http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 7 No 3 2022

RESEARCH ARTICLE

# Application of Lineament Density Extraction Based on Digital Elevation Model for Geological Structures Control Analysis in Suwawa Geothermal Area

Intan Noviantari Manyoe[1,*], Ronal Hutagalung[1]

[1] *Geological Engineering Major, Faculty of Mathematics and Natural Science, Universitas Negeri Gorontalo, Bone Bolango Regency, Gorontalo, Indonesia.*

* Corresponding author : intan.manyoe@ung.ac.id
Tel.:+62-812-8002-3410
Received: Nov 12, 2021; Accepted: Sep 23, 2022.
DOI: 10.25299/jgeet.2022.7.3.8085

**Abstract**

The tectonic condition of Gorontalo, which is located in the north of Sulawesi Island has implications for the spread of geothermal potential. The area in Gorontalo with the largest geothermal potential is the Suwawa area, Bone Bolango Regency. Therefore, this study aims to develop a model of lineament extraction from a digital elevation model and analyze the geological structure control based on the lineament distribution. This research is useful for the development of knowledge in the geothermal field, especially the study of permeability and structural control in geothermal areas. This research is beneficial for the community because it can detect the permeability zone in more detail which is the basis for the utilization of geothermal potential. The factors studied in this study are the geological lineament density and the geological structures. To achieve the research objectives, extraction methods and model analysis include analysis of permeable and control of geological structures. The lineament extraction model from the digital elevation model in the Suwawa geothermal area shows that there is a moderate to high agreement for lineament extraction from NATIONAL DEM data and low to moderate agreement for lineament extraction from SRTM data. The lineament distribution showing moderate to high density occupies the southern, eastern, and western parts of the Suwawa geothermal area. The presence of a lineament controls the circulation of geothermal fluids in the Suwawa geothermal area.

**Keywords:** Model, Geothermal, Geology, Lineament, Structure.

## 1. Introduction

Geothermal energy is energy that comes from the interior of the earth which is formed due to the heat content in the earth interior. This overview describes the mechanisms of heat transfer in the mantle and crust (Barbier, 2002). The sources of geothermal energy in the world are categorized into geothermal reservoirs with high enthalpy and geothermal reservoirs with low enthalpy (Kaczmarczyk et al., 2020; Martín-Gamboa et al., 2015). The use of geothermal in the world is used directly or indirectly and has been proven to be able to encourage economic progress (Glassley, 2010; Rybach, 2015).

Geothermal resources are closely related to regional tectonic conditions (Tzanis et al., 2020). Gorontalo, which is located in eastern Indonesia, is flanked by the Indo-Australian, Eurasian and Pacific macro plates (Advokaat et al., 2017) and the Philippine microplate (Hall et al., 1995) which has implications for geothermal spread (Manyoe and Hutagalung, 2020). Plate collisions cause magmatism. The activity of magma and residual magma can cause heating of the accumulated subsurface water and become a geothermal reservoir (Manyoe and Hutagalung, 2020; Siahaan et al., 2005).

Gorontalo's geothermal potential is located in the areas of Suwawa, Pentadio, Bongongoayu, Dulangeya and Pohuwato. Gorontalo's geothermal potential has not been fully utilized as well as the world's geothermal potential. Geothermal utilization in Gorontalo is focused on direct use of the tourism sector. One of the areas that has the largest geothermal potential is the Suwawa geothermal area, Bone Bolango Regency.

The Sumawa Geothermal Working Area Consists of Lombongo, Pangi, Libungo, Hungayono. Tulabolo Timur. Research that has bee carried out in the suwawa geothermal area which provide a lineament extraction model for the Suwawa geothermal area has only been carried out in the Libungo Area (Manyoe and Hutagalung, 2021, 2020).

It is important to research the lineament density extraction model to determine the development of the extraction model and control of geological structures in the research area. The lineament density extraction model will be based on a digital elevation model. The control structure will be made based on the distribution of the lineament in the study area. This research will cover the information gap in the geothermal field in the research area that has not been carried out by previous researchers.

This research is useful for the development of geothermal science, especially the development of extraction and control models of geological structures in geothermal areas. The purpose of this study is to develop a lineament extraction model from a digital elevation model in the Suwawa geothermal area. To analyze the control of geological structures based on the lineament distribution in the Suwawa geothermal area. Extraction is a process to detect lineament based on digital data. In this study, lineament extraction is based on a digital elevation model. The development of the lineament extraction model in this study was based on National DEMNAS and SRTM.

