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Delineation of Banyumas Sub-Basins using Gravity Anomaly Based on Trend Surface Analysis Equation

Deliniasi Sub-Cekungan Banyumas Menggunakan Anomali gayaberat berdasarkan Persamaan Trend Surface Analysis

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Abstract - A study using gravity methods in the Banyumas Basin, located in the southern part of Central Java, Indonesia had been conducted to generate a map for regional geological features in sub-volcanic basin related to petroleum system. This study used the first and second-order of Trend Surface Analysis (TSA) to separate gravity anomaly into regional and residual components. Matrix inversion is applied to obtain constants values for both the first and second-order of TSA. To interpret geological features related to oil and gas study, residual components are used for gravity anomaly. Residual anomaly is also compared for both first and second order of TSA with a regional geological map to validate the result. Residual anomaly from the second order of TSA showed a very comparable result to geological features, as shown in the regional geological map, compared to those of the first order of TSA. These results also showed a strong contrast of some important geological features such as the Gabon-Nusakambangan Formation outcrop, Karangbolong outcrop, and the eastern part of the south Serayu mountain arc. This study also displayed two potential subbasins i.e Citanduy and Majenang sub-Basin that might be a possible setting in which source rocks of the Banyumas Basin were deposited. From this study, it can be concluded that TSA showed a reliable result of separating gravity anomaly data set into regional and residual components.

Keywords: Gravity anomaly, Banyumas Basin, petroleum system, trend surface analysis (TSA).

Abstrak *- Studi dengan menggunakan metode gayaberat telah dilakukan di Cekungan Banyumas, yang terletak di bagian selatan Jawa Tengah, Indonesia. Studi ini dilakukan untuk menghasilkan fitur geologi regional di cekungan sub-vulkanik yang terkait dengan sistem perminyakan. Persamaan Trend Surface Analysis (TSA) orde pertama dan kedua digunakan untuk memisahkan anomali gayaberat menjadi komponen regional dan residual. Inversi matriks diterapkan untuk mendapatkan nilai konstanta untuk TSA orde pertama dan kedua. Untuk menginterpretasikan fitur geologi yang terkait dengan studi minyak dan gas, digunakan komponen sisa dari anomali gayaberat. Anomali sisa untuk TSA orde satu dan kedua dibandingkan dengan peta geologi regional wilayah studi sebagai validasi hasil. Anomali sisa dari TSA orde dua menunjukkan hasil yang sangat sebanding dengan fitur geologi, dibandingkan orde pertama TSA. Hasil ini juga menunjukkan kontras yang kuat dari beberapa fitur geologi penting seperti singkapan Formasi Gabon-Nusakambangan, singkapan Karangbolong dan bagian timur busur pegunungan Serayu Selatan. Studi ini juga menunjukkan dua sub-Cekungan yang potensial yaitu sub-cekungan Citanduy dan Majenang yang berpotensi sebagai tempat terendapkannya batuan sumber di Cekungan Banyumas. Dari studi ini, disimpulkan bahwa TSA menunjukkan hasil yang dapat diandalkan untuk memisahkan data anomali gayaberat menjadi komponen regional dan residual.*

KataKunci: *Anomali gayaberat, Cekungan Banyumas, sistem petroleum, trend surface analysis (TSA).*

BACKGROUND

Gravity is one of the geophysical methods which have been widely used for a preliminary survey on oil and gas exploration. This method has an important contribution in determining the 128 sedimentary basins in Indonesia (Geological Agency, 2009). There are at least 13 sedimentary basins in Java Island. 8 of them, located in the southern part of Java Island, are (mostly) covered by the volcanic deposit. Lack of geology and geophysical (G&G) study in such area makes it “terra incognita” for oil and gas exploration (Satyana, 2015). To delineate subsurface geological features related to the petroleum system in the Banyumas Basin, residual components of gravity data sets are used. In the literature, there are a variety of methods to separate gravity data sets into their regional and residual components such as preferential filtering (Guo et al., 2013), upward continuation (Nettleton et al., 1954; Jacobsen, 1978), matched ?ltering (Spector, 1970), etc. Previous study (Hidayat et al., 2020) has also been performed band pass filter to separate regional and noise components away from residual components of gravity data sets in the Banyumas Basin. In this work, it is aimed to derive an equation that is easy to understand using the TSA equation. TSA itself is a mathematical technique to separate a given map into its two components i.e regional and residual components (Davis & Sampson, 1986). In the recent study, the first order of TSA equation has been performed to separate gravity data sets of the Anambra Basin in south-eastern Nigeria, it showed a better result compared to polynomial technique derived automatically using computer program (Obasi et al., 2016). To evaluate the reliability of this method, it performed the first and second order of TSA equation, then validated our results by comparing them to existing data in the study area i.e the result of Passive Seismic Tomography study (Hidayat et al., 2021; Setiawan et al., 2021), regional geological map, etc. a good acceptance between our results and existing data so it will confirm the reliability of this method.

