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LINEAMENT EXTRACTION AND THE CORRELATION TO VEGETATION AND MOISTURE INDICES FOR GROUNDWATER PREDICTION IN SOUTH BENGKULU, INDONESIA

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Abstract - Lineament represents the geological features in response to a weak zone that might manifest groundwater potential. The research aims to determine the relationship between the lineament extraction and vegetation and surface moisture indices. The study was conducted in South Bengkulu, Bengkulu, based on Shaded Relief images at azimuth 0°, 45°, 90°, and 135° from Digital Elevation Model (DEM) image processing through DEMNAS (8 meters). Then, analysis of vegetation and moisture indices using Normalized Difference Vegetation Index (NDVI), Normalized Difference Moisture Index (NDMI), and Moisture Stress Index (MSI) from Landsat 8 OLI/TIRS extraction image. The Pearson Linear correlation method is used for correlation analysis. Based on the analysis of the lineament data, there are 12,206 lineament patterns, dominantly trending in NW-SE, N-S, and NE-SW. The lineament density parameters show the density level 0 km/km^2 -10.44 km/km^2. The results of the correlation of data on lineament density to the image index have positive and negative trend values, namely: NDVI (0.16), NDMI (0.37), and MSI (-0.43). From the results, the highest density is straight to the vegetation and high surface moisture. Therefore, the analysis is useful as an initial indicator of the potential presence of groundwater.

Keywords*:* Groundwater, lineament remote sensing, DEM, Landsat 8

1. INTRODUCTION

Lineament aspects contain line objects formed from processed satellite imagery that describes morphological expressions marked by straight lines on the surface. The morphological expression is a deformation process on the earth's surface characterized by the formation of valleys and river flows. Then lineament analysis can explain the relationship between morphology and tectonic processes that form geological structures in rocks. The application of lineament forms can be carried out in the form of flow and valley aspects, surface depression aspects, aspects of vegetation type and changes in soil properties, and topographical aspects that have the possibility of geological structural phenomena, such as faults, folds, and joints (Epuh et al., 2020). The geological structure, in some cases, can block the incoming groundwater flow path due to the small pore space in the subsurface (Sahoo et al., 2018). The small pore space in the subsurface causes an increase in the volume of groundwater and affects the high moisture on the subsurface and surface, causing vegetation to grow to form a straight line (Sahoo et al., 2018). The geological structure area deformation can be described as a line pattern on the map as a weak zone and has good porosity and permeability characteristics to be used as a manifestation of groundwater (Sahoo et al., 2018)

The research area is in South Bengkulu. Geographically, it is bordered by Lahat Regency, South Sumatra (north), Seluma Regency (West), Indian Ocean (South), and Kaur Regency (east) **(Figure 1**). Geologically, the area is part of the Bengkulu Basin area as the forearc basin (Yulihanto, 1995).

The study's objective is to predict the presence of groundwater based on the parameters obtained from lineament extraction and correlated based on the vegetation and moisture indices. Lineament extraction is made by processing DEM data while processing vegetation and moisture indices with Landsat 8 OLI/TIRS images. The vegetation index used is the Normalized Digital Vegetation Index (NDVI), and the moisture index is the Normalized Digital Moisture Index (NDMI) and the Moisture Stress Index (MSI). A high lineament density index has the potential for the presence of groundwater so that it can affect the presence of vegetation and moisture on the surface.

