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Mapping and Analysis of Peatland Subsidence Using GIS: A Case Study of Karya Tani Village, Indonesia

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ABSTRACT

This study was conducted in Karya Tani Village, Kempas District, Indragiri Hilir Regency, an area where signs of peatland subsidence have become increasingly evident. Surface subsidence of peat is notably observable through the exposure of root systems in perennial vegetation, particularly on community-managed lands. Subsidence represents a serious environmental threat, serving as a key indicator of peatland degradation. Though gradual, this process can result in extensive ecological damage and, in extreme cases, the irreversible loss of land. Accordingly, mapping and analyzing subsidence rates using Geographic Information Systems (GIS) is crucial for assessing the spatial extent and severity of this phenomenon. Field observations were conducted to document subsidence indicators, which were primarily identified through mature coconut trees exhibiting exposed root systems above the soil surface. Data collection was carried out over a 30-day period, from October 27 to November 27, 2022, in Karya Tani Village. Subsidence rate mapping was performed using ArcGIS software, employing the Topo to Raster interpolation method for spatial analysis. The results indicate that subsidence rates in the study area range from 2.75 to 6.50 cm/year, with an average rate of 4.45 cm/year.

1. Introduction

Peat soils typically consist of approximately 90% water and 10% vegetative solids. As a type of wetland, peatlands require careful water management to prevent excessive water loss, which

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is essential for controlling land subsidence. Subsidence is the process of surface lowering in peatlands, driven by several interrelated factors including the lowering of the groundwater table due to drainage, decomposition, soil oxidation, microbial activity, land clearing, and peatland fires. One of the primary issues arises when drainage canals are constructed to reduce water saturation in the root zone of plants. While these canals aim to improve agricultural viability, they often lead to unintended consequences, such as the drying of peat soils. Once dry, peat loses its water retention capacity, exacerbating subsidence. Moreover, due to its intrinsic properties, previous studies have reported that once peat reaches a certain level of dryness, it becomes hydrophobic and is unable to reabsorb water effectively.

In the eastern coastal region of Riau, particularly in Karya Tani Village, Indragiri Hilir Regency, signs of peatland subsidence have been observed. This surface lowering is evident from the exposure of perennial plant roots on local farmlands, indicating ongoing subsidence in the area. Although the process of peat surface decline occurs gradually, it is continuous and irreversible. Subsidence poses a significant threat as a key indicator of peatland degradation, progressively leading to the deterioration and eventual loss of these ecosystems. Given this context, the present study aims to analyze and map the rate of subsidence occurring in the peatlands of Karya Tani Village. The objective is to identify critical areas and propose appropriate mitigation strategies to anticipate and reduce the adverse impacts of peatland subsidence.

This study aims to map the spatial distribution of peat surface subsidence using Geographic Information System (GIS) technology and to analyze the rate of subsidence occurring in the peatlands of Karya Tani Village through direct field measurements and interviews. The primary benefit of this research is to quantify both the magnitude and rate of subsidence in the area, thereby producing a detailed subsidence map that can serve as a basis for mitigation planning. Such information is critical for informing strategies to manage and control the extent of subsidence in peatland areas.

