# UNCERTAINTIES IN MAPPING THE AREA OF PEATLAND AND ESTIMATING THE DEPTH AND VOLUME OF PEAT IN CENTRAL KALIMANTAN, INDONESIA

Martin Stahlhut and John O. Rieley
School of Geography, University of Nottingham, UK
Contact Email: lgxms@nottingham.ac.uk

## SUMMARY

The availability of reliable maps is a precondition for the effective management and protection of the remaining peatlands in Central Kalimantan. Existing maps are critically assessed, and suggestions are made for the efficient implementation of future surveys, in order to fill the knowledge gaps.

## INTRODUCTION

Where the production of organic matter exceeds the decomposition rate, organic soils are formed. Depending on the accumulation rate and their age, the depth of the organic layer ranges from a few centimetres to more than 10 metres. This study focuses on peat soils that are defined as organic soils where, amongst other criteria, the thickness of the organic layer exceeds 50 cm (Notohadiprawiro, 1996). Therefore, an assessment of the peat thickness has important consequences for the delineation of peatlands. Peat thickness information also plays an important role for the demarcation of protected areas – in Indonesia e.g., peat more than 3 m thick (theoretically) enjoys total protection from any kind of development. While the scientific basis for the 3 m demarcation line is debatable, it nevertheless offers a justification to at least preserve certain deeper sections of a peat dome. A further purpose of peat thickness estimates is an assessment