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Estimating Bedrock Depth Based on Total Magnetic Field Anomaly Data in Medan City Area in the Northern Sumatra Basin Using the Peter Half Slope Method

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ABSTRACT

The Peter Half Slope method is valuable for estimating rock depths using total magnetic field anomaly data. It relies on graphical analysis and practical rules to gauge the depths of magnetic sources. This method finds significant utility in magnetic interpretation, measuring half the maximum slope distance on magnetic anomaly curves. The primary objective of this research is to determine anomaly depths within Medan City by applying the Peter Half Slope method. The study employs total magnetic field anomaly data from the Medan city area, a part of the Northern Sumatra Basin. The research methodology includes data preparation, reduction to the pole transformation, profile creation, maximum slope computation, half-slope determination, and identifying tangent points on both minimum and maximum curves. The difference between these tangent points is then calculated to derive the depth of the bedrock. Based on the depth calculations using criteria for very thin, intermediate thickness, and very thick bodies, depths of 401, 301, and 240 meters were obtained, resulting in an average depth of 314 meters. This method plays a pivotal role in characterizing subsurface rock structures and is essential for geophysical analysis and magnetic data interpretation.

INTRODUCTION

The depth of the underlying bedrock is a critical factor that significantly impacts the manifestation of vibrations and resonance in the soil and infrastructure when subjected to seismic ground movements. The occurrence of soil-infrastructure vibration and resonance is strongly influenced by the depth of the bedrock in response to seismic activity (Farazi et al., 2023; Manea et al., 2020; Rahman et al., 2021).

Inversion modeling computations have been specifically designed to analyze topography, utilizing geomagnetic data gathered through ground surveys close to the Earth's surface. This method involves intricate computations to extract valuable insights into the geological features and structures present. Through a comprehensive examination of the collected geomagnetic data, a detailed understanding of the Earth's topography can be achieved (Wahyudi, 2023).

Geophysical testing often involves using the magnetic technique to map the distribution of rocks with varying susceptibility beneath the Earth's surface. The magnetic technique is based on detecting variations in the Earth's magnetic field caused by anomalies in magnetized objects beneath the surface (Ramdani et al., 2023). This technique operates on the principle that all subsurface objects exhibit some magnetic influence (Asyqari et al., 2019). A key

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indicator of this magnetic influence is magnetic susceptibility, which measures the degree of magnetization an object exhibits when exposed to a magnetic field. Magnetic susceptibility refers explicitly to a material's ability to become magnetized, determined by the material's susceptibility value (Alisna & Sinuraya, 2021). Understanding magnetic susceptibility provides valuable insights into a material's response to external magnetic forces, offering a deeper understanding of its magnetic behavior and characteristics within a given magnetic environment (Parigi et al., 2019). This technique is particularly effective in creating horizontal contours that reveal the presence and distribution of magnetized rocks (Alrahmadana et al., 2022; Jayanti et al., 2023; Sulandari et al., 2023). Analyzing susceptibility values makes it possible to differentiate between magnetized and non-magnetized rocks, providing valuable insights into subsurface composition (Muchlis & Elders, 2020). Techniques such as the Mag2dc software and the Peter Half Slope method can gain additional depth information to enhance this horizontal mapping (Alimuddin, M., & Rustadi, 2022; Heningtyas et al., 2020).

Mag2DC software is utilized for 2D modeling based on magnetic field anomaly data to determine the subsurface rock distribution pattern aligned with the research objectives (Arafat et al., 2020; Bohal et al., 2023; Sehah et al., 2021). This process integrates geological information from the research site and involves constructing graphic models through a trial-and-error approach. Input values such as inclination, declination, depth, susceptibility, and IGRF values are iteratively adjusted to refine the model and achieve accurate results (Kette et al., 2020; Syafitri et al., 2021).

On the inside, the half-slope method, commonly called the “half-slope method,” is a magnetic interpretation technique that involves assessing depth indices measured at half the slope of the anomaly curve. This method approximates the magnetic source's depth (Kurniawan et al., 2020). Named after its proponent, Peter's half-slope method, or the "Peter's half-slope method," is a graphical approach grounded in theoretical principles and practical guidelines for estimating the depth of the magnetic source (Padmawidjaja, 2019). Researchers employed Peter's half-slope method to infer the depths of magnetic bodies beneath the Earth's surface (Olufemi et al., 2020).

