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TECHNO-ENVIRONMENTAL PLANNING OF AN EXPLORATION CAMPAIGN IN PROTECTED AREAS – THE CASE OF THE BOMBO-LUMENE HUNTING ESTATE AND RESERVE (D.R. CONGO)

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ABSTRACT

Planning is a strategic approach that determines the orientations and objectives of a society in relation to the evolution of its territory. It serves as an appropriate tool for promoting sustainable development. In this context, the primary aim of this study was to design an exploration campaign in protected areas to minimize the potential risks that this initiative could pose to the well-being of local populations. Furthermore, it is crucial to establish new perspectives that could assist exploration engineers in conducting their various studies under normal and safe conditions.

Through the techniques, methods, and tools applied during this study, we have discovered a central structure in our study area, which we consider a significant element that could certify the presence of a hydrocarbon deposit. Planning thus proves to be one of the most effective solutions for successfully carrying out an exploration campaign in protected areas, with the objective of minimizing the negative impact on the targeted site. By integrating appropriate management strategies and involving stakeholders, we can ensure a harmonious coexistence between exploration activities and environmental preservation.

Keywords: gravimetric data, Bouguer's anomaly, tilt derivative, planning gravimetric, magnetic prospecting

INTRODUCTION

The Bombo-Lumene hunting estate and reserve in the Democratic Republic of Congo is home to a rich biodiversity of flora and fauna, characterized by dense rainforest, rivers and lakes, as well as mountains and hills, with the reserve's unique ecosystems providing a natural habitat for a wide variety of animals and plants. This protected area covers more than 4,000 km^2 and is home to a wide variety of animal species, including elephants, lions, hippos and crocodiles. The presence of numerous streams and rivers also ensures the preservation of several species of fish and amphibians. While subsistence hunting was originally permitted within the Bombo-Lumene estate, it was strictly regulated to enable sustainable management of animal populations, In addition, the reserve is also equipped for ecological tourism with camping areas and comfortable accommodation [10],[14],[26].

The aim of our study is to draw up a technical and environmental plan for an exploration campaign in protected areas, in order to put in place a number of strategies, techniques and precise methods that will help us to carry out our various studies in good conditions, without damaging the environment of the study area. We used the geological and geophysical data available in our study area to get an idea of the geological and geophysical situation [11], [20-21].

The geological data used enabled us to draw up all the different geological maps possible, to get an idea of the geology of the site, while the gravimetric data enabled us to study and analyze the variations in space and time of the Earth's gravity field [13].

This study will fill a number of gaps in the knowledge base, by setting up strategies and precise methods. Previous studies may lack precise information on the study area due to the methods or techniques used in previous years. Nowadays, we can use tools and techniques such as Arcgis, Geosoft, Surfer, spatial species distribution modelling, participatory mapping techniques and matrix analysis to find out if there really is a core structure in our study area, which for us will be a very important element on which we can say that there is the presence of a hydrocarbon deposit. Due to a lack of strategies and methods, it was difficult to carry out an oil exploration campaign in protected areas (parks), and to obtain precise information that would help us to carry out in-depth studies [19-20],[25].

Since we have used highly advanced methods, techniques, tools and strategies to analyze the geological and gravimetric data for our study area, the results of these analyses have enabled us to put in place new and precise perspectives that will enable us to carry out our various studies with much greater precision.

METHODS AND MATERIALS

Methodology

In the course of our study, we used the following methods:

- Data collection: We acquired Bouguer gravity data via the ICGEM platform, and geological data in shape file format, i.e. usable in ArcGis, for the study area. These data enabled us to draw up the geological map of the area and the various gravity anomaly maps [13];

- Analytical: The analytical method enabled us to process and interpret the gravity data using software (Surfer and Geosoft). To do this, we used regional-residual separation methods to process the data [12],[18];
- Interpretation and discussion: the aim of this stage was to give a geological meaning to all the results obtained from processing the gravity data. In other words, we had to read the various maps and, on the basis of geological hypotheses, derive geological information. We also consulted various documents relating to the subject under study.

