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Potential Areas of Land Subsidence in Karst Landscape: Case Study in Ponjong and Semanu District, Gunungkidul Regency, Yogyakarta, Indonesia

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***Abstract*— *Sinkhole* is a depression of the land surface, causing hazardous effects on the karst landscape. Land subsidence is a phenomenon of sinkhole formation due to karstification. Land subsidence associated with any of the existing evaporite-karst sinkholes Land subsidence is a gradual settling or sudden sinking of the Earth's surface, which can be very dangerous as it relates to life on the surface and infrastructure planning. Ponjong and Semanu District, Gunungkidul Regency, are included in the Gunung Sewu Karst area, with landscapes highly influenced by the karstification process. Decision-makers need increasing attention to make assessments also mitigation on karst management. This study aims to determine the potential areas of land subsidence caused by natural factors in the karst landscape in the Ponjong and Semanu District, Gunungkidul Regency using integrated geospatial technology. For making some maps, we initially need a process from SRTM. Land Surface Temperature map, The Normalized Difference Vegetation Index (NDVI) map, slope map, and geological map are integrated into a GIS platform using the scoring and matrix then the overlay method. Descriptive spatial analysis of potential subsidence area is based on land surface temperature, vegetation factor, slope inclination, and geological formation related to altitude. The results show that approximately 80 percent of Ponjong and Semanu District places are high potential land subsidence areas. Policymakers can use this distribution of the potential regions of land subsidence as essential spatial planning in Gunungkidul Karst, especially in Ponjong and Semanu district.**

***Keywords*— Gunungkidul karst; land subsidence; potential areas, scoring overlay.**

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I. INTRODUCTION

The land subsidence occurring in the karst areas is related to sinkholes caused by the subsidence [1]. A sinkhole is a depression of the land surface that impacts the karst landscape [2], [3]. Subsidence from sinkhole collapse is common in areas underlain by water-soluble rocks such as carbonate and evaporite rocks [4]. Land subsidence is the subsidence of a surface due to a loss of support from the natural dissolution process [5]. The terrain is a process of karstification of the interaction results between endogenous methods and the exogenous process of molding the Earth's surface into specific morphologies, which are different from those of non-limestone [6]. There is secondary porosity of limestone resulting from dissolving and forming channels with a cavity diameter large enough so that large amounts of water can flow at high speed [7].

Enlargement of cavities in the karst area, eventually leading up to sinkhole formation. Sinkholes are a subtle type of hazard, causing severe and unexpected damage to the anthropogenic environment [8]. Land subsidence associated with any existing evaporite-karst sinkholes Land subsidence is a gradual settling or sudden sinking of the Earth's surface [9]. Land subsidence is not research-focused as a leading natural hazard in Indonesia. Land subsidence attracts much attention from the government, community, industry, and academia in other countries [9].

Land subsidence in a newly formed or long-established sinkhole, can be very dangerous in the territorial aspect of life on the surface and infrastructure planning, especially settlements [11], [12]. A sinkhole is an area of ground with no natural external surface drainage; when it rains, it stays inside the sinkhole and typically drains into the subsurface [12]. Sinkholes can vary from a few feet to hundreds of acres and less than 1 to more than 100 feet deep [14]. Human-made infrastructure and buildings and transportation arteries have expanded onto karst terrains formerly rural and sparsely developed [15].

To reveal the potential areas of land subsidence in the karst area, we selected a typical karst area, i.e., Ponjong and Semanu District, Gunungkidul Regency series Gunungsewu Karst, which is strongly influenced by the process of karstification. In both districts, there are many *sinkhole/doline* phenomena [16]. According to the division of Java's physiography [17], the area of Gunungsewu includes the southern mountain area of the western part of East Java. The karst landscape at Gunungsewu is one of the limestone conservations landscapes in Indonesia [18]. Research on the potential land subsidence in Ponjong and Semanu District is needed to spatially view potential land subsidence areas at sinkhole sites and other parts of the karst landscape. The purpose of this research is to analyze the possible location of land subsidence formed based on the driving and controlling factors in Ponjong and Semanu District, Gunungkidul, Yogyakarta, Indonesia [19], [20].

II. MATERIALS AND METHOD

A. Background

One of the two parameters used as a variable for assessing land subsidence in the karst landscapes is the soluble rock characteristics, especially in limestone minerals. Due to limestone dissolution, the karstification process is generally influenced by two factors: the driving and controlling factors [19]. The driving factor determines the speed and perfection of the karstification process. Meanwhile, influencing factors determine whether the karstification process is running or not.

