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Comparison of Land Surface and GGMPlus Satellite Gravity Data Results (Case Study: The Kalibening Basin)

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Abstract: As technology develops, many satellite gravity data with world coverage and high resolution have become available, one of which is GGMPlus. However, the quality of the resulting satellite gravity data is still doubtful, because the GGMPlus satellite data is the result of calculations. This research will compare satellite data with land surface data in the Kalibening Basin area to see the precision and correlation of satellite data with land surface data. Land surface data was obtained from field measurements using Scintrex CG-5 with a grid between stations of 500-1000m and GGMPlus satellite gravity data with a distance between points of 600m. The results obtained show that the residual anomaly maps have many similarities, while the regional anomalies provide quite significant differences between the two data. The slicing results show a density contrast that is similar to the two data and matches the geological boundaries of the Kalibening Basin. Based on the results obtained, GGMPlus data can be an alternative to fill the gaps in field data or as supporting data in disaster mitigation and exploration in general. The correlation between land surface data and GGMPlus is quite rational with a value of R^2 = 0.95 and RMSE = 6.89mGal.

Keywords: GGMPlus; Gravity; Kalibening; Land surface

Introduction

The gravity method is one of the often used methods in geophysical exploration (Rosid et al., 2023; Zhang et al., 2019) and disaster mitigation (Haribowo et al., 2021; Rosid et al., 2022; Sehah et al., 2022). This method can provide an overview of the subsurface geological structure based on laterally density contrast (Balkan et al., 2023; Casallas-Moreno et al., 2021; Rosid et al., 2022; Setiadi et al., 2018). The structure can be either a fault or a lithological boundary of a rock (Hasanah et al., 2016; Moeck, 2014). There are several surveys in the gravity method, namely terrestrial or land surface, airborne, satellite (Kern et al., 2003; Shih et al., 2015), marine and shipborne surveys (Abdallah et al., 2022). This survey was carried out by direct measurement of gravity in the field so that this data has an accuracy of 0.01 to 0.001 mGal (Rivas, 2009), compared to airborne gravity surveys which have an accuracy of above 1 mGal (Novák et al., 2003) and marine gravity surveys conducted in the Gulf of Mexico with an accuracy of 1.7 mGal and 3.75 mGal in the Canadian Arctic (Sandwell et al., 2013). These terrestrial gravity data have shortcomings because surveys are costly, take a long time to months depending on the number of survey points and are subject to challenging field conditions (Latifah, 2010; Rivas, 2009). Heavy terrain conditions such as mountains and valleys will be a serious obstacle. Most surveyors are not willing to take risks, so in the abyss areas, a lot of data is empty. The recent advancement of technology, complete satellite gravity data with measurement coordinate points and altitude values are available. However, the sensitivity to high-frequency satellite gravity data is still low, as are the omissions and commission errors resulting from the process of spherical harmonic equations (Gunter et al., 2006).

Many studies have been conducted to demonstrate the accuracy of this satellite data, including the use of GEOSAT and ERS satellite data. The Topex results are better as they have higher resolution for mapping the hydrocarbon basins on Timor Island (Yanis et al., 2020). On the construction of a new gravity reference station in

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Banda Aceh, a comparison has been made between land surface data and Topex. The difference between the Gobs value and the reference station is 13.97 mGal and -61.14 mGal, respectively (Irwandi et al., 2021). Satellite gravity data is also used for oil prospecting in Tanimbar Basin, which shows CBA results with an RMS of 16.5 mGal (Yanis et al., 2019). Validating satellite gravity with terrestrial gravity in the geothermal prospect area shows that the GGMplus satellite data has a good level of validity at shallow depths, but not good enough for deep depths (Atmaja, 2020). GGMPlus data has also successfully identified fractures in Mamasa, confirmed by the spread of the Mamasa earthquake hypocenter from November 2018 to February 2019 (Rosid et al., 2017). The results of GGMPlus data processing succeeded in mapping the existence of fault planes that cross the Umbulan spring, Banyubiru spring and Ranu Grati Maar (Rafi et al., 2023). The GGMPlus satellite can show the existence of faults that form Ronggojalu Springs, Paras Springs and Keramat Springs, apart from that these faults are active Probolinggo fault alignments (Putra et al., 2023). The satellite gravity data does not require high costs, can cover difficult areas such as mountains and valleys, and can easily expand study. GGMPlus satellite gravity data with a 200 m grid has a higher resolution than the Topex satellite with a 2000 m grid. This study uses GGMPlus gravity data to see the level of accuracy of the results regarding land surface data which is seen based on mapping the Kalibening basin pattern and surrounding faults which have not been studied in the area. By carrying out this study, it is hoped that it can fill the gap in gravity data on the land surface or even use GGMPlus gravity data as the main data, and can be an alternative for exploration in areas with relatively extreme terrain.

