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Contribution of Spatial Data Analysis in the Evaluation of the Reliability of Radiometric Measurements at the Luiswishi-Likuni Mining Site in the Province of Haut-Katanga (Democratic Republic of Congo)

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Abstract:- This study concerns the quality control of radiometric data measured in the Luiswishi-Likuni mining site. Before undertaking an assessment of the radiometric contamination of a site with the aim of providing decision support tools for its rehabilitation, it is necessary to ensure the quality of the data acquired. Thus, based on solid and reliable foundations, uncertainties during the different stages of the decision-making process will be better controlled and the final quality of the project improved. To do this, an acquisition of radiometric data using a Geiger counter allowed us to carry out 13 radiometric profiles with the aim of mapping the intensity of radioactive radiation in this area. Data processing consisted of carrying out a geostatistical analysis (estimation error, histogram, data dispersion, etc.) and improving the signal/noise ratio by frequency analysis 'Fast Fourier Transform (FFT)' of the signal. Kriging made it possible to calculate and categorize the estimation error into 3 precision zones: High, Medium and low depending on the spatial distribution of the measurements. The histogram and the QQ-plot diagram of the data confirm that they obey the normal law because we observe values aligned along the line with minimal dispersion at both ends of the line. The FFT low-pass filter, with a window of 3 and a cutoff frequency of 0.166 Hz, produced a smoothing well suited to the radiometric data which appeared noisy due to the fact that they were acquired near the city of Lubumbashi. This significantly increased the signal-to-noise ratio, making the data usable for any future modeling.

Keywords:- *Radiometric Data, Quality Control, Geostatistics, Frequency Filtering.*

I. INTRODUCTION

The Luiswishi-Lukuni mining site is located in the Kipushi territory near the city of Lubumbashi in the Haut-Katanga province in DR Congo. This area located in the "Katanga copper arc" has metals from the copper group, tin, precious metals and iron. Its deposits are among the richest in the world, particularly in terms of copper and cobalt (Jean Omasombo Tshonda, 2018). Uranium is widely distributed in most deposits where copper and cobalt are mined. It therefore constitutes the main source of natural radioactivity of telluric origin in the copper-cobalt belt of the Haut Katanga province. This constitutes a very high risk of contamination of neighboring populations, particularly the town of Kawama adjoining the open-air quarries of Luiswishi-Lukuni.

The objective of this work is to show how to visualize, process and interpret the measured geophysical data and to ensure their validity as best as possible before going further in their analysis. For this, different tools were used and are discussed below: geostatistics, improvement of the signal/noise ratio, which are then advantageously supplemented by data visualization and mapping tools. This quality control therefore takes place upstream of any modeling in order to best circumscribe the uncertainties with the aim of reducing hazards by reducing the risk of bad discoveries.

II. MATERIALS AND METHOD

➢ *Field Equipment*

In addition to a Garmin GPS for taking the geographic coordinates of each station, natural radiometric measurements of telluric origin in the study area were taken using a digital Geiger counter, brand " Alert Inspector Detector", with serial number: 06474 (fig. 1).

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Fig 1 Geiger counter: Alert Inspector Detector.

➢ *Laboratory Equipment*

The raw radiometric data collected in the field were grouped into an MS Excel database. Frequency analysis of the data for background noise attenuation was carried out with OriginLab software, while geostatistical analysis and mapping of the results were carried out on ArcGIS. All of this software allowed us to carry out various processing and interpret the results obtained.

➢ *Method*

A radiometric survey, like any other geophysical prospecting, generally includes three stages: data acquisition, data processing and interpretation of the results.

- **Data Acquisition**: This consisted of carrying out a geophysical survey in the study site equipped with a Geiger counter and a GPS. This survey allowed us to carry out 13 radiometric profiles based on the geology, primarily taking measurements of the background noise (0.39 µSv/h) on the site of the Department of Geology of the University of Lubumbashi. A pre-feasibility study was previously carried out with the aim of defining the routes to take and the direction of the radiometric profiles;
- **Data processing:** This step essentially consisted of carrying out a quality control of the radiometric data measured by geostatistical analyzes (estimation error, histogram, data dispersion, etc.) and improving the signal/result ratio by "Fast Fourier Transform (FFT)" frequency analysis of the signal;
- **Interpretation of the results:** At this stage, it was a question of giving meaning to all the maps and graphs generated at the end of the data processing, as well as drawing a conclusion on the quality and reliability of the radiometric measurements acquired in the Luiswishi-Likuni site.

III. GENERAL OVERVIEW OF THE STUDY AREA

➢ *Geographical Framework*

The Luiswishi-Lukuni mining site is located approximately 25 km northwest of the city of Lubumbashi in the Haut Katanga province. Its geographical coordinates are as follows:

- Latitude: 10° 31' 12'' South.
- Longitude: 27° 25' 42'' and 27° 27'' 25'' East.

It is crossed by National Road number one (RN1) as well as the railway linking Lubumbashi to Likasi. This site constitutes the first occurrence where uranium was detected as a companion to copper and cobalt in Katanga. However, with the discovery in 1915 of the Shinkolobwe deposit presenting a greater uranium potential, the Luiswishi reserves were judged to be of little significance to justify development. This site has 2 very distinct sectors: the open-air mines (quarries) of Luiswishi and Lukuni currently in operation and the towns of the city of Kawama (Fig. 2).

Fig 2 Satellite Image of the Luiswishi Site
(Source: Google Earth, August 14, 2020).

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The Luiswishi-Lukuni sector, like the southern part of the Haut-Katanga Province, enjoys a sub-tropical climate characterized by an alternation of a dry season from May to September characterized by relatively cold temperatures and a humid rainy season whose duration varies between 5 and 6 months from November to March. The months of October and November are the hottest with temperatures reaching 35°C, while the months of June and July experience significant drops in temperatures of up to 5°C.

