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Application of Geographic Information System (GIS) to Solid Mineral Resources Information Management

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In this paper, a typical GIS information retrieval model for topographical, geological, minerals and land use maps developed. A 5-layer data topographical and geological information modelling and retrieval for a typical mineral region (Niger Delta, Nigeria) was also designed, for the use of government agencies and prospective investors. We also examined how GIS can be used to select reclamation plan options; from land use and land cover maps.

Key words**:** Information, Topographical maps, Geological maps, Mineral resources, Land-cover, Degradation, Environment.

Introduction

Solid minerals are natural resources of great technological and commercial importance as raw materials for several branches of modern industries. The new Nigerian national policy on solid minerals that was introduced in January, 1999 (Daisi 2000) is geared towards a private sector has led development of the vast mineral resources of the country (Onyemaobi 2001), including the Niger Delta region. A solid mineral development policy is placed to ensure an orderly development of the mineral resources of a region or country by providing clear rules for predictable behaviour of the authorities, unambiguous regulation for the exploitation of the minerals and a clearly prescribed pattern of such development with clearly defined roles of different interest groups (World Bank 2000). There is nothing more reassuring for any investor than to know that his investments are secure wherever he decides to make such investments in expectation of adequate returns. This reassurance could only be guaranteed with a proper legal framework in place.

The Federal Government of Nigeria has provided such legal framework by the promulgation of Minerals and Mining Act No.34 of 1999 (FGN Gazette 1999). Under the operative constitution of the Federal Republic of Nigeria, 1999, section 4, the National Assembly shall have power to make laws with respect to any matter included in the exclusive legislative list (FRN Constitution 1999). Out of which, item 39 provides for the legislative powers of the National Assembly to be exercised with respect to "Mines and minerals, including oil field, oil mining, geological surveys and natural gas". The Minerals and Mining Act No.34 of 1999 is set to achieve the desired result of attracting foreign investments into Nigeria's huge untapped mineral resources by removing all known obstacles to private sector participation and further provides adequate protection to such investors in the minerals industry. To effectively achieve these tasks, it is desirable that an adequate modern information database should be provided. The application of Geographical Information System (GIS) comes handy in this regard.

Working principle of GIS. GIS is a set of procedures and computer hardware / software for organizing, storing, retrieving, analyzing, and displaying geographical and other data. Desktop GIS is an immensely powerful computer mapping system and a tool for managing information of any kind according to where, it is located. In the strictest sense, a GIS is a sophisticated computer based on mapping and information retrieval system, a system capable of assembling, storing, manipulating and displaying geographically references information (Smith 2000). The total GIS includes operating personnel and the data that enter into the system. Every GIS system consists of three primary components namely: (i) a powerful computer graphics program that is used to draw a map (ii) one or more external databases that are linked to the objects shown on the map. This linkage permits changes entered into the database to be immediately displayed on the map and questions could be asked about the database directly from the map and (iii) a set of analysis tools that can be used to graphically interpret the externally stored data, for example by showing objects or regions that meet certain criteria in different colours or shadings (USGS 2002). To form a true GIS, all three components must be integrated. Forest (2001) stated that GIS links sets of features and their attributes and manages them together in units called themes or layers. Themes are made up of

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features with a set of common attributes. All the themes or layers for a geographical area are taken together to make up a GIS database. For example, all mineral deposits have locations, thickness, angle of dip, strike, itc. The themes or layers in a GIS database can be used to analyze multiple situations and solve multiple problems. The design of a GIS database is strong because it's flexible. New themes can be added themes can be to create more themes, or combine themes if they have common characteristics or old ones can be deleted from a GIS database.

The target area for this study of application of GIS to solid mineral resources information management is the Niger Delta region of Nigeria, comprising of the oil producing states of Abia, Akwa Ibom, Bayelsa, Cross Rivers, Delta, Edo, Imo, Ondo and Rivers. The Niger Delta Development Commission (NDDC) has recently been set up by the Federal Government to oversee the development of the area. The region is one of the largest wetlands in the world and covers an area of about 90,000 Km^2 (Alan and Strahler 1997). The objective of this paper is to develop a typical GIS information retrieval model for topographical maps, geological maps, mineral maps and landcover maps. A 5 layer data topographical and geological information modeling for Niger Delta region of Nigeria was also designed.

Materials and Methods

The methodology for the study includes:
(i) Application of Global Positioning System (GPS), satellite imagery, and Geographic Information System (GIS) to define, delineate and map out the solid mineral deposits in the Niger Delta region.

