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Research Article

Structural Framework of the Nyi Sindurejo Geothermal System Revealed by Gravity Data Analysis, East Java, Indonesia

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ABSTRACT

The “Nyi Sindurejo” geothermal manifestation in Batu City, East Java, is an atypical geothermal feature. It is located in the central part of Batu City, relatively distant from the active volcanic center. Although it is close to the Kasinan and Songgoriti geothermal systems, no previous specific geoscientific study has evaluated its structural framework and geothermal potential. This study aims to analyze the structural controls of Nyi Sindurejo and assess its possible relationship with adjacent geothermal systems. We utilized Digital Elevation Model (DEM) data to extract geomorphological lineaments and GGMplus data to examine anomaly contrasts. Lineaments were identified and mapped based on topographic features. The gravity data were analyzed to delineate subsurface density differences. Geomorphological lineament analysis reveals a dominant N-S trend with a secondary NNW-SSE orientation. No structural trends appear to connect Nyi Sindurejo with the Kasinan-Songgoriti geothermal systems. The residual Bouguer anomaly indicates local variations in subsurface density without significant continuity toward adjacent geothermal areas It represents a local system rather than being connected to the nearby Songgoriti-Kasinan geothermal areas.

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1. INTRODUCTION

The availability of energy is a crucial component in supporting sustainable national development. Indonesia's primary energy structure remains dominated by fossil fuels, whose reserves are increasingly being depleted (Ministry of Energy and Mineral Resources, 2024). Natural gas reserves are projected to last for only about two decades, while petroleum resources may be exhausted within approximately 62 years (Anderson & Rezaie, 2019; Nasruddin et al., 2016). This situation necessitates an accelerated transition to renewable energy sources with baseload capability, among which geothermal energy stands out for its reliability, continuous availability, and strategic significance for long-term energy security (Alqahtani et al., 2023; Feng et al., 2025; Puppala et al., 2023).

East Java is an active volcanic region hosting several geothermal systems, characterized high-temperature fumaroles, magmatic gases such as H_2S and SO_2, and solfatara zones at the summits of active volcanoes (Daud et al., 2019; Novianti et al., 2024). These surface manifestations reflect active hydothermal alteration and the development of geothermal systems along the volcanic arc (Pereira et al., 2022). Batu City is located in the northeastern sector of the Arjuno-Welirang Volcanic Complex and is also influenced by surrounding volcanic systems, including Kawi-Butak and Anjasmoro (Aris et al., 2021). These volcanic complexes form a structurally complex region in which geological lineaments and fault systems play a critical role in controlling hydrothermal fluid pathways (Utama et al., 2025). The interaction between volcanic activity, regional structural frameworks, and variable rock permeability creates geological conditions conducive to the formation of geothermal manifestations (Suryantini et al., 2025).

Several geothermal manifestations have been identified in Batu City, namely Cangar, Kasinan, and Songgoriti, each of which develops within distinct geological areas and volcanic structural domains. The Songgoriti geothermal system is hosted within volcanic breccia and lava units (Lestari et al., 2020), whereas the Kasinan system occurs in more massive volcanic rocks (Lestari et al., 2023). Between these two systems lies a newly observed thermal manifestation known as "Nyi Sindurejo," located in the central part of Batu City and relatively distant from the active volcanic centers. Its urban location, combined with the absence of clear surface geological indicators, makes the characteristics and structural controls of this manifestation difficult to interpret. Understanding surface lineament patterns and shallow density variations is therefore essential, as surface information alone is insufficient to identify weak zones that may govern hydrothermal fluid pathways (Zaini et al., 2022).

In this study, geospatial lineament analysis and gravity-based geophysical approaches are employed to provide an initial assessment of the structural factors controlling the newly observed "Nyi Sindurejo" geothermal manifestation. The lineament analysis derived from SRTM DEM data is used to identify surface-level structural orientations and potential fracture zones (Prabowo et al., 2021; Rauf et al., 2023), while residual gravity anomalies extracted from GGMplus data help evaluate shallow subsurface density variations that may govern geothermal pathways (Puspita et al., 2024). These two methods are widely applied in early-stage geothermal investigations because lineament patterns and gravity anomaly contrasts are often associated with fault-controlled permeability and shallow hydrothermal alteration zones (Barkah & Daud, 2021). Such approaches are particularly advantageous in areas with limited geological exposure, such as urban environments, where direct field observation of structural features is restricted.

This integrated method provides an initial analytical framework for evaluating whether the Nyi Sindurejo geothermal manifestation is structurally aligned with the verified geothermal systems of Songgoriti and Kasinan, or whether it reflects a more localized geothermal setting. The findings at this stage are intended to support the development of targeted hypotheses for subsequent geophysical surveys and higher-resolution investigations. Accordingly, this study offers early structural insights and establishes a foundation for more detailed subsurface assessments, ensuring that further exploration efforts are methodologically justified and geologically relevant.