Materials

- ✓ ArcGIS 10.8: Geographic information system software used to store, analyze, visualize and manage geographic data for the purpose of creating maps ;
- ✓ Geosoft: This software is mainly used to process and interpret geoscientific data, particularly in the fields of geophysics and geology;
- ✓ Surfer: Surfer is a software package that provides powerful tools for the visualization, analysis and interpretation of geophysical data, contributing to a better understanding of subsurface geology and informed decision-making in various geological projects.

LOCATION OF THE BOMBO-LUMENE HUNTING ESTATE AND RESERVE

The Bombo-Lumene Hunting Estate and Reserve lies between coordinates 4°20' and 5°80' South latitude and 15°50' and 16°20' East longitude, with an average altitude of 600m. The distance from downtown Kinshasa is 120 kilometers on the Batéké Plateau in the city-province of Kinshasa. Access is via the Nationale n°2 or the Kinshasa-Bandundu road. The entrance to the estate is halfway between the villages of Dumi and Mbankana. The Domaine is located in the extreme north of the Commune of Maluku, City of Kinshasa, and covers an area of around 350,000 hectares or 350 km^2 [4],[15],[26].

Ministerial Order no. 07 of February 10, 1968, creating the Domaine, sets its boundaries according to the following coordinates:

- North: Route Kinshasa-Kenge, from where it is crossed by Rivière Bombo to where it is again crossed by Rivière Lufimi;
- East: Rivière Lufimi to where it crosses the Kinshasa-Kenge road upstream to its tributary with Rivière Idiondo, the southern boundary of Kasangulu territory;
- West: Rivière Bombo, from Route Kinshasa-Kenge to its confluence with Rivière Muti-Mutiene and Mpili to its southern source;
- South: the southern boundary of the Kasangulu Territory, [26].

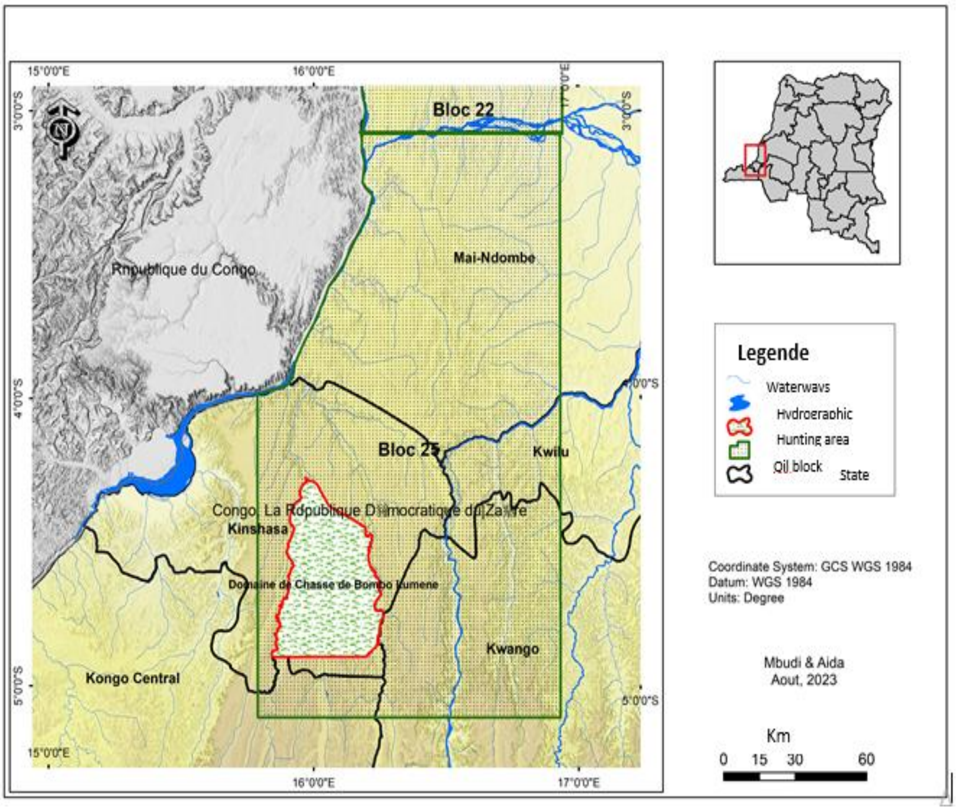

Figure 1*. Location of the Bombo-Lumene hunting area and reserve on block 25 developed using Arc GIS software*