(ii) Global Positioning System (GPS) in conjunction with high resolution remote sensing and GIS to be used for land studies to provide high accuracy ground truth data related to solid minerals, health, safety reclamation and environmental effect of mining in the Niger Delta region.

(iii) A typical GIS information retrieval model for topographical map, geological map, minerals map and land use map to be developed.

(iv) A 5 data layer topographical and geological information modelling and retrieval for a typical mineral region to be designed, for the use of relevant government agencies and prospective investors.

The plan included the following:

*Step 1.*Generation of the topographical map of the entire regions showing roads, towns and villages, lowlands and highlands. This includes (a) acquisition of satellite images, (b) satellite image interpretation and (c) production of topographical maps.

*Step 2.*Production of geological maps of the area. Note: the existing maps were produced in the early 60's using area photograph. These were updated.

*Step 3.*Re-connaissance survey and mapping of areas of known mineral deposits on the map to produce mineral map of the region.

*Step 4.*Ground-truthing data collection to confirm features observed on the satellite imaginary and to get the proper coordination using Geographical Positioning System (GPS) equipment.

*Step 5.*The use of GIS to integrate all spatial data, and provide information on the following points: (a) mineral name (b) location of the mineral using GPS values, (c) probable area of coverage and deposit sites, (d) probable thickness and grade, (e) proved reserves and / or volume, (f) what conditions exist at a particular location? (g) can the mineral be mined economically? (h) possible effects of the exploitation on the environment-farmland, forest, ecosystem and building, etc? (i) the impact of waste facilities on the environment and (j) what are the possible industrial linkages?

Results and Discussion

Since a map is the main method of representing the location of geographical/geological features on the landscape the latest GIS software was used to produce relevant mineral, topographical, geological and land use maps for the nine states in the Niger Delta area. These maps are made up of different geographical features represented as points, lines, and/or areas. Each feature was defined by its location in space (with reference to a coordinate system). The attributes such as the rock formations/soil types in a mineral resource site were typically represented graphically by using different symbols or colours. For the application of GIS technology, attributes have been coded in a form in which they can be used for data analysis. This would imply loading the attributed data into a database system and linking it to the graphical features. Geographical/geological data, often referred to as spatial data features, would be referenced in a coordinate system that models a location of mineral resources on the earth surface. The coordinate systems are usually of various types. For natural/mineral resource application, the most common are:

(1) geographic coordinate such as latitude and longitude e.g. 56 27^{o}. 111′
(2) a map projection e.g. topographical, geological and mineral maps.

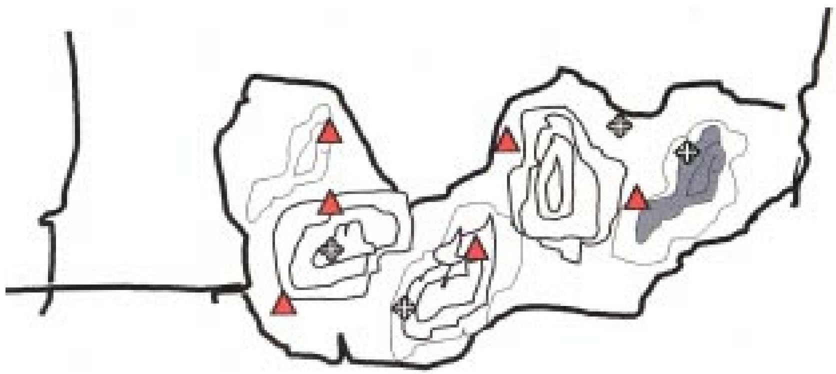

Fig 1. A typical topographical map for information retrieval for Niger Delta region.

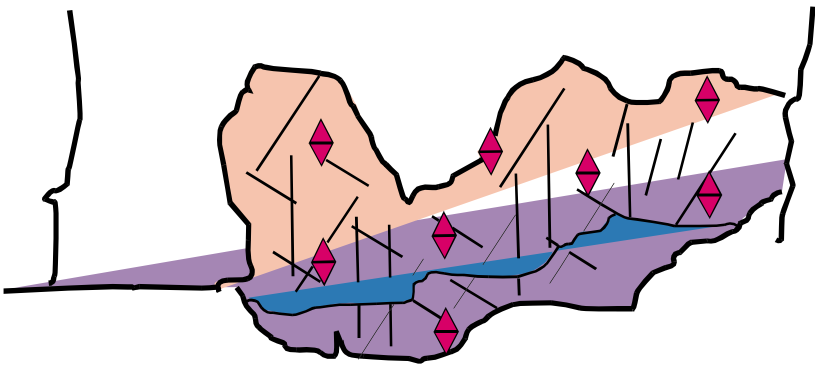

Fig 2. A typical geological map for information retrieval for Niger Delta region.