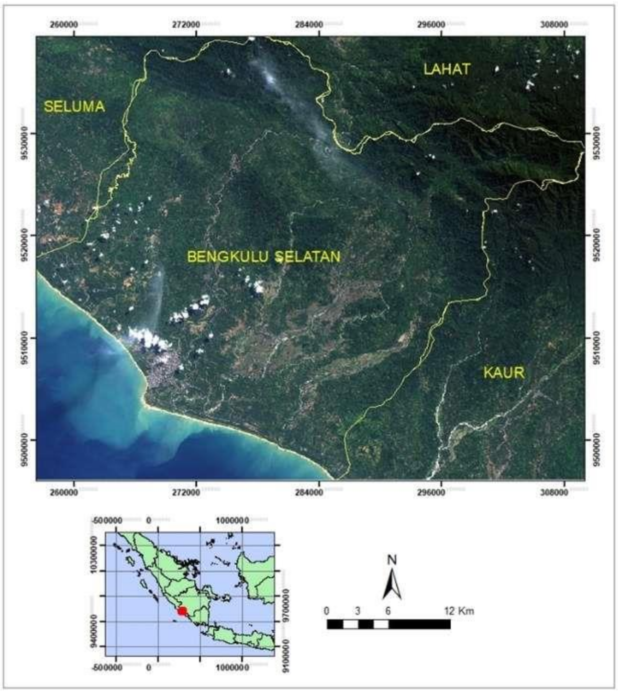

Figure 1. The location of the research area

Tectonically, South Bengkulu is part of the tectonic of Sumatra Island, which is on the edge of the Sunda Shelf caused by the oblique subduction process of the Indian Ocean Plate under the Eurasian Continental Plate. The formation of the Sunda arc-trench system is the product of an oblique zone that extends from the Burma Plate in the north to the collision zone on the Australian Plate against Indonesia in the east. (Yulihanto et al., 1995). The Bengkulu Basin was formed by expanding the Paleogene rift system in the South Sumatra Basin as far as 100 km to the northwest along a transcurrent fault in the Early-Middle Miocene (Yulihanto et al., 1995). This activity occurred when the Burma Plate experienced a dextrally sliding movement along with the Sumatran fault system. Then tectonic activity on the island of Sumatra formed the direction of the Mentawai fault system that appeared along the western edge of the island of Sumatra (Yulihanto et al., 1995).

Based on the stratigraphy (Amin et al., 1993) of the Bengkulu Basin, the Hulusimpang Formation is outcropped, consisting of lava, volcanic breccia, and tuff of the Oligocene-Miocene. Then the Seblat Formation is a formation with fingering contact boundaries to the Hulusimpang Formation with rock compositions of alternating claystone, calcareous claystone, siltstones with sandstone intercalation, and conglomerates of Early–Middle Miocene. The intrusion of granite and diorite through the Hulusimpang and Seblat Formation occurred in the Middle Miocene. The Lemau Formation was deposited in a transitional area to shallow seas, such as sandstone, claystone, and carbonate claystone. The Seblat Formation was deposited in the Middle-Late Miocene, and the Simpangaur Formation was formed in a transitional environment. The rocks that make up the formation are sandstone, tuffaceous sandstone, mollusk claystone, and conglomerate. The depositional of the Simpangaur Formation is Late Miocene-Pliocene. The Bintunan Formation (tuffaceous claystone, conglomerate, and tuff) was deposited over the Simpangaur Formation. The Bintunan Formation was deposited in Plio-Pleistocene with a fluvial depositional environment. At the top of stratigraphy sequences, the Quartenary Alluvium deposit consists of boulders, gravel, sand, silt, and mud (**Figure 2**).

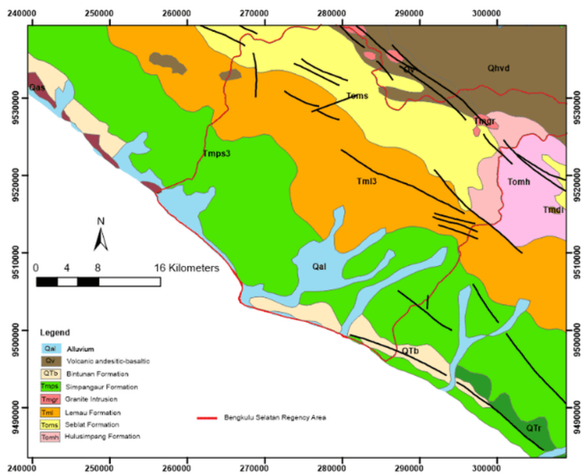

Figure 2. Geology map of Bengkulu Basin (Amin et al., 1993; Setyowati et al., 2018)

2. DATA AND METHODOLOGY

The research is based on Geographic

Information System data using remote sensing methods to map parts of the research object on a large scale. The data used are Digital Elevation Model (DEM) data with a data resolution of 8 meters and Landsat 8 OLI/TIRS satellite imagery.

