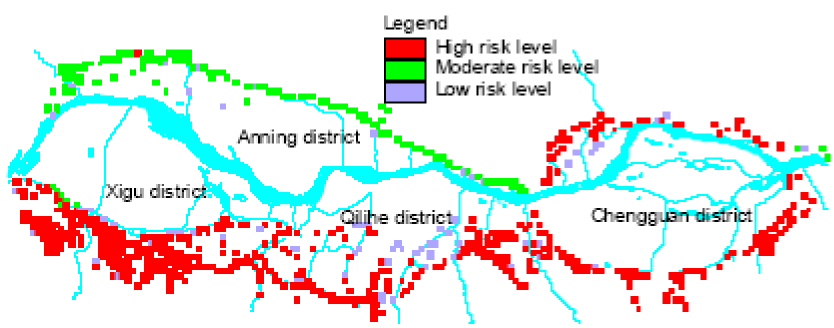

Figure 12b: The distribution map of slope types around Lanzhou city (Wang et.al, 2004).

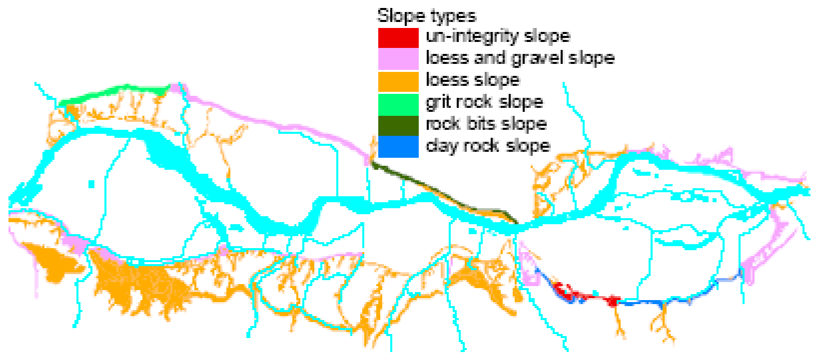

Figure 12c: Seismic stability zonation map of slopes around Lanzhou city (2% probability of exceedance in 50 years)   (Wang et.al, 2004).

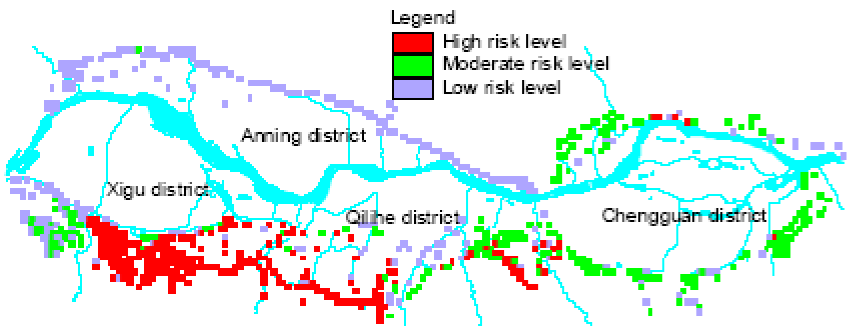

Figure 12d: Seismic stability zonation map of slopes around Lanzhou city (10% probability of exceedance in 50 years)   (Wang et.al, 2004).

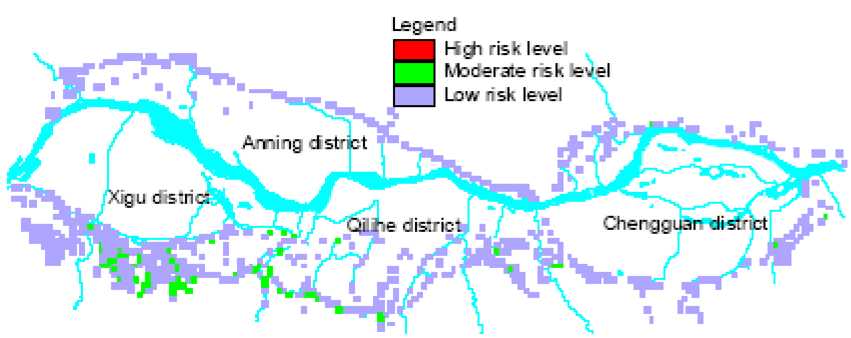

Figure 12e: Seismic stability zonation map of slopes around Lanzhou city (63.5% probability of exceedance in 50 years)   (Wang et.al, 2004).

