Chapter

GIS and Database Management for Mining Exploration

Jonas Didero Takodjou Wambo and Wenzi Tanni Quinter

Abstract

The mining sector has several tools which permits mining exploration works to be done in the most efficient and time conscious way as possible. This chapter is focus on Geographic Information Systems (GIS) and Database and aims to show how this combined approach can help in mineral exploration. It is all about building a database and GIS system capable first of all to assess if a geological/geographical data taken from the field is valid or wrong and to effectively manage mining data in a GIS designed to positively influence any mining exploration project from its earliest stages to the end of the project. We focus on Meiganga area where we have been involved.

Keywords: GIS, database, spatial analysis, mining exploration

1. Introduction

GIS and database are conceptualized frameworks that are designed to capture, gather, input, store, manage and analyze geographical data. Rooted in the science of geography, GIS integrates many types of data. It analyzes layers of information into visualizations using maps and 3D scenes with this unique capability. GIS reveals deeper insight into data, such as patterns, relationships, and situations helping users make smarter decisions. GIS is specialized in geographical related data unlike database which is able to handle non-geographical data. The application of GIS and Database management in the initial stages of ore mineral exploration has a significant impact on reducing exploration and exploitation prices [1–3]. The effective management of natural resources in many areas of applied geoscience is influenced by obtaining detailed geological/geographical information from various sources [1, 2]. Exploration geologists are generally confronted with various problems mainly related to the difficulty of covering large areas (time and limited access, natural and human risks) leading to a disparity in the information collected and methods of extrapolation and interpolation used for map model [1, 2]. The quality of data collected, is very crucial in determining the success or failure of any mining project activity. Proper handling of this data enters into one of the factors to be respected to ensure their reliability. With the rapid advancements in technology, the management of complex data is somehow easy. Essentially the mining sector has several tools which permits work to be done in the most efficient and time conscious way as possible. GIS coupled with Database management stand out as indispensable way to achieve this goal.

The spatial relationship of deposits can be assessed using spatial analysis with the support of a GIS, which can help unravel the geological processes that have been crucial in the formation of a particular type of mineral deposits [4, 5]. Thus, the systematic analysis of spatial data can facilitate the identification of mineral deposit properties within a metallogenic province [4, 6, 7]. Studying the spatial distribution of mineral deposits and the relationship between mineral deposits and determining geological factors using spatial analysis with GIS seems to be a suitable approach that can provide invaluable information at the start of any mining project.

Principally, the technique approach that we will dwell on in the course of this chapter is GIS and Database. The objective of this work is to build a database and a GIS system capable first of all to assess if a geological/geographical data taken from the field is valid or wrong and to effectively manage mining data in a GIS designed to positively influence any mining exploration project from its earliest stages to the end of the project. We focus on Meiganga area where we have been involved.

2. Generalities in GIS, database management

2.1 GIS

A GIS is a system capable of entering, storing, modifying, recording, query, reorganizing, analysis, and display as well as presenting alphanumerically and graphically data located in space to solve a problem, support a decision, and help to plan. It comprises of functional modules allowing to create and modify, to interrogate and to represent cartographically data located in space. There are several components when working on a GIS Project. These consists of setting up a GIS unit, the design, development and information of a reliable database, the implementation of a knowhow for the launch of a dynamic GIS, the use of simple GIS software to fill in the heritage database, acquisition of a suitable hardware platform. Also, there are several basic questions that a GIS should be able to answer such as:

- **Where?** Where is this object, this phenomenon? Where are all the objects of the same type? *(This question allows highlighting the spatial distribution of an object).*

- **What?** What can we find there? *(It is a question of highlighting all the objects or phenomena present on a given territory).*

- **How?** What are the relationships that exist or not between objects and phenomena? *(This is a problem of spatial analysis).*

- **When?** When did the changes occur? What is the age and evolution of a particular object or phenomenon? *(A problem of temporal analysis).*

There are two fundamentally different types of GIS data used in GIS projects:

- **Vector data:** Which are structured data used to store spatial data like lines, points, and polygons. They are based on vectors as opposed to space occupancy raster structures.

- **Raster Data:** A map in a raster data divides the entire study area into a regular grid of cells in a specific sequence. The data completely fill the space of the map.

The power of a GIS comes from the ability to relate different information in a spatial context and to reach a conclusion about this relationship. Most of the information on the world contains a location reference, placing that information at some point on the globe. A GIS, therefore, can reveal important new information that leads to better decision making.

2.2 Importance of GIS in mining exploration

Several authors have studied on the importance of GIS in mineral exploration [3, 8–12]. During mineral exploration vast amounts of spatial data are collected. Geo Science information which commonly consist of geological, geographical, geophysical and geochemical information, are gathered routinely from satellite and airborne sensors in a digital form. Large sets of ground survey data are also stored in digital form as argued by [13, 14]. Accordingly, integration of field survey data, maps, and other information for the purpose of mineral exploration and resource estimation is a very time consuming task. However, GIS can accomplish such a task in a time efficient and cost-effective manner (**Figure 1**). Moreover, the state and federal agencies involved in the mine permitting process are adopting the GIS format as the standard for communicating spatial data.

Although GIS is able to manage data like database management systems, mining exploration projects use to store data in other databases. That is because of the semantic form of data. Meaning that usually, they contain information describes as "*good for spatial purpose*" and other that are used for assessment, management, and validation. Do not forget that, mining companies also use these two types of database for backup of their data and for the distribution.

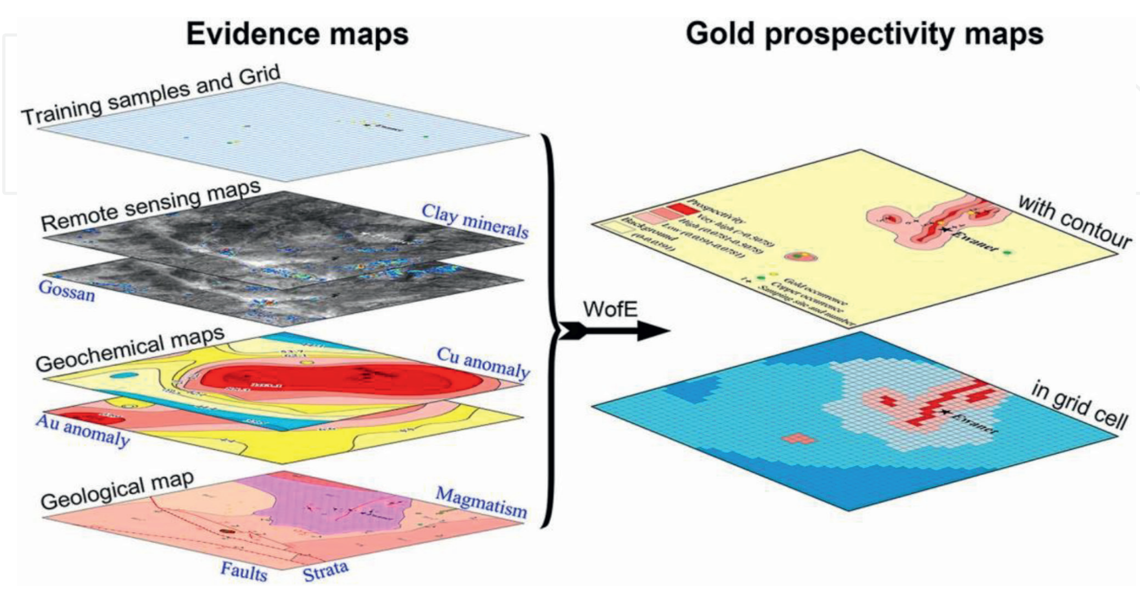


Figure 1.
Synthetic representation of the application of GIS in mineral exploration [15].

2.3 Database management

A database is a collection of related data stored in a manner that enables information to be retrieved as needed. This typically consists of tables (a collection of related records), fields and records. Field is a single category of data to be stored in a database like name and their abbreviations, telephone number, etc. Fields are collection of related fields information in a database. Excel and Access are forms of database software. Databases are important because of their: low level of redundancy, faster response time, lower storage requirements, easier to secure, increased data accuracy. Many types of database exist depending of the level of usage. We will name here the two most widely used in the level of single users and small projects:

A Single-User Database System is located on a single computer and is designed to be accessed by one user. This type of database is widely used for personal applications and very small business.

A Multiuser Database System is designed to be accessed by multiple users (most business databases today).

A database with only one table is sometimes called a flat-file database.

2.4 Importance of database in mining projects

Database are used in mining exploration project because of: (1) Their property to be imported into a GIS or to mining software, mostly in case they contain geographical information system like coordinates; (2) They permit to write and adopt their Standard operations procedures (SOP) by codification which leads the whole of their field work.

Thus, for a sample to enter the database, a name must be given, an identity, coordinates, location, prospect and project name (**Figure 2A**). If a name does not already belong to the database built, an error occurs. The notebook of the geologist is considered as database in some projects. In others, printed spread sheets of excel are used for (**Figure 2B**). So that the physical database exists and the numeric database exists also.

3. Methodology

3.1 Main phases

Given that GIS and database are meant to respond to a specific need, it is imperative that, objectives of the task ahead should be clearly outlined to suit expectations most accurately. In an early stage of mining projects wherein stream sediment sampling and large scale mapping is carried out, there are three main phases which are Planning, Field work, Assessment and data validation as seen in **Figure 3**. Each phase has special tools, expertise and logistics. This chapter is design going through those phases of the work laying emphasis on the Meiganga toposheet.

3.2 Technical settings

Every project has its specifications when it comes to choosing the types of tools and software in order to achieve the work. In this case the equipment used include: the GIS and database equipment which consist of a laptop, notebooks, and GPS. GIS software like ArcGIS 10.5 can be chosen to build maps and make geospatial analysis. Basecamp is also used with the aim to send maps and planned points inside the GPS.