Method

The study area is located in Kalibening District, Banjarnegara Regency which borders Pekalongan Regency. Geologically, Kalibening District can be classified into several rock formations as shown in Figure 1 (Condon et al., 1996). Lake deposits and alluvium (Qla) consisting of sand, silt, muds and clay, these rocks form the Kalibening basin. Jembangan volcanic rock (Qj) consists of andesitic lava and volcanic clastic rocks, especially hypersthenic andesite, in the form of lava flows, breccias, lava and alluvium (Qjo and Qjm). These rocks are located east to the north of the Kalibening basin with a fairly high topography. Ligung Formation (QTlb) consists of volcanic breccias (agglomerates) composed of andesite, hornblende andesite lava and tuff which is the upper part of the Ligung Formation. This formation is to the west of the Kalibening basin. The Halang Formation (Tmph) consists of tuffaceous sandstones, conglomerates, marls and claystones. The lower part of this formation is andesitic breccia with thicknesses varying from 200 m in the south to 500 m in the north. This formation is to the south of the Kalibening basin. Rambatan Formation (Tmr) consisting of shale, marl and limestone sandstone containing small foraminifera with a thickness is more than 300 m.

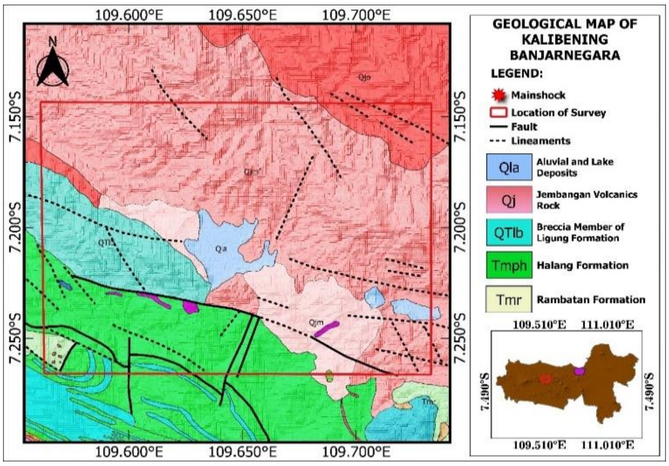

Figure 1. Geological map of Kalibening, Banjarnegara Regency modified from Condon et al. (1996). The red box is the scope of the study area

This study uses two types of gravity data: land surface and satellite GGMPlus. The land surface was acquired with the Scintrex CG-5 gravimeter, with a distance between stations of 500 m to 1000 m. Whereas the GGMPlus satellite data is secondary data obtained from the page *https://ddfe.curtin.edu.au/gravitymodels/GGMplus/data/*.

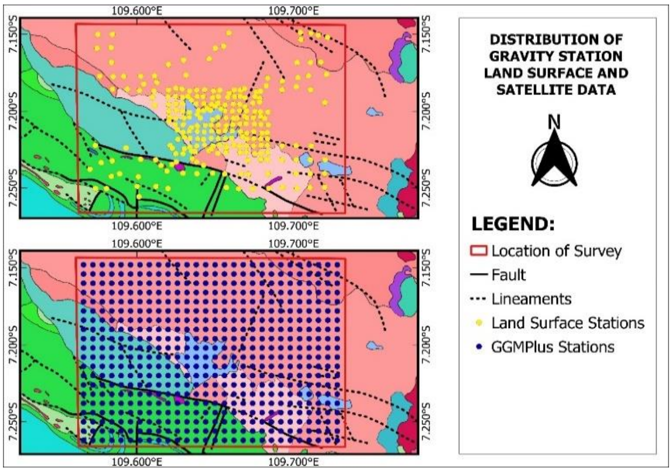

Figure 2. Distribution of the station points (a) land surface and (b) GGMPlus satellite data in the Kalibening area

The data provided by Curtin University of Australia. This data does not come from observations but is calculated by forward gravity modeling of the SRTM topography (Karimah et al., 2020), the distance between stations in this study modified to 600 m to adjust to the land surface distance shown in (Figure 2). This study was conducted by comparing the two data based on data processing methods to data analysis. Both data are processed using the same method, namely the polynomial method and the gravity derivative method.

The polynomial method assumes that the regional surface is a smoother field model based on the value of the polynomial order (Thurston et al., 1992). The principle of the polynomial method is a mathematical approach to determine the optimal order of the smallest square of the regional component based on the obtained constant value (Blakely, 1995), with a polynomial equation (Menke, 2018).

$$G(x_i, y_i) = C_0 + C_1x_i + C_2y_i + C_3x_iy_i + C_4x_i^2 + C_5y_i^2 + \epsilon \quad (1)$$

where i = 1, 2, 3, …, n a number of orders, G is a regional Bouguer anomaly, x and y are coordinates and C_0, … C_n are constants.

The polynomial method produces regional and residual anomalies that are more consistent with geological information (Martínez-Moreno et al., 2015). Indrawati et al. (2020) has also used polynomials to separate regional-residual anomalies in order n = 2 with a good correlation coefficient value. Sari et al. (2012) has conducted a comparative study of filtering methods for the separation of regional-residual anomalies and shown smaller error results compared to other methods. The separation of regional-residual anomalies used moving average, polynomial and inversion methods with a minimum error value of 1.85% (Purnomo et al., 2016). In addition, there are still many uses of the polynomial separation method in various regions such as the Eastern Dead Sea Coast, Jordan (Al-Zoubi et al., 2013), Gruta de las Maravillas, Aracena, Southwest Spain (Martínez-Moreno et al., 2015), Northern Logone Birni Sedimentary Basin, Cameroon (Nguimbous-Kouoh et al., 2017), Wadi Allaqi, Eastern Desert, Egypt (Helaly, 2019), Ziway-Shala basin, central Main Ethiopian rift (Kebede et al., 2020). The study flow can be seen in Figure 3.

