Lineament Extraction Analysis Using Digital Elevation Model (DEM) in Lahendong Geothermal Area, North Sulawesi

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Abstract. Sulawesi is located in the triple junction which makes it has a high complex tectonic setting implicated for the emergence of geothermal potential. Existing geological structure near the research area is only in the top-right of the research area which far from any of the hot spring points. This research aims to analyze the lineament extraction to find out the alleged structure and the density area to determine the permeability of the Lahendong geothermal area using National Digital Elevation Model (DEMNAS) data imagery. Digital Elevation Model (DEM) data is processed using Remote Sensing Photogrammetry application to produce lineament extraction. Lineament density map is carried out using a Geographic Information System (SIG) application and then processed to generate rosette diagram. Based on the lineament extraction and lineament density analysis result, we can interpret that the Lahendong geothermal area is dominated with high density, which is interpreted as good permeability. Lineaments in the Lahendong geothermal area is northwest-southeast and almost north-south. The extracted lineament is also providing the alleged structure in the research area.

1 Introduction

Sulawesi Island lies within Eastern Indonesia in a highly complex and dynamic plate tectonic settings located at the meeting of three major tectonic plates (triple junction) namely, the oceanic/continental Indo-Australian, predominantly continental Eurasian and oceanic Pacific/Philippine Sea plates [1]. The North Sulawesi subduction zone has been active since about and located to the north of an earlier Tertiary volcanic arc [2, 3]. The North Arm of Sulawesi Island has several active volcanoes along the Sangihe Island and Minahasa Area. The Tondano caldera formed by large volume explosive eruptions and caldera collapse. It contains small inactive post-caldera volcanoes and active geothermal system such as Lahendong Geothermal area [4].

In recent years, remote sensing method has been commonly used because it provides a lowcost research by utilizing technology especially for pre-eliminary exploration. Moreover, remote sensing data are also able to provide data that alleviate the field work, it can reach areas that cannot be reached by human physical capabilities. Remote sensing is used for many purposes, such as lineament analysis [5-9] which is useful for geothermal exploration. Further investigation can be carried out through geological, geochemical, and geophysical studies [10-12].

Based on regional geological structure, the subduction of North Sulawesi is thought to have been active since the Early Tertiary and resulted in the emergence of a Tertiary volcanic arc stretching from Tolitoli - Gorontalo to near Manado which is an old volcanic belt. Tectonic events on the Sulawesi Island have taken place from the early Tertiary by the North Sulawesi subduction, resulting North-South stress. The second period was marked by the emergence of a dextral strike-slip fault trending northwest-southeast. The third period is characterized by the emergence of the East Sangihe subduction with almost west-east to north-south direction, which is estimated to be active in the Early Quarter and resulted in a Quaternary volcanic strip that was exposed in the south area [13-15].

Existing geological structure near the research area is only in the top-right of the research area with northwest - southeast direction which far from any of the hot spring points. As we know that, hot spring formed at places where the geological structure such as faults or fractures that can provide a high-permeability channel for deep water path. Hot springs is the manifestation of geothermal that develop in places where volcanism currently or has occurred recently, so that magma or/and extremely hot rock resides close to the Earth surface.

Previous research by Koestono, et al showed that the geological structure in Lahendong is trending Northeast (NE) - Southwest (SW), East (E) - West (W), Northwest (NW) - Southeast (SE) and North (N) - South (S) [16].

This research aims to analyze the lineament extraction to find out alleged structure and the density area so we can determine the Lahendong Geothermal area permeability using National Digital Elevation Model (DEM) data imagery.

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2 Materials and Method

2.1 Research Location

Lahendong geothermal research area is in the North Arm of Sulawesi Island and become the first developed field in the eastern Indonesia which is the part of volcanic arc extending from Sangihe to Minahasa area. Lahendong Geothermal located in the southern part of Tomohon City and is about 30 km from Manado, the Capital of North Sulawesi Province with the elevation is about 750 m above sea level [5]. The research area's astronomical location is between 124°45'0" - 125°0'0" E and 1°7'30" - 1°30'0" N and have total 14 hot spring points. Lahendong geothermal area composed of Volcanic Rocks (Tmv), Tondano Tuff (QTv), Young Volcanic Rocks (Qv), Lacustrine and Fluviatil Deposits (Qs), and Alluvium (Qal).

