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Contribution of Remote Sensing in Mapping the Geomorphology and Land Cover of the Eastern Part of the West-Congo Basin in Order to Planning an Oil or Mining Exploration Survey

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Abstract:- This study addresses the aspect of the analysis and interpretation of satellite images for the study of geomorphology and land cover for the planning of an oil/mining exploration mission in the eastern part of the West-Congo basin. To do this, we used Landsat 8 OLI and SRTM satellite images downloaded respectively on April 11 and 13, 2022 from the earthexplorer.usgs.gov platform. Using data processing and digital mapping tools, we produced 2D and 3D Digital Elevation Models from the SRTM image. This allowed us to observe that, with the exception of the valleys located near the watercourses, the entire area is characterized by a rapid alternation of hills and valleys on the geomorphological level, a phenomenon which could make a ground exploration more or less difficult in this region. We also applied RGB = 432 and RGB = 452 color compositions using, for the latter, a combination of the spectral bands of Red (Band 4), Near Infrared (5) and Blue (2). These colored compositions have been supplemented by the Calculation of the Normalized Difference Vegetation Index (NDVI) which allows a better visualization of land cover by accurately classifying areas of heavy vegetation and sparse areas. The superposition of the results on the geological map of our study area allowed us to see that the vegetation covered the entire eastern part, the domain of the supergroups of the 'schisto-gréseux' and the Cuvette Centrale, unlike the domain of the formations of the schisto-calcaire which, meanwhile, is occupied by bare ground. In this zone, the lithological contacts and/or the faults as well as the majority of the watercourses are oriented in the NW-SE direction. It would therefore be appropriate for the profiles that will be drawn for geophysical and/or geochemical measurements to be oriented in the NE-SW direction in order to perpendicularly intersect the main geological structures encountered in this region.

Keywords: *West-Congo Basin, Landsat 8, SRTM, Digital Elevation Model, Oil And Mining Exploration, D.R. Congo.*

I. INTRODUCTION

The Democratic Republic of Congo is an immense territory with innumerable natural resources, especially in the forestry, agricultural, mining, energy and petroleum sectors. It therefore offers a unique environment in the world for entrepreneurs seeking to invest in the aforementioned areas. Unfortunately, a large part of the national territory remains unexplored, inevitably leading to ignorance of the natural resources that the soil and subsoil of certain potentially rich regions may contain. This is the case of the Kongo-central province and more precisely of the West Congolese supergroup which remains summarily explored compared to other supergroups such as Katanga for example. Apart from the confirmation of its very high potential in limestone, a very useful material for the manufacture of cement, some mining occurrences (gold, copper, iron, vanadium, etc.) mapped by the Royal Museum for Central Africa (RMCA, 2005) as well the confirmation of the hydrocarbon indices located in Kimpese, Mbanza-Ngungu and Kisantu by the Ministry of Hydrocarbons (J. Pilipili, 2013), knowledge of the soil and subsoil of this region remains incomplete to this day. Thus, in this study, we analyzed and interpreted Landsat 8 and SRTM satellite images with 30 m spatial resolution using GIS and remote sensing software in order to better model and visualize the geomorphology, hydrography, the land cover and the geology of our study area in order to plan a field exploration mission there. Indeed, in addition to the results obtained at the end of this study, carrying out a geophysical (gravimetric and magnetic) and geochemical campaign remains one of the best solutions to consider for mapping regional and local geological structures. The superimposition of the models obtained at the end of this study on the maps resulting from the implementation of the geophysical and geochemical surveys will certainly lead to the identification and precise characterization of the substances of economic interest in this region.

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➢ *Data and Materials*

For the realization of this work, several multi-source data were integrated, processed and mapped. It is:

- The Landsat 8 OLI satellite image, precisely the scene named "LC81820632018159LGN00" downloaded on April 11, 2022 on the earthexplorer.usgs.gov platform in GeoTIFF format;
- The SRTM (Shuttle Radar Topography Mission) satellite image with a spatial resolution of 30 m downloaded on April 13, 2022 also on the earthexplorer.usgs.gov platform in GeoTIFF format;
- A polygonal shapefile containing the different geological units of the D.R. Congo in accordance with the study conducted by the RMCA (Royal Museum of Central Africa) in collaboration with the Ministry of Mines of the D.R. Congo (Fernandez Alonzo and al., 2015);
- Several shapefile or tabular administrative data, such as countries, provinces, territories, localities and rivers, etc. which allowed us to geolocate our study area in order to limit our prospecting work to it.

As part of this work, data processing, mapping and interpretation of results were carried out using software such as ArcGIS 10.8, Envi 5.3, Surfer 21 and Global Mapper 21.

II. METHODOLOGY

In any scientific work, the first question to consider is the methodology adopted. For the realization of this work, in a first step, we proceeded to the review of the pre-existing geological studies carried out in the West-Congo basin and the consultation of the books and documents relating to the various methods and techniques of processing and the interpretation of the satellite images. Then, as listed in the previous point, we used multi-source data for the development of this work. A GIS is one of the most powerful information technologies because it aims to integrate knowledge from multiple sources and creates an ideal multi-sector environment for collaboration (Antoine Denis, 2013). Using data processing and mapping tools, we were able to:

- Create Digital Elevation Models from the SRTM image and visualize them in 2D and 3D;
- Apply the normal color composition (RGB = 432) and the false color composition (RGB = 452) using a combination of the Red (Band 4), Near Infrared (5) and Blue (2) spectral bands of the Landsat 8 image which allows a better visualization of the vegetation cover;
- This colored composition was supplemented by the calculation of the spectral index or pseudo-channel called Normalized Difference Vegetation Index (NDVI) which accurately discriminates between vegetation cover and sparse areas;
- Overlay the results on the geological map of the region in order to better understand the existing relationships between geomorphology and land cover with the surface geology.

➢ *Description of the Study Area*

- *Location*

Located in the east of the Kongo-Central province precisely in the territories of Madimba and Mbanza-ngungu, our prospecting area is an integral part of the West-Congo basin. The area of the study zone is approximately 1,653 km². Figure 1 below shows the location of the study area.

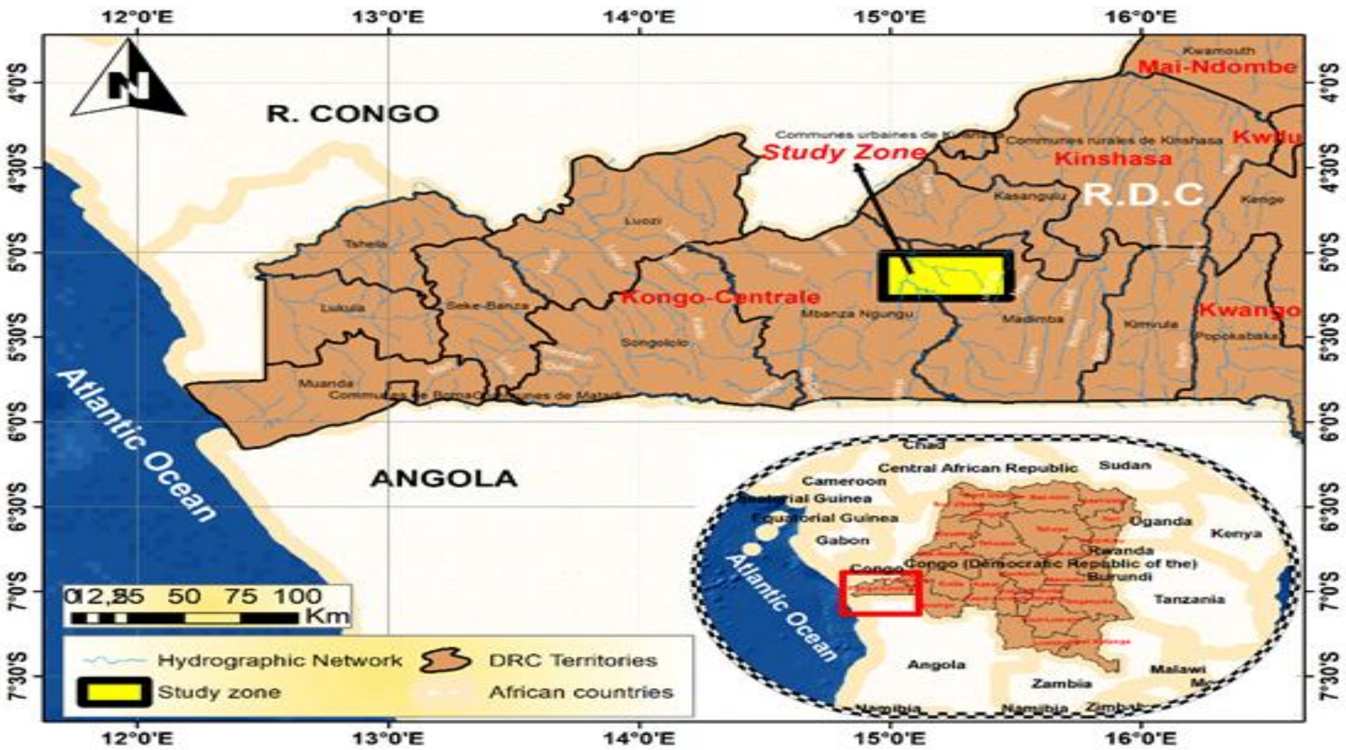

Fig 1 Location Map of the Study Zone

The geographic coordinates of the area are given in table 1 below.

