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Towards a process of the implementation of a geographic information system in the management of cadastral data in case of a volcanic eruption / South Flank of the Nyiragongo volcano / DR Congo: An example for the land tenure circumscription of Goma from 2015 to 2020

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Abstract

The study on the process of the Implementation of a Geographic Information System in the Management of Cadastral Data in case of a volcanic eruption was conducted in the district of Volcano, a part of the city of Goma, the most affected by the problem of urbanization and exposed to volcanic risks. The goal of this work is to establish a Geographic Information System to manage the parcels of the city of Goma with precision despite the passage of a volcanic eruption, the progress made in the field of information management system, the development of reliable and fast techniques of data collection and processing, the evolution of the hardware, the rapid decrease of its cost and that of the software allow to consider that the technical problems are largely overcome today Many cities have put in place a land use planning system and a system for the management of cadastral data; in our country, more specifically in the city of Goma, comprehensive studies on the geographic information system remain relatively weak. This work focuses on the general application of GIS in the management of cadastral data. Firstly, a presentation of geographic information system was evoked in this work, then a freezing of a cadastral block, of the city of Goma, subdivision will be set up. Secondly, a study of the importance of the implementation of a management system of the cadastral data through the GIS system will be analyzed.

Keywords: Volcanic eruption, southern flank, SIG, cadastral, Nyiragongo, land district

Introduction

In the last decade, cadastral systems have undergone a significant conceptual modernization and have become, with the progress made in the geomatics sector, true informational infrastructures of territorial governance. Indeed, cadastral information is now used for purposes as diverse as development planning, land use control, natural hazard prevention and sustainable development. The cadastre of the DR Congo in general and of the Province of North Kivu in particular of the Goma Land Constituency does not escape these major trends. It is currently undergoing a major reform aimed at improving the system of protection of land rights, while promoting its multipurpose use and the creation of value-added applications. Despite some difficulties inherent to the realization of cadastral projects of this magnitude, the experience in Canada, the USA and Latin America can be qualified as a success. The need for a Geographic Information System (GIS) is urgent in all the land districts of the province of North Kivu, particularly in the southern flank of the Nyiragongo volcano.

The study on the Land Governance Analysis Framework (LGAF) in the DRC published in February 2013, revealed that the DRC has no real experience in planning and managing both urban and rural disasters1. However, it is becoming increasingly clear that modernization projects of cadastral systems neither achieve the previously set goals nor implement the many possibilities presented by modern cadastral system concepts. A gap between cadastral concepts and the reality of modernization with the introduction of a GIS in the cadastre is observed almost everywhere. In order to examine this problem and to try to identify the possibilities and the feasibility of this system, far from being an exhaustive study, the present work aims at setting up a Geographic Information System to administer the parcels of the city of Goma with precision even after the passage of a disaster such as a volcanic eruption, and to have the history of its land domain. Despite the criticism, cadastral systems are thus relevant instruments for our country, but within the limits of their functions, namely to be a public graphic register of land parcels and registration of individual parcels. By virtue of their technical characteristics (coordinate systems, cartographic modeling, accuracy, completeness), cadastral systems can be integrated later into more comprehensive geo-spatial data infrastructures, and thus make an informational contribution to territorial governance. It is within this framework that we have directed the subject of the present work on the management of the data of the cadastral service in case of a volcanic eruption on the southern flank of the Nyiragongo volcano in the province of North Kivu following the implementation of a geographic information system. Thus, the question of the implementation of a comprehensive Geographic Information System to improve the management of the data of the cadastral service after the passage of a volcanic eruption in the province of North Kivu has drawn our attention

Study environment and work methodology geographical location of the city of Goma

Fig 1

The city of Goma is located in the Southern Hemisphere east of the Greenwich meridian, more precisely in the 35th M zone. For the rest of this work, we will use the projected coordinate system RGRDC_2005_UTM_Zone_35S which corresponds to the city of Goma. In accordance with the dcree N° 89/127 of May 22, 1989, the city of Goma is

De limited: In the north through the rural area of Nyiragongo - to the south by Lake Kivu - In the east by the Republic of Rwanda - To the west by the Virunga National Park which operates it from the Massi territory in accordance with ordinance.

The city of Goma currently covers an area of 61,434,318.896,303 m2, the commune of Goma occupies 29,232,851.911459 m2 and that of Karisimbi 32,201,466.984843 m2 . The city of Goma is located south of the equator between the border city located at 1° 41' 36" latitude South and 29° 13' 31" longitude East, it borders Gisenyi to the east. The geographical limits of the city of Goma are those recognized at the time of the transfer of the country to national sovereignty in 1960.

Climate, vegetation, soil and relief

The average annual temperature in Goma is 19.8 °C and the average rainfall is about 1192 mm per year (average from 1971 to 2017) at the OVG weather station and at Goma airport.

Temperatures are softened by altitude.

