Oil and Gas Exploration in Ethiopia using GIS

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Abstract

Geographical Information System (GIS) had been utilized by PETRONAS in planning for its oil and gas exploration project in Ethiopia. Integrated geological maps had been developed using various data types such as topographical map, Digital Elevation Model (DEM), lithology, strike and dips, folds and faults, satellite images, cultural data, leads and prospects map to identify the best prospect to find oil and gas. Then, GIS was utilized to get the best seismic lines layout for seismic survey purpose. This method has save cost and time. This paper will provide an overview of how GIS is being utilized for oil and gas exploration work in the Ethiopian project.

Keywords: Integrated geological maps, seismic planning

1. E&P GIS Project Team, Petroleum Management Unit, PETRONAS
2. Ethiopia Project Team, Exploration Department, PETRONAS Carigali Sdn. Bhd.

1.0 Introduction

Exploration of oil and gas in remote operations has always depended on topographical surface especially in planning the best routes for seismic data acquisition for complex geological mapping, thus resulting in high cost and time during operations on the site. The Ethiopia project team utilized ArcGIS as a mapping tool to integrate geological data in generating complex geological structures of Ethiopia blocks. Such optimized seismic survey planning has resulted in reducing cost and time in determining the best routes and other factors during operations survey.

2.0 Project History

Petroliam Nasional Berhad; ("PETRONAS") was formed in 1974 under the Petroleum Development Act. PETRONAS, through its exploration wing, PETRONAS Carigali Overseas Operations (PCOSB) has been in operation in Ethiopia since 2003 with six (6) Petroleum Production Sharing Agreements (PPSA) comprising of five (5) explorations and one (1) development signed with Government of Ethiopia.

The PPSA covers two distinct regions namely Gambella and Ogaden Basins. Gambella has one (1) exploration block and Ogaden has eight (8) exploration blocks and two (2) development fields. PCOSB is the operator of all the nine (9) Blocks and the two (2) development fields.

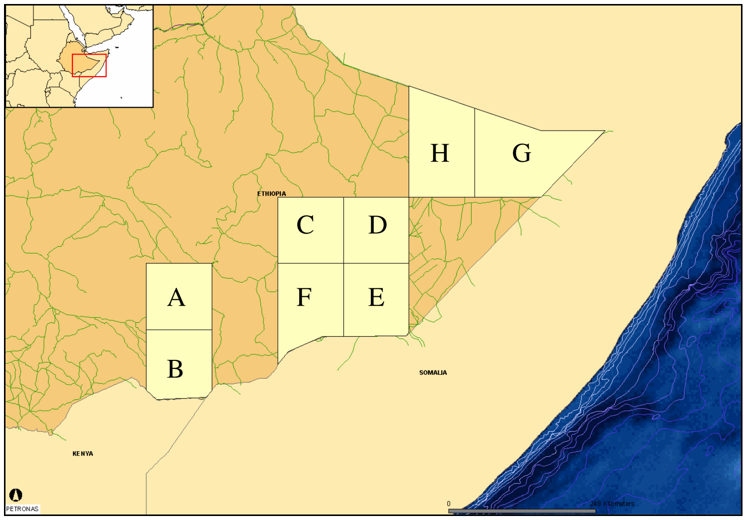


Figure 1: PCOSB Blocks in Ethiopia (Source: IHS Energy, 2007)

3.0 GIS in PETRONAS

Enterprise GIS started operations in PETRONAS through Petroleum Management Unit (PMU) since 2005 with its main objectives in centralizing geospatial database to assist exploration and production business within domestic and international operations.

PMU with PCOSB (Ethiopia) worked together in utilizing GIS in planning and decision making of seismic survey operations in Ethiopia. With ArcGIS capabilities in handling huge spatial databases and coordinate integrity, the seismic planning improved time consumption in determining the best seismic lines location, which reflects the data quality during operations.

4.0 Geological Background and Projects Challenges

Ethiopia is located in eastern Africa in the southern Red Sea region. It borders Sudan on the west, Eritrea on the north, Djibouti and Somalia on the east, and Kenya on the south. The topography of Ethiopia consists of a central high plateau bisected by the Ethiopian segment of the Great Rift Valley into northern and southern highlands and surrounded by lowlands, more extensive on the east, where PCOSB blocks are located and southeast than on the south and west.