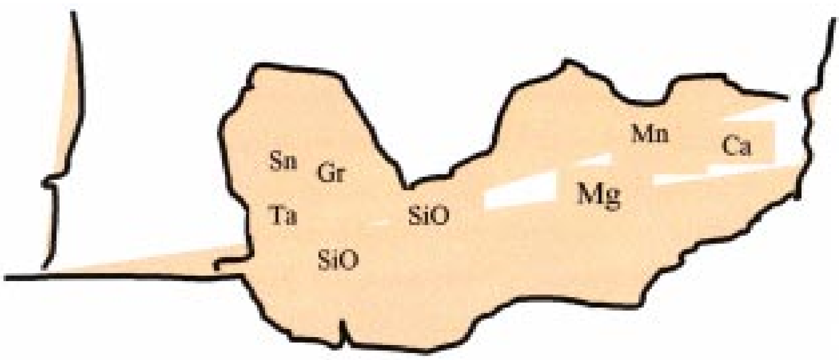

Fig 3. A typical mineral map for information retrieval for Niger Delta region.

(3) a legal survey description

Maps could then be prepared in digital format and topologically cleared, geo-referenced and in industry standard topological format, using the latest GIS software. Example of information that would be shown for topographical map, mineral map and land cover map are discussed below:

Topographical maps. Examples of information that appeared on topographical maps include those shown in Table 1 and Fig 1.

Geological maps. Geological maps were produced for each state and the entire Niger Delta region at locations where minerals are identified and the information in GIS format will appear as shown in Table 2 and Fig 2.

Mineral maps. Mineral maps were produced for each state and the entire region. The attributed data for each mineral map in GIS form will contain the information shown in the Table 3 below. However, only the location objects will appear on the map as shown in Fig 3.

Table 1
Data for topographic map

Common identifier	Retrievable information				
	Elevation	Relief	Landscape	Vegetation	Soil type
Contour lines, bench marks and some acronyms as location object	e.g. heights above and below reference datum	e.g. valley, mountains, etc.	Description of form, etc.	Type and extent	Type and conditions

Table 2
Data for geological map

Common identifier	Retrievable information			
	Lithographic boundaries	Geologic unit	Strike, dip	Structure
A symbol or an acronym e.g. location object.	e.g. number of stratigraphic units.	e.g. sedimentary, basement complex, particular rock type etc.	e.g. 210^{o}NE/20^{o}W	e.g. Joints, faults, bedding planes

Table 3
Data for mineral map

Common identifier	Retrievable information						
	Mineral (ore) name	Location	Assay values	Reserve	Associated minerals	Depth of occurrence	Uses
A symbol or an acronym e.g. Tin (Sn) as location object.	Cassiterite	e.g. GPS Positions, Northing, Easting, and Elevation nearest . settlement, etc	% Valuable mineral, e.g. 45%Sn or 0.45Sn.	Probable or Proven Trace, large, very large.	Tantalium (Ta), Wolframite (Wo), etc.	Surface deposit or deep seated deposit with specifics on depth of occurrence.	e.g. Production of tin plates, alloys etc.

Table 4
Data for land use map

Common identifier	Retrievable information						
	Features	Possible conversion	Plant type	Animal species	Hydrology	Activities	Possible conflict
Symbol or an acronym as location object.	e.g. Pit, tunnel, lagoon, etc.	e.g. Reclamation for agriculture(A) games(G), Water Resources (W) aquaculture(K), etc.	Types	No., and types	State	Farming fishing, etc.	e.g. State boundaries, ethnic boundaries, etc.

Land use maps. The metadata for this section covered the pre - exploitation and post - exploitation nature of land for each mine site. Examples of retrievable information are shown in Table 4 and Fig 4. Some of the retrievable information is applicable in post - exploitation simulation of land as well.