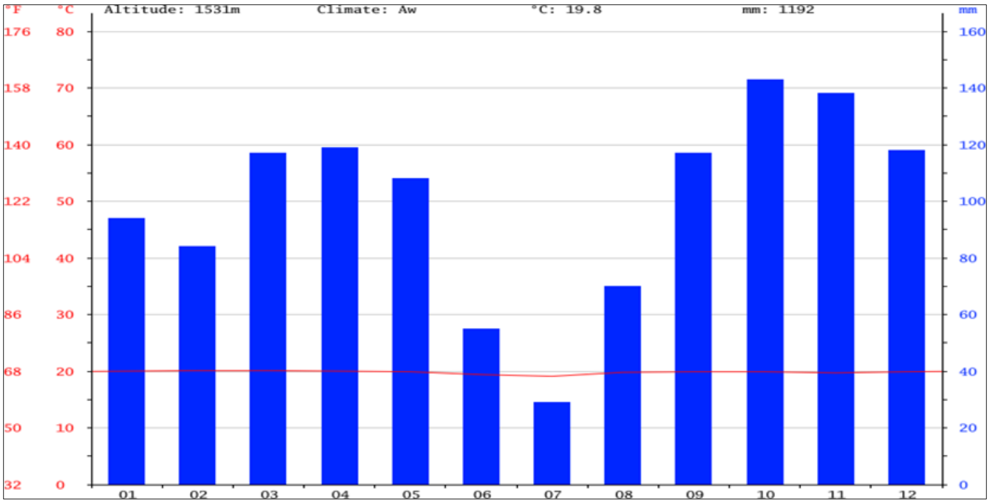

Fig 2

The city has experienced from 1971 to 2017 a global warming of 2.7 °C due to urbanization and expansion of the city poorly or not programmed and accelerated that do not follow all the urban planning standards leading to large-scale deforestation, poor management of domestic waste.

Also to the intense traffic of cars and motorcycles that emit CO in their exhaust. Also to the multiplication of gas stations and welding which contribute by their activities to emit greenhouse gases in the atmosphere. Goma is situated at the foot of the Nyiragongo and Karisimbi volcanoes, which is why it is covered by volcanic soil and has little relief. Volcanism with fine pyroclastic products projected into the atmosphere as ash, dust from heavy traffic, motorcycles and people that increase the condensation nuclei and thus the clouds in the atmosphere, and to the gases emitted including water vapors that also constitute a greenhouse gas. The consequences of this warming are, in recent years, a disruption of the seasons, an increasingly high intensity of rainfall that reaches 1800%; The dry season: it lasts 3 months (June, July and August). This is the period of seasonal unemployment, a period of economic crisis when the fields are fallow. However, it is difficult to determine this season because in recent years it has been raining even during this season. The rainy season:it is the longest. It is a period of cultivation2.

We know that the temperature decreases as the altitude increases. This is why mountain climates are very different from those of the plains. In this entity, the climate is closely linked to the relief. The temperature varies between 15° and 30°C, the altitude is between 1250m and 2700m.

Precipitation is abundant and increases with altitude. Indeed, it is not enough to see that precipitation increases with altitude or to consider the quantities of rainfall but rather its distribution during the year. Such an analysis allows to determine the rainy and dry months, the beginning and the end of the dry season.

Research Methodology and Technique

Considering the volume of work for the elaboration of a GIS in the Land Registry of the Commune of Goma/RD Congo, we chose the Quartier les Volcans because it is well endowed. To set up our GIS; used a database called geodatabase. A geodatabase allows the management of objects with their descriptive and geometric information in a database. A real-world entity is represented by an object corresponding to a record in a relational table. Unlike a coverage, the schema of a geodatabase is not predefined. The user can organize the stored objects as he wishes. The structure of the tables used to store the data is specific to ArcGIS. You need either ArcInfo or ArcEditor to manage it. There are two types of geodatabases: the personal geodatabase and the multi-user geodatabase. In the personal geodatabase the objects are stored as a Microsoft Access ".mdb" file. It is used for only one user (single user editing). The multi-user geodatabase on the other hand, offers the possibility of multi-user editing thanks to versioning. The multi-user geodatabase is a database managed in a database management system (DBMS).3 In order to meet the different objectives set out in this work, we have developed a personal database that contains the different information collected in the field and those collected during the documentation stage within the cadastral service of the Goma district. For the field survey we used the GPS Gamin 64 to take the Cartesian coordinates. The collected data were downloaded by Mapsource software and processed i.e. projected by ARCGIS 10.3 software and plotted as polygons. According to the "feature" form, our database in the Volcanoes neighborhood contains essentially two types of data as shown in the menu below:

- Polygons: contain data that may have an area; the city, the communes (districts), the neighborhoods, the subdivisions, the cadastral blocks and the parcels. For our study area we have surveyed the polygons of the blocks (fig. n°2 in appendix)
- The points: contain the point data of the vertices

i.e. the boundaries or the corners of the plots

Fig 3: Geographic database

The modes of representation of the data in numerical form [4]

For the representation of data in digital form, there are two fundamentally different types: The raster or grid mode and the vector mode. Each mode has its advantages for different tasks and some software offer only one of them. For image processing the raster mode is more useful. GIS on the other hand relies on vector mode. "GIS work in a privileged way in vector mode, even if they are able to integrate, and sometimes process, raster images."