Geological/Stratigraphical Settings

Based on a previous study, oil and gas seepage are found in the Banyumas Basin (Satyana, 2015). It is an indication that mature source rock had been formed in this area. In 2018, Center for Geological Survey carried out geological fieldwork to collect oil and gas seepage around the Banyumas Basin and perform laboratory analysis. Geochemical analysis suggests that oil and gas seepage from the Banyumas Basin is derived from a deltaic fluvial depositional environment which deposited in the Late Cretaceous to Eocene (Setiawan, 2019). Unfortunately, there is no such outcrop found in the study area to be sampled and further analyzed, because the oldest Rock outcrop, which is found in the study area, is an Oligocene – Middle Miocene volcanic of the Gabon Formation.

Based on the regional geological map in the study area, which is shown in Figure 1, the stratigraphy of our study area follows the following sequence:

a. Gabon Formation, which is an Oligocene-Middle Miocene volcanic sequence, is known as the oldest rock outcrop found in the south-western part of our study area.

b. Deposition then followed by Pemali Formation consisting of Lower-Middle Miocene turbidite deposits.

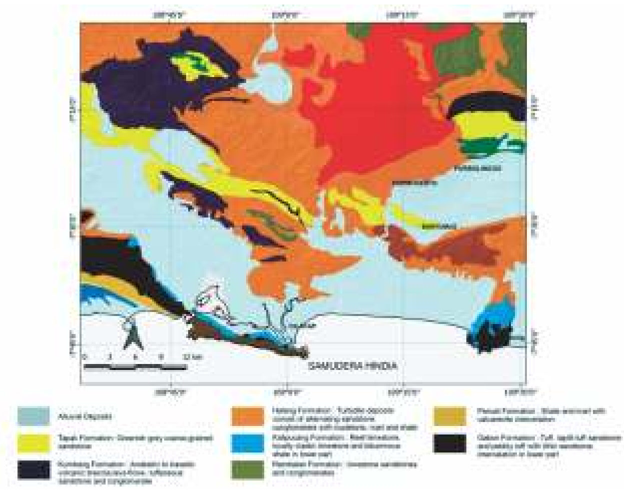
c. Then followed by the Rambatan Formation, consisting of limestone, sandstones, and conglomerates, was deposited on the Middle Miocene.

d. Then, the Kalipucang Formation which is consisting of Middle Miocene limestone.

e. Halang Formation which consists of sandstone which is Middle Miocene -Early Pliocene turbidite deposits.

f. The volcanic facies of the Kumbang Formation, deposited in the Middle Pliocene consisting of sandstone breccias.

g. Furthermore, the Middle Pliocene – Late Pliocene of Tapak Formation consisting of sandstone, intercelation of calcarenite with marl, and finally the volcanic and basalt of the Quartenery volcanic facies.



Sumber: modified from Budhitrisna, 1986; Djuri et al., 1996; Asikin et al., 1992; Kastowo, 1975; Simandjutak & Surono, 1992).

Figure 1. Regional geology map of study area.