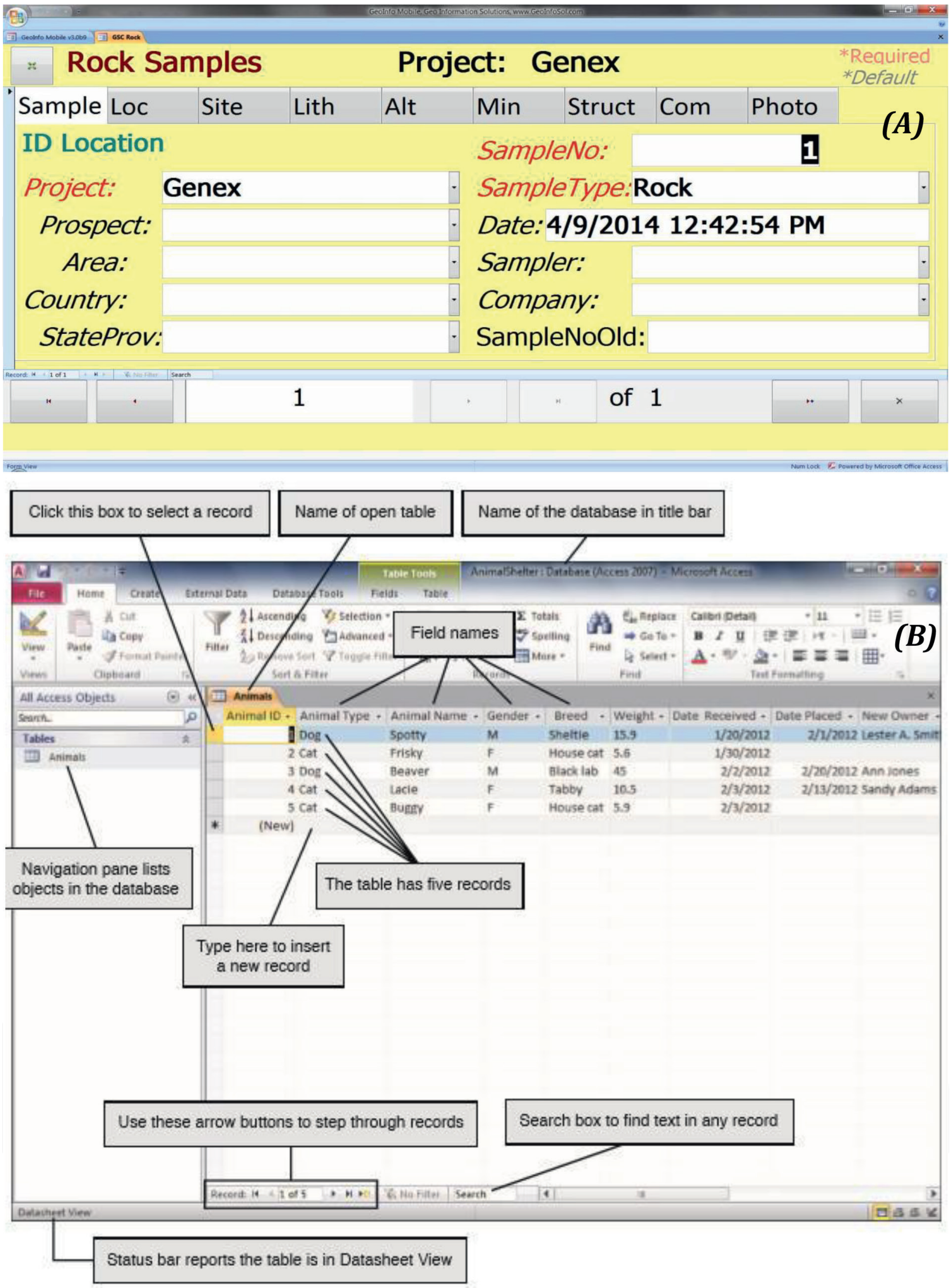


Figure 2.
Database formats: (A) presentation of geographic information and SOP and (B) presentation of non-geographical data.

The same software can be used to extract prospectors' tracking and recorded points, the coordinate system used in the building of maps can be WGS 1984, with UTM as units. As regarding database, Microsoft Access can be used to build tables and record related field information. The software is also used to record all the codes employed during the work i.e. rock codes, initials of the geologists, abbreviations of the targeted

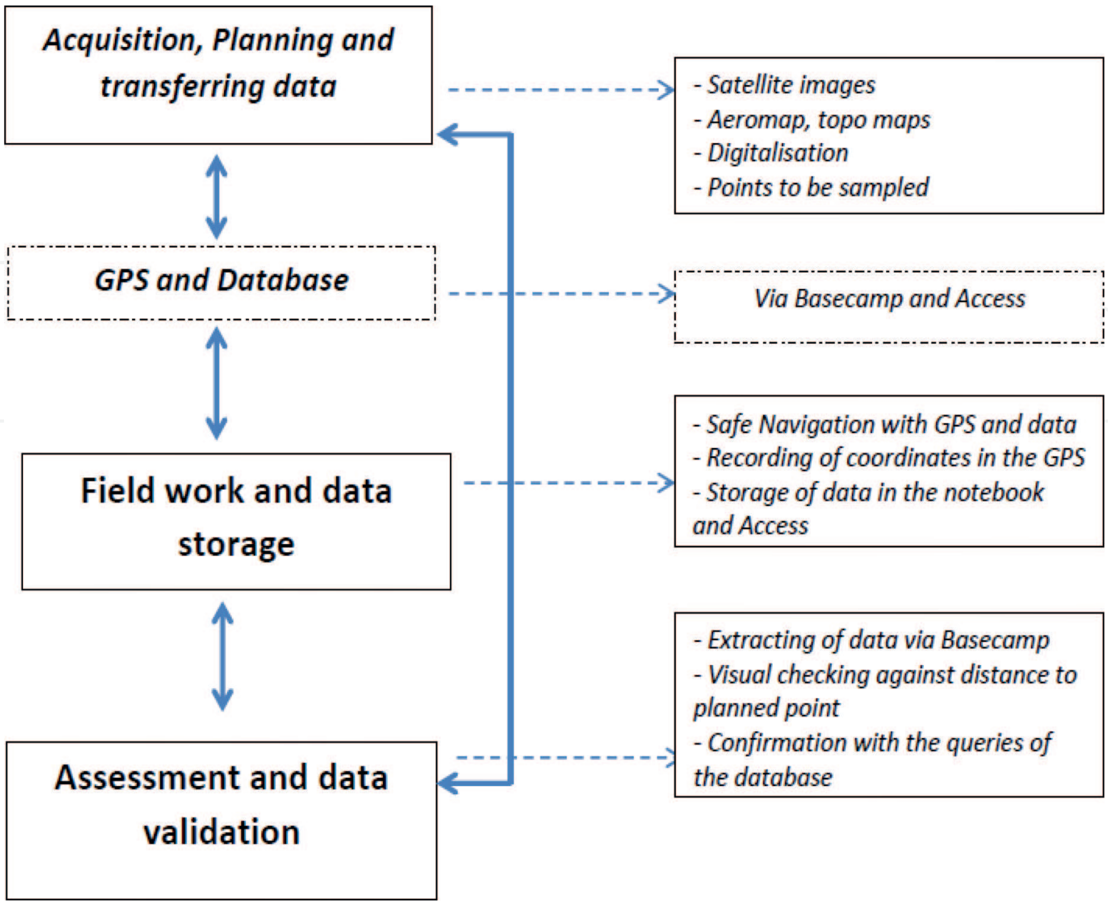


Figure 3.
Flowchart of the methodology of study.

zone, and other information. For airborne geophysical data, Geosoft can be used for analysis.

3.2.1 Acquisition, planning/transferring

The planning phase entails collection of data that will be used by the project. It ends with the transfer of data into a GPS and into a PC. Data collected can contain geographical and non-geographical features.

3.2.2 GIS and maps

At the end of the planning phase, three types of resources related to the GIS are available i.e. physical maps, a raster map inside a GPS, and the GIS inside the PC. The GIS of the project should contain all the necessary maps for the team to work on the field. It consists of the information concerning basemaps, topographic maps, Digititial Terrain Model (DTM) or hill shade, hydrography, administrative units and planned points. ArcGIS software can easily store the GIS. Here some fields and maps can be activated or deactivated, in order to find additional information for the field team. The GIS is used to convert all the above maps into one raster in order to be manipulated in other systems. When converted, the maps are printed to obtain physical maps (**Figure 4**). The same maps can be sent into GPS for the navigation through Basecamp software.

The term basemap is seen often in GIS and refers to a collection of GIS data and or orthorectified imagery that form the background setting for a map. Satellite images can

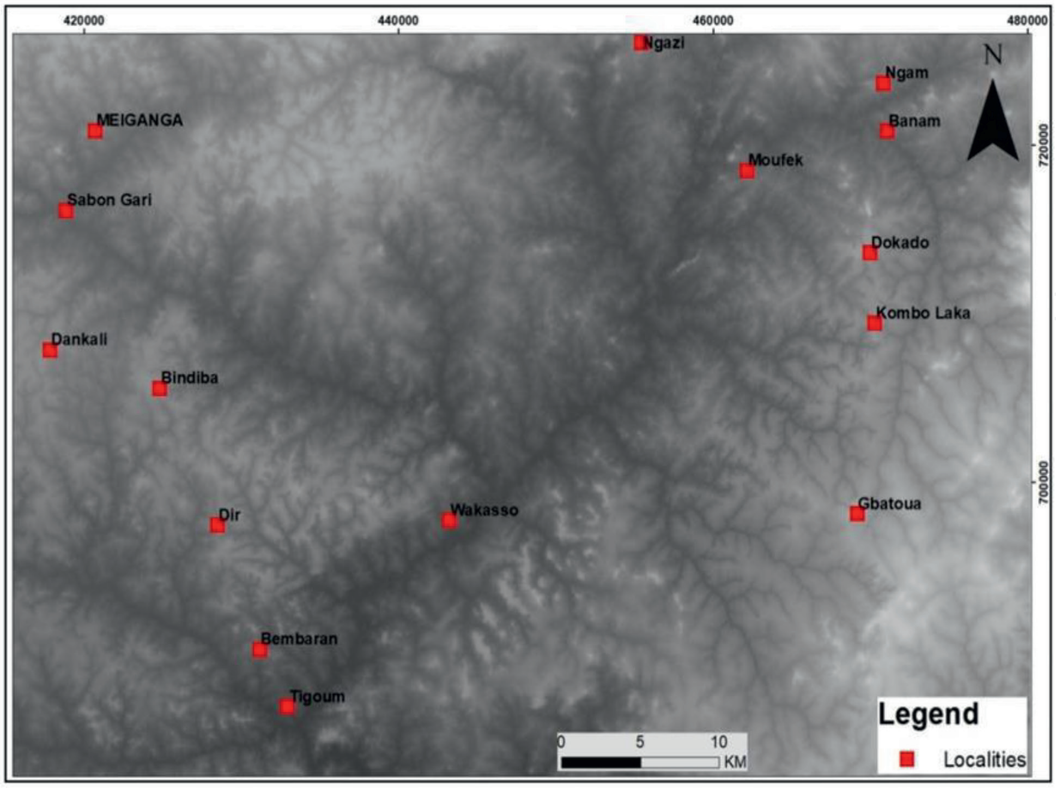


Figure 4.
Satellite image (SRTM) of the study area with 30 m of resolution.

be collected from free verified available platforms like United States Geological Survey (USGS). They store geographical information, localization, and many others important features. The function of the basemap is to provide background detail necessary to orient the location of a map. Basemaps serve as a reference map on which you overlay data from layers and for geologists to be able visualizes geographic information.

The shaded relief is also used to highlight the forms of the relief and enhance the quality of the map (**Figure 5**). The hillshade function produces a gray scale 3D representation of the terrain surface, with the sun's relative position taken into account for shading the image. It is a technique for visualizing terrain determined by a light source and the slope and aspect of the elevation surface; this tool creates a shaded relief raster from a raster. The illumination source is considered to be at infinity. The hillshade raster has an integer value range of 0–255 m.

Figure 6 shows hydrography map of the study area. It is a survey map which reveals the waterway system of the study area. The hydrographic pattern is dense with the main stream being the Lom River with the primary tributary being; mikila and several second order streams.

A topographic map is a detailed and accurate illustration of man-made and natural features on the ground such as roads, railways, power transmission lines, taken from the national institutions are put on the basemaps and used for geo-referencing and digitalization of roads and streams. Topographic maps are raster maps like basemaps. They store information related for topography information. Localization and streams are also a part of them (**Figure 7**). This help for digitalization.

