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GIS APPLICATIONS IN GEOLOGICAL MAPPING AND GEOCHEMICAL SURVEYS OF THE RUTSHURU PLAIN

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Abstract: One of the most handicaps for developing countries in the field of environmental management is, besides gaps in environmental information and inadequate communication systems including basic telephone facilities and Internet connectivity, the lack of basic and thematic information on natural resources. For example, in the context of Democratic Republic of Congo (DRC), topographic maps as well as land cover, vegetation, geological, hydrological and pedological maps, where they exist, were mainly produced during the 1950s, 1960s or 1970s and therefore are outdated. This situation compromises country capacity to generate environmental information and manage the sustainability of natural resource in the region.

The geological mapping and geochemical surveys of the sedimentary deposits of the Rutshuru Plain have been selected as an example to improve geological resource management by using Geographic Information Systems (GIS) technology. Geological information can play a vital role in environmental planning. Indeed, over short distances, the non-consolidated sediments may have horizontally, as well as vertically greatly different properties, e.g., with regard to bearing capacity, cohesion, permeability, and these causes great differences in usage as well as in vulnerability within small area [1]. The main goal of this study is to improve management of geological resources in a small area of DRC.

Keywords: Geographic information systems (GIS), geological mapping, geochemical surveys, and resource management

1 INTRODUCTION

Nowadays, the demands placed on the earth create a critical situation regarding traditional geological exploration targets such as fossil energy sources, minerals, and ores, but also to commonplace materials, like building materials, such as stones, gravel, sand, and clay, and groundwater should not be forgotten [1]. The accumulative damage that has and continues to be inflicted on the planet is a current preoccupation. Furthermore the preservation and protection of the environment is considered as a prerequisite for sustainable development. Indeed, the process of sustainable development of natural resources is one of today's priorities of many governments. It is only possible on the basis of the availability of environmental data or information and the continuous monitoring of such up to date sets. Rapid access and integration of available information resources is also essential to support the decision-making process for environmental and natural resources management.

The spatial information needed to fully support sustainable development is missing in most parts of the world. In developing countries, besides gaps in environmental information and inadequate communication systems including basic telephone facilities and Internet connectivity, basic and thematic information on natural resources is lacking, scattered and outdated. However at least 75 % of the population lives in these countries, and it is there where the alarming population growth occurs. The consequence of this growth is the increased need for food and common building materials. There is a need therefore to continuously monitor the state of the environment and generate environmental information and manage the sustainability of natural resource in these regions. Too little is known about the availability of natural resources, their location in space, and their quantity. No regional thematic maps are currently available, except for mining and mineral exploitation.

Considering, for example, the need on common building materials, it quite evident that an adequate geological inventory followed by integrated geological digital thematic mapping and GIS database should be done by geoscientists for management of the environment. Indeed, a better decision-making need to be made by engineers, geoscientists, planners and public authorities in all fields involved in the use and control of the earth. Thus, to make the best possible use of the required natural environment information, by the geosciences as well as by the side of the decision- and policy-making authorities, one need to use geographic information systems (GIS) technology in order to integrate, store, manage and present the spatial information in a manner that can be digested by non-geoscientists, e.g. users (private, planners) and public authorities.

Furthermore, geoscientists need to understand the spatial relationship between all the various kinds of spatial data that they collect. Mineral exploration requires the simultaneous consideration of many kinds of spatial evidence for mineral deposits, such as the geology, structure, geochemical and geophysical characteristics of a region, as well as the location and type of past mineral discoveries.

The main goal of this study is to improve management of geological resources in a small area of Democratic Republic of Congo (DRC). The attention will be focussed on geological mapping and spatial distribution of heavy mineral as well as the associated typical rock types by using heavy mineral association deposit model. Another goal is to develop and maintain a comprehensive source of geological data and information that can be easily accessed and used by public, local policy makers, and research scientists. The operations that are carried out in this study are in many respects very similar to those designed by Van Biesen et al. [2], [3], for monitoring and sustainable management of marine environment.

2 BACKGROUND

The site selected for this study is the Rutshuru plain, which is located in the Western African Rift Valley, between the Virunga volcanoes field on the south, and Lake Edward on the north (Fig.1). It is bordered on the west by Mitumba Mountains and on the east by Sarambwe Mountains. The topography of the Rutshuru plain is heavily marked by several escarpments, some meters high, which have a general north-south direction, as result of tectonic activity. The Rutshuru plain consists of three grabens. These include, from east to west, respectively:

- The Ishasha graben is situated in the east and is drained by the Ishasha River, which forms the natural border between Uganda and DRC. The Ishasha graben is separated from the Rutshuru graben by the Kasoso plateau, which is tilted to the west.
- The Ruthuru graben is located in the central part and is drained by the Rutshuru River. It forms the main graben, and it is separated from the Rwindi graben by Kasali horst.
- The Rwindi graben is situated in the west and is drained by the Rwindi River (Fig. 1).