METHODS AND MATERIALS

The survey was acquired 501 land survey gravity data points to cover about 70 x 100 km of study area around Banyumas Basin (as shown in Figure 2). Each measurement point was complemented with DGPS measurement to obtain an accurate position and elevation. Then, the data is performed some corrections to reduce gravity data sets to create a Complete Bouguer Anomaly (CBA). To separate CBA into regional and residual components, the TSA equation is applied to find solutions for both the first and second-order of TSA, it is designed a simple matrix inversion code using the MATLAB program and found constants value to obtain both regional and residual anomaly, while Geosoft Oasis Montaj Program was applied to plot gravity anomaly contour maps. Finally, the comparison is conducted to the curve response of residual anomaly derived from the first order to those of second-order of TSA. Some important geological features are also covered by the study areas such as the eastern and western part of South Serayu Mountain Arc, then Gabon-Nusakambangan Formation and Karangbolong high which is located in the south-western part and south-eastern part of the study area respectively.

Trend Surface Analysis Equations

Trend Surface Analysis is a geological term for a mathematical technique which is used to separate one set of a map into its regional and residual components (Obasi et al., 2016). In gravity anomaly case, it involves polynomial equation and least square inversion process to find solution of all the unknown parameters.

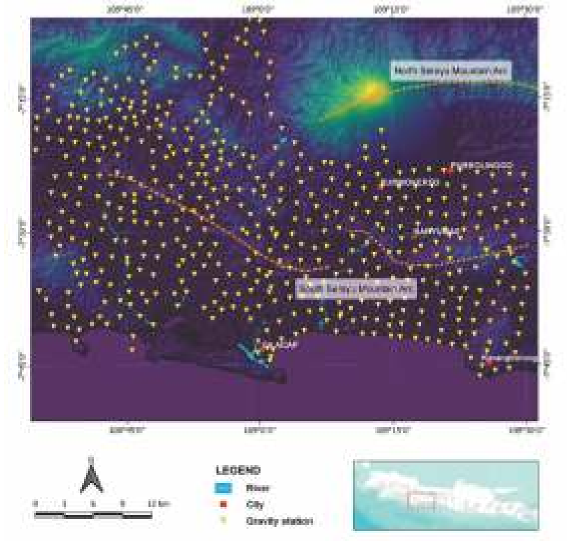


Figure 2. Distribution of 501 gravity dan DGPS data points to cover 70 x 100 km of study area.

The Bouger Anomaly value is a combination of regional anomaly and residual anomaly (Davis & Sampson, 1986; Unwin, 1975). Simply put, it can be expressed by (1).

$$\Delta g_B = \Delta g_{REG} + \Delta g_{RES} \quad (1)$$

Where:

Δg_B = *Complete Bouger Anomaly*

Δg_{REG} = *Regional Gravity Anomaly*

Δg_{RES} = *Residual Gravity Anomaly*

To evaluate the reliability of Trend Surface Analysis (TSA) Equation to separate Complete Bouger Anomaly (CBA), we tried to compare first order and second order of TSA. (2) and (3) respectively are first order and second order of TSA that is used in this study.

$$\Delta g_{REG} = ax_i + by_j + c \quad (2)$$

$$\Delta g_{REG} = ax_i + by_j + c + dx_i^2 + ey_j^2 + fx_i y_j \quad (3)$$

$$\Delta g_{RES} = \Delta g_B - \Delta g_{RES} \quad (4)$$

Where:

e_{ij} = *Residual Anomaly Reading*

Y_{ij} = *Bouger Anomaly Reading*

x_i = *Measurement points in x direction*

y_j = *Measurement points in y direction*

$$e_{ij} = Y_{ij} - (ax_i + by_j + c) \quad (5)$$

$$e_{ij} = Y_{ij} - (ax_i + by_j + c + dx_i^2 + ey_j^2 + fx_i y_j) \quad (6)$$

Residual anomaly of first and second order of TSA are shown in (5) and (6) respectively. To obtain solution of those overdetermined problems, least square equation is used which is expressed in (7).

$$S = \sum_{\substack{i=1 \\ j=1}}^{N} (e_{ij})^2 \quad (7)$$

$$S = \sum_{\substack{i=1 \\ j=1}}^{N} \left(Y_{ij} - (ax_i + by_j + c)\right)^2 \quad (8)$$

$$S = \sum_{\substack{i=1 \\ j=1}}^{N} \left(Y_{ij} - (ax_i + by_j + c + dx_i^2 + ey_j^2 + fx_i y_j)\right)^2 \quad (9)$$