Dolina, sinkhole, enclosed land depression, and caves can be identified using high-resolution imagery and aerial photography [21]. Images that can be utilized to determine the formation of karstification results include Landsat image, Rapid Eye, IKONOS, ASTER, and DEM SRTM [22]. The image data is then processed using ArcGIS with a weighted *overlay* method to know the morphometry of Dolina. The analysis method uses a GIS method with several land-use variables, geomorphology, shallow sediment thickness, distance to drainage network, and fracture distance. Meanwhile, the AHP criteria model *(Analytical Hierarchy Process) was* chosen to determine the weights of some subsidence determinants, i.e., degree of slope, lithology, altitude, residual distances to geological structure or geological alignment, and land use [20].

The potential areas approach to using the Geography Information System. The Normalized Difference Vegetation Index (NDVI) map, Land Surface Temperature map, geological map, and slope map were integrated into a GIS platform on the scoring overlay method [23], [24]. Furthermore, the potential subsidence area's descriptive spatial analysis is based on vegetation factors, land surface temperature, geological formation, and slope.

B. Land Surface Temperature (LST)

LST is an essential factor to reflect the environmental changes of the underlying surface and the physical and chemical processes in the karst area [25]. Land surface temperature (LST) is an essential parameter in investigating the shifting of the surface energy balance in surface materials and surface physical and chemical processes. It is currently widely used in soil, hydrology, biology, and geochemistry [26]. Land Surface Temperature is processed from Landsat 8 imagery using two TIRS bands, band 10 and band 11. These two bands have different wavelengths, namely 10.5 - 11.5 µm for band 10 and 11.5 - 12.5 µm for band 11. Both bands area thermal band, which has an excellent resonant wavelength measure surface temperature. In-band 10 can measure lower temperatures, while band 11 can measure higher temperatures, resulting in measurement, it can be seen the interval measured at the higher temperature. Table I shows the soil surface temperature classification.

TABLE I
MATRIX OF LAND SURFACE TEMPERATURE

Classification	Land Surface Temperature (Celcius)	Score
Low	19,67-22,04	3
Medium	22,04-24-41	2
High	24.41-26-78	1

C. Normalized Difference Vegetation Index

Vegetation can effectively influence LST by selectively absorbing and reflecting solar radiation energy and regulating latent and sensible heat switch. Normalized difference vegetation index (NDVI) is a vegetation indicator that is generally utilized to study the relationship between LST and vegetation. The density data of vegetation was made by making an approach using the Normalized Difference Vegetation Index (NDVI) [26]. Normalized Difference Vegetation Index is processed from Landsat 8 imagery, which has been download from earthexplorer.gov. The value of NDVI ranged from −1 to 1. Generally, NDVI > 0 in the growing season indicates vegetation cover. An increase in the NDVI value indicates an increase in green vegetation. NDVI > 0.5 shows good vegetation growth status and large coverage density. The formula for NDVI is expressed in Eq. 1[23].

$$NDVI=(\rho5-\rho4)/(\rho5+\rho4), NDVI=(\rho5-\rho4)/(\rho5+\rho4), \quad (1)$$

where, for Landsat 8, ρ_4 is the Band 4 red band (0.64–0.67 µm) reflectance, and ρ_5 is the Band 5 near-infrared band (0.85–0.88 µm) reflectance.

A combination of a red band (band 5) and band NIR (band 4) is used to measure the vegetation density. One of the benefits of the vegetation index can be used to look at vegetation density levels. Increasing vegetation density in a karst landscape can further encourage the dissolution process. NDVI is created using ArcGIS 10.2.1 software by utilizing an algebra tool map. The classification class of vegetation index is shown in Table II.

TABLE II
MATRIX OF NDVI

Classification	Vegetation Index	Score
Low	0.174-0.274	1
Medium	0.274-0.354	2
High	0.354-0.55	3

D. Altitude and Geological Formation

An essential parameter in mapping land subsidence's potential is the karst area's geological formation or thickness. The altitude value of the rocks' thickness is taken from the DEM height data representing the depth of lithology that can be karstified. The stone's depth can be estimated by looking at the stratigraphy of rock in the Surakarta-Giritronto geological map sheet [27]. For making altitude areas need the process from SRTM. Digital image processing techniques were carried out for Shuttle Radar Topography Mission (SRTM) 90m resolution Digital Elevation Model which has been downloaded from the website srtm.csi.cgiar.org. The altitude area > 500 m has a score of 3, 300-500 m has a score of 2, and an area with an altitude of 0-300 m has a score of 1. The altitude area of Ponjong and Semanu District is shown in Table III.