Digitalized data are built by the GIS unit. The team digitalizes streams and roads mainly based on the basemap and the topographic map. The result here is a vector map. The objective is to have a digitalized feature as they are easy to manage than raster maps.

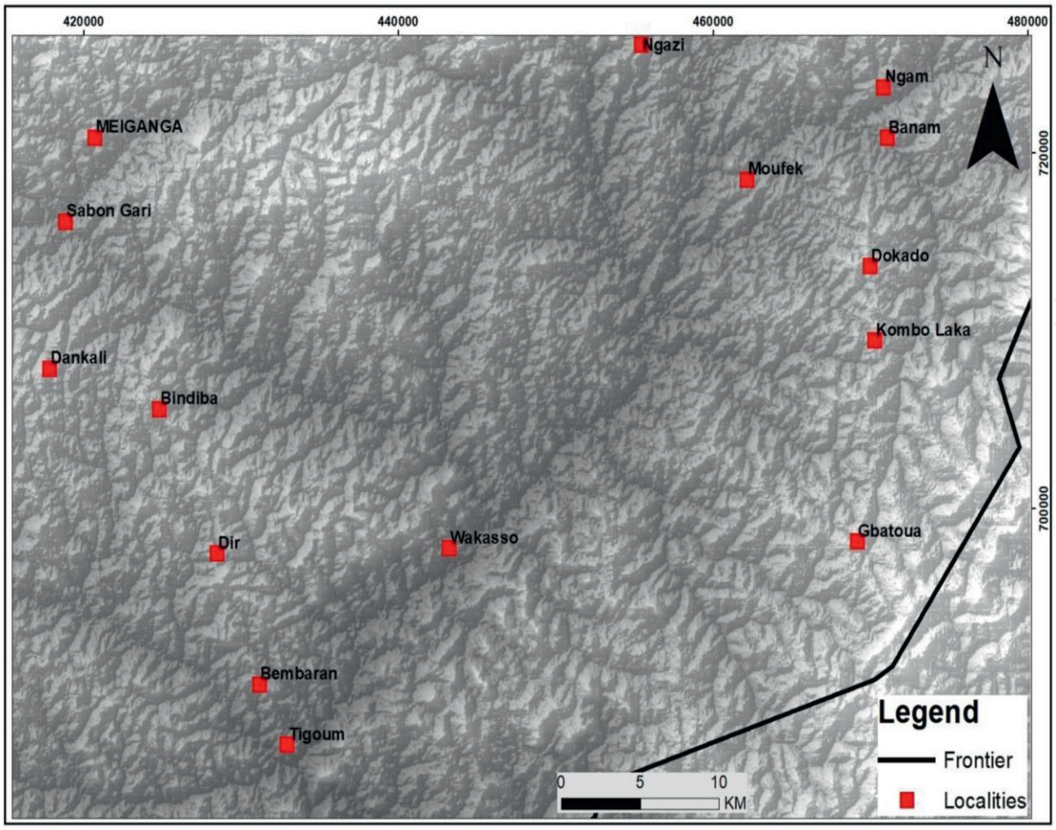


Figure 5.
Shaded relief of the zone derived from satellite image.

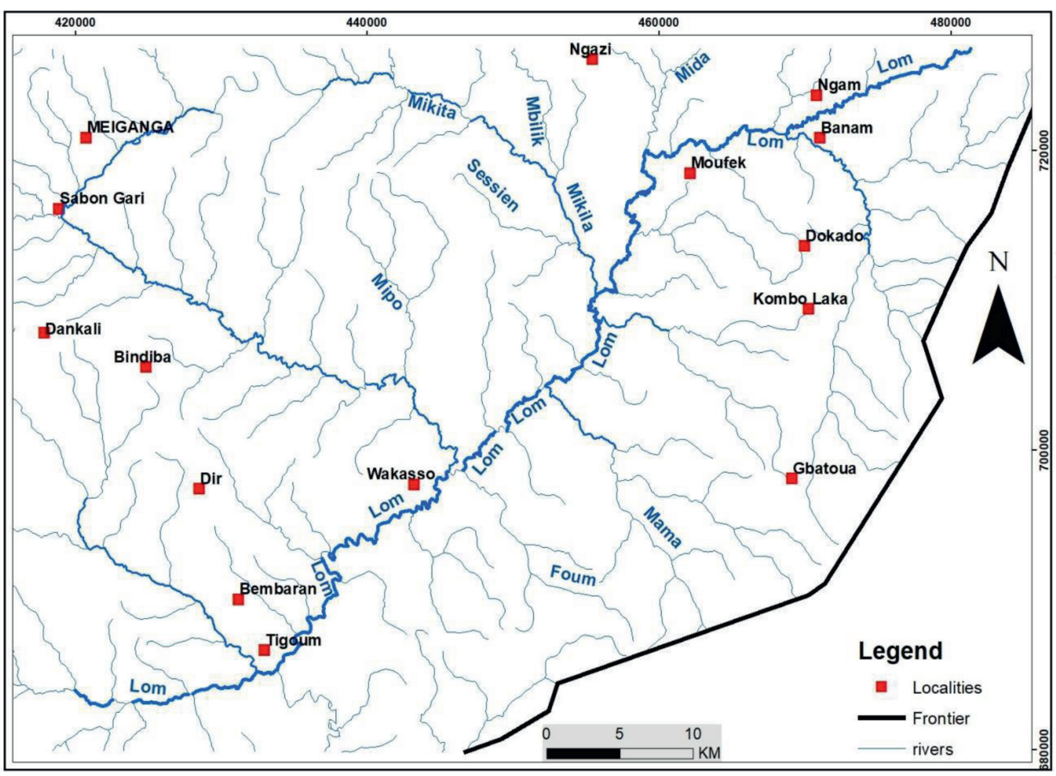


Figure 6.
Hydrography of the study area derived from the satellite map.

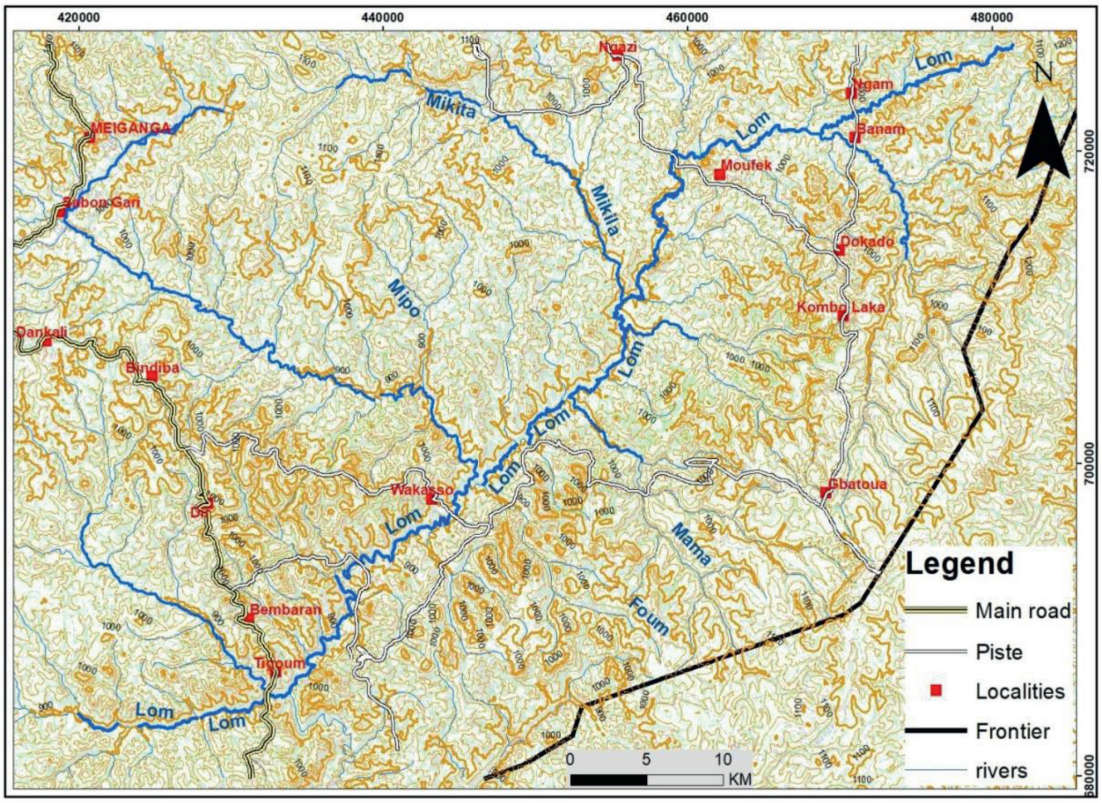


Figure 7.
Basemap of the Meiganga area showing contours, hydrography and localities constructed from the above maps.

Final Map: Planned points are points to be sampled on the field. The streams to be sampled are a part of the norms established by the project's needs (**Figure 8**) we see that the Lom river is flowing following the NW° SE direction.

3.2.3 Database and notebook

In Microsoft Access a database consists of one single file. The file contains all the tables of the database, the relationships, queries, forms (user windows), and many other things like:

- **The Standard operations procedures** which contains all the information related to how the work must be done on the field i.e. codes inherent to the project. A geologist named *Quinter Tanni* is attributed an initial like QT. Amphibolite and granite can be abbreviated like AMP and GRT respectively. Meiganga toposheet is named MEI (**Figure 9**). These codes help to secure information related to the project, for identification purposes, classification, retrieval and management of useful data.

- **The database** helps in the storage and management of all the information above including: geographical related data (maps and vectors) and non-related geographical data (codes, phones…).

At the end of the planning stage, a database is available inside the laptop of the geological team on the field to enter data collected. The database contains at this level only the planned points, the area where they are situated, and the name of the geologist authorized to enter the database (**Figure 9**). There are also codes for filling

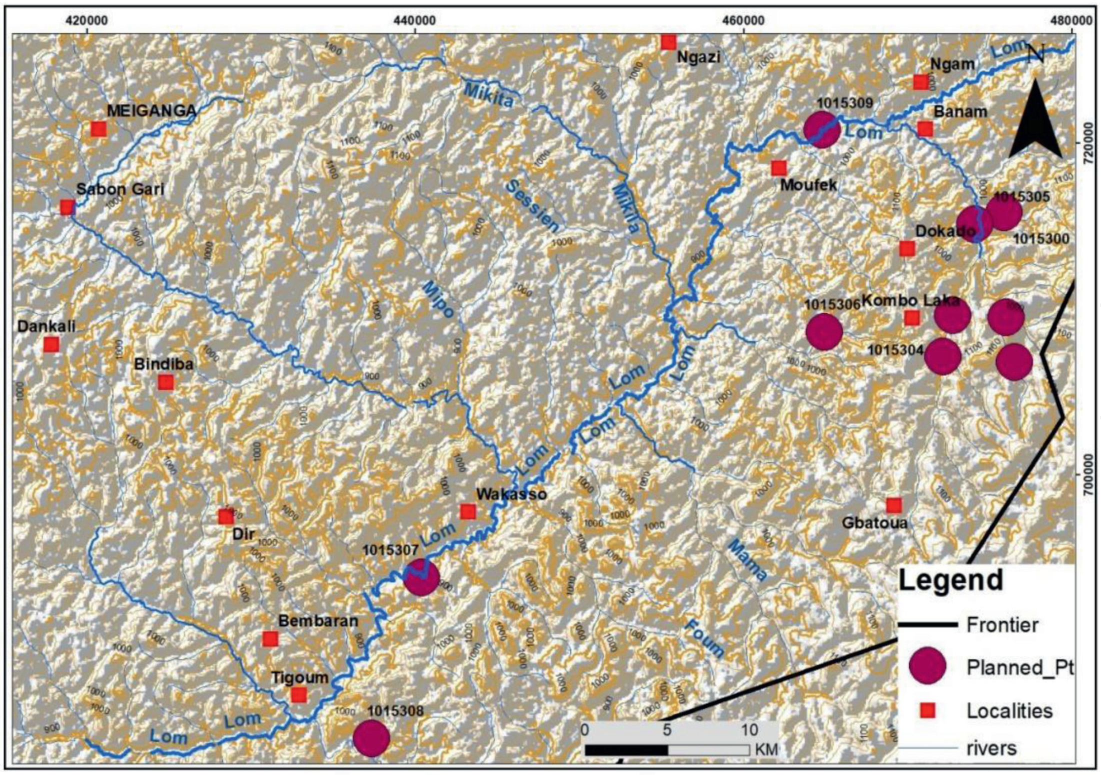


Figure 8.
Final map of the planning phase containing planned points, hydrography, contours, and forms of relief.