## 2. Methods

### 2.1. Research Location

Astronomically, the Suwawa area and its surroundings are located at coordinates 0°27'0” - 0°34'5” North Latitude and 123°8'0” - 123°18'5” East Longitude. Based on its geographical position, the research area is located in Central Suwawa District, South Suwawa District, and East Suwawa District. Lombongo Geothermal is located in Central Suwawa District and Libungo Geothermal is located in South Suwawa District. Pangi geothermal, East Tulabolo geothermal and Hungayono geothermal are located in East Suwawa District. The research area is in the Bone Bolango Regency, Gorontalo Province.

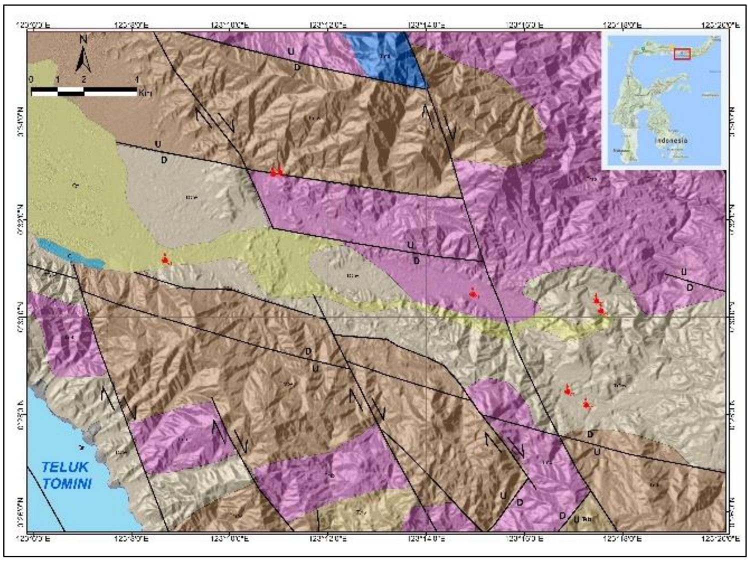


Fig. 1. Regional geology of research location (Apandi and Bachri, 1997).

The research area is part of the volcanic-plutonic strip of North Sulawesi, which is mostly composed of volcanic rock and breakthrough rock (Hinschberger et al., 2005; Sompotan, 2012). The order of rocks from the oldest to the youngest rocks based on the Regional Geological Map of the Kotamobagu Sheet by (Apandi and Bachri, 1997) is the Bilungala Volcanic Rock Formation (Tmbv), Bone Diorite (Tmb), Pinogu Volcanic Rock (TQpv) and Qpl Formation (Lake Deposits).

Bilungala Volcanics (Tmbv) and Bone Diorite (Tmb) formed in the Middle Miocene to Early Pliocene. Pinogu Volcanics (TQpv) formed in Middle Pliocene to Early Plistocene. Lake Deposits (Qpl) formed in Middle Plistocene to Holocene (Apandi and Bachri, 1997; Perelló, 1994).

### 2.2 Data Collection

Lineament data collection is done by downloading digital elevation model data or DEM from the Geospatial Information Agency (BIG) and the United State Geological Survey (USGS).

**Table 1.** The value of each parameter used in the LINE algorithm (Abduh et al., 2021).

| No | Extraction Parameters | Score |
|---|---|---|
| 1 | RADI (Radius Filter) | 10 |
| 2 | GTHR (Gradient Threshold) | 75 |
| 3 | LTHR (Length Threshold) | 25 |
| 4 | FTHR (Line Fitting Error Threshold) | 3 |
| 5 | ATHR (Angular Difference Threshold) | 1 |
| 6 | DTHR (Linking Distance Threshold) | 40 |

The straightness detection and extraction process uses the Segment Tracing Algorithm (STA). An effective method for automatic lineage detection and extraction is the Segment Tracing Algorithm (STA) (Koike et al., 1995) because it can detect more lineaments at low contrast and parallel to solar illumination on optical sensor satellite images than other similar methods.

### 2.2. Data Processing and Interpretation

The straightness detection and extraction process is carried out on a digital elevation model derived from IFSAR data (5m resolution), TERRASAR-X (5m resolution) and ALOS PALSAR (11.25 m resolution) and stereo-plotting masspoint data.

The detection and extraction process is continued using a Geographic Information System (GIS) application to compare the extraction results with regional geological structures. The analysis was carried out by looking at the distribution pattern of the lineament and the regional geological structure.

The comparison of lineament patterns and regional geological structures is continued with data processing using the Rockworks application to obtain the direction of the lineament stress. Furthermore, a geological structure control analysis was carried out based on the lineament distribution.