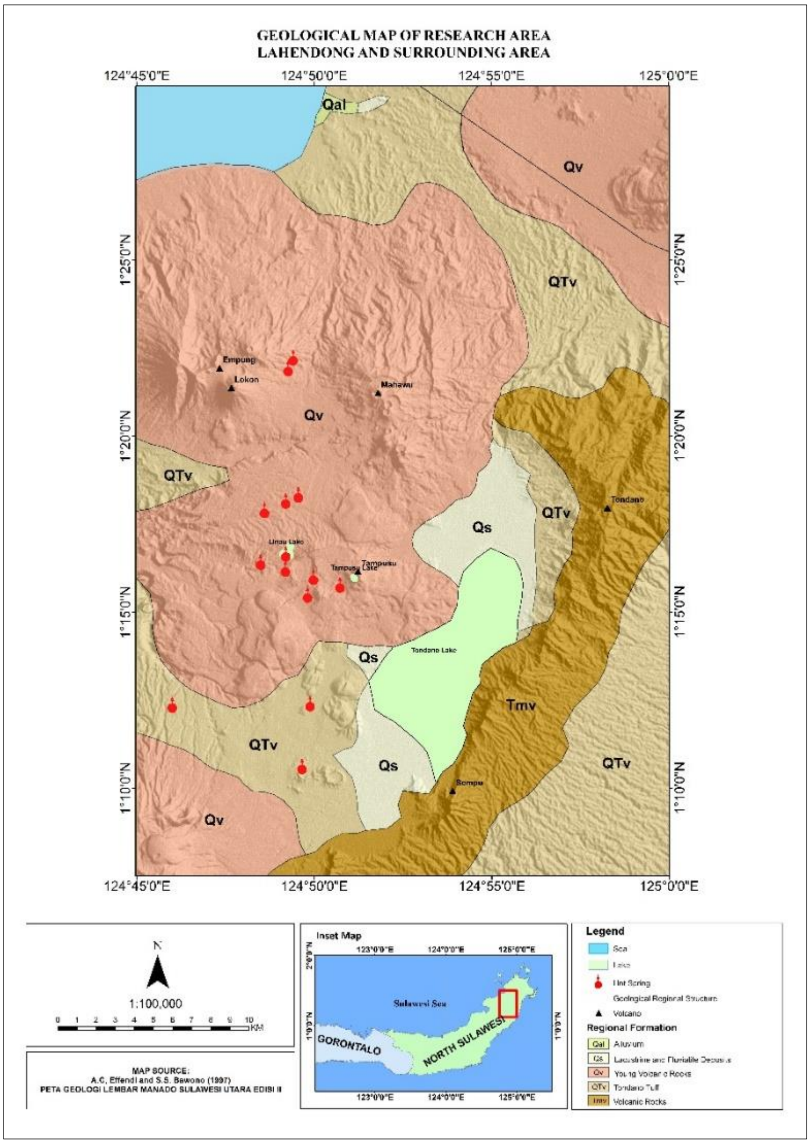

Fig. 1. Regional Geological Map of Research Area (After Effendi and Bawono, 1997).

Volcanic Rocks (Tmv) is approximately early miocene-late miocene, composed of lava, tuff, and breccia. Tondano Tuff (QTv) is estimated from pleistocene to holocen, composed of coarse volcanic clastic mainly of andesitic compositions with angular to sub-angular components, characterized by abundant pumice fragment, tuff, lapilli tuff, breccia. Young Volcanic Rocks (Qv) are composed of lava, lapili, bomb, ash. Lacustrine and Fluviatil Deposits (Qs) are composed of sand, silt, conglomerat, marly clay. Alluvium (Qal) are composed of boulders, cobbles, pebbles, sand, and mud. Young Volcanic Rocks (Qv), Lacustrine and Fluviatil Deposits (Qs), and Alluvium (Qal) units are from holocene. There's a major geological regional structure in the upper part of research area that is NW-SE intersecting Tondano Tuff (QTv) and Young Volcanic Rocks (Qv) (Fig.1).

