DOI 10.4430/bgo00447

# The line unit levelling method of airborne gamma-ray spectrum anomaly information based on wavelet filtering by layers

C. Xiong[1,2], X. Wang[2], H. Chen[2], X. Wang[2] and H. Wu[1,2]

[1] Engineering Research Center of Nuclear Technology Application, East China University of Technology, Nanchang, China
[2] School of Nuclear Science and Engineering, East China University of Technology, Nanchang, China

(Received: 12 September 2023; accepted: 3 December 2023; published online: 16 February 2024)

***ABSTRACT*** Airborne gamma-ray spectrometry (AGS) is a technical method that uses an aircraft as the carrier to measure airborne geophysical fields. Due to the high detection efficiency and low working cost, AGS is suitable for large-scale operations and measurements conducted jointly across land and sea. However, the accuracy is strongly associated with the detection arrangement, which may easily cause banding anomalies distributed along lines. The line unit levelling method is used to eliminate such differences occurring between the banding anomaly and mineralisation anomaly; however, artificial influence is inevitable as the parameter setting depends on experience. This paper proposes a new line unit levelling method combined with the wavelet transform theory and variation coefficient theory. This method adopts wavelet transform to perform multi-scale decomposition on the data per measurement line unit, and effectively removes non-geological background information through soft threshold filtering. The results prove that this method can significantly reduce the errors caused by time domain batches, narrow the anomaly range, and improve the recognition accuracy of ore-causing anomaly points. Moreover, the shape of the anomalies is consistent with the ground anomaly inspection results, and the distribution of radionuclides can be restored in the surveying area.

**Key words:** airborne gamma-ray spectrometry, anomaly information, wavelet transform, line unit levelling.

## 1. Introduction

Airborne gamma spectrometry (AGS) is one of the main regional aero-geophysical methods (Grasty, 2012). About 80% of China's large- and medium-sized uranium deposits were discovered with this method (Liu *et al*., 2002; Wan *et al*., 2012). Due to the low intensity of AGS detection, the signals caused by ore bodies are easily influenced by other external environmental factors (information reflected on the detector by lithology, soil type, humidity, vegetation coverage density, water area distribution, etc.) (Ge *et al*., 2016; Xiong, 2016). Due to the susceptibility of the factors, such as measurement height, atmospheric radon concentration and cosmic rays, the measured raw data generally contains a large number of anomalies caused by non-ore-causing information. As a result, the ore-causing anomaly information is easily submerged in interference signals.

For the AGS data levelling technology, the method currently chosen by scholars is predominantly gamma line analysis, which employs pre-processing techniques, such as altitude measurement, topography measurement, and corrects atmospheric radon (Grasty *et al.*, 1995; Zhang *et al.*, 2011; Wu *et al.*, 2016). Courbin *et al*. (1999), Billings *et al*. (2003), and Druker (2016) successively published research results on quantitative inversion problems. Minty (2003) and Minty and Ross (2016) proposed the use of the three dimension (3D) quantitative inversion technique to perform 3D terrain levelling on AGS data. Mi *et al.* (2013) used terrain levelling coefficients to perform terrain levelling on AGS data based on the dynamic characteristics of aerial surveys. Jurza *et al*. (2005) and Minty (2012) studied the effects of atmospheric radon changes on AGS and proposed three methods to remove atmospheric radon disturbances. Ge *et al.* (2010) and Gu *et al*. (2014) proposed an atmospheric radon levelling technique based on the improved spectral ratio method for airborne gamma spectrometry, which effectively corrected the atmospheric radon disturbances on AGS data. These existing methods, while widely accepted and implemented in AGS analysis, are only efficient in the case of uniform sampling detection.

The AGS measurement carrier (aircraft) is constrained by factors such as terrain and weather conditions, so field operations cannot maintain a uniform speed throughout the flight, resulting in non-uniform distances between the sampling points of the measured AGS data. The nuclide specific activity value in a measured single point is affected by the values of its neighbouring areas, which are formed by a number of non-equidistant survey points along the survey line direction. Therefore, the measurement results are easily affected by error caused by time domain batches, which is reflected by the banding anomaly distribution along the flight line on the contour map.