Co-referenced systems and projections

There are several coordinate systems

- The Cartesian coordinate system (The basic method of locating a point in space is to place it in a Cartesian coordinate system. This location system is always accompanied by a unit of measurement (cm, m, km, etc.)).
- The Geographic Coordinate System (The basic method of locating a point on the earth is to locate it in a geographic coordinate system (GCS). The GCS includes a unit of measurement, a prime meridian
- The projected coordinate system The CGS is different from a projected coordinate system because it does not preserve any interesting geometric properties (angle, area, distance)

Latitude and Longitude

To locate a point on the earth two measurements are needed: a latitude and a longitude, the latitude measures the distance of the point from the parallel called the equator and the longitude measures the distance of the point from the meridian of Greenwich which is usually the Prime Meridian of a GCS [Figure 1 (a)]. Thus latitudes range from 90 degrees North to 90 degrees South and longitudes range from 180 degrees West to 180 degrees East.

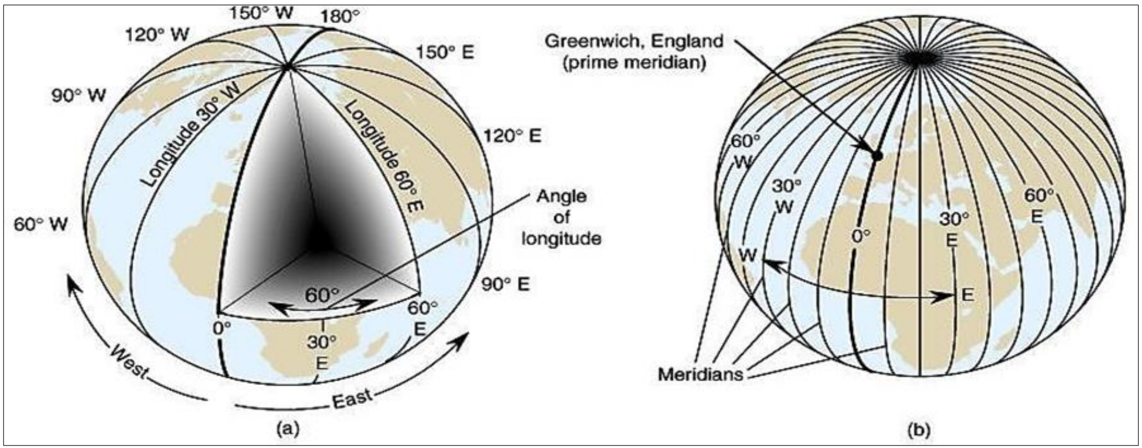

Fig 4: Figure 4 Longitude representation: figure (a) shows the longitudinal angle of the earth measuring 60 degrees and figure (b) shows the Greenwich meridian as well as the arrangement of the other meridians

ArcGIS Software Environment

Presentation of ArcGIS

In this work we will use the ArcGIS software, more precisely ArcGIS Desktop, a software from ESRI. This software is composed of three modules with different functionalities: ArcMap, ArcCtalog and ArcToolbox. These applications represent the methodological foundations and access keys for a GIS user: Maps, Data and Tools.

- ArcMap is the environment for processing cartographic data and writing cartographic documents. Its key functions are the visualization, creation, edition, consultation, analysis and updating of cartographic or geographic data. Geographic information is displayed on a map in the form of layers. Each layer represents a particular type of feature. A layer does not contain data but refers to a data source, which is stored on disk or elsewhere.
- ArcCatalog is a data-oriented application for the management, localization and navigation of spatial data. All necessary data connections are defined in it. These connections can call up folders on disk, network databases or ArcIMS internet servers.
- ArcToolbox is an application for the implementation of all geographic processing operations. It includes data analysis and format conversion functionalities. This application can be considered as the new interface for presenting the geoprocessing functions of ArcInfo. In the old Arc/Info these functions had to be accessed through a command-driven interface. As mentioned before ArcGIS still offers a command-driven interface, which is called "Arc" and whose functions can be accessed by typing commands.

Data storage in ArcGIS

In geographic information systems we are not only interested in attribute information, which describes an object and which we know from a traditional database, but also in geometric information (the shape, the location of an object) and the topology of an object. Geographic information is therefore composed of geometric, descriptive and topological information. In GIS all this information is stored with an object. ESRI uses the term feature when talking about an object, which represents geographic information. In this work, we use the term "object", when we talk about more general geographic information and "feature" to talk about geographic objects explicitly in ArcGIS.

To any object stored in GIS are attached two pieces of information: Attribute information that describes an object and geometric information. To represent the geometric information, a representation is needed (the graphic information). "For the graphic information, it is a question of representing it with the only constraint of seeking the best legibility allied to a certain aesthetic.

In GIS there is a difference between geographic information data and image source data. For geographic information data (Features) ArcGIS offers three different storage formats: shapeflles, coverages and geodatabases. Shapefiles and coverages are file based feature models.

They store the geometric information of a feature in binary files and use unique identifiers to link this information to the attribute information of an object stored in a table in another file. The geodatabase is a DBMS (database management system) model. In this model features are stored as columns in a relational database table. The columns contain the coordinates and attribute information of one feature at a time.