The Peter Half Slope method, employed in the analysis of magnetic data, aims to ascertain the depth of subsurface basement structures. It entails the examination of magnetic anomalies and the computation of the slope found in the linear segment of the anomaly curve (Muchtar et al., 2022; Patro et al., 2023). This slope is subsequently halved to derive the depth to the basement. The methodology presupposes the magnetic anomaly results from a consistent magnetic layer above the magnetic base. Widely applied in geophysical analysis and magnetic data interpretation, this method proves valuable for characterizing subsurface structures. Metode Peter's Half Slope (PHSM) is a quantitative technique employed in geophysical analysis to determine the depth of magnetic sources (Adegoke & Layade, 2019).

The utilization of the Peter Half Slope method aids in characterizing subsurface features by estimating depth through the application of the half-slope technique. This approach involves analyzing magnetic data to discern underlying structures (Rosado-Fuentes et al., 2021). The method entails calculating the slope of the magnetic anomaly curve, dividing it by two, and deriving the basement depth. It proves beneficial in geophysical analysis and the interpretation of magnetic data for characterizing subsurface structures. In subsurface characterization, this method contributes to determining the depth and properties of rocks beneath the Earth's surface (Adegoke & Layade, 2019; Ajay et al., 2023).

The half-slope technique provides a means to estimate the depth of an anomaly source by dividing the slope of the magnetic anomaly curve by two (Wahyuni, 2015; Yuni & Fisa, 2020). This approach utilizes the midpoint of the magnetic anomaly curve and involves drawing two parallel lines touching the curve to calculate the slope. The Peter Half Slope method employs this technique to estimate basement depth, contributing to geophysical analysis and the interpretation of magnetic data for a more detailed understanding of subsurface structures (Olufemi et al., 2020; Sirait, 2021).

The literature on using the Peter Half Slope method in geomagnetic methods is rarely found. Hopefully, this research will increase the literature regarding the Peter Half Slope method. This study aims to prove the effectiveness of the Peter Half Slope method in estimating the depth of subsurface anomaly objects through the comparison of models (synthesis) with and without the addition of random values as error values (Astawa et al., 2016; Widhiyatmoko et al., 2022). The research aims to better understand subsurface structures and obtain information on rock depths that can be useful for natural resource exploration (Novianto et al., 2020; Putri, A. A., & Adhi, 2023).

METHODS

The North Sumatra Basin, a key back-arc basin in Indonesia, is known for its significant oil and natural gas production potential, attracting successful exploration by both local and international companies. Before modeling, this research first processes measurement data from the North Sumatra Basin, particularly in Medan. The modeling process utilizes Mag2DC, Surfer, and MATLAB 2019 software. Surfer is employed explicitly for processing magnetic field data and generating contour anomalies in 2D and 3D dimensions, which are crucial for detailed analysis and interpretation (Rahman et al., 2021; Simbolon et al., 2020; Sirait, 2021).

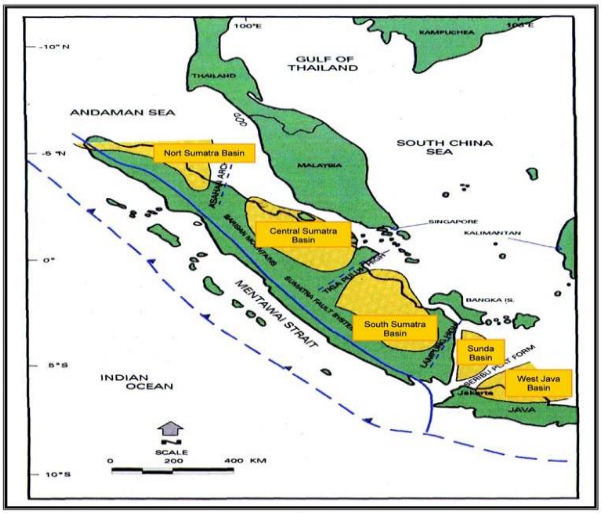

Figure 1. The Location of the North Sumatra Basin and Its Boundaries (Pertamina & BEICIP, 1985; Astawa et al., 2012).

The Mag 2DC software models underground structures matched with the data. Meanwhile, MATLAB is used to find the upper and lower boundaries. In Mag2dc, the inclination used is -8.9449, and the declination used is -0.405429. According to the IGRF map, the IGRF value used is 42005.77, with a profile bearing 330.