## 3. Result and Discussion

The research area based on physiographic studies is divided into northern volcanic mountains, northern intrusive mountains, northern karst mountains, southern volcanic mountains, southern intrusive mountains, southern karst hills, fluvial plains, and coastal plains. The fluvial plain occupies the central part of the study area. The coastal plain occupies the southern part of the study area.

The northern volcanic mountains are composed of breccia lithology, tuff, lapilli tuff, dacite, and rhyolite. The northern karst mountains are composed of limestone. The northern and southern intrusive mountains are composed of diorite, granodiorite, and granite. The southern karst hills are composed of reef limestones. Fluvial plains are composed of claystone, sandstone, and gravel. The coastal plain is composed of sand, clay, silt, gravel and gravel.

There are 5 (five) areas with geothermal potential in the Suwawa area. Manifestation data collection is carried out at 9 (eight) points. Two points in the Lombongo area, 1 (one) point in the Pangi area, 2 (two) points in the Libungo area, 2 (two) points in the Hungayono area and, 2 (two) points in the East Tulabolo area.

The types of geothermal manifestations of Libungo 1 and Libungo 2 are hot springs. The hot springs are located at an altitude of 44 meters above sea level and 30 meters above sea level. The temperature of Libungo hot springs is in the range of 81-82.6 °C. The air temperature ranges from 30-32 °C. The flow direction of Libungo 1 and Libungo 2 hot springs is northeast-southwest with a discharge of 1.20 m3/s for Libungo 1 and 4.50 m3/s for Libungo 2.

The chemical characteristics of Libungo hot springs can be seen from the pH value. Libungo 1 and Libungo 2 hot springs have a pH of 7.8. Libungo 1 and Libungo 2 hot springs have iron oxide deposits. Other physical characteristics are odorless, tasteless, and colorless.

The types of geothermal manifestations of Lombongo 1 and Lombongo 2 are hot springs. The hot springs are located at an altitude of 112 meters above sea level and 107 meters above sea level. The temperature of the Libungo hot springs is in the range of 42-48 °C. The flow direction of Lombongo 1 and Lombongo 2 hot springs is northeast-southwest with a discharge of 0.213 m3/s for Lombongo 1 and 0.31 m3/s for Lombongo 2.

The chemical characteristics of Lombongo hot springs can be seen from the pH value. Lombongo 1 hot spring has a pH of 5 and Lombongo 2 has a pH of 6. The Lombongo 1 and Lombongo 2 hot springs have iron oxide deposits. Other physical characteristics are odorless, tasteless, and colorless.

The type of geothermal manifestation of Pangi is hot springs. The hot springs are at an altitude of 112 meters above sea level. The temperature of Pangi hot springs is in the range of 56 °C. The flow direction of Pangi hot spring is northeast-southwest with a discharge of 0.213 m3/s.

The chemical characteristics of Pangi hot springs can be seen from the pH value. Pangi hot spring has a pH of 5. Pangi hot spring has iron oxide deposits. Other physical characteristics are odorless, tasteless, and colorless.

The types of geothermal manifestations of Hungayono 1 and Hungayono 2 are hot springs. The hot springs are at an altitude of 165 meters above sea level. The temperature of the Hungayono hot springs is in the range of 30-33 °C. The flow direction of Hungayono 1 and Hungayono hot springs is northeast-southwest with a discharge of 0.0004632 m3/s for Hungayono 1 and 0.0004632 m3/s for Hungayono 2.

Chemical characteristics of Hungayono hot springs can be seen from the pH value. Hungayono 1 hot spring has a pH of 6.1 and Hungayono 2 has a pH of 6.3. Hungayono 1 and Hungayono 2 hot springs have deposits of iron oxide and travertine. Another physical characteristic for the two hot springs of Hungayono is that it smells of iron, tastes salty, and is colorless.

The types of geothermal manifestations of East Tulabolo 1 and East Tulabolo 2 are hot springs. The hot springs are located at an altitude of 185 meters above sea level and 129 meters above sea level. The temperature of the East Tulabolo hot spring is in the range of 47-50 °C. The air temperature ranges from 30 °C. The direction of flow of the East Tulabolo 1 hot spring is east-west and East Tulabolo 2 is southwest-southeast with a discharge of 0.0030 m3/s for East Tulabolo 1 and 0.00015 m3/s for East Tulabolo 2.

Chemical characteristics of the Tulabolo hot spring East can be seen from the pH value. The Tulabolo Timur 1 and Tulabolo Timur 2 hot springs have a pH of 6.3. Tulabolo Timur 1 and Tulabolo Timur 2 hot springs have sulfur deposits. Other physical characteristics are sulfur odor, salty taste, and colorless.