Table 1 Geographic Coordinates of the Vertices of the Study Area

Vertices	Longitude (D°M'S'')	Latitude (D°M'S'')
Upper Left	14°58'12"E	05°00'15"S
Upper Right	15°28'14"E	05°00'15"S
Lower Right	15°28'14"E	05°16'11"S
Lower Left	14°58'12"E	05°16'11"S

➢ *Geographical Framework*

- *Climate and Vegetation:*

The area is located south of the equator and has a humid tropical climate with alternating seasons. It has two main seasons: the rainy season and the dry season. The rainy season has seven months (September, October, November, December, January, April and May). The dry season, meanwhile, lasts only five months (February-March for the short season; June-August for the season itself). Depending on the season, temperatures vary from 20 to 30°C, 1200 mm to 1600 mm for rainfall (CAID, 2017). As far as vegetation is concerned, it should be noted that the climate prevailing in this area favors the development of grassy plants and therefore allows, depending on soil humidity conditions, the establishment of tree species (Delvoy, 1951).

- *Relief and Hydrography:*

This region is entirely located in the valley of the great Inkisi River. The latter is a watercourse with a length of about 555 km which divides our study area into two parts: the west coast located in the territory of Mbanza-ngungu and the east coast located in the territory of Madimba. The area is also watered by many fast and violent rivers such as the Lukunga River and the tributaries of the great Inkisi River. The area has two types of soil: sandy clay and sandy clay.

➢ *Human Description*

Our study zone is located in the territories of Madimba (about 80%) and Mbanza-ngungu (about 20%). It is therefore entirely located in the district of Lukaya located in the province of Kongo-Central. Based on Kongo habits and customs, its culture is purely African. Here are some descriptions of its human characteristics (CAID, 2017):

- *Main Ethnic Groups:* the area is occupied by the Kintandu (65%), Kimbeku (20%) and Kimbata (15%) tribes;
- *Diet:* the dish most consumed in this region is fresh cassava or in the form of Chikwangue, accompanied by pondu, beans or mfumbwa with smoked fish;
- *Health Situation:* the General Reference hospital St. Luc de Kisantu, Ngidinga hospital and several health centers in the Madimba territory as well as the Kimpangu General Reference Hospital and other health centers in the Mbanza-ngungu territory oversee the health aspect in this zone. It should be noted that the most recurrent diseases in this area are: malaria, respiratory tract infections, typhoid fever, arterial hypertension and malnutrition;
- *Security Situation:* the study area is currently calm.
- *Source of Energy:* the natives use embers and kerosene as sources of energy in the villages and electricity, although insufficient, in the large towns such as Kisantu and Mbanza-ngungu.
- *Road Infrastructure*: in this area, the majority of roads are dirt.

➢ *Data Processing and Results*

Data processing and analysis were done automatically with computer tools in order to extract the information we need for this study. However, digital processing and analysis are still used to support and complement human interpretation. Thus, we carried out various processing and several images derived from the initial scenes were processed, to retain only very few that we considered important.

➢ *SRTM Data*

SRTM images are data from topographic satellites obtained by the "Shuttle Radar Topography Mission" radar system. Radars use long wavelength waves (from 1 cm to 1 m). They transmit a microwave radio signal to the target and detect the backscattered part of the signal. Backscattered signal strength is measured to discern different targets, and the delay between signal transmission and reception is used to determine the distance (or range) to the target. The advantage of using radar images is that the longer waves pass through the cloud layer, drizzle, dust and light rain since they are not sensitive to atmospheric scattering which affects the shorter waves. This property allows detection in almost all atmospheric conditions, and therefore the acquisition of data at all times (Canada Center for Remote Sensing).

The SRTM image used in this work has a spatial resolution of 30 m and was downloaded using Global Mapper software on April 13, 2022 to the United States Geological Survey platform (earthexplorer.usgs.gov). In our case, it was used for the generation of Digital Elevation Models and for the superposition of the results of the analysis of Landsat 8 images as well as geological data. The following figure 2 shows us the downloaded raw SRTM image.

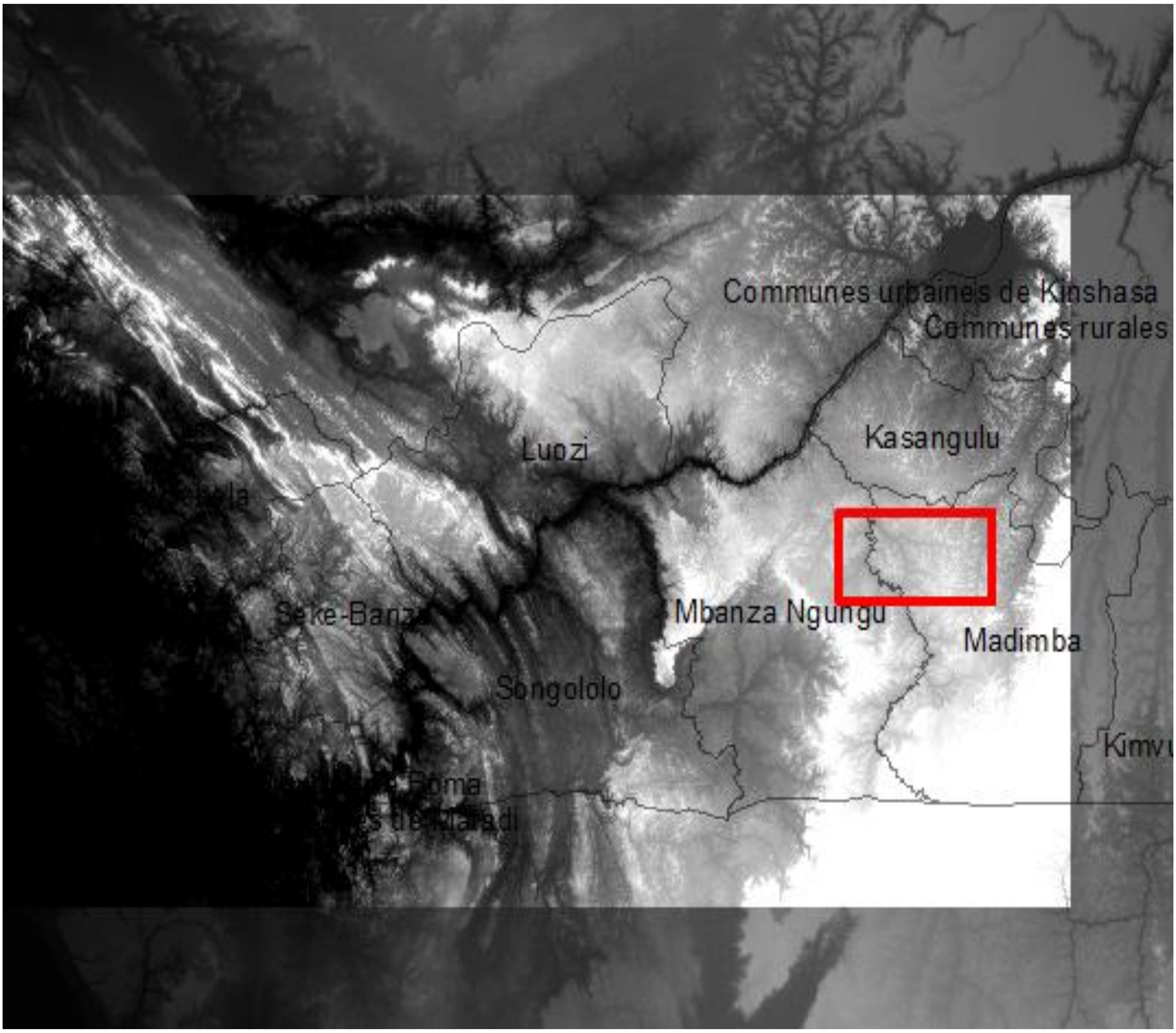

Fig 2 Raw SRTM Image of the Study Area Downloaded via Global Mapper on April 13, 2022 (Source: earthexplorer.usgs.gov)

We downloaded a very large SRTM image covering the entire Kongo-Central province from which we only extracted the image corresponding to the contours of our study area in accordance with the geographic coordinates given in Table 1.