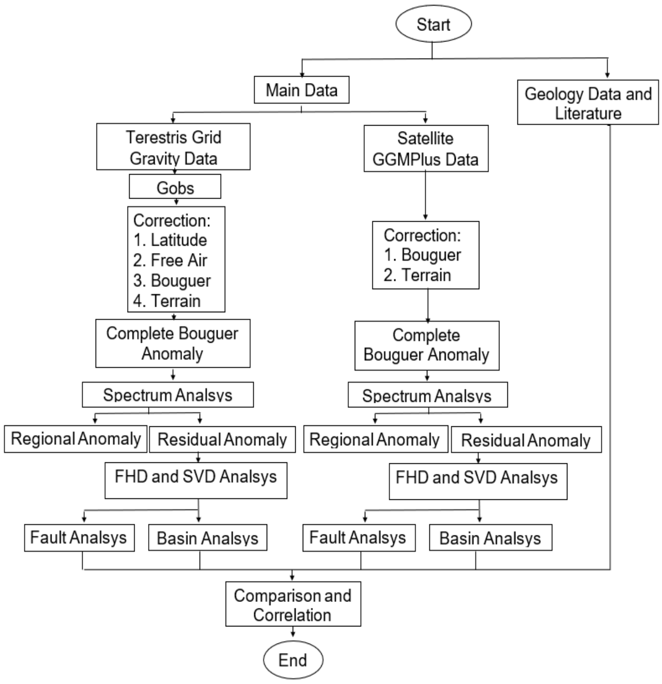

Figure 3. The flowchart of this study

Result and Discussion

CBA (Complete Bouguer Anomaly) maps are generated after various corrections, from drift to terrain. Both data, surface and GGMPlus data, use the same Bouguer density value of 1.8 g/cm3 which obtained from the Parasnis method of surface data. Figure 4 shows the CBA results of both data which have quite significant differences. This might due to the land surface data spread that does not cover mountainous areas, so the maximum value on the CBA land surface is only around 78.58 mGal. Meanwhile, the results of the CBA GGMPlus show more complex values because the spread of data covers the entire area of study.

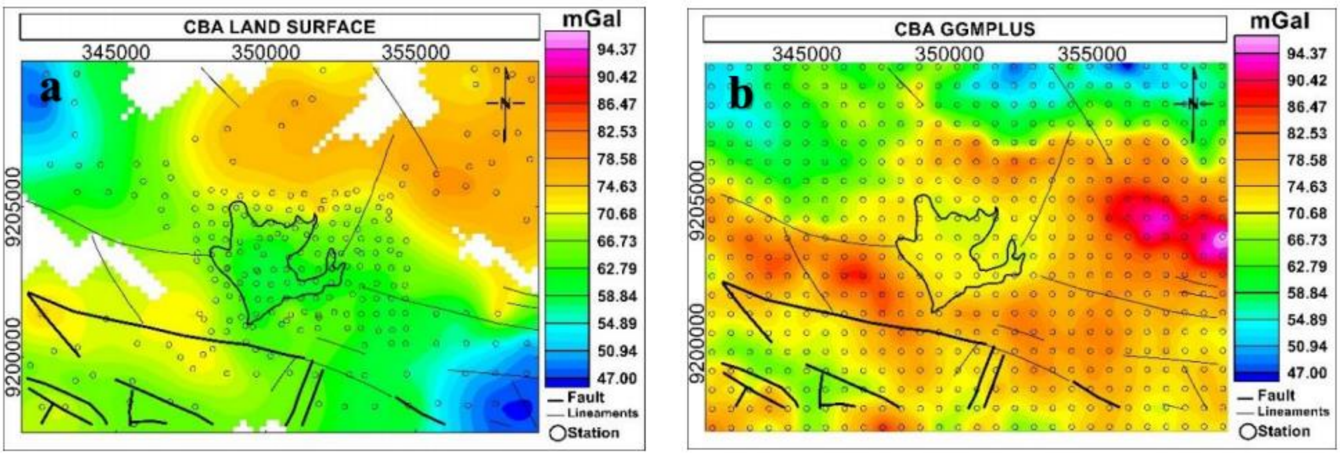

Figure 4. Map of CBA (a) land surface and (b) GGMPlus

The separation of regional and residual anomalies using the polynomial method was carried out using the order-n polynomial equation approach. In this study, polynomials of order 1, order 2, order 3, and order 4 were applied. The results of regional anomaly separation showed very significant differences between land surface and GGMPlus data (see Figure 5). The land surface results showed regional anomaly differences between orders 1 and 2, but there were no significant differences for orders 2 to 4. The GGMPlus data showed that from order 1 to order 3, there were significant differences of regional anomaly. In orders 3 and 4, the patterns are almost similar. High-value regional anomalies in land surface outcomes are located in the northeast of the study area, while GGMPlus results are in the southeast and east directions of the study area.

