

# Spatial analysis of land subsidence potential due to lowland conversion (case study at Tanjung Api-Api)

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## Spatial analysis of land subsidence potential due to lowland conversion (case study at Tanjung Api-Api)

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**Abstract.** The conversion of lowland area into special economic zones at Tanjung Api-Api will trigger environmental degradations, one of which is land subsidence. Land subsidence potential is caused by several natural environmental factors, which are soil type, soft soil thickness, topography, geological conditions, and rainfall, and non-natural factors, which are caused by land use or land cover, groundwater extraction, building density and others. Multicriteria analysis was conducted to obtain the weight of each factor, then the factor was overlaid to determine the level of land subsidence based on land use or land cover. Spatial analysis has been done to many factors causing land subsidence. The results showed that industrial estates and housing areas have a high potential for land subsidence. Mitigation efforts must be carried out to reduce severe land subsidence at the built-up area.

### 1. Introduction

Lowland area is a vulnerable area, which is unstable to environmental changes. The conversion of lowland areas on a large scale can trigger environmental problems. The Problems are environmental degradation such as land subsidences, floods, forest fires, carbon emissions and biodiversity reductions in lowlands, the decrease in the quality of life, and even economic losses. Indications of land subsidence at Tanjung Api-Api have been seen in residential areas such as damage to house floors and the roads [1].

Tanjung Api-Api is a very strategic area because it functions as a seaport area and industrial area. Tanjung Api-Api is expected to encourage economic growth in South Sumatra. The determination of this area as an exclusive economic zone will trigger the growth of high residential and changes in lowland ecosystems. The hoarding of lowland is done to get land areas that are used as residential, industrial, agricultural and plantation. The massive conversion of lowlands will cause positive and negative impacts on the environment and humans. The construction of infrastructure and residential areas in Tanjung Api-Api will require special handling due to unstable soil conditions. One of the negative impacts caused by the conversion of lowlands is land subsidence.

Land subsidence is caused by excessive groundwater extraction, building loads, soil types, and tectonic influences [2,3,4,5]. The high potential of soil subsidence will occur in the Tanjung Api-Api area because the types of soil in the Tanjung Api-Api region are in the form of organic soil, organic clay, and clay [6,7]. The condition of groundwater fluctuations and the types of constituent soil found in lowland areas will trigger land subsidence due to the landfill process [8].

Changes in land use or land cover into industrial estates and residential areas have caused land subsidence in Indonesia and the world. In general, the land subsidence in Jakarta, Semarang, Bandung,



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and Surabaya is caused by the increasing growth of industrial estates and housing areas. The changes in land use result in excessive groundwater extraction and soil consolidation due to building loads [9, 10,11,12,13]. According to the study of land use or land cover change at Tanjung Api-Api, there was a conversion of land use or land cover of the mangrove forest area into a plantation and aquaculture area in the Tanjung Api-Api area (Air Telang, Banyuasin) from 1989 to 2013 [14]. Changes in land use or land cover due to the increase in built-up areas, which are housing areas, infrastructure buildings and buildings, will cause an increase in surface temperature and environmental degradation [15].

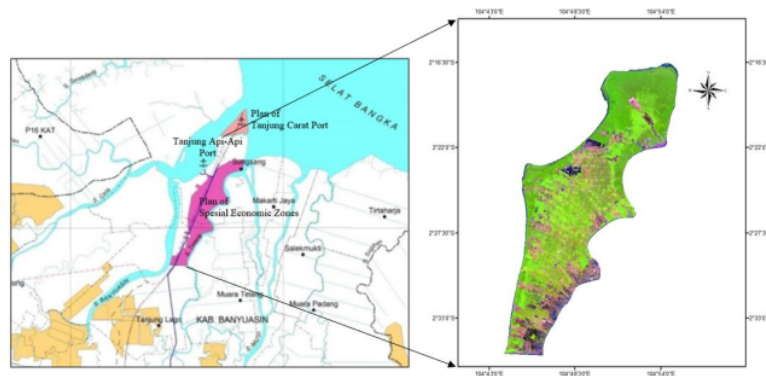
Spatial analysis is one of the models developed to link various spatial environmental information. By using multicriteria analysis, it can be seen that the area has the potential to experience land subsidence so that mitigation efforts can be carried out in the area in order to create sustainable development in lowlands [16-26].

This paper aims to present a spatial model of land subsidence potential that will occur in lowland areas, especially in the Tanjung Api-Api area due to land conversion because of the growth of industrial estates and residential areas.