2. Literatur Review

Peatlands store large amounts of soil carbon and freshwater, constituting an important component of the global carbon and hydrologic cycles. Accurate information on the global extent and distribution of peatlands is presently lacking but is needed by Earth System Models (ESMs) to simulate the effects of climate change on the global carbon and hydrologic balance [1]. Peatlands are areas formed from the accumulation of partially decomposed plant remains, with a minimum thickness of 50 cm or more. Peatland surface subsidence refers to the physical lowering of peat soil elevation, resembling a gradual sinking or settling of the land. Subsidence is an important issue on the utilization of peatland. If the subsidence is not controlled, it will cause flooding and land degradation. Subsidence influenced by age of plants, landuse, bulk density 50-100 cm, water table, water level in drainage canal and distance from the drainage canal [2]. The rate of land subsidence in the Solec peatlands (Poland) ranges from 0.08 to 2.2 cm/year, with 46% of this being due to chemical processes and 54% to physical processes [3]. In practice, peatlands are often drained through the construction of canals to make the land suitable for various uses. This drainage reduces the volume of water stored in the peat soil and causes the peat structure to become fragile and shrink. More than 90% of Southeast Asia's peatlands are subsidence at an average rate of 2.2 cm per year due to deforestation and drainage, leading to loss of productive land and flooding [4]. In northern Japan, GIS-based mapping combining elevation data, soil surveys, soil type, land development period, current land use, and soil cover thickness to allow for the inclusion of peatlands [5]. Repeated shrinkage eventually leads to land subsidence. Land subsidence in tropical peatlands is evident in areas drained for agriculture and oil palm plantations, while stable areas are associated with intact forests [6]. Spatial and temporal variations in peat subsidence rates are primarily determined by the depth to the water table, and are strongly influenced by the depth to the water table [7].

Another contributing factor to subsidence is the decomposition process, which alters peat conditions from anaerobic (oxygen-poor) to aerobic (oxygen-rich). This change activates decomposer microbes, accelerating the breakdown of organic matter and further contributing to peatland subsidence. An observable indication of subsidence in the field is the exposure of plant root systems above the soil surface. Lowering of the groundwater level accelerates peatland subsidence, which causes physical changes in organic matter and carbon emissions due to microbial oxidation [8]. Documentation of subsidence events observed in the field can be seen in figure 1.

Fig 1. Subsidence in Peatlands

Geographic Information System (GIS)

In general, a map is a representation of the Earth's surface depicted on a flat plane and scaled down to a specific ratio. A map is essentially a form of data designed to generate geographic information through the organization and integration of other earth-related datasets to analyze, estimate, and produce cartographic representations. Mapping, on the other hand, refers to the process of measuring, calculating, and illustrating the Earth's surface using specific methods or techniques. ArcGIS is a modern GIS software developed by ESRI (Environmental Systems Research Institute). The material presented includes GIS concepts as a system designed to work with data containing spatial references and geographic coordinates, map literacy, introduction to and operation of ArcGIS, spatial data input and management, the use of ArcCatalog, and map layout composition using ArcMap. A Geographic Information System integrates digital maps with various types of data, making the presentation of mapping information significantly more efficient. GIS can represent real-world geographic data (Earth’s surface) on a computer screen. Therefore, GIS is essentially the digital equivalent of a traditional paper map. The ArcGIS interface is shown in figure 2.