The first step is to find the values of inclination, declination, and the IGRF value on the website https://www.bmkg.go.id/ using the research location in North Sumatra, specifically in Medan.

This study's process is data processing and analysis, which involves removing regional magnetic disturbances and processing the magnetic data.

The second step involves correcting the measurement data for diurnal and IGRF corrections. Diurnal correction aims to correct deviations in the Earth's magnetic field caused by the influence of solar radiation and time changes using the formula:

$$\Delta H = H_P - H_{IGRF} \pm H_d$$

ΔH represents the total anomaly, Hp is the measured anomaly value, H_{IGRF} is the magnetic field value, and H_d is the diurnal correction.

The third step involves modeling using Surfer software with the total magnetic field data and then performing a slice on the processed and previously corrected map results.

The fourth step is to input the sliced total magnetic anomaly values into the Mag2dc software and input the inclination, declination, and IGRF values. Next is to match regional geological data in the Medan area to obtain a suitable monopole curve.

The fifth step involves inputting the curve data from the Mag2dc software into MATLAB using the Peter Half Slope script. After running the script, you will input upper and lower bounds and provide input values for x minimum, y minimum, x maximum, and y maximum. After inputting these values, the MATLAB profile will generate an image depicting the results of calculations using the Peter Half Slope method.

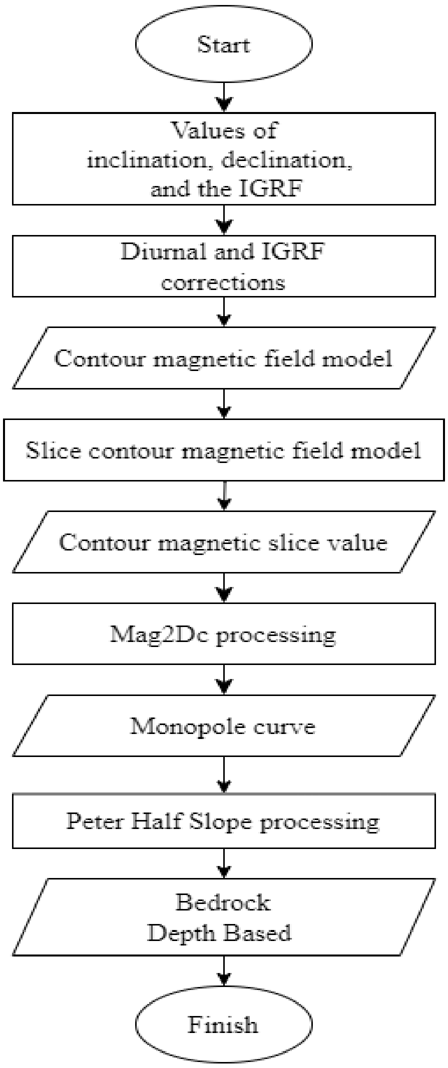

Figure 2. Flow Chart

RESULTS AND DISCUSSION

Geographic coordinates of 3° 30 define the research area boundaries' - 3° 43' North Latitude and 98° 35' - 98° 44' East Longitude. When converted into decimal coordinates, the research area boundaries of the North Sumatra Basin, or more precisely, the city of Medan, are located between 3.5° to 3.7167° North Latitude and 98.5833° to 98.7333° East Longitude.

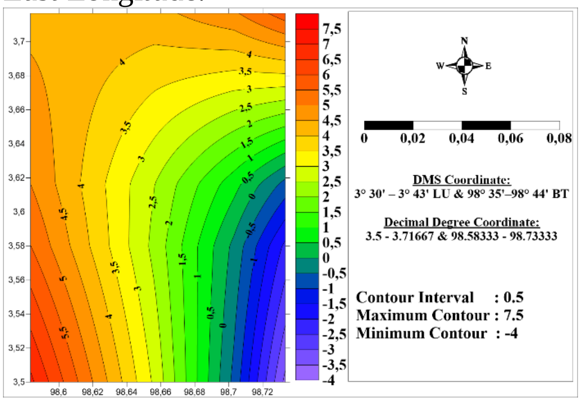

Figure 3. Contour Map of Total Magnetic Field Anomalies in the Research Area

In **Figure 3**, the Medan city area exhibits magnetic values ranging from approximately -4, indicated by the purple color, to high values around 7.5, marked by red.