The study area is drained by the Luiswishi, Kiswishi, Muome and Lukuni rivers which belong to the watershed of the large Kafubu river. The vegetation of the Haut Katanga Province in general and that of the study area in particular is made up of four main units. These are:

- Open forest: covering more than 80% of the territory and including large trees and a grassy herbaceous layer;
- Dense dry forest: characterized by a population of different strata of smaller size. It grows on land covered with lateritic crusts;
- Gallery forest: comprising narrow strips covering the banks of certain watercourses as well as the surroundings of marshy areas;
- Savannas and steppes, mainly grassy, found in areas with sandy cover.

The soils developed on this area belong to the group of rhodic ferric soils. They correspond to polygenic soils of yellow or reddish colors, deeply altered with a ferric horizon and developed mainly thanks to the action of termites.

IV. RADIOMETRIC MEASUREMENTS IN THE STUDY SITE

Tracing profiles or sections is an essential step in the acquisition of a measured or calculated geophysical/geochemical parameter. These profiles expressing the variation in natural radioactivity of telluric origin as a function of distance are very important in monitoring the intensity of radioactive radiation in a given region. Thus, in order to cover a maximum area in the Luiswishi–Likuni mining site, we surveyed 13 radiometric profiles oriented, for the most part, in the NE-SW direction (fig. 3).

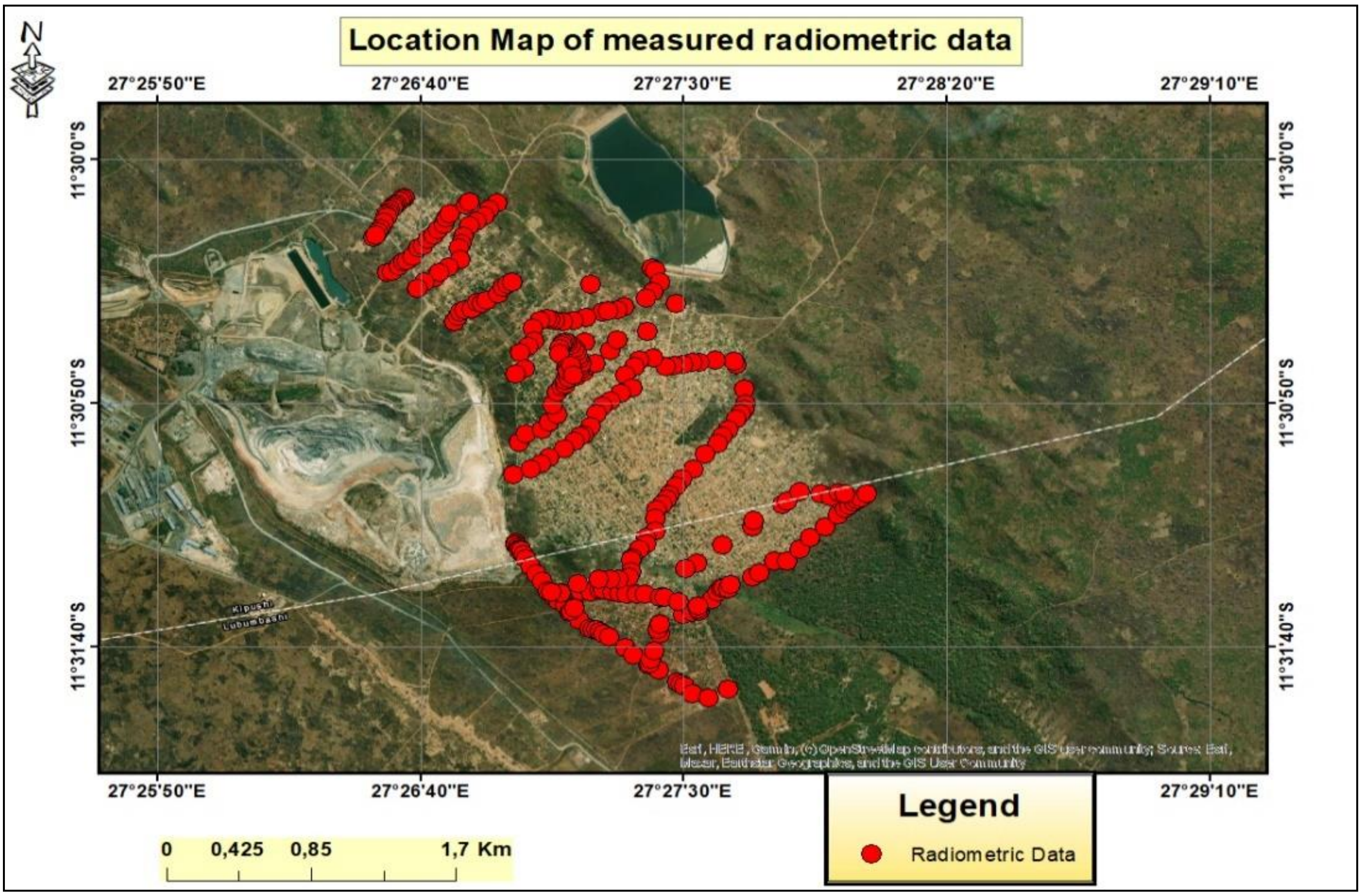

Fig 3 Map of the Spatial Distribution of Measured Radiometric Data.

The results obtained from our research will be presented in relation to the profiles (sections) of radiometric data samples and in relation to the curves of the evolution of the rates of natural radioactivity of telluric origin for each profile. Note that it is not easy to represent all of these data in this work due to their multitude, which justifies the choice of presenting only the first 10 stations of the AA' profile for illustrative purposes (Tab. 1).

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Table 1 Geographic Coordinates and Radioactivity levels on AA' Section.