Presentation and discussion of the results

Structure of the cadastral database in the land district of the commune of Goma

In geographic information systems we are not only interested in attribute information, which describes an object and which we know from a traditional database, but also in geometric information (the shape, the location of an object) and the topology of an object. Geographic information is therefore composed of geometric, descriptive and topological information. In GIS all this information is stored with an object. Let us recall that we have used the ArcGIS software, within the framework of the present work. In this work we will use the term "feature", as used by ESRI when talking about an object, which represents geographic information. Later on we will use the term "object", when we talk about more general geographic information and "feature" to talk about geographic objects explicitly in ArcGIS. To any object stored in GIS are attached two pieces of information: Attribute information that describes an object and geometric information. To represent the geometric information we need a representation (the graphic information). "For the graphic information, it is a question of representing it with for only constraint to seek the best legibility allied to a certain aesthetic."5 In GIS there is a difference between geographic information data and image source data. For geographic information data (features) ArcGIS offers three different storage formats: shapefiles, coverages and geodatabases.

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Development of a GIS in the volcanoes district, Goma commune

The different classes of the database

A. Polygones

The file used as a matrix for our work for the entire city, neighborhoods and parcels was taken from the OCHA-Goma website6.

The city of Goma has two communes, Karisimbi and Goma. These two communes form the two districts of the city of Goma. We have added the information of the buildings that correspond to the 2D planimetric projection of the different buildings located in the different targeted plots.

B. The Points

A single layer carries the point information. In this work, this layer contains the information on the vertices of the polygons where the coordinates were taken from the corners of each parcel.

The different field names for each data class

In this part we have focused much more on the data we have collected: it is about subdivisions, cadastral blocks, plots and buildings.

A. Subdivision

In our geographic database, the data on the Volcanoes housing estate contains the safe information as shown in this menu:

- The name: we have given each subdivision a name
- Constituency: The name of the constituency in which our study is located has also been assigned.
- City: We have also assigned a name to the city where the district and the subdivision is located.
- Observation: this field is reserved for the various observations relating to a given subdivision.
- Apart from these four fields we also have other fields that are automatically regenerated and that carry information on the area and perimeter of each allotment.
- The Object ID field carries the information about the object or invoice number and the Shape field carries the information about the data type.

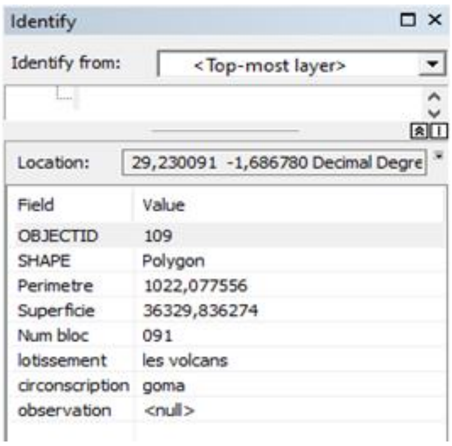


Fig 5: Identification of the fields of the Volcanoes subdivision

B. Cadastral blocks

Commonly called polygons, cadastral blocks are blocks of several parcels separated by public roads. Apart from the fields Object ID, Shape, Perimeter and Surface, which contain information about the object number, geometry, perimeter and surface of each object respectively. The cadastral block objects contain the following fields (see menu on the right):

- Block number
- Subdivision
- District
- Observation: this field contains the different observations related to the different cadastral blocks

