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# The Influence of Land Subsidence on Risk of Constructing 150 kV Transmission Tower for South Sumatra – Bangka Belitung Interconnector

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***Abstract***

*Transmission system is one of the national essential objects and should be reliable when functioning. Moreover, disturbances in transmission system can lead to disruption of the service function. A common risk to the reliability of electric distribution is land subsidence on transmission tower. Furthermore, the 150 KV interconnector of South Sumatra-Bangka Belitung (Sumsel-Babel) is located in the coastal area of Banyuasin sub-district, South Sumatra. This area is a river delta with peat and clay soil structures and is prone to land subsidence. Therefore, this research aimed to identify environmental factors that affect land subsidence and cause risk to transmission tower. In the context of this research, Copras (Complex Proportional Assessment) and MCSA (Multi Criteria Spatial Analysis) were used for parameter weighting and risk assessment of tower location, respectively. The results of an expert survey to assess risk of potential land subsidence at tower location showed five parameters, namely, land use, distance to waters or potential flooding, land slope factor, soil type, and conus value. Individual parameters were weighted quantitatively and qualitatively based on the opinions of academic experts. Specifically, the qualitative method was performed by weighting based on criteria and sub-criteria, which were analyzed using adjustment based on the opinions of academic construction experts. On the other hand, spatial analysis of locations at risk of land subsidence was conducted using GIS software. Based on the assessment results obtained, land use criteria had the largest weighting influence of 0.3 and the smallest weighting on the cone value was 0.1. Finally, tower location that are most at risk of land subsidence are on peatland, near water, and clay soil.*

***Keywords:*** *AHP, Peatland, MSCA, Risk, Transmission Tower.*

## INTRODUCTION

### Background

Indonesian government is building a 150 kV SUTT interconnection transmission connecting South Sumatra province with Bangka Belitung Islands to reduce the 48.6 MW electricity deficit. Specifically, the 150 kV SUTT transmission line was built through Tanjung Api-Api Special Economic Zone (KEK), in the coastal area, Banyuasin II sub-district, Banyuasin regency(Andriani et al., 2018). It is crucial to be aware that coastal area of Banyuasin 2 is a river delta with peat soil material structure and types of clay silt, which have a relatively high possibility for land subsidence (Ibrahim et al., 2018). The number of transmission points in this area is 59 towers and the distance between two consecutive towers is approximately 350 m. However, determining the location of each tower is based on considerations to minimize the potential for land subsidence, distance from the river, gap from settlements, and avoiding protected forest areas.

Long-term soil subsidence affects tower foundation thereby causing risk to the operational services. To accommodate changes that may occur at each stage, the design of project needs to be flexible(Sohn et al., 2020). Following this process, tower foundation structure has been designed according to the data from the cone penetration test. According to the results of the soil investigation, the type of foundation used in the fifty-nine 150 kV SUTT tower is a deep foundation type, specifically pile and bore pile foundations. In addition, the use of deep foundations for tower has been adjusted to the planned location of tower on peat soil with clay and silt

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structures. Generally, coastal areas face risk of rising sea levels which has the potential to affect the quality of infrastructure (Gallina et al., 2016). When determining the location of the foundation, coastal environmental factors, such as land subsidence, are considered because they often affect the condition and service life of tower.

Conceptually, land subsidence is the process of land surface movement caused by changes in soil volume. This process can occur gradually or rapidly, directly affecting the environmental surroundings. The factors causing land subsidence include natural, soil structure, and building mass (Artini et al., 2023). To assess risk factors from environmental influence on the construction of 59 150 KV transmission, risk assessment was conducted. In this context, GIS method (Andriani et al., 2018) was used for five parameters that influence environmental factors. Meanwhile, COPRAS and MCSA were used for risk parameter weighting and the risk assessment of tower location, respectively (Putranto et al., 2020).

## LITERATURE REVIEW

### Risk Assessment

Risk is an integral part of every activity and it is considered to be deviations from the desired level positively or negatively. Therefore, risk analysis is very important for the selection of construction types and coordination of construction work. It is crucial to be aware that risk sources in construction projects can be internal or external. Typically, internal risk is caused by several factors including project design, materials, human resources, and equipment. Meanwhile, external risk is attributed to natural, social, and economic environment.

Risk assessment in construction projects can be carried out using AHP method. Typically, risk of tower collapsing can lead to both financial and non-financial losses. Financial losses occur when tower cannot perform its function, necessitating the construction of a new tower. Aside from the cost of construction, financial losses can also occur due to electricity supply interruptions. On the other hand, non-financial losses arises from increasing customer complaints due to electrical disruptions,  which often require prolong time to repairs and replacement.