2. METHODOLOGY

2.1. Research Sites

Batu city is part of the northeastern sector of the Arjuno-Welirang volcanic complex, which forms part of the active Quaternary volcanic arc of East Java (Hadi et al., 2010; Zulaikah et al., 2023). The geological conditions of the study area are compiled from the Geological Map of the Malang Sheet and the Geological Map of the Kediri Sheet, which delineate three main lithostratigraphic units: (1) the Old Anjasmara Volcanic Formation (Qpat) in the northern sector, consisting of volcanic breccia, lava, tuff, and intrusive bodies; (2) the Kawi–Butak Volcanic Formation (Qpkb) in the western area, characterized by volcanic breccia, lava, tuff, and laharic deposits; and (3) the Upper Quaternary Volcanic Deposits (Qv(p)) in the southern sector, representing volcanic products of Mount Panderman (Figure 1).

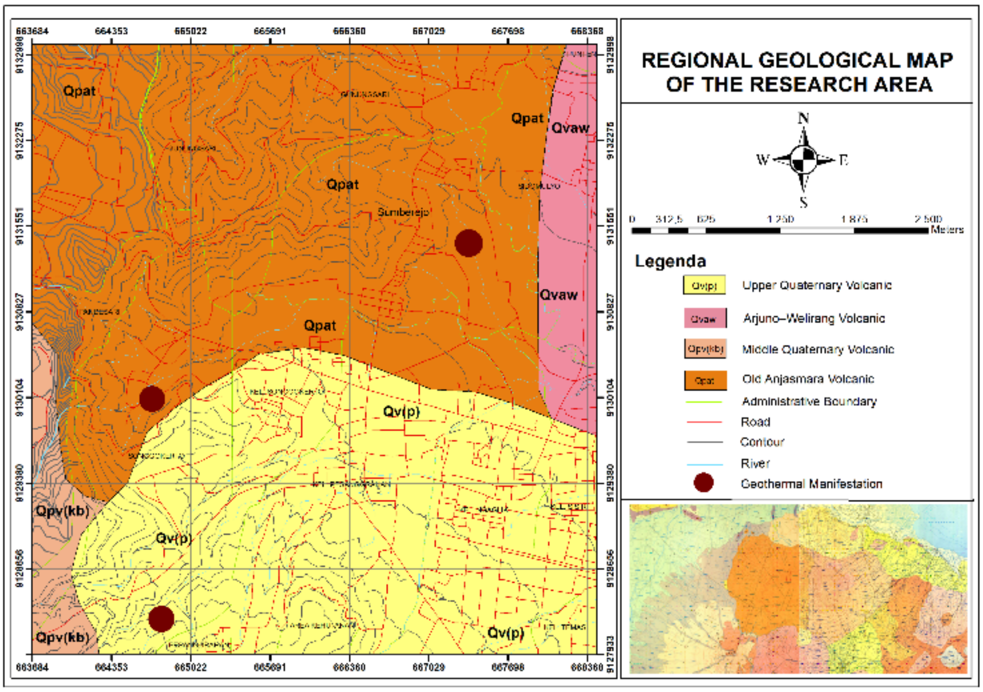

Figure 1. Geological map area of interest, modified based on the geological map of Malang sheet and Kediri sheet (Santosa & Atmawinata, 1992)

These Quaternary volcanic units produce the hilly to mountainous terrain that characterizes the landscape of Batu City (Mao et al., 2024). The Songgoriti manifestation develops on volcanic deposits derived from Mount Kawi and Mount Panderman, composed primarily of andesitic lava and pyroclastic material in the upper stratigraphic layers. This zone is also associated with older andesitic–basaltic units belonging to the Anjasmoro Complex, which constitute the regional structural basement. The Nyi Sindurejo geothermal manifestation is located in Sumberejo Village, directly behind the Batu City Among Tani Hall, and lies within the structural corridor connecting the Kasinan and Songgoriti geothermal systems. Geographically, it lies in the central part of Batu City and serves as an important surface point for understanding the geological context of the regional volcanic system.

2.2. Lineament Morphology

DEMNAS (National Digital Elevation Model of Indonesia) data used for linaeament morphology extraction obtained from http://tides.big.go.id/DEMNAS/, which integrates IFSAR (5 m), TERRASAR-X (5 m), and ALOS PALSAR (11.25 m) sources and is published by the Indonesian Geospatial Information Agency (BIG, 2018). The DEM provides a sufficiently high-resolution representation of surface morphology, allowing detailed visualization of topographic discontinuities that are suitable for detecting structural lineaments in volcanic terrains, including those associated with geothermal activity (Barkah & Daud, 2021). Processing data involved generating shaded relief images at five illumination angles (0°, 45°, 90°, 135°, and 180°) using PCI Geomatica and ArcGIS (Figure 2). Lineament extraction was performed semi-automatically on multi-directional shaded relief images using the LINE algorithm in PCI Geomatica 2016 (Abduh et al., 2021; Bakker, 2024). Lineament extraction was performed semi-automatically using the LINE module in PCI Geomatica 2016, supported by multi-directional illumination filtering. This approach has been widely applied in recent structural mapping studies using DEM-based lineament detection (Alaoui et al., 2025; Ranjbari et al., 2023). The resulting lineaments were compiled to produce a Fracture Frequency Density (FFD) map, and structural trends were analyzed through rose diagrams (RockWorks) (Figure 3). Overlay analysis with gravity residual anomalies was then conducted to evaluate whether Nyi Sindurejo exhibits structural continuity with the Kasinan–Songgoriti geothermal systems or represents a localized geothermal domain.