With the extensive use of digital maps and continuous development of computer graphics, data post-processing technology has become a new direction for research in the field of AGS data processing by referring to spatial filtering and other digital maps and digital image processing theories.

In this study, a wavelet-based line unit levelling method is applied to adjust the raw data of the AGS in the study area, and a single survey line is used as a levelling unit to filter the wavelet domain so as to eliminate the banding anomaly distribution in the data processing result. This method can correct the data in corresponding survey lines by using the approximate signal values of a specific line, obtained by wavelet decomposition, and, then, selected as background values. The difference between the corresponding original data and line background values is considered as a levelling coefficient. Through this method, abnormal data distribution can be effectively eliminated, data quality and reliability can be improved, and a more accurate and reliable data support can be provided for subsequent research and analyses.

## 2. The wavelet line unit levelling method

Since the target of the AGS survey is the value distribution and variation of radionuclides in near-surface strata media (i.e. soils, rocks), the detectors receive unsteady data signals. Compared to the fast Fourier transform, the wavelet transform offers the advantages of multi-scale analyses, which can be used to adjust the observation scales as required. This method shows a relatively better applicability for processing complex and non-equidistant, non-stationary data signals such as AGS data.

The wavelet line unit levelling method is a data levelling method of the AGS line based on wavelet domain. The method uses surveying lines as a levelling unit to perform wavelet decomposition, filtering and reconstruction on different scales for each surveying line in order to correct the detecting line data.

The definition of continuous wavelet is:

$$\psi_{a,b}(x) = \left|\frac{1}{\sqrt{a}}\right| \psi\left(\frac{x-b}{a}\right), \quad a > 0; \quad b \in R \tag{1}$$

where, $\psi_{a,b}(x)$ is the mother wavelet function, $a$ is the zoom factor, $b$ is the displacement factor. Assuming that $a = 2^j$, $b = k \times a$, $j \in Z$, then, the continuous wavelet transform can be discretised:

$$\psi_{j,k}(x) = 2^{-j/2}\psi\left(2^{-j}x - k\right). \tag{2}$$

In this paper, $f(x) \in L$ denotes a survey line signal, $x$ denotes a survey point. Consequently, the discrete wavelet transform is:

$$WT_f(j,k) = \langle f(x), \psi_{j,k}(x)\rangle = 2^{-j} \int f(x)\psi\left(2^{-j}x - k\right)dx. \tag{3}$$

In the AGS detection process, two main distraction factors can lead to errors caused by time domain batches:

1) AGS is a non-stationary point measuring method. The detector measures and records full spectrum data in each time unit (generally per second). Due to the topography of the flight study area, it is impossible to maintain a uniform speed in the aerial survey work. As a result, the measured data is not a single point nuclide specific activity value targeted by a global satellite positioning system, but a comprehensive reflection of the radionuclide specific activity value of several non-equidistant neighbouring measurement points along the survey line;
2) Due to the large measurement flight area between the survey lines, the flight time interval between each survey line and the adjacent survey line in the same area is relatively large. Measurements are affected by many factors, resulting in a significant staircase effect between data from different lines.

According to the wavelet transform, anomaly information can be referred to as detail signals in the frequency domain, while background information corresponds to the approximate signals. The airline measurement data can be divided into several detail parts on different scales, and an approximate part can be divided by multiple wavelet decomposition. This approximate part can be regarded as the superposition of geological background information and banding false anomaly information. AGS surveys focus on anomaly information (details following wavelet decomposition) in mineral resource exploration. For this reason, from the perspective of anomaly information extraction, the approximate part can be filtered out.