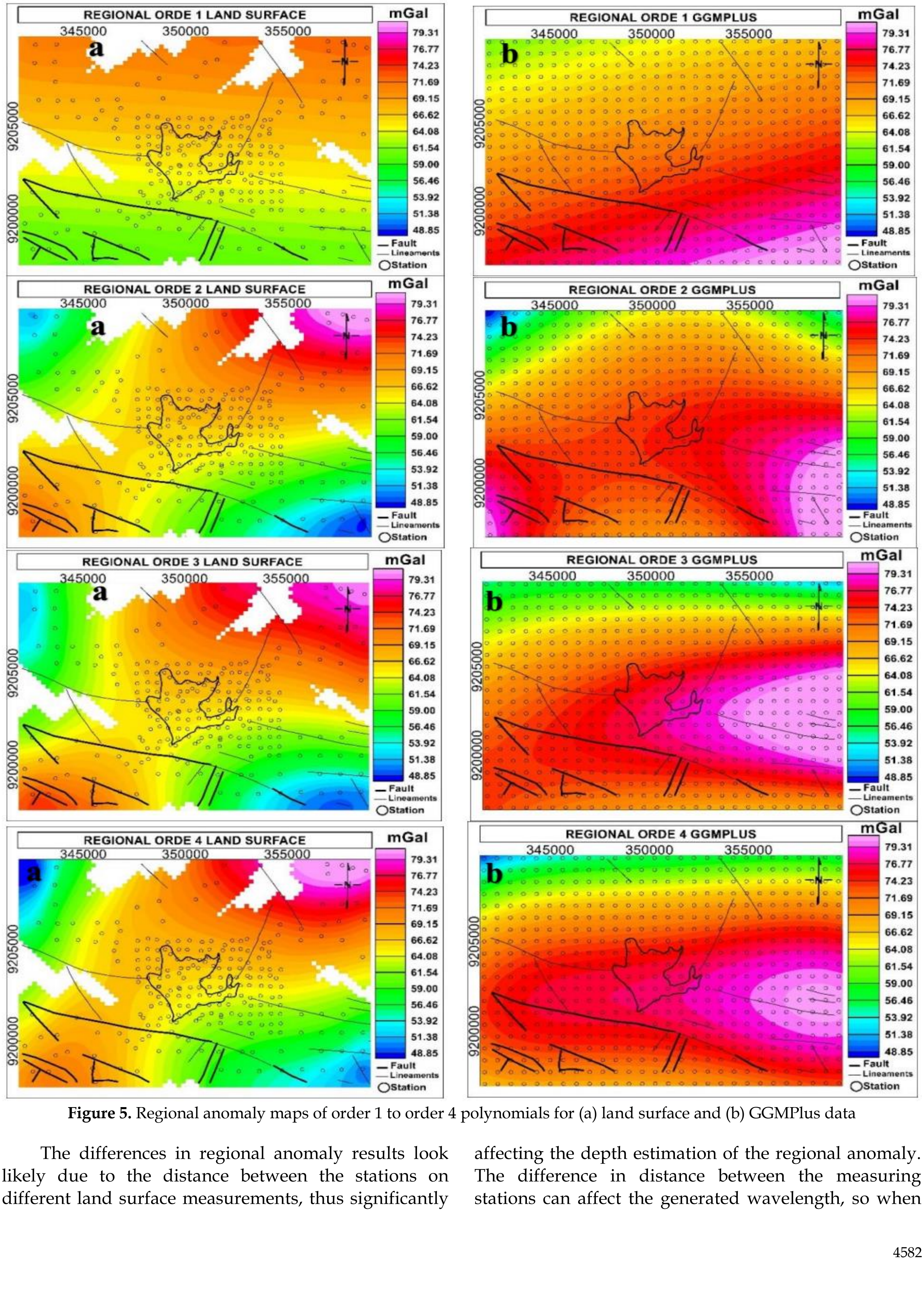

Figure 5. Regional anomaly maps of order 1 to order 4 polynomials for (a) land surface and (b) GGMPlus data

The differences in regional anomaly results look likely due to the distance between the stations on different land surface measurements, thus significantly affecting the depth estimation of the regional anomaly. The difference in distance between the measuring stations can affect the generated wavelength, so when the distance is longer, the estimated depth of the resulting anomaly is deeper (Sari et al., 2012). GGMPlus results showed a more homogeneous regional body anomaly due to the bigger distance between uniform measurement stations.