DATA ANALYSIS

This stage concerns the analysis of the geological and geophysical data available in the study area, in order to gain an idea of the geological and geophysical situation in the area before embarking on fieldwork. It should be pointed out that the data in our possession are essentially geological (lithological) and gravimetric.

Analysis of geological data

Given the security issues at stake in the study area, it was difficult to carry out a geological reconnaissance survey. Nevertheless, based on geological data for the DRC in shape file format from MRAC [18-19], we drew up a geological map of the study area to give an idea of the site's geology, which is presented as follows.

When we look at the image above, we see that our study area is made up of several geological formations, the majority of which are recent Paleogene, Neogene formations, containing polymorphic sandstones, the sand series and alluvium, which we consider to be recent deposits very rich in organic matter. These deposits date from the Cenozoic to the Quaternary [18].

Analysis of gravimetric data

Gravimetry involves measuring, studying and analyzing variations in space and time in the gravity field of the Earth and other bodies in the solar system. It is closely related to geodesy, the study of the Earth's shape and the measurement of its dimensions and deformations [3],[11],[18].

The gravimetric method involves measuring the vertical component of the gravity vector using a gravimeter. This is in fact an accelerometer, since it measures the same thing according to the principle of equivalence. However, a gravimeter is specialized in measuring a vertical acceleration close to the Earth's normal gravity, and with a high degree of precision around this value. These measurements are made by profiling the entire area to be studied. Although the legal unit of gravity acceleration (g) is $m.s^{-2}$, gravimetric campaign results are often given in gal (in honor of Galileo). The conversion is as follows:

$$1gal = 1cm.s^{-2} \text{ or } 10^{-2}\, m.s^{-2} \quad (1)$$

Since we're looking to measure a very small variation in the field strength, the measurement is tricky to carry out, and also requires great precision when positioning the measuring stations. Here, we will draw up all the different possible maps, process the data and interpret them in order to find a satisfactory result for our study.

Bouguer anomaly map

Bouguer's anomaly is the algebraic sum of all corrections plus the remaining difference between measured g and its theoretical value. [28]. Bouguer's anomaly is the gravimetric response caused by density heterogeneities in the subsurface. The following treatments can be applied to gravity data (fig. 2).