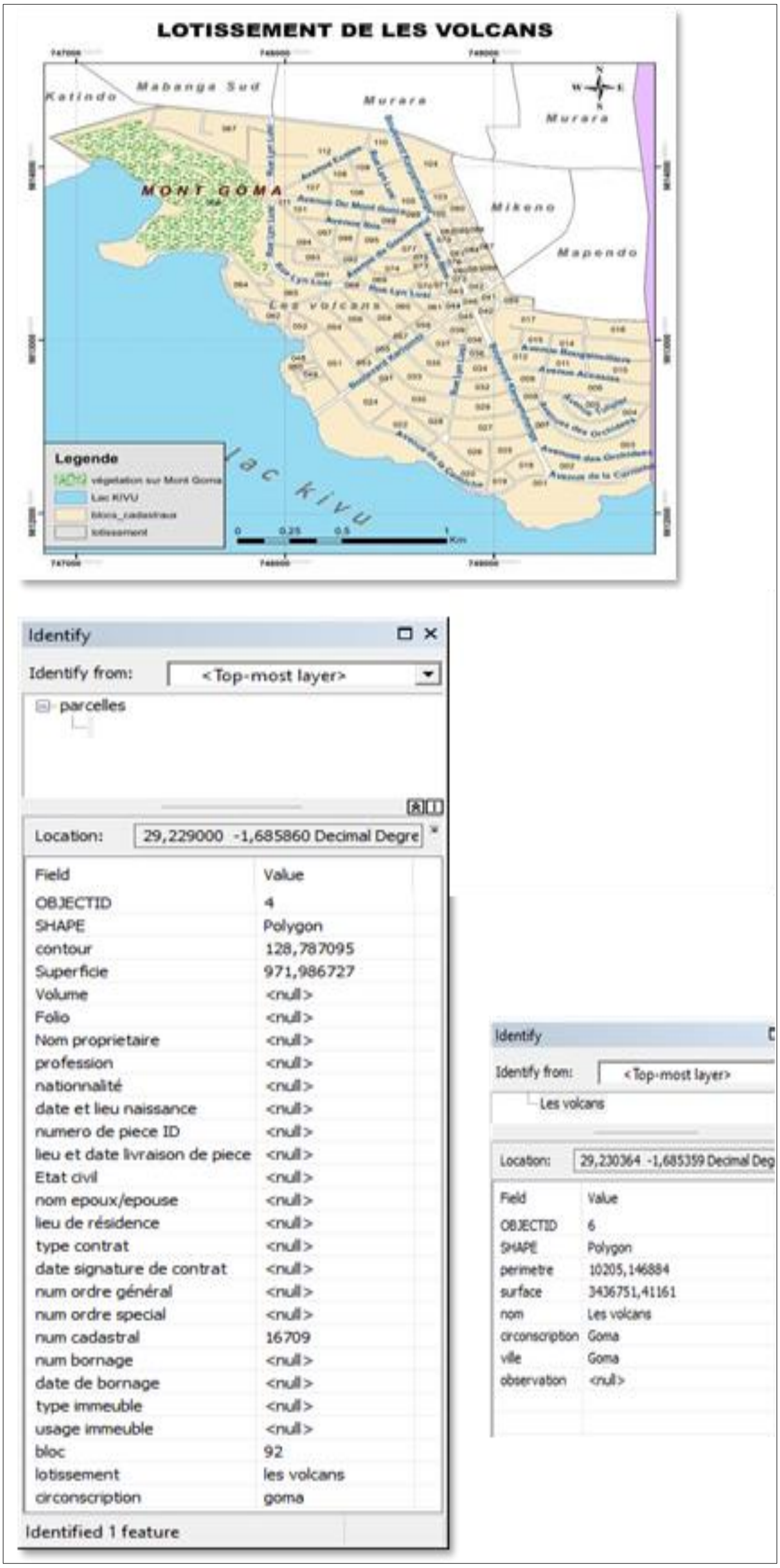


Fig 6: This plan shows the subdivision of the Volcanoes district in the commune of Goma with the different cadastral blocks (polygonal), each cadastral block being identified by its number and shows the different fields in the plot GDB

C. The plots

In addition to the fields Object ID, Shape, perimeter and area; the feature or parcel object carries the following information:

- Volume and Folio:
- **Owner's name:** gives all the names of the owner of the parcel
- **Profession:** contains information about the owner's profession

- **Nationality:** Indicates its nationality
- **Date and place of birth:** Give the place and date of birth of the owner
- **Civil status:** Give your civil status
- **No of Husband or Wife**: gives the name of the owner's wife if it is a man and that of the wife if it is a woman; if the owner is married.
- Place of residence: gives the place of residence of the owner
- **Contract type:** Specifies the type of contract
- **Date of contract signature:** Bears the date of the parcel contract signature
- **General order number:** Bears the general order number for each parcel.
- **Special order number:** Gives the special-order number for each parcel.
- **Cadastral number:** Bears the cadastral number for each parcel
- **Boundary number:** Gives the boundary number for each parcel
- **Date of demarcation:** Indicates the date of demarcation for each parcel
- Type of building: gives information about the building in the parcel, specifying its type
- Use of the building : gives information on the use of the building
- Block : gives the number of the cadastral block
- Subdivision: gives information on the name of the subdivision where the plot and the block are located - District: locates the subdivision belonging to

D. Building

Here the building is represented in 2D, the building class carries the following information:

- **Object ID and Shape:** Respectively carries information on the object number and its shape
- **Type of building:** Gives information about the type of building in the house
- **Cadastral number:** Gives the cadastral number of the parcel where the building is located.
- **Owner:** contains information on the identity of the owner of the parcel.
- **Observation:** gives the different observations on each building.