## 2. Material and method

### 2.1. Study area

Tanjung Api-Api is one of the lowland areas on the east coast of Sumatra island in the Banyuasin district, South Sumatra. Geographically, the Tanjung Api-Api area is located at  $104^{\circ} 45'$  to  $104^{\circ} 55'$  E and  $2^{\circ} 17'$  to  $2^{\circ} 24'$  S (figure 1).



**Figure 1.** Location of research.

Tanjung Api-Api area has a flat topography, 0 - 2%, and a land surface height of about 1 - 5 m. Based on the geological map of Palembang sheet, Tanjung Api-Api area is a quarterly formation consisting of swamp deposits, which are mud - silt - and sand, blackish gray which contains many plant residues in the form of roots and leaves, remnants of rotten wood pieces, humus, and peat (figure 2).



**Figure 2.** Geological map of Palembang sheet.

Most of the soil in this area consists of soft soil in the depth of more than 20 meters and peat soil with a thickness of fewer than 2 meters. Soil condition of Tanjung Api-Api area is moist to saturated, has a clay, has a large and not well-consolidated coefficient of consolidation and shrinkage limit so that these conditions will trigger land subsidence in case the land is loaded. Tanjung Api-Api area is influenced by tidal conditions because the area is located among the Banyuasin river, Telang river, Bangka strait, and the overall Tanjung Api-Api area which has a swamp ecosystem. Tides occur in one day with a maximum level of 2.39 meters. The results of the research showed that water at Tanjung Api-Api region is the brackish water having the content of sodium (Na) of 1050 mg/liter, chloride (Cl) of 1909,1 mg/liter, pH of 4.55 and corrosive groundwater [6].

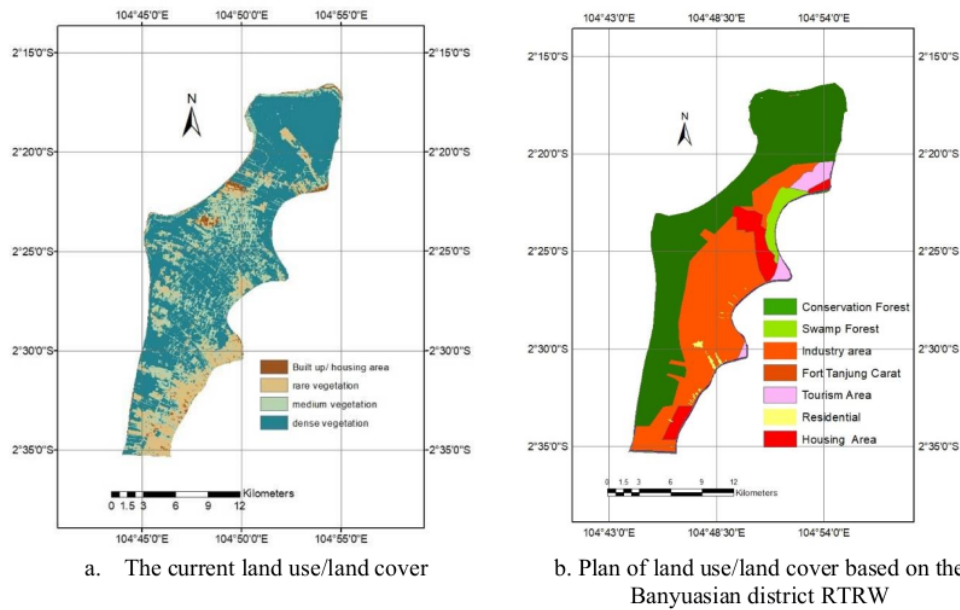
### 2.2. Data analysis

Spatial analysis is done using Quantum Gis version 3.8.1. An analysis is carried out using the AHP (Analysis Hierarchy Process) based on the opinions of people who are experts in the field of geotechnics and the environment to obtain the weight of the factors that cause land subsidence.

In this study, eight thematic maps were used, namely maps of soil type, soft soil thickness, land use or land cover, embankment height, groundwater extraction, topography, geological conditions, and rainfall. By using overlapping techniques and Multi-Criteria Spatial Analysis (MCSA), further zoning of land subsidence will be obtained with two conditions, namely the existing condition and the condition of the planned development of the Tanjung Api-Api area. Figure 3 showed a map of current land use and land use based on the spatial plan of the Banyuasin region.

In this study, three models were used based on variations in land use or land cover, groundwater extraction, and embankment height. Modeling is done based on the weight values of groundwater extraction and embankment height.

- Model 1. The potential of land subsidence in case the groundwater and variations in embankment height for each land use or land cover plan are not used.
- Model 2. The potential of land subsidence in case the water sources from shallow wells and variations in embankment height for each land use or land cover plan are used.
- Model 3. The potential for land subsidence in case the water sources from deep wells or bore wells and variations in embankment height for each land use or land cover plan are used.