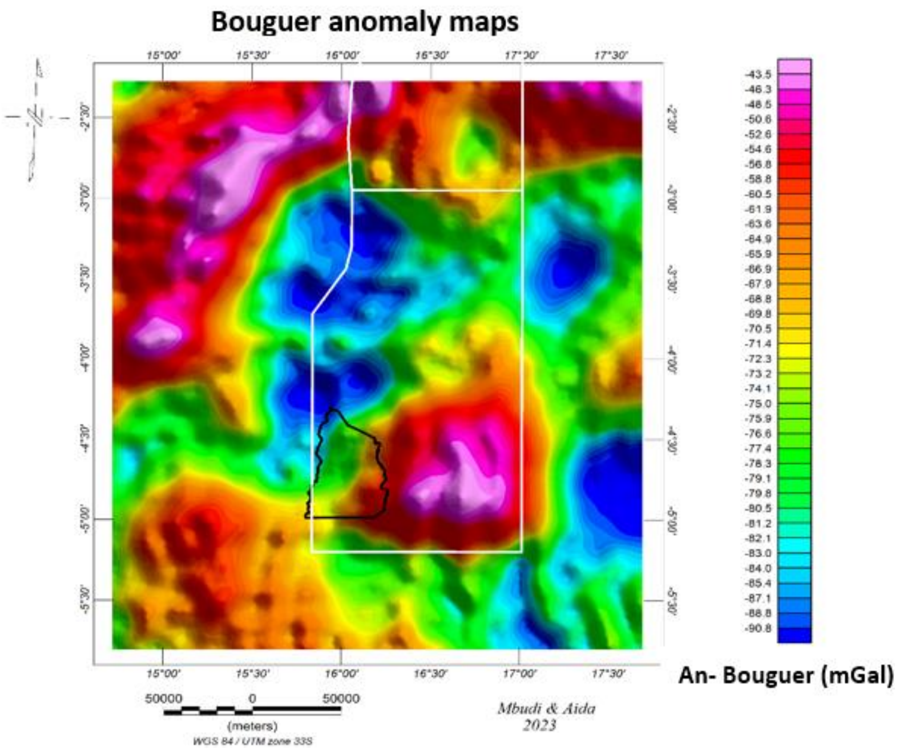

Figure 2. *Bouguer anomaly map developed using surfer software*

Based on the intensity of the anomalies, we can see on the Bouguer anomaly map that the north-western side of Block 25 is much more dominated by low anomalies ranging from

-90.8 mgals to -81.2 mgals and represented by the blue color. However, we note that the S-E part of the study area is characterized by high values of red anomalies. Within the Bombo-Lumene domain, we also note the presence of low and high anomalies, between which we observe average anomalies in yellow-green.

Residual regional separation

Once all the corrections have been applied, we obtain a Bouguer anomaly map that generally demonstrates two characteristics (Bouguer's anomaly represents the sum of the effects of all the bodies below the surface) [3]:

- Regular, continuous gravitational field variations over long distances, known as regional variations. They are produced by heterogeneities at great depths;
- Superimposed on these regional variations, and often masked by them, we observe small local perturbations of the gravitational field that are secondary in dimension but primordial.

The Bouguer anomaly data used in this work come from the International Centre for Global Earth Models (ICGEM) platform. These include 2784 stations, presented with a sample of 20 stations (Table 1), from which the data were used to produce the Bouguer anomaly map shown in Fig. 2.

***Table 1**. Sample of Bouguer anomaly data from ICGEM* [13]

Longitude (Degree)	***Latitude (Degree***	***Bouguer anomaly (mGal)***
14,88	-2,43	-73,96422778
14,93	-2,43	-78,99776314
14,98	-2,43	-78,97450161
15,03	-2,43	-74,77287999
15,08	-2,43	-70,04888897
15,13	-2,43	-66,84097975
15,18	-2,43	-65,18433527
15,23	-2,43	-64,12374498
15,28	-2,43	-63,11369362
15,33	-2,43	-63,23677728
15,38	-2,43	-64,48959294
15,43	-2,43	-64,33331301
15,48	-2,43	-62,38876321
15,53	-2,43	-61,01986983
15,58	-2,43	-59,94401077
15,63	-2,43	-58,00968539
15,68	-2,43	-57,33328546
15,73	-2,43	-58,06215377
15,78	-2,43	-56,84992859
15,83	-2,43	-54,37888231

Regional anomaly map

Depending on the purpose of the survey, it is necessary to:

- Smooth and remove surface effects to retain only depth effects (regional);
- Smooth out the effects of deep sources and subtract them to obtain surface anomalies (residual) [3],[17];

The resulting map of regional anomalies is as follows (figure 3).