DEM is used in the lineament density analysis. Data processing was carried out by creating a shaded relief overlay based on the light height of 45^o and the azimuth angle of irradiation 0^o, 45^o, 90^o, and 135^o. The following process is making lineament patterns based on the LINE modulus algorithm parameters. Parameters in the LINE modulus are divided into 6, namely RADI, GTHR, LTHR, FTHR, ATHR, and DTHR. The input value in the parameter (Table 1) was adjusted to the input data reference according to (Sahoo et al., 2018).

1. **RADI** (Filter Radius): Parameter to determine the lineament radius of the detected filter on the modulus with a parameter value range of 0 to 8192

2. **GTHR** (Gradient Threshold): The parameter determines the minimum gradient level limit on the edge pixels to obtain a binary image. The parameter value ranges from 0 to 255.

3. **LTHR** (Length Threshold): Parameter for specifying the minimum length of the curve at the pixel scale. The parameter value ranges from 0 to 8192.

4. **FTHR** (Line Fitting Error Threshold): The parameter determines the polyline's error rate in pixel scale. Parameter values range from 0 to 8192.

5. **ATHR** (Angular Difference Threshold): Parameter to determine the maximum angle contained in a polyline segment created in degrees. So the data value ranges from 0 to 90.

6. **DTHR** (Linking Distance Threshold): Parameter for specifying the minimum distance of the pixel scale seen at the endpoints of two connected vectors. The parameter value ranges from 0 to 8192.

Table 1. Specifications of lineament extraction parameters from Sahoo et al. (2018)

NAME	DESCRIPTION	VALUES
RADI	Filter Radius (pixel)	10
GTHR	Gradient Threshold	90
LTHR	Length Threshold (pixel)	30
FTHR	Line Fitting Error Threshold (pixel)	10
ATHR	Angular Different Threshold	30
DTHR	Linking Distance Threshold (pixel)	20

Lineament extraction is made in lineament density maps to map zones of indications of geological structures in the form of faults and joints. This can make it possible to predict the potential for groundwater in the area.

Landsat 8 OLI/TIRS imagery is a multispectral satellite image consisting of 11 multispectral bands and has a spatial resolution of 30 meters and 15 meters. Image data acquisition was obtained on June 14, 2020. First, image retrieval was taken based on specifications with a small cloud presence (10%). Then, the Landsat 8 OLI/TIRS image was subjected to atmospheric correction to get the image condition with optimal irradiation to reduce the risk of data misinterpretation. The atmospheric correction method uses the FLAASH method on multispectral bands. The following process is image sharpening with the Gram-Schmidt Pan-sharpening method based on the Landsat 8 OLI/TIRS image sensor. So that the initial image specifications were originally 30 meters resolution changed to 15 meters.

Landsat 8 image data that has been corrected will be calculated based on the specified index, namely NDVI, NDMI, and MSI. The calculation is carried out on different bands according to the formula.

The Normalized Difference Vegetation Index (NDVI) calculation is carried out to detect areas with the influence of vegetation level

(Sahoo et al., 2018). The NDVI value scale is -1 to 1 with the following formula

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \qquad (1)$$

Then the moisture condition of land can be done with two image value indexes, namely the Normalized Digital Moisture Index (NDMI) and the Moisture Stress Index (MSI). NDMI monitors the moisture condition of the vegetation on the image object. The highest NDMI value indicates high moisture conditions with a value of 1, while the lowest suggests a value of -1. NDMI is calculated by the following equation (Sewnet and Naqvi, 2016):

$$NDMI = \frac{(NIR-SWIR1)}{(NIR+SWIR1)} \qquad (2)$$

MSI analysis is used to monitor the level of moisture stress caused by changes in the ecosystem. This index can interpret the calculation of drought of the water content area. The MSI equation is as follows (Ceccato et al., 2001):

$$MSI = \frac{(SWIR1)}{(NIR)} \qquad (3)$$

The correlation can relate to two variables based on measurement statistics. Pearson correlation is a method that is widely used in connecting two object variables, x, and y, respectively (Pei et al., 2019). The correlation value describes a relationship of determination between variables that influence each other with a maximum weight of 1. For example, the correlation method can explain the relationship between the lineament density to the vegetation and moisture index in predicting the groundwater potential of an area.