Tertiary and Quaternary sedimentary rocks (fluvial-lacustrine in origin and mainly composed of blocs, gravel, sand, silt and clay) and volcanic rocks form the main body of the Rutshuru plain. The Mitumba, Sarambwe, and Kasali mountains are mainly composed of undifferentiated Precambrian rocks.

However, at least seventy percent of the areas constitute the protected Virunga national park. The population lives at the uplifted blocs (‘terraces’) situated in the eastern part of the plain. An important economical settlement takes place at this location, e.g. coffee plantations of familial and industrial sizes.

During the last five years, the Rutshuru ecosystem has been greatly degraded The Congolese civil war has had major environmental consequences in this area. This brutal conflict is seen today as a barrier to needed investment and economic development in Democratic Republic of Congo. At present two main problems occur in this region as result of the civil war and the increasing population pressure and human activities:

- an increased arrivals of refugees in an already overcrowded zone;
- Quality, preservation and management of natural environment.

Indeed, there are at present increased demands for food, requiring a tripling of the present agricultural production, with an effect on the present water balance paired with the need to control drought and erosion, and also an increased need for common building materials. Thus, gravel, sand, and clay for construction are of major importance, and are mined from escarpment slope, terraces and rivers, causing damage to the environment in the form of unexpected slope erosion. Therefore the problem of space in this area is not only related to the question of the number of people per square km, but also to the necessity of protection and of sustainable management of the natural environment.

Conserving this region and preventing further degradation (i.e. environmental degradation as result of the impact of extraction of building materials and cutting of trees for building houses and for new plantations), as well as restoring some sites, requires scientific understanding of the geomorphologic processes and the geologic framework in which the dominant processes operate.

3 GIS IMPLEMENTATION

3.1 Methodology

The GIS was used in this study in order to improve management of geological resources. As mentioned above, there is an increased need for building materials such as gravel, sand, and clay. At present, knowledge of the spatial distribution of these materials and their availability is very limited. No regional thematic maps are currently available. Better understanding will be achieved through fundamental studies focusing for example on geomorphology, lithology, stratigraphy, and sedimentology. Such monitoring information on lithology and sedimentology is critically needed for the improvement of management of sand and gravel resources.

The GIS technology tools were therefore used to transfer available maps and other spatially related data into digital formats, to store, manipulate and manage data obtained from geological field surveys and laboratory analyses, and to combine them in a single geo-referenced file.

Three steps were thus necessary to collect data needed for the designing and the implementation of the geological information system of the Rutshuru plain:

- Data collection
- Field surveys (to correct and enhance phase 1 interpretation)
- Integration into GIS (data management, spatial analysis and integrated geological thematic mapping)

3.1.1 Data collection

The data used in this study comes from four sources:

- black and white aerial photographs taken in 1958 at 1:40.000 scale;
- some scarce paper maps of the area;
- some scientific reports;
- Satellite imagery of the region and its environs needed to fix our locations.

In spite of the fact that we start this study with information that should be considered as imprecise, uncertain and out to date, these data were useful because they provide a rough model of the area.

3.1.2 Field surveys

Field surveys were conducted in 1986, 1988 and 1989. The objectives were to correct and enhance step 1 interpretation, to define and map main lithostratigraphic units, and to fix their chronostratigraphic position. These ground surveys were completed by laboratory analyses, e.g. geochemistry studies (isotopes, heavy minerals), radiometric dating (K/Ar and C^{14}), and paleomagnetism studies.

The field surveys were also necessary to identify areas suitable for building materials and to ensure environmental protection by minimising the cutting and clearing of vegetation.

The data acquired from the aerial photography interpretation and the three field surveys has been processed and is outlined in detail by Yamba [4], Yamba & Boven [5]. Nine lithostratigraphic units, which illustrate the wide variety of sedimentary environment in this region, were thus defined based on:

- observable lithological features including composition and grain size;
- certain basic sedimentological information such as types of sedimentary structures and cyclic sequences;
- the presence or the absence of paleopedological features, e.g. root traces, hydromorphical features (gley or pseudogley), iron or carbonate concretions;
- Geochemistry characteristic of sediments by studying the heavy mineral content.

Radiometric dating methods (K/Ar, C^{14}), paleomagnetic polarity, and geomorphological studies were also applied in order to give a relative age to these geologic units. The results of the surveys have allowed to define main lithostratigraphic units (Fig.1) of the area [4], [5].