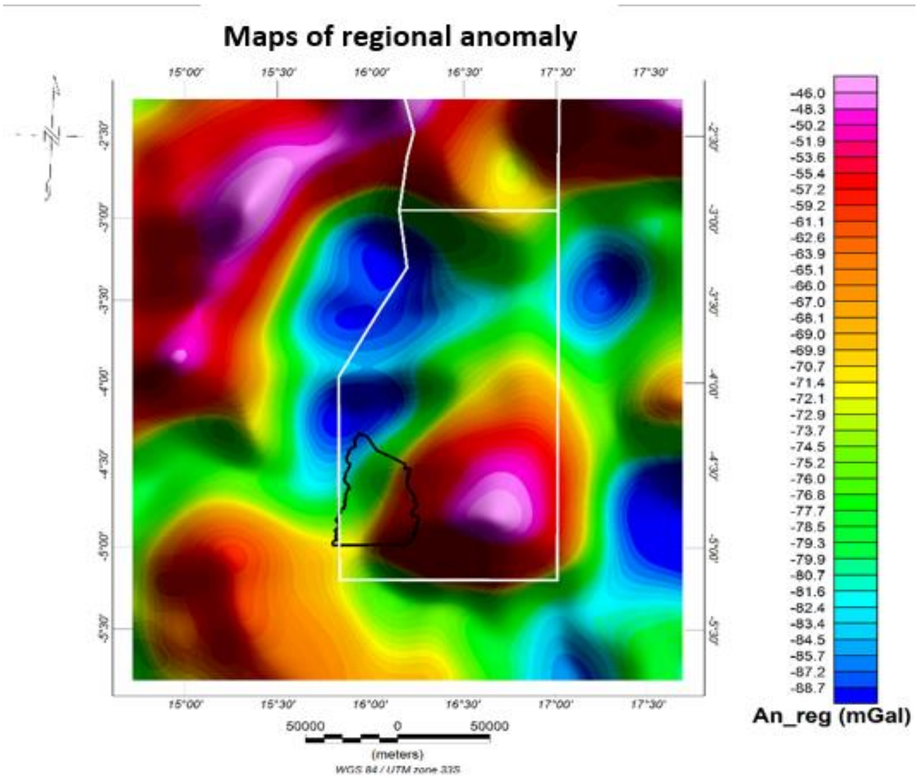

***Figure 3**. Map of regional anomalies in the study area developed using Surfer software*

Residual anomalies map

Residual anomalies are mainly produced by heterogeneities located in the upper part of the Earth's crust. They are often the result of mineralization or reservoirs. In order to observe these anomalies, it is necessary to subtract the regional anomaly from our data. To separate the regional from the residual, we can either [9],[20],[21]:

- Graphically smooth the profile;
- Graphically smooth the contour lines;
- Calculate the regional analytically or apply a filter (usually by computer);
- Calculate the effect of the source to be eliminated if its geometry and density are known, in order to subtract it from the Bouguer anomaly (modeling).

Using the same reasoning, after separating the Bouguer anomaly we succeeded in producing a residual anomaly map to deduce the shallow information of our study area (figure 4).