The lineament extraction model was developed from a digital elevation model in the Suwawa geothermal area. The development of the lineament extraction model was obtained from NATIONAL DEM and SRTM. Comparisons will be made on the results of data processing and analysis using NATIONAL DEM and SRTM, then structural control analysis on the emergence of hot springs based on NATIONAL DEM and SRTM.

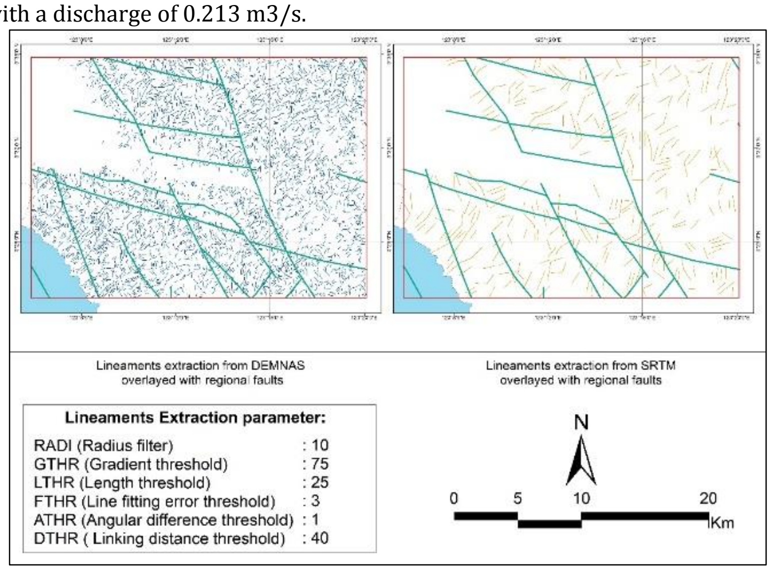


Fig 2. The extraction of lineament of data National DEM and SRTM.

National DEM and SRTM data extracted in the Geomatica application resulted in straightness in the Suwawa geothermal area. National DEM data was obtained from Geospatial Information Agency while SRTM data was obtained from USGS. Lineament extraction parameters are RADI 10, GTHR 75, LTHR 25, FTHR 3, ATHR 1, and DTHR 40. The extraction results show that lineament extraction from NATIONAL DEM produces more lineaments than lineament extraction from SRTM. Subsequently, the alignment between the extraction lineament and the regional geological structure of the Suwawa geothermal area was made (Figure 9).

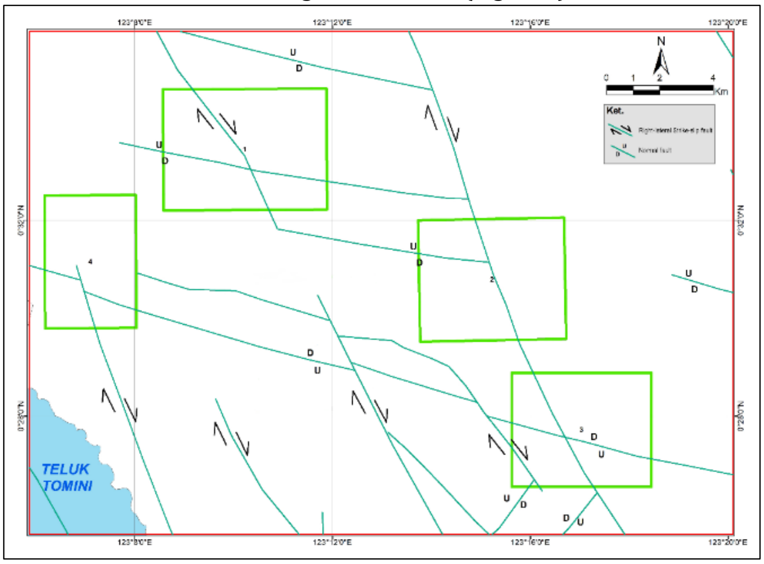


Fig 3. Region rapprochement extraction of alignment with the geological structure.

Agreements are made in four areas, namely region 1, region 2, region 3, and region 4. Region 1 is an agreement between lineament extraction with geological structures trending northwest-southeast and east-west. Region 2 is an area of correspondence between lineament extraction with geological structures trending northwest-southeast and east-west.

Region 3 is an area of conformity between lineage extraction and geological structures trending northwest-southeast and east-west. The southwest part of Region 3 has regional geological structures trending northwest-southeast and northeast-southwest. Region 4 is an area of conformity between lineage extraction and geological structures trending northwest-southeast and east-west.