Land subsidence can cause the collapse of high-voltage electricity buildings. Extreme risk (collapse) can last for a relatively long time, causing transmission tower not to perform its functions as expected. It is crucial to be aware that risk level of transmission tower in Tanjung Api-api can be categorized as low, moderate, high, or extreme. Specifically, low-level risk occurs in transmission tower, namely cracks in the foundation structure due to the influence of land subsidence, while extreme risk is land subsidence that damages foundation structure.

The level of land subsidence can be influenced by various factors, including natural environmental factors (Mansur et al., 2022)and human factors. Natural environmental factors occur due to volcanic earthquakes, soil types, and the influence of waterlogging. Meanwhile, human factors are caused by groundwater exploitation, urban growth, high urbanization rates, and more. The level of risk is determined by weighting the predetermined criteria. The research is expected to improve the decision-making process and provide additional arguments, in assessing risk of construction projects using MCSA (Trialfhianty et al., 2022) and COPRAS methods (Vaissi & Sharifi, 2019) and assist in monitoring the maintenance of transmission tower.

### Multi-Criteria Decision Making

COPRAS is included in Multi Criteria Decision Making (MCDM) method (Asemi & Asemi, 2022). Consequently, this method is an effective tool in determining policies related to transportation infrastructure (Konstantinos et al., 2022). COPRAS is one of the decision-making methods based on various criteria (Podvezko, 2011). The COPRAS method is conducted by ranking alternatives based on predetermined criteria. Moreover, the criteria are divided into 2 categories, namely profitable criteria and unprofitable criteria. One of the advantages of COPRAS method is that it can determine the level of alternative utility. This method has been widely used in decision-making in the infrastructure sector (Liu et al., 2023).

## Multi-Criteria Spatial Analysis (MCSA)

MCSA is part of the methods used in decision-making on a policy based on simulation modeling of criteria and factors determined according to the objectives to be achieved (Vinogradova-Zinkevič et al., 2021). The data used were sourced from spatial data (map data), which is further weighed based on the determined criteria and sub-criteria. In addition, Geographic Information System (GIS) methods are required to process analyze and present data (Vaissi & Sharifi, 2019).

# METHODOLOGY

## Data and Location

The location of the 150 kV South Sumatra-Babel interconnector was in the coastal area of Banyuasin Regency. This area contained Delta of Banyuasin River and Musi River estuaries with coordinates of Longitude 104$^{o}$ 45’ 51.12” - 104$^{o}$ 55’ 19.2” East and latitudes 02$^{o}$ 31’ 6.96” – 02$^{o}$ 16’ 32.24” South. Typically, this location had Peat Soil Structure, Clay, and Silt soil types with hard soil depths of up to 20 m. In addition, the topography was undulating with a maximum height of 5 m above sea level. Based on interpretation of Citar Satellite TM 8 , the central part of land used for research was protected, namely peatland. While on the edge of the river, the delta was surrounded by Mangroves with conditions that were still quite good. Part of land area where transmission tower points were built was a transmigration area with oil palm plantations and tidal rice plants.

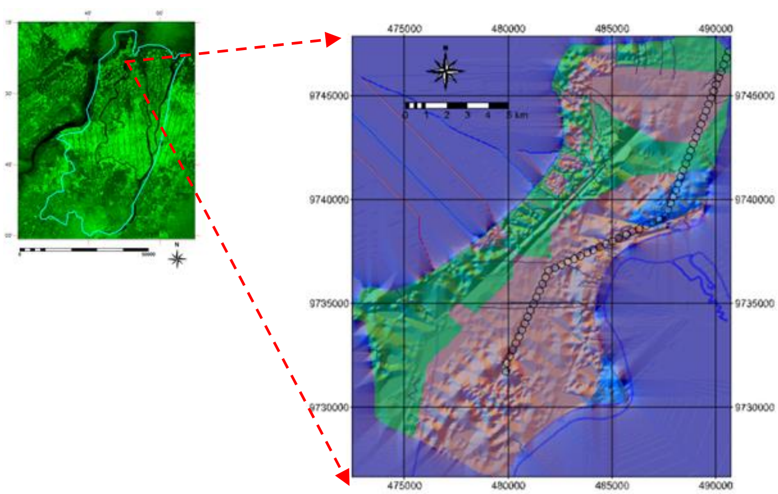


**Figure 1:** Topographic Conditions and Land Use in the Banyuasin Delta research area

**Source:** TM 8 OLI Image Land use Interpretation Results, and DTM analysis

## Data Source

Spatial and non-spatial data were obtained from related institutions. To obtain land use maps, TM 8 OLI Satellite Imagery was used (https://store.usgs.gov/user/login).