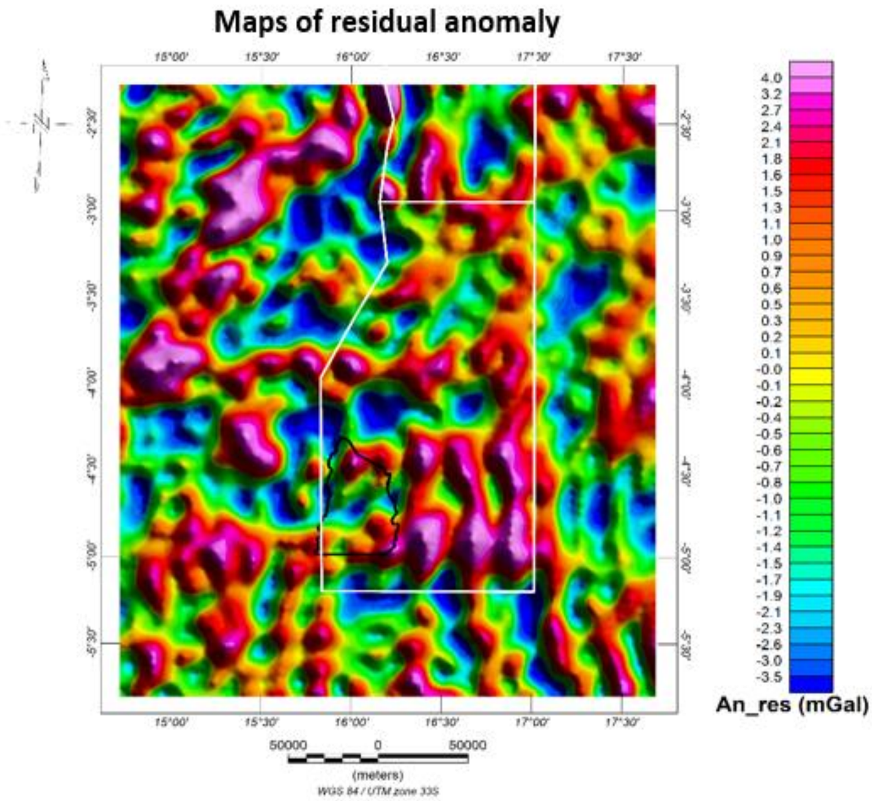

Figure 4. *Residual anomalies map developed using Surfer software*

Tilt derivative map

The tilt derivative (Tilit derivative) remains one of the most powerful grid enhancement tools, with sunshading. It reveals low-amplitude features better than fractional vertical derivatives such as FVD. As shown here, the directional tilt derivative is a simple enhancement that highlights more subtle trends, particularly linear features rather than discrete anomalies. Of course, as with all images derived from data grids, care should be taken when using images derived from directional tilt [9],[18],[22].

Contour detection on gravity data is a common technique in geophysical interpretation, enabling faults to be detected thanks to high density contrast. Tilt derivative (TDR) is a potential field data processing technique that detects edges of structural bodies by enhancing contours. We applied this tilt derivative filter to residual anomalies to locate shallow structures (faults) in Block 25 and then compared them with hydrographic lineaments [11-12] (Figure 5).

Tilt Derivative (TDR) filtering is used for residual anomalies to detect the edge of geological structures in the study area. According to figure 5, the distribution of derived tilt values ranges from -1.3 rad to 1.3 rad. The TDR value is positive for the source, zero for the edge close to the vertical source, and a negative value for the other responses where the source edge can be considered a fault. The source edge can be considered as a fault, dip and rock density contrast. Figure 5 shows that the TDR enhancement technique enables fault structures to be studied clearly and unambiguously thanks to edge detection [2],[18] (figure 5).