Employee_Initial	Employee_Name	Employee_Title
QT	TANNI Quinter	Geologist
JX	XXXXXX	Geologist
PY	XXXXXX	Geologist
JZ	XXXXXX	Supervisor

PROSPECT	
NAME	CODE
Meiganga	MEI
Poli	
Rey Bouba	

ROCK TYPE		
Group	Description	Code
Sedimentary	Claystone	SCY
Metamorphic	Schist - Muscovite	SCHM
	Schist - Chlorite	SCCL
	Greenschist (undif	GST
	Quartzite	QZT
	Gneiss	GN
	Amphibolite	AMP
Igneous	Gabbro	MG
Others		

Figure 9.
Codes in use, built at the planning phase.

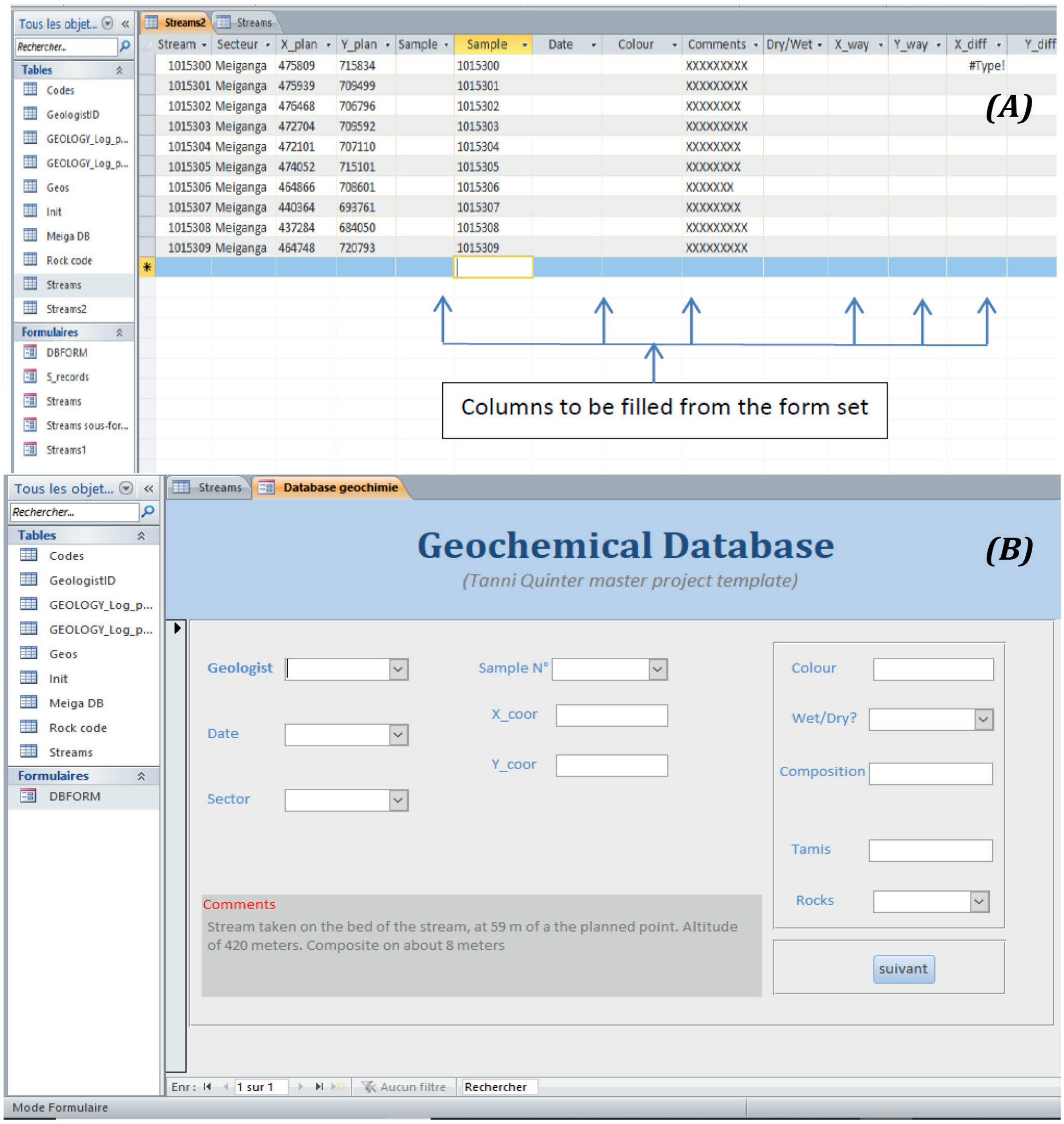


Figure 10.
(A) Database at the planning phase. (B) Empty form set at the planning phase.

the tables in the right way (**Figure 10A** and **B**). The user, a geologist who has to enter the data inside, access it through a form set. This used to be calling a soft database.

4. Field work/data storage

The field work consists of sampling the planned points and recording the associated data. The importance of GIS and database are with a great significance here. Effectively, the team on the field uses the planned data installed in the GPS and the database to collect the data and store them.

During the data sample collection phase, geologists use the GIS to plan their movements on the field, given that roads and topography are not uniform. With the GIS, a geologist can adopt the use of another road avoiding steep slopes. The GPS helps the geologist in navigation on the field. Inside the GPS, all the maps are inserted in order to help the geologists go through to their target. The GPS also contains pre-planned points done in the GIS. Also, the GPS ensures that the geologist is within a reasonable distance to sample the target, record the coordinates and mark the point with a specific name as defined in the SOP of the project. The geologist records inside his field notebook, others characteristics of the sample like color, texture, and environment etc. At this stage, the notebook is considered like the hard database. When the field trip is finished, all the data taken contained in the GPS and the notebook are recorded inside the database. Access can be used for such project. At this stage, it is consider being a soft database. Tracking and other data from the GPS are also extracted via Basecamp software capable to extract and send data from GPS. Those tracking and stored data will be called later in the GIS to assess the work achieved.

A map containing the area of interest is put into a GPS to ensure the safe navigation of a prospector on the field. In the case of the Meiganga topo sheet, pre-defined points are sampled following the GPS guiding and recorded (MARK) button to collect GPS coordinates on the sample points acting as a reference which will be further checked and validated once the prospector is back from the field. This exercise on the field is not complete without orderly labelling.

5. Assessment/data validation

Generally, assessment and data validation is done after fieldwork. All the sampled points are extracted from the GPS via Basecamp software, and then they are transformed in gpx format. The gpx can be imported in ArcGIS software. The first assessment done is the visual checking whereby the supervising team observes all the points and ensures that the collected points match with the planned ones and all SOP are respected before they are validated. If one of the points taken does not match with the planned one, then a particular attention is given to them for rectification. Two situations can arise here with the visual checking after measuring the distance between the planned and sampled points:

- If the point collected is above a certain distance say 100 meters, the best approach is to check if the target stream is the one sampled. Also, we can proceed to check other characteristics precisely the environment and to listen to the explanations of the prospector in order to validate the point.

- If the distance of 100 meters is not respected and the visual checking confirms that it's not the targeted stream that are been sampled, then the point is not valid.

After the visual assessment, the ACCESS database is also checked in order to verify that data entered here are in conformity to the information pertaining to the sampled point on ArcGIS. For example, no sample can be entered without their geologic characteristics.

6. Case study of the Meiganga area

6.1 Data and storage

6.1.1 Characteristics of stream sediments

Maps built from GIS help the geologist to navigate wisely towards the planned points and pick the sample. Those samples are packed inside plastic bags in order to be sent to the laboratory for analysis. Geological characteristics of the sample are then recorded inside the field note book and the database ready at the planning phase. Those characteristics are used further for interpretations. In the course of this work, two types of samples were taken i.e. stream sediment and rock sample:

- For stream sediments, five kilograms of the sample is required (**Figure 11A** and **B**). Although when the sample is wet, the weight can go up to seven. Apart of the coordinates, characteristics of the sample which have geological significance are recorded apart; those are color, composition, contamination (**Table 1**). Every sample receive a unique identity called ID like QTXXX (with QT = initial of Tanni Quinter; XXX = sample number planned).

Figure 11.
Field campaign: (A) picture showing sampling of stream sediments following preplanned sample points and (B) darkish brown color of stream sediment in a codified sample bag.

Sample	Characteristic	Color	Material	Contamination
Sample	Humid	Brown	Sandy	Organic
QT1015300	Humid	Dark gray	Intermediary	Village
QT1015301	Humid	Grayish	Clayey	Organic
QT1015302	Dry	Dark	Intermediary	Village
QT1015303	Wet	Grayish	Clayey	Organic
QT1015304	Dry	Brownish	Sandy	Organic
JX1015305	Humid	Brownish	Sandy	Road
PY1015306	Wet	Grayish	Clayey	Road
JX1015307	Wet	Dark gray	Intermediary	Organic
PY1015308	Dry	Brownish	Sandy	Gold panning

Table 1.
Characteristics of stream sediments.

Figure 12.
Field campaign investigations: (A) showing the geological description of a rock outcropping in flat and (B) darkish gray color of granite sample.

Sample	Grain size	Color	Wheateri	Name
RQT001	Medium	White gray	MW	Granite
RQT002	Coarsed	Gray pink	FR	Granite
RQT003	Coarsed	Gray pink	FR	Granite
RQT004	Coarsed	Gray pink	MW	Granite
RQT005	Medium	White gray	MW	Granite
RQT006	Medium	White gray	FR	Granite
RQT007	Medium	White gray	FR	Granite
RQT008	Coarsed	Gray pink	MW	Granite
RQT009	Medium	Gray pink	MW	Granite
RQT010			SW	Granite

Table 2.
Geological characteristics of rocks (MW = moderately weathered; SW = strongly weathered, FR = fresh rock).