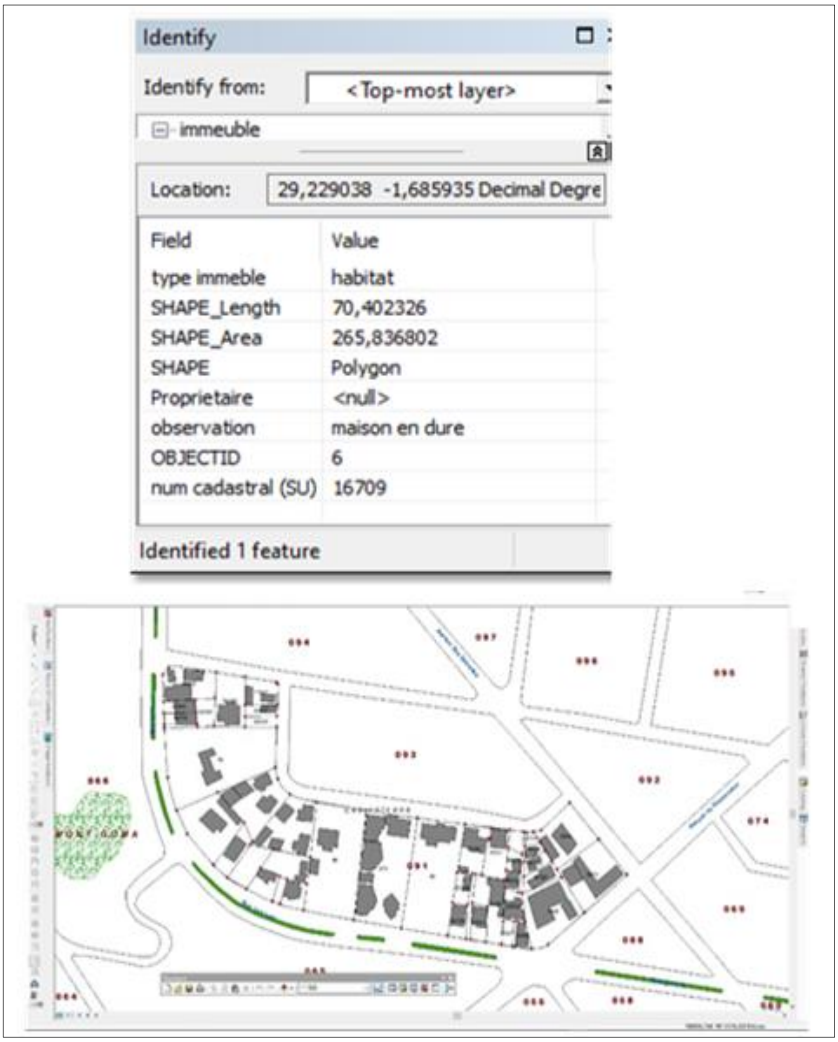


Fig 7: Here we have in digital each plot with the buildings and the second one shows them without building and shows the different fields in the building GDB

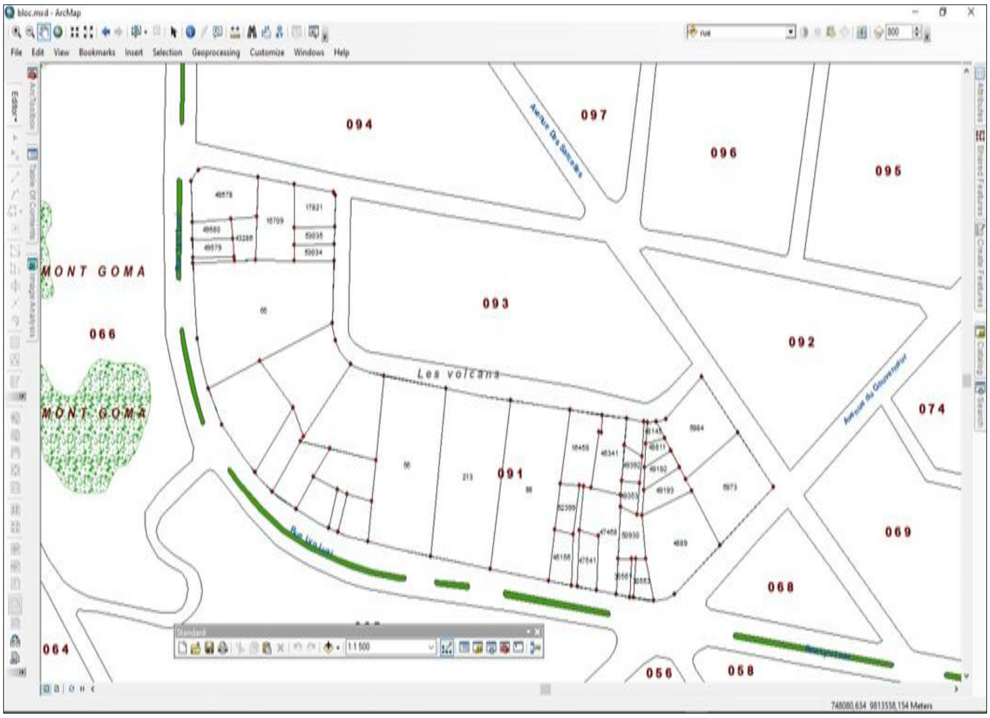
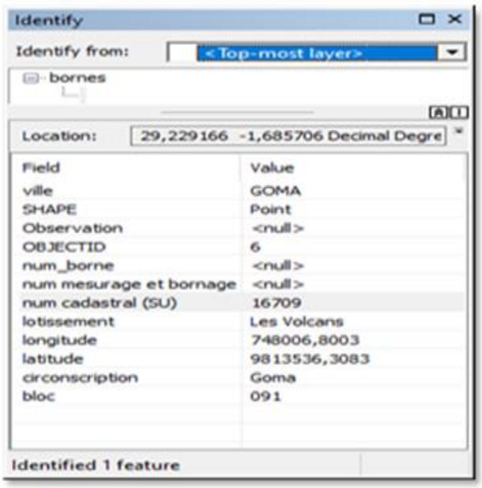


Fig 8: We have here each parcel without building in this class of data, the fields Shape, Object ID, carries respectively information on the geometry and the number of the object (terminal) of which

And the fields

- City
- Observation on the terminal
- Terminal number
- Num measurement and demarcation
- Cadastral number of the parcel
- Subdivision
- X and Y coordinates of the terminal ;
- District where the terminal is located and Block


Identify

Identify from: <Top-most layer>

bornes

Location: 29,229166 -1,685706 Decimal Degre

Field	Value
ville	GOMA
SHAPE	Point
Observation	<null>
OBJECTID	6
num_borne	<null>
num mesurage et bornage	<null>
num cadastral (SU)	16709
lotissement	Les Volcans
longitude	748006,8003
latitude	9813536,3083
circonscription	Goma
bloc	091

Identified 1 feature

Fig 9: This map is an illustration of a portion drawn from the cadastral map. It carries information on the block constituting our study area and shows the different fields in the terminal GDB

Figure 13 and 14: these two figures show the different parcels located in the cadastral block that we have assigned 091, each parcel has the cadastral number that we received from the cadastral board during the documentation stage.
The first figure shows each parcel with buildings and the second shows them without buildings.