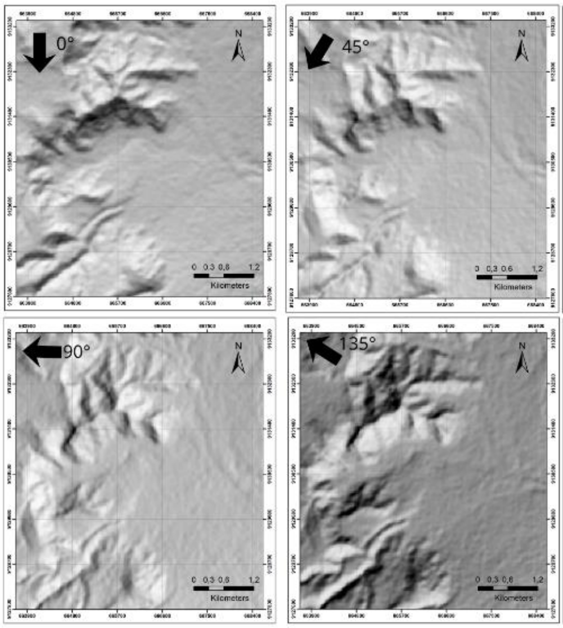

Figure 2. Multi-azimuth shaded relief generated from DEM with illumination directions of 0°, 45°, 90°, and 135°

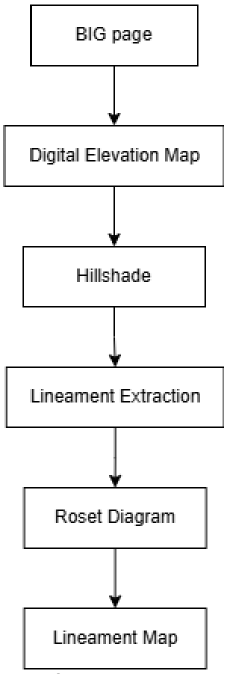

Figure 3. Lineament mapping flowchart derived from DEM-based hillshade and structural orientation analysis

2.3. Gravity Method

The gravity method was applied to characterize subsurface density variations within the Kasinan, Songgoriti, and Nyi Sindurejo geothermal areas. Gravity disturbance data were extracted from the Global Gravity Model Plus (GGMplus), a high-resolution gravity model derived from ultra-fine topography and satellite gravity measurements, offering spatial resolutions of up to ~200 m (Hirt et al., 2013; Suprianto et al., 2021; Supriyadi et al., 2022). The gravity data were downloaded from the Murray Lab, Caltech, in .txt format, includes gravity disturbance information. The elevation data were obtained from the USGS Earth Explorer and height information. Elevation data required for topographic and Bouguer corrections were acquired from the USGS EarthExplorer.

Quality control procedures were conducted prior to anomaly computation, including removal of statistical outliers, verification of consistency between DEM-derived elevations and GGMplus height information, and inspection for gridding artefacts. These steps ensured that the dataset was free from numerical discontinuities before applying gravity reductions. Gravity readings were corrected to obtain the Complete Bouguer Anomaly (CBA) using a workflow implemented in software Oasis Montaj. Free-air anomalies were computed using the standard free-air gradient (0.3086 mGal/m), followed by Bouguer corrections using a reduction density ρ = 2.67 g/cm³, which is suitable for volcanic terrains in East Java. Terrain corrections (TC) were computed using a combined inner and outer DEM approach to minimize the effects of extreme topographical variations characteristic of volcanic landscapes, in which high-resolution local elevation values were applied to the near-station (inner) zone, while the broader topographic effects (outer zone) were modeled using DEM-based terrain corrections. This procedure follows the hybrid inner–outer correction concept demonstrated in recent gravity studies in Indonesian volcanic regions (Gunawan & S Alawiyah, 2021). The Complete Bouguer Anomaly (CBA) was then obtained using:

$$\Delta g_{CBA} = \Delta g_{FA} - \Delta g_{B} - TC$$

To enhance deeper subsurface signals, CBA grid was processed using upward continuation. Several continuation heights,400 m, 700 m, and 900 m, were tested to evaluate the progressive attenuation of short-wavelength anomalies and the stabilization of long-wavelength regional trends. The procedure follows the approach (Kebede et al., 2020), showed the optimal continuation height is obtained at the level where shallow, noise-dominated anomalies are sufficiently suppressed while deeper, geologically meaningful features remain coherent and spatially consistent. Among the tested heights, 900 m produced the most stable regional field, effectively smoothing high-frequency variations without over-attenuating the broader anomaly patterns associated with deeper density structures. This selected continuation height was then used to generate the regional field, which was subtracted from the CBA to obtain the residual anomaly map, used for delineating geothermal prospective zones. The workflow diagram is shown in Figure 4.