Determining depth in the Medan city area within the North Sumatra Basin is essential for regional geological understanding and natural resource potential assessment. The Peter Half Slope method is one of the geophysical techniques used to measure depth using geomagnetic data. In the study (Layade, 2023), the Peter Half Slope method was used to estimate the depth of the Basin.

The geomagnetic data used in this research was obtained through magnetic surveys conducted along the North Sumatra Basin (Muchtar et al., 2022; Rizal et al., 2019). These data include magnetic field intensity values and horizontal and vertical components.

Next, the Peter Half Slope method is implemented to obtain depth information (Innocent et al., 2019) in Medan City. This method is based on the relationship between the change in the magnetic field gradient and the depth of subsurface objects. A data processing algorithm is utilized to implement this method, which includes calculating the magnetic field gradient, data refinement, and depth estimation.

The magnetic patterns observed in the plot of total relative magnetic intensity along the traverses displayed positive and negative anomalies, marked by significant peaks (Popoola et al., 2021; Putra & Raguwanti, 2021).

The research results indicate that the Peter Half Slope method is highly effective in determining depth in Medan City, part of the North Sumatra Basin. From the research results, it can be said that the Peter half slope method is very effective for determining the depth of a basin. This is demonstrated by processing using Surfer, mag2dc, and MATLAB software, which is processed well and shows the existence of basins using the Peter half slope method. This method aids in producing depth maps that provide valuable information about subsurface structures and depth variations in the research area (Muchlis & Elders, 2020; Spencer et al., 2019).

The research analysis provides depth insights and reveals a relationship between the depth in Medan City and regional geological characteristics. This suggests that the Peter Half Slope method can be used to further understand the relationship between subsurface structures and regional geology in that area (Akpa et al., 2023).

The Peter Half Slope method with geomagnetic data is an approach that can be used for determining depth in Medan City within the North Sumatra Basin. This research contributes significantly to understanding regional geology and the potential for natural resources in the study area (Mallick et al., 2019; Simbolon et al., 2020).

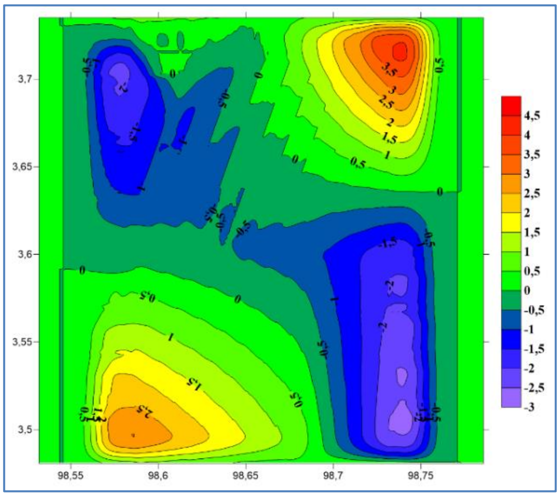

Figure 4. Contour Map of Geomagnetic Results Using FFT in Medan City

The results obtained from the Mag2dc software processing appear as a monopole curve arising from the objects' anomalies in the synthetic data used. In the modeling process, several Earth's magnetic field parameters are required, such as the IGRF (International Geomagnetic Reference Field) value, declination angle, inclination angle, and other (Nagarajan, 2020) model parameters, as seen in Table 1.

Table 1. The Modeling Parameters

No	Parameters	Value
1	IGRF Value	420005.77
2	Declination Angle	-0.405429
3	Inclination Angle	-8.9449
4	Bearing Profile	330
5	Reference Height	3
6	Strike Length	100
7	Maximum *Depth*	500
8	Susceptibility	0.02

The magnetic susceptibility value is influenced by lithological (characteristic) factors and the mineral content of a rock. The susceptibility value is high when the rock contains significant magnetic minerals. In the research, it was found that Andesite lava rock has a susceptibility value of 0.02. The determination of this susceptibility value can be modeled as shown in the diagram below.