Latitude (°)	Longitude (°)	Elevation (m)	Radioactivity Rate (µSv/day)	Stations
-11.516179	27.449627	1336	7.48	A01
-11.515699	27.45002	1337	7.88	A02
-11.515481	27.450882	1338	7.41	A03
-11.51501	27.451239	1340	5.36	A04
-11.514575	27.45166	1342	7.94	A05
-11.51406	27.451384	1345	6.22	A06
-11.5133	27.45164	1346	6.75	A07
-11.513028	27.451878	1347	6.35	A08
-11.512883	27.452052	1346	8.27	A09
-11.51263	27.452051	1347	6.22	A10

The figure below shows the location of AA' section and the variation in radiometric intensity throughout its profile (fig. 4).

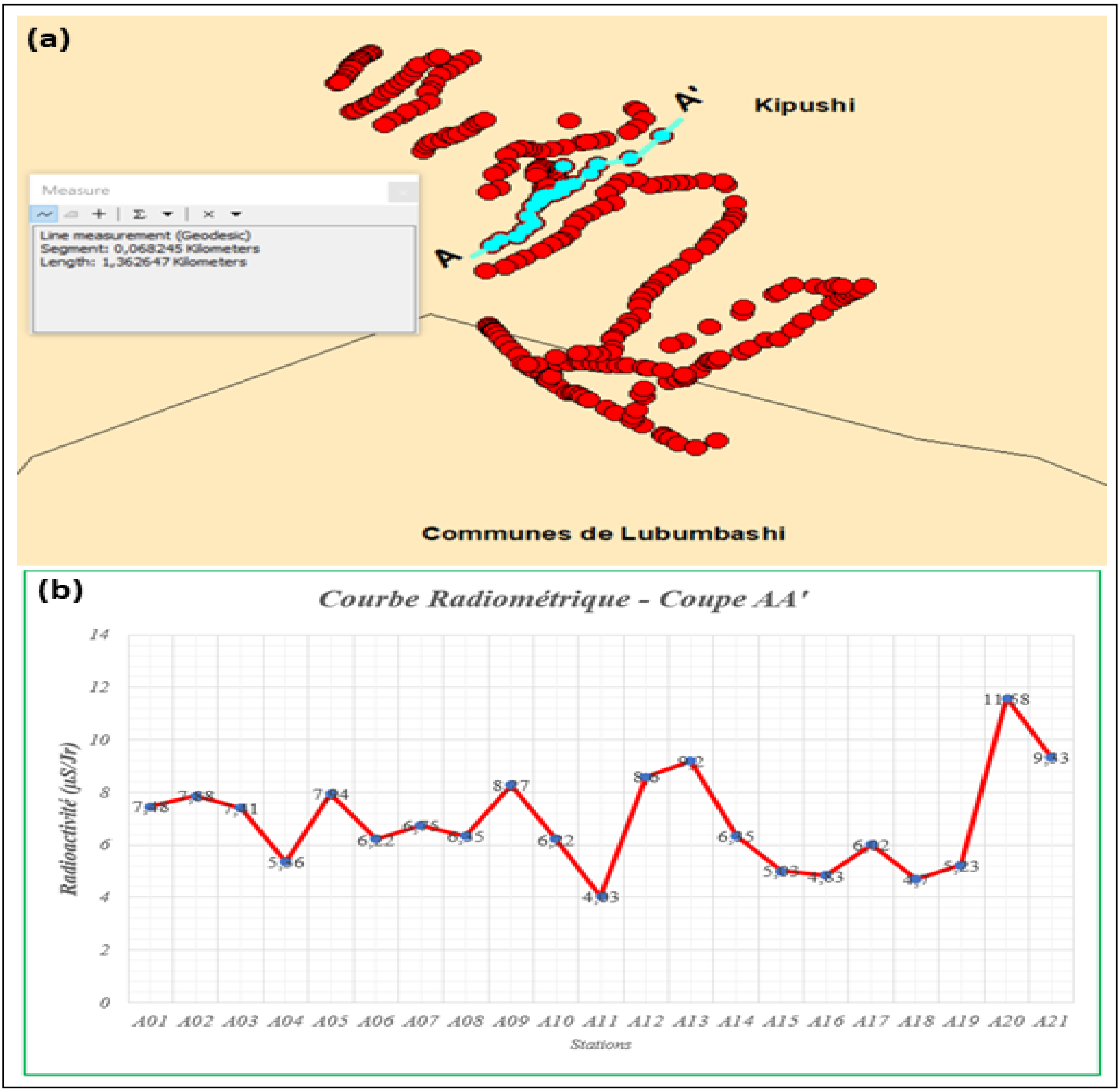

Fig 4 (a) Location of Section AA'; (b) Radiometric Curve of Section AA'.

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The AA' radiometric section is 1362 m long and was acquired near the wastewater settling basin of the open-air Luiswishi-Lukuni deposit, in front of the “MORIDJA” school near the mining debris. We observe a peak rate of natural radioactivity of telluric origin at 14.58 µSv/day (station A20), a minimum of 4.03 µSv/day (station A11) which is not negligible and an average of 6.90 µSv/ day.

V. RESULTS AND DISCUSSIONS ON THE RELIABILITY OF RADIOMETRIC MEASUREMENTS

A. Geostatistical Analysis of Data

This geostatistical analysis essentially consisted of carrying out a quality control of the measured radiometric data in order to determine their degree of reliability (or precision) in the interpretation of the results. This is how we used a powerful geostatistics extension called “Geostatistical Analyst” contained in the ArcGIS software to estimate areas where estimation errors are more or less significant (fig. 5).