Furthermore weathering and erosion of surrounding Precambrian rocks and Tertiary and Quaternary volcanic rocks produces a dispersion halo of heavy minerals in the fluvio-lacustrine sediments. Therefore heavy mineral study has allowed to establish the relation between heavy mineral provenance and their mineral association on one hand, and between age and weathering processes (in term of abundance of some unstable heavy minerals) on the other hand. The bromoform heavy liquid (density: 2.88) was used for separating heavy mineral from a loose aggregate. A centrifuge was needed because the finer heavies tend to be suspended by the surface tension of the heavy liquid and settle very slowly. Then the heavy mineral grains were mounted whole in an epoxy resin for examination.

3.1.3 Integration into GIS

3.1.3.1 Spatial data Integration

The Bentley Microstation 95 CAD software and the Intergraph Modular GIS Environment (MGE) were used to improve spatial data handling, spatial analysis and geological thematic maps production, and to maintain the link between the relational database information and the maps (graphic elements).

The geological paper map of the area, as result of aerial photograph interpretation, field surveys, and laboratory analyses, were first converted to digital Microstation CAD format. The vector model, which is defined by three standard geometric elements (point, line and polygon or area), was used for this purpose. Microstation 95 provides complete graphics capabilities that let us draw vector geometry, which represents spatial data. Then the Rutshuru spatial database was built and includes the following set of graphic elements:

- The spatial extension of the different lithostratigraphical (or geological) units defined on step 2 is represented on the maps by a set of lines enclosing a ‘geographic’ region.
- Faults and rivers are displayed as lines.
- Each polygon contains an area centroid, which is graphically displayed as a point. It contains attribute information about a geographic region.

It should be noted that each feature is linked to a descriptive information into the database (feature table). In some cases, the graphic data or graphic element can be also associated with an attribute data table. For example, the area centroid in this study is defined as an attributed feature because it is composed of both graphic element and an attribute (non-graphic) database record. Thus, it contains two linkages, one attribute or descriptive linkage for the feature record and one linkage to the corresponding user-defined attribute or measured record. This makes spatial database query and retrieval more efficient and thus faster. While faults, rivers, and lithostratigraphic unit boundaries are considered as an unattributed feature or graphic feature because it is composed of only graphic elements. The graphic element contains only one linkage for the feature record [6].

3.1.3.2 Rutshuru geological attribute database

All the data collected from geological field observations and measurements (laboratory analyses) were evaluated, merged, managed and stored into a relational database. Informix database management system (DBMS) running on Unix workstations, and later Oracle and Microsoft Access, running on Windows 95 and Windows NT operating systems were used for this purpose. These attribute data were then coupled to the geographical unit to allow geographically referenced queries, e.g. by spatial query manipulations in an interactive computer session.

Thus, a geological database for the Rutshuru plain has been constructed from geological field observations and measurements (laboratory analyses). The collected data were organised into tables following the relational constraints.

The Rutshuru G.I.S. currently works with 5 tables, the feature table dedicated to store graphic elements, a lithostragraphic table designed to store the main lithostratigraphic units (Table1), a chronostratigraphic table for geological age (Table2), heavy-mineral table (Table3), and heavy mineral association table (Table4).

3.1.3.3 Spatial analysis.

As a result the Rutshuru G.I.S. database provides both spatial and attributes database. Therefore the analysis that is the ability to combine the basic data elements in the form of a question can be performed and is a complementary activity to data visualisation. This helps the user to find the reasons behind the spatial pattern about the occurrence or the absence of some features where they are supposed to be. For example, one can look for the geological units (Fig.1) that are composed mainly of gravel and sand; another can try to find the geological units that have a high concentration of some kinds of heavy mineral and try to explain why. For this last case, heavy mineral association model was used. Indeed, any mineral or combination of minerals may occur in clastic rocks. The success of provenance determinations in sedimentary or clastic rocks depends on the presence of some minerals, which are quite diagnostic of specific origins. Metamorphic rocks contain many diagnostic minerals, such as andalousite, staurolite, disthene (=kyanite), and sillimanite, which do not occur in magmatic rocks. While, zircon, tourmaline, rutile, are generally agreed to be the most ubiquitous and abundant monopaque heavy mineral in sediments. These minerals can originate either in magmatic or in metamorphic conditions. Because of this, provenance information must be extracted from intraspecific conditions, such as color, isomorphic substitutions, and trace element content [7].

The survey of the heavy mineral association in medium to coarse sand and gravelly sand deposits of the Rutshuru plain indicates the following heavy mineral association: métamorphic - pyroxene – ubiquitous - amphibole. This spectre of heavy mineral association is nearly similar to all lithostratigraphic units described in the Rutshuru plain. It shows that the source of the heavy minerals in the sedimentary deposits of the plain of the Rutshuru must be find in the undifferentiated Precambrian and the Cainozoic basalt rocks. But the concentration of these minerals in the sedimentary rocks is function of geological age and weathering processes. Some minerals are stable and can resist to tropical weathering processes and others are unstable; therefore their concentration decreases with geological age and tropical weathering processes.