The plateau varies from 1,500 to 3,000 meters above sea level and features mountainous uplands separated by deep gorges and river valleys, especially in the north. The highest point is Ras Dashen at 4,620 meters in the northern highlands. In the east, the Denakil Depression, part of the Rift Valley, is in places 115 meters below sea level and is one of the hottest places on earth. Working area, Block 3&4, is located in Ogaden Basin, which is in south East of Addis Ababa, near Kenya and Somalia.

PCOSB Blocks belongs in the semi desert area with three geographical terrains that includes mountain, hills and plain, which causes the field operation inconvenient. The layers of rocks and big pieces of stone and gravel can be seen frequently, indicating that the surface soil is very thin with an average thickness between 0.5 to 1 meter, overlying possible bedrock or large boulders. The Genale River, which flows throughout the year, runs through western blocks. The climate is semi-arid with the rainy season extending from October till April. Fortunately, the rainfall is very little. The average temperature during the dry season is about 38℃. There are some residents, and the residents live on farming.

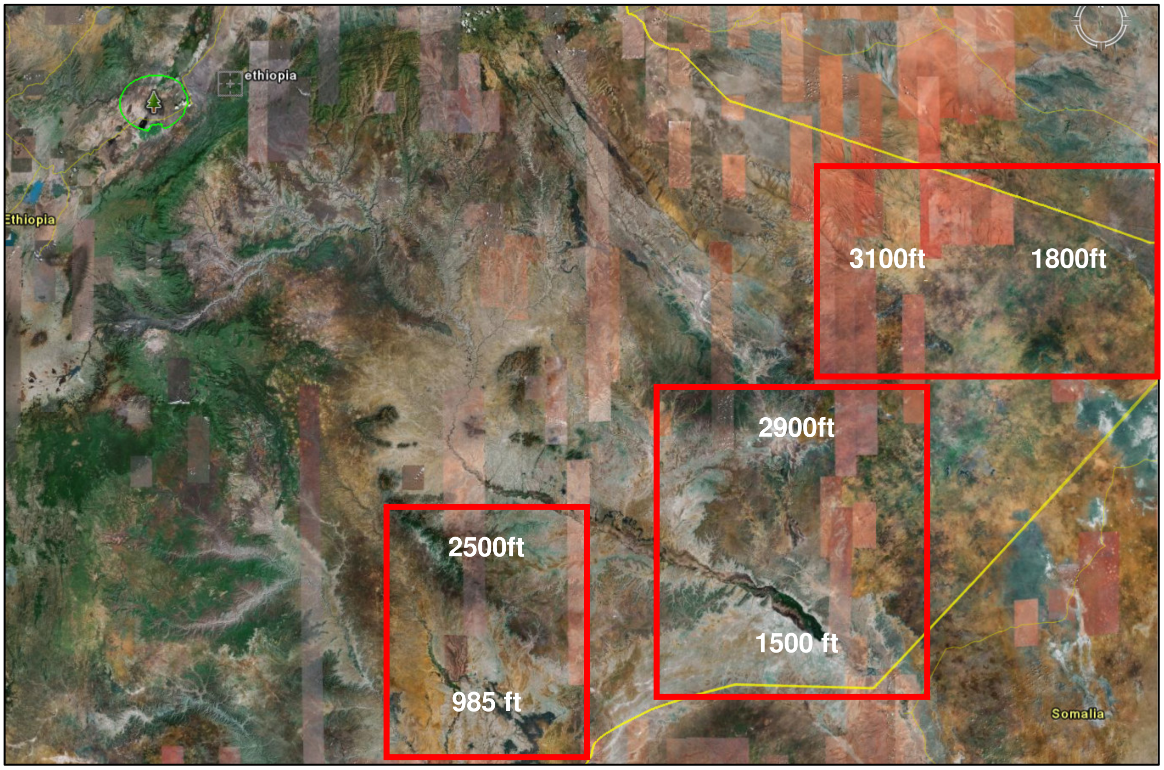


Figure 2: Surface Topographical of PCOSB Areas from Satellite Image

Figure 3: Rough terrain in operations areas

This topographical and climate factor posed several challenges during the Ethiopia exploration seismic survey projects;

a) Access to our blocks/areas limited due to rough topographical surface and this has affected seismic survey lines planning;
b) Difficulties in measuring and identifying the best routes of survey lines which reflects the poor data collection of subsurface; and
c) Health, Safety and Environmental (HSE) matters

In exploration projects, one of the first steps taken is the creation of reconnaissance maps. Such maps are typically produced relative to the available datasets from previous geological and geophysical study integrated with latest datasets, which can present distinct trends, patterns and anomalies of surface and subsurface structures and which can then be used to evaluate and determine the seismic routes.