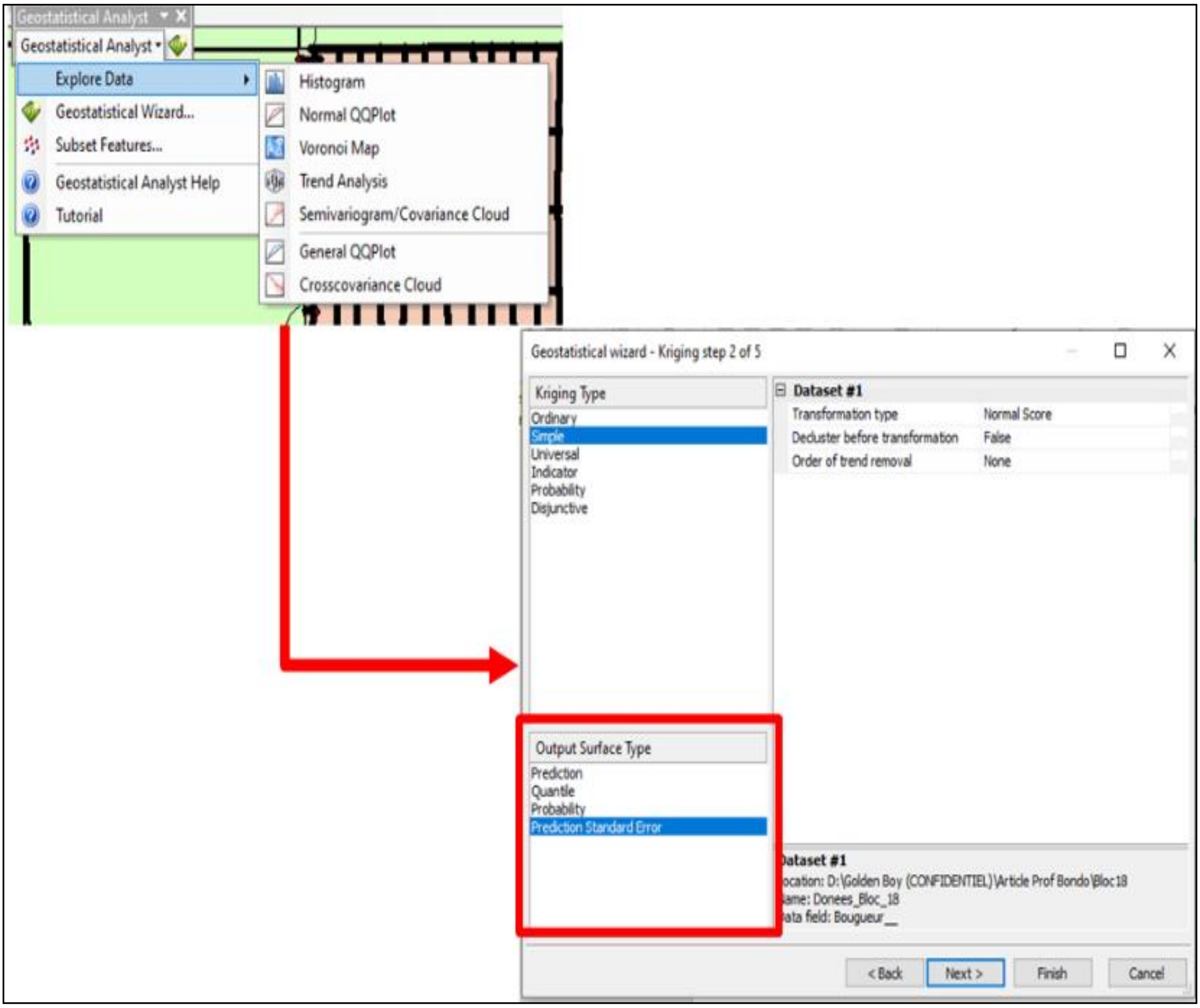

Fig 5 “Geostatistical Analyst” Extension of ArcGIS Software.

The geostatistical method chosen is Kriging. Kriging is the optimal method, in the statistical sense, of interpolation and extrapolation. This is the most accurate estimation method. Unlike all other methods, it also allows us to calculate the estimation error (Yves Gratton, 2002). It is this quantification of the estimation error that we have mapped (fig. 6).

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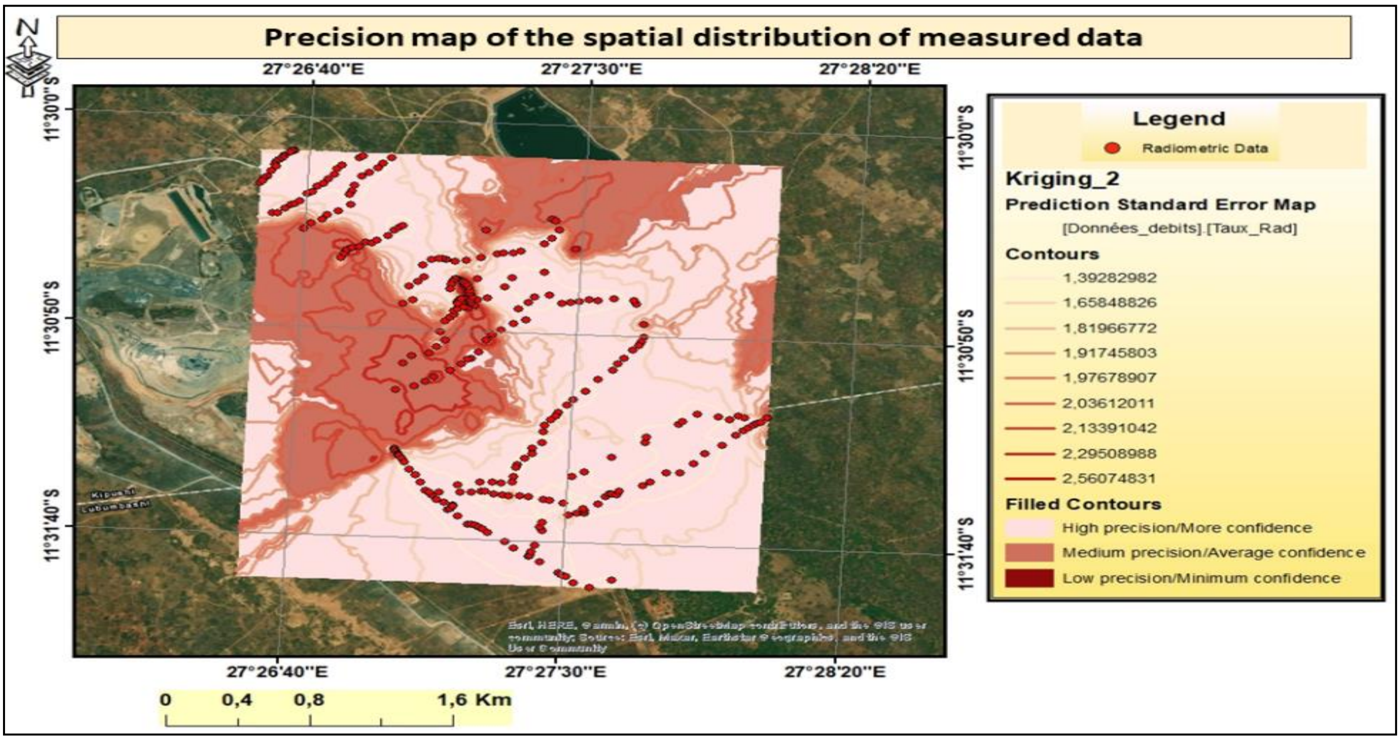