➢ *Digital Elevation Model*

From our SRTM satellite image, we generated a classification based on the variation in altitude (z) as a function of longitude (x) and latitude (y) in order to produce Digital Elevation Models (DEMs) in 2D and 3D to have a fairly precise image of the geomorphology of the study area. Indeed, a DEM corresponds to a representation in digital form of the relief of a geographical area. This model can be composed of point vector entities (side points), linear (level curves), surface (facets) or represented in raster mode (cells) (J-P. Cherel, 2010). The developed DEM allowed us to reconstitute a synthetic image view of the terrain and to quantitatively manipulate the terrain studied.

To create a DEM, we used Global Mapper and Surfer software. The steps are as follows:

- Download the SRTM image in GeoTIFF format with 30 m spatial resolution;
- Extraction of the image using the shapefile and the geographic coordinates of the vertices of the study area as a reference;
- Import the SRTM image into the Surfer software in order to classify the altimetric variation in the study area;
- Superimpose various shapefiles of the different administrative entities of the area;
- Create 2D and 3D shaded relief maps (Fig. 3).

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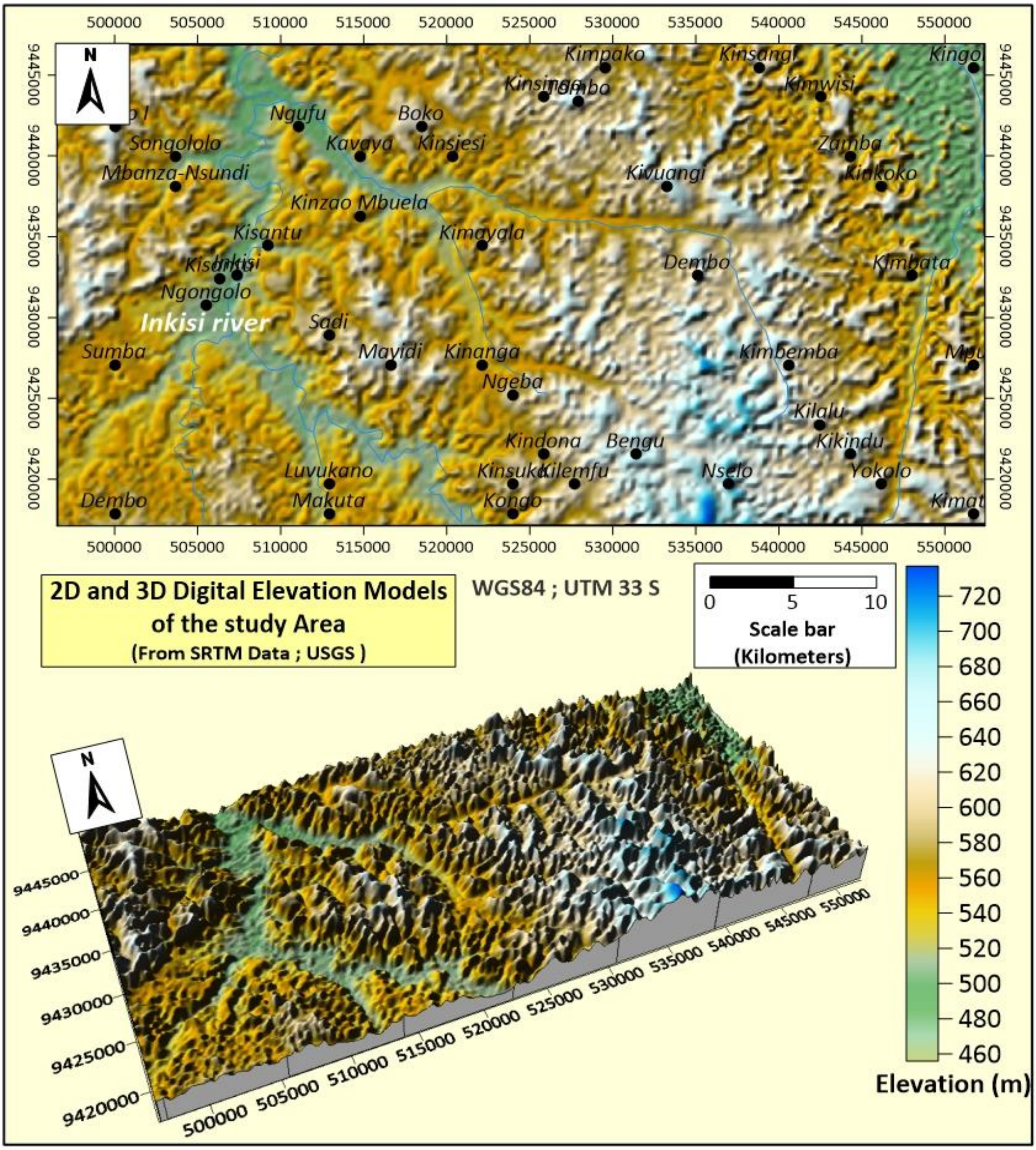

Fig 3 2D and 3D DEM of the Study Area

This DEM shows us that the geomorphological variability observed is representative of the relief observed in this region. The altitudes vary between 460 m along the rivers such as the Inkisi River and 720 m in the hills of the localities of Bengu, and Nselo in the south-east of the area. We note that the area is characterized by rough relief constituted by a rapid alternation of hills and valleys on the geomorphological level covering almost the entire area with the exception of areas located near watercourses. There are rapid variations of peaks and troughs on the 2D DEM, a phenomenon that is even more accentuated on the 3D DEM. A Ground exploration can be more or less difficult because of the somewhat rugged terrain in this region.

➢ *Profile 2D Modeling*

In Figure 4 below, we have drawn a topographic profile starting from the south-west near the Inkisi River, towards the north-east on the hills of the locality of Kivuangi.

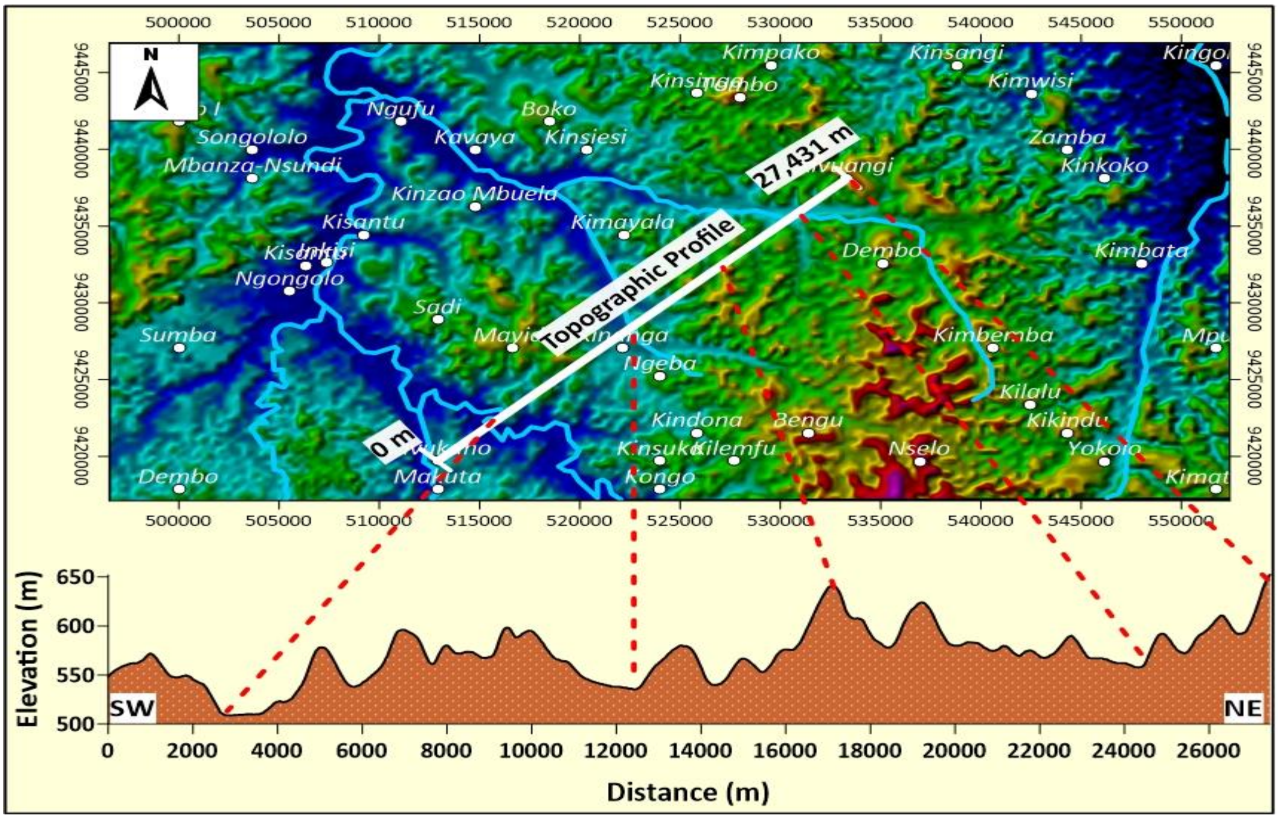

Fig 4 Location of the Topographic Profile on the DEM of the Study Area

This topographic profile was drawn over a distance of 27,431 m in the SW-NE direction. There is a strongly undulating relief and an altitude gradient of 50 m between the plains and the hills and of 100 m between the low altitude areas located near the rivers and the hills. The most significant peaks are located at a distance of 17,000 m and 27,431 m. This profile also shows us that the slopes in this region are not very steep because the horizontal distances between the peaks and the troughs are far greater than their height differences. This state of affairs would favor the implementation of a ground survey in this region.