Soil-type data was obtained from the interpretation of TM 8+ satellite imagery and the results of the research area's borehole sondir, as well as the results of testing in the Laboratory in 2022. Land subsidence potential was analyzed using InSAR method, from Sentinel 1 imagery. Furthermore, watershed boundaries and drainage networks in the research area were presented using a 7.5 m resolution Digital Elevation Model (DEM) from DEMNAS (National Digital Elevation Model) downloaded from (https://tanahair.indonesia.go.id/demnas/#/).

**Table 1: Data Sources and Requirements**

| Data | Source Data Analysis Method | Analysis Method |
|---|---|---|
| Soil Type | Sentinel 1 Satellite Imagery (10 m) and Landsat 8 OLI + Satellite Imagery (30 m and 15 m Panchromatic) (Download: https://scihub.copernicus.eu/dhus & https://earthexplorer.usgs.gov/) | NDSI (Normalized Difference Soil Index) NDSI = (SWIR – NIR) / (SWIR + NIR) |
| Land Use | | NDVI (Normalized Difference Vegetation Index) NDVI = (NIR – Red) / (NIR + Red) NDBI (Normal Difference Built-Up Index (SWIR - NIR)/(SWIR + NIR) |
| Waterlogging (Swamp) | | MNDWI (Modified Normalized Difference Water Index) MNDWI = (Green – SWIR )/ (Green + SWIR) |
| Land Subsidence | Sentinel 1 Imagery (2020) | InSAR Method |
| Soil Investigation | South Sumatra - Babel Transmission Network Project Activities Plotting spatial data and data from soil structure analysis | Plotting spatial data and data from soil structure analysis |
| DEM Nas | DEM Nas (https://tanahair.indonesia.go.id/demnas/#/) | DEM hydroprocessing |
| Expert | Questionnaire | Weighting (AHP and COPRAS) |

## RESULT AND DISCUSSION

The implementation of the research used weighting of criteria and sub-criteria based on expert opinions analyzed using adjustment method. The determination of tower with the greatest potential to experience land subsidence was assessed using COPRAS. Additionally, MCSA method was used to determine the location of tower with the potential to experience risk.

In determining the risk value, it is carried out by weighting based on assessments from academic experts who have previously conducted the same research in the Banyuasin Regency area. There were five criteria used in weighting risk value of land subsidence in tower construction, namely land use type, distance to water bodies, land slope, soil type, and cone value.

### Determination Of Weights Using Method Was Conducted with The Following Stages

Develop the values for the five criteria based on questionnaire data obtained from academic expert opinions.

**Table 1: Criteria weight value**

| Criteria | Land use | Potential for Inundation | Slope | Type of Soil | Conus Value |
|---|---|---|---|---|---|
| Weight | 0,3 | 0,1 | 0,125 | 0,3 | 0,175 |

**Source:** Analysis results

Compile the values for each sub-criterion based on questionnaire data obtained from expert opinions.

**Table 2 : Sub-criteria weight value**

| Criteria | Weights | Sub Criteria | | | | | |
|---|---|---|---|---|---|---|---|
| Land use Planning | 0,3 | protected forest | rice field | Settlement | Industrial | Not deff. | |
| | | 0,075 | 0,175 | 0,25 | 0,5 | 0 | 1 |
| Type of Soil | 0,3 | Sand | silt | clay | not deff. | Not deff. | |
| | | 0,3 | 0,325 | 0,375 | 0 | 0 | 1 |
| Distance from Body of Water | 0,1 | < 10 m | 10-20 m | 20-30 m | >30 m | Not deff. | |
| | | 0,45 | 0,275 | 0,175 | 0,1 | 0 | 1 |
| Slope | 0,125 | < 8 % | 8-15 % | 15-30 % | 08-15% | > 45 % | |
| | | 0,05 | 0,1 | 0,2 | 0,275 | O,375 | 1 |
| Cone value (Cm2/Kg) | 0,175 | < 50 | 50-100 | 100-200 | >200 | Not Deff. | |
| | | 0,475 | 0,3 | 0,15 | 0,075 | 0 | 1 |
| Sum | 1 | | | | | | |