ArcGIS was then utilized to map the study area by integrating various datasets to develop a better picture especially in topographical surfaces

5.0 Geophysical Methods in Hydrocarbon Exploration

In oil and gas exploration, geophysical applications like seismic methods, gravitational methods and to a lesser degree, magnetic methods will determine and locate the geological structures suitable for the accumulation of oil. The applications of those methods will results different approach of determination prospect area;

Magnetic	Gravity	Seismic
Will determine:	Will determine:	Can tell:
a) Limits of basins	d) Basin shape and extent	a) Types of structures
b) Depth to basement	e) Structural trends	b) Structural character
c) Basement lineations	f) Fault locations	c) Relation of different features
	g) Prospects and leads	d) Sediment velocities
		e) Sediments which flow
		f) Unconformities
		g) Direction of sediment source
		h) Elements of geological history
		i) Inferences from reflection character
		j) Inferences of depositional environment
		k) Inferences of age
		l) Problems in mapping
		m) Prospect leads and prospects definition
		n) Leads as to gas accumulation

Table 1: Geophysical Methods

The geophysical exploration method using seismic techniques consists of an energy that sends a sound wave into the earth, the wave reflects off geologic layers, returns to the surface and is recorded using motion sensitive receivers. The result describes the traveling time taken from the source until reaching the receiver. Data processing algorithms convert the recorded waves into an image of the earth's subsurface structure. This image is widely used as an exploration tool by the oil and gas industry.
These methods were used during exploration and appraisal study of Ethiopia project. The project commenced from regional framework of the area through basin study, to determine the potential

play (possible hydrocarbon accumulation), until the seismic 2D and 3D design to understand the subsurface of the targeted areas (*see Figure 4*). Seismic projects typically cover tens to hundreds of source and receiver points within each square mile. Surveying each point is a requirement to obtain accurate position and elevation. Projects of this magnitude require extensive planning, scheduling, and communication resulting in a constant need for a variety of surface maps and models. GIS is a tool providing multiple benefits for such operation, especially in areas of rough terrain.

a) Regional Geological Mapping using GIS

Prior to the study of the blocks, geological data was captured from previous study conducted and from many sources. This process will evaluate the targeted areas by comparing and re-evaluate potential targets.

During the evaluating of geological structures of the areas, integrated geological maps were generated. This comprises the gravity and magnetic with DEM and topography overlays. The maps were to picture the shape of the basin, play, prospects and leads.

The maps were generated from many data sources, either digital or hardcopy. Hardcopy maps were geo-referenced to verifying coordinate systems for Ethiopia and overlay with other datasets in single coordinate systems.
The ability of ArcGIS in integrating data has played a key role in reducing time in resolving some of the issues for example uncertainty of coordinate systems, misplaced of location from data sources, etc.