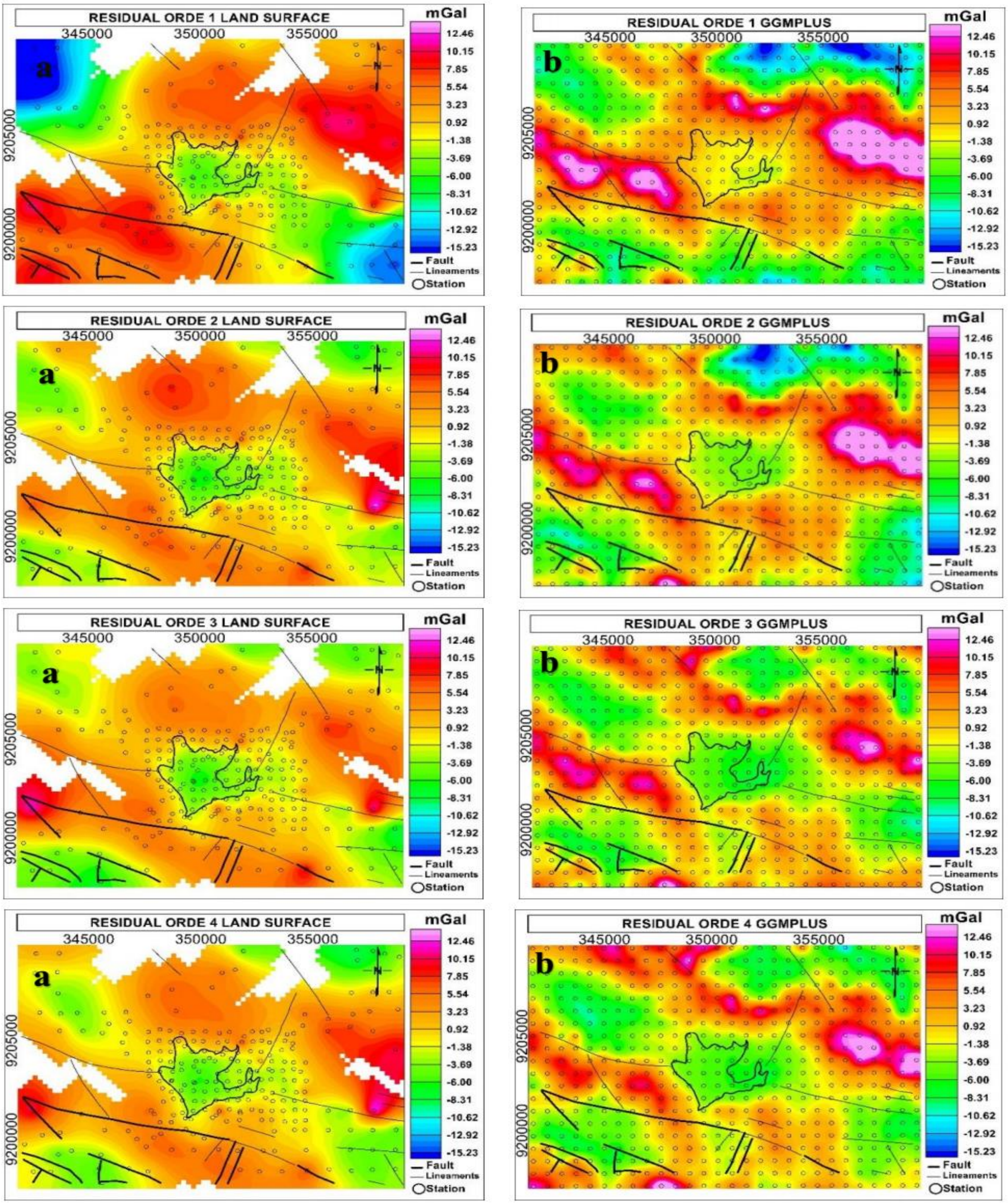

Figure 6. Residual anomaly map of order 1 to order 4 polynomials for (a) land surface and (b) GGMPlus data

From the comparison of the residual anomaly map, in Figure 6, the two maps show quite similar images. Order 1 of the two data sets showed complex results, but the southern land surface part of the basin had high gravity values (orange to red), while the GGMPlus on the same part had low gravity values (green). In the basin area, the land surface results have a low value (green), while GGMPlus has a high gravity yield (yellow to orange), so the results of the order 1 of the two data show different results. Then, order 3 in the basin area of both data is dominated by the same gravity value, which is low (green), but the southern part of the land surface basin is still dominated by the high gravity value (orange), while in GGMPlus there is still a low gravity value (green), as well as in order 4. As a result, there are still differences between the two datasets for orders 3 and 4. In general, an anomaly that has a rather significant similarity between these two data sets is a residual anomaly of order 2. Both the order 2 maps of residual anomaly show similarities corresponding to the geology of the study area. Determination of order in the polynomial method is used to show subsurface geological conditions. Whereas in order 2 which indicates the equation is more heterogeneous, so that the resulting anomaly results are more in line with the geological conditions in the field. The larger the order used, the more heterogeneous the Bouguer anomaly approach will be and will not produce a boundary between regional and residual (Sari et al., 2012). The study results in determining the order in the polynomial method are also emphasized that the separation of regional-residual anomalies in order 2 has a good correlation coefficient and RMS error value compared to other orders (Indrawati et al., 2020; Sari et al., 2012).