**Source:** Analysis results

## Determination of Risk Value with COPRAS Method

From the criteria weight value and sub-criteria weight obtained through AHP method, the next step was to determine tower risk classification using COPRAS method. Stages in determining the decision-making classification using COPRAS method included (1) Compiling the normalization of decision matrix (D), (2) Normalizing decision matrix, (3) Determining the normalized decision matrix weight (D′), (4) Calculatinthe minimum and maximum indexes for each alternative, (5) Calculating the relative weight of each alternative, and (6) Calculating the quantitative usefulness (Ui) for each alternative. The results of the calculation stages above, the weight of risk value of each classification were obtained as follows. For each criterion that had been set, a different classification was obtained. Additionally, the last classification was on the type of soil, namely 3 classifications which included sand, silt, and clay. While the most classifications, 5 classifications were on the slope of land including <8%; 8-15%; 15-30%; 30-45%; >45%.

**Table 3 : Classification of risk values based on criteria**

| **Criteria** | **Weights** | **1 Class** | **2 Class** | **3 Class** | **4 Class** | Sum |
|---|---|---|---|---|---|---|
| Land use Planning | 0,3 | Industrial state | Settlement | Rice field | protected forest | |
| | | 0,5 | 0,25 | 0,175 | 0,075 | 1 |
| Type of Soil | 0,3 | Clay | silt | Sand | not deff. | |
| | | 0,375 | 0,325 | 0,3 | 0 | 1 |
| Distance from Body of Water | 0,1 | < 10 m | 10-20 m | 20-30 m | >30 m | |
| | | 0,45 | 0,275 | 0,175 | 0,1 | 1 |
| Slope | 0,125 | > 45 % | 30-45 % | 15-30 % | 8-15% | |
| | | 0,375 | 0,275 | 0,2 | 0,1 | 1 |
| Cone value (Cm2/Kg) | 0,175 | < 50 | 50-100 | 100-200 | >200 | |
| | | 0,475 | 0,3 | 0,15 | 0,075 | 1 |
| Sum | 1 | 2,175 | 1,425 | 1 | 0,35 | |

**Source:** Analysis results

## Determination of Risk Value on Installed Tower Using MCSA Method

Determination of risk value of installed tower was based on the criteria and classification of risk factors identified using COPRAS method and spatial analysis was conducted using MCSA. All elements of the environmental factors criteria, including land use, soil type, distance to water bodies, land slope, and conus value from soil investigations, were mapped in spatial form using the same coordinate and georeferenced system. Moreover, the results were then analyzed spatially using the addition and multiplication methods of each class and criteria weight.

## Land Use Criteria

The research area was a river delta area located between two river estuaries, namely Musi River and Banyuasin River. Land use in the research area was dominated by tidal swamp land and surrounded by Mangrove Forest. Additionally, Tidal land agriculture dominated the productive areas in the research area.

Land use criteria consisted of several sub-criteria including industrial areas, settlements, agriculture, and protected forests. Based on the weighting results, the highest sub-criteria obtained were industrial areas at 0.5 and the lowest sub-criteria were protected forests at 0.075.

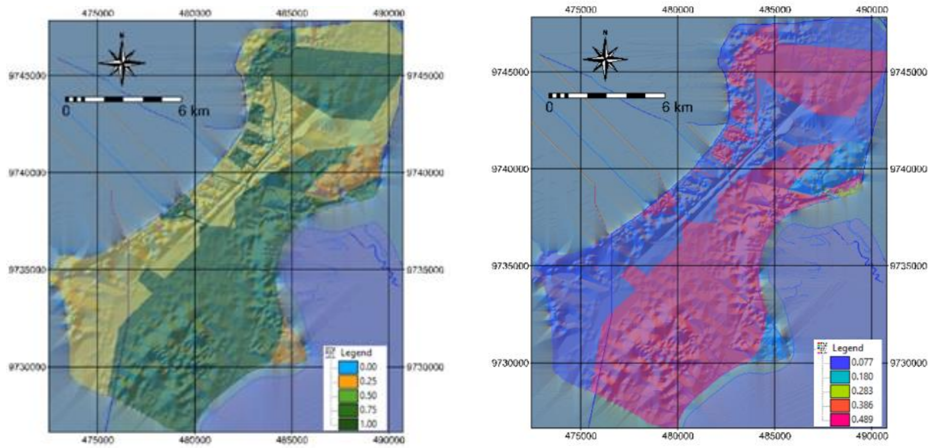


**Figure 2.** Land Use Weight (left) ; (b) Land use sub-class classification (right)

**Source:** Analysis results

## Soil Type Criteria

The results of the interpretation of multispectral remote sensing imagery in 2020, the soil conditions in the research area were Glei Humus Organosol Association, Grayish Brown Alluvial, and Light Gray Alluvial. Based on the results of the interpretation of TM 8+ satellite image composite, in 2020, there were 2 (two) types of rock textures in the research area, namely claystone and dusty clay and sandstone.