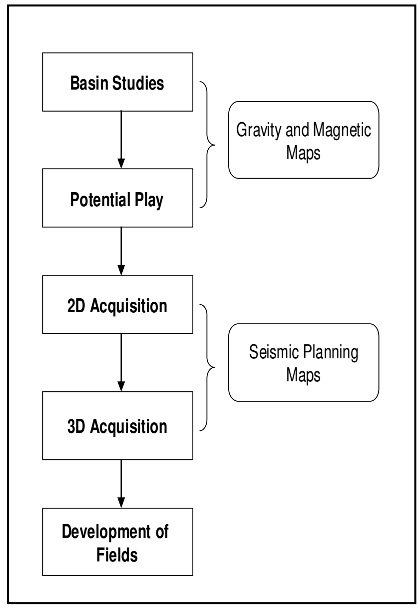


Figure 4: Exploration Workflow

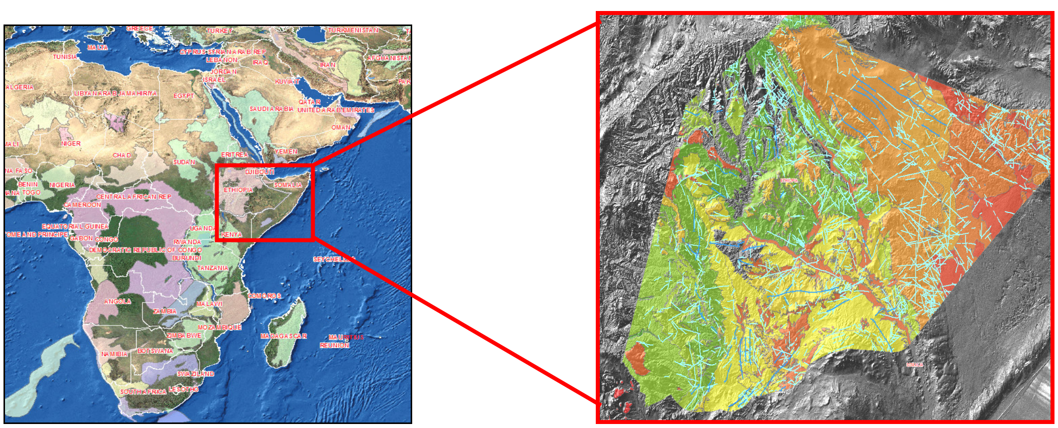


Figure 5: Regional Geological Mapping using ArcGIS

b) Seismic Survey Planning

Increased efficiency has brought the cost and time of seismic survey operations. Careful planning can result in more cost-effective acquisition and processing, and in data of sufficient quality to benefit the most advanced processing.

Before the first shot is fired or the first traced recorded, geophysicists must determine the best route to reveal the subsurface target. Generally, they would also consider locations and types of sources and receivers and the time and labor required for acquisition. Many additional factors, including HSE issues, must be taken into account such as:

1) Topography – seismic line must be as straight as possible for better data acquisition – how flat is the topography;
2) HSE matters; access due to political situations, safety, etc
3) Subsurface structures;
   a. Inline seismic basically must follow the dipping topographical structures (*Figure 5*)
   b. Crossline seismic must follow the strike of the topographical structures for accurate seismic reflection data (*Figure 6*)

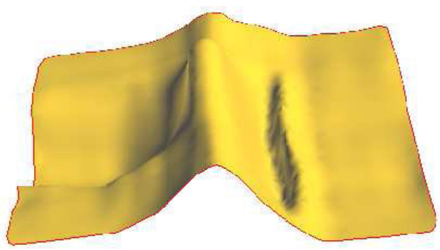


Figure 6: View from strike direction

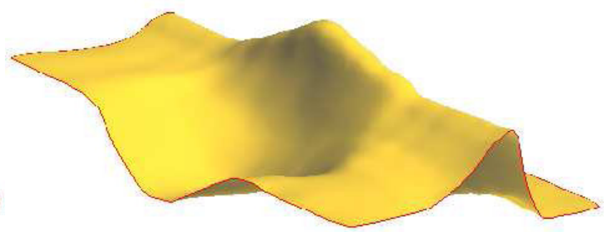


Figure 7: View from dip direction

Conceptual of strike and dip structures in determining the seismic lines (Crossline and Inline)

Those factors reflect the survey lines determination. For example, the western blocks, A and B that have a rough topographical surface, range from 160m to 1500m, disrupt the crosslines which has been planned straight from bottom to the end of the block. The disruption is determined by visualizing topographical surfaces from DEM and Hillshade of the area found the valley in the middle of the planned survey lines (*see figure 8*).

By integrating the datasets and visualizing using ArcGIS, the exploration geophysicists shifted the lines to a new location. The process improved the understanding of site survey area and reduces time of accessing and dropping seismic sources while in operations.