## 3. Selection of wavelet basis functions for filtering

Different wavelet basis functions and decomposition levels are strongly correlated with the processing results. Generally, the optimal decomposition layers can be determined by selecting the coefficient of variation (*CV*). Since ore-forming areas hold high *CV*s, the *CV* of gamma spectra can reflect the variation degrees of the uranium, thorium, and potassium concentration (Sun, 2009; Daubechies, 2011). In anomaly extraction in AGS data, the *CV* is used to characterise the discrete data degree and predict ore-forming probability (Zhang and Xiong, 1990; Cressie,1992):

$$CV = \frac{\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i-\bar{X})^2}}{\bar{X}} \quad (4)$$

where $\bar{X}$ is the average value of a nuclide of the aerial line; $n$ is the total number of points in the aerial line; $X$ is the content value of a nuclide in the study area. The $CV$ is the ratio of the mean square deviation to the mean value of all the survey points within the aerial line. The larger the $CV$ value, the more heterogeneous the distribution of radioactive elements. After decomposing the original data by wavelet, the low frequency part is filtered out, but the signal structure remains the same and the $CV$ value does not change significantly. After decomposing to a certain critical value, further steps can, clearly, distort the signal and the curve shape. In addition, the $CV$ value will change.

The AGS data is discrete. Currently, processing is performed using five types of wavelet basis functions: daubechies (dbN), symlets (symN), coiflets (coifN), biorthogonals (biorNr.Nd), and reverse biorthogonals (rbioNr.Nd). The characteristics of these functions are shown in Table 1. The

Table 1 - Comparison of the characteristics of wavelet basis functions (dbN, symN, coifN, biorNr.Nd, rbioNr.Nd).

| **Wavelet name** | **Abbreviation** | **Characteristics** |
|---|---|---|
| Daubechies | dbN | Orthogonality<br>Biorthogonality<br>Approximate symmetry<br>Reconstitution: 2N-1<br>Decomposition:2N-1<br>Filter: 2N |
| Symlets | symN | Orthogonality<br>Biorthogonality<br>Approximate symmetry<br>Reconstitution: 2N-1<br>Decomposition: 2N-1<br>Filter: 2N |
| Coiflets | coifN | Orthogonality<br>Biorthogonality<br>Approximate symmetry<br>Reconstitution: 6N-1<br>Decomposition: 6N-1<br>Filter: 6N |
| Biorthogonals | biorNr.Nd | Non orthogonality<br>Biorthogonality<br>Dissymmetry<br>Reconstitution: 2Nr+1<br>Decomposition: 2Nd+1<br>Filter: Max (2Nr, 2Nd) +2 |
| ReverseBiors | rbioNr.Nd | Non orthogonality<br>Biorthogonality<br>Dissymmetry<br>Reconstitution: 2Nr+1<br>Decomposition: 2Nd+1<br>Filter: Max (2Nr, 2Nd) +2 |

levelling procedure for survey lines, using the wavelet line unit levelling method, is the following:

1) select a wavelet basis function and perform wavelet transform on a single survey line with Eq. 3;
2) reconstruct the detail signals after wavelet transform;
3) calculate the *CV* of the survey line after reconstruction;
4) increase the decomposition level and repeat steps 1 and 2 until the preset decomposition level is reached. Since the iterative algorithm for wavelet decomposition is down sampling, the amount of data, at each iteration, will be reduced by half. Therefore, the preset decomposition level depends on the amount of measurement data;
5) select the optimal decomposition level before the *CV* changes. Correct the original survey lines sequentially.

## 4. Results and discussion

### *4.1. Overview of measuring instruments and the study area*

The experimental data was collected and processed through the AGS863 AGS detection system (Fig. 1). The AGS863 AGS detection system consists of two boxes of sodium-iodide (NaI) crystal detectors. The detection system is fixed on a Y12 transport aircraft. The measurement platform is equipped with a data acquisition system, radio altimeter, and global satellite positioning system.

The study area is about 295 km$^2$ located in the Inner Mongolia Autonomous Region, with 21 survey lines and 6,705 survey points arranged in it. The geological map of the study area is shown in Figs. 2 and 3, respectively. The lithology of the area mainly consists of granite, sandstone, and volcanic clastic sedimentary rocks. The presence of lead-zinc ore and iron ore in the south-