Jasmi (1997) used the topographic map and digital elevation data, geology map, land use map, distance map that generated from fault, drainage and road map respectively, and remotely sensed data (satellite data and aerial photographs) for slope instability assessment and hazard zonation mapping of Cameroon Highlands, Malaysia. He used Information value method developed by Yin and Yan (1988) for this landslide hazard analysis. On the basis of his studies he prepared a risk assessment map of the area (Figure 13).

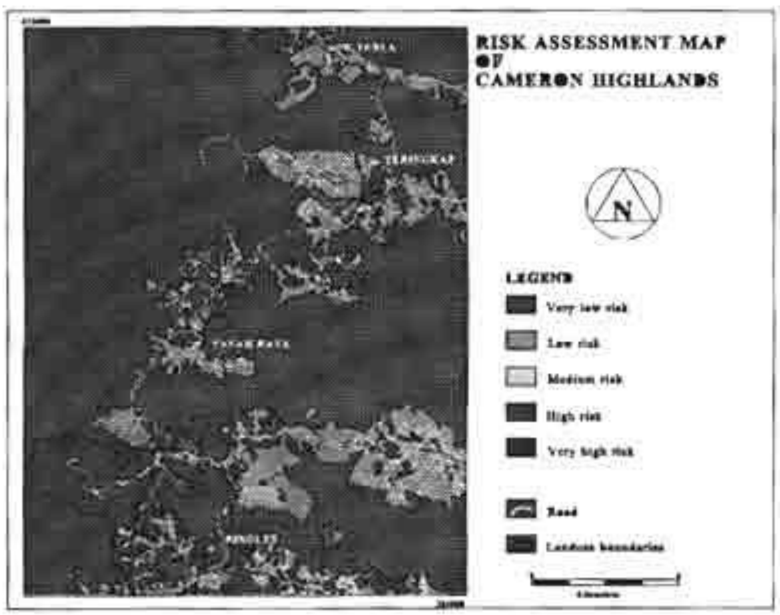

Figure 13 : Risk assessment map of Cameroon Highlands (Jasmi, 1997).

6 Discussion

The basic question that arises from this paper is that why we need GIS? Different workers have preferred to implement GIS because of the following reasons: (1) Continuous increase in data size requires a huge database system which is easily accessible to all. (2) GIS is a good tool for updating maps and transferring information from one scale to another within no time. Before GIS this was a very tedious and time consuming job. (3) The spatial analysis part of GIS is very useful for certain statistical analysis, and interpreting different images and maps. In land seismic operations GIS has shown improved project management and efficiency. Also report and map generation, and Project analysis and “post-mortems” has become much easier through statistical variance analysis within GIS. GIS provides the balance of data quality, economics and environmental impact. Different workers also showed how GIS helps a new company in deciding to enter a new basin, selecting focus area, l;icensing geophysical/geologic data, acreage acquisition, partnering , exploration, drilling and facility planning, and reservoir management.

7 Conclusion/Summary/Recommendations

The industry has numerous powerful geological and geophysical planning, evaluation, processing, and analysis tools. To date, limited operational tools exist to effectively manage today’s complex 3D projects. This initiative addresses these requirements with an effective implementation of GIS technology. The benefits of GIS are improved project management; improve survey quality by making use of the most current information, improved community relations and reduced exposures (e.g. trespass, damage, liability), improved safety through hazard recognition and demarcation, comprehensive map and report production for each user/client, comprehensive and up-to- date reporting, scheduling, and cost-control analysis, project archiving and direct import into other applications, analyses, and downstream processes etc. In the end, a comprehensive GIS database that incorporates cultural, geologic, geophysical, engineering, infrastructure, and business-related data can allow a company to analyze the different data types more effectively and gain insights that are not otherwise apparent.

Further, on the basis of our study, I would like to recommend the following:

- Different exploration companies covering a common geographic area should work together to develop a single GIS because this will save their money and will provide all the companies with more information.
- Companies should induct more GIS experts to enhance the efficiency of their work and to improve the quality of their results.

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