Fig 6 Map of Standard Error Prediction on Measured Radiometric Data.

It should be noted that the greater the precision in an area, the smaller the estimation error and vice versa. The map above shows us the spatial distribution of the precision of the measured radiometric data. The scale is subdivided into 3 categories:

- The high precision zone of whitish color where there is more confidence in the interpretation of the results. It occupies a very large area (around 3/5 of the total area);
- The medium precision zone, pale red in color;
- The dark red colored low precision area.

Observation of the histogram of the radiometric data illustrated in Figure 7 shows a normal distribution. The density of radiometric values is concentrated in the class interval from 0.476 to 0.754 and is less significant in the interval 1.003 to 1.897.

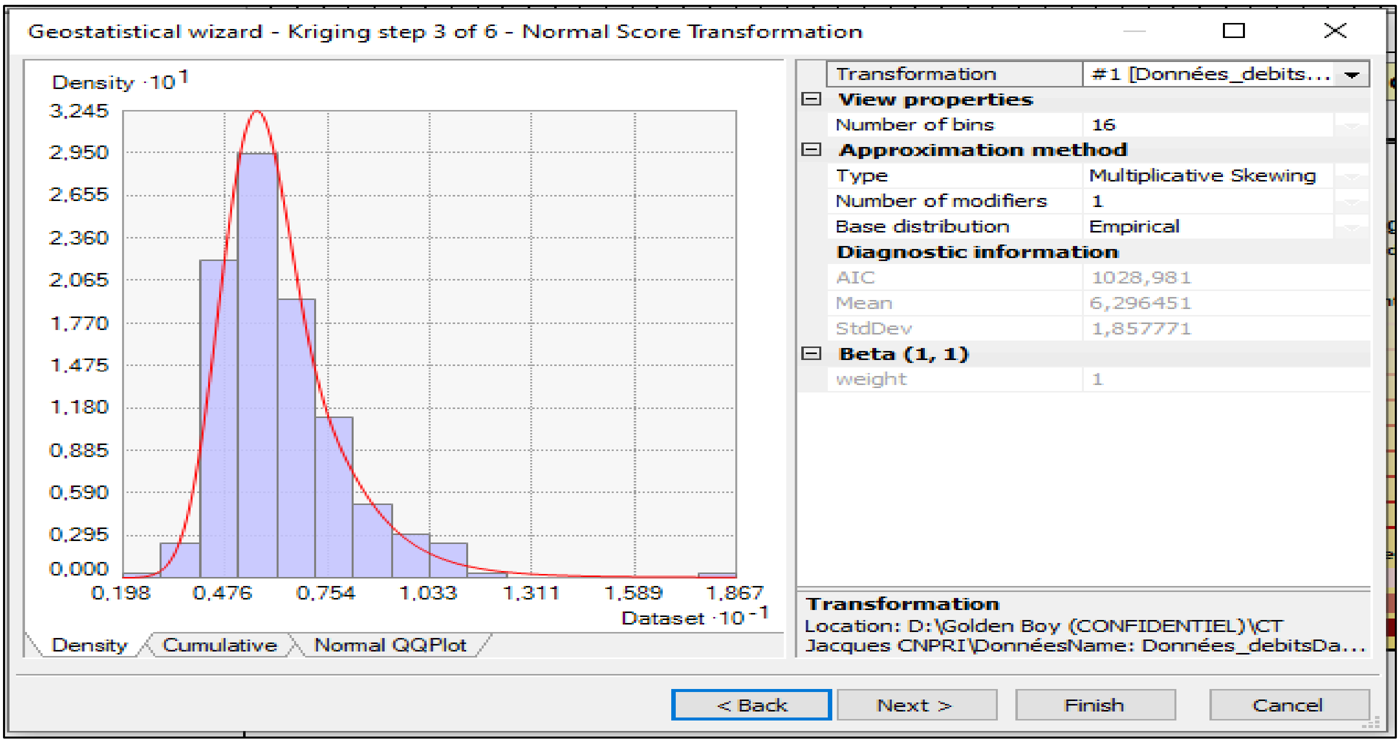

Fig 7 Histogram of Radiometric Data.

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The QQ-Plot diagram below was generated to evaluate the dispersion of measured radiometric data (fig. 8).