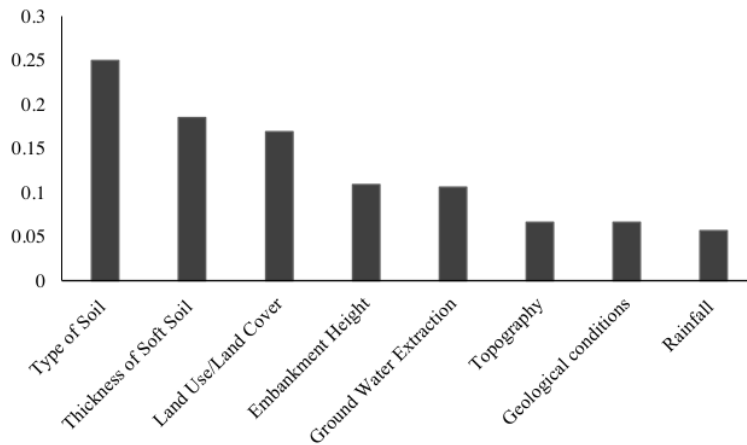
**Figure 3.** Map of land use or land cover at Tanjung Api-Api area.

### 3. Results and discussion

In general, Tanjung Api-Api area has the same regional characteristics as follows: the type of soil is clay or silt, which thickness is 11m to 20m; geological conditions consist of swamp deposits; the topography is flat; the rainfall is high. Based on these characteristics, the Tanjung Api-Api area has the potential for land subsidence. The potential level of land subsidence depends on the type of land use or land cover, the load of construction, and groundwater extraction.

#### 3.1. Evaluation of factors causing land subsidence using the Analytical Hierarchy Process (AHP) method.

Land subsidence is caused by several factors, namely natural and human factors. Natural factors that cause land subsidence are soil type, soft soil thickness, topography, geological conditions, and rainfall. While the non-natural or human factors that trigger land subsidence are land use or land cover, groundwater extraction, embankment height, and others. To determine the land subsidence potential, weighting and scoring are carried out from these factors using questionnaires obtained from the experts in the geotechnical and environmental. Figure 4 showed the weight of factors causing land subsidence, by using the Analytical Hierarchy Process (AHP).



**Figure 4.** Weights factors causing land subsidence.

Table 1 showed the weighting results and scores for each criterion and sub-criteria of the factors that cause land subsidence.

**Table 1.** Weight and score of non-natural factors causing land subsidence.

Parameters	Weight	Score	Value
Land Use/ Land Cover			
a. Industrial area	0.169	47.90	7.76
b. Residential/ housing		22.90	3.71
c. Trade and service area		18.70	3.03
d. Agriculture/ plantation		6.80	1.10
e. Bare land		3.60	0.60
Embankment Height			
a. 2 m	0.109	70.20	7.58
b. 1 – 2 m		19.00	2.05
c. < 1 m		10.80	1.17
Ground Water Extraction			
a. Not using groundwater	0.106	13.00	7.738
b. Shallow wells		14.00	1.484
c. Deep wells		73.00	1.378

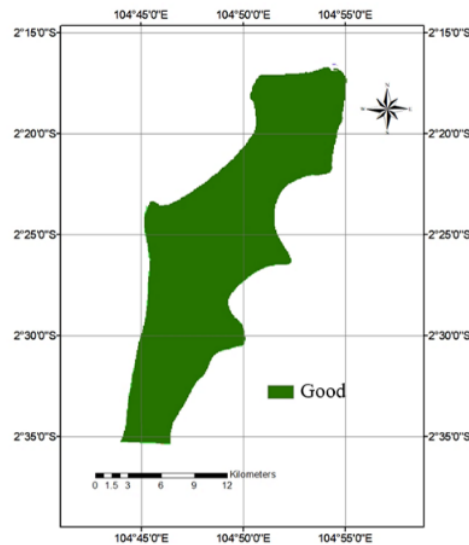
Figure 4 showed that there are five main factors that cause land subsidence: soil type, soft soil thickness, land use or land cover, embankment height, and groundwater extraction. Parameters that have a high weight value indicate that these parameters are the main factors causing land subsidence, while other parameters are supporting or less essential factors that can lead to land subsidence. The supporting or less essential factors are topography, geological conditions, and rainfall, each of those has a weight value < 0.1. The higher the weight value and score indicate that the area has a high potential for land subsidence. In this study, the area was divided into five zonings based on the highest weight value and the lowest weight value. Table 2 showed the interval score for land subsidence potential.