To obtain minimum value of S, we used operation of partial derivatives with respect to constants a, b and c equals to zero (10) for the first order of TSA and to constants a, b, c, d, e and f equals to zero (11) for the second order of TSA.

$$\frac{\partial S}{\partial a}=\frac{\partial S}{\partial b}=\frac{\partial S}{\partial c}=0 \qquad (10)$$

$$\frac{\partial S}{\partial a}=\frac{\partial S}{\partial b}=\frac{\partial S}{\partial c}=\frac{\partial S}{\partial d}=\frac{\partial S}{\partial e}=\frac{\partial S}{\partial f}=0 \qquad (11)$$

The result of partial derivative (10) and (11) can be expressed in matrix as shown in (12) and (13) respectively for first and second TSA equation. (12) and (13) are typical matrix form to determine constants to separate gravity anomaly using TSA equation (Obasi et al., 2016; Unwin, 1975).

$$\begin{bmatrix} \sum_{i=1,j=1}^{N} x_i^2 & \sum_{i=1,j=1}^{N} x_i y_j & \sum_{i=1,j=1}^{N} x_i \\ \sum_{i=1,j=1}^{N} x_i y_j & \sum_{i=1,j=1}^{N} y_j^2 & \sum_{i=1,j=1}^{N} y_j \\ \sum_{i=1,j=1}^{N} x_i & \sum_{i=1,j=1}^{N} y_j & N \end{bmatrix} * \begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sum_{i=1,j=1}^{N} Y_{ij} x_i \\ \sum_{i=1,j=1}^{N} Y_{ij} y_j \\ \sum_{i=1,j=1}^{N} Y_{ij} \end{bmatrix} \qquad (12)$$

$$\begin{bmatrix} \sum x_i^2 & \sum x_i y_j & \sum x_i & \sum x_i^3 & \sum x_i y_j^2 & \sum x_i^2 y_j \\ \sum x_i y_j & \sum y_j^2 & \sum y_j & \sum x_i^2 y_j & \sum y_j^3 & \sum x_i y_j^2 \\ \sum x_i & \sum y_j & N & \sum x_i^2 & \sum y_j^2 & \sum x_i y_j \\ \sum x_i^3 & \sum x_i^2 y_j & \sum x_i^2 & \sum x_i^4 & \sum x_i^2 y_j^2 & \sum x_i^3 y_j \\ \sum x_i y_j^2 & \sum y_j^3 & \sum y_j^2 & \sum x_i^2 y_j^2 & \sum y_j^4 & \sum x_i y_j^3 \\ \sum x_i^2 y_j & \sum x_i y_j^2 & \sum x_i y_j & \sum x_i^3 y_j & \sum x_i y_j^3 & \sum x_i^2 y_j^2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \end{bmatrix} = \begin{bmatrix} \sum Y_{ij} x_i \\ \sum Y_{ij} y_j \\ \sum Y_{ij} \\ \sum Y_{ij} x_i^2 \\ \sum Y_{ij} y_j^2 \\ \sum Y_{ij} x_i y_j \end{bmatrix} \qquad (13)$$

(all sums $\sum_{i=1,j=1}^{N}$)

To simplify matrix form in (12) and (13), they can be rewritten as matrix form in (14)

$$GH = I \qquad (14)$$

Where matrix H is equivalent to constants a, b, c in (12) and a, b, c, d, e, f in (13). Finally, we determined solution for each constant by using matrix inverse as shown in (15).

$$HG^{-1} = I \qquad (15)$$

Correlation and Determination Coefficient

To understand the statistical relationship between data (CBA) and our results (first and second order of TSA), we calculated correlation and determination coefficients. Correlation coefficient itself is a quantity that gives the quality of a least squares fitting to the original data (Weisstein, 2006), while coefficient of determination is a statistical term to assess how strong the linear relationship between two variables. Pearson correlation coefficient is applied (Freedman et al., 2007) which is shown by (16), while coefficient of Determination (Di Bucchianico, 2008) is shown by (17).