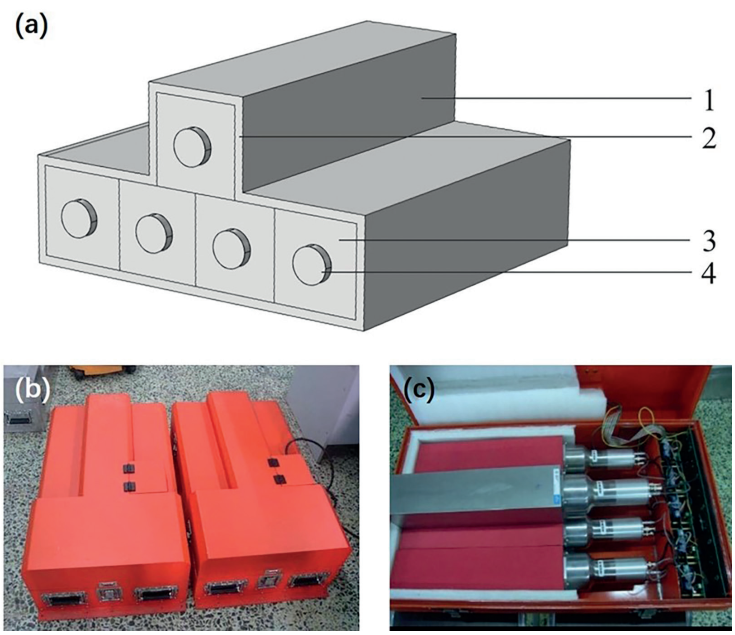


Fig. 1 - Diagram of AGS863 AGS system: a) 1 - metal shell, 2 - anti-vibration thermal insulating materials, 3 - crystal + PMT + precircuits, 4 - signal output port; b) aspect with detector packaging; c) NaI crystal array.

eastern part of the study area is confirmed. A histogram of the uranium content in the survey area is shown in Fig. 4. The uranium concentration, generally, follows a normal distribution. The average uranium concentration value is 4.1 µg/g (with the highest value reaching 37.2 µg/g), the lower detection limit of the detector is 0.01 µg/g (as the histogram only represents the calculated values, some uranium content data is below the detection limit), and the standard deviation is 3.2 µg/g.

### *4.2. Selection of optimal wavelet functions and decomposition levels*

Five typical discrete wavelet basis functions (dbN, symN, coifN, biorNr.Nd, rbioNr.Nd) are chosen and operated in the decomposition process. Survey line no. 20, with the most obvious banding anomaly distribution, is selected. The maximum decomposition level is set at six, according to the number of survey points. The processed *CV* is shown in detail in Table 2. In the same wavelet basis function, with the increase of decomposition level, the variation tendency of most of the *CV*, obviously, at first increases and, then, decreases, reaching the extreme value at the fourth decomposition level. The fourth decomposition level can be considered as a sign of separation between the detail signals and the approximate signals of the original survey line. At the fourth decomposition level, the rbio3.7 *CV* is the largest and the change is the most severe.

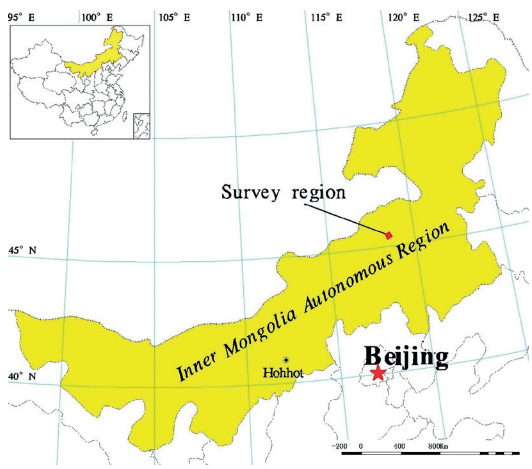


Fig. 2 - Index map of the site survey region.