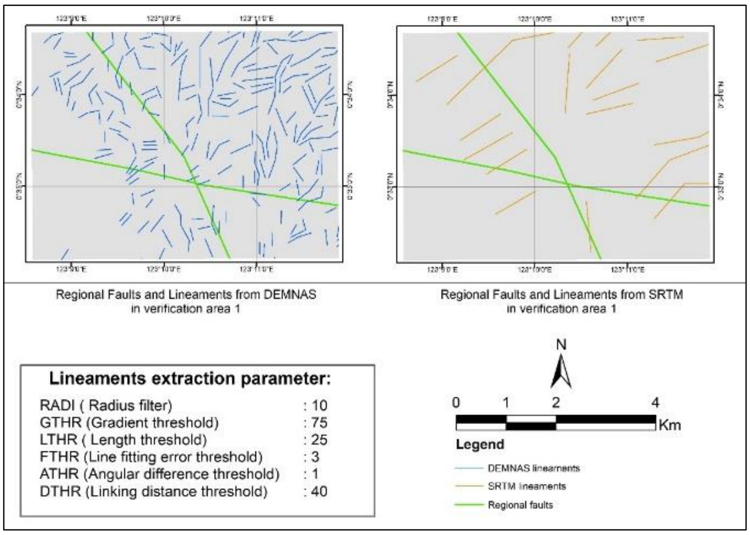


Fig 3. Verification area 1 between regional geological structure with lineament of extraction result from National DEM and SRTM.

The result of lineament extraction in region 1 shows the number of lineaments from National DEM data is 176 and the number of lineament extractions from SRTM data is 18. There is a regional structure with a northwest-southeast trend which is cut by an east-west trending regional structure. The regional geological structure trending northwest - southeast in region 1 is a geological structure located in the northern part of the Suwawa geothermal area. The regional structure with a northwest-southeast trend is a right-hand fault and the regional structure with an east-west trend is a normal fault.

There is a correspondence between lineament extraction from National DEM data and SRTM data with regional geological structures. The regional geological structure trending northwest-southeast from the National DEM data is in high agreement with the lineament extraction with a northwest-southeast trend. The regional geological structure with an east-west trend from the National DEM data corresponds highly to the east-west trending lineage extraction. The regional geological structures trending northwest-southeast and east-west from the SRTM data are in low agreement with the lineaments extraction trending northwest-southeast.

The result of lineament extraction in region 2 shows the number of lineaments from NATIONAL DEM data is 194 and the number of lineament extractions from SRTM data is 20. There is a regional structure trending northwest-southeast and a regional structure trending east-west. The regional geological structure trending northwest-southeast in region 2 is a geological structure located in the middle of the

Suwawa geothermal area. The regional structure with a northwest-southeast trend is a right-hand fault. The regional structure with an east-west trend is a normal fault.

There is a correspondence between lineament extraction from National DEM data and SRTM data with regional geological structures. The regional geological structure trending northwest-southeast from the National DEM data is in high agreement with the lineament extraction with a northwest-southeast trend. The regional geological structure with an east-west trend from the National DEM data is moderately consistent with the east-west trending lineage extraction. The regional geological structure trending northwest-southeast from the SRTM data is low in agreement with the lineament extraction with a northwest-southeast trend. There is no lineament in the east-west trending structure from the SRTM data so it does not have a match.

The result of lineament extraction in region 3 shows the number of lineaments from National DEM data is 188 and the number of lineament extractions from SRTM data is 21. There is a regional structure trending northwest-southeast and regional structure trending east-west. In the southwest part of Region 3 there is a regional geological structure trending northwest-southeast and northeast-southwest.

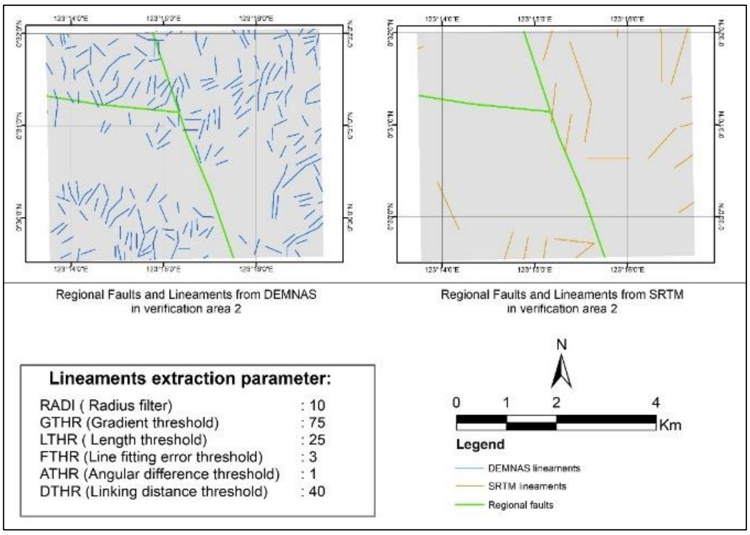


Fig 4. Verification area 2 between regional geological structure with lineament of extraction result from NATIONAL DEM and SRTM.