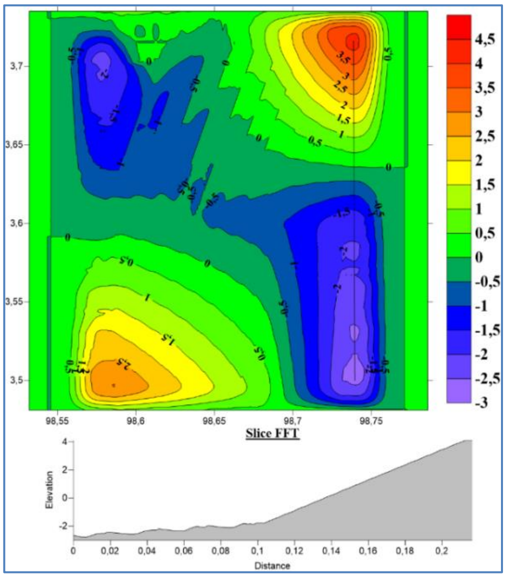

Figure 5. The Result of Contour Map Slicing of Geomagnetic FFT in Medan City Using Surfer

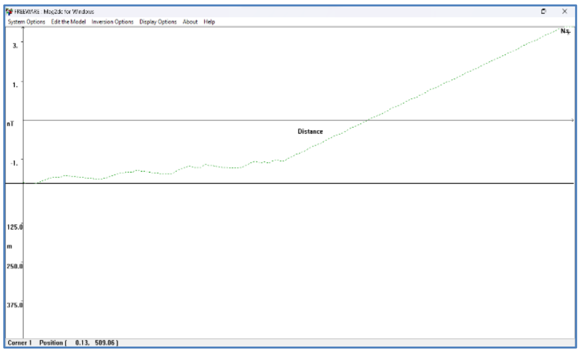

Figure 6. The FFT Curve Display in Mag2dc

The FFT (Fast Fourier Transform) curve above represents the transformation of a signal from the time domain to the frequency domain. The FFT curve shows the contribution or strength of different frequencies in the signal. For several reasons, magnetic data in the time domain is converted into the frequency domain. For example, magnetotelluric (MT) instrumentation measures geophysics' electric and magnetic fields over time. However, the data of interest are impedances and the ratio of the electric and magnetic fields. The data are processed by splitting the series into segments (time windows) and Fourier transforming from the time domain to the frequency domain to calculate the impedances from the measured time series. This is commonly done using the Fast Fourier Transform (FFT). Converting to the frequency domain reduces the data set, as the final data set contains much fewer frequencies than time samples.

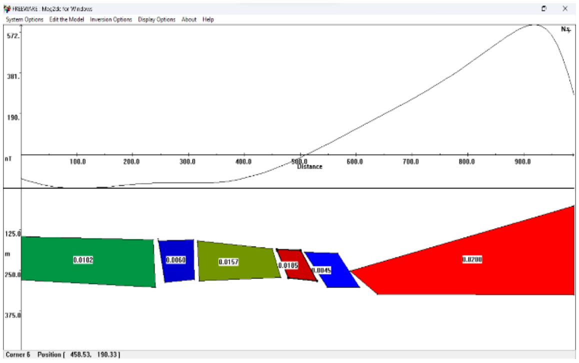

Figure 7. The Result of Modeling Using Mag2dc

Modeling in the Mag2dc software was conducted using a trial-and-error method. This involved varying the depth, rock thickness, and susceptibility values until a similarity was found between the magnetic anomaly curve and the calculated model curve. **Figure 7** demonstrates that the error values are sufficiently small, indicating the capability to represent the subsurface geological model in the Medan City area. After completing the modeling, the data was exported in ASCII format and subsequently processed using MATLAB and the Peter Half Slope Script.

A lower boundary of 44 and an upper boundary of 73 were obtained during the MATLAB processing. The input values for X1, Y1, X2, and Y2 were set to 430, -501.9, 720, and 116.8, respectively.

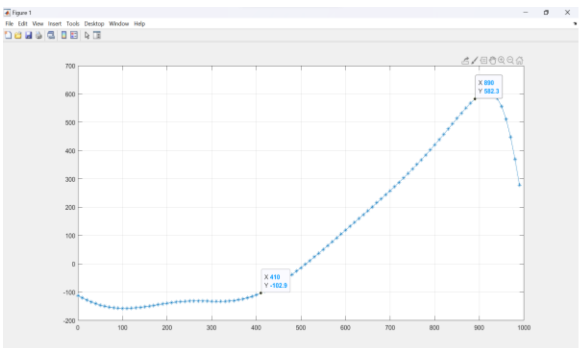

Figure 8. Display the Values at the Upper Limit and the Lower Limit

After inputting the parameter values into MATLAB, it will produce results, as shown in the image above. This model sequenced X1, Y1, X2, and Y2 values as 410, -102.9, 890, and 582.3. In this processing, the Dp1, Dp2, and Dp3 values are also sequenced as 401.5457, 301.1593, and 240.9247.