- For rocks, a fresh part of the rock which can permit to make good geological observations like grain size matrix, color, alteration mineral is picked (**Figure 12A** and **B**). The sample here must also help to build tin section in case of interesting features inside like alterations minerals as sulfurs. Every sample receives a unique ID like RQTXXX (with R = initial for rock; QT = initial of Quinter Tanni; XXXX = sample successive rock number) **Table 2**.

The database is filled during this phase though a form set. **Figure 13** shows a form set we built as an example. A form set is a user interface of the database. Its importance is to avoid bad manipulation. The interface is built by the Database management team. The geologist is the user. The information primarily

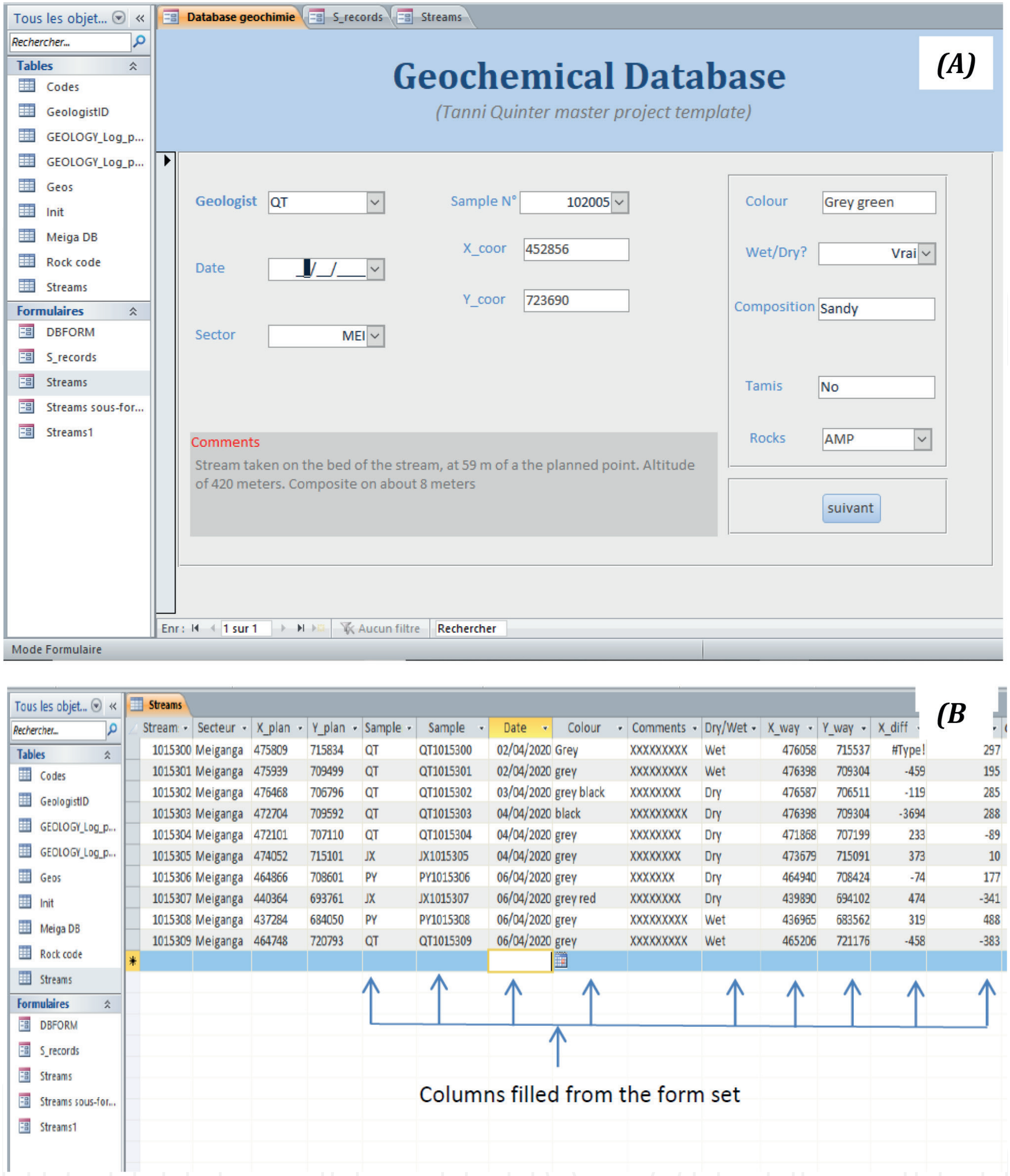


Figure 13.
(A, B) Filled form set built for the project. (B) Filled database.

recorded inside his notebook should be filled. The result is an integral database (**Figure 13**).

6.2 Tracking and waypoints

6.2.1 Tracking

During navigation, the geologist stores the road used inside his GPS through tracking (**Figure 14**). Tracking is recorded automatically. They show at which distance the

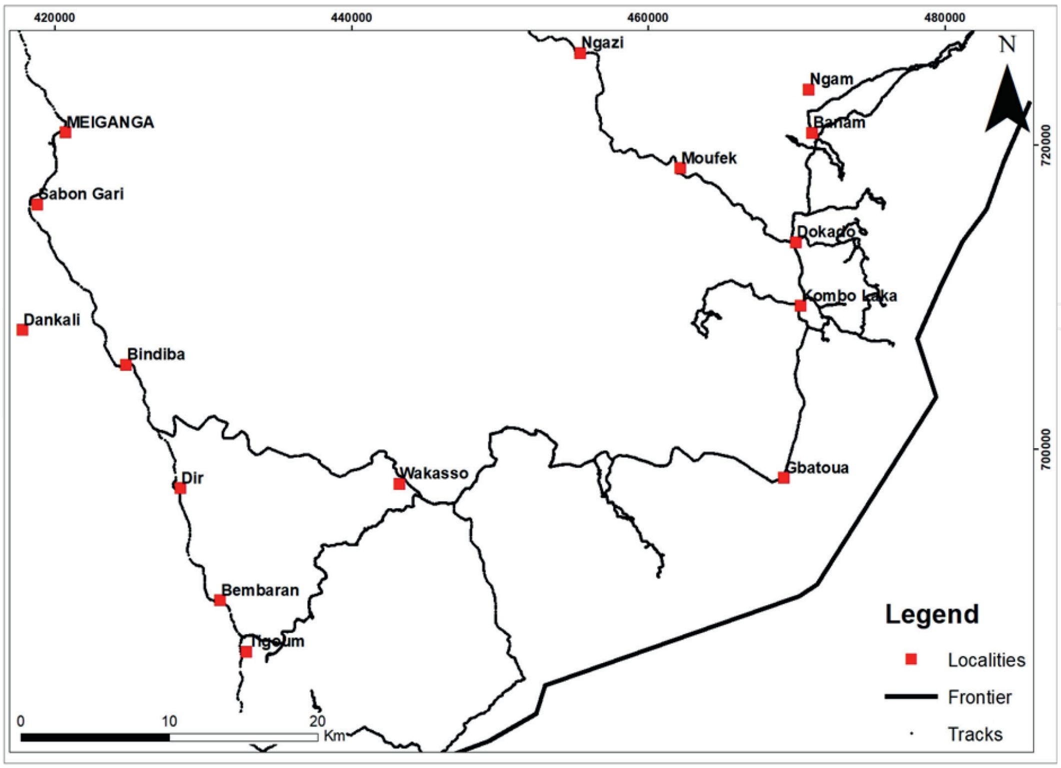


Figure 14.
Tracks extracted from the GPS of geologist on the field.

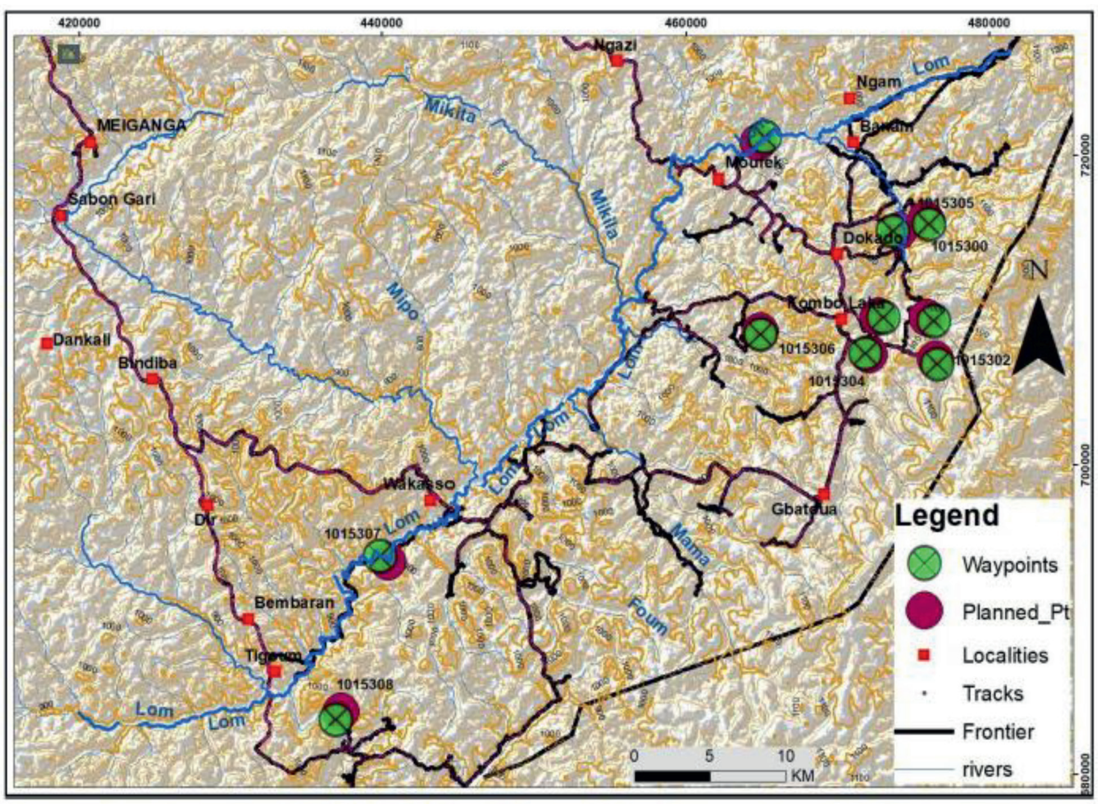


Figure 15.
Tracking and waypoints versus planned points (waypoints = stream sediments sampled).

geologist was from the point to sample. At the end of this stage, the tracking produced is extracted and stored in GPX format in Basecamp software. This will be used later for the assessment phase.

6.2.2 Stream sediment waypoints

Waypoints are points marked by the geologist while on the field (**Figure 15**). Every time a point is collected, a waypoint is marked inside the GPS, and coordinates of the points are recorded. Those waypoints are also extracted in GPX format and stored in Basecamp for assessment and validation.

6.2.3 Rock waypoints

Waypoints are also concerning rocks recorded on the field. Some are sampled and the others are just marked and observed. Those rocks information will help for the enrichment of the geological map (**Figure 16**). Although the information related to rocks are not assessed with the same importance as the stream sediments, they are also with great information and used later to link geochemical anomalies and the surrounding rocks formation. Since we know that the geochemical signature of the stream sampled bear the information of the rock where the sediments sampled are coming from. At this point, the tracking is used to assess if the geologist effectively reach the rock observed or sampled. Those waypoints are also extracted in gpx format and stored in Basecamp and inside the database.