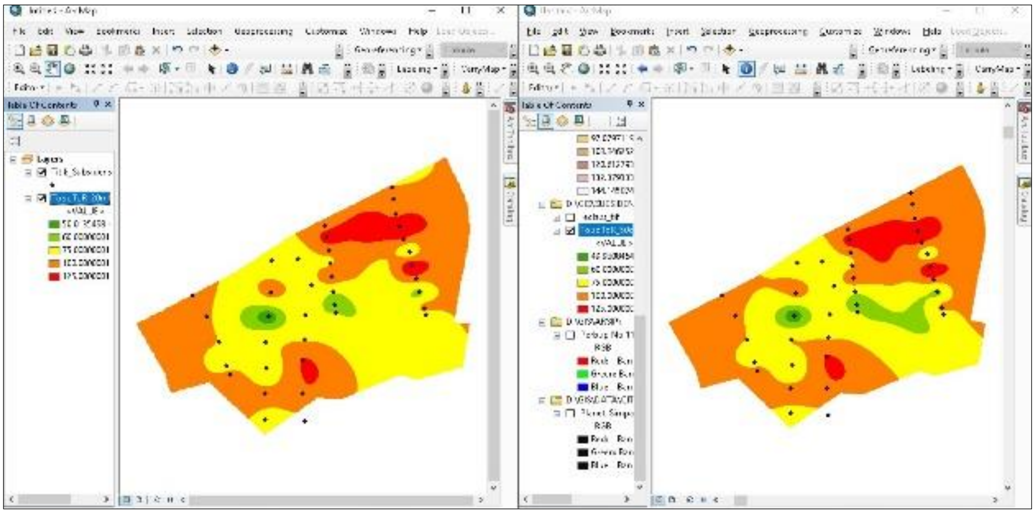

Fig 2. ArcGIS Software Interface

Avenza Maps

Avenza Maps can be described as a geotagging application that uses the "GPS" or "Location" feature, which can be run on smartphones. One of the advantages of this application is that once it is installed and set up, it no longer requires an internet connection to be used in the field. The use of Avenza Maps begins with installing the application on a smartphone, then importing maps and utilizing the map functions. These map functions include marking locations (marking points), editing information (placemarks), tracking, measuring distance and area, and exporting data in various file formats.

3. Methods

The location of this research is in Karya Tani Village, Kempas Subdistrict, Indragiri Hilir Regency, Riau Province.

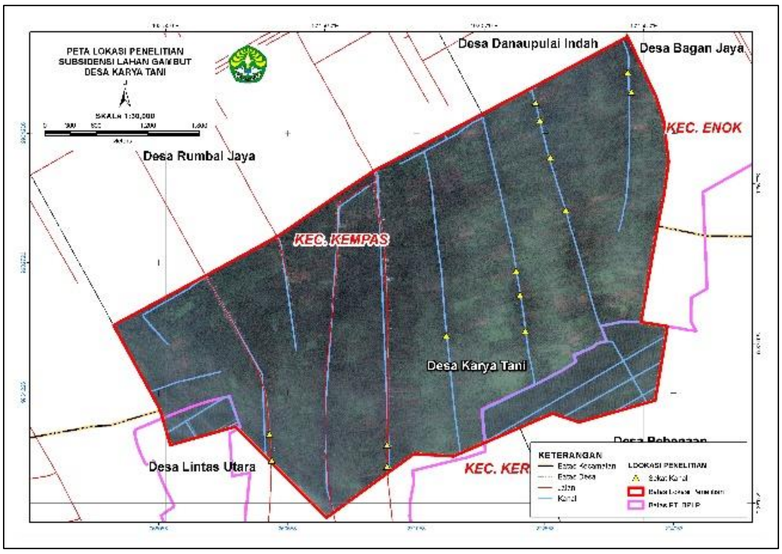

Fig 3. Research location

Field data collection in this study involved direct measurement of observable subsidence phenomena in the field. These phenomena were identified primarily in mature coconut trees, characterized by the visible exposure of their root systems above the ground surface, indicating a lowering of the peatland surface.

The steps for data collection in the field were as follows:

a. Determination of subsidence measurement points in the field using the transect method, with an interval of approximately 500 meters between each point.
b. The transect path for subsidence measurement points was conducted parallel to each ditch, approximately 200 meters from the ditch, across five canals/ditches: Parit Kasian, Parit Haji Tari, Parit Timbul, Parit Tumin, and Parit Jujum. A total of 38 subsidence measurement points were established.
c. The subsidence measurement on the coconut trees was carried out by measuring from the soil surface to the surface of the roots, identifying areas with visible subsidence, which were then aligned with a wooden stick and measured using a roll meter with a metal plate.
d. The diameter of the coconut tree trunks was measured using the DBH (Diameter at Breast Height) method. A roll meter was wrapped around the trunk of the tree, ensuring it was straight and tight around the tree. The circumference of the trunk, as recorded on the meter, was noted. The tree's diameter was calculated by dividing the circumference by pi (3.14). For example, if the circumference was 110 cm, the diameter would be 110/3.14 = 35.05 cm.
e. The duration of subsidence was determined by the age of the tree, which was obtained through interviews with the landowners.
f. The collected data, including subsidence magnitude, trunk circumference, and the age of the coconut trees, was recorded, and the geographical positions were recorded using Avenza Maps.