Peter's half-slope method estimates the depth of a magnetic anomaly based on two position points on the anomaly data. The algorithm starts by selecting the lower and upper boundaries of the data, then performs half-slope estimation using the `polyfit` function. After obtaining the estimated line, the algorithm calculates the slope of the line and requests two additional position points. Additional line coefficients are calculated using the half-slope of the estimated line to produce two lines that divide the anomaly into three parts. The additional input of two position points is used to calculate the width of the anomaly at three points located at half the slope of the estimation line. Visualization of the final results can be seen through the plotted magnetic anomaly graph.

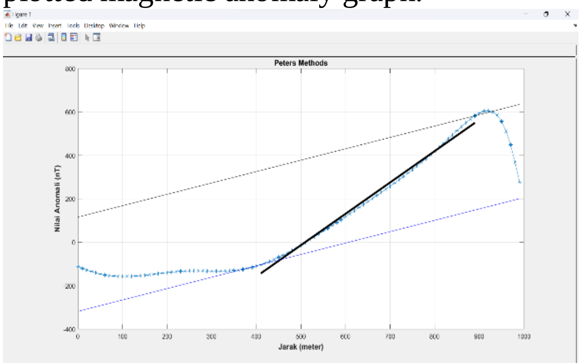

Figure 9. The Processing Results Using MATLAB

When averaged, the average value obtained is 314.4458. The model also produces a value of theta equal to 55.2881.

```
teta =

   55.2881

Lihat gambar !
titik X1 : 410
Tititk Y1 : -102.9
titik X2 : 890
Tititk Y2 : 582.3
```

```
Dp1 =

  401.5457

Dp2 =

  301.1593

Dp3 =

  240.9274
```

Figure 10. Results of data processing in MATLAB

The obtained results estimate the Medan City area depth using the Peter Half Slope method. These parameter values provide information about the depth of objects beneath the surface in the Medan City area. Coordinates X1, Y1, X2, and Y2 depict specific locations or positions that are the focus of the research.

Furthermore, the values Dp1, Dp2, and Dp3 are the results of depth calculations in the Medan City area. These values indicate the estimated depth of objects beneath the surface at the specified points. The obtained results are Dp1, 401.5457 meters, Dp2, 301.1593 meters, and Dp3, 240.9274 meters.

Based on the Peter Half Slope method, the average depth in the Medan City area is 314.4458. This result provides important information regarding the Medan City area's subsurface structure and depth variations.

CONCLUSION AND SUGGESTION

This research utilized the Peter Half Slope method with geomagnetic data to determine anomaly depths in the Medan area within the North Sumatra Basin. The research results indicate that this method effectively determines depths in the Medan area and produces depth maps that provide crucial information about subsurface structures and depth variations in the research area. Additionally, a correlation between depths in the Medan area and regional geological characteristics was discovered.

Furthermore, the study was extended to Medan, and the Peter Half Slope method was successfully applied to estimate depths in that area. Based on the Peter Half Slope method, the Medan city area's depth is estimated to be between 240.9274 meters and 401.5457 meters or with an average depth of 314.4458 meters. This conclusion demonstrates that the Peter Half Slope method, combined with geomagnetic data, is a valuable approach in geological research, providing essential insights into geological structures and natural resource potential in the North Sumatra Basin, including the city of Medan.

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AUTHORS CONTRIBUTION

SR and RJS contributed to formulating ideas, and LDS and YK contributed to data processing. ID and R contributed to the interpretation of data. SR and RJS played a role in formulating ideas, while LDS and YK contributed to the data processing. The interpretation of the data was carried out by ID and R. This collaborative endeavor involved a diverse array of contributions, with SR and RJS focusing on the conceptualization of ideas, LDS and YK handling the intricacies of data processing, and ID and R providing valuable insights through the interpretation of the data.

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