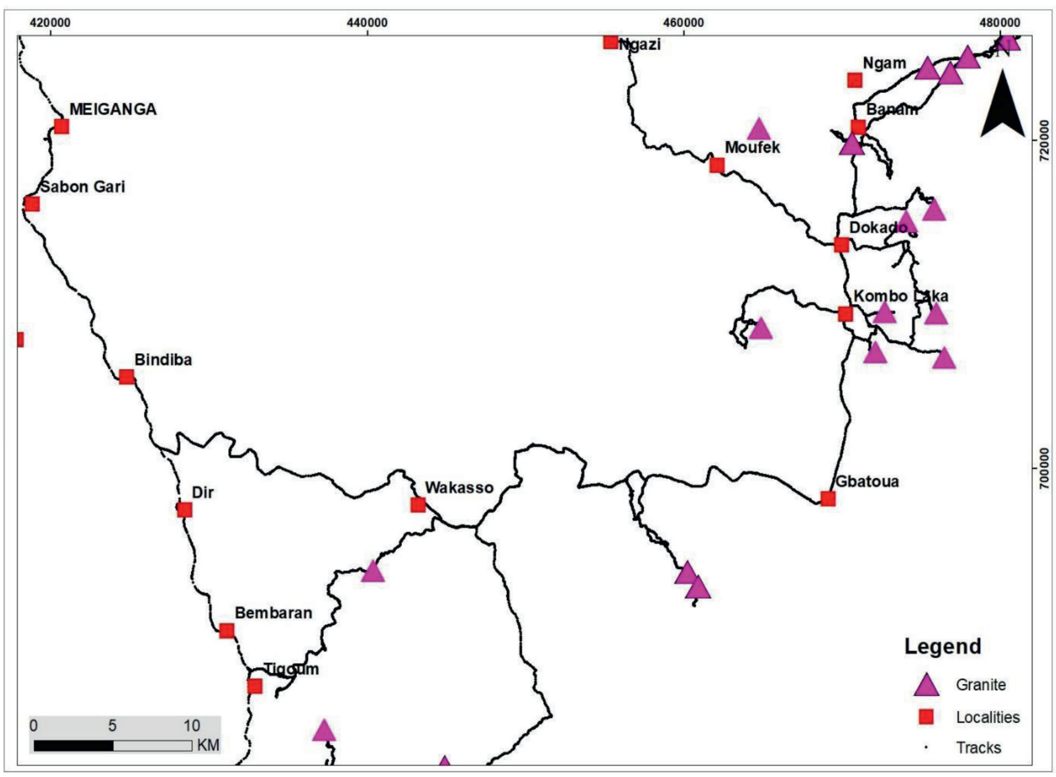


Figure 16.
Tracking and waypoints showing sampled and observed rocks (triangles = observed granites).

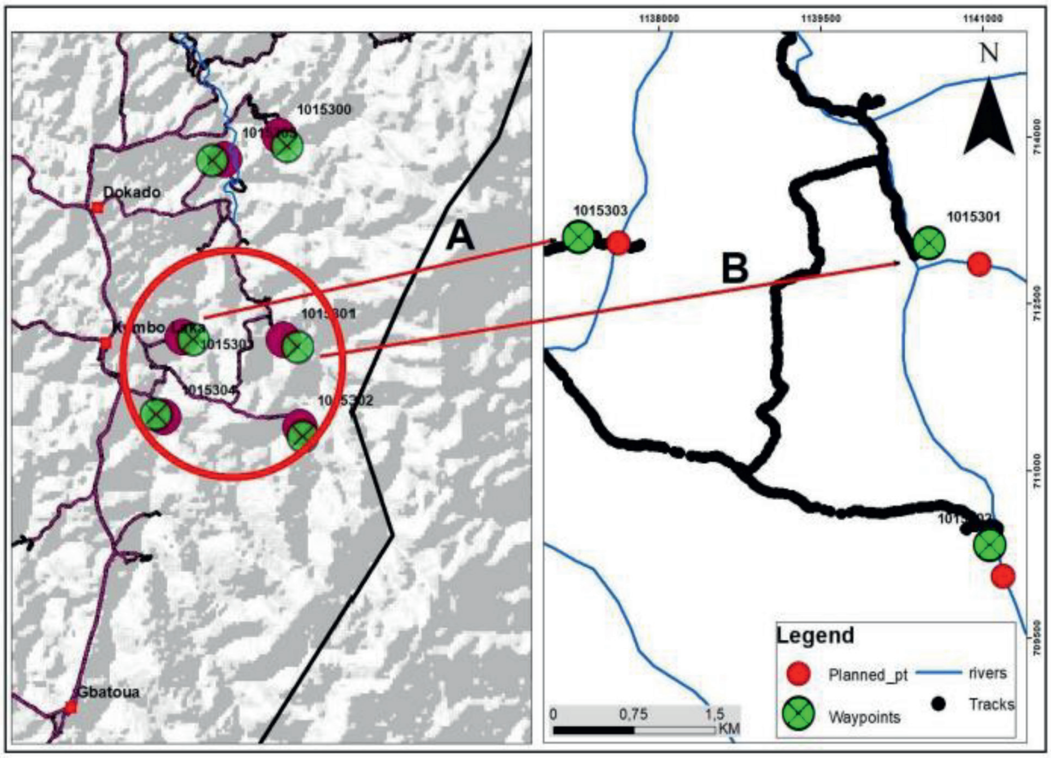


Figure 17.
Valid and invalid data after investigation.

7. Assessment and data validation

7.1 Valid data

The assessment process is made in two phases. The first is the visual checking and the second the parameters checking. According to the supervising team, at the end of this phase, data is valid when minimum criteria are met:

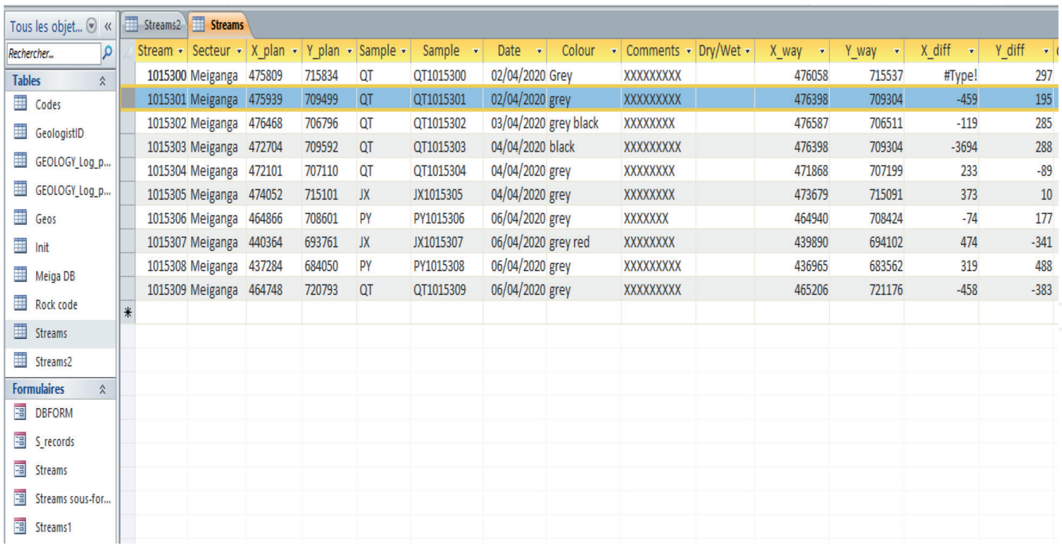
- Coordinates of sampled points correspond to those of planned points.
- Coordinates of the points sampled are within a distance of 100 m with the planned one, and situated on the same river.

The tracking of the geologist attests his movement towards the point planned to be sampled.

If a point does not respect the above criteria (**Figure 17**), an investigation is made in order to invalidate it effectively or not. Thus, the GIS is checked again to understand if the river has not shifted or if the targeted one does not exist. The database is assessed to understand the comments of the geologist.

Case A: Valid data after visual checking on the GIS. Tracks prove that the geologist effectively reach the targeted planned points. But he did not found the stream at that place. One of the reasons is that the river shifted at the left. So he came back where the stream crossed to sample. In that case, all the minimum criteria contained in the SOP (Standard operation procedures) are met.

Case B: Invalid data after visual checking on the GIS. Tracks prove that the geologist did not reach the targeted stream, or the targeted point. And the distance between



Stream	Secteur	X_plan	Y_plan	Sample	Sample	Date	Colour	Comments	Dry/Wet	X_way	Y_way	X_diff	Y_diff
1015300	Meiganga	475809	715834	QT	QT1015300	02/04/2020	Grey	XXXXXXXXX		476058	715537	#Type!	297
1015301	Meiganga	475939	709499	QT	QT1015301	02/04/2020	grey	XXXXXXXXX		476398	709304	-459	195
1015302	Meiganga	476468	706796	QT	QT1015302	03/04/2020	grey black	XXXXXXXX		476587	706511	-119	285
1015303	Meiganga	472704	709592	QT	QT1015303	04/04/2020	black	XXXXXXXXX		476398	709304	-3694	288
1015304	Meiganga	472101	707110	QT	QT1015304	04/04/2020	grey	XXXXXXXX		471868	707199	233	-89
1015305	Meiganga	474052	715101	JX	JX1015305	04/04/2020	grey	XXXXXXXX		473679	715091	373	10
1015306	Meiganga	464866	708601	PY	PY1015306	06/04/2020	grey	XXXXXXX		464940	708424	-74	177
1015307	Meiganga	440364	693761	JX	JX1015307	06/04/2020	grey red	XXXXXXXX		439890	694102	474	-341
1015308	Meiganga	437284	684050	PY	PY1015308	06/04/2020	grey	XXXXXXXXX		436965	683562	319	488
1015309	Meiganga	464748	720793	QT	QT1015309	06/04/2020	grey	XXXXXXXXX		465206	721176	-458	-383

Figure 18.
Checking of the database to see difference and comments. Note the X_diff case of −459 m between the planned and the waypoints recorded.

the waypoints and the planned one is >100 m. In that case, all the minimum criteria contained in the SOP (Standard operation procedures) are not met (**Figure 18**).

Data are declared invalid when they do not meet primary criteria of valid data, nor the additional ones. In that case, the point has to be collected again.

7.2 Validation of rock

Validation of rock sampled and observed is basically done by following the tracking of the geologists. If all the tracks cross the sampled and observed points, thus all the points are considered valid. In the following map, all the points are considered valid because the tracking confirms it to be so (**Figure 19**).

7.3 Contribution of our work

7.3.1 Data and their reliability

Following the work we achieved during the project, we learned that data taken on the field act as pointers used to determine whether or not the company will be a failure or a success. Attention needs to paid so as not to spend money to go back to get data which was not well collected. Thus, it is necessary to ensure as much as possible, that these data are representative and comprise significant geological information to understand them. Global positioning system coordinates of points are important. The conditions of samples and their characteristics are also important so that we can better comprehend for example whether a sample is contaminated.

