Peat depth mapping using grid interpolation from terrestrial peat drilling points data: A case study in Zamrud National Park

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Abstract. Zamrud National Park is the peak of the peat dome in the Kampar Peninsula. Peat depth data is needed as a baseline to maintain the balance of the water reservoir and carbon stock. Currently, available peat depth data is predictive photogrammetric data. Soil survey activities need to be carried out to provide accurate and up-to-date data. This research aims to map the peat depth using the best grid interpolation technique. Peat depth measurements were carried out terrestrially, while peat depth mapping used inverse distance weighted, kriging, and spline interpolation techniques. Drilling observation points are arranged based on a system of longitudinal transects and transverse transects in a northeast-southwest direction. The distance between longitudinal transects is 500 m and between transects is 1,000 m. The results showed that the Zamrud National Park area has diverse peat depths ranging from 5.3 to 16.7 m. The Kriging interpolation technique gives the best mapping accuracy results. The standard deviation value is 1.9 is smaller, the accuracy value is 98.82% higher, and the thickness of the dominating peat is 8.4-9.4 m for 7,093.47 ha (24.42% of the total park area).

1 Introduction

Peat swamp forests play an important economic and ecological role in providing timber and non-timber products, water supply, flood control and play a significant role in carbon storage [1,2]. The presence of peat soil in peat swamp forest areas functions as a buffer for the surrounding area because it has a water storage capacity that reaches thirteen times its weight [3]. Peat soils are also capable of storing carbon reserves 10 times greater than forests on mineral soils [4,5]. This ability is influenced by the thickness of the peat soil, with a thickness of 100 cm having a carbon stock of 400-700 t.ha^{-1} [6,7]. The thicker the peat soil, the higher the carbon stock stored and the greater the water storage capacity of the peat [8].

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Peat depth can be used as a basis for area management and sustainability because of its function as a water provider and flood control [9]. Accurate and up-to-date information on peat depths is not yet available in this area. The current peat depth map is a 1:50,000 scale photogrammetric map produced by the Center for Agricultural Land Resources in 2019 [10,11]. The peat depth map produced by measuring peat thickness terrestrially is useful for knowing and providing information on peat depth, peat maturity [12], and the latest peatland potential area in detail [13] by making direct observations in the field.

Mapping peat depth can be used as a basis for more targeted peatland management. Using remote sensing data and field data modeled using several interpolation techniques is one way to determine the peat depth map [14]. The use of interpolation techniques is the process of estimating values in areas that are not sampled or measured for the purposes of preparing maps or distributing values throughout the mapped area [15,16]. The use of this interpolation technique is very efficient because it requires a short time and relatively low cost [17,18].

This research measured peat thickness terrestrially and mapped it using the IDW, Kriging and Spline interpolation technique in the Zamrud National Park area. The unavailability of accurate data and the uncertainty of peat thickness in this area is the main basis for this research.

2 Methods

2.1 Study location

The research was conducted in the Zamrud National Park area, Siak Regency, Riau Province. Soil sampling took place for three months starting from March to May 2022. Based on the Minister of Environment and Forestry's decree number 350/Menlhk/Setjen/PLA.2/5/ 2016, the park has been designated as a 31.480 ha protected habitat for flora and fauna. This exotic peat swamp forest is located at the top of a peat dome on the Kampar Peninsula. Land cover consists of primary forest vegetation (19,736 ha), secondary forest (8,704 ha), large island lake (2,416 ha), lower lake (360 ha) and the rest is bush or open land. The protected area is surrounded by community oil palm plantations and plantation forest companies (PT Arara Abadi, PT Andalan Pulp and Paper, PT Ekawana Lestari Dharma and PT National Timber), while around the lake 299 oil wells managed by the Badan Operasi Bersama (BOB) PT Bumi Siak Pusako-PT Pertamina Hulu as well as local fishermen's huts have been operated [19,20]. These activities can be a threat to the function of the area.

2.2 Field and laboratory measurements

The main soil survey was conducted terrestrially through a grid system on longitudinal transects and transverse transects in a northeast-southwest direction. The distance between observation points on the longitudinal transect was 500 m and between observation points on the transverse transect was 1000 m, with a maximum deviation of 200 m. Transect directions and observation points were guided using the avenza maps application. Field data from 170 peat boring observation points around Pulau Besar Lake and Danau Bawah (Fig. 1) included peat thickness, peat maturity, land cover, water level, drainage and substratum.