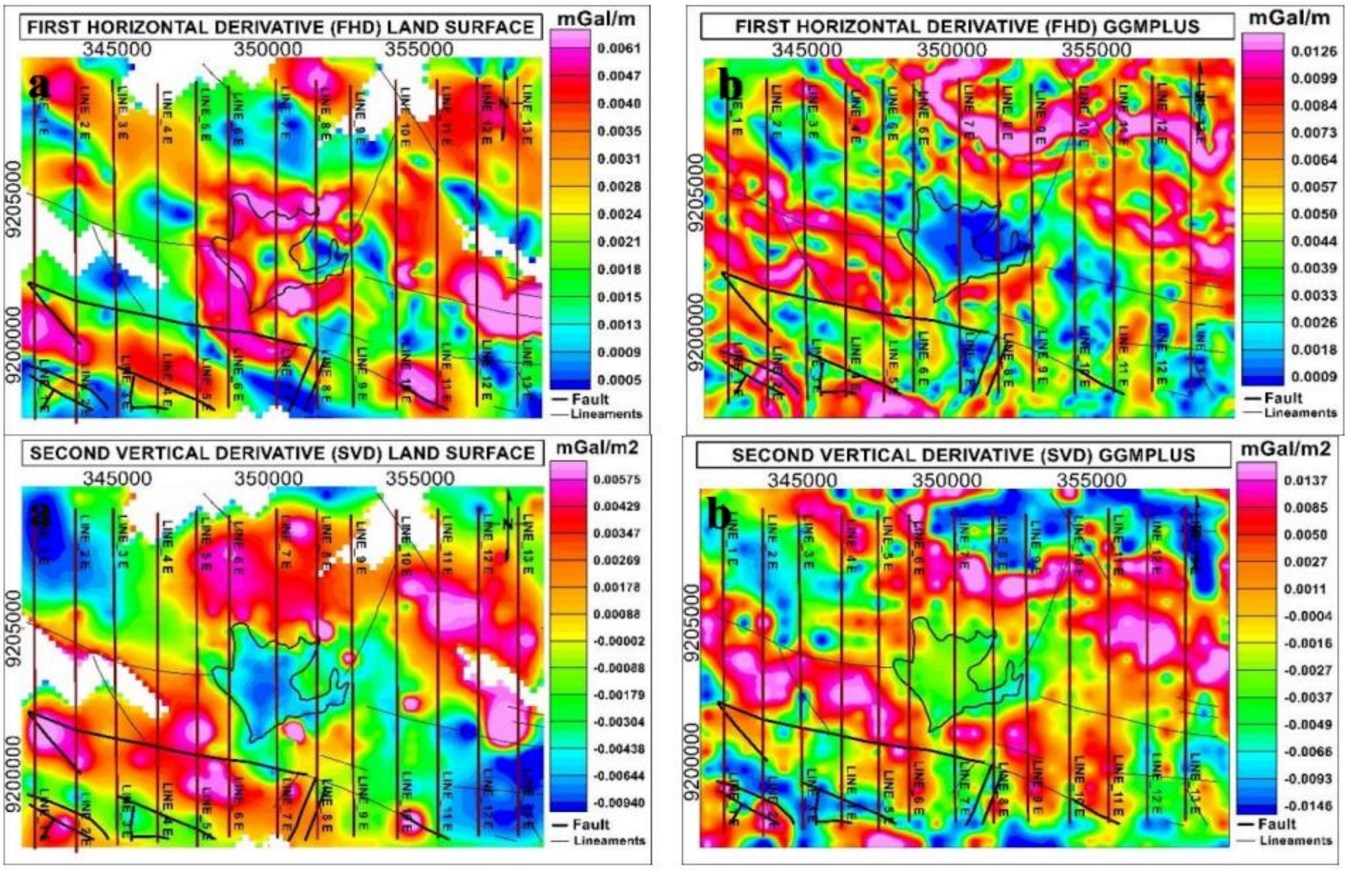

Figure 7. Map of residual order 2 FHD and SVD results on (a) land surface and (b) GGMPlus data

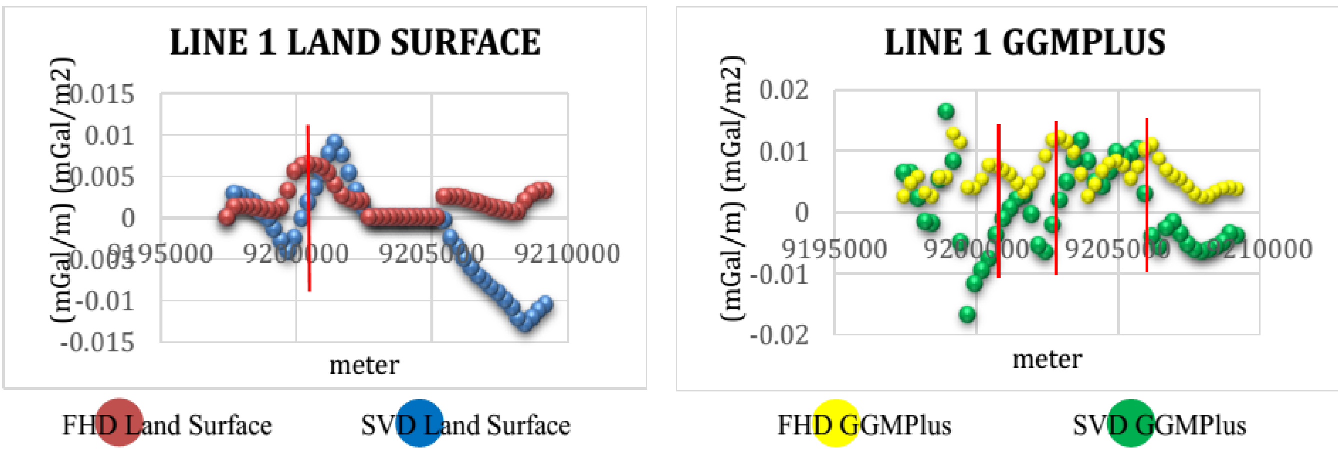

Figure 8. Slicing results on line 1 of FHD and SVD map land surface (left) and GGMPlus (right)

Furthermore, a fault analysis of the two data were carried out based on the First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) values from the results of an order 2 residual anomaly which have geological similarities from the two data. The results of FHD and SVD were sliced to analyze the contrast anomaly of the lateral direction shown in Figure 7. A contrast anomaly can be seen on changes in the contact field of the layer on the SVD anomaly curve in the form of a zero line and on FHD marked by the maximum value (Minarto et al., 2021; Rosid et al., 2017; Yusvinda et al., 2020), this is shown in red line in Figure 8 (only shows line 1). Contrast anomaly can be caused by the presence of density contrast. This contrast anomaly can represent the presence of faults or boundaries of subsurface rock formations.