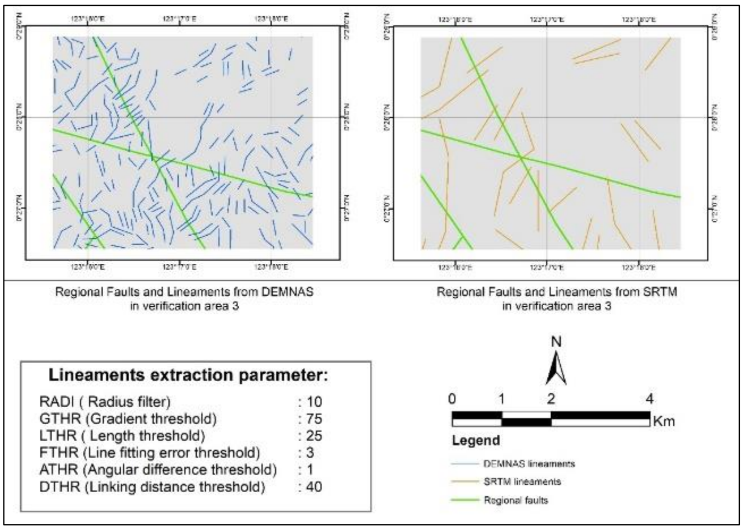


Fig 5. Verification area 3 between regional geological structure with lineament of extraction result from National DEM and SRTM.

The regional geological structure trending northwest-southeast in region 3 is a geological structure located in the southeastern part of the Suwawa geothermal area. The regional structure with a northwest-southeast trend is a right-hand fault. Regional structures trending east-west and northeast-southwest are normal faults.

There is a correspondence between lineament extraction from National DEM data and SRTM data with regional geological structures. The regional geological structure trending northwest-southeast from the National DEM data is in high agreement with the lineament extraction with a northwest-southeast trend. The regional geological structure with an east-west trend from the National DEM data is moderately consistent with the east-west trending lineage extraction. The southwest part of Region 3 has a regional structure trending northwest-southeast which corresponds to moderate and northeast-southwest which corresponds low to the lineament.

The regional geological structure trending northwest-southeast from the SRTM data is low in agreement with the lineament extraction with a northwest-southeast trend. The regional geological structure with an east-west trend from National DEM data corresponds low to the east-west trending lineage extraction. The southwest part of Region 3 has a regional structure trending northwest-southeast which corresponds to low and northeast-southwest which corresponds low to the lineament.

The results of lineament extraction in region 4 show that the number of lineaments from National DEM data is 56 and the number of lineament extractions from SRTM data is 3. There is a regional structure with a northwest-southeast trend and an east-west trending regional structure. The regional geological structure trending northwest-southeast in region 4 is a geological structure located in the western part of the Suwawa geothermal area. The regional structure with a northwest-southeast trend is a right-hand fault. The regional structure with an east-west trend is a normal fault.

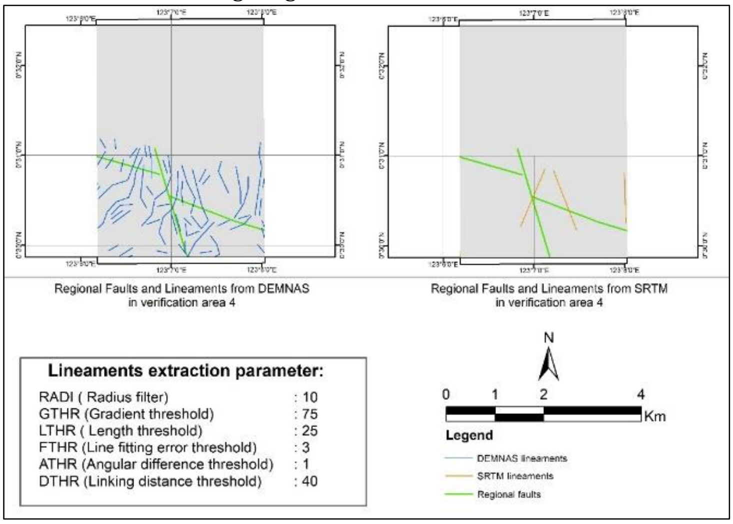


Fig 6. Verification area 4 between regional geological structure with lineament of extraction result from National DEM and SRTM.