(a)

(b)

(c)

Fig 4. Data collection in the field

4. Results and Discussion

The subsidence rates observed across the five transects—Parit Kasian, Parit Timbul, Parit Haji Tari, Parit Tumin, and Parit Jujum—exhibit significant spatial variability, reflecting the heterogeneity of peatland degradation within Karya Tani Village (table 1). Subsidence magnitudes ranged from a minimum of 50 cm in Parit Timbul to a maximum of 156 cm in Parit Jujum. Specifically, Parit Jujum experienced the highest average subsidence of 110.36 cm, followed closely by Parit Tumin (102.20 cm), Parit Kasian (99.43 cm), Parit Haji Tari (98.25 cm), and Parit Timbul (87.71 cm). These variations in subsidence could be attributed to differences in local hydrological conditions, land use practices, and drainage intensities, which warrant further investigation. The age distribution of coconut trees in these transects also varied, with mean ages ranging from 20 years in Parit Haji Tari to 26 years in Parit Jujum. The correlation between tree age and subsidence rates suggests that older trees generally correspond to higher subsidence, which is consistent with the prolonged exposure of peat soils to drainage and oxidation processes over time. Trunk diameter measurements provided additional insight into vegetation characteristics potentially related to subsidence dynamics. The average trunk diameters ranged from 28.98 cm in Parit Kasian to 34.55 cm in Parit Haji Tari. Notably, Parit Haji Tari, despite having relatively smaller average subsidence, exhibited the largest average trunk diameter, which may indicate local variations in growth conditions or peatland hydrology affecting tree development.

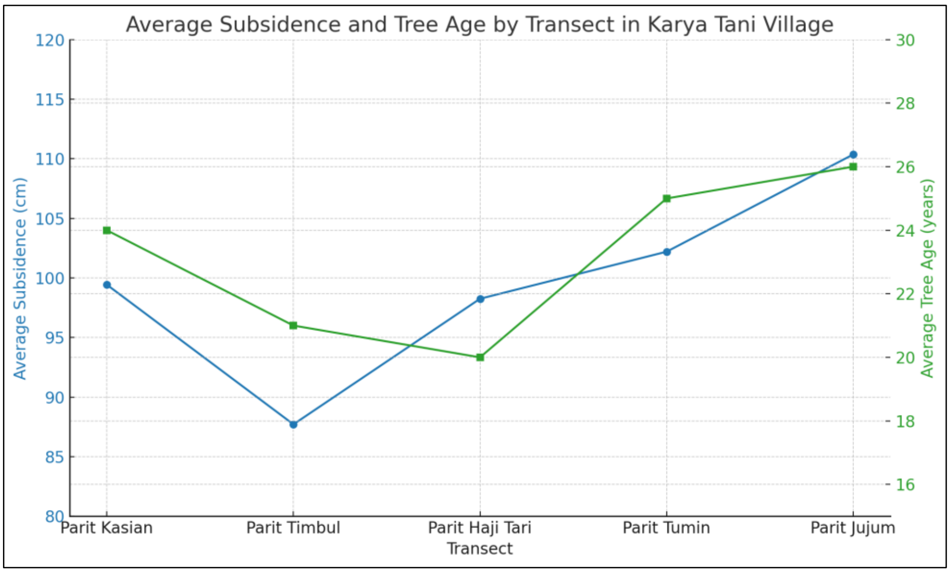

Fig 5. Average Subsidence and Tree Age by Transect in Karya Tani Village

The combined analysis of subsidence magnitude, tree age, and trunk diameter highlights the complex interactions between biotic and abiotic factors influencing peatland degradation. The highest subsidence observed in Parit Jujum aligns with the presence of relatively older trees, suggesting cumulative impacts of peat oxidation and land management over decades. Conversely, lower subsidence in Parit Timbul corresponds with younger vegetation and possibly less intense drainage interventions. These findings underscore the urgent need for site-specific management strategies. The spatially variable subsidence patterns imply that uniform mitigation approaches may be ineffective. Instead, targeted interventions—such as rewetting, controlled drainage, or vegetation management—should be prioritized based on localized subsidence rates and ecological conditions. In conclusion, this study demonstrates that peatland subsidence in Karya Tani Village is a heterogeneous process influenced by multiple factors, including drainage, vegetation age, and growth characteristics. Mapping these dynamics through integrated field measurements and GIS-based analysis provides a critical foundation for developing effective mitigation and conservation strategies to preserve peatland ecosystems and prevent further land degradation.