TABLE III
MATRIX OF ALTITUDE AREAS

Classification	Altitude (m)	Score
Low	< 300	1
Medium	300 – 500	2
High	>500	3

E. Slope

The slope is one of the most crucial hydrology factors because of subsurface flow velocity and runoff rate over the area of interest [28]. Digital image processing techniques were carried out for Shuttle Radar Topography Mission (SRTM) 90m resolution Digital Elevation Model which has been downloaded from the website srtm.csi.cgiar.org. It is processed into altitude data and slope data. To process height data is done with ArcGIS 10.2.1 software. The initial step is to cut the DEM data based on the administration of the study area. The next stage is to make the grade slope based on the class of Van Zuidam [28]. Pre-processed DEM data require radiometric correction. Such corrections are necessary to correct pixel values in satellite images due to radiometric errors and enhanced image visualization. Radiometric errors occur due to signal strength changes, atmospheric noise, and solar elevation angles [29].

TABLE IV
MATRIX OF SLOPE

Class	Slope (%)	Score
Flat	<20	3
Ramps	>20-40	2
Rather Steep	>40	1

The potential subsidence area is made using the overlay method consisting of the variable of surface temperature, vegetation density index, rock thickness interpreted from height, slope, and type of rock. Scores for each parameter are in the range 1 to 3. The minimum score indicated that the parameter does not significantly affect the land subsidence, and the maximum score affects the most. After we get the maximum and the minimum number, we can classify this score into low, medium, and high. The detail of the potential subsidence region matrix is shown in Table V. The total value of the high possible area is 15. The potential medium region is 10, and the total score of the low potential region is 5.

Rock or geological variables derived from rock formations containing limestone content are Wonosari Formations with score 3, and Oyo Formation having disclosure 2. Besides, the soil structure that develops in the rock formations also influences the potential subsided. The value of vegetation density is taken from the density type. Areas with a dense vegetation density had a score of 3, a region with moderate vegetation density having a score of 2, and a region with a rare vegetation density having a score of 1. In the area of ground surface temperature, the value is taken from the degree of temperature. The region with low temperature has a value of 3, the region with medium temperature has a value of 2, and the region with high temperature has a value of 1. The amount of slope variables is reprocessed with the slopes in the study area. Slopes with 0-20%, the percentage have a value of 3, which means having a high potential to occur subsidence. Slopes with a 20-40%, the portion have a value of 2, which means having a moderate potential, and a slope with a rate> 40% has a value of 1, which means it has a low potential [22].

TABLE V
MATRIX OF POTENTIAL AREAS OF LAND SUBSIDENCE

No	Variable	Score	Class
1	NDVI	3	High
	LST	3	
	Altitude	3	
	Slope	3	
	Rock on geology formation	3	
2	NDVI	2	Medium
	LST	2	
	Altitude	2	
	Slope	2	
	Rock on geology formation	2	
3	NDVI	1	Low
	LST	1	
	Altitude	1	
	Slope	1	
	Rock on geology formation	1	

III. RESULT AND DISCUSSION

Potential Areas of Land Subsidence comprises 5 variables, i.e., Land Surface Temperature (LST), Normalized Difference Vegetation Index (NDVI), altitude, slope, and rock that exist in geological information. The maps of these five variables are shown in Fig 1 until Fig 5. Ponjong and Semanu Districts' land surface temperature ranges between 19.67-26.78 ° C (Fig. 1 and Table I). Low land surface temperatures ranging from 19.67-22.04 have an area of 10.9 km2 or 3.86%. The land surface temperature with range 22.04-24.41 has an area of 93.13 km2 or 32.97%. Surface temperature high land has an area of 178.41 km2 or 63.17. The land surface temperature in Ponjong and Semanu Districts dominated by high temperatures, covering almost all Semanu District regions except a little in the south and the western part of Ponjong District. Land surface temperature is covering the southern part of Semanu District. Low land surface temperature only occupies a small area in the central part of Ponjong District. The low land surface temperature is one of the drivers of subsidence in the study area. The optimum temperature for collecting CO2 for the dissolving process is in the range 0 ° - 20 ° C. Lower water temperatures will be possible binding CO2 for the dissolving process due to the reduced solubility of CO2 (gas) in hot water. Thus, calcite or other crystals' solubility in pure water decreases when the temperature increases [6].