3. RESULTS AND DISCUSSION

Based on the results of lineament extraction on the overlaying of shaded relief, the lineament patterns formed on the ridges and valleys randomly adjust the morphological conditions in the DEM (**Figure 3).**

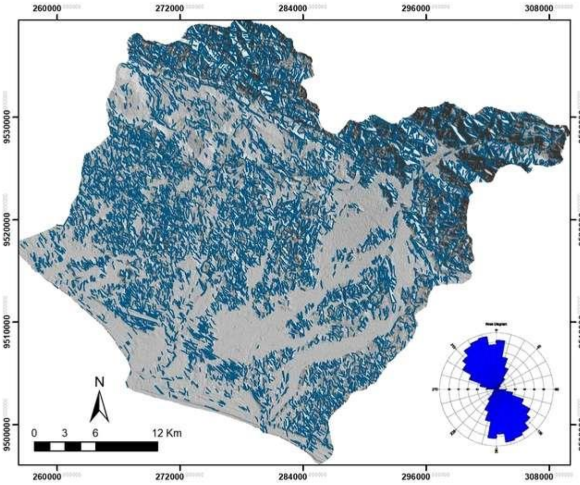

Figure 3. Lineament extraction of South Bengkulu

The extraction results showed that there were 12,206 lineament patterns extracted. It is known that the shortest length of the extracted lineament pattern is 250 m, while the most extended length is 3499.71 m. The trend in the straight line shows that the dominant trending pattern is NW-SE. The dominance of the lineament pattern formed by the automatic algorithm method is similar to the structural pattern formed in the Pliocene – Pleistocene compressional tectonic phase in the South Sumatra Basin (Kusnama et al., 1993). The tectonics formed from a series of inversion processes that resulted in the uplift of the South Sumatra basin resulting in the reactivation of the fault with positive inversion formations related to the volcanic activity of the Orogeny Barisan (Kusnama et al., 1993). However, the compressional phase in the Bengkulu Basin occurred after the deposition of the Miocene – Pliocene Formation and is related to the tectonic phase of the South Sumatra Basin, which occurred in the Middle Miocene – Recent as a compressional phase of the formation of the back-arc basin (Pulunggono et al., 1992; Yulihanto et al., 1995).

Figure 4 describes the area with the lineament density level based on lineament extraction. The lowest density is the 0 - 1.93 km^{-1} interval marked by a red gradation on the map with 16% of the area . The lowest density area is a significant watershed with large floodplain morphology. In addition, it was observed in the southern part of South Bengkulu, which is an indication of the urban and coastal environment. In contrast, the highest density is in the interval of 3.77 - 10.44 km^{-1}, marked by a blue gradation. The blue density area observed is the dominance of hilly and mountainous regions. The lineament density indicates the flow permeability zone, which is interpreted as a result of deformation in the area undergoing geological structure formation tectonic processes, with the result that the higher the lineament density of space indicates a weakening zone that triggers the development of secondary permeability in rocks (Epuh et al., 2020).

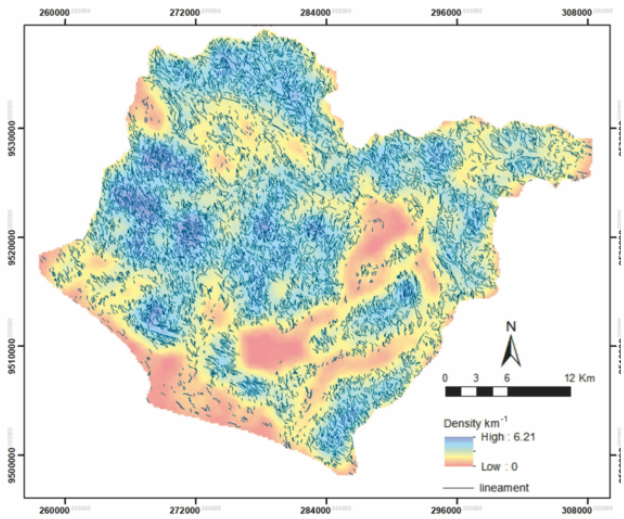

Figure 4. Lineament density map of South Bengkulu

Next, the result of transforming Landsat 8 imagery into vegetation and moisture indices uses NDVI, NDMI, and MSI. Based on the vegetation index through the NDVI, several areas show the level of vegetation index. For example, the highest value of NDVI is 0.973204, and the lowest is -1 (**Figure 5**).