- *Landsat 8 Data*

The processing of Landsat 8 OLI (Operation Land Imager) satellite images constitutes for this work a great instrument which brings us back more or less to the reality of things on the ground insofar as the starting scene does not give any information as presented on the image below (fig. 5).

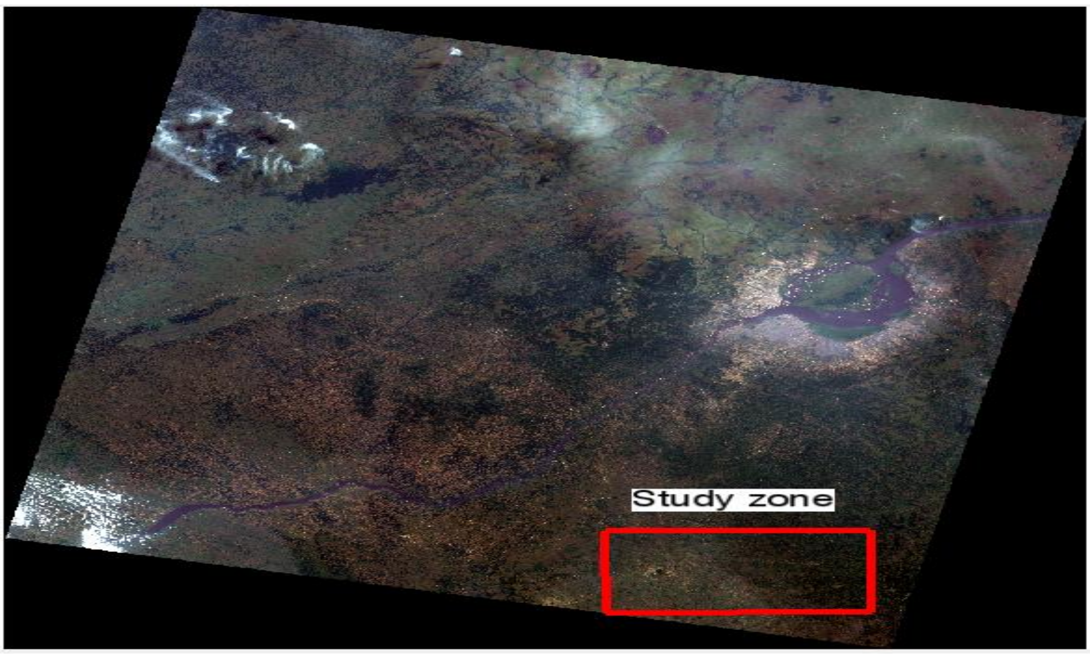

Fig 5 Landsat 8 Image Scene Covering the Study Area Downloaded on April 11, 2022 (Source: Earthexplorer.Usgs.Gov)

The Landsat 8 image that we used for our work was uploaded to the earthexplorer.usgs.gov platform on April 11, 2022. We chose the scene named "LC81820632018159LGN00" with Path: 182 and Row: 63. It contains 11 spectral bands, most of which have a spatial resolution of 30 m compared to 80 m for Landsat images of previous generations. Only the bands which have the same spatial resolution (bands 1, 2, 3, 4, 5, 6 and 7) are multispectral, and will therefore be coupled for processing. By importing the image into the Envi software, the latter classifies the bands directly using its Metadata file as follows (fig. 6):

- Bands 1, 2, 3, 4, 5, 6 and 7 are multispectral;
- Band 8 is panchromatic;
- Band 9 is intended for the detection of high clouds (Cirrus); And
- Bands 10 and 11 correspond to thermal infrared.

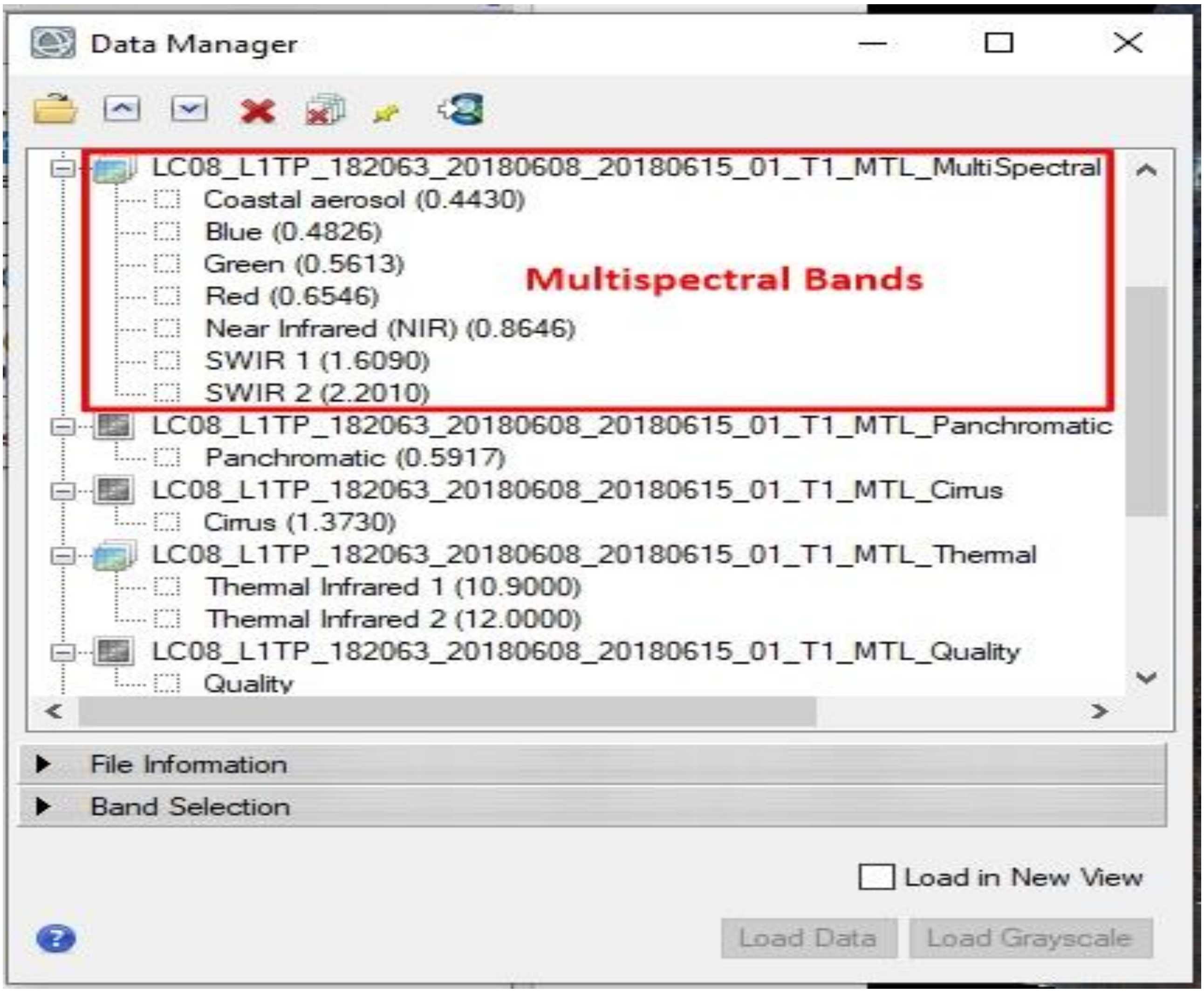

Fig 6 The Data Manager Window on the Envi Software (Showing the Distribution of the different Bands)

The processing of the multispectral bands of the Landsat 8 scene in the study area focused on:

- ✓ The gathering of the different multispectral bands “Layer stacking” followed by the extraction of the image corresponding to the limits of our study area using the shapefile and the geographic coordinates of the vertices of the study area as references;
- ✓ Processing for the characterization of the different elements of land cover in the region such as the colored compositions followed by an unsupervised classification;
- ✓ Calculation of the Normalized Difference Vegetation Index (NDVI) to better appreciate the vigor and quantity of vegetation in our study area.