Ponjong and Semanu Districts' vegetation density, Ponjong and Semanu Districts have three value density classifications

(Figure 2 and Table II). The rare vegetation index class with a value range of -0.4494 -0.2747 has an area of 6,033 km2 or 2.99% of the study area's total area and is scattered in the northern part Semanu Regency. Medium vegetation index with a range of 0.2747 - 0.3543 has an area of 169.53 or 84.15%. This vegetation index dominates in both research districts, which are scattered in almost all research areas. The regions with a dense vegetation index with an NDVI value range of 0.35433-0.5506 have an area of 25.89 km2 or 12.85%.

Green plants as a type of land cover that affect subsidence can be detected using the vegetation index. Land cover is also a driving factor for karstification because dense land will have an abundance of CO_2 in the soil due to the overhauling of organic remains (branches, twigs, leaves, animal carcasses) microorganisms [18]. Organisms from green plants are generally the leading cause of $CaCO_3$ deposition by taking CO_2 from water in the photosynthesis process.

Ponjong and Semanu Districts are sub-districts in Gunungkidul Regency, located in the regions with an altitude of 100 - 700 masl based on contour lines obtained from processed SRTM DEM imagery from the study area (Fig 3). The classification is taken from the Van Zuidam classification for geomorphological slope classification but is unbeatable to the study area's conditions. In general, Ponjong District has areas with higher contours than Semanu District. The altitude of Ponjong District and Semanu Subdistrict is getting to the West. The lower the altitude and vice versa, the higher the altitude towards the East. The research area's minimum height is in Semanu District, 131 masl, and the maximum height is in Ponjong District, 760 masl.

The height is shown in Fig 3 can represent the thickness of limestone types present in the two research districts. The thickness of the dominant rock formation is the Wonosari Formation (Tmwl). This rock formation has a thickness with a range between 500-1000 meters [27].

The rock formation was formed in the Cenozoic era in the Miocene period. Ponjong and Semanu Districts, the majority of which belong to the Wonosari-Punung Formation, which is the unity of Karst Wonosari, the essential part of the Karst Gunungsewu mega system. The type of rock with Wonosari-Punung Formation spread mostly in Ponjong and Semanu Districts in the research area (Fig 4). This dominant rock formation is found in Semanu Subdistrict and Central to South of Ponjong Subdistrict. The Wonosari-Punung Formation (Tmwl) comprises clastic limestone sediments, limestone reefs, limestone napal, tuffa, and limestone conglomerates. The environments in this formation settle in shallow sea neritic zones with lithology dominated by layered limestone and reefs. This formation is also composed of sandstone, tuff, and silt rock. The region in this formation has a topography of slopes with steep hills composed of limestone conglomerates as a precipitate in the form of talus and surrounding hills from the reef. This formation has a thickness between 300 - 800 meters.