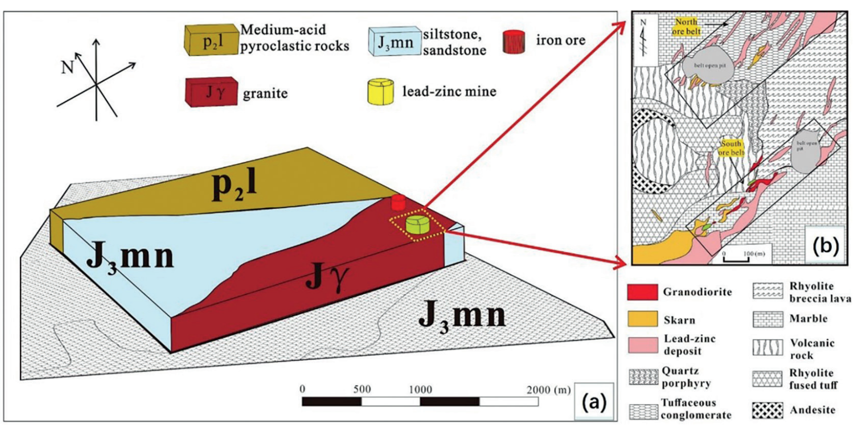


Fig. 3 - Geological map of the target area (a) and of the anomaly inspection area (b).

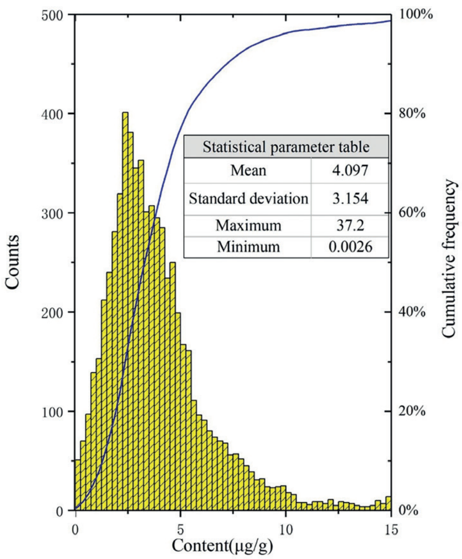


Fig. 4 - Histogram of uranium content in the survey region.

Therefore, rbio3.7 is selected as the wavelet basis function to decompose survey lines at the fourth level and reconstruct the approximate signals.

The rbio3.7 scale function and wavelet function graphs are shown in Fig. 5, and the comparison graph of a certain line, before and after levelling, is shown in Fig. 6. The overall uranium concentration trend in the survey line, before and after levelling, is consistent. Due to

Table 2 - *CV* decomposition.

| **Wavelet basis function type** | **Number of layers** | | | | |
|---|---|---|---|---|---|
| | **2** | **3** | **4** | **5** | **6** |
| db2 | 1.6404 | 1.8632 | 1.8436 | 1.6307 | 1.5207 |
| db3 | 1.7327 | 1.6309 | 1.8323 | 1.6957 | 1.5405 |
| db4 | 1.6850 | 1.8725 | 1.7214 | 1.6231 | 1.5980 |
| db5 | 1.5492 | 1.5889 | 1.8903 | 1.7192 | 1.5650 |
| sym2 | 1.6404 | 1.8632 | 1.8436 | 1.6306 | 1.5206 |
| sym3 | 1.7327 | 1.6308 | 1.8322 | 1.6957 | 1.5404 |
| sym4 | 1.8015 | 1.6148 | 1.7717 | 1.7102 | 1.5816 |
| sym5 | 1.7184 | 1.6990 | 1.9226 | 1.6305 | 1.5455 |
| coif2 | 1.7769 | 1.7441 | 1.7783 | 1.7198 | 1.5575 |
| coif3 | 1.7561 | 1.6285 | 1.7353 | 1.6503 | 1.5701 |
| coif4 | 1.7414 | 1.6655 | 1.9387 | 1.6694 | 1.5839 |
| coif5 | 1.7087 | 1.5861 | 1.8329 | 1.7318 | 1.6057 |
| bior2.4 | 1.6743 | 1.6339 | 1.8012 | 1.6921 | 1.5536 |
| bior3.7 | 1.5832 | 1.6424 | 1.9331 | 1.6848 | 1.5808 |
| bior6.8 | 1.6583 | 1.6815 | 1.7444 | 1.6791 | 1.5580 |
| rbio2.4 | 1.6471 | 1.6134 | 1.7530 | 1.7015 | 1.5414 |
| rbio3.7 | 1.6050 | 1.6192 | 1.9508 | 1.6692 | 1.5881 |
| rbio6.8 | 1.6447 | 1.6974 | 1.7288 | 1.6868 | 1.5536 |