➢ *Analyzes of Colored Compositions*

After the Layer stacking operations and the extraction of the image corresponding to the limits of our study area, we obtained the basic image which corresponds to the normal colored composition, i.e. the Red, Green and Blue channels (RGB) are allocated to bands 4, 3 and 2 respectively (fig. 7).

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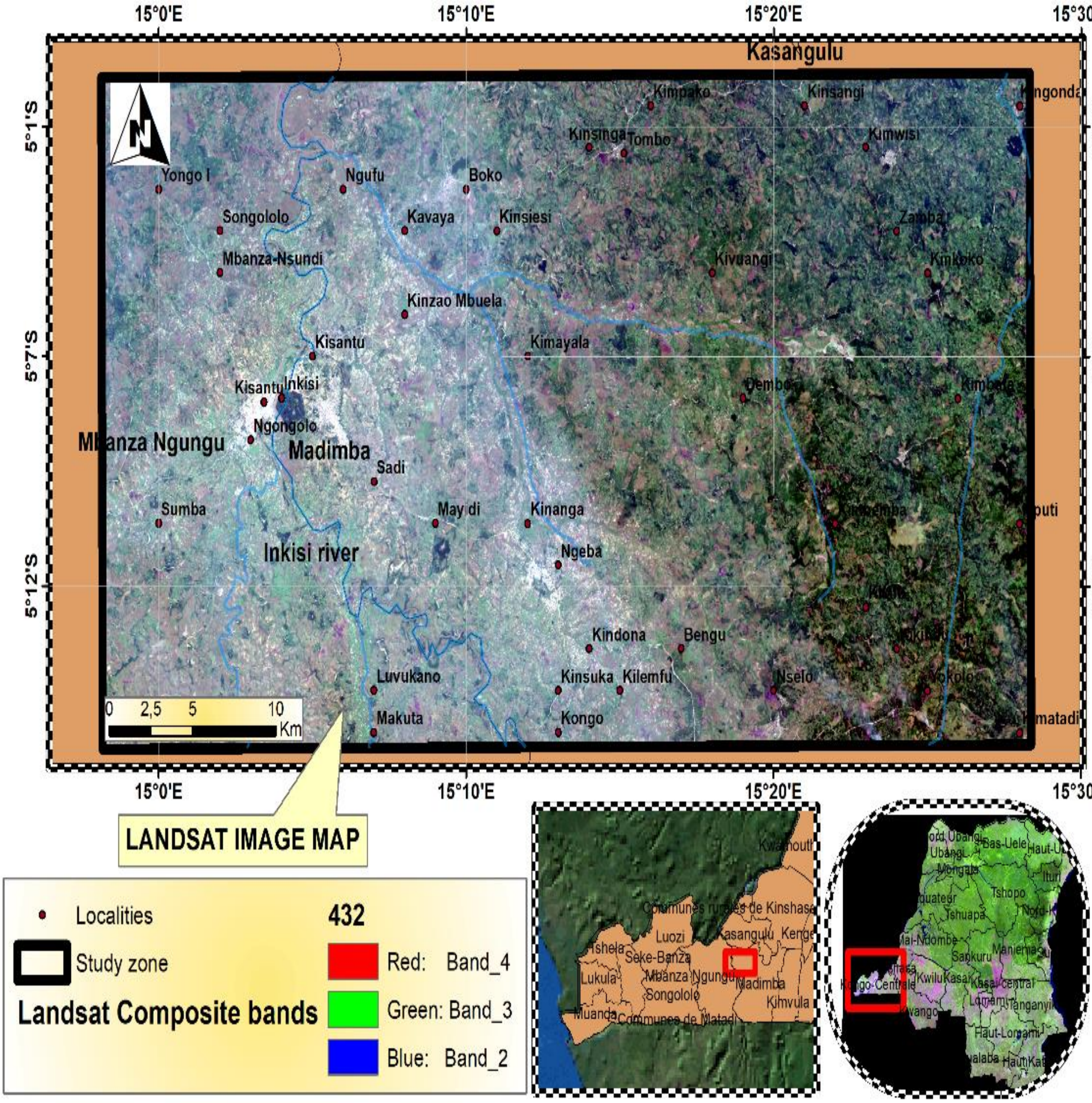

Fig 7 Landsat Image Map Arranged in Normal Color Composition (RGB = 432) of the Study Area

The Landsat image above shows us the land cover of this area. The area is subdivided into two parts: The bright area which covers the entire western part which corresponds to bare ground or covered by a low vegetation cover; and the dark area of the image that occupies the entire eastern part corresponding to the presence of vegetation cover in the region. Note the presence of inhabited areas such as the localities of Kisantu and Ngongolo which are clearly visible to the west of the image.

We have just seen that to visualize an image in color, three channels and three bands are required, unlike “gray scale” visualization which requires only one band and therefore only one channel. Note that all combinations other than RGB = 432 are called "false color composition" because the spectral bands that you are going to assign to the 3 RGB channels do not correspond to these 3 colors. False color compositions have the advantage of allowing the visualization of data not belonging to the visible spectrum, for example, infrared, but also radar, hyperspectral, elevation data, etc. In other words, they transform non-visible data (but recorded by a sensor) into visible data. To do this, we validate the RGB option in the “Layer properties” dialog box of the Landsat image and then assign the corresponding color to each of the bands (figure 8).

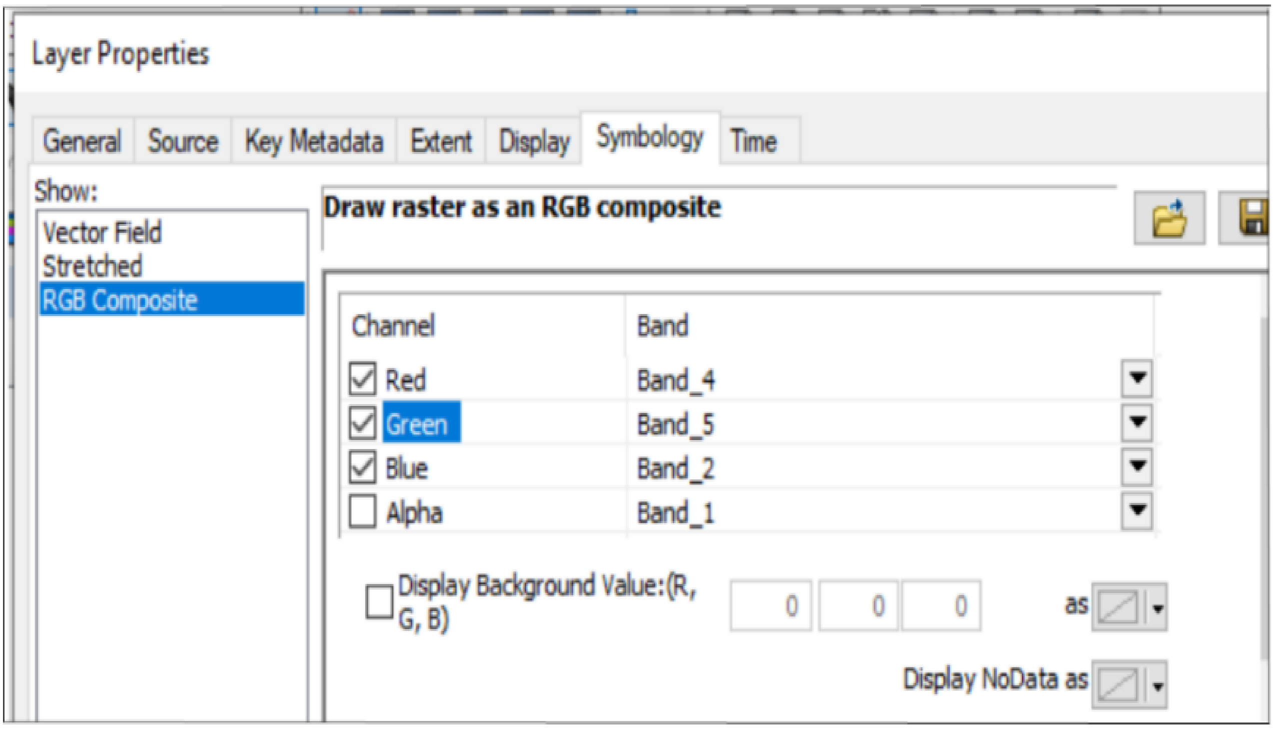

Fig 8 The Layer Properties Window for Creating the False Color Composition (RGB = 452) on the Arcgis Software

On the dialog box above, we applied the false color composition using a combination of the Red (Band 4), Near Infrared (5) and Blue (2) spectral bands of the Landsat 8 image which allows better visualization of the vegetation cover. The following figure shows us the map of this false color composition RGB = 452 (fig. 9).