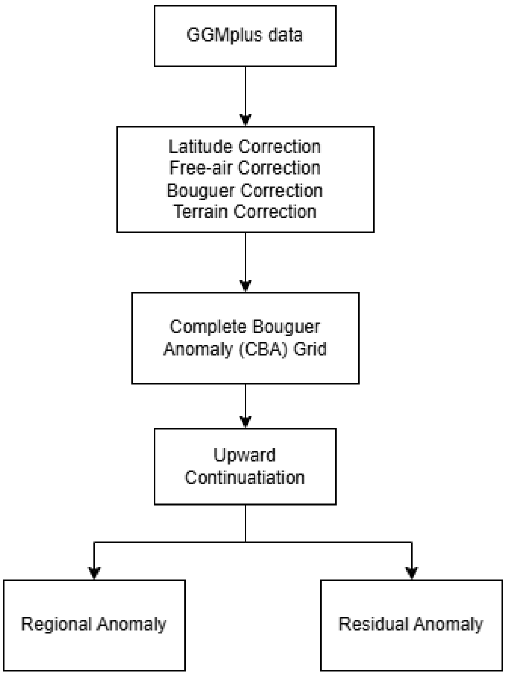

Figure 4. Gravity processing workflow from GGMplus data

3. RESULTS AND DISCUSSION

3.1. Lineament Morphology

Geological structures constitute a primary controlling factor in geothermal systems, particularly in volcanic environments, where faults and fractures act as preferential pathways for hydrothermal fluid migration and circulation. Therefore, lineament analysis represents an essential preliminary step in geothermal exploration, as it enables the identification of structurally weak zones associated with enhanced subsurface permeability. In this study, lineament analysis was conducted to characterize the dominant structural patterns within the study area using Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data. The extracted lineaments, as shown in Figure 2, represent topographic expressions such as stream alignments, valleys, faults, fractures, lithological contacts, and geothermal manifestations (Arrofi & Abu-Mahfouz, 2023). Based on the extraction results, 28 lineaments were identified within the study area. Individual lineament lengths range from 0.312 km to 1.926 km, indicating the presence of structures at local to intermediate scales. Most lineaments have lengths of less than 1 km, whereas several lineaments exceeding 1 km in length suggest more persistent structures that may control subsurface structural frameworks. Lineament density analysis reveals clear spatial variations across the study area. Relatively higher lineament densities are observed in the Songgoriti-Kasinan sector, which is characterized by numerous intersecting and overlapping lineaments. In contrast, the Nyi Sindurejo area exhibits lower lineament density. However, lineaments in this sector display more consistent and well-organized orientation patterns. These differences in lineament density indicate distinct structural control mechanisms between the two areas. In the Songgoriti-Kasinan sector, higher lineament density reflects greater structural complexity and the potential development of more diffuse permeability pathways. Conversely, in the Nyi Sindurejo area, despite the lower number of lineaments, the consistent orientation patterns suggest that the geothermal system is likely controlled by more focused local to intermediate-scale structures, such as minor faults and discrete fracture zones.

Orientation analysis using a rose diagram (figure 5) indicates that the dominant lineament trend in the study area is oriented north–south (N–S). In addition, a secondary dominant orientation is identified in the north-northwest to south-southeast (NNW–SSE) direction. These orientation patterns are consistent with the regional structural trends of the Batu area, which are influenced by the interaction between volcanic activity and the regional stress regime of the Arjuno–Welirang Volcanic Complex. The dominance of N–S and NNW–SSE orientations suggests that structures aligned along these directions play a critical role in controlling surface morphology and subsurface permeability. Faults and fractures developed parallel to these orientations are likely to act as preferential pathways for hydrothermal fluid migration, particularly at zones of structural intersection.

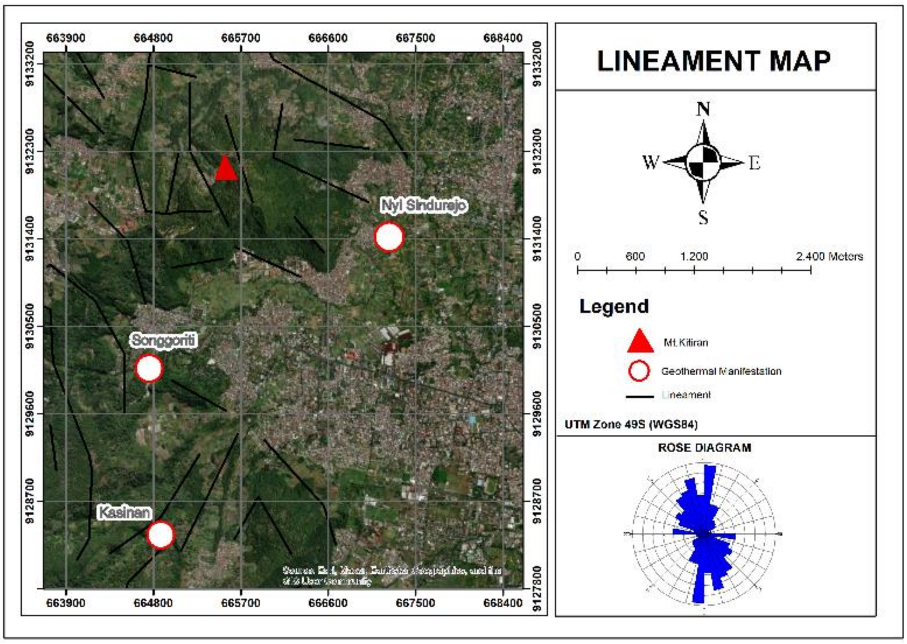

Figure 5. Lineament extraction map derived from DEM-based hillshade analysis, displayed over a Google Earth basemap. Black lines represent extracted lineaments and red symbols indicate geothermal manifestations within the study area. The rose diagram (right) shows the dominant fracture orientations identified from the lineament dataset.