2.2 Data Collection

This research was conducted using National Digital Elevation (DEM) data that obtained from Geospatial Information Agency (Badan Informasi Geospasial). DEMNAS data have a detailed image, so it can provide better results compared to other DEM data downloaded from other places (e.g earthexplorer, CGIAR Consortium for Spatial Information, etc.). DEMNAS data is set up from several data sources comprise TERRASAR-X (5m resolution), (5m resolution), and ALOS PALSAR (11.25m resolution). The DEMNAS spatial resolution is 0.27 arcsec by adding stereo-plotting masspoint data, which higher and better than SRTM DEM, ALOS PALSAR, ASTER GDEM, etc resolution that only has 1-arcsecond (~30m) resolution.

2.3 Data Processing and Interpretation

The Digital Elevation Model data that has been obtained will then be processed to produce lineament extraction. The lineament extraction of DEMNAS data is carried out using Remote Sensing Photogrammetry application. This lineament extraction used to create morphology lineament map to find the creater/circular feature.

Then lineament extraction will be used to create lineament density map. The lineament extraction result from Remote Sensing Photogrammetry application is polyline, while the lineament density map requires a single line form of straight-line data input. Hence, this is done by using Geographic Information System (GIS) software with split lineament tool to create a single line data input. The split lineament of the DEMNAS data produces 14105 single-line with varying length. The lineament density map then will be analyzed and interpreted to provide the research area permeability level.

In addition, a rosette diagram is also made to determine the direction that affects the lineament in Lahendong geothermal research area by entering X1, Y1, X2, Y2 value that obtained by using calculate geometry attribut tool of the lineament extraction.

3 Result and Disscussion

The result of DEM (Digital Elevation Model) data extraction is the lineament of the research area that carried out using Remote Sensing Photogrammetry application. There are 14 hotsprings in the west part of Tondano lake, percisly the 7 of them located around the Linau lake which was considered as old volcano (Fig 2).

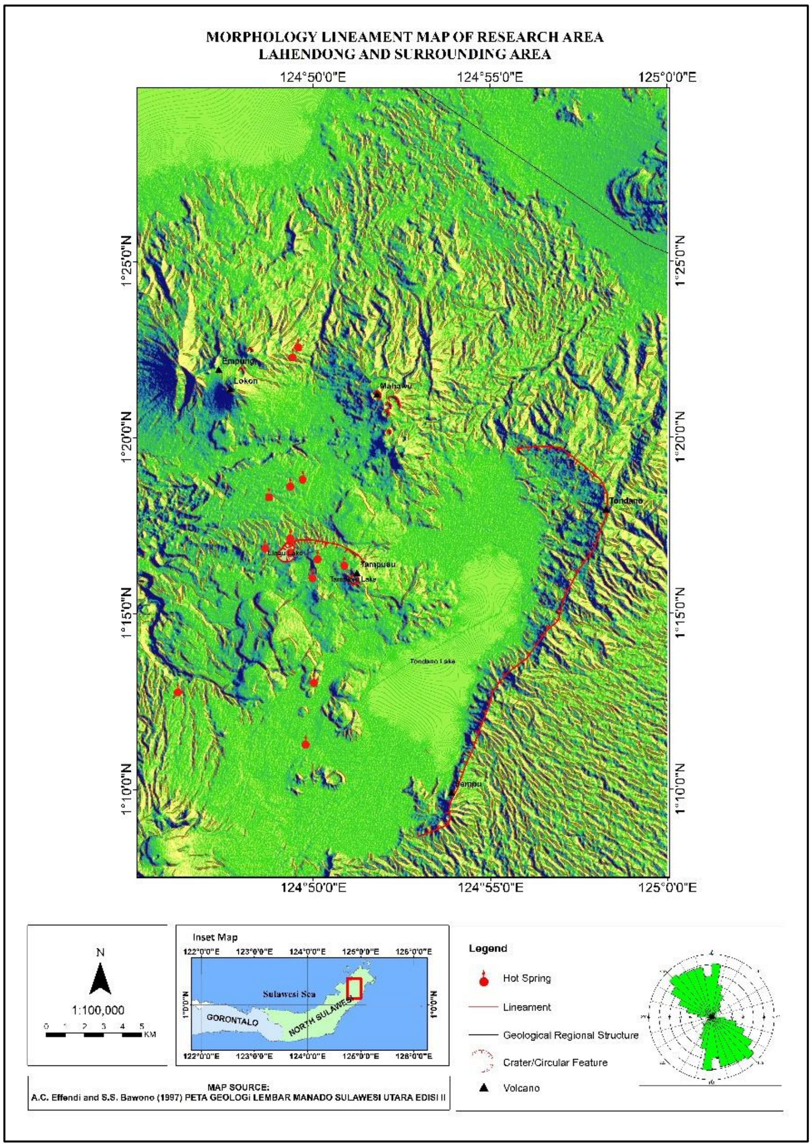

Fig.2. Morphology Lineament Map of research area

Essentially, the morphology of the Lahendong research area is surrounded by ridges, hills, and composite volcanoes with basin or depression zones presence in the Lahendong research area (Fig.2). Based on the morphology lineament map, there are eight circular feature that interpreted as old craters or recent craters of volcanoes.