Contamination for example significantly influences the obtainable quality of data. While an organic content is always present, gold can be present in a sample because of the gold panning site near like the one in Kombo Laka village at the east part of the map (**Figure 20**). During the assessment, it can be see that the village is up the sampled point and understand why an abnormal concentration of gold is present here and none in the samples near.

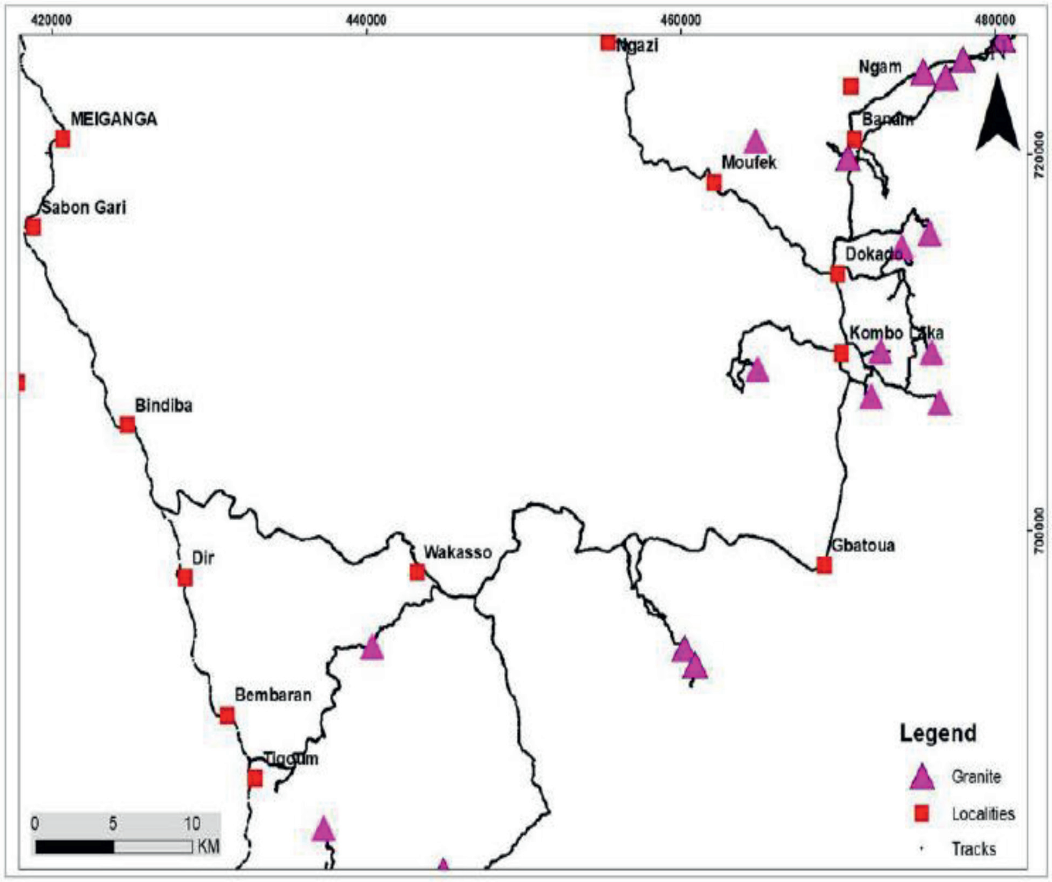


Figure 19.
Tracking versus sampled and observed rocks.

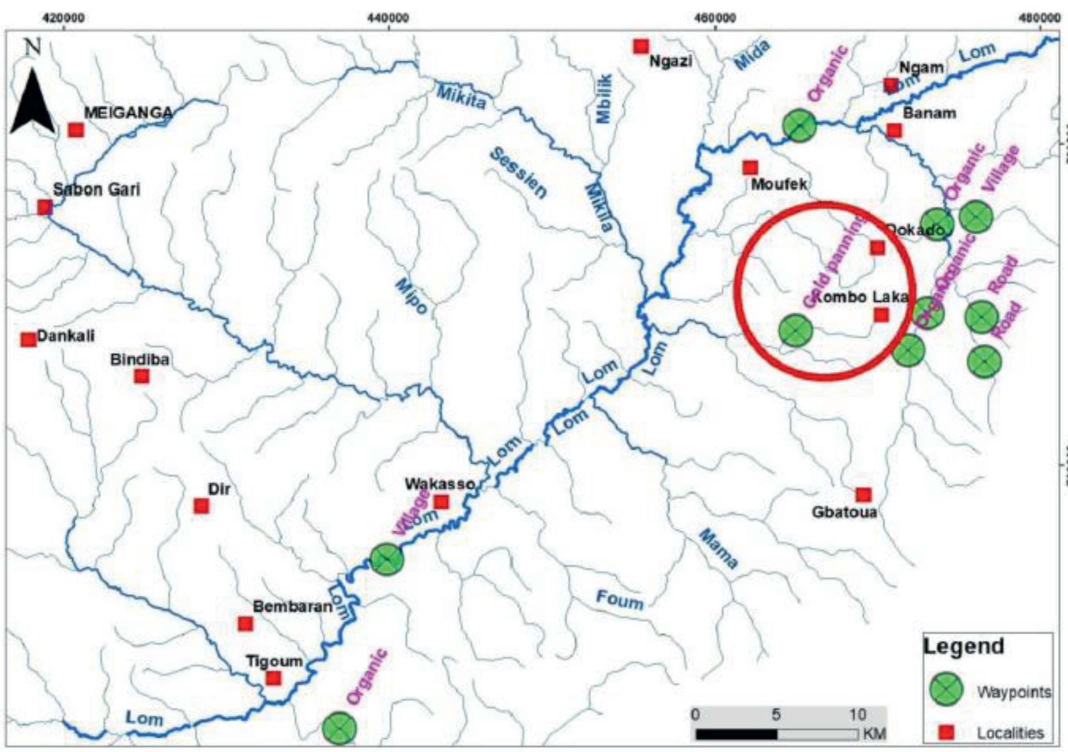


Figure 20.
Analysis of factors of contamination. The point is situated near the gold panning site.

Some tools that mining companies and mining projects use are Database and GIS. To use them effectively ask for skills and comprehension of the whole process to take reliable data than to discard some or retaken others.

7.3.2 Tools developed

The database has been effectively built in a software called Access and can allow the geologists of a mining company to record the data from the field without compromising the reliability of the database, this through the form sets. The same database permit to keep records that help for the assessment of data collected from the field. The database can be coded and adapted for any mining company and project. Inside every mining projects and company, a special team is dedicated to design, manage and secure the database.

Speaking about GIS, mining company can use the same hierarchy of our tools to take all the power of GIS and their importance at the very planning phase where all the data to be used on the field are collected and put together to allow a field team to deploy themselves safely. But also to assess the data they bring in order to validate them. Some data can be wrong. To avoid a mining company to rely on them and fall in failure, the data must be assessed and validated. Tracking and waypoints are used for that at this stage. But GIS and database also help further for interpretations of the data and their behavior.

7.3.3 Interpretation and sketch geological maps

When samples are taken, their geochemical anomaly helps to find ore bodies. Stream sediments is an exploration tool, which plays a significant role in geochemical exploration by identifying possible sources of anomalous element concentration. Sampling is done on rock debris, soil or other materials which has undergone erosion and transportation within a catchment basin upstream of a sampling site. It is thus representative of the geochemistry of materials from the upstream drainage basin. The collection and analysis of these stream sediments (silt, sand, mud, clay) in a stream or riverbed, either dry or wet are common methods for exploration. Stream sediments are used for geochemical analysis for enhancement of geological understanding.

Rock types can be differentiated by geochemical signatures in stream sediment data. But rocks can also help to draw sketch of geological maps. Those geological maps are then compared to the existing ones in other to understand how wrong were the map or not. The **Figure 21A** and **B** below shows a sketch of geological map built from the granites sampled in the Meiganga region.

7.4 Disadvantages of using GIS

Though GIS could benefit users from different disciplines it also has some disadvantages:

- *Expensive:* GIS setup is complex, in addition to the cost of the equipment and frequent updating of datasets or data models may lead to errors in results.

- *Real-time parameters*: The handling of growing datasets is an overall challenge to the GIS system.

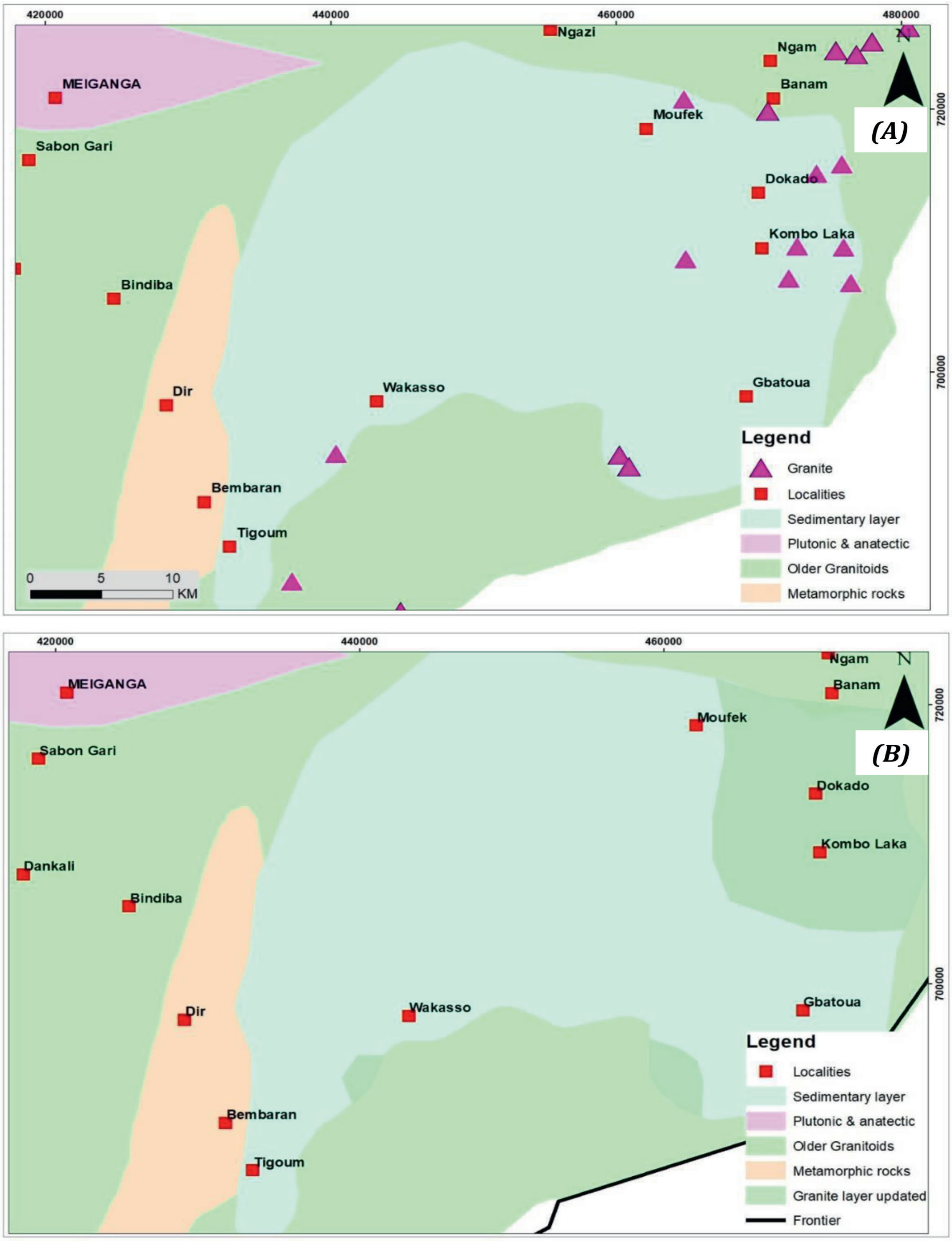


Figure 21.
(A, B) Sketch of geological map of the study area derived from sampled areas.