There is a correspondence between lineament extraction from National DEM data and SRTM data with regional geological structures. The regional geological structure trending northwest-southeast from the National DEM data is in high agreement with the lineament extraction with a northwest-southeast trend. The regional geological structure with an east-west trend from the National DEM data is moderately consistent with the east-west trending lineage extraction. The regional geological structures trending northwest-southeast and east-west from the SRTM data are low in agreement with the lineaments extraction trending northwest-southeast.

The result of lineament extraction from National DEM and SRTM data shows that lineament extraction from National DEM data produces a larger number of lineaments than lineament extraction from SRTM data. The results of lineament verification from National DEM and SRTM data with regional geological structures show that lineament from National DEM data has a moderate to high agreement with regional geological structures. Meanwhile, the lineament of the SRTM data has a low to moderate agreement with the regional geological structure.

### 5.3 Geological Structure

National DEM and SRTM data extracted and processed using Geomatics and Geographic Information Systems (GIS) applications produced a lineament density map (Figure 15). Lineament density maps can be used to determine the permeability of the Suwawa geothermal area. Areas with good permeability have high straightness density values.

Based on the lineament density map, it is interpreted that the Suwawa geothermal area is divided into high, medium and low density areas. The high density area occupies the southern, eastern and northern parts of the Suwawa geothermal area. The medium density area occupies the southern, eastern and northern parts of the Suwawa geothermal area. The low density area occupies the northwest part of the study area extending to the center of the Suwawa geothermal area and the southwest part of the Suwawa geothermal area.

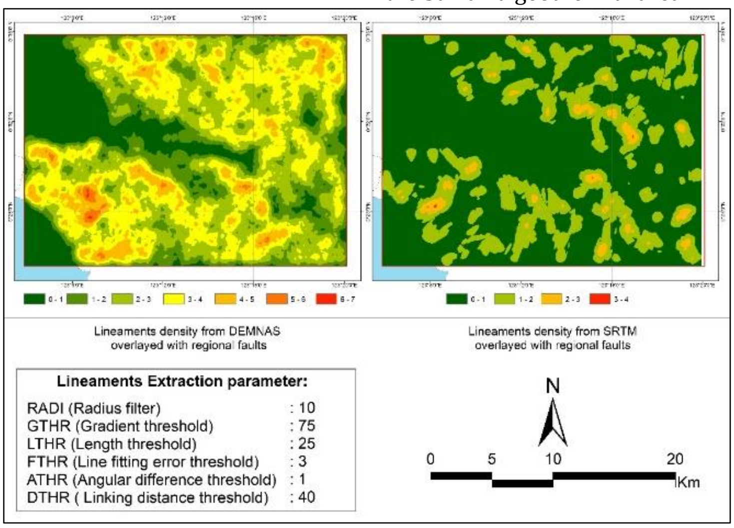


Fig 7. Density of Suwawa geothermal area straightness.

The southern, eastern and northern parts of the study area are included in the medium to high density area because they are associated with the geological structure of the study area with a northwest-southeast trend and an east-west trending structure. The appearance of hot springs in the Suwawa geothermal area is in a medium to high density area which is also influenced by geological structures that are in line with the lineament. The high lineament density in the Suwawa geothermal area has implications for a good level of permeability.

The northwest part extends to the center of the Suwawa geothermal area, which is included in the low density area. Likewise, in the southwest part of the Suwawa geothermal area which is included in the low density area. These two parts are not associated with geological structures. The part of the Suwawa geothermal area that falls into low density is the fluvial plain and coastal plain. The absence of lineament in this section results in a low level of lineament density which has implications for poor permeability.

Based on the lineament density map, the study area is dominated by high density areas. The high-density areas are scattered in the southern, eastern, and northern parts of the Suwawa geothermal area so that in general the research area has a good level of permeability. Geothermal areas with good permeability levels are interpreted as areas with good water infiltration rates. Thus, the presence of a lineament controls the circulation of geothermal fluids in the Suwawa geothermal area.

## 4. Conclusion

The lineament extraction model from the digital elevation model in the Suwawa geothermal area shows that there is a moderate to high agreement for lineament extraction from National DEM data and low to moderate agreement for lineament extraction from SRTM data. Lineament distribution showing moderate to high density occupies the southern, eastern, and western parts of the Suwawa geothermal area. The presence of a lineament controls the circulation of geothermal fluids in the Suwawa geothermal area.