4 CONCLUSIONS

This study shows that the Rusthuru plain offers a great potential availability of vast deposits of gravel, sand, and clay. This geologic information is based on data obtained by field surveys, mapping, sampling, geochemical surveys and laboratory analyses. The GIS technology tools were necessary for the integration of these data into single geo-referenced file and for producing thematic geologic maps. The interpretative geological maps as result of this study provide a fundamental framework for research and management in this area. They provide information on the geological units and on the nature of sediments. They provide also information essential for determining the spatial distribution of building materials and identifying suitable areas for their extraction. All this information can be used as a guide to the future resource management of the Rutshuru plain or the assessment of gravel, sand and clay resources, monitoring strategies, and other research studies.

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Fig. 1: Geological map of the Rutshuru Plain (modified, after Yamba & Boven [5]).

Table1: Main Lithostratigraphic units defined in the Rutshuru Plain.

Formation Name	**Member**	**Formation_id**	**Lithology**	**Age_code**
Kahunga Fm.		1	Fluviatile cross-bedded sand, silt and clay	10
Kasali Fm.		2	Colluvium and poorly sorted blocks	10
Vitshumbi Fm.		3	Littoral coarse to fine sand, silt, clay and peat	11
Kabasha Fm.		4	Red colluvium and poorly sorted blocks	12
Nyahanga Fm.		5	Carbonate deposit: tuffs and travertine	20
Kasoso Fm.		6	Sand and clay (cyclic sequences)	30
Buturande Fm.	Nkwenda	7a	Sand and silty clay (cyclic sequences) with iron (ferric) concretions	30
Buturande Fm.	Rwindi	7b	Sand and silty clay (cyclic sequences) with $CaCO_3$ and iron concretions.	40
Bwisha Fm.	Bunyangula	8a	Gravel, and cyclic sequences of sand and clayey silt	40
Bwisha Fm.	Kisharo	8b	Blocks (crudely bedded and cemented)	50
Bitengo Fm.		10	Mudstone (clayey silt cemented), cross-bedded sand and gravel	50
Virunga_Basalts		11	Basaltic rocks	61
Precambrian Rocks		9999	Undefined metamorphic rocks	9999

Table2 Chronostratigraphic table applied to the Rutshuru Tertiary-Quaternary deposits.

Age Code	**Age**
10	Holocene
11	Upper Pleistocene to Holocene
12	Late Upper Pleistocene
20	Upper Pleistocene
30	Middle Pleistocene
40	Lower Pleistocene
50	Upper Pliocene to Lower Pleistocene
61	Neogene
9999	Precambrian

Table3: Heavy mineral distribution (average values) table in some geological units of the Rutshuru plain.

Formation_id	Sediment_type	Tourmaline	Zircon	Rutile	Anatase	Andalousite	Staurolite	Disthene	Garnet	Epidote	Augite	Aegirine	Diopside	Enstatite	Hornblende	Actinolite	Anthophyllite	Glaucophane
1	m. to c. sand *	10	6	9	1.33	4	17.67		7		18.33	0.33	0.67	1	24.67	0.33		
3	m. to c. sand	20.5	17	14	1	7.5	23.5				12.5	1.5			2.5			
6	m. to c. sand	31	10.54	10.54	0.91	13.91	17.91	0.45	1		8.54	0.54	0.09	0.27	3.18	0.36	0.64	0.09
7a	m. to c. sand	27	18.67	20.33	2.33	12	12.67	0.33	0.33	0.33	3.67		0.67	0.33	1.33			
7b	m. to c. sand	20.67	8	16	0.67	4.33	22.67	0.67	0.33		13.33	2.33			10.33			

* m. to c. sand = medium to coarse sand

Table4: Geochemical attribute table showing heavy mineral association (average values)

Formation_id	Sediment_type	Ubiquitous*	Metamorphic**	Garnet	Epidote	Pyroxene***	Amphibole****
1	m. to c. sand	26.33	21.67	7		20.33	25
3	m. to c. sand	52.5	31			14	2.5
6	m. to c. sand	52.99	32.27	1		9.44	4.27
7a	m. to c. sand	68.33	25	0.33	0.33	4.67	1.33
7b	m. to c. sand	45.34	27.67	0.33		15.66	10.33

* Ubiquitous = Tourmaline, zircon, rutile and anatase; ** Metamorphic = Andalousite, staurolite, disthene (kyanite); *** Pyroxene = Augite, aegirine, diopside, enstatite; **** Amphibole = Hornblende, actinolite, anthophyllite, glaucophane.