Table 1. Summary of subsidence measurements, coconut tree age, and trunk diameter across transects in Karya Tani Village

Transect	Subsidence Range (cm)	Average Subsidence (cm)	Tree Age Range (years)	Average Tree Age (years)	Trunk Diameter Range (cm)	Average Trunk Diameter (cm)
Parit Kasian	81 – 126	99.43	18 – 32	24	24.20 – 33.12	28.98
Parit Timbul	50 – 110	87.71	10 – 27	21	21.33 – 39.49	29.53
Parit Haji Tari	65 – 138	98.25	13 – 25	20	28.66 – 38.85	34.55
Parit Tumin	86 – 112	102.20	18 – 30	25	22.93 – 40.76	32.48
Parit Jujum	65 – 156	110.36	16 – 35	26	25.16 – 37.90	31.75

Based on the processed subsidence data using ArcGIS software, the subsidence magnitude map is shown in figure 6 below.

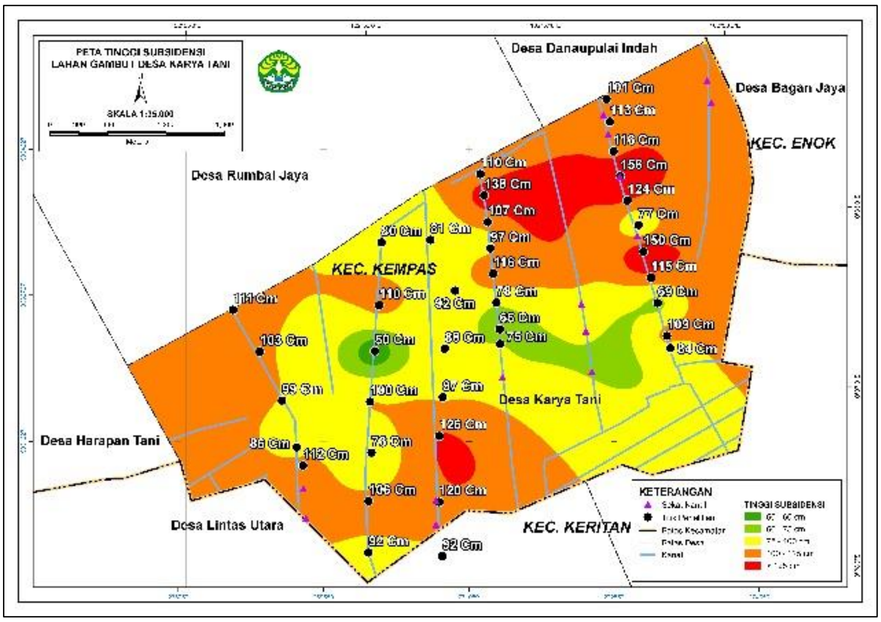

Fig 6. Peatland Subsidence Map of Karya Tani Village

Subsidence magnitudes were classified into five categories: 50–60 cm, 60–75 cm, 75–100 cm, 100–125 cm, and >125 cm. Subsidence in the 50–60 cm class covered an area of 6.76 ha, accounting for 0.34% of the total area of Karya Tani Village. The 60–75 cm class spanned

96.87 ha (4.39% of the total area), while the 75–100 cm class occupied 768.2 ha (39.06%). The most extensive subsidence occurred in the 100–125 cm class, covering 960.73 ha (48.85% of the total area). Conversely, the >125 cm class comprised 134.04 ha (6.82%).