The results of the weighting of the soil type sub-criteria showed that the highest weight was 0.375, the lowest was the sand sub-criteria with a value of 0.3, and silt weight was a value of 0.325.

**Table 4: Distribution of Soil Types in the Research Area**

| Type of Soil | LS_HA | Organic Material | Texture | Permeability |
|---|---|---|---|---|
| Alluvial Greyish Brown | 12.593,34 | medium-high | Dusty Clay | Slow |
| Gley humus organosol association | 2.162,79 | medium-high | Clay | Slow |
| Light grey alluvial | 7.129,06 | medium-high | Dusty Clay | A bit slow |

From Figure 3, the soil classification criteria in the research area were dominated by rock types in the form of clay and dusty clay based on soil type and texture.

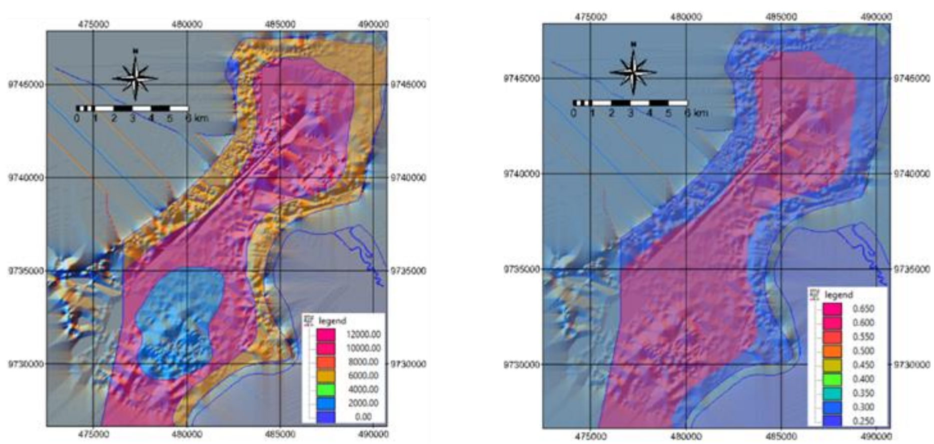


**Figure 3**. Distribution of Soil Types based on texture (left), (b) Classification of Soil Types based on constituent textures (right)

**Source:** Analysis results

## Distance Criteria to Water Bodies

The criteria distance to water bodies had four sub-criteria, namely distance <10 m; 10-20 m; 20 – 30 m, and > 30 m. Among the four sub-criteria, the highest weight was the sub-criteria <10 m with a value of 0.562, and the lowest was the sub-criteria >30 m with a value of 0.080. When the location of tower point is close to a body of water, a river, or a swampy area, the location could be considered at risk of flooding. This signified that risk of land subsidence was higher compared to areas that were free from water puddles. Following this scenario, the weight of each sub-criteria was shown in Figure 4.

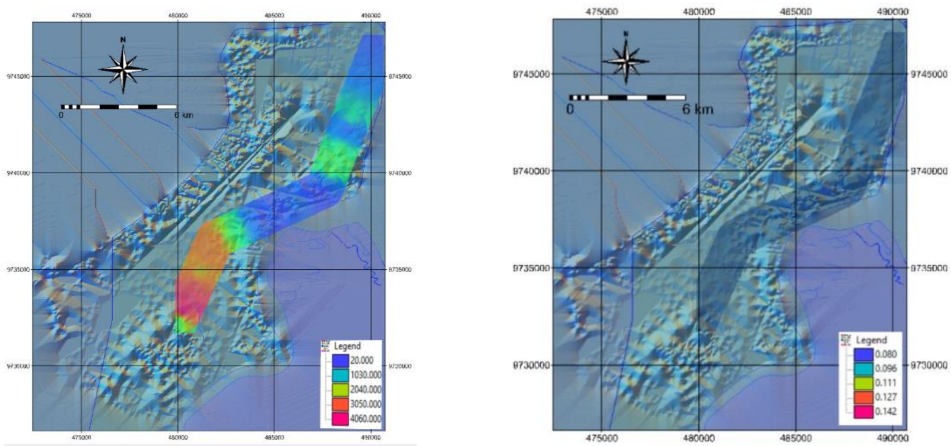


**Figure 4**. Distance to a water body (left); (b) Classification of distance weight to the water body (right)

**Source:** Analysis results

## Land Slope Criteria

The topography of the research area had various levels of slope, ranging from flat (0-8%), gentle (8-15%), hilly (15-45%) and steep (> 45%). In addition, the topographic conditions were dominated by a slope level of <8%, namely in the form of plains and swamps covering an area of 38,466.24 Ha, gentle locations covering 124.44 Ha, hilly locations covering 162.12 Ha and steep slopes with an area of 0.8 Ha.