$$r = \frac{n\sum_{i=1,j=1}^{N} X_i Y_j - \left(\sum_{i=1}^{N} X_i\right)\left(\sum_{j=1}^{N} Y_j\right)}{\sqrt{\left[\sum_{i=1}^{N} X_i^2 - \left(\sum_{i=1}^{N} X_i\right)^2\right]\left[\sum_{j=1}^{N} Y_j^2 - \left(\sum_{j=1}^{N} Y_j\right)^2\right]}} \qquad (16)$$

$$R^2 = \left(\frac{n\sum_{i=1,j=1}^{N} X_i Y_j - \left(\sum_{i=1}^{N} X_i\right)\left(\sum_{j=1}^{N} Y_j\right)}{\sqrt{\left[\sum_{i=1}^{N} X_i^2 - \left(\sum_{i=1}^{N} X_i\right)^2\right]\left[\sum_{j=1}^{N} Y_j^2 - \left(\sum_{j=1}^{N} Y_j\right)^2\right]}}\right)^2 \qquad (17)$$

RESULT AND ANALYSIS

Using (15), we obtained the value of constants a = 9.434e+09, b = 3.0729e+11 and c = 3.3513e+04 for the first order of TSA equation, while a = 9.4344e+09, b = 3.0729e+11, c = 3.3513e+04, d = 2.6888e+15, e = 2.8176e+18, and f = 8.6500e+16 for the second order of TSA equation. These constants were substituted to (2) and (3) to obtain regional gravity anomaly for first order and second order of TSA equation respectively. Then, by using (4), it is obtained for residual gravity anomaly. Figure 3 shows CBA contour map after applying gravity data corrections. High anomalies in south-western part of study area are interpreted as responses of the Gabon-Nusakambangan Formation outcrop, while those in south-western part of study area are interpreted as responses of the Limestone of Karangbolong Formation outcrop.

Line-A as shown in Figures 3 and 4 to compare between anomaly response of CBA and regional anomalies derived from both first and second order of TSA. As shown in Figure 5, second order of TSA produced a quadratic curve while first order of TSA produced straight line to fit CBA curve. Using (17), obtained R12 = 0.724886 which represents variance between first order of TSA and CBA, and R22 = 0.847886 which represents variance between second order of TSA and CBA. Concluded that the higher of TSA order, the more fit regional anomaly values by obtaining to be compared to CBA. It also means that a very high order of TSA will produce a near zero value of residual anomaly.

Response of residual anomaly for both first and second order of TSA are also compared to see anomaly contrast of some geological features (Line A – A', Line B-B' and Line C-C' in Figures 6a and 6b). Figure 6b shows a very comparable result with regional geological map as shown in Figure 1.

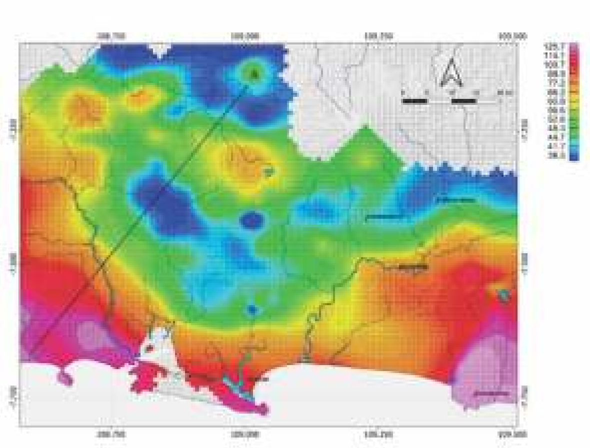


Figure 3. CBA contour map which covered about 70 x 100 km of study area. Line-A is used to sample CBA rensponse to compare it to regional anomaly which we derived from first and second order of TSA.

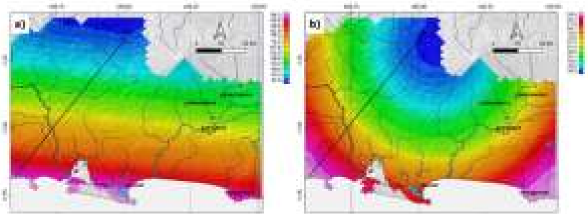


Figure 4. Comparison of regional gravity anomaly derived from a) first order of TSA and b) second order of TSA.