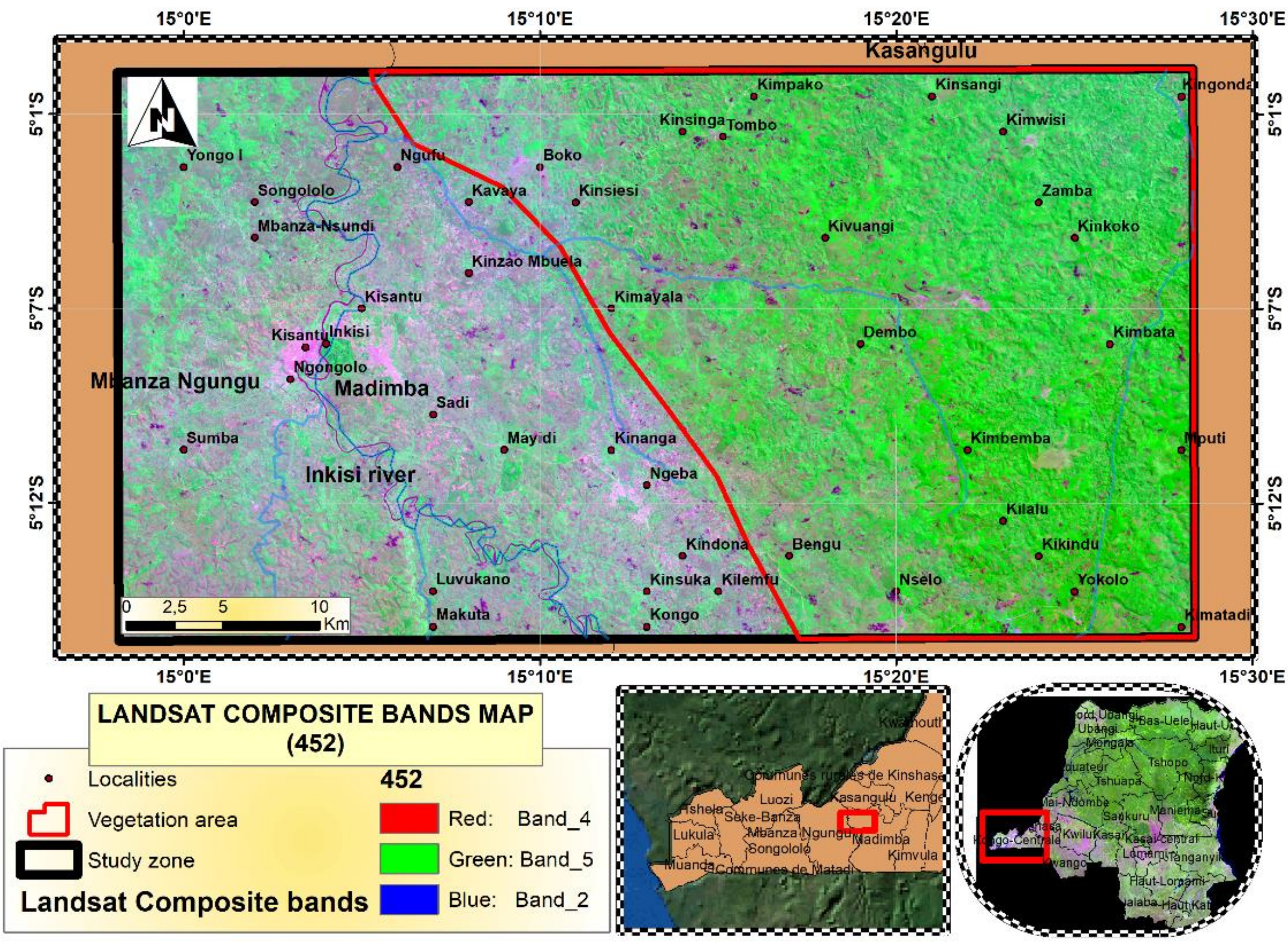

Fig 9 Landsat Image Map Arranged in False Color Composition (RGB = 452) of the Study Area

On this map, the vegetation zones are clearly visible than on the previous map. They appear in bright green color because of having assigned the green channel to the near infrared spectral band (band 5). Note that chlorophyll, a molecule found inside leaves, strongly absorbs radiation at red and blue wavelengths, but reflects green. Leaves that contain a maximum of chlorophyll are therefore greener than leaves that contain less. The internal structure of the leaves acts as an excellent diffuse reflector for infrared wavelengths. If our eyes could perceive infrared, the leaves would look very bright under these wavelengths. Vegetation reflects a greater amount of near infrared radiation than the color green radiation. Therefore, we used the near infrared band to determine the surface of the vegetation. The limits of the latter have been highlighted in red outline on the map above and it covers the entire eastern part of the study area.

- *Calculation of the Normalized Difference Vegetation Index (NDVI)*

In remote sensing, indices are part of the processing methods known as multispectral transformations. They consist in converting the luminance measured at the level of the satellite sensor into quantities having a meaning in the field of the environment. In addition to the RGB = 452 false color composition produced and analyzed in the previous point, we have calculated the spectral index or pseudo-channel called the "Normalized Difference Vegetation Index" (NDVI) which accurately discriminates the areas of high vegetation cover as well as sparse areas. This index is constructed from the Red (band 4) and near infrared (band 5) channels according to the following relationship:

$$NDVI = \frac{Near\ infrared\ -\ Red}{Near\ infrared +\ Red}$$

NDVI values are in the range between -1 and 1 (Sylvie DANIEL and al., 2006).

In our case, we used the "Image Analysis - NDVI" extension of the ArcGis software with spectral bands 4 and 5 to calculate this index in accordance with the equation above (fig. 10).