Based on the weighting results, information obtained showed that the sub-criteria for land slope with the highest weight was very steep with a weight of 0.428 and the lowest was flat with a weight of 0.059.

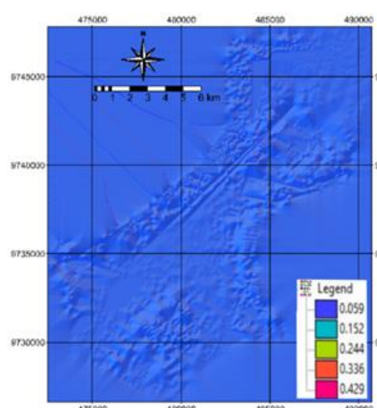


**Figure 5:** Land slope weight classification

Source: Analysis results

## Conus Depth Criteria (Qc)

Soil exploration was intended to determine the condition of the soil structure. This process could be considered when determining the construction type of transmission tower foundation. The data set used in the research was synthetic borehole data from the results of soil investigation, including vertical distance to the top and bottom of the ground surface. Furthermore, the unit value of each component represented the value of the soil structure which had a different soil-bearing capacity value for various types of foundations that were used. Soil Mechanics experts used the data to calculate the capacity based on the assessment of the spatial variability of the soil bearing capacity thickness, which was technically important for determining the ratio of the foundation strength that was used according to the capacity at that location.

The existing soil structure consisted of the arrangement of rock grains, elasticity, water content, hardening, etc. When these parameters were examined in the laboratory, various types and conditions were interpreted and spatially mapped according to the soil investigation parameters that exist on a geomorphological basis.

A spatial description in this context could assist in interpreting the conditions of the natural environment. Furthermore, the soil layer (stratification) was known and was classified based on the cone value (qc) of the soil, the depth of the hard soil, the amount of adhesive resistance (JHP), NSPT value, at several depth elevations (usually per 2-3 m) in the end. This data was required to calculate the soil-bearing capacity, foundation-bearing capacity, and pile-bearing capacity in the relevant area. In addition, the weighting criteria for cone were divided into several sub-criteria, namely qc <50 kg/cm2, 50 - 100 kg/cm2, 100 - 200 kg/cm2, and> 200 kg/cm2. Based on the results of the weighting classification, the highest weight value was obtained in the sub-criteria <50 kg/cm2 with a value of 0.305, and the lowest weight in the sub-criteria> 200 kg/cm2 with a value of 0.182. Figure 6 showed the weight classification for each cone value sub-criteria in the research area.

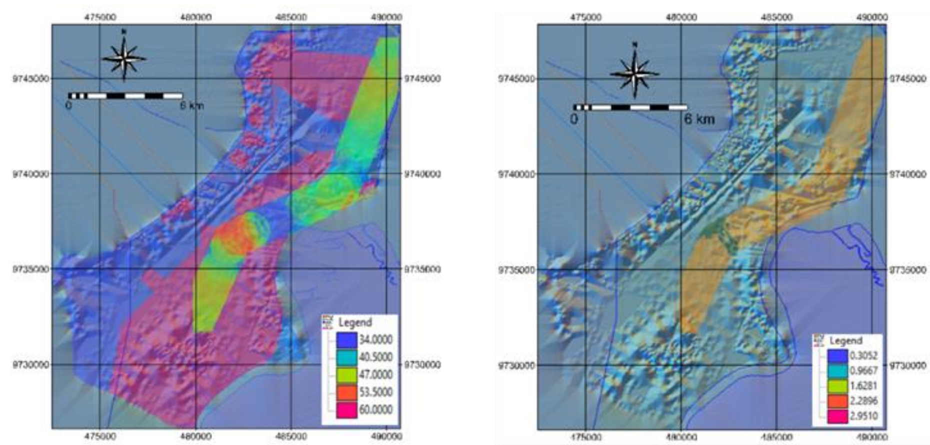


**Figure 6:** Distribution of conus value depth at 59 points along Tower location including (*left*) and Classification of conus value criteria weight (*right*)