Table 5

Prototype of the application of GIS for topographical and geologial information modelling and retrieval for Delta State

The principal purpose is to portray and identify the features on the surface and sub-surface of the Earth as faithfully as possible within the limitations imposed by the scale. These features include those of the mineral resources, cultural landscape as well as those of the terrain and the relief (see below):

Name of NDDC State	Primary data	2nd layer data	3rd layer data	4th layer data	5th layer data
				Longitude	
			Elevation		
				Latitude	
		Topography	Relief	Salt - water swamp	
			Natural	Fresh - water swamp	
		Landscape			
			Cultural	High Forest	
			Natural	Guinean Savanna	
	Topographical data	Vegetation			
Abia			Man - Made	Sudan Savanna	
			Sandy		
Akwa Ibom		Soils	Clayey	Sahel Savanna	
			Loam	Dolomite	Location
			Mineral	Glass sand	Co-ordinates
Bayelsa		Type of Available minerals data	Industrial Minerals	Feldspar	Estimated Reserve
			Fuel/oil		
Cross - River	Geological data		Non-metallic	Granite	
			Minerals	Gravel/sand	Grade
Delta	Environmental Assessment data				Use
			Costal zone		
Edo		Type of Geological formation data	Recent alluvial Sediment basin		
			Older sedimentary Basin		
Imo			Metal sedimentary zones		
Ondo	Conflict Management data		Basement complex		
Rivers		Status of geological work (exploration)			

Requirement: GPS equipment, Project vehicle, GIS powerful computer sets plus appropriate software.

Note: Similar data would be generated for all the nine NDDC States.

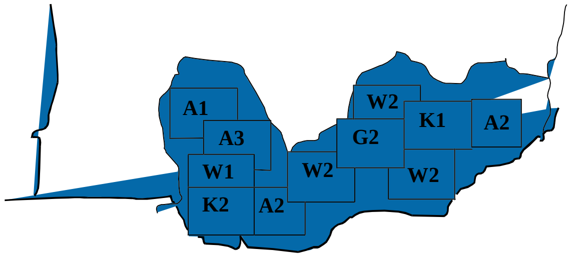

Fig 4. A typical land use map for information retrieval for Niger Delta region.

The topographical, geological mineral and land - cover maps are examples of result and presentation format in GIS. In addition to these map configuration other details of the meta data could be provided. Examples in this case may include data source, type and date of acquisition, value variation, map name, scale, projection, accuracy and coverage.

Within the framework of the GIS, geological, mineral and topographical maps and other mineral informations could be put in the form of Interactive Geologic Interpretation System (IGIS). Existing software such as ARCINFOR, Arc view, MapInfo, written for micro-computers that make possible mapping on a combined digital topographic and image base, could be used for this assignment. The IGIS software could be used to integrate image processing techniques, computer graphics and the CAD/CAM environment. It is therefore, provides a competent tool for topographical analysis including topographic profiling and slope measurement; photogeologic mapping including strike and dip determination; seismic analysis and 3-D block diagram generation. The IGIS which is made up of three sections viz; the VICAR environment, the transitional environment and the Intergraph environment could then be run on an Intergraph VAX computer under the VAX/VMS operating system and it will display image and vector data on peripherals. Data logging, analysis and display could be done in the VICAR environment. The transitional environment allows a bi - directional flow of data between the VICAR / IBIS and the Intergraph environments. Surface profile, sub-surface rendering and 3-D block diagram generation and rota-tion could be performed in the Intergraph environment.

5-Layer data information modelling and retrieval. Different information layers could also be provided for a typical section of the region. A prototype 5-layer information modelling and retrieval for Delta State is shown in Table 5. The 1st column consists of the name of the NDDC State while the primary (1st) layer consists of data being modelled (i.e. topographical and geological data). The 2nd layer data consists of topography, landscape, vegetation and soil type for the topographic data and status of geological work, geological formations and available minerals for the geological data. The 3rd layer consists of sandy, loamy and clay soils for soil data and industrial minerals, metallic, non-metallic and fuel oil for the available minerals. The 4th layer consists of longitude and latitude for elevation data and dolomite, feldspar, glass sand for industrial mineral data. The 5th layer consists of location, co-ordinates, estimated reserve, grade and uses for feldspar mineral. This could go on and on until the required information is adequate and exhausted.

Conclusion

New trends in GIS arose from the means in which maps were being produced and used for resource assessment (like solid minerals), land evaluation (for re-clamation options) planning (for re-use of mined-out areas). Essentially, the concept focuses on the ability to develop a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial geographical data for specific analysis and inquiry.

With the increasingly widespread, combined implementation of remote sensing and GIS technology, more solid mineral resources professionals have been provided with efficient and accurate tools for mapping and maintaining management information on mineral resources in region like the Niger Delta of Nigeria. GIS technology is expanding, allowing for greater integration of remote sensing with digital cartography. This may provide the means to produce more accurate geological and topographical maps.

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