The geological map (in Figure 1) becomes validator in determining the boundaries of rock formations, faults and the Kalibening Basin. This basin was formed as a result of the movement of the Kalibening-Wanayasa shear fault, so that there is an open location to form a subsidence which over time forms a basin called the Kalibening Ancient Lake. Since Kalibening area is an ancient lake, the area has thick sediment that has not been consolidated (BMKG Banjarnegara, 2018), so there is a significant density contrast at the margins of the basin (number 1 in Figure 9). The results of the slicing show that the land surface has a correspondence with geological data, especially in the basin area. The suburban boundaries of the basin have a high degree of compatibility (accuracy) with the geological map boundaries shown by a cross (X). Besides being able to map basins well, the two data can also map fault structures quite well as shown in Figure 8. However, the empty of land surface data in the west of the basin has caused the fault structures at numbers 2 and 5 to be less well mapped. This proves that data emptiness will result in the loss of a lot of important information. While the GGMPlus results on the fault structure number 2 and 5 show the same agreement with the geological data. However, in GGMPlus there are several results that are not verified by geological data and are different from the results of the land surface (with white circles) in Figure 10b, especially on fault structure number 3.

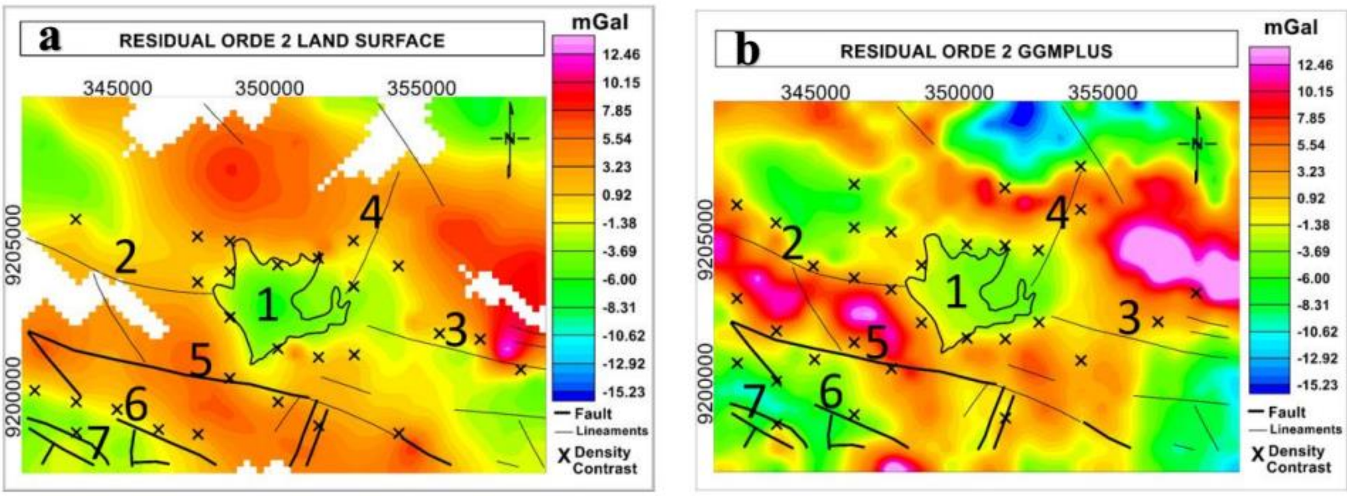

Figure 9. Residual anomaly map of (a) land surface and (b) GGMPlus with density contrast points in cross, x