**Table 2.** The interval score of land subsidence potential.

The Potential of Land Subsidence	Interval Score
Good	7.55 – 16.64
Low	16.65 – 25.73
Medium	25.74 – 34.82
High	34.83 – 43.91
Very high	43.92 – 53.00

**3.2. Existing conditions of land subsidence potential**

Figure 5 showed that the condition of the existing area has a low potential for land subsidence (S value between 18.90 to 22.01). This fact is because most of the land use or land cover in the Tanjung Api-Api area consists of mangroves, plantations or agriculture, dryland agriculture, and shrubs, all of which have little weight on land subsidence compared to residential and industrial areas [28]. Currently, the housing area has a low potential for land subsidence because the density of housing in the Tanjung Api-Api area is very low, so that the loading of infrastructure and extraction of groundwater is low, besides that many communities still use houses on stilts.



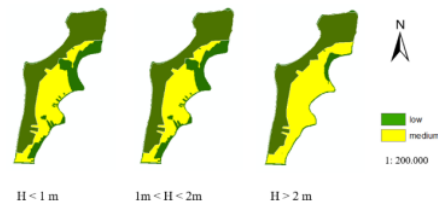
**Figure 5.** Existing Condition of Land Subsidence Potential.

**3.3. Land subsidence potential due to conversion to built-up area**

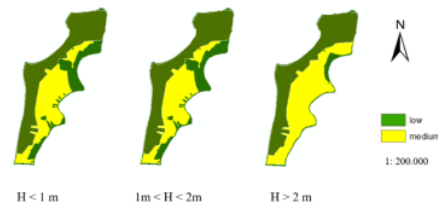
The construction of Special Economic Zones in Tanjung Api-Api will cause land conversion from plantation or agricultural areas to industrial estates and housing areas. Based on the District Spatial Planning Banyuasin for 2010-2030, the Tanjung Api-Api area will be developed into several strategic



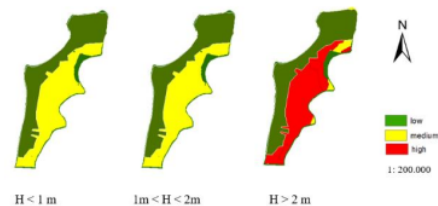
areas of South Sumatra Province, one of which is the Special Economic Zone. The construction of industrial estates and housing areas will lead to groundwater extraction and land reclamation. The spatial model is divided into three models based on the source of groundwater extraction and embankment height. The results of spatial analysis are shown in figure 5.



Model 1. The potential of land subsidence in case groundwater was used.



Model 2. The potential of land subsidence in case shallow wells was used.



Model 3. The potential of land subsidence in case deep wells was used.

**Figure 6.** The potential of land subsidence based on variations of height of embankment and groundwater extraction.

Spatial analysis showed that the results based on models 1 and 2 have the same potential pattern of land subsidence. The conversion of lowland functions into industrial estates caused a medium-level potential of land subsidence, while mangrove forests and tourism areas in residential areas have a low-level potential of land subsidence. The low potential for land subsidence in residential areas is due to the absence of groundwater exploitation. The absence of groundwater exploitation is because the community obtains water from other sources such as rainwater and because the building load is still low due to the embankment height of  $< 2\text{ m}$ . The increase of embankment height ( $h > 2\text{ m}$ ) causes an increase in load which must be borne by the subsoil; as a result, the potential for soil subsidence is medium.

Model 3 showed that industrial estates and residential areas have high land subsidence potential due to the embankment height of  $> 2\text{ m}$  and the presence of deep well water extraction. Height of

embankment of > 2m will cause additional loads, while the use of deep wells or bore wells can cause emptying of cavities in the soil so that there will be a compaction of soil grains that causes soil subsidence. The occurrence of high potential for land subsidence is because of the increase of the load that must be borne by the subgrade. In addition, the occurrence of high potential for land subsidence because the compressible soil will be more easily deformed due to loading and changes in ground level [29-33].

The high potential of land subsidence in industrial estates and residential areas is also caused by a large number of activities in the area resulting in an increase in groundwater extraction and also large-scale stockpiling of lowlands to avoid flooding and tides.

#### 4. Conclusions

Based on the spatial analysis performed, the conversion of lowlands area into industrial estates and housing area potentially cause the land subsidence, compared to the potential of land subsidence occurrence in agriculture, plantation, and bare land areas. Groundwater extraction using deep wells and land reclamation with embankment height more than 2 m triggers high land subsidence in the Tanjung Api-Api area.

#### Acknowledgements

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