NDMI map shows the lowest value is 0.357489 while the highest value is 1. Lineament maps overlaid with NDVI show good correspondence where areas with a high index have a dense lineament density, and so does the NDMI (**Figure 6**).

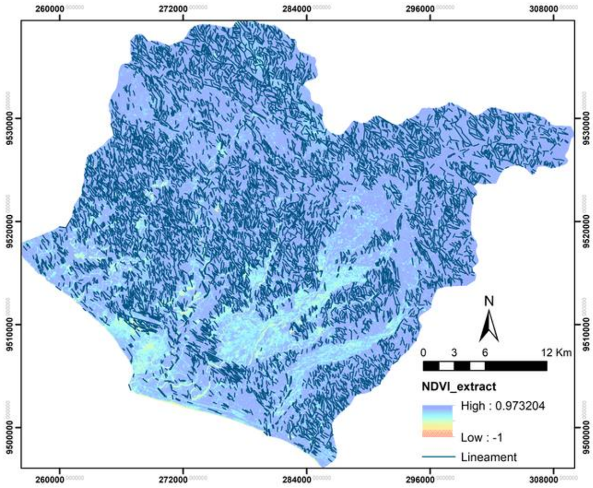

Figure 5. NDVI map overlaid by lineament patterns

Based on **Figures 5** and **6**, there are regional class differences based on surface moisture which indicates a factor in water content in an area. A high level of water content is generally followed by an increase in the level of green vegetation so that groundwater can appear in the area (Sahoo et al., 2018).

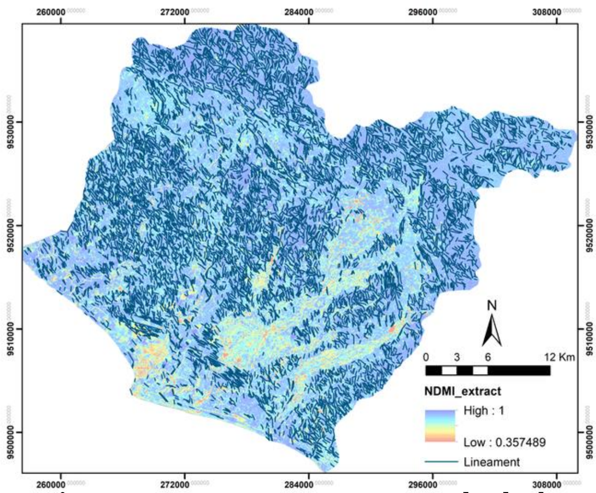

Figure 6. NDMI map overlaid by lineament Patterns

Thus, MSI's lowest value is -0.388009, and the highest value is 0.637175 (**Figure 7**). The MSI overlaid by the lineament map shows that lineament density reflects the MSI area with low weights. With the Result, the lineament pattern corresponds to areas with high moisture levels.

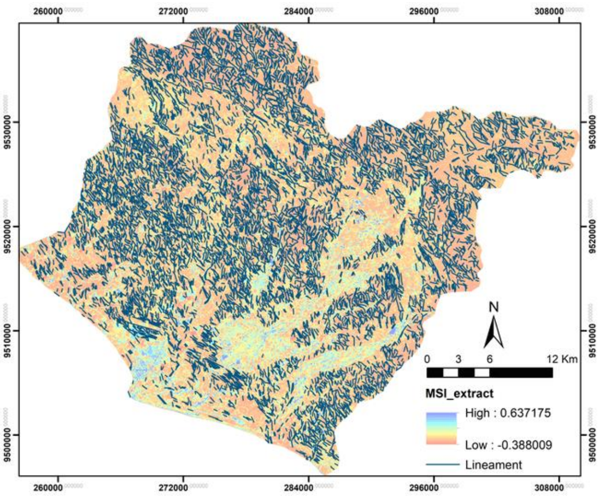

Figure 7. MSI Map overlaid by Lineament Patterns

The correlation results are shown in the value of R^2. It is known that the lineament density relationship with the lowest to the highest indices, namely MSI ($R^2 = 0.49$), NDMI ($R^2 = 0.632$), and NDVI ($R^2 = 0.635$) (**Figure 8**). The spatial correlation is based on 625 observation points or the equivalent of a distance of ±3 km on the map. The correlation analysis's principle of the relationship between the variables x and y shows that the variables are related to or influence each other.