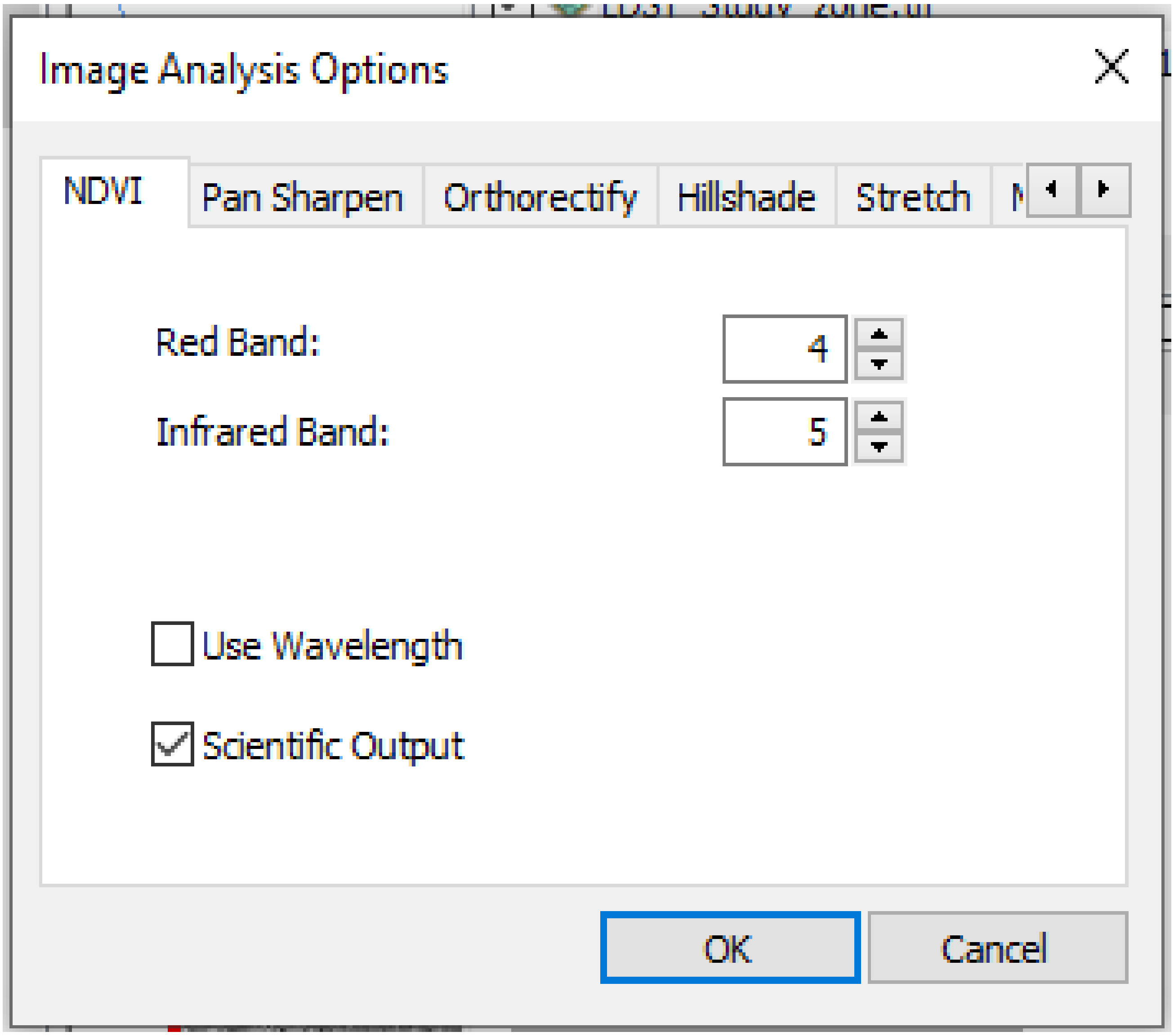

Fig 10 Image Analysis Window for NDVI Calculation on ArcGis Software

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The following figure shows the map of the NDVI index of the study area (fig. 11).

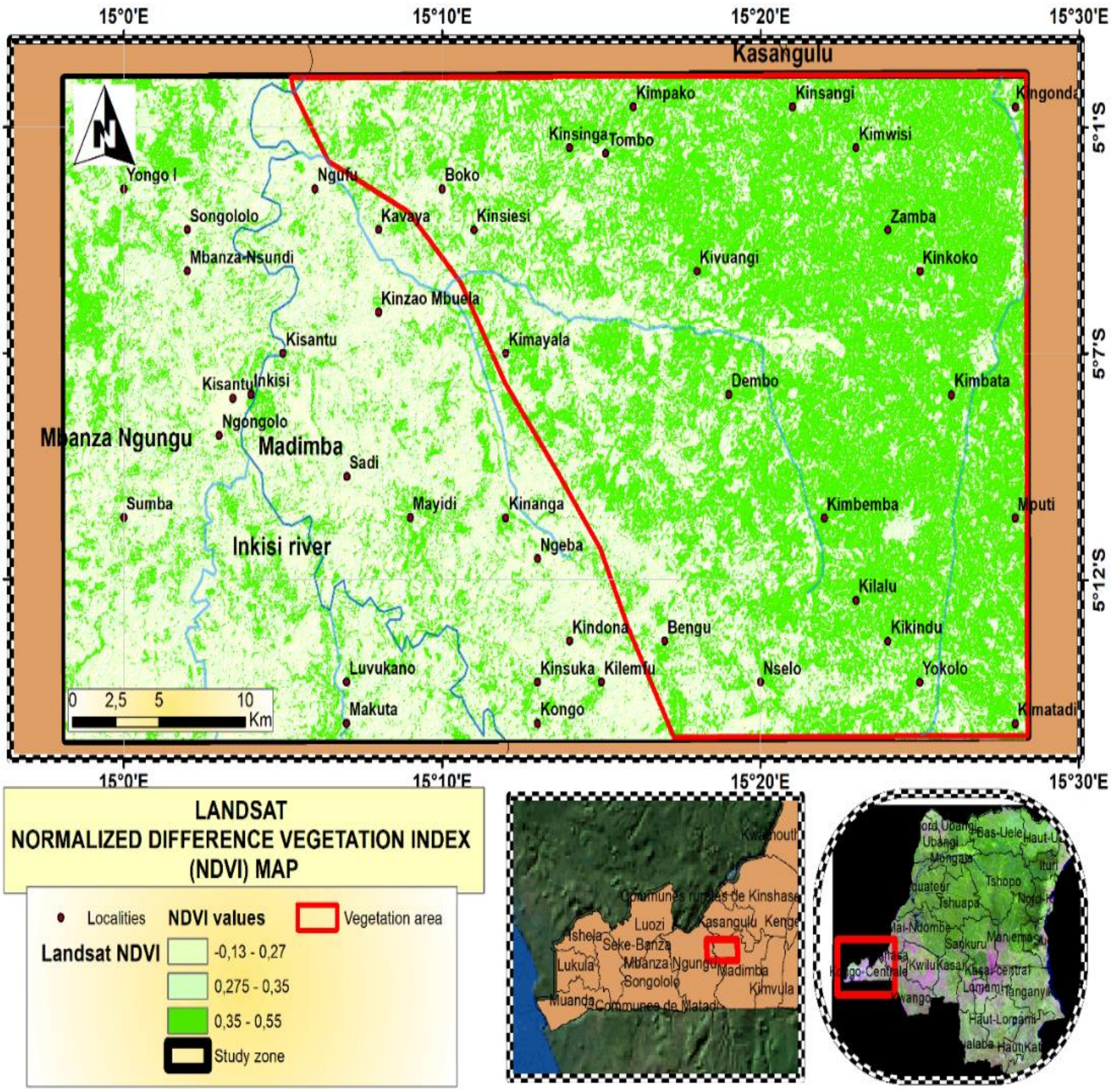

Fig 11 NDVI Map

NDVI values on this map range from -0.13 to 0.55:

- Negative values are essentially generated by clouds and water for which the reflectance in the red is greater than that of the near infrared;
- Values between 0 and 0.27 represent bare ground, the reflectance being roughly of the same order of magnitude in the red. They cover the western part of the study area;
- Values that are between 0.27 and 0.55 cover the entire eastern part of the study area. They indicate the presence of vegetation with higher chlorophyll activity than in the rest of this area.

➢ *Correlation of the Results with the Geology of the Region*

Our study area is located in the West-Congo supergroup which has long been the subject of geological studies to deepen knowledge of his natural resources. Apart from confirming its very high potential in limestone, a very useful material for the manufacture of cement, these geological studies have also highlighted some mining occurrences (gold, copper, iron, vanadium, etc.) (RMCA, 2005) as well as the presence of oil seeps located in Kimpese, Mbanza-ngungu and Kisantu by the Ministry of Hydrocarbons (J. Pilipili, 2013). Recent studies on the lithostratigraphy of the DR Congo published by Fernandez Alonzo and al., 2015 have enabled us to produce a simplified geological map of our study area (fig. 12 a) and to superimpose the results obtained with the results from the analysis of satellite images (fig. 12 b).