Peat depths was measured from the peat surface until it reached the mineral soil layer (substratum). Observations of peat thickness were made by inserting a peat drill bit into the soil and then lifting it up. If no mineral soil has been lifted, the drill bit is inserted again with the addition of a drill rod. This was done gradually until the peat drill bit touched the mineral soil. The peat thickness was calculated using the formula: PD = (B1 x B2) - (B3 + B4), where

PD = thickness of peat sediment (cm); B1 = number of drill rods; B2 = length of each drill rod (cm); B3 = length of remaining drill rod (cm); B4 = mineral soil removed (cm).

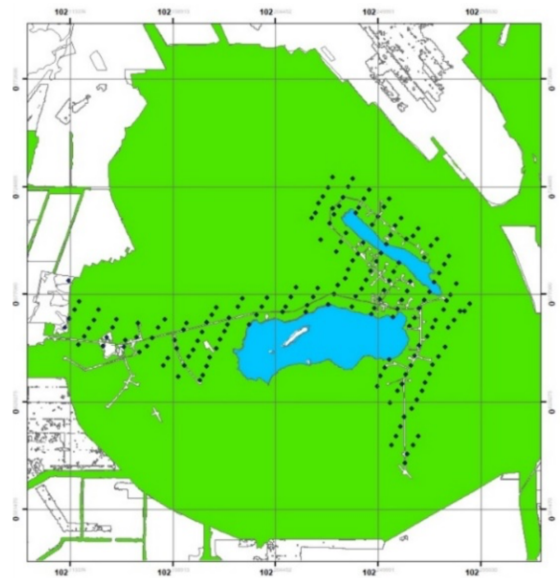

Fig. 1. Map of peat drilling observation points.

Peat maturity was determined by taking a handful of peat, squeezing it and examining the fibers left in the hand at depths of 0-50 cm, 100-150 cm and 300-350 cm. If the fiber content is high (>75%) it is called fibric maturity, medium fiber content (17-75%) is called hemic maturity, and low fiber content (<17%) is called sapric maturity [21]. This method is very informative and only requires close observation of the peat in the field and describes the peat and its structure in quantitative values. Land characteristics observed during peat boring observations are land cover, water table, drainage and substratum.

2.3 Statistical analysis

Geospatial analysis of peat thickness points using IDW (inverse distance weighted), Kriging and Spline interpolation techniques. A comparison of the three techniques was analyzed using analysis of variance (Anova) to select the best technique for mapping peat thickness [22] in Zamrud National Park. Descriptive statistical analysis was also conducted to explain the characteristics of peat thickness, such as peat maturity, land cover, water table, drainage and peat substratum.

3 Result

3.1 Mapping of peat depth

Peat depths in Zamrud National Park is categorized as deep to extreme deep. Peat thicknesses of 5-6 m were found in the middle of the two lakes at 25 points. Likewise, a thickness of 7-9 m was found around two lakes with 80 points. A thickness of 8-10 m was found in the southeast with 30 spots. The extreme thicknesses of 10-16 m are 34 points and 16.5 m thickness is 1 point found at Beruk location towards the west of the study site. The percentage of each thickness class in the peat drilling points is presented in Table 1. Wetlands

International, the Ministry of Forestry and BBSDLP have also published that the peat in this area is very deep [10].

The maturity level of peat is dominated by hemic and fibric at the upper, middle and lower depths. [13,20] also reported that thick peat is mostly dominated by fibric-hemic peat, while shallow and thin peat is dominated by sapric peat. The maturity of sapric peat indicates that the water table is below the surface during a long dry season in aerobic conditions so that some of the organic material has been completely decomposed. Hemic peat shows a zone where the water table rises and falls during the dry season so that some of the organic material has been decomposed and some has not. The fibric maturity of the water table is close to the ground surface and is always inundated, making it very difficult for the organic material to decompose [21]. Based on the assessment of changes in maturity, the main influencing factor is the water level [5,8,9].

Table 1. Peat depth in the Taman Nasional Zamrud area.

Peat depth class (m)	**Terrestrial peat drilling points**	
	Total	**%**
5-6	25	14,71
6-7	48	28,23
7-8	26	15,29
8-9	16	9,41
9-10	20	11,76
10-11	7	4,12
11-12	2	1,18
12-13	4	2,35
13-14	8	4,71
14-15	7	4,12
15-16	6	3,53
16-17	1	0,59
Total	170	100,00

The condition of canopy cover at all drilling points is dominated by dense canopy 84.12%, medium 12.94% and sparse 2.94%. The land cover at various drilling points was dominated by primary peat swamp forest covering 28,257.90 ha or 97.26%. Peat swamp scrub covers 449.40 ha or 1.55%. This cover is mixed with burnt forest, riparian and hut areas. Mining cover with an area of 345.90 ha or 1.19% is a BOB oil and gas facility with a variety of oil wells mixed with open land, bushes, shrubs and grass along the shoulder of the operational road.