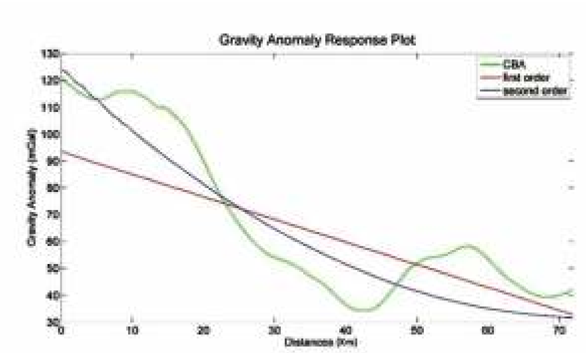


Figure 5. Gravity anomaly response plot along Line-A. Green line represents CBA response, red line represents regional anomaly derived from first order of TSA, blue line represents regional anomaly derived from second order of TSA.

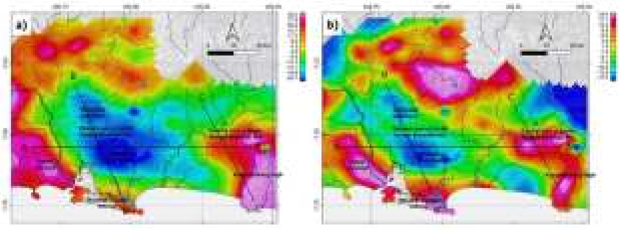


Figure 6. Comparison between residual anomaly derived from a) first order of TSA and b) second order of TSA. Residual anomaly derived from second order of TSA shows a strong anomaly contrast which is comparable to regional geological map (Figure 1) and some geological features (i.e western and eastern south Serayu Mountain arc) as shown in Figure 2.

To shows anomaly contrast quantitatively for both first and second order of TSA through Line A – A', Line B – B' and Line C – C' it can be compared residual anomaly response as shown in Figure 7. Simply put, comparison of residual anomaly response in Figures 7a and 7c can be described as follows:

a. Line A – A' crossed 3 important geological features (the Gabon-Nusakambangan Formation outcrop characterized by high anomaly in the western,the citanduy Basin characterized by low anomaly, and eastern part of south Serayu Mountain Arc in the eastern part of Line A -A'). Blue line, which represents residual anomaly derived from second order of TSA, showing a very strong contrast in all of geological features, while red line, which represents residual anomaly derived from first order of TSA, does not show a very strong contrast in eastern part of the South Serayu Mountain Arc.

b. Line B -B' crossed 4 important geological features i.e the Majenang sub-Basin, the Citanduy sub-Basin, western part of the South Serayu Mountain arc, and the Nusakambangan Formation outcrop. Both Majenang and Citanduy sub-Basin which are separated by the Western part of south Serayu Mountain arc can be characterized quantitatively through first and second order of TSA (as seen in Figure 7b), but a weak contrast of residual anomaly derived from first order of TSA make it quite difficult to be characterized qualitatively (proven by Figure 6a where the Majenang sub-Basin seems unseparable from the Citanduy sub-Basin). In the southern part of Line B – B', both first and second order of TSA showed a strong contrast of Nusakambangan Formation outcrop making it easy to characterize from Figures 6a and 6b.

c. Line C -C' crossed 2 important geological features i.e eastern part of the south Serayu Mountain arc and the Karangbolong Formation outcrop (Karangbolong high) as seen in Figure 7c. Quantitatively, both features can be characterized through high anomaly along Line C – C'. However, unlike residual anomaly from first order of TSA, residual anomaly which is derived from second order of TSA shows a very strong contrast to separate high anomaly from the south Serayu Mountain arc away from those of the Karangbolong high.

From Figures 6 and 7, residual anomaly derived from first and second order of TSA are reliable to characterize geological features quantitatively. While qualitatively, second order of TSA shows stronger anomaly contrast to characterize geological features making it easier for geological interpretation. Figure 8 shows qualitative interpretation from residual anomaly derived from second order of TSA. Some geological features such as the Gabon-Nusakambangan Formation outcrop, the south Serayu Mountain arc and Karangbolong high are well characterized by residual anomaly and also confirmed by regional geological map of study area. Using residual anomaly from second order of TSA, it can also delineate 2 sub basin which might be a possible setting where Eocene source rocks of the Banyumas Basin were deposited i.e the Majenang and Citanduy sub-Basin.