There is a circular feature to the east of Lake Tondano which stretches for approximately 30 km, this is thought to be a caldera. There's also another caldera around the Linau Lake with approxiamately 5 km long. Five circular features located around Mahawu Volcano with a diameter is about 1km with the opening direction to the east - northeast, two circular features at the top of Lokon-Empung Volcano with ±1km diameter opens to east, and one circular feature in the top of Tampusu volcano and has been occupied with water to form Tampusu Lake which is thought to be a crater lake.

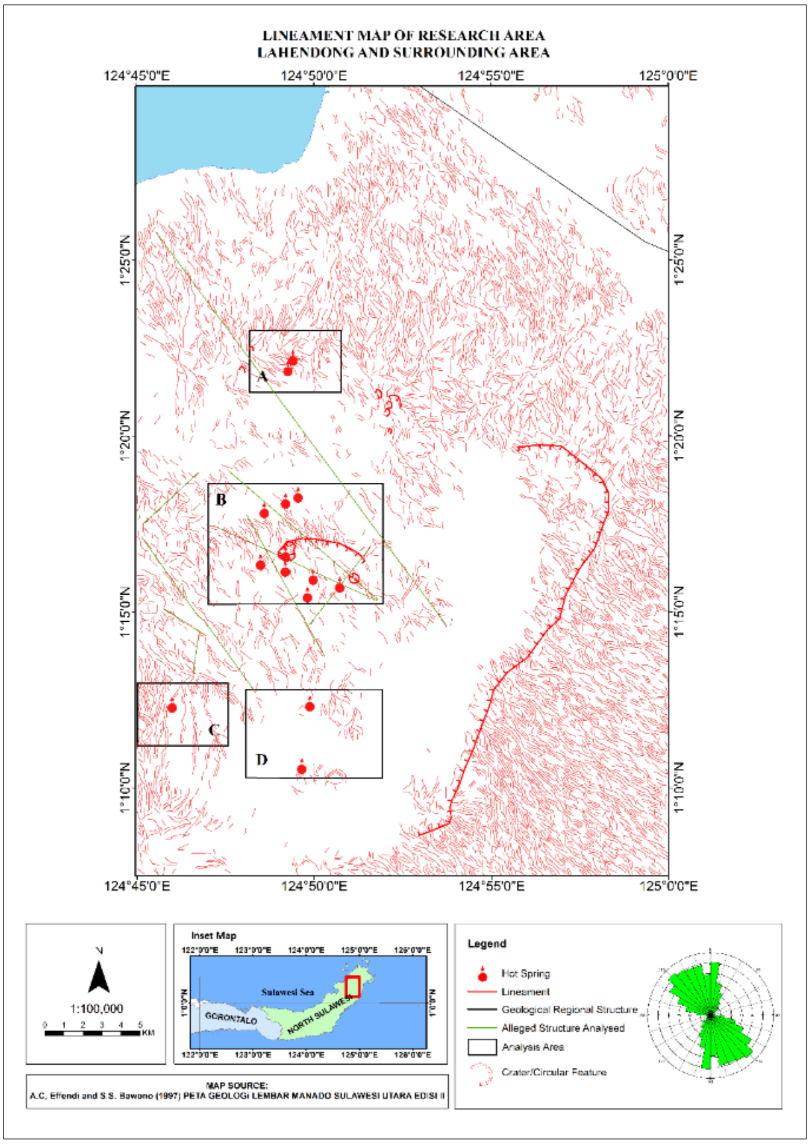

Fig.3. Existing hot springs, alleged structure analysed, and lineament extraction of research area

Based on the lineament extraction map (Fig. 3) the rosette diagram analysis result of lineament extraction using DEM imagery in the study area are predominantly northwest-southeast. This could signify that the geothermal system in Lahendong research area is influenced by North Sulawesi subduction [14] with trending northwest-southeast.