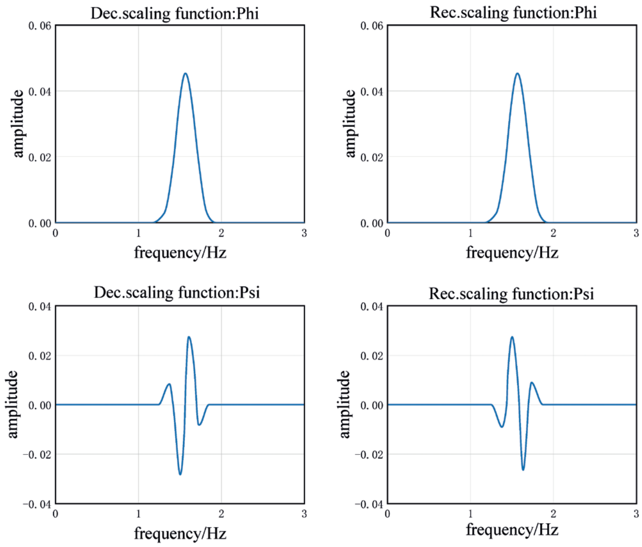


Fig. 5 - The rbio3.7 scale and wavelet functions.

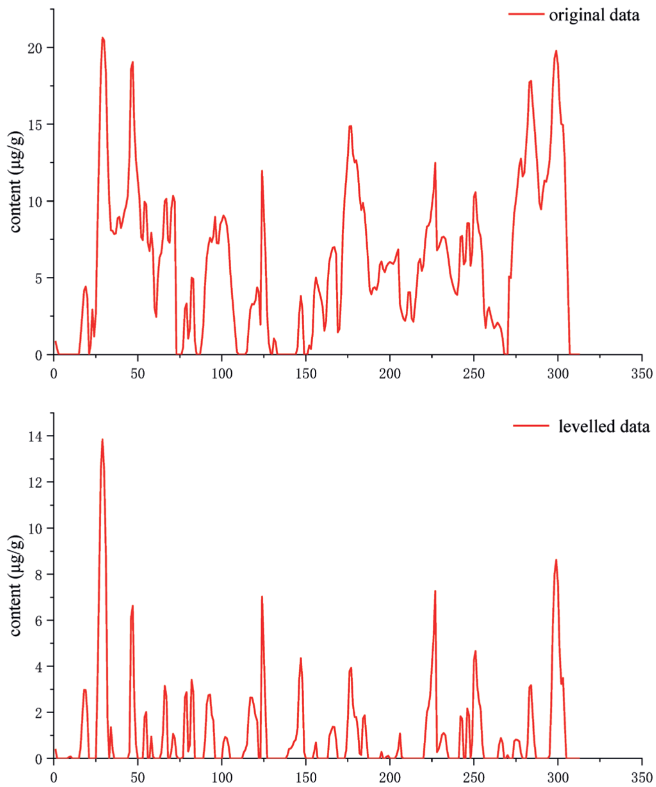


Fig. 6 - Comparison of original data and levelled data.

the error caused by time domain batches, some measurement points, before levelling drastically and irregularly fluctuated. The distribution of the specific activity values near survey points no. 140 and no. 260 is platform-like. After levelling, some areas in fluctuating parts became stable, the peak shape of the high value areas remained basically unchanged, and the platform-like anomaly areas in the survey line disappeared.

### *4.3. Levelling results and analyses*

Interpolation is a method of inferring values at unknown positions based on known data points, and spatial interpolation extends this inference in space to generate estimates for the entire region. The Kriging gridding method is implemented to conduct spatial interpolation (128×128) on the measured original discrete data and rbio3.7 line unit levelling data of the fourth decomposition level, respectively. The contour map between original and corrected U concentration (Fig. 7) is made according to the EJ-T 1032-2005 AGS standard.