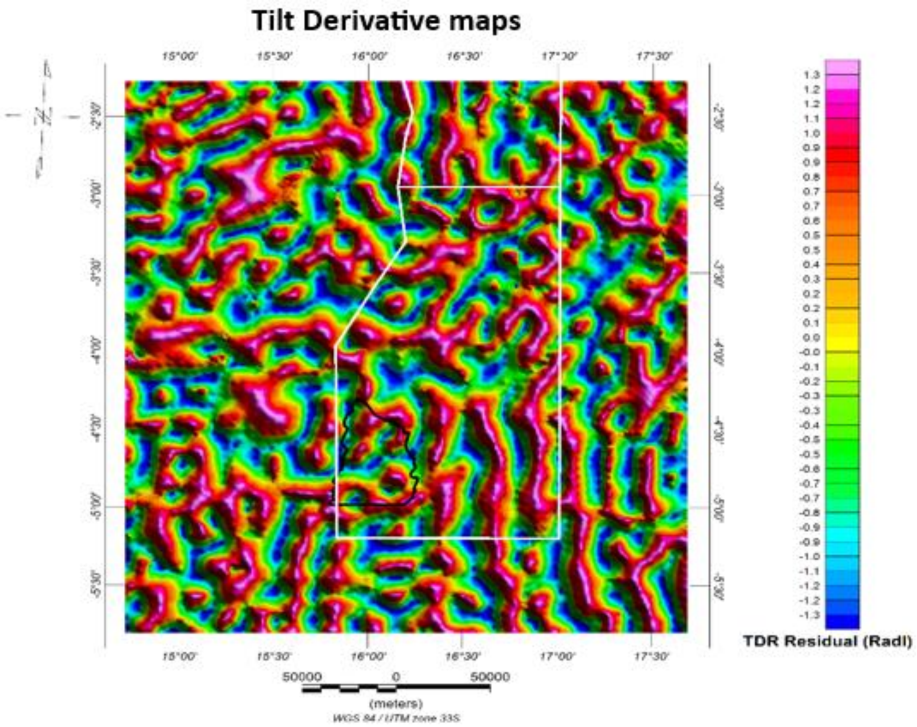

Figure 5. Tilt Derivative for residual anomalies developed using Surfer software

TECHNICAL PLANNING

Planning the geological survey

Geological surveying is a very important step, giving us an idea of the types of geological formations in a region, as well as their structural and stratigraphic aspects [1],[23],[24]. In order to plan a geological survey campaign in block 25, we plan to work along 5 geological sections, all oriented NE-SW, as shown in figure 6 below [5-6]. The lengths in (km) of these geological sections are shown in Table 2 below.

***Table 2**. Planned geological section lengths* [13],[18]

Names	*Length* (km)
Geological section 1	77,98150794
Geological section 2	135,2565517
Geological section 3	133,1208377
Geological section 4	131,3237683
Geological section 5	82,66825286

Planning gravimetric and magnetic prospecting

Two geophysical methods were planned as part of this work. These are gravimetry and magnetometry. These methods will be carried out by airborne survey on a grid of 2 km between survey lines and 40 km between control lines (figure 7) [5],[25],[26]. A total of 22 survey lines are planned, for a total linear distance of around 4,566 km. The planning of seismic prospecting will depend on the results of the gravity surveys.

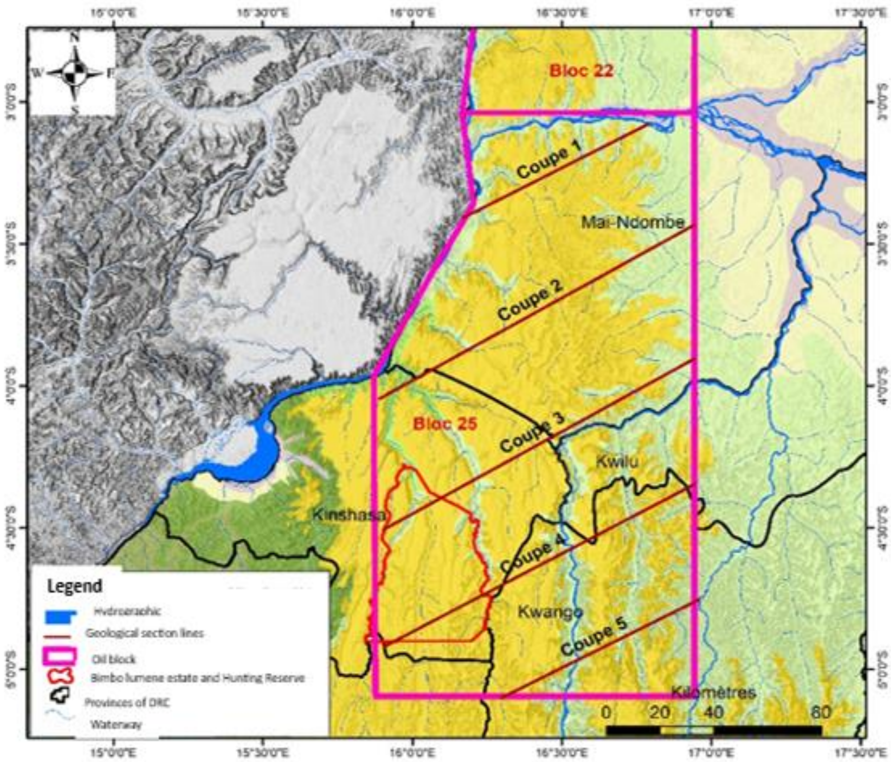

Figure 6. *Planning a geological survey in Block 25 developed using Surfer software*