The water table at the drill points is classified as shallow to moderate. Shallow water tables (3-48 cm) were found at 168 drilling points. A shallow water table will better maintain the condition of the peat soil during the dry season or when there is no rain. Peat drainage is closely related to the water management of peatlands. Drainage conditions in this study were categorized as obstructed out of 170 peat thickness drilling points (100%). Obstructed drainage conditions allow the water flow to slow down and collect water in the canal so that it is infiltrated to wet the peatland [14].

The substratum in the mineral layer is dominated by clayey marine sediments containing pyrite, with the highest average pyrite content of 1.88% in peat thicknesses >13 m. The pyrite content is evidenced by the presence of pyrite froth. The pyrite content is evidenced by the presence of froth and a pungent odor when the peat substratum is treated with H_2O_2 solution. Pyrite is harmful to vegetation growth when it oxidizes and releases sulfuric acid in amounts >2%. This oxidation can be inhibited by adjusting the water level so that it is always above the pyrite layer [9].

3.2 Grid interpolation

Interpolation of peat thickness points using the IDW technique produces an area of 29,053.21 ha with a minimum thickness of 5.4 m and a maximum thickness of 16.6 m spread throughout the Zamrud National Park area (Fig. 2).

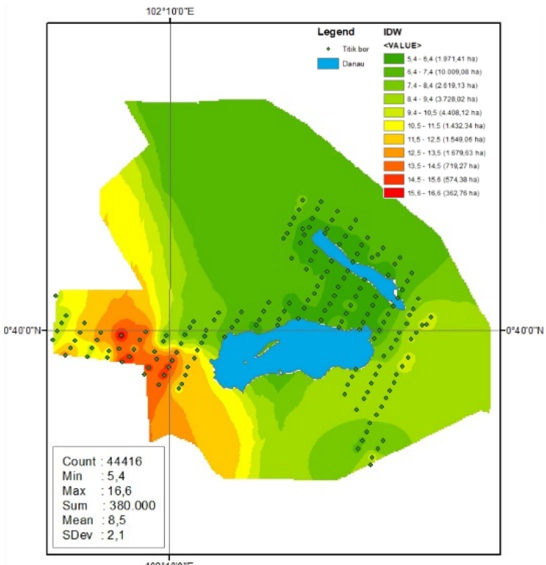

Fig. 2. Result of peat depth map using the IDW interpolation technique.

The peat thickness area produced using the kriging interpolation technique is 29,042.62 ha with a minimum thickness of 5.4 m and a maximum thickness of 16.6 m spread throughout the area (Fig. 3). The peat thickness using this technique is dominated by a peat thickness of 8.4-9.4 m with an area of 7,082.89 ha (24.39% of the total area). Kriging interpolation can be classified into stochastic interpolation which offers error assessment with predicted values assuming random errors. This technique uses linear combinations to estimate values between data samples.

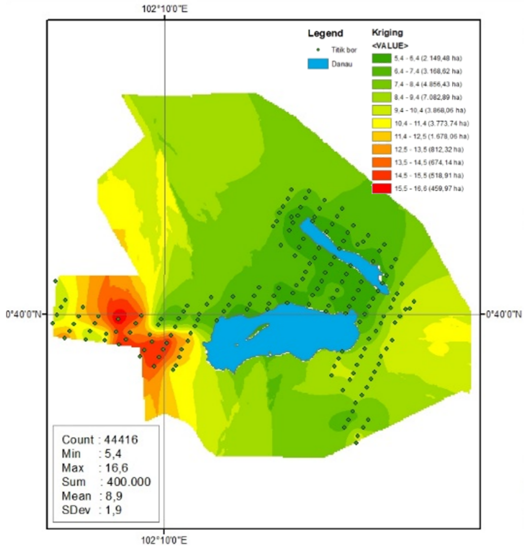

Fig. 3. Result of peat depth map using the Kriging interpolation technique.

Peat thickness using spline interpolation techniques shows an area of 29,050.42 ha with a thickness ranging from 5.3 m to 16.7 m spread throughout the Zamrud National Park area (Fig. 4).