3.2. Gravity

Gravity data processing using GGMPlus reveals variations in gravity anomalies that reflect differences in geological composition and subsurface structural configuration in the Batu area. The Complete Bouguer Anomaly (CBA) map (Figure 6) shows gravity values ranging from 71.3 mGal to 78.4 mGal, indicating significant lateral density contrasts across the study area. CBA values are classified into relatively low and high anomaly zones based on their distribution in the dataset. The low anomaly zone is characterized by values closer to the lower boundary (approximately 71.3-74.5 mGal), whereas high anomaly zone is characterized by values exceeding approximately 75.5 mGal. Spatially, low anomaly zones, represented by blue to green color gradients, are predominantly observed in the southern and northeastern parts of the study area. These zones are associated with volcaniclastic and sedimentary formations, such as tuff and alluvial deposits. In contrast, high-anomaly zones (red to pink) in the central to west area correspond to volcanic rocks, including andesitic lava and breccia of the Qpat formation (Sujanto et al., 1992). These high gravity values indicate compact, massive subsurface materials, possibly related to older volcanic products of the Anjasmara volcanic complex.

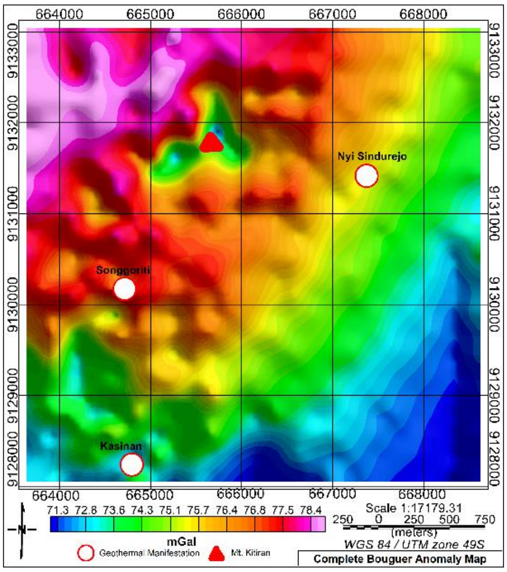

Figure 6. Contour map of complete Bouguer anomaly derived from GGMplus gravity data

Spectral analysis was applied to separate the CBA into regional and residual components. The residual gravity anomaly map (Figure 7), obtained by removing the regional component, highlights localized subsurface density variations that are particularly relevant for geothermal interpretation. Residual anomaly values range from −2.0 mGal to +3.5 mGal, indicating pronounced density contrasts. Low residual anomaly zones (values lower than approximately −1.0 mGal) are mainly observed in the northern part of the study area and are interpreted as regions of reduced subsurface density. These zones are spatially associated with the volcanic body of Mount Kitiran and may reflect highly fractured or altered volcanic materials that could serve as pathways for geothermal fluid circulation and potentially indicate a local heat source. Conversely, higher residual anomalies (greater than approximately +2.0 mGal) suggest the presence of higher density subsurface materials, which are interpreted to be associated with volcanic rocks. Zones exhibiting sharp lateral changes in residual gravity values indicate strong subsurface density gradients, which are interpreted as structural or lithological boundaries. These boundaries are likely controlled by fault systems that influence subsurface permeability and fluid migration. The spatial association between low residual gravity anomalies, geothermal manifestations, and structurally controlled features supports the interpretation that gravity anomalies in the Batu area are closely linked to structural controls on the geothermal system, particularly in the Nyi Sindurejo region.

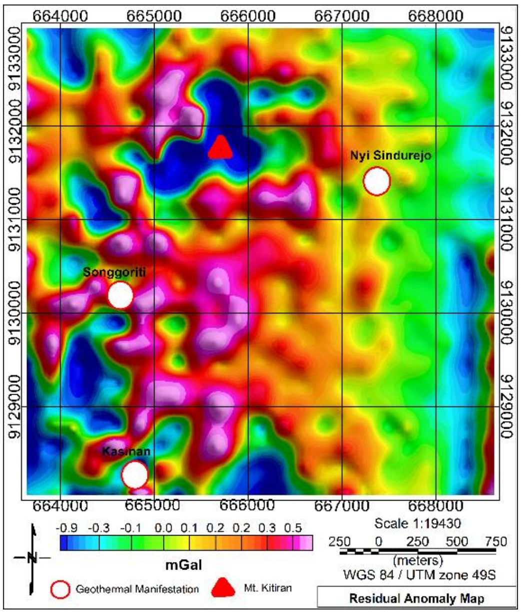

Figure 7. Contour map of residual anomalies derived from GGMplus gravity data

3.3. Integrated Geology Structural and Gravity Interpretation

The integration of morphological lineaments and residual gravity anomalies was conducted through spatial overlay and visual interpretation of georeferenced maps to identify spatial correspondences between structural features, gravity anomaly patterns, and geothermal manifestations in the Batu area. This integrated approach aims to provide a preliminary identification and comparison of geothermal expressions. Based on the overlay results, three geothermal manifestation zones can be identified, namely Nyi Sindurejo, Songgoriti, and Kasinan (Figure 8), each exhibiting distinct combinations of gravity anomaly characteristics and structural patterns. The Nyi Sindurejo area is characterized by predominantly low residual gravity anomalies spatially associated with volcaniclastic deposits, such as breccia and tuff, which are generally indicative of lower subsurface density. These features suggest the presence of altered volcanic materials or shallow zones with enhanced permeability. The manifestation at Nyi Sindurejo is spatially associated with minor N–S-oriented lineaments, indicating localized structural control. The possible influence of heat related to the Mount Kitiran volcanic body to the north is considered at a conceptual level.