DISCUSSION

First and second order of TSA are applied to separate gravity data sets into its regional and residual components. Response of regional anomaly derived from higher order of TSA resulted the more fit response curve of the data (CBA), it also means that residual data derived from higher order of TSA will result a near zero value.

To validate the reliability of this method, it can be compared these results to regional geological data and confirmed that residual anomaly derived from second order of TSA showed very comparable result to regional geological data. According to residual anomaly derived from second order of TSA, it can delineate 2 sub-basins which separated by the south Serayu Mountain Arc which have also been stated by Passive Seismic Tomography result in this study area (Hidayat *et al.*, 2021; Setiawan *et al.*, 2021).

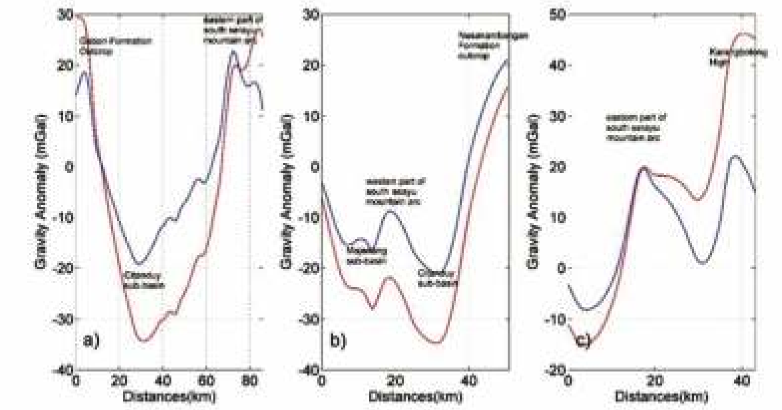


Figure 7. Residual anomaly response plot along a) Line A – A' b) Line B – B' and c) Line C – C'. Red line represents residual anomaly derived from first order of TSA, blue line represents residual anomaly derived from second order of TSA.

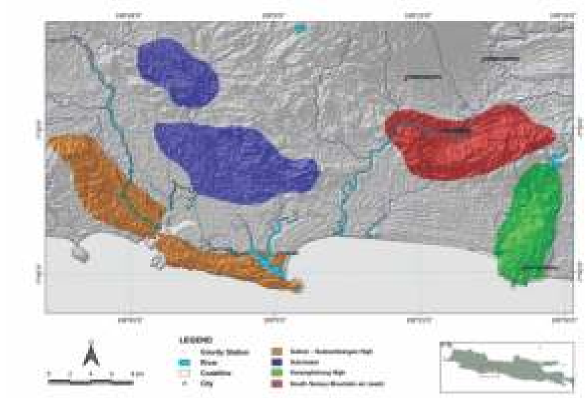


Figure 8. Interpretation of some geological features. The Gabon-Nusakambangan Formation outcrop, Karangbolong High, south Serayu Mountain Arc, and 2 sub-Basin (i.e the Majenang and Citanduy subbasin) can be depicted through residual anomaly derived from second order of TSA.

CONCLUSIONS

Hence, it can be concluded that both first and second order of TSA are quantitatively reliable to delineate some geological features. But qualitatively, second order of TSA showed a sharper contrast to delineate some sub-basins in study area. For preliminary study of oil and gas exploration, gravity is a very important geophysical method, and TSA is one of methods that is reliable to derive regional and residual components from gravity data sets for interpretation purposes.

AUTHOR CONTRIBUTIONS

HH, SS, ZSP contributed on field work to acquire gravity and DGPS data. HH, GMLJ, MM, JHS, AS and AI contributed on data processing and data analysis. All authors are main contributors in preparation of the manuscript. All authors have read and approved the final manuscript.

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REFERENCES

Asikin, S., Handoyo, A., Hendrobusono, S., and Gafoer, S., 1992. *Geology of the Kebumen Quadrangle, Java, Scale 1:100.000*. Geological Research and Development Centre, Bandung-Indonesia.