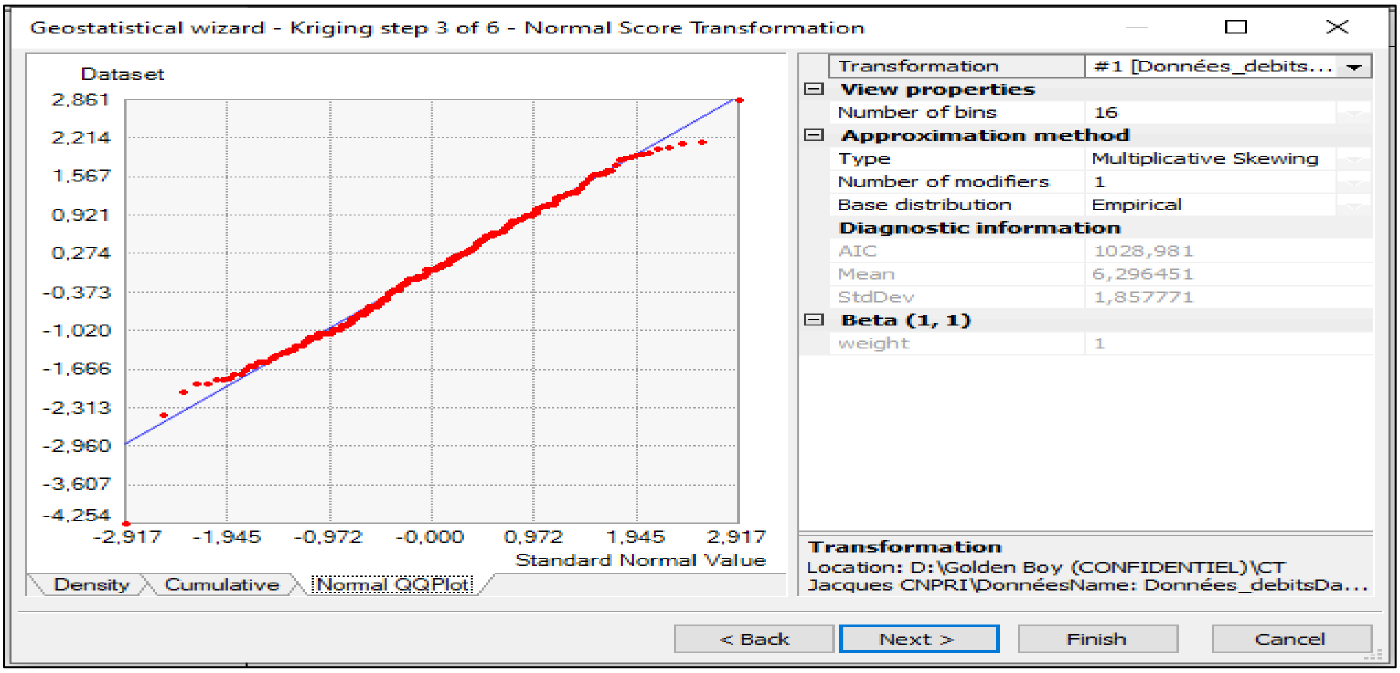


Fig 8 QQ-plot Diagram of Radiometric Data.

The QQ-plot diagram of measured radiometric data confirms, as in the previous case of the histogram, that the data obeys the normal law because the values are aligned along the line with minimal dispersion at both ends of the line. This state of affairs confirms the reliability of the measured data.

The Kernel Density (Spatial Analyst) algorithm calculates a magnitude per unit area from point features or polylines using a Kernel function to fit a slightly tapered surface to each point or polyline. Density calculations also depend on calculating precision on spatial data. It is recommended to use the "Geodesic" method for regional studies and the "Planar" method if the analysis is to be carried out over a local area with a projection that accurately maintains distances within the study area. The application of the second method produced the density map of the measurement points carried out below (fig. 9).