The lineament analysis was made between the existing hot springs with the lineament extraction (Fig.3). The lineament is divided into four regions which are region A, region B, region C, and region D (Fig.4).

Region A is a region between lineament extraction with two existing hot springs. In the region A, the lineament extraction trending almost north (N) – south (S). Region B is between the lineament extraction and eight existing hot springs, the lineament of region B trending is almost northwest (NW) – southeast (SE). Region C is between lineament extraction and one existing hot spring, region C lineament trend is almost north (N) -south (S). Region D is the area between lineament extraction with two existing hot springs, the lineament extraction trend northwest (NW) -southeast (SE) (Fig.5).

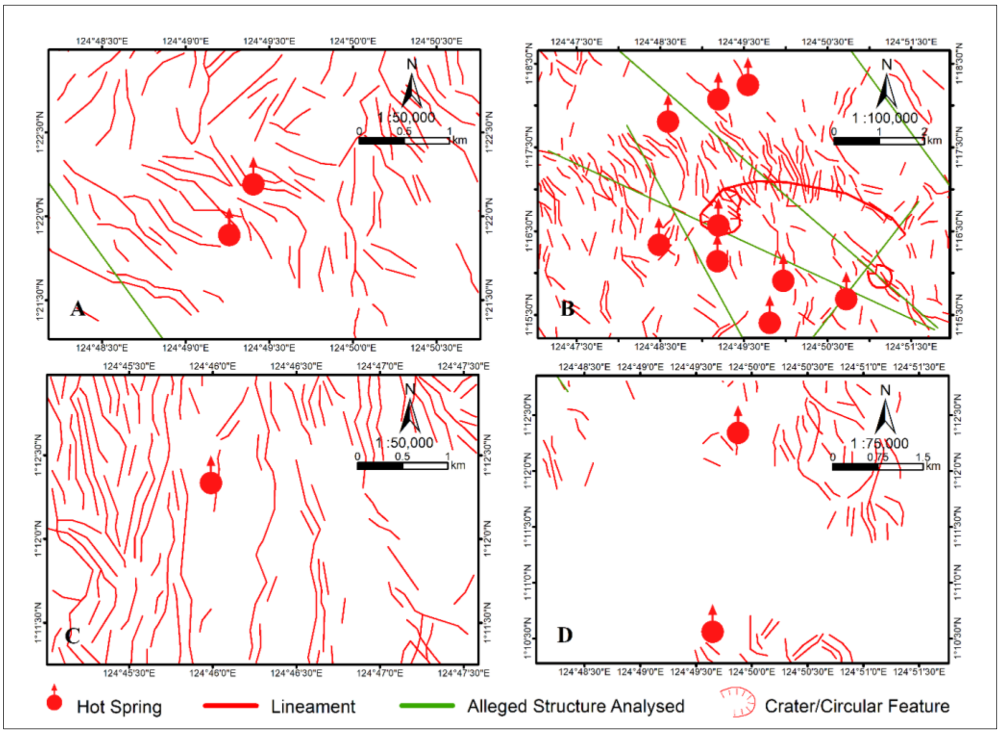

Fig.4. Existing hot springs, alleged structure analysed, and lineament extraction