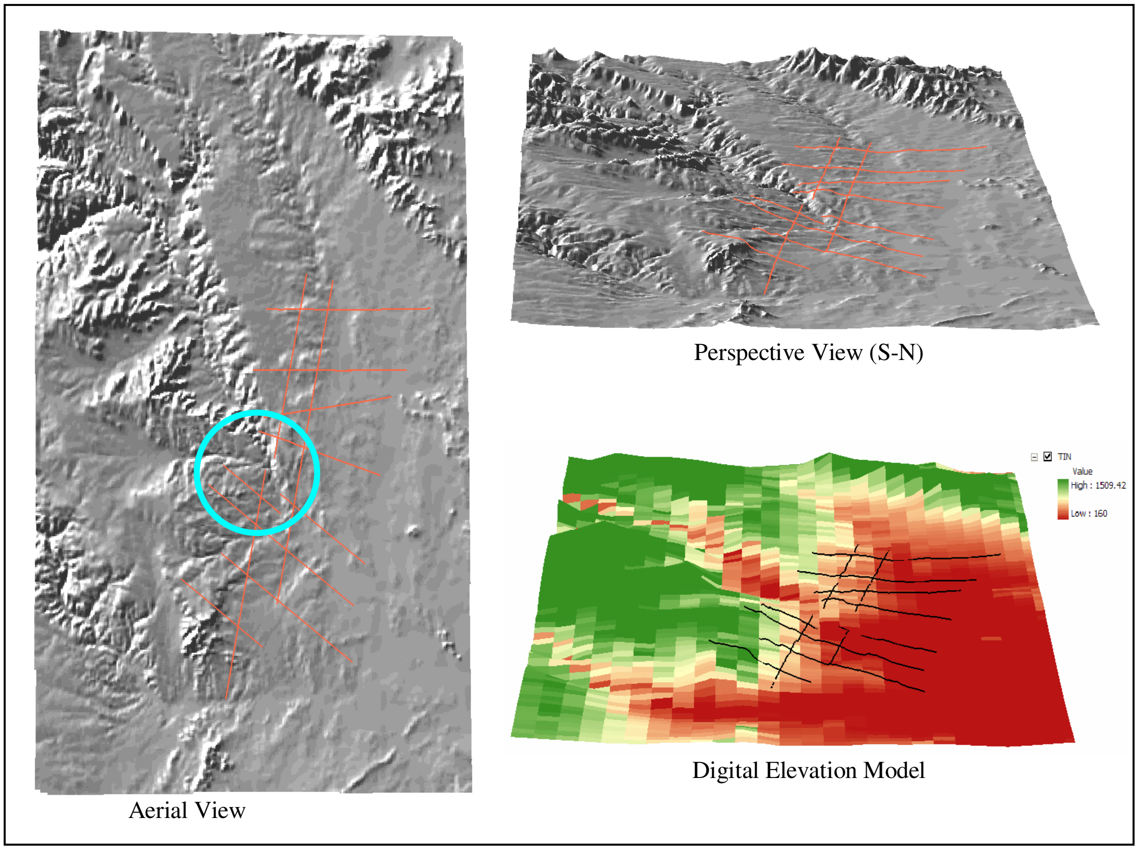


Figure 8: Topographical Analysis using ArcGIS 3D

c) Integrated Geological Maps

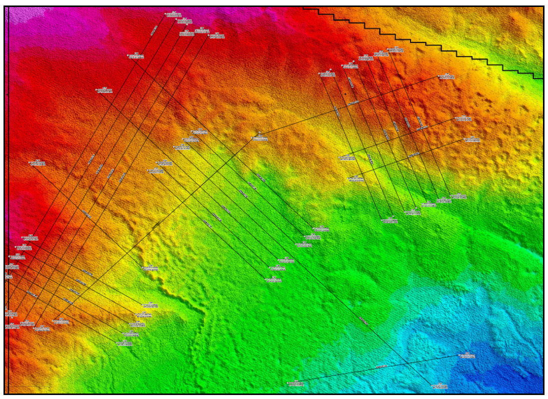
Exploration requires the analysis of a lot of different types of data such as satellite imagery, digital elevation model (DEM), seismic surveys, surface geology studies, subsurface and cross-section interpretations and images, well locations and existing infrastructures information. GIS can tie these data together to the location in question and allow us to overlay, view and manipulate the data in the form of a map to thoroughly analyze the potential of seismic survey lines locations.

Initially, multi-disciplinary geosciences survey was conducted of the country. Multiple potential study locations were selected by;

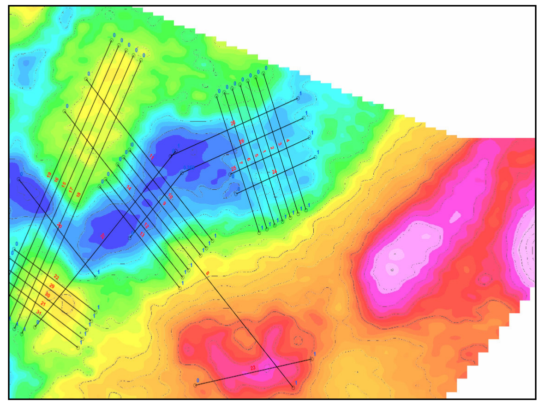
a) The study of surface lineaments, fractures and circular and accurate anomalies identified from satellite images and aerial photographs.
b) Analysis and graphical representations of fracture orientations, lengths and density. The fundamental fracture characteristics used for structural interpretation were characterized with hybrid geosciences workstation.
c) Investigation of regional geology and geophysical elements.
d) Mapping and analysis for areas with:
    i. Older structures that could be identified and mapped by a 2D and 3D seismic survey; and
    ii. Topography allowing easy vehicle access in relatively to unwooded areas.