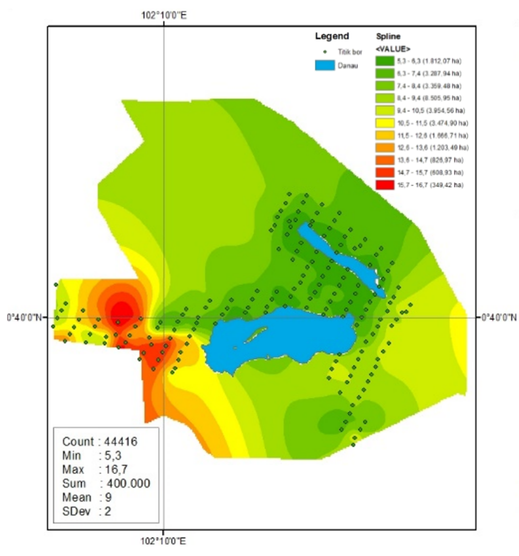

Fig. 4. Result of peat depth map using the Spline interpolation technique.

4 Discussion

Comparison of IDW, Kriging and Spline interpolation techniques in determining the best continuous function at position points among the input data samples used [23]. This comparison can be a means of design, analysis and evaluation of an interpolation algorithm that requires consideration of accuracy targets [24,25]. The results of the comparison of IDW, Kriging and Spline interpolation techniques are presented in Table 2.

Table 2. Comparison of IDW, Kriging and Spline interpolation.

Statistical classification	Interpolation		
	IDW	Kriging	Spline
Count	44416	44416	44416
Min	5,4	5,4	5,3
Max	16,6	16,6	16,7
Sum	380.000	400.000	400.000
Mean	8,5	8,9	9
SDev	2,1	1,9	2
Accuracy (%)	97,06	98,82	98,23
Wide (ha)	29.053,21	29.042,62	29.050,42

The accuracy of grid interpolation can be determined based on its standard deviation value. IDW interpolation has a standard deviation value of 2.1, Kriging interpolation 1.9 and Spline interpolation 2. The interpolation of peat thickness points using the kriging interpolation technique has a standard deviation value (1.9) and is the smallest standard deviation value compared to the other techniques. The standard deviation value shows the accuracy of the interpolation method used, the smaller the standard deviation value, the higher the accuracy of the interpolation method. Thus, the most accurate interpolation technique is Kriging, but this is different from the research conducted by [15,26], which gave the best accuracy results to the IDW interpolation technique in sea surface temperature analysis.

The percentage accuracy of peat thickness by calculating the number of each thickness class that matches the map can also be used as a basis for determining the accuracy of the interpolation method used. The best accuracy percentage value is found in kriging interpolation with an accuracy of 98.82% which is higher than spline interpolation 98.23% and IDW interpolation 97.06%. The variogram calculated for a data set in Kriging interpolation does not apply to other data sets [17,27].

The standard deviation value in IDW interpolation is 2.1, which is the highest value compared to the standard deviation values in other interpolations. This happens because the data samples are sparse and uneven, most likely producing data that is not as desired [17,27]. The IDW technique is one of the surface interpolation techniques with input points in the form of plot center points that are randomly and evenly distributed. According to Mustofa and Widyatmanti [11], the IDW technique estimates attribute values at unsampled points using a linear combination of sample values and weighted by an inverse function of the distance between points. This technique also assumes that each point has a local influence and the value of the point decreases with distance [18].

The standard deviation value in the spline interpolation technique is 2. This spline technique is very good at estimating low and high values that are not present in the data sample. In addition, this method is also quite good at modeling the resulting surface and will pass through the peat thickness drilling points. However, when adjacent sample points have large differences in value, this method does not work well [23,26]. This is because the spline technique uses a slope calculation that changes based on distance to estimate the shape of the resulting surface.

5 Conclusion

Mapping peat depth in the Zamrud National Park using the Kriging interpolation technique has the best accuracy compared to other interpolation techniques. The accuracy of Kriging interpolation has a standard deviation value of 1.9 which is the lowest value compared to other standard deviation values. The percentage accuracy of peat depth by calculating the number of each thickness class that matches the map can also be used as a basis for determining the accuracy of the interpolation method used. The best accuracy percentage value is found in kriging interpolation with an accuracy of 98.82%, which is higher than the IDW interpolation of 97.06% and spline of 98.23%. Thus, the mapping of peat drilling points is more accurate using grid interpolation.

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