In Fig. 7a, due to the error caused by time domain batches, banding anomaly distributions of different degrees appears in areas nos. 1 to 4. Among them, due to the presence of metal ore deposits in area no. 1, ore-causing anomalies are superimposed on banding false anomalies to form an area, with an elliptical anomaly area. In addition, irregularly connected anomaly areas are shown in areas nos. 2, 3, and 4, which are abnormally distributed in a banding shape along the aerial surveying lines. These banding anomalies are clearly large-scale interference information caused by non-ore-causing anomalies, and are superimposed with the ore occurrence anomalies, which substantially interfere with ore-causing anomaly identification and the following anomaly verification process.

In particular, in area no. 1 of Fig. 7b, the connected anomaly belt is divided into two small-range strong anomalies, and their shapes are approximated to “C”. Comparison with the AGS ground verification results shows that the anomaly information (such as anomaly shape) processed by the wavelet line unit levelling method, the location of ore-causing anomaly points and the extent of the anomaly area, are consistent with ground verification results. This proves that the wavelet line unit levelling method can filter the banding false anomaly information caused by the time domain batches, and can accurately identify AGS ore-causing anomaly information from disturbed data. Once the ground has been verified, areas nos. 2, 3, and 4 are all found to be banding false anomaly distribution areas with no anomalies. The intensity and range of the banding anomalies are clearly reduced, yet the anomaly concentration trend does not change. The line unit levelling method can significantly correct the anomalies caused by the distortion of the line data while keeping the geological background information substantially unchanged.

## 5. Conclusions

The wavelet line unit levelling method applies the *CV* to select the optimal wavelet basis function and optimal decomposition level, which can prevent the influence of subjective factors on the wavelet selection. The selected wavelet basis function is used to perform wavelet transform on the lines, which can correct the impacts on the detection result caused by time domain batches. The result shows that, after raw data levelling, ore-causing anomaly positions are clearer and more accurate.

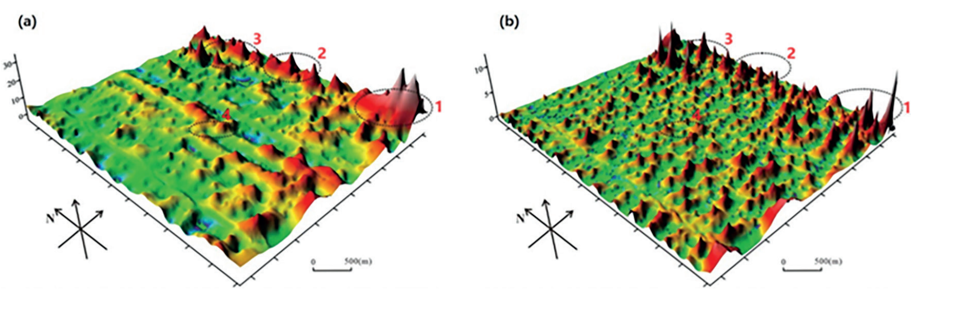


Fig. 7 - Uranium concentration contour map: a) original; b) levelled.

The anomaly area decreases, the interference information around the ore occurrence (caused by the time domain batches) disappears, and the intensity and range of the banding anomalies are reduced consequently. The false anomaly information, caused by data distortion, is filtered and radionuclide distribution in the surveying area is restored. The corrected data can provide reliable information, to support future exploration work, by narrowing the scope of ore-causing anomaly.

**Acknowledgments.** The authors wish to express their gratitude to associate professor Fei Li for the English language review. This work is supported by the National Natural Science Foundation of China (no. 12205044 and no. 12265003), Jiangxi provincial Natural Science Foundation (no. 20212BAB201005), Open fund of Engineering Research Center of Nuclear Technology Application, Ministry of Education (no. HJSYJB2021-13) and Doctoral Startup Fund of East China University of Technology (no. DHBK2019152).