Discussion of the Results
The data presented in the present work were collected in the Circonscription Foncière de Goma, precisely in the Quartier les Volcans. In the field we collected the data with a topographic survey using a Garmin 64 portable GPS.
Apart from the coordinates which were recorded in the GPS, the other elements were recorded on an elaborate form. For this purpose we created a shapefile of the drawing of the measurements.
To check if the collected and processed data are accurate, we projected the obtained drawing on a geo-referenced Google earth image. Different data were corrected, reinforced with these satellite images in ArcGis 10.5 to obtain a correct and presentable plan of the blocks and parcels.
A complete database has been established in our work that includes all the necessary information and a more or less exact location for each parcel, block and subdivision.
This information will be useful not only for the Land Registry, Urbanism, but also for the financial authorities of the province and the municipality that collect the taxes, but also for the police, the fire department of the city...
During the corrected localization of the blocks and plots and of the subdivision we have also noticed by superimposing them on the cadastral plate of the district, we have also found a difference between the measurements on the cadastral plate and our results as also noticed by Figure 14: shows the different fields in the terminal GDB MUNGUIKO MUHIRI Michel7 in his end of cycle work at the national school of the cadastre and real estate titles on the problem of the localization of the plots on the cadastral plates of the subdivision of the land district of Goma "case of the subdivision Kyeshero". As Musafiri Safari Joseph8 and Bonane Barayasesa Bitwayiki9 suggested in their works, the digitization and a good localization of the plots and blocks will avoid the superposition of the cadastral titles and the granting to the applicants the plots of less than three ares.
We recommend to the persons in charge of all the land districts of the province of North Kivu in particular and of the DR Congo in general, to put in place in their entities a complete Geographic Information System, the use for the topographic surveys by the surveyors of high precision equipment such as kinematic or differential GPS.
This is to have more precision and avoid errors because these are reflected in the unregistered plots and avoid the land disputes that result from this. Here are the cards explaining what we were able to do throughout our end-of-cycle work:

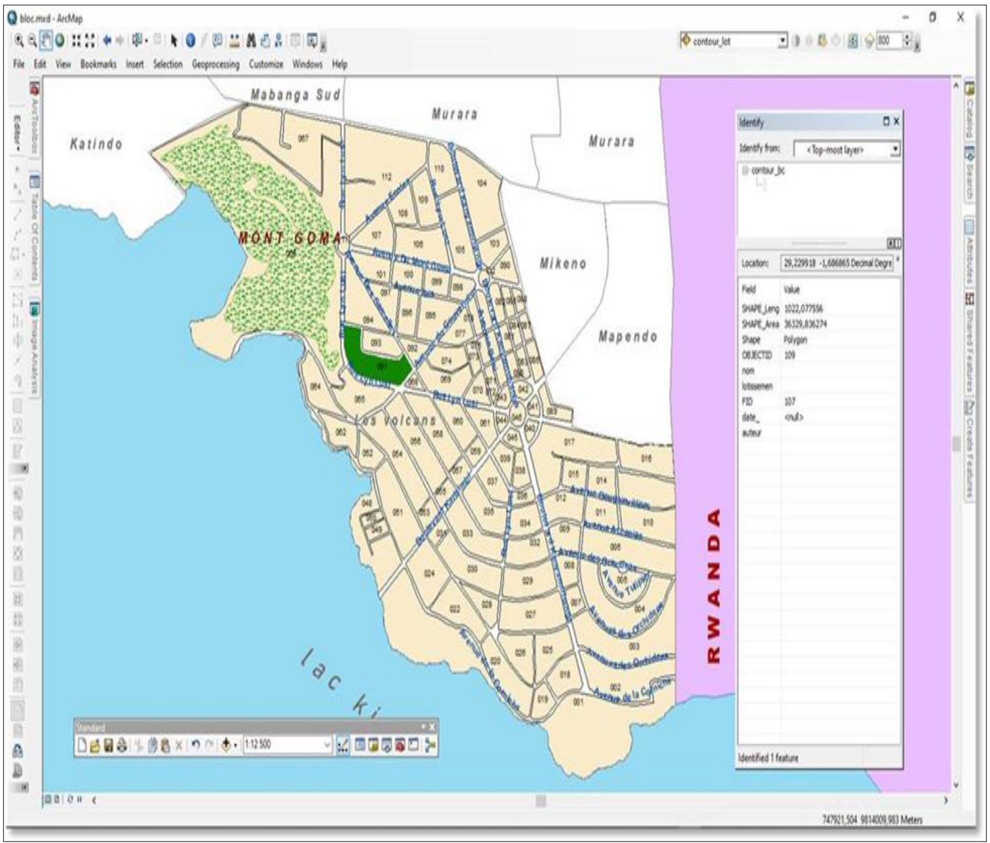


Fig 10: This map shows the allotment of Les Volcan, in green it is the block in which the entirety of the present work is focused. In our database this allotment is visible from the scale of 1/12500 to 1/5000