## Acknowledgments

The authors would like to thank to the Research and Community Service Center of Universitas Negeri Gorontalo for funding this research.

## References

Abduh, A.G., Usman, F.C.A., Tampoy, W.M., Manyoe, I.N., 2021. Remote Sensing Analysis of Lineaments using Multidirectional Shaded Relief from Digital Elevation Model (DEM) in Olele Area, Gorontalo. J. Phys. Conf. Ser. 1783. https://doi.org/10.1088/1742-6596/1783/1/012095

Advokaat, E.L., Hall, R., White, L.T., Watkinson, I.M., Rudyawan, A., BouDagher-Fadel, M.K., 2017. Miocene to recent extension in NW Sulawesi, Indonesia. J. Asian Earth Sci. 147, 378–401. https://doi.org/10.1016/j.jseaes.2017.07.023

Apandi, T., Bachri, S., 1997. Peta Geologi Lembar Kotamobagu, Sulawesi. Pusat Penelitian dan Pengembangan Geologi, Bandung.

Barbier, E., 2002. Geothermal energy technology and current status: an overview. Renew. Sustain. Energy Rev. 6, 3–65. https://doi.org/10.1016/S1364-0321(02)00002-3

Glassley, W.E., 2010. Geothermal Energy Renewable Energy and the Environment. CRC Press, New York.

Hall, R., Ali, J.R., Anderson, C.D., Baker, S.J., 1995. Origin and motion history of the Philippine Sea Plate. Tectonophysics 251, 229–250. https://doi.org/10.1016/0040-1951(95)00038-0

Hinschberger, F., Malod, J.A., Réhault, J.P., Villeneuve, M., Royer, J.Y., Burhanuddin, S., 2005. Late Cenozoic geodynamic evolution of eastern Indonesia. Tectonophysics 404, 91–118. https://doi.org/10.1016/j.tecto.2005.05.005

Kaczmarczyk, M., Tomaszewska, B., Operacz, A., 2020. Sustainable Utilization of Low Enthalpy Geothermal Resources to Electricity Generation through a Cascade System. Energies 2020, Vol. 13, Page 2495 13, 2495. https://doi.org/10.3390/EN13102495

Koike, K., Nagano, S., Ohmi, M., 1995. Lineament analysis of satellite images using a Segment Tracing Algorithm (STA). Comput. Geosci. 21, 1091–1104. https://doi.org/10.1016/0098-3004(95)00042-7

Manyoe, I.N., Hutagalung, R., 2021. The Extraction and Analysis of Lineament Density from Digital Elevation Model (DEM) in Libungo Geothermal Area, Gorontalo, in: 4th IGEOS: International Geography Seminar. Bandung.

Manyoe, I.N., Hutagalung, R., 2020. Subsurface Shallow Modelling Based on Resistivity Data in The Hot Springs Area of Libungo Geothermal, Gorontalo. J. Geosci. Eng. Environ. Technol. 5, 87–93. https://doi.org/10.25299/jgeet.2020.5.2.5094

Martín-Gamboa, M., Iribarren, D., Dufour, J., 2015. On the environmental suitability of high- and low-enthalpy geothermal systems. Geothermics 53, 27–37. https://doi.org/10.1016/J.GEOTHERMICS.2014.03.012

Perelló, J.A., 1994. Geology, porphyry CuAu, and epithermal CuAuAg mineralization of the Tombulilato district, North Sulawesi, Indonesia. J. Geochemical Explor. 50, 221–256. https://doi.org/10.1016/0375-6742(94)90026-4

Rybach, L., 2015. Classification of geothermal resources by potential. Geotherm. Energy Sci. 3, 13–17. https://doi.org/10.5194/GTES-3-13-2015

Siahaan, E.E., Soemarinda, S., Fauzi, A., Silitonga, T., Azimudin, T., Raharjo, B., 2005. Tectonism and Volcanism Study in the Minahasa Compartment of the North Arm of Sulawesi Related to Lahendong Geothermal Field, Indonesia. Proc. World Geotherm. Congr. 24–29.

Sompotan, A.F., 2012. Struktur Geologi Sulawesi, Perpustakaan Sains Kebumian, Institut Teknologi Bandung. Perpustakaan Sains Kebumian, Institut Teknologi Bandung, Bandung. https://doi.org/10.1007/978-3-642-33335-4_197877

Tzanis, A., Efstathiou, A., Chailas, S., Lagios, E., Stamatakis, M., 2020. The Methana Volcano – Geothermal Resource, Greece, and its relationship to regional tectonics. J. Volcanol. Geotherm. Res. 404, 107035. https://doi.org/10.1016/J.JVOLGEORES.2020.107035