**Source:** Analysis results

## Determination of Priority of Installed Tower Monitoring Based on Copras Method With Mcsa

In determining the priority of land subsidence on tower using COPRAS method, it was necessary to know the benefit criteria and non-benefit criteria. Distance from water and land slope were non-benefit criteria with the potential for land subsidence. Meanwhile, the cone depth criteria, land use, and soil type were benefit factors. Based on the determination of alternative tower that had the greatest risk of land subsidence using COPRAS method, approximately 10 towers were firstly prioritized (T30, T33, T34, T39, T40, T41, T42, T43, T48, and T44). The second priority was 22 towers (T20, T31, T38, T47, T49, T18, T19, T22, T23, T24, T25, T26, T27, T28, T29, T32, T36, T45, T46, T21, T35, T37, T56, T57), while the third priority was 27 towers (T56, T57, T59, T62, T64, T66, T67, T50, T53, T54, T55, T58, T60, T61, T63, T65, T51, T52, T9, T10, T11, T12, T13, T14, T15, T17, and T16). Tower with the highest risk were spread into plantation areas and industrial areas.

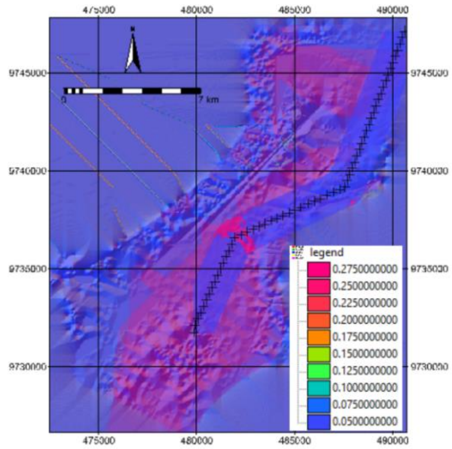


**Figure 7:** Distribution of installed tower with monitoring priorities based on the determination of COPRAS method and spatial analysis based on MCSA method

**Source:** Analysis results

## Land Subsidence Research Based on Satellite Image Analysis with InSAR Method

The data used in land subsidence analysis was SAR Sentinel-1A level 1 image from ESA (European Space Agency) downloaded from the Alaska website https://search.asf.alaska.edu/ for the period 2018 to 2023. This SAR image has the characteristics of SLC (single-look complex) type of C-band sensor (ESA, 2019).

SAR Image Extraction with InSAR used the D-InSAR method (Ruiz-Armenteros et al., 2018)(Ahmad et al., 2017) which included (1) importing additional data and information, (2) image coregistration, (3) initial processing (4) interferogram and calculating coherence, (5) interferogram filtration (6) Phase unwrapping, (7) absolute phase to height, and (8) absolute phase to displacement.

At the interferogram stage (VV phase), land subsidence was shown in the location area along the installed transmission line. However, this phase is still ambiguous because it was still in +2phi to -2phi phase unit. The interpretation of this interferogram phase showed a change in the shape of the surface of the installed transmission line area.

Based on Figure 8, VV phase value in both periods (2018 and 2023) was -3.14 to 3.14 phi. Furthermore, VV phase can vary in value due to the dry or rainy season conditions in the research area. Differences in VV phase values were also caused by the type of data or the quality of input data, particularly concerning accuracy and precision.

## Vertical Displacement Extraction for the 2018-2023 Period

At the finite phase of displacement, three files were integrated, namely coherence, unwrapped phase, and DEM. In this stage, the basic parameters used were product coherence threshold (0.2), vertical displacement, slope displacement, custom direction displacement, X dimension (5 m), Y dimension (5 m), window size interpolation (7), and dummy removal. Based on Figure 8(a), the vertical displacement value around Delta Banyuasin estuary research area in the period from October 2018 to August 2023 was around -9.13 to 9.13 cm. In general, the area around Banyuasin Delta experiences negative subsidence or vertical displacement. Based on Figure 8(b), the vertical displacement value along the 150 kV transmission tower line is dominated by values of -0.030 to 0.090 m. In general, along transmission tower line, subsidence occurred, which was located in the range of -3 to + 9 cm for every five years. Along the 150 kVa transmission tower line, there was also a positive uplift or vertical displacement of 0.1 to 9 cm every five years. Furthermore, subsidence phenomenon occurred for five years from August 2018 to August 2023 and was included in the category of low vertical displacement (low deformation). Meanwhile, Banyuasin Delta estuary was not directly affected by volcanic movements or activities and tectonic plates (M.G. Bishop, 2001). This activity was known from research on the Semangko Fault active zone area (Bock et al., 2012). Visually, tower T.19 - T.27 point had the largest subsidence value compared to the long section profile line T.1 - T.18. In addition, the largest subsidence value was -4 cm at a distance of 3 km from the starting point. The phenomenon of significant land subsidence occurred along the long segment profile line in five years since August 2018.