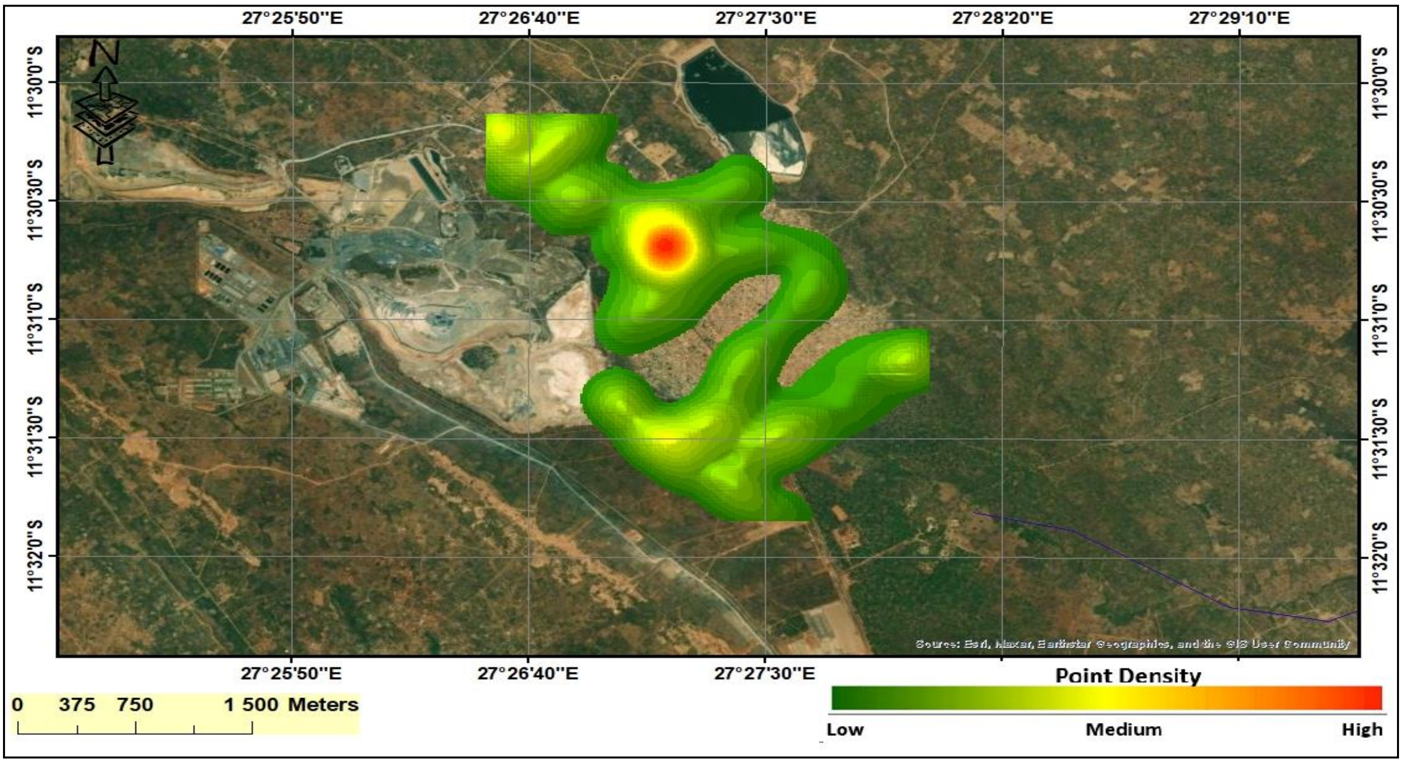


Fig 9 Map of the Density of Radiometric Measurement Points in the Luiswishi-Likuni Site (Software: Esri ArcGIS).

The density values above are distributed across zones, going from the lowest densities (greenish colors) to the highest (yellowish and reddish colors).

B. Filtering and Attenuation of Background Noise

➢ *Sources and Origins of Noise in Data Acquisition*

Background noise can be defined in two ways: On the one hand, background noise is any unwanted signal that is nevertheless measured and recorded; It is also the set of variations or anomalies which are only measured at a single station.

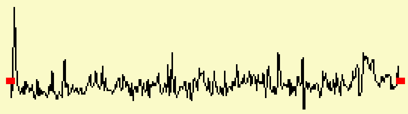
The origins of background noise are multiple, we distinguish:

- **Background noise of geological origin:** caused by various minerals in the soil or in the bedrock near the surface and which affect the measurements;
- **Background noise of natural or environmental origin:** this is the case of ground vibrations caused by the movement of trees in the wind, which disrupt the data;
- **Background noise of artificial origin:** this is the case of ground vibrations which occur when a terrestrial geophysical survey is carried out near an urban and/or industrialized area;
- **Background noise of instrumental origin:** coming from errors in execution or correction of measurements.

➢ *Improvement of the Signal-to-Noise Ratio*

Indeed, the sources of background noise differ depending on the type of survey, its objectives and the spacing between measurements. To reduce this background noise, we applied appropriate filtering using OriginLab software. Table 2 shows the radiometric database imported into the OriginLab software and the amplitude of the noisy signal from the radiometric measurements at the Luiswishi-Likuni site.

Table 2 Radiometric Database and Amplitude of the Noisy Signal from Measurements at the Luiswishi-Likuni Site (OriginLab Software).

	A	B	C(Y)	D(X)	E(Z)	G(Z)
Long Name	N°	STATION WAY-POINT	LATITUDE	LONGITUDE	ALTITUDE	TAUX DE RADIOMETRIE
Units			(°)	(°)	(m)	(µSv/Jr)
Sparklines						
1	1	L001	-11,52192	27,44943	1350	8,6
2	2	L002	-11,52202	27,44946	1351	5
3	3	L003	-11,52215	27,44958	1349	12,4
4	4	L004	-11,52229	27,44965	1346	23,6
5	5	L005	-11,52234	27,44965	1343	12,8
6	6	L006	-11,52236	27,44974	1343	8
7	7	L007	-11,52258	27,44987	1341	7
8	8	L008	-11,52283	27,45	1340	6,1
9	9	L009	-11,52326	27,45024	1340	6
10	10	L010	-11,52366	27,45057	1339	7,4
11	11	L011	-11,52413	27,45089	1338	5,9
12	12	L012	-11,52467	27,45114	1336	8,6
13	13	L013	-11,52497	27,45147	1335	7
14	14	L014	-11,52524	27,45171	1334	7,6
15	15	L015	-11,52544	27,45207	1334	6,2
16	16	L016	-11,52587	27,45233	1332	6,5
17	17	L017	-11,52629	27,45281	1332	7,6
18	18	L018	-11,52681	27,45335	1332	6
19	19	L019	-11,52684	27,45356	1332	4,8
20	20	L020	-11,52686	27,45372	1331	5,7
21	21	L021	-11,527	27,45391	1331	8,7
22	22	L022	-11,52713	27,45407	1330	5,3
23	23	L023	-11,52731	27,45438	1330	7,2

Luishya | Luiswishi-Likuni

Note that when the noise is significant, this results in sudden and random jumps or variations on the profiles. This is how, using the analysis tools, the software allows you to choose the “Signal Processing” extension to achieve smoothing. A dialog box (fig. 10) opens and allows you to directly choose the column of data concerned by the smoothing (Radiometry Rate).