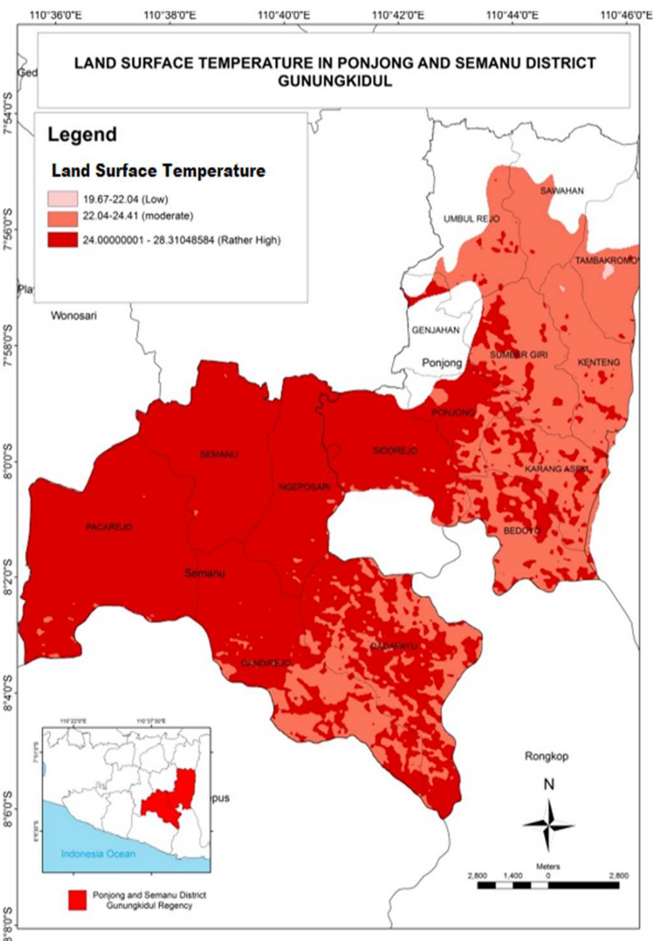

Fig 1. Land Surface Temperature Map

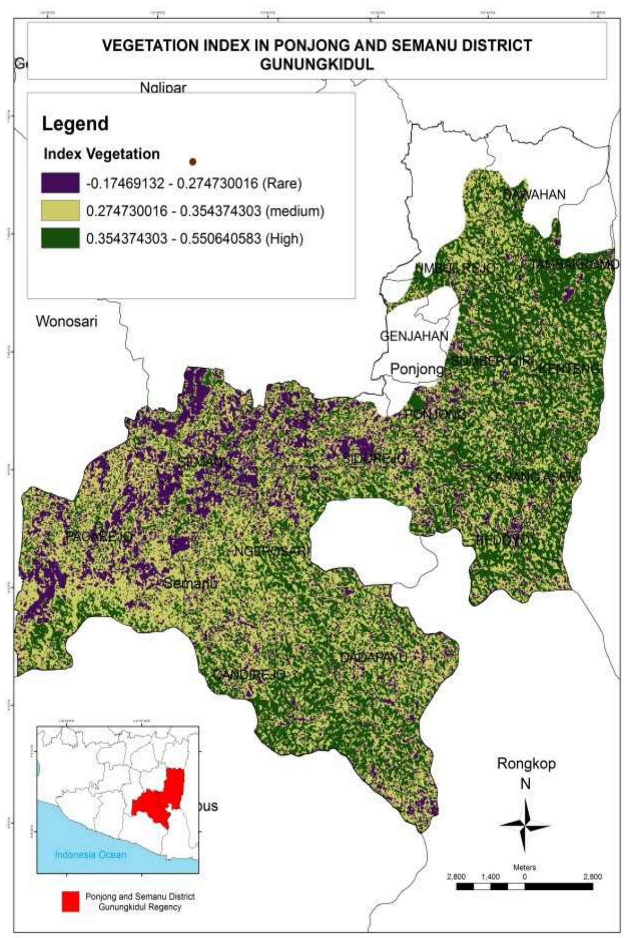

Fig 2. NDVI Map

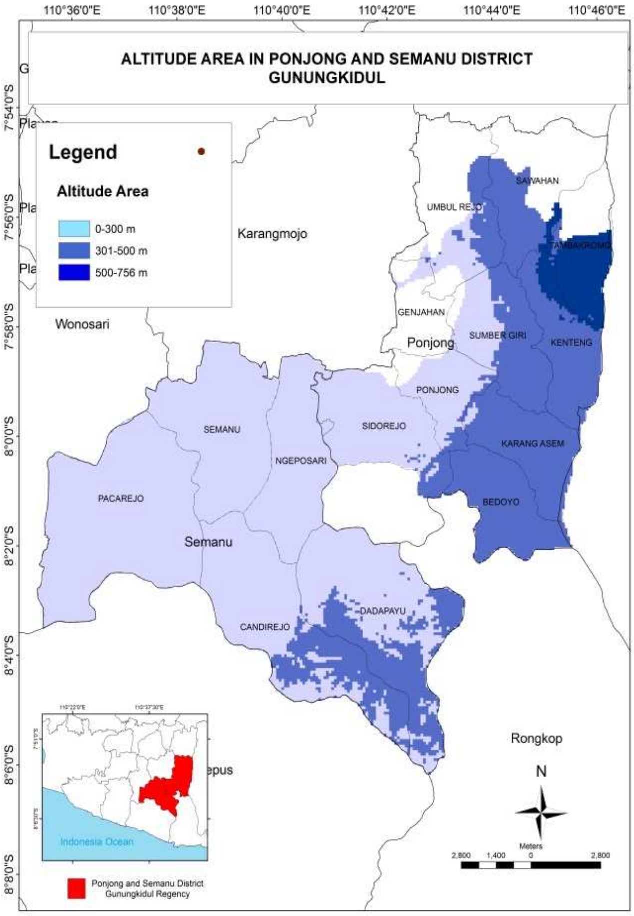

Fig 3. Altitude Map

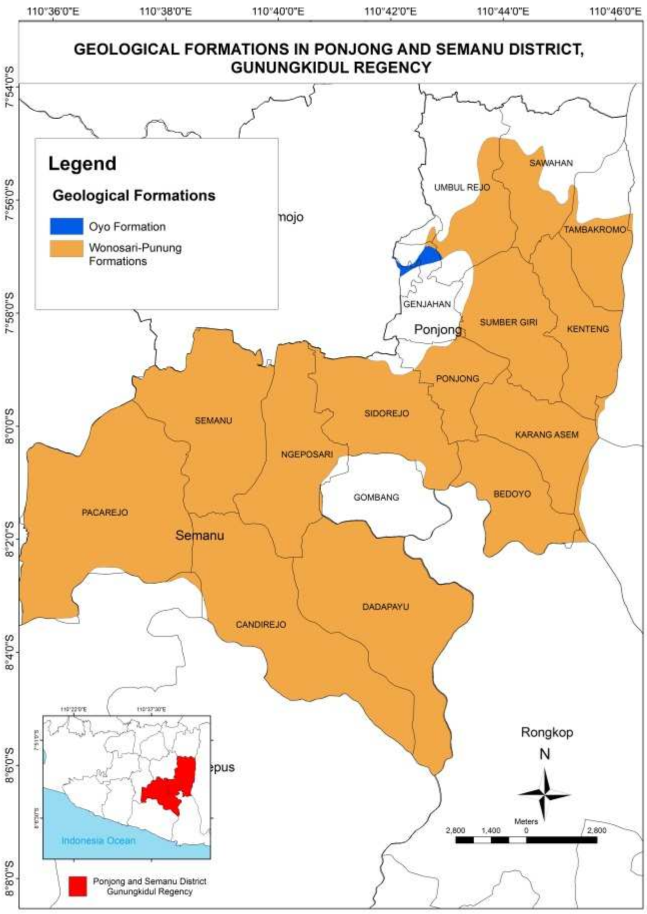

Fig 4. Formation of Geology Map

The Oyo (Tmo) formation of Central Miocene to Late Miocene comprises classical limestone sediments formed of limestone sandstone, tuff, layered limestone, limestone conglomerate, and tuff. In this formation composed of tuff limestone, this formation's deposition environment is a shallow sea nettle zone and is influenced by volcanic activity. This Oyo formation has a thickness of up to 350 meters. The dispersion of rock formations is shown in Fig 4. One of the parameters used as a variable for assessing soil subsidence in karst landscapes is the rock characteristics soluble, especially in limestone minerals, such as calcite, aragonite, and dolomite [19]. Karst rocks containing high $CaCO_3$ will dissolve easily [18]. The higher the $CaCO_3$ content, the more developed the karst landforms.

Ponjong and Semanu Districts, Gunungkidul Regency have a geological structure in geological contacts scattered in Ponjong Regency. Another geological structure found in the two sub-districts is in the form of tight geological alignments. This geological straightness density indicates that topographic conditions limit the structural geological system below the soil surface.

Besides, the dense geological alignment can mean an underground river flow system. The existence of geological alignment is associated with subsidence. The straight-line distance with subsidence is in the buffer <200 m meters. The fact of structural geology and straightness and the presence of subsidence can be seen in Figure 5.

One of the parameters used as a variable for assessing land subsidence in karst landscapes is fracture and stocking. Apart from burly, the structural geology that affects subsidence is a fault [19]. A fault is a fractured structure that has undergone a shift. Stiffness is a structure of cracks/fractures formed in rocks due to a force acting on the rock and has not transformed [30].

The slope of the slopes in the Ponjong and Semanu Districts ranges from 2% -46%, as shown in Figure 6. The 0-20% slope areas are scattered in the northern part of Semanu District and the western part of Ponjong District. This area has 39,893 km^2 or 93.09% of the total area of the study area. The slope area of 20 - 40% is spread almost evenly in the southern part of Semanu District and the eastern part of Ponjong District. This area covers 2,779 km^2 or 6.49% of the total area of the study area. The slope area> 40% is spread longitudinally from north to south in the eastern part of Ponjong Regency and a little in the southern part of Semanu Regency. This area covers 0.182 km^2 or 0.42% of the total area research area.