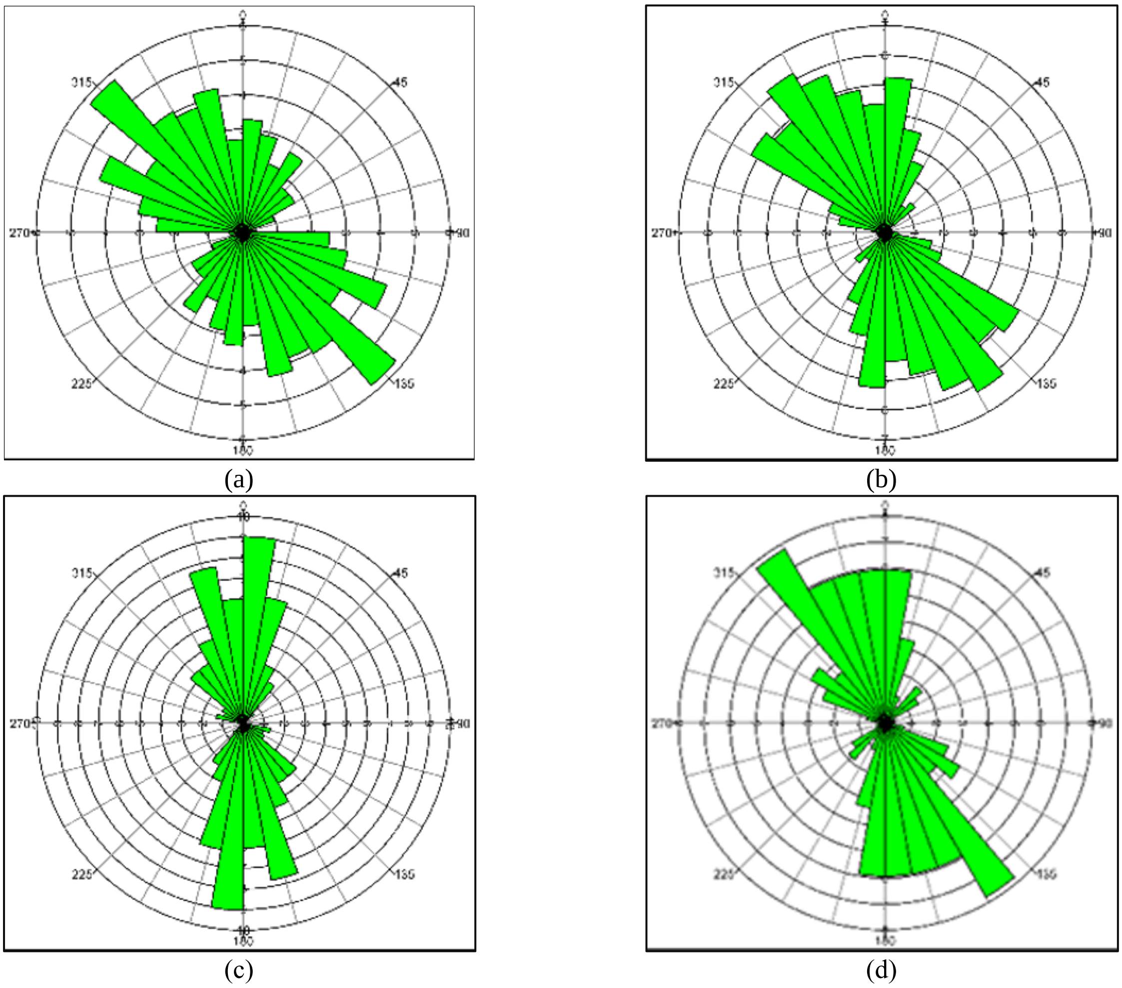

Fig.5. (a) Region A trending northwest-southeast (NW-SE). (b) Region B trending northwest-southeast (NW-SE). (c) Region C trending almost north-south (N-S) (d) Region D trending northwest-southeast (NW-SE).

In general, the Lahendong geothermal area lineaments are north (N) – south (S) and northwest (NW) – southeast (SE), based on the literature the direction of this stress is similar with the trend of North Sulawesi subduction and the East Sangihe subduction [14, 15].

Based on lineament extraction data analysis, the observed alleged structure lines were drawn (shown by green line). There are about 7 (seven) alleged structures around the hotspring point, especially around the Linau Lake. This alleged structure mostly northwest-southeast (NW-SE) direction.

The lineament density map that processed with Remote Sensing Photogrammetry application and Geographic Information System (GIS) application used to determine the Lahendong geothermal permeability area.