The Songgoriti and Kasinan manifestations display different gravity and structural characteristics compared to Nyi Sindurejo. The Songgoriti area is associated with volcanic breccia and lava formations and exhibits moderate residual gravity anomalies, which are commonly interpreted as reflecting fault-controlled permeability pathways within volcanic terrains (Lestari et al., 2020). In contrast, the Kasinan area is characterized by relatively higher residual gravity anomalies, suggesting denser volcanic rocks and potentially deeper subsurface conditions. The spatial differences observed among these three manifestation zones reflect variability in near-surface geological conditions and structural settings across the Batu area. Overall, the integrated interpretation suggests that the distribution of geothermal manifestations in Batu City is closely linked to variations in gravity anomalies and structural configurations. Within the scope of this study, these results offer an initial framework for understanding spatial differences among geothermal occurrences and serve as a basis for more detailed subsurface investigations.

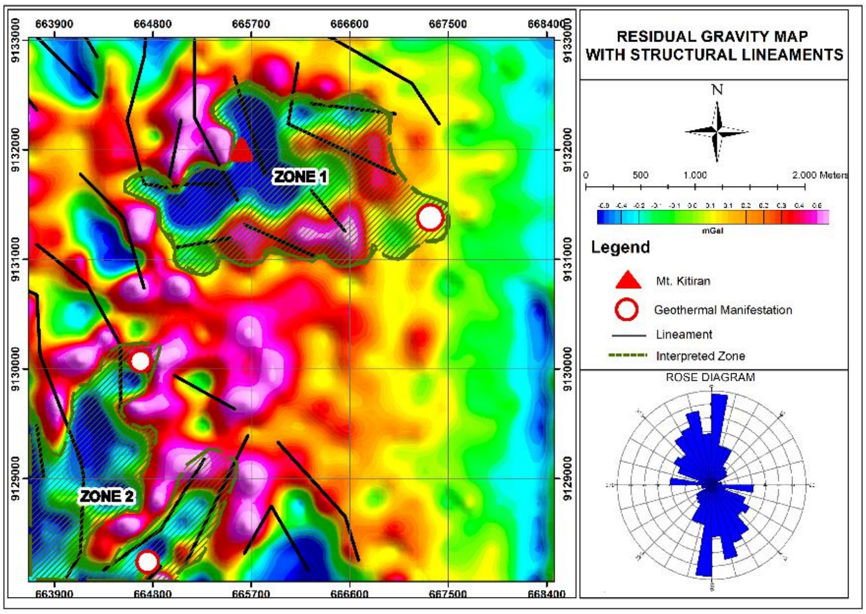

Figure 8. Integrated map of residual gravity anomalies and morphological lineaments highlighting structural patterns and potential geothermal zones in Batu City. Black lines represent extracted lineaments, red circles mark geothermal manifestations, and the rose diagram illustrates the dominant structural orientations controlling the geothermal system

4. CONCLUSION

This study presents a preliminary gravity-based and structural interpretation of geothermal manifestations in the Batu City area through the integration of residual gravity anomalies and morphological lineament patterns. The analysis, conducted using spatial overlay of georeferenced datasets, allows the identification and comparison of geothermal expressions. The results indicate that geothermal manifestations in Batu City, namely Nyi Sindurejo, Songgoriti, and Kasinan, exhibit distinct spatial associations with gravity anomaly characteristics and structural patterns. The Nyi Sindurejo manifestation is predominantly associated with low residual gravity anomalies and localized N-S oriented lineaments, suggesting shallow subsurface conditions characterized by lower-density volcaniclastic materials and localized structural control. These findings provide an initial geological framework for recognizing and distinguishing geothermal expressions in Batu City based on gravity and structural indicators. Further investigations incorporating additional subsurface constraints, such as geophysical inversion, structural continuity analysis, or cross-sectional modelling, are required to resolve deeper geothermal system architecture and inter-manifestation relationships.

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CONFLICT OF INTEREST
The authors declare that there are no conflicts of interest regarding the publication of this article.

AUTHOR CONTRIBUTION
Laily Nur Hofi: Conceptualization, methodology, formal analysis, interpretation, data curation, visualization, writing - original draft. Sukir Maryanto: Supervision, conceptualization, writing - review & editing. Agus Naba: Supervision, writing - review & editing. Adi Susilo: Supervision, methodology, interpretation, writing - review & editing. Didik Rahadi Santoso: validation, writing - review & editing. Herman Tolle, Justinus Satro, E.M. Takla: Review & editing.

DATA AVAILABILITY
The authors confirm that the data supporting the findings of this study are available within the article. Gravity data were obtained from the GGMPlus global gravity model, while topographic data were derived from Shuttle Radar Topography Mission (SRTM) datasets.

DECLARATION OF GENERATIVE AI
The authors acknowledge the use of generative AI tools (e.g., Gemini and ChatGPT) in the preparation of this manuscript, specifically for language editing and grammar correction. The authors take full responsibility for the content and conclusions of this work.

ETHICS
Not applicable.