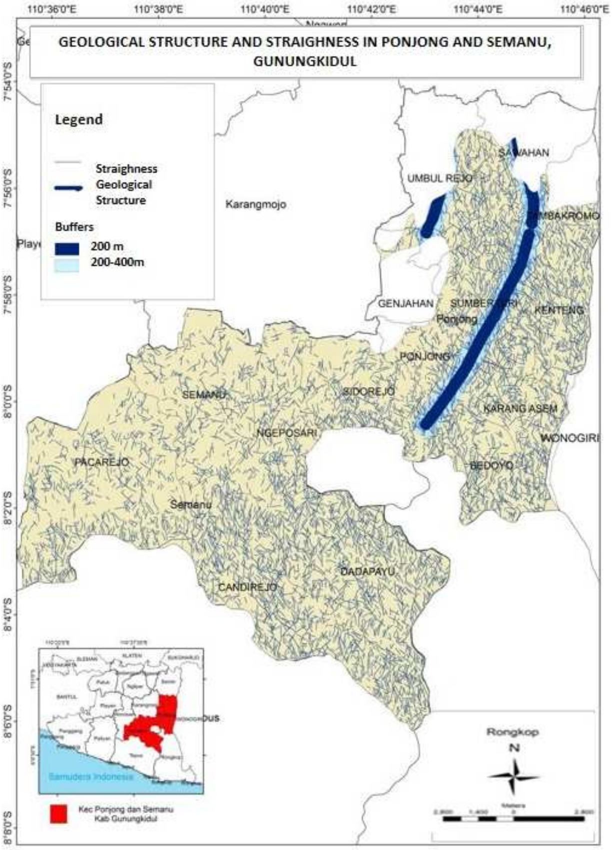

Fig 5. Buffer Map of Geological Structure and Straightness

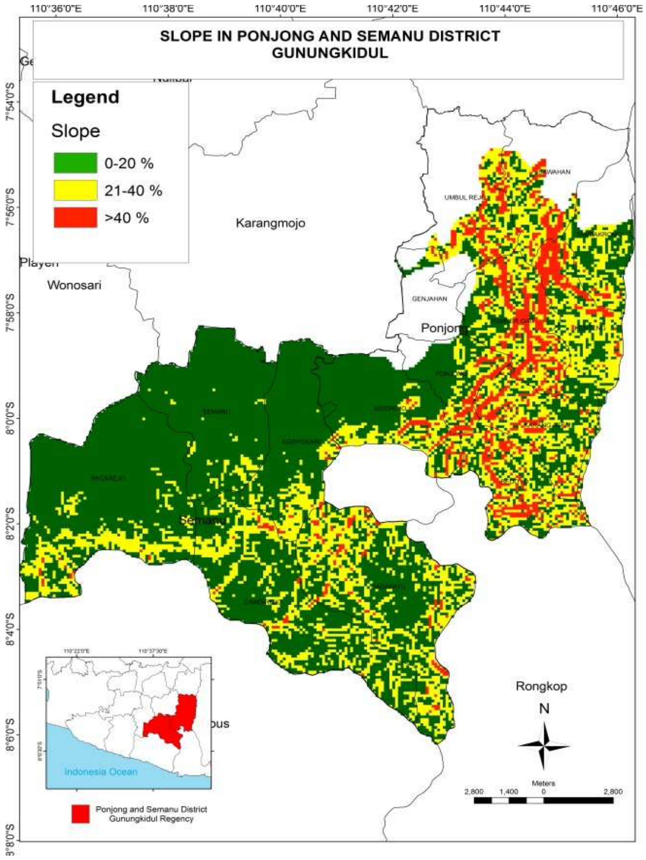

Fig 6. Slope Map

TABLE VI
POTENTIAL AREAS OF LAND SUBSIDENCE

No	Classification	Large of Areas (km2)	Suitable Areas of by Land Subsidence (%)
1	Low	0.036	0
2	Medium	4.52	11
3	High	38.23	89
Total		42.76	100

The potential areas of yield from the ground surface temperature map's raster overlay, the index of vegetation density, slope, altitude, and geological formation are shown in Figure 7. The potential regions formed are 3 classifications, i.e., low, medium, and high potential areas. The prospective area that has been made is validated by the point of subsidence in the field. The processing results show that the high potential damage has the broadest site, 38.23 km2, or 89.42%, and is spread almost in Semanu District and the western part that stretches from north to south Ponjong Regency. The potential area for medium land subsidence is ranked second with an area of 4.52 km2 or 10.57%. The potential region is stretching from north to south of the eastern part of the Ponjong Subdistrict. The low subsidence potential only covers a small area with an area of 0.036 km2 or 0.01%. The validation results are shown in Table 6.