Moreover, social media enables people to create profiles and to share content including images, video, and web links and to connect with their friends, colleagues, and relatives (Luo et al., 2022). Since this is a trend among most youngsters, strategic marketers increasingly use social networking platforms to advertise their brands and ideas.

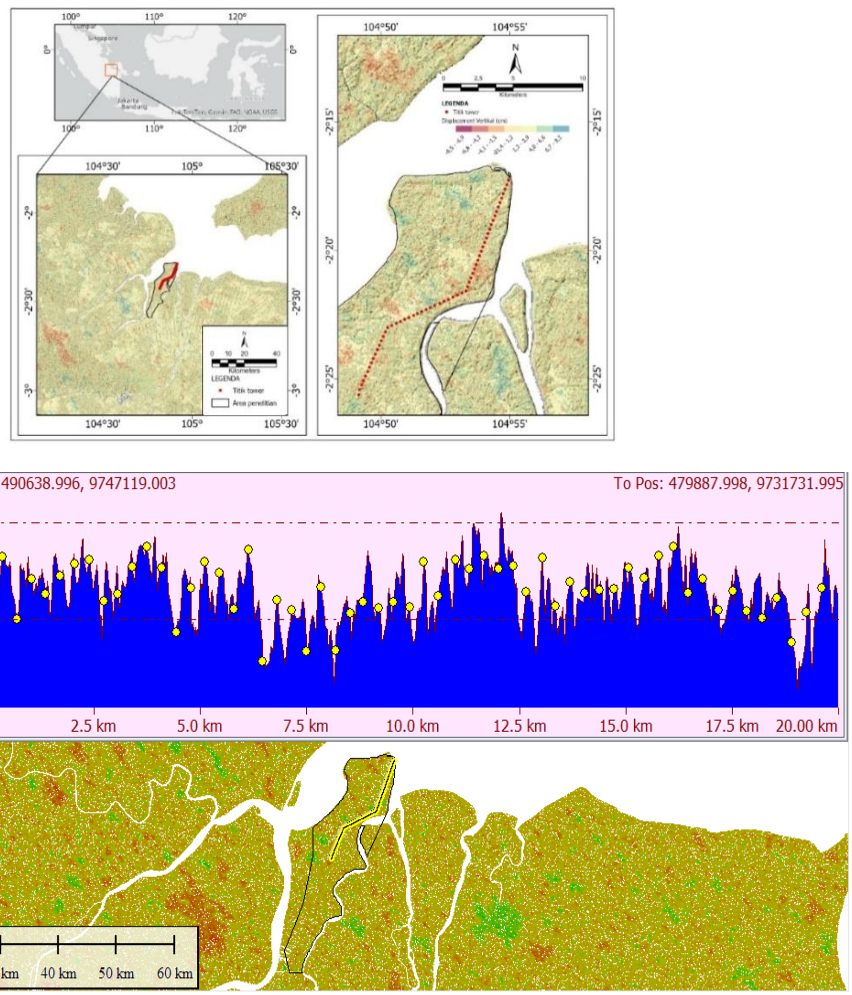


**Figure 8**. Land subsidence in the Banyuasin Delta region and (top) and Long section profile of vertical displacement along Transmission Line of Tower Locations installed in the period 2018-2023 (Yellow line, bottom).

**Source:** Interpretation Analysis results

Transmission tower located in the highest land subsidence area using SMCA method included T13 to T22 and T38 to T67. Tower with the highest risk based on SMCA was located in industrial area and tower land contour had land slope of 00 - 80 degrees.

## CONCLUSION

According to the research on the influence of land subsidence, the following conclusions were described.

The analytical result showed that land use had the greatest risk influence on land subsidence in 150 kV transmission tower, with a weight of 0.3. Meanwhile, the smallest risk was the cone value with a weight of 0.1.

Based on an assessment using Copras method, the priority of tower location with the most impact on land subsidence was land slope and distance to water bodies. In particular, these factors had vulnerability values between 2,175 and 0.352.

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