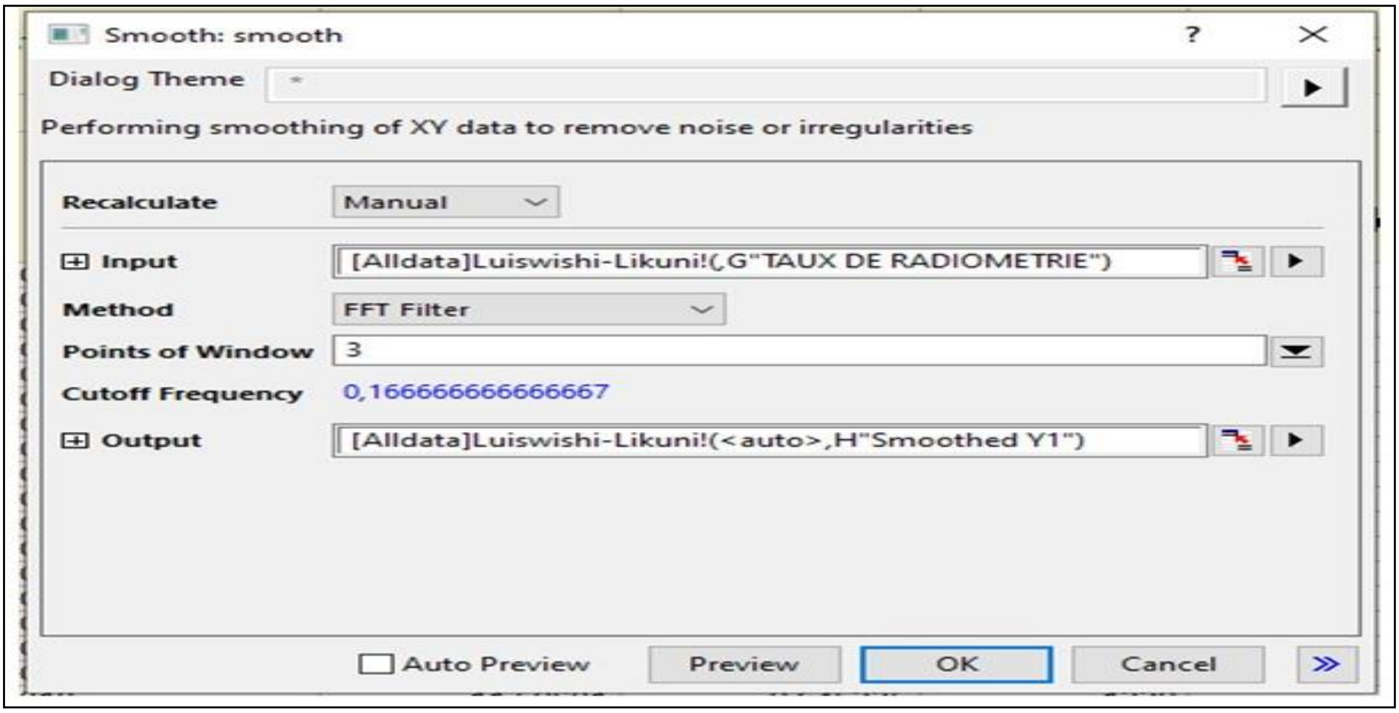


Fig 10 Dialog Box for Filtering Radiometric Measurements (OriginLab Software).

The appropriate method is the Low-pass FFT (Fast Fourier Transform). We noted that the data from the Luiswishi-Likuni site appear quite noisy due to the fact that the survey was done near the city of Lubumbashi which is a large urban center. The degree of noise being evaluated, the parameters related to the filtering window (Point of Window) and the Cutoff Frequency are summarized in table 3 below.

Table 3 Frequency Analysis Parameters.

Sites	Point of Window	Cutoff Frequency (Hz)
Luiswishi-Likuni	3	0.166

Note that the larger the filter window, the higher the signal wavelength and the lower the Cutoff Frequency. The filtering results are displayed either in table form (Tab. 4).

Table 4 Visualization of Filtering Results on the Database (Luiswishi-Likuni Site).

G(Y)	H(Y)
TAUX DE RADIOMETRIE	TAUX DE RADIOMETRIE (Filtré)
(µSv/Jr)	
	3 pts Low-Pass FFT smooth of "TAUX DE RADIOMETRIE"
8,6	10,19855
5	11,25615
12,4	12,29571
23,6	12,74788
12,8	12,23132
8	10,79987
7	8,94096
6,1	7,3189
6	6,42309
7,4	6,33789
5,9	6,76231
8,6	7,23984
7	7,43226
7,6	7,26708
6,2	6,89653
6,5	6,53785
7,6	6,32563
6	6,26673
4,8	6,29371

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Furthermore, these checks and corrections are implemented in such a way as to always keep the original table for reference. On the two amplitudes above, we notice that the Low-pass filter produced a smoothing well suited to the radiometric data which appeared very noisy. This operation is carried out before any other form of processing because it helps reduce background noise. Attenuation of noisy frequencies significantly increased the signal-to-noise ratio, making the data usable for any future modeling.

VI. CONCLUSION

The first step in a study of probably polluted sites and soils is to check the quality of the data in order to ensure the reliability necessary for the project as a whole. This work therefore set itself the objective of showing how to visualize, process and interpret the radiometric data measured at the Luiswishi-Likuni site and to ensure as best as possible their validity before going further in their analysis. By carrying out this work, a second objective is achieved: the data is better understood thanks to different representations, by nature more visual and informative than simple tables.

Data acquisition was done in a directional manner: 13 radiometric profiles oriented, for the most part, in the NE-SW direction, with a total of 2,000 radiometric measurements collected using a “Radiation” type Geiger counter Alert Inspector” and a Garmin GPS. The data obtained were grouped into an MS Excel database to facilitate frequency analysis for background noise mitigation via OriginLab software as well as geostatistical analysis and mapping of results on ArcGIS. The geostatistical analysis consisted of calculating the estimation error on the one hand, as well as analyzing the histogram and the QQ-Plot diagram of the data on the other hand. The frequency analysis, for its part, focused on the application of a low-pass filter in order to attenuate the background noise. The results obtained proved that the spatial distribution of the stations as well as the attenuation of noisy frequencies make reliable measurements for a more in-depth study on the impact of natural radioactive radiation of telluric origin on the populations of surrounding cities.

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