This study complements the previous research in the same region [19] by adding the vegetation density factor from NDVI and Land Surface Temperature [21]. The addition of causative factors can provide a new view that the vegetation that thrives due to the land surface temperature can provide predictions about where the subsidence is located [15]. Using an analysis unit in the form of sub-district administration provides an overview of the distribution of land subsidence points in certain areas to reference disaster mitigation efforts by stakeholders in the future.

However, there are limitations in this study because of the accuracy of the Landsat satellite imagery used [26]. To increase the resulting quality from the GIS method, both in the research object's location or the area of potential land subsidence, analysis through more detailed satellite imagery is required. Besides, the thickness of rock formation on the surface due to erosion can cause a thick layer of layered limestone and reefs to determine land subsidence accuracy in the research area accurately. It is recommended for similar studies in karst landscapes with land subsidence. The results required additional data that would determine the level of erosion so that the thickness of the weathered rock can be resolved with a more precise thickness.

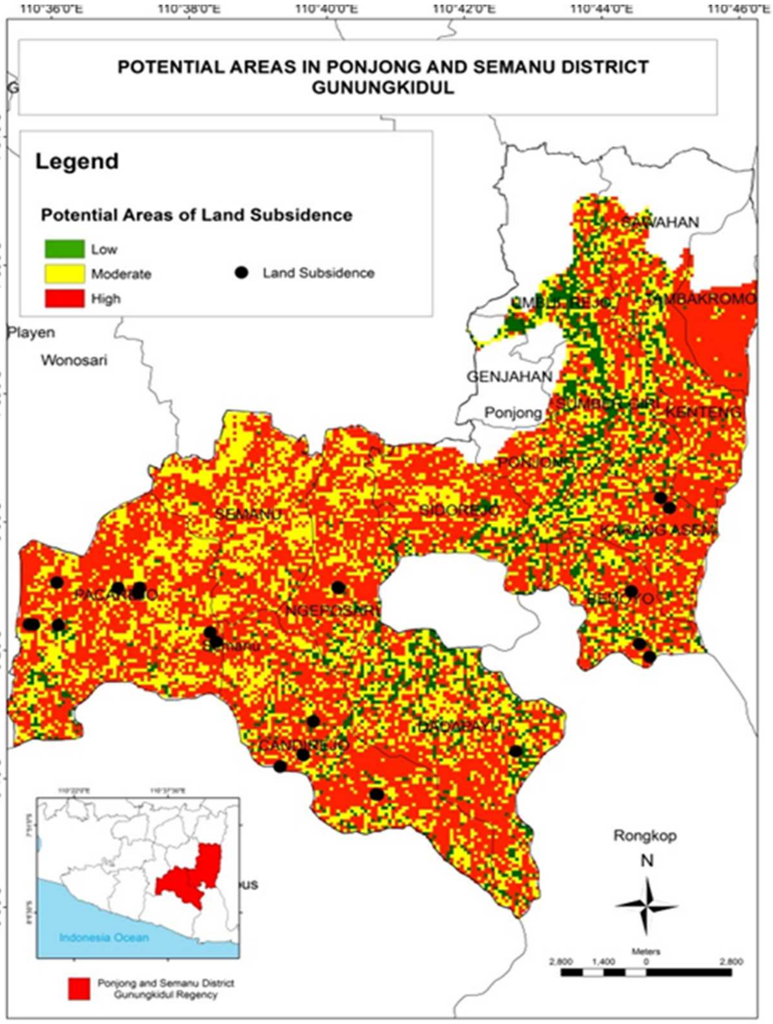

Figure 7. Potential Areas of Land Subsidence

IV. Conclusions

The potential areas of land subsidence in Ponjong and Semanu Districts, Gunungkidul Regency, consist of three classifications: high, medium, and low potency. The results show that most Ponjong and Semanu districts are high potential land subsidence areas with 38.23 km2. The number of land subsidence events is evidenced by the fact that 80 percent of the degradation points obtained are in high probability classification areas. Thus, land subsidence occurs because it is driven by land surface temperature and vegetation density controlled by the slope and geological formation. Enhanced measurement potential of land subsidence has led to improve constraints on models of subsidence processes. Policymakers can use this distribution of potential land subsidence areas as essential spatial planning and predict potential future subsidence in Gunungkidul Karst, especially in Ponjong and Semanu district.

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