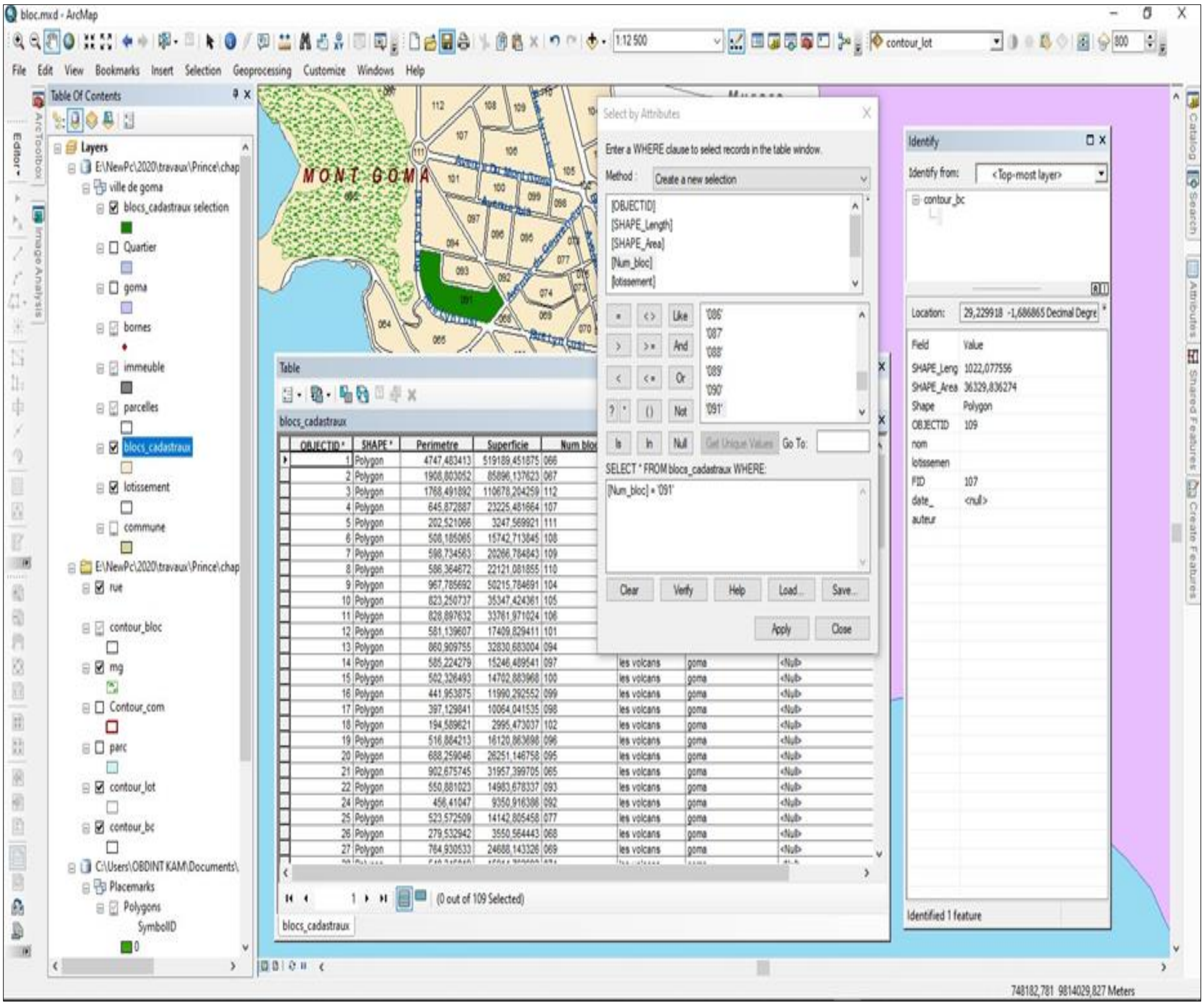


Fig 11: These two images illustrate the attribute table and a way to query our database from the attribute table

General Conclusion

The cadastre is a public institution, which does not depend only on technological development projects. Its usefulness develops gradually, as a result of the applications that its various users will develop. If we had to retain only one lesson from the example of the Quebec cadastre, it would be that it is today the result of a long process of maturation that has favored its integration into a set of legal, political, economic and social institutions. Countries wishing to develop similar instruments will not be able to do without this maturation. There are things that technological progress alone cannot offer.

After comparing the data collected in the field with the data received from the land registry of the commune of Goma, we found some errors in the floors in the archives of the Goma land registry office.

These errors can be corrected by making all these data digital in order to have a clear vision of all the activities by creating an effective database. This database would allow us to avoid having to deal with disputes, overlaps, and can help for a good administrative management of plots.

Something that is not done, from where we said to ourselves that the bad management of the cadastral data is administrative that technical.

The data collected in the field and from the cadastral map were processed and analyzed while comparing them with satellite images. During this stage, a geographical database (geodatabase) was designed. This geodatabase, carries the information on each parcel, each cadastral block of the allotment of the Volcans district, allotment where we worked this present research project.

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