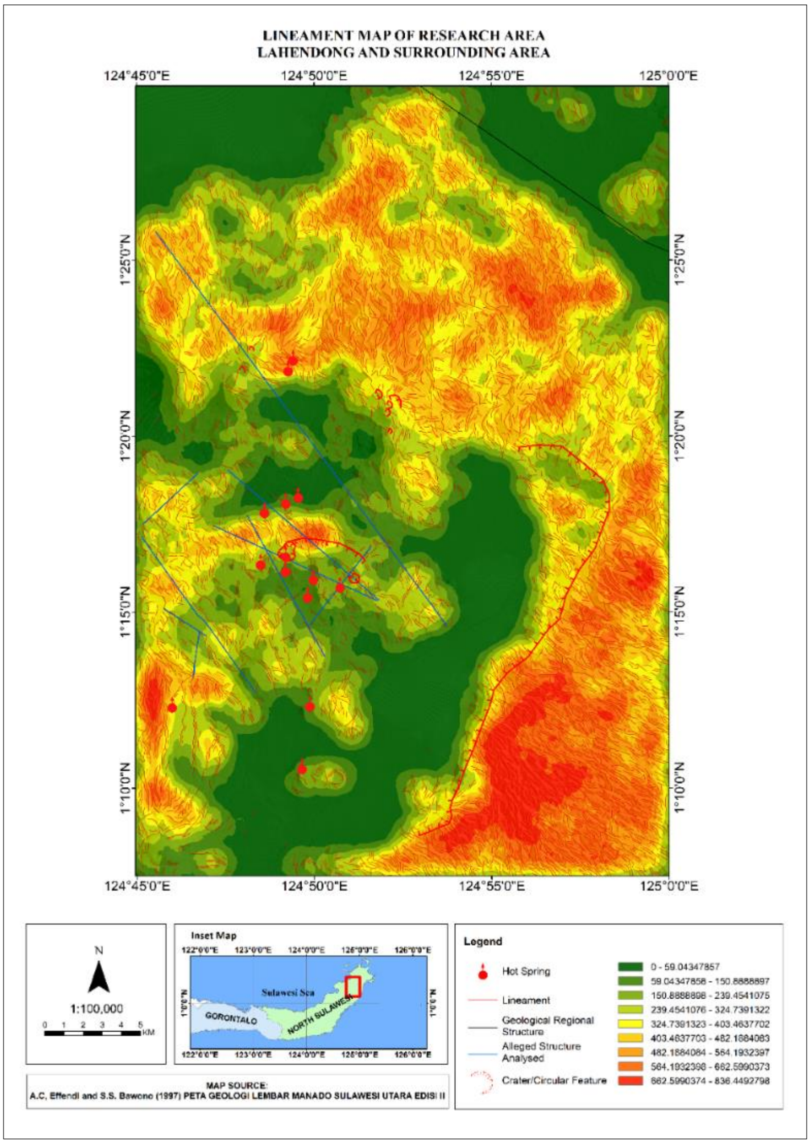

Fig.6. Lineament Density Map of Research Area

Based on the Lineament Density Map (Fig.6), Lahendong geothermal area is divided into three density areas which high density, medium density and low density. This is shown by the red to green gradation color on map, where the high areas are represented in red, the medium in yellow, and the low areas in green.

High density areas of Lahendong geothermal area including the southeastern, some parts of northern and eastern area, and a bit of central and southwestern part of the Lahendong geothermal research area. The medium density areas are including some parts in the northern and western part of the research area. Low density area including the northwestern, northeastern, and the central part of the research area.

The southeastern, and eastern parts of the research area are encompas in high areas of density related with the caldera rim in the east part of Tondano lake. A bit of central part of the research areas are associated with the caldera rim around Linau lake which has the hottest springs appearance of the Lahendong geothermal area, and also the alleged structure from this research with northwest-southeast direction.

The northern, western, and the central parts are included in the medium density and the low-density areas because it is the fluvial plain and the lake. The high level of lineament density indicates that the area has good permeability, while the low level of lineament density indicates that the area is poorly permeable. Based on the lineament density map, the Lahendong research area is dominated with high density areas. The high level of lineament density indicated the research area has good permeability which provides good fluid circulation.

Based on the lineament density map, the research area dominated by high density areas. The high-density areas are scattered in southeastern, some parts of northern and eastern area, and a bit of central and southwestern part of the Lahendong geothermal research area so that the research area dominated with good level of permeability. Geothermal areas with good permeability levels are interpreted as areas with good water infiltration rates. So that, the presence of a lineament controls the circulation of geothermal fluids in the Lahendong geothermal area.

4 Conclusion

Based on the lineament extraction, it was found the alleged structure with northeast-southeast (NE-SW) direction dominated and northeast-southwest (NW-SE) direction. Lineament map between hot springs and lineament extraction showed that the hot springs manifestation dominated in lineament trending northeast-southeast (NE-SW). Based on the lineament density map, the research area is dominated by high level of lineament density areas that signify the research area has good permeability which provides good fluid circulation.

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