REFERENCES

Abduh AG, Usman FCA, Tampoy WM, Manyoe IN. (2021). Remote sensing analysis of lineaments using Multidirectional Shaded Relief from Digital Elevation Model (DEM) in Olele Area, Gorontalo. *Journal of Physics Conference Series*, 1783(1), 012095. doi:10.1088/1742-6596/1783/1/012095

Alaoui MM, Kacimi I, Diani K, Morarech M. (2025). Integrating remote sensing and knowledge-based systems for structural lineament mapping in the Rif Belt. *Geosciences*, 15(9), 336. doi:10.3390/geosciences15090336

Alqahtani F, Aboud E, Ehsan M, Naseer Z, Abdulfarraj M, Abdelwahed MF, El-Masry N. (2023). Geothermal exploration using remote sensing, surface temperature, and geophysical data in Lunayyir Volcanic Field, Saudi Arabia. *Sustainability*, 15(9), 1-21. doi:10.3390/su15097645

Anderson A, Rezaie B. (2019). Geothermal technology: Trends and potential role in a sustainable future. *Applied Energy*, 248, 18-34. doi:10.1016/j.apenergy.2019.04.102

Aris M, Elvian VA, Pradana ID, Sinaga MT. (2021). Developing geothermal manifestation as geotourism site: A case study of cangar geothermal manifestation. 43rd Scientific Annual Meeting of Indonesian Association of Geophysicist: Geoscience for Energy, Society, and Sustainability, Semarang, Indonesia.

Arrofi D, Abu-Mahfouz IS. (2023). Delineating reservoir area using geologic remote sensing analysis, Jizan (Saudi Arabia): Implications for geothermal exploration. *Geoenergy Science and Engineering*, 228, 212033. doi:10.1016/j.geoen.2023.212033

Badan Informasi Geospasial (BIG) Badan Infomasi Geos. (2018). Digital Elevation Model Nasional (DEMNAS).

Bakker E. (2024). Multidirectional Lineament Analysis from DEMNAS Digital Elevation Model, Application for Detection Permeability Zone Tulehu Geothermal Field. *Central Moluccas*, 5(2), 111-118. doi:10.23960/jgrs.ft.unila.292

Barkah A, Daud Y. (2021). Identification of Structural Geologyat the Tangkuban Parahu Geothermal Area, West Java Based on Remote Sensing and Gravity Data. *AIP Conference Proceedings*, 2320. doi:10.1063/5.0038809

Daud Y, Nuqramadha WA, Fahmi F, Sesesega RS, Fitrianita, Pratama SA, Munandar A. (2019). Resistivity characterization of the Arjuno-Welirang volcanic geothermal system (Indonesia) through 3-D Magnetotelluric inverse modeling. *Journal of Asian Earth Sciences*, 174, 352-363. doi:10.1016/j.jseaes.2019.01.033

Feng H, Hu Q, Zhao P, Ai M, Wang S, Zheng D. (2025). Geothermal detection study using remote sensing data by combining machine learning and deep learning: A case study of Huanggang City. *Geothermics*, 130, 103338. doi:10.1016/j.geothermics.2025.103338

Gunawan I, Alawiyah S. (2021). Terrain Correction in Gravity Data Processing using Hybrid Land Survey and Shuttle Radar Topography Mission Digital Elevation Model : A Case Study in Mount Pandan , Indonesia Terrain Correction in Gravity Data Processing using Hybrid Land Survey and Shutt. *9th Asian Physics Symposium*, 1-6. doi:10.1088/1742-6596/2243/1/012012

Hadi MN, Kusnadi D, Sugianto A. (2010). Penyelidikan Terpadu Geologi, Geokimia dan Geofisika Daerah Panas Bumi Arjuno - Welirang, Kabupaten Mojokerto dan Malang, Provinsi Jawa Timur. Pusat Sumber Daya Geologi.

Hirt C, Claessens S, Fecher T, Kuhn M, Pail R, Rexer M. (2013). New Ultrahigh-Resolution Picture of Earth's Gravity Field. *Geophysical Research Letters*, 40(16), 4279-4283. doi:10.1002/grl.50838

Kebede H, Alemu A, Fisseha S. (2020). Upward continuation and polynomial trend analysis as a gravity data decomposition, case study at Ziway-Shala basin, central Main Ethiopian rift. *Heliyon*, 6(1), e03292. doi:10.1016/j.heliyon.2020.e03292

Lestari FA, Maryanto S, Santoso DR. (2019). Continuity Reservoir Magnetic Anomaly at Kelud, Kasinan-Songgoriti, and Arjuno-Welirang of Geothermal Area, East Java Indonesia. *SSRG International Journal of Applied Physics*, 6(3), 111-117. doi:10.20508/ijrer.v9i2.9182.g7655

Lestari NAG, Maryanto S, Santoso DR. (2020). Identification of Kawi-Songgoriti Geothermal Prospects Based on Fault and Fracture Density (Ffd). *Journal of Environmental Engineering & Sustainable Technology*, 7(2), 18-25.