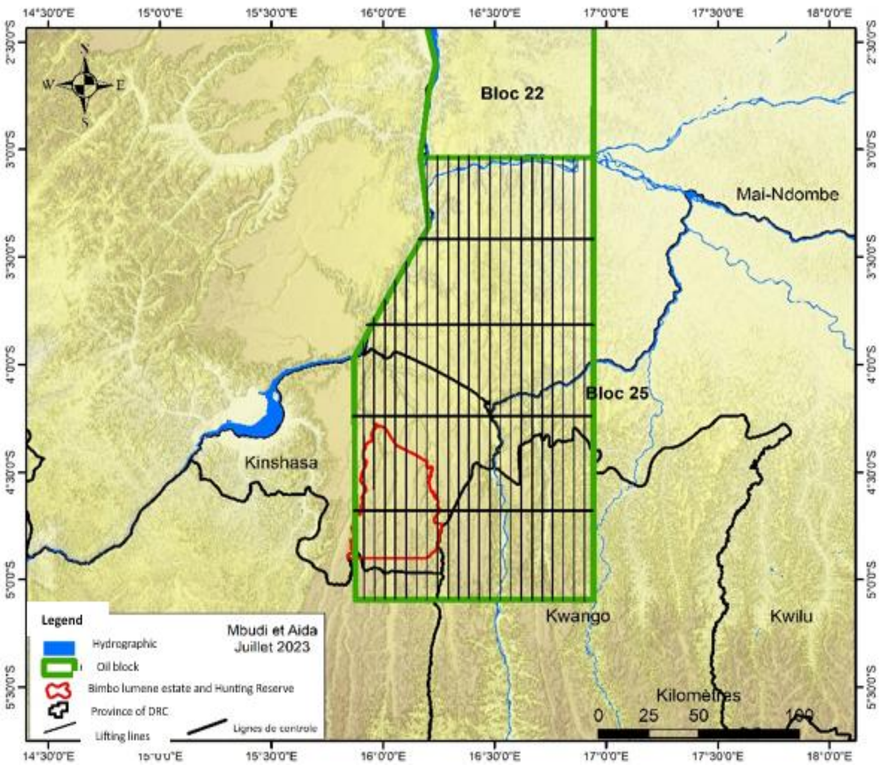

Figure 7. *Gravity and magnetic survey planning developed using Surfer software*

CONCLUSIONS

This work has focused on the contribution of techno-environmental planning to an exploration campaign in protected areas. To this end, we focused on Block 25 of the DRC's Central Cuvette, one of the 27 oil blocks covered by the Congolese government's calls for tenders last year, and which includes a protected area known as the Bombo-Lumene Hunting Estate and Reserve.

We present the Bombo-Lumene hunting area and reserve, outlining its geographical context, history, flora and fauna, as well as other protected parks and reserves. Block 25, and in particular its western part (Bombo-Lumene), most of which lies in Kinshasa, boasts a biodiversity of flora and fauna, characterized by dense rainforest, rivers and lakes, and a wide variety of animal species such as elephants, lions, hippos and crocodiles.

Finally, we presented and analyzed existing geological and geophysical (gravity) data from Block 25, providing an understanding of the geological aspect of the area, dominated by Cenozoic to Quaternary formations. Next, we analyzed the gravimetric data for the area, acquired via ICGEM's online platform. These data enabled us to map the distribution of Bouguer, regional and residual anomalies in the subsurface, and to gain an idea of the likely deep geological structures that could contain the hydrocarbons.

The final stage of this work was devoted to the techno-environmental planning of the actual prospecting. To achieve this, 5 geological sections were planned, following the NE-SW direction, and an airborne gravity/magnetic survey was carried out over a total linear distance of 4,566 km. Carrying out the planned geological and geophysical campaigns would therefore improve geological knowledge of the area and have less impact on the Bombo-Lumene domain. The airborne gravity/magnetic survey is the best method to have data about rocks and structural models without disturbing the fauna. Any seismic survey, necessary to highlight hydrocarbons (at depths suitable for generation and conservation), will require a well-thought-out design to protect the environment.

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