Through the integrated datasets using GIS, raster data, such as aerial photos or satellite imagery, can be incorporated with vector data, and surface culture, such as contours, topographic landmarks, digital elevation model or points of interest can be presented. Maps of the following features and characteristics were created in the first phase of exploration reconnaissance mapping program:

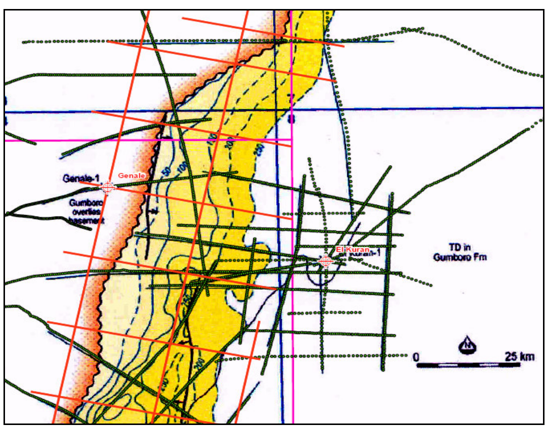
- Topography maps inclusive of satellite images, DEM and TIN
- Cultural maps of Ethiopia from public data and internal datasets
- Geophysical maps inclusive of gravity, magnetic and geological datasets
- Seismic survey design maps inclusive of 2D and 3D



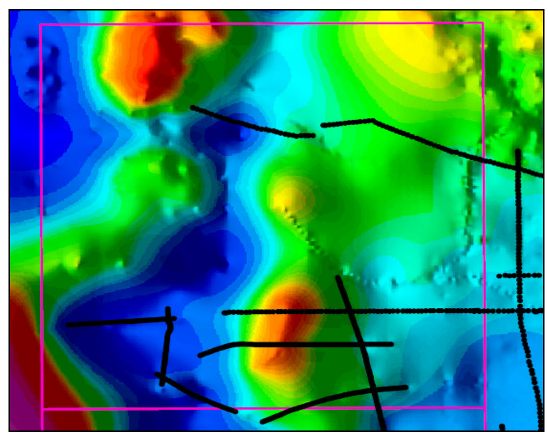
(a) Topography from SRTM



(b) Gravity Map with seismic lines



(c) Seismic Overlay with Subsurface



(d) Magnetic map overlay with seismic lines

6.0 Benefits of GIS

Discovering new sources of petroleum ahead of the competition is one key to staying successful in the petroleum industry. Petroleum exploration is a very complicated field dependent on a multitude of variables of datasets. The benefits of utilizing GIS for the Ethiopia project were:

- Time saved in designing seismic survey by:
    - Less exposure to HSE risks by planning the best routes of seismic direction from topographical evaluation from DEM, satellite images and topographical maps.
    - Major issues of coordinate's discrepancy can be resolved in ArcGIS – GeogCRS and ProjCRS

- Costs saving:
  - From seismic survey design
  - Reece survey will lead into the site operations.
- Integration of the contribution of various team members through cross-discipline interpretation and software functionality.
- Provision of new methods for visualizing data sets through the use of symbology.
- Dynamic mapping of digital databases.
- Presentation of data in various forms such as maps, charts, data tables and query results.
- Sharing of integration of and access to centralized databases via computer networks or the internet through web-based GIS
- Linkage of multiple software applications and formats.
- The project data will be archived into centralized GIS database (Geodatabase) will be useful for revision in future study of the areas

7.0 Conclusions & Suggestion

The purposes of this study is to demonstrate the exploration workflow by utilizing GIS in designing seismic survey with integration of geological, geophysical and other data to improve the exploration process in terms of cost, accuracy and time. The Ethiopia study has demonstrated this by compiling, registering, and analyzing data obtained from various methods (Remote Sensing, Geophysics, etc) in GIS for part of PCOSB Blocks in Ethiopia.

The ability to compare and integrate various datasets through GIS, individually or in combination, enables the exploration geoscientist to extract the maximum information possible of the study area, for example, surface topography, fault structures, dip-strike structures, HSE matters and applies to design of the seismic survey prior to the operations on-site. This exploration process has improved the confidence of the survey to be conducted and efficiency of saving cost and time.

Acknowledgement

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