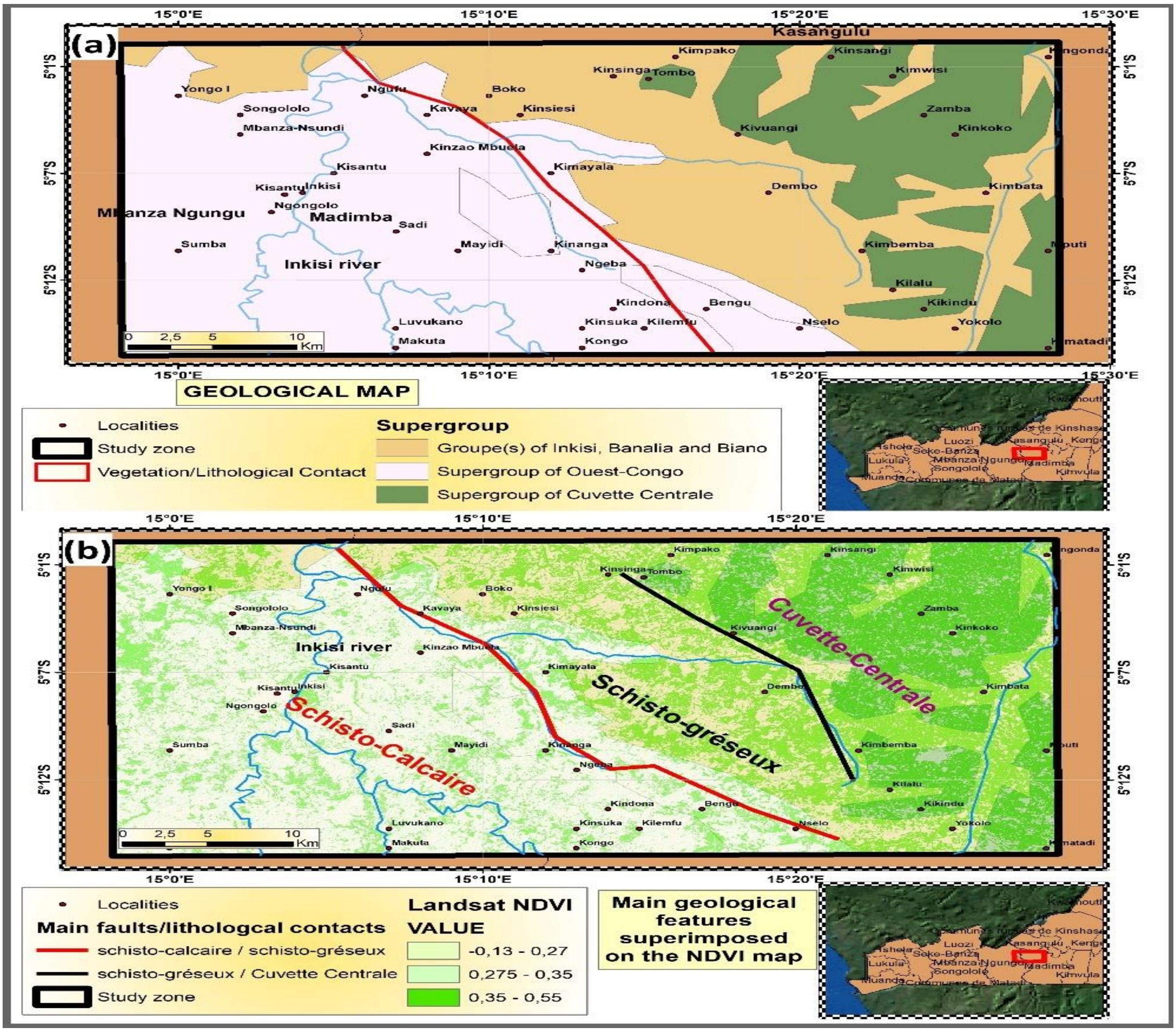

Fig 12 (a) Geological Map; (b) Main Geological Features Superimposed on the NDVI Map

On the geological map, we note that our study area is occupied by the following formations: the Neoproterozoic schisto-calcaire supergroup in the west, the Paleozoic schisto-gréseux supergroup in the center and the Cretaceous formations of the Cuvette Centrale in the east. The Main geological features superimposed on the NDVI map reveals the following important information:

- The vegetation is highly developed in the domains of the schisto-gréseux supergroups and of the Cuvette Centrale, contrary to the domain of the schisto-calcaire formations;
- The limit of the vegetation zone corresponds to the lithological contact or to a fault between the schisto-calcaire and the schisto-gréseux. This limit also corresponds to the passage of the river which has its source near the locality of Ngeba in the south-east and which flows into the Inkisi River near the locality of Ngufu in the north-west;
- The lithological contact between the schisto-gréseux and the Cuvette Centrale is not directly observable on the satellite image, however, it partly corresponds to the passage of the river which flows near the localities of Kimbemba and Demba;
- In this zone, the lithological contacts and/or the faults as well as the majority of the watercourses are oriented in the NW-SE direction;
- It should therefore be noted that the alignments of the hydrographic network form the lineaments which reflect a geological reality disturbing the network: passage of a fault or a lithological contact.

One of the benefits of converting satellite data into a three-dimensional model of the surface and subsurface is that the highly visual final product allows explorers to better see and understand the different geomorphological and geological features of the study area. In figure 13 below, a 3D model has been generated by integrating the DEM, the NDVI as well as the geological data.

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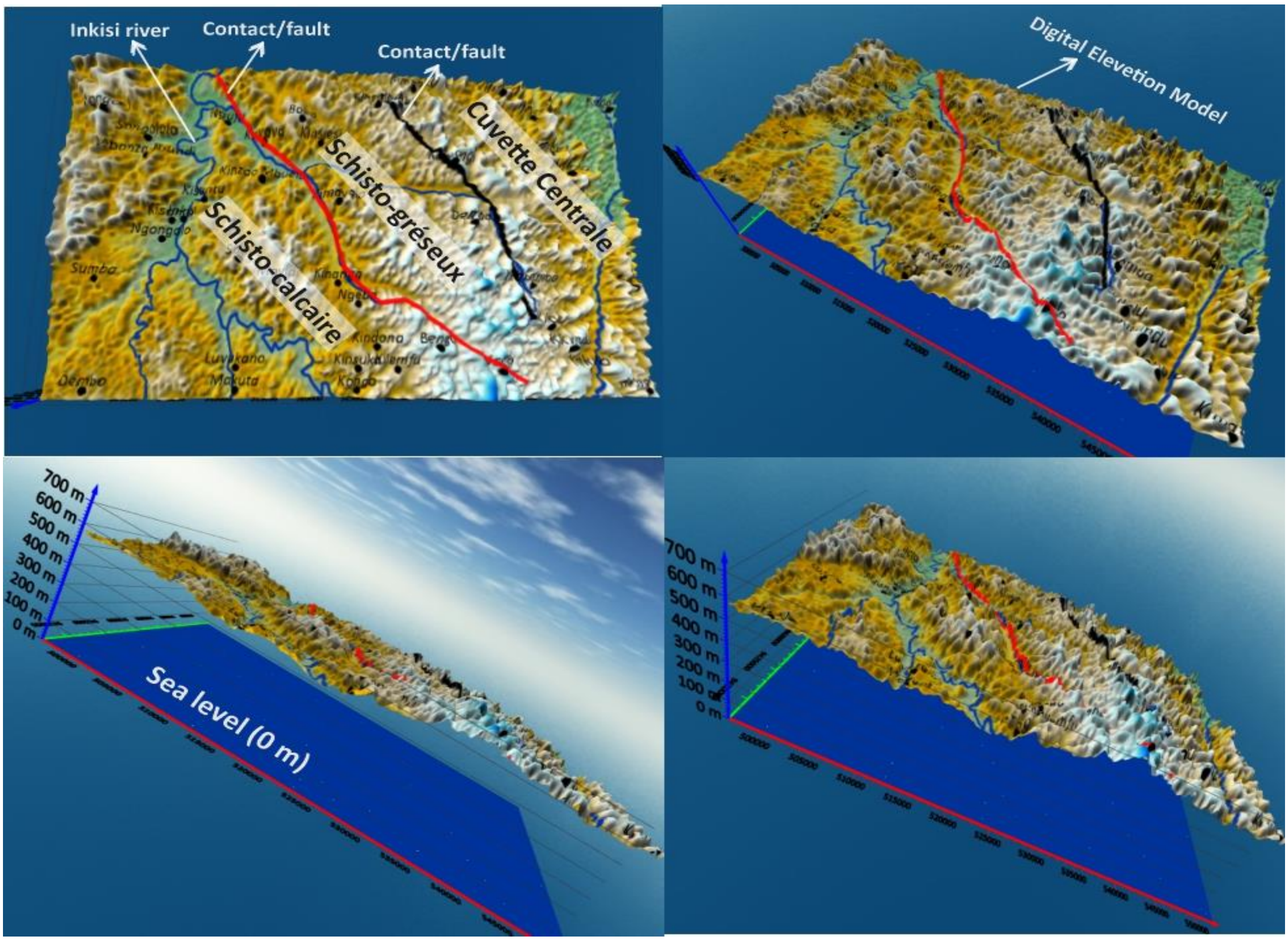

Fig 13 3D DEM of the Study Area

III. CONCLUSION

The West-Congo basin remains summarily explored despite the confirmation of its very high limestone potential, the highlighting of some mining occurrences as well as the presence of certain hydrocarbon indices. This study concerned the analysis and interpretation of Landsat 8 OLI and SRTM satellite images with the aim of improving our knowledge of the geomorphology and land cove of this area. As a result, we have produced Digital Elevation Models, generated the normal color composition (RGB = 432) and the false color composition (RGB = 452) which allows a better visualization of the vegetation cover. The Calculation of the NDVI accurately discriminated between areas of heavy vegetation and sparse areas. We found that the whole area is characterized by a rough relief consisting of a rapid alternation of hills and valleys on the geomorphological level, with the exception of areas located near watercourses. There are rapid variations of peaks and troughs on the 2D DEM, a phenomenon that is even more accentuated on the 3D DEM. Ground exploration could be more or less difficult because of the somewhat rugged terrain in this region. The calculation of NDVI superimposed on the regional geology revealed that the limit of the zone of the vegetation corresponds to the lithological contact or to a fault between the schisto-calcaire and the schisto-gréseux. This limit also corresponds to the passage of the river which flows in the SE-NW direction. As for the contact between the schisto-gréseux and the Cuvette Centrale, it is not directly observable on the satellite image, however, it partly corresponds to the passage of the river which flows near the localities of Kimbemba and Demba at the east. In this zone, the lithological contacts and/or the faults as well as the majority of the watercourses are oriented in the NW-SE direction. Therefore, for geophysical and/or geochemical prospecting, we recommend drawing profiles in the NE-SW direction in order to intersect the main geological structures encountered in this region.

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