Lestari NAG, Maryanto S, Santoso DR. (2023). Derivative Analysis for Estimating Subsurface Structures in the Kawi-Songgoriti Geothermal Area. *AIP Conference Proceedings*, 2540, 1-11. doi:10.1063/5.0106820

Mao X, Chen Y, Liu Z, Yang X, Li S, Wang D, Chen G. (2024). Hydrothermal alteration and its geochemistry of the Xiadian gold deposit, Jiaodong Peninsula, China: Implications for fluid-rock interaction processes and mineral exploration. *Ore Geology Reviews*, 170, 106134. doi:10.1016/j.oregeorev.2024.106134

Ministry of Energy and Mineral Resources. (2024). Handbook of Energy & Economic Statistics of Indonesia 2023. Kementerian ESDM RI.

Nasruddin IAM, Daud Y, Surachman A, Sugiyono A, Aditya HB, Mahlia TMI. (2016). Potential of geothermal energy for electricity generation in Indonesia: A review. *Renewable and Sustainable Energy Reviews*, 53(2016), 733-740. doi:10.1016/j.rser.2015.09.032

Novianti E, Realita A, Prastowo T. (2024). Analisis dan interpretasi anomali gravitasi untuk identifikasi potensi sumber panas bumi di Gunung Arjuno-Welirang. *Smithsonian Institution*, 13, 13-24.

Pereira M, Matias D, Viveiros F, Moreno L, Silva C, Zanon V, Uchoa J. (2022). The contribution of hydrothermal mineral alteration analysis and gas geothermometry for understanding high-temperature geothermal fields - The case of Ribeira Grande geothermal field, Azores. *Geothermics*, 105, 102519. doi:10.1016/j.geothermics.2022.102519

Prabowo A, Verdiansyah O, Prabowo R. (2021). Extraction of Lineament Density Analysis from ASTER DEM for Determine the Vein Direction. Proceedings of the 2nd International Conference on Industrial and Technology and Information Design, Yogyakarta, Indonesia. doi:10.4108/eai.30-8-2021.2311530

Puppala H, Saikia P, Kocherlakota P, Suriapparao DV. (2023). Evaluating the applicability of neural network to determine the extractable temperature from a shallow reservoir of Puga geothermal field. *International Journal of Thermofluids*, 17, 100259. doi:10.1016/j.ijft.2022.100259

Puspita MB, Aprilla AN, Maryanto S, Sari RPH. (2024). Preliminary Study of Subsurface Geological Setting Based on the Gravity Anomalies in Karangrejo-Tinatar Geothermal Area, Pacitan Regency, Indonesia. *International Journal of Geophysics*, 2, 1-9. doi:10.1155/2024/9976867

Ranjbari MR, Vagheei R, Salehi H. (2023). Integration of Landsat-8 and Sentinel-1 dataset to extract geological lineaments in complex formations of Tepal mountain area, Shahrood, North Iran. *Advances in Space Research*, 71(1), 936-945. doi:10.1016/j.asr.2022.08.061

Rauf J, Kayambo MR, Nurjana I, Manyoe IN. (2023). Lineament extraction analysis using Digital Elevation Model (DEM) in Lahendong Geothermal Area, North Sulawesi. *E3S Web of Conferences*, 400, 01009. doi:10.1051/e3sconf/202340001009

Santosa S, Atmawinanata S. (1992). Peta Geologi Lembar Kediri, Jawa Skala 1:100.000. Pusat Penelitian dan Pengembangan Geologi.

Sujanto, Hadisantono R, Kusnama RC. (1992). Geologic Map of the Turen Quadrangle, Jawa. Geological Research and Development Centre.

Suprianto A, Adi S, Cahyono BE. (2021). Correlation Between GGMPlus , Topex and BGI Gravity Data in Volcanic Areas of Java Island Correlation Between GGMPlus, Topex and BGI Gravity Data in Volcanic Areas of Java Island. *Journal of Physics: Conference Series*, 1825(1), 012023. doi:10.1088/1742-6596/1825/1/012023

Supriyadi, Soraya V, Suprianto A, Priyantari N. (2022). Identification of Blawan-Ijen fault based on GGMplus Gravity Data Using Second Vertical Derivative (SVD) Analysis. 3rd International Conference on Physical Instrumentation and Advanced Materials. *AIP Conference Proceedings*, 2663(1), 040005. doi:10.1063/5.0108055

Suryantini, John E, Carranza M, Wibowo H, Prihadi A. (2025). Geothermics Geothermal exploration drilling targeting based on GIS spatial analysis of existing well and geophysical data : Case study in the Kamojang geothermal. *Geothermics*, 132, 103425. doi:10.1016/j.geothermics.2025.103425

Utama PP, Pratomo SU, Haty IP. (2025). Rare Earth Elements (REEs) Potential in Active Geothermal Systems : A Global Review and Regional Study at Mount Slamet, Indonesia. *Eksplorium*, 46(1), 15-26. doi:10.55981/eksplorium.2025.11407

Zaini N, Yanis M, Abdullah F, Van Der Meer F, Aufaristama M. (2022). Exploring the geothermal potential of Peut Sagoe volcano using Landsat 8 OLI/TIRS images. *Geothermics*, 105, 102499. doi:10.1016/j.geothermics.2022.102499

Zulaikah S, Damayanti CS, Hafiz, Hapsoro CA, Laksono YA, Iswanto BH, Herrin JS, Hasan MFR. (2023). Magnetic Signature and Element Content of Upflow and Outflow Hotspring in Arjuno-Welirang Geothermal System. *International Journal on Advanced Science, Engineering and Information Technology*, 13(3), 1202-1209. doi:10.18517/ijaseit.13.3.18009