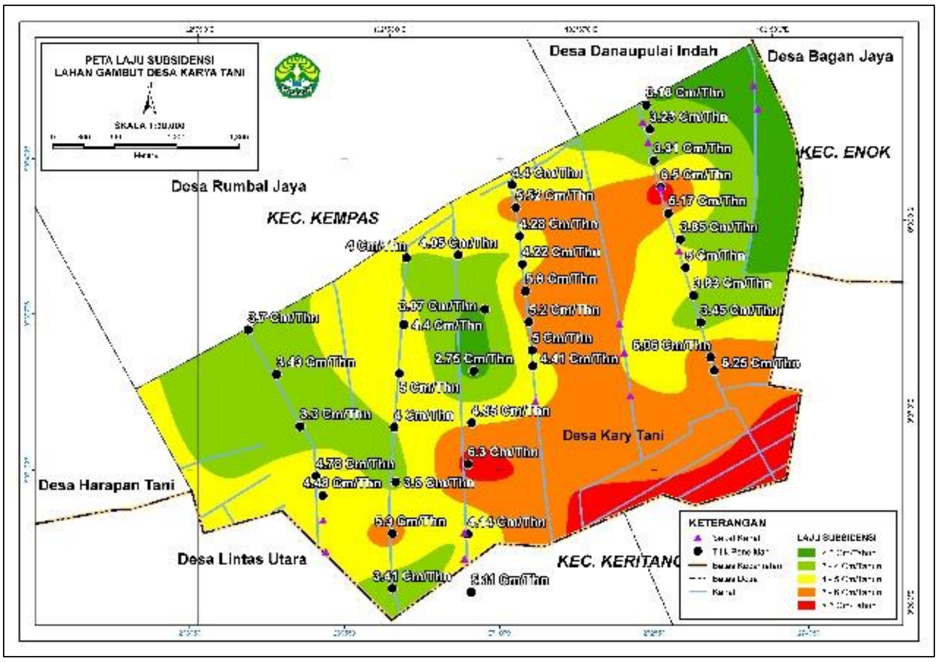

Fig 7. Peatland Subsidence Rate Map of Karya Tani Village

The subsidence rates identified in this study are classified into five categories: less than 3 cm/year, 3–4 cm/year, 4–5 cm/year, 5–6 cm/year, and greater than 6 cm/year (figure 7). Based on the raster data analysis in ArcGIS, the area experiencing a subsidence rate of less than 3 cm/year covers 134.28 hectares, accounting for 6.83% of the total area of Karya Tani Village. A subsidence rate of 3–4 cm/year affects 530.46 hectares (26.97%), while the 4–5 cm/year rate spans 670.79 hectares (34.11%). The area with a 5–6 cm/year subsidence rate covers 523.58 hectares (26.62%), and finally, the area with a subsidence rate exceeding 6 cm/year comprises 107.49 hectares or 5.47% of the total area. The highest subsidence rates, indicated by red and orange on the map, are likely associated with regions that have deeper peat layers, ranging from 2 to 3 meters. These areas may also contain a dense network of drainage canals, which accelerate water outflow and contribute significantly to subsidence. Furthermore, population concentrations are higher along these canal systems, potentially intensifying land use and drainage activity. Surface erosion or land degradation processes—where peat surfaces are washed away by rainfall and subsequently drained into canals—are also likely contributing factors. Additionally, the peat in these areas may still be in an immature state (fibric peat), which is more prone to subsidence. Thus, the less decomposed the peat, the higher the rate of subsidence observed.

5. Conclusions

The mapping of peatland subsidence in Karya Tani Village was carried out using ArcGIS software, with spatial interpolation performed through the Topo to Raster method. Subsidence magnitudes were categorized into five classes: 50–60 cm, 60–75 cm, 75–100 cm, 100–125 cm, and greater than 125 cm, representing the estimated cumulative vertical displacement. The findings confirm the occurrence of peatland subsidence in the study area, with annual rates ranging from 2.75 to 6.50 cm/year and an average rate of 4.45 cm/year. These results highlight the ongoing degradation of peatland in Karya Tani Village, emphasizing the need for integrated land management and monitoring strategies to mitigate further environmental impact.

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