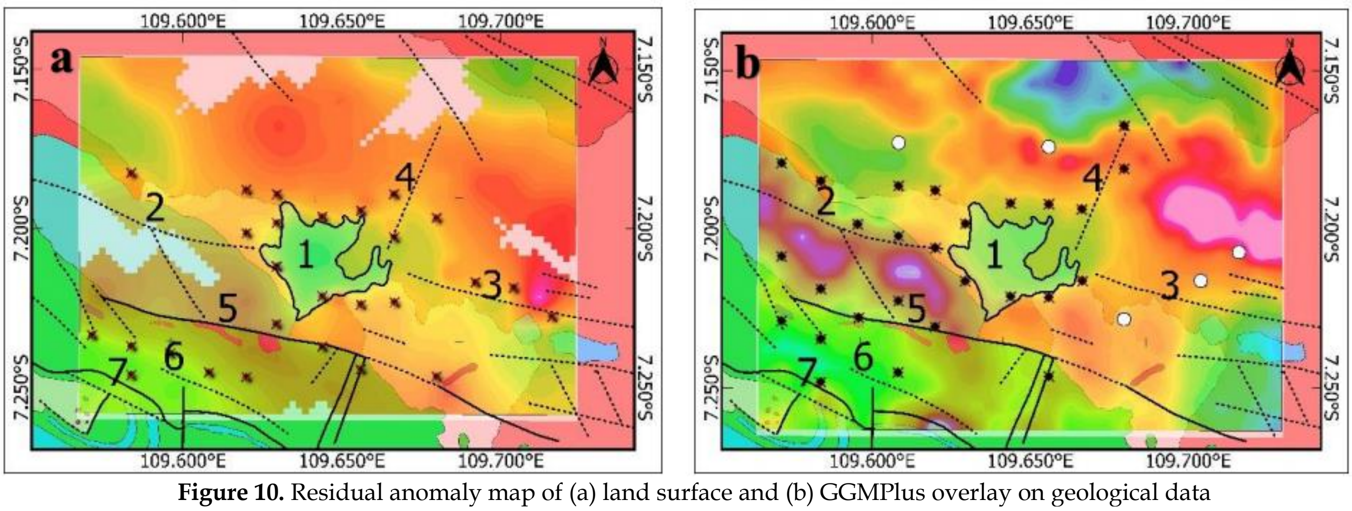

Figure 10. Residual anomaly map of (a) land surface and (b) GGMPlus overlay on geological data

In general, GGMPlus satellite gravity used has a sufficient degree of accuracy to detect the geological features present in this area, although its anomaly shape is not exactly the same as the gravity land surface. The existence of this satellite gravity data can provide the fullness of information from the void of land surface data. However, in the utilization of readings of geological features that are more regional, the validity level of satellite gravity is still not good. To find out the suitability of the GGMPlus gravity data and the land surface gravity, a data correlation from the 17 stations that are close to each other is performed (see Figure 11 (a)). The correlation of both data results in a value of 0.9474, or 95% with RMSE of 6.89 mGal shown in Figure 11 (b). These results give an idea that GGMPlus satellite data is good enough and still reasonable to use as an alternative to land surface data.

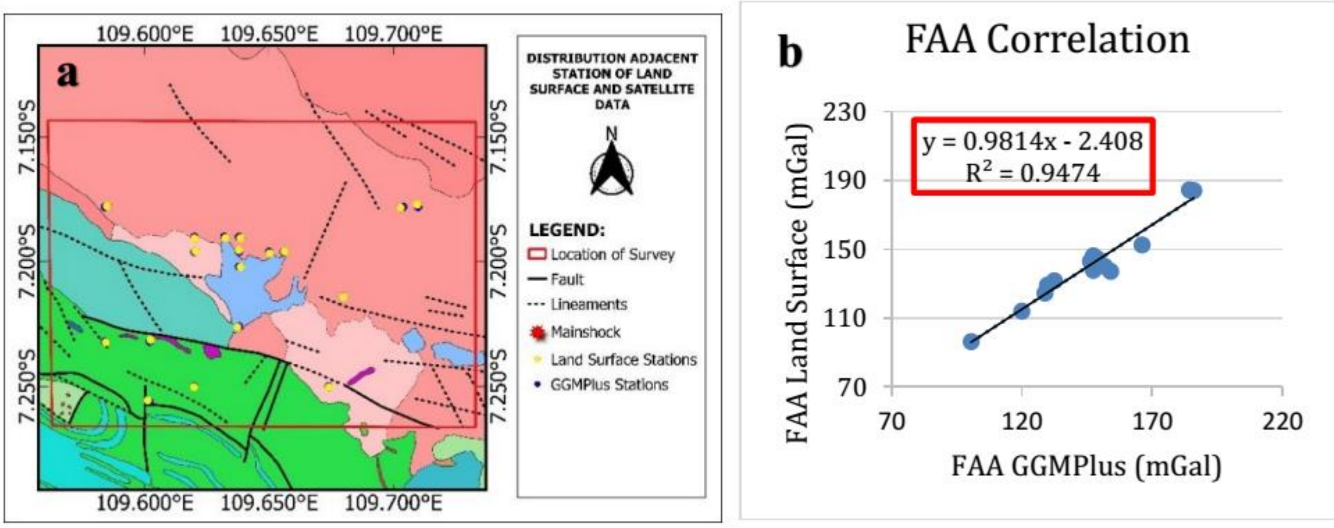

Figure 11. (a) Map with the same coordinate points. (b) Graph of GGMPlus correlation to the land surface

Conclusion

This study was conducted to show the precision of GGMPlus satellite gravity data on land surface data. Based on the results of residual anomaly mapping, the GGMPlus gravity data has a lot of compatibility with the gravity land surface. However, on the regional map, there are very significant differences, especially in the eastern part, where the land surface has low gravity result while GGMPlus shows a high gravity value. This is due to the difference in the distance between stations on the land surface data, thus affecting the depth of the regional anomaly. Through geological interpretation, the land surface and GGMPlus results show a good contrast of anomalies, especially in the basin area. The GGMPlus results succeeded in mapping the fault structure which was not well mapped from the land surface results due to empty data in this area. GGMPlus gravity penetration provides good enough results for studying more shallow geological features than deep geological characteristics by having a matching rate of 95% of field data with an error of 6.89 mGal.

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Author Contributions
Conceptualization, M.S.R; methodology, M.S.R.;P.A.P.W.; validation, F.R.T.S.; formal analysis, P.A.P.W.;F.R.T.S.; writing — original draft preparation, P.A.P.W; writing — review and editing, M.S.R.;F.R.T.S.; data curation, P.A.P.W.; supervision, M.S.R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflicts of interest.

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