A high R^2 value can interpret a relationship between two variables to an area's high porosity and permeability for groundwater potential. The previous description explains that lineament identification allows a site with surface and subsurface conditions related to porosity and water permeability. The lineament identification process targets morphological needs formed by erosion processes and geological structures, such as hills, valleys, and river flows (Alonso-Contes, 2011). High moisture levels and green vegetation support predicting areas that have groundwater potential. It is known that moisture and vegetation conditions are in line with lineament analysis because they show a high correlation (R) which is calculated in the study of the lineament correlation to NDVI (Sahoo et al., 2018) and NDMI (Alonso-Contes, 2011).
The different results are obtained from the correlation between MSI and lineament density,

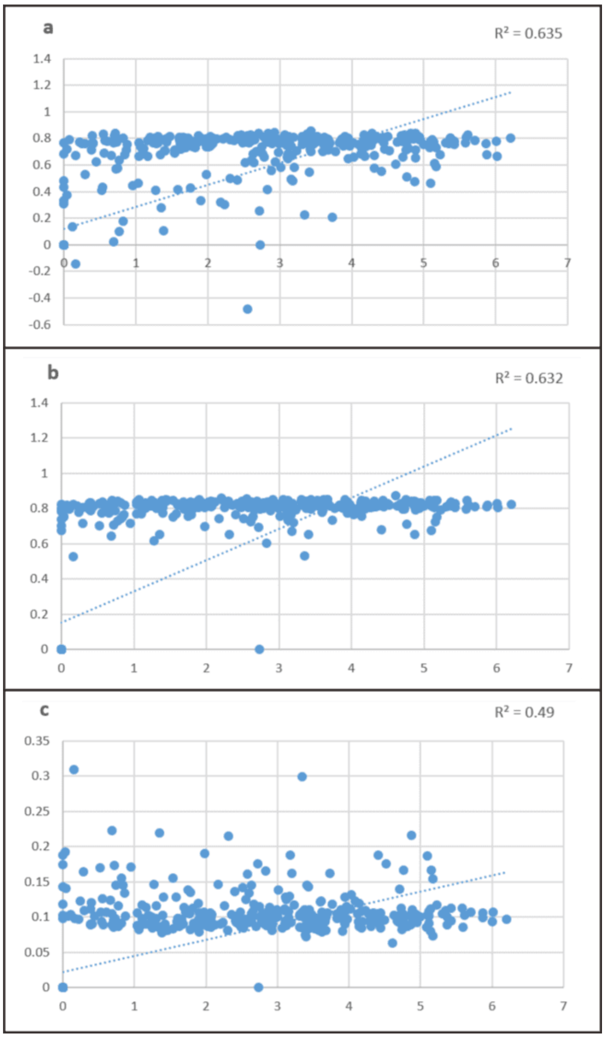

Figure 8. Graphic correlation Density between: a) NDVI, b) NDMI, c) MSI

smaller than NDVI and NDMI. Characteristics in the MSI reflect conditions on the surface which means that it focuses on research on surface water flows or pools. In most cases, MSI is often used in mapping drought and forest fire areas (Elhag and Bahrawi, 2017).

4. CONCLUSIONS

Based on lineage extraction, it shows a lineament pattern that is dominantly trending NW-SE, which means that the condition of the area is part of the tectonic phase related to Barisan Orogeny. Then based on the lineament density, there are areas with high density which show a high level of density as an indication of a weak zone or prone to deformation. The correlation between density and NDVI, NDMI, and MSI from lowest to highest, namely MSI

($R^2 = 0.49$) and NDMI ($R^2 = 0.632$), and NDVI ($R^2 = 0.635$). Lineament density of DEM helps determine weak zone points in the region, which indicates the presence of fluid deposited or flowing through the fracture gap.

Mapping of groundwater potential is needed to increase community groundwater needs. However, this research cannot be used as the primary reference for indicating groundwater potential due to the research is only mapping groundwater predictions in South Bengkulu. Therefore, it is necessary to have supporting data such as hydrogeological maps, geology, and borehole data acquisition based on field observations.

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