- *Geographical errors increase with larger-scale data*: The quality of the data collected directly affects the accuracy of the end system. Geographic errors will also affect net results since GIS handles large-scale data.

- *Relative loss of resolution*: Every technology has negotiable errors when deployed. In this Meiganga study area, some predefined points were displaced and did not fall on target streams (**Figure 22**).

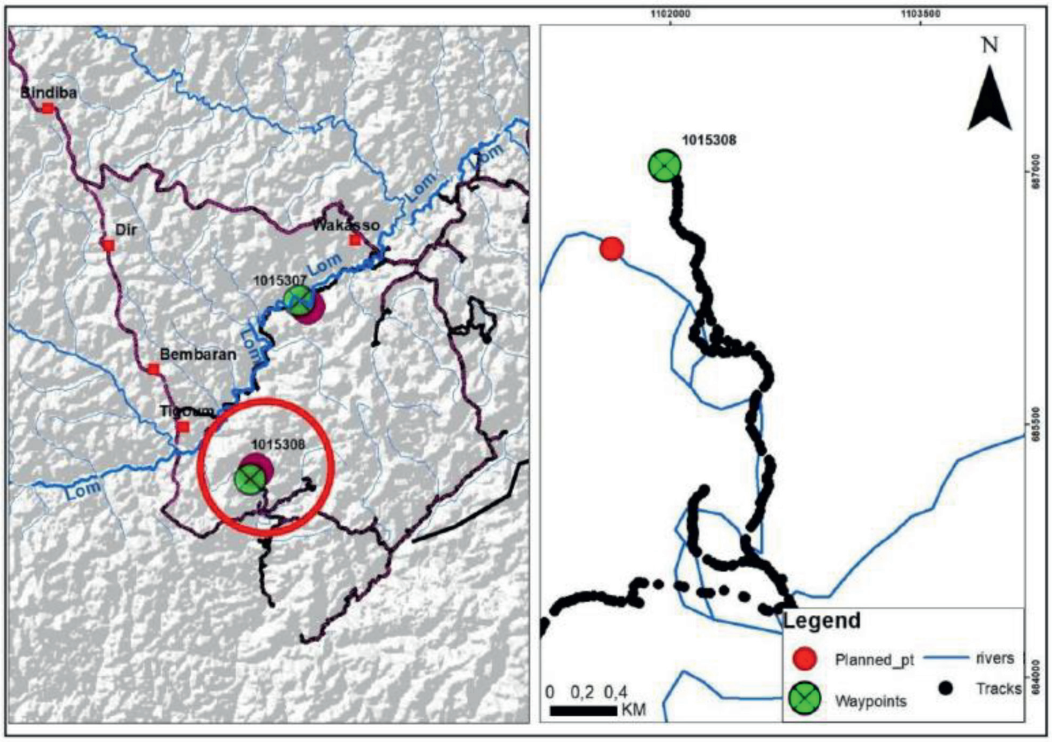


Figure 22.
Example of error. When zoomed, the point 1,015,308 which seems to be well placed on the stream, is shifted for more than 100 m.

- *Positional accuracy and precision*: Accuracy and precision are the functions of the scale at which a map (paper or digital) is created. The no spatial data linked to location may also be inaccurate or imprecise. Inaccuracies may result from mistakes of many sorts. No spatial data can also vary greatly in precision. Precise attribute information describes phenomena in great detail.

- *Violation of privacy*: The user community is not limited to authorized persons. So there is threat in the usage of data displayed from the GIS system.

- *Error-prone interpretation* could lead to failure of system implementation thus affecting the economic strategy of the implementer.

- *There might be failures in initiating or additional effort* required in order to fully implement the GIS but there might be large benefits to anticipate as well.

- *There is a lack of trained teachers in the domain*: Though GIS and remote sensing have been introduced in some universities, still the subjects have not yet been taught to the fullest extent. Moreover, a link between secondary education and higher education must be established for a wide spread and its continuity in the system. Prior knowledge of GIS is a prerequisite to train the trainers.

7.5 Improvements on GIS

GIS of the future may be very well done if already the following aspects are understood and objectives outlined following, other aspect such as: Planning, system design, implementation, maintenance of the software should be observed.

7.5.1 Planning

Your plan should answer the question: What information do I hope to gather? In planning its major contribution is to give us with an organized set of data which can help professionals to manage complex scenarios relating to the selection of site, environment impact, study of ecosystem, managing risk regarding the use of natural resources, sustainability issues, managing traffic congestion, routing of roads and pipelines etc.

Precise and accurate data is the core driving factor of any successful project. GIS is equipped with almost all those tools and functions that enables user to have access to the required data within a reasonable time.

Analysis is one of the major and most influential phases. Analysis guides us about the validity or correctness of design or we can say that analysis is a method which supports our design. Some of the analyses that can be performed by GIS are: water distribution analysis, traffic management analysis, soil analysis, site feasibility analysis, environment impact analysis, volume or area analysis of catchment, river or canals pattern analysis, temperature and humidity analysis, elevation etc. The construction phase involves the assemblage and putting into place the various tools to attain the objectives already established.

Lastly the operations phase, is the execution of a set of activities using all tools to acquire the necessary data. This last phase may, if not always necessitate a deployment of a qualified person to the field to obtain useful information.

8. Conclusion

At the end of this investigation which consisted of highlighting the importance of GIS and database in early stage of mining exploration, the objectives assigned, that were to build a reliable database and a GIS to ensure the planning phase is optimized and the results of this work meets standard operations procedures. The database built is capable to record and store geological and non-geographical information without being compromised by the mis-manipulation of geologists while at the same time it helps to ensure distances between sampled points and the planned ones do not exceed a certain distance.

The GIS is able to gather maps and geographical data for planning the field work and assessing results. Tools developed can then be used by any mining exploration project or company to work wisely and respect norms inside the mining sector. GIS and database are used in both Greenfield exploration projects to establish mining blocks based on statistics and in the brownfield exploration projects to do analysis using statistical methods like variograms to understand the behavior of our deposit. These analyses create grade control which guides in exploitation giving ideas of areas of high grade and low grade hence a suitable beneficiation method to be employed. The Meiganga area permitted us to effectuate the deployment and testing of our tools. However, some limitations have been highlighted concerning GIS. This shows that GIS and Database will always need to be in conformity with field work.

Acknowledgements

Part of the data presented here form a part of the second author's Master Thesis supervised by Dr. TAKODJOU WAMBO Jonas Didéro and M. NTOOGUE Paul Rene that was defended at the University of Yaoundé I, Cameroon. We gratefully acknowledge anonymous reviewers for their critical and constructive comments of the manuscript. We are thankful to Consulting and Training in Geosciences (CONTGEO) Research Centre for Mineral Exploration Targeting, for providing facilities during preparation of the earlier version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Author details

Jonas Didero Takodjou Wambo[1,2]* and Wenzi Tanni Quinter[2]

1 California Institute of Technology, Pasadena, CA, USA

2 University of Yaounde I, Yaounde, Cameroon

*Address all correspondence to: jonasdidero@gmail.com

References

[1] Binam Mandeng EP, Bondjè Bidjeck LM, Takodjou Wambo JD, Taku A, Bineli Betsi T, Solange Ipan A, et al. Lithologic and structural mapping of the Abiete–Toko gold district in southern Cameroon, using Landsat 7 ETM+/SRTM. Comptes Rendus Geoscience. 2018;**350**(3):130-140

[2] Takodjou Wambo JD, Pour AB, Ganno S, Asimow PD, Zoheir B, dos Salles R, et al. Identifying high potential zones of gold mineralization in a sub-tropical region using Landsat-8 and ASTER remote sensing data: A case study of the Ngoura-Colomines goldfield, eastern Cameroon. Ore Geology Reviews. 2020;**122**:103530

[3] Takodjou Wambo JD, Ganno S, Djonthu Lahe YS, Kouankap Nono GD, Fossi DH, Tchouatcha MS, et al. Geostatistical and GIS analysis of the spatial variability of alluvial gold content in Ngoura-Colomines area, Eastern Cameroon: Implications for the exploration of primary gold deposit. Journal of African Earth Sciences. 2018;**142**:138-157

[4] Lisitsin V. Spatial data analysis of mineral deposit point patterns: Applications to exploration targeting. Ore Geology Reviews. 2015;**71**:861-881

[5] Gumiel P, Sanderson DJ, Arias M, Roberts S, Martín-Izard A. Analysis of the fractal clustering of ore deposits in the Spanish Iberian Pyrite Belt. Ore Geology Reviews. 2010;**38**(4):307-318

[6] Carlson CA. Spatial distribution of ore deposits. Geology. 1991;**19**(2):111-114

[7] Agterberg FP. Fractal modeling of mineral deposits. Proceedings 24th APCOM Symposium. 1993;**1**:43-53

[8] Porwal A, Carranza EJM. Introduction to the special issue: GIS-based mineral potential modelling and geological data analyses for mineral exploration. Ore Geology Reviews. 2015;**71**:477-483

[9] Carranza EJM, Hale M. Spatial association of mineral occurrences and curvilinear geological features. Mathematical Geology. 2002;**34**(2):203-221

[10] Carranza EJM, Mangaoang JC, Hale M. Application of mineral exploration models and GIS to generate mineral potential maps as input for optimum land-use planning in the Philippines. Natural Resources Research. 1999;**8**(2):165-173

[11] Asadi HH, Hale M. A predictive GIS model for mapping potential gold and base metal mineralization in Takab area, Iran. Computers & Geosciences. 2001;**27**(8):901-912

[12] Bonham-Carter GF, Agterberg FP. Arc-WofE: A GIS tool for statistical integration of mineral exploration datasets. Bulletin of the International Statistical Institute. 1999;**52**:497-500

[13] Setyadi H, Anggayana K. Database management and quality assurance is key of success in exploration. Procedia Earth and Planetary Science. 2013;**6**:42-49

[14] Setyadi H, Widodo LE, Notosiswoyo S, Saptawati P, Ismanto A, Hardjana I. GIS modeling using fuzzy logic approach in mineral prospecting based on geophysical data. AIP Conference Proceedings. 2016;**1711**(1):070002

[15] Fu C, Chen K, Yang Q, Chen J, Wang J, Liu J, et al. Mapping gold mineral prospectivity based on weights of evidence method in Southeast Asmara, Eritrea. Journal of African Earth Sciences. 2021;**176**:104143