Budhitrisna, T., 1986. *Geology of Tasikmalaya, Java, Scale 1:100.000*. Geological Research and Development Centre, Bandung-Indonesia.

Davis, J. C., and Sampson, R. J., 1986. *Statistics and Data Analysis in Geology (Vol. 646)*. John Wilwy & Sons, New York.

Di Bucchianico, A., 2008. Coefficient of Determination (R2). Encyclopedia of Statistics in Quality and Reliability. doi:10.1002/9780470061572.eqr173

Djuri, M., Samodra, H., Amin, T.C., and Gafoer, S., 1996. *Geology of Purwokerto and Tegal, 2nd edition*. Geological Research and Development Centre, Bandung-Indonesia.

Freedman, D., Pisani, R., and Purves, R., 2007. *Statistics (International Student Edition)*. Pisani, R. Purves, 4th Edn. WW Norton & Company, New York.

Geological Agency., 2009. *Indonesia Sedimentary Basin Map*. Center for Geological Survey, Geological Agency, Bandung-Indonesia.

Guo, L., Meng, X., Chen, Z., Li, S., and Zheng, Y., 2013. Preferential Filtering for Gravity Anomaly Separation. *Computers & Geosciences*, 51: 247-254.

Hidayat, H., Nugraha, A.D., Priyono, A., Marjiyono, Setiawan, J.H., Sahara, D.P., and Setiawan, A., 2021. Travel Time Tomography to Delineate 3-D Regional Seismic Velocity Structure in the Banyumas Basin, Central Java, Indonesia, Using Dense Borehole Seismographic Stations. *Front Earth Sci*, 9.

Hidayat, H., Subagio, S., and Praromadani, Z.S.A., 2020. Subsurface Geological Structure Interpretation Based on Updating Gravity Data of Banyumas Basin, Central Java. J*urnal Geologi dan Sumberdaya Mineral*, 21(3): 111-118.

Jacobsen, B.H., 1987. A Case for Upward Continuation as a Standard Separation Filter for Potential-Field Maps. *Geophysics*, 52(8): 1138-1148.

Kastowo., 1975. *Geology of Majenang, Scale 1:100.000*. Direktorat Geologi Indonesia, Bandung

Nettleton, L.L., 1954. Regionals, Residuals, and Structures. *Geophysics*, 19(1): 1-22.

Obasi, A.I., Onwuemesi, A.G., and Romanus, O.M., 2016. An Enhanced Trend Surface Analysis Equation for Regional–Residual Separation of Gravity Data. *Journal of Applied Geophysics*, 135: 90-99.

Satyana, A.H., 2015. Subvolcanic Hydrocarbon Prospectivity of Java: Opportunities and Challenges. *Indonesian Petroleum Association, Thirty–Ninth Annual Convention and Exhibition*, May 2015, IPA15-G-105.

Setiawan, A., Zulfakriza, Z., Nugraha, A.D., Rosalia, S., Priyono, A., Widiyantoro, S., and Hidayat, H., 2021. Delineation of Sedimentary Basin Structure beneath the Banyumas Basin, Central Java, Indonesia, Using Ambient Seismic Noise Tomography.

Setiawan, R., 2019. Sistem Hidrokarbon pada Tatanan Vulkanik: Konsep dan Studi Kasus [Hydrocarbon System related to Volcanism: Concepts and Case Studies]. *Publikasi Khusus Eksplorasi Hidrokarbon di Sistem Vulkanik*, 9-21

Simandjutak, T.O. and Surono., 1992. *Geology of Pangandaran, Scale 1:100.000, 1308–2*. Geological Research and Development Centre, Bandung-Indonesia.

Spector, A. and Grant, F.S., 1970. Statistical Models for Interpreting Aeromagnetic Data. *Geophysics*, 35(2): 293-302.

Unwin, D.J., 1975. *An Introduction to Trend Surface Analysis, Concepts and Techniques in Modern Geography*. In Geo Abstracts, University of East Anglia, Norwich (No. 5).

Weisstein, E.W., 2006. Correlation Coefficient. https://mathworld. wolfram. com/