REFERENCES

Billings S.D., Minty B.R. and Newsam G.N.; 2003: *Deconvolution and spatial resolution of airborne gamma-ray surveys.* Geophys., 68, 1257-1266, doi: 10.1190/1.1598118.
Courbin F., Magain P., Kirkove M. and Sohy S.; 1999: *A method for spatial deconvolution of spectra.* The Astrophysical J., 529, 1136-1144, doi: 10.1086/308291.
Cressie N.; 1992: *Statistics for spatial data*. Terra Nova, 35, 321-323.
Daubechies I.; 2011: *Ten lectures on wavelets*. Springer Verlag, Berlin, Germany, 341 pp.
Druker E.; 2016: *Processing of airborne gamma-ray spectrometry using inversions*. In: Extended Abstracts 25th International Geophysical Conference and Exhibition - Interpreting the Past, Discovering the Future, ASEG, Adelaide, Australia, vol. 2016, pp. 1033-1040, doi: 10.1071/ASEG2016ab147.
Ge L., Gu Y., Zhang Q., Ma Y. and Cheng F.; 2010: *Radon background correlation using spectral-ratio method in natural gamma-ray spectrometry*. Nucl. Tech., 33, 844-848.
Ge L., Xiong S., Zeng G., Fan Z., Ni W. and Zhou S.; 2016: *Airborne gamma-ray spectrum detection and application.* Science Press, Beijing, China, 189-195, in Chinese.
Grasty R.L.; 2012: *Uranium measurement by airborne gamma-ray spectrometry*. Geophys., 40, 503-519.
Grasty R.L. and Minty B.R.S.; 1995: *A guide to the technical specifications for airborne gamma-ray surveys*. Australian Geological Survey Organization, Canberra, Australia, 89 pp.
Gu Y., Ge L., Xiong S., Zhou J. and Fan Z.; 2014: *Spectral-ratio radon background correction method in airborne gamma-ray spectrometry based on Compton scattering deduction*. At. Energy Sci. Technol., 48, 147-151, doi: 10.7538/yzk.2014.48.01.0147.
Jurza P., Campbell I., Robinson P., Wackerle R and Cunneen P.; 2005: *Use of 214Pb photopeaks for radon removal: utilising current airborne gamma-ray spectrometer technology and data processing.* Explor. Geophys., 36, 322-328.
Liu Y., Gu R. and Hou Z.; 2002: *Airborne radiometrics survey.* Geophys. Geochem. Explor., 26, 250-252.
Mi Y., Fan Z., Zhou X. and Wan J.; 2013: *The terrain correction method for airborne gamma-ray spectrometry survey.* Geophys. Geochem. Explor., 37, 1034-1038, doi: 10.11720/j.issn.1000-8918.2013.6.15.
Minty B.; 2003: *Accurate noise reduction for airborne gamma-ray spectrometry.* Explor. Geophys., 34, 207-215.
Minty B.; 2012: *Multichannel models for the estimation of radon background in airborne gamma-ray spectrometry.* Geophys., 63, 1986-1996.
Minty B. and Ross B.; 2016: *The 3D inversion of airborne gamma-ray spectrometric data*. Explor. Geophys., 47, 150-157.
Sun Z.; 2009: *Study on usage of coefficient of variation for statistics of magnetic parameters of samples.* Geol. Prospect., 45, 65-69.
Wan J., Xiong S. and Fan Z.; 2012: *The status and prospects of airborne gamma-ray spectrometry technology and its application.* Geophys. Geochem. Explor., 36, 386-391.
Wu H., Ge L., Luo Y., Liu Y. and Liu F.; 2016: *Analyzing airborne gamma-ray spectrum by the least square method*. Nucl. Tech., 39, 110201, doi: 10.11889/j.0253-3219.2016.hjs.39.110201.
Xiong C.; 2016: *The research on anomaly information extraction of airborne gamma-ray spectrum survey.* Doctoral dissertation at Chengdu University of Technology, Chengdu, China, 96 pp.
Zhang Q., Ge L., Gu Y., Zengh G., Lin Y. and Wang G.; 2011: *The unfolding of NaI(Tl) γ-ray spectrum based on maximum likelihood method.* Nucl. Tech., 34, 569-574.
Zhang W. and Xiong S.; 1990: *Airborne gamma-ray spectrometric variation coefficient — a useful parameter for interpretation*. Geophys. Geochem. Explor., 14, 276-284.

*Corresponding author:* Hexi Wu
Engineering Research Center of Nuclear Technology Application
East China University of Technology, Ministry of Education
418th Guanglan Road, 330013 Nanchang, China
Phone: +86 187 7919 1725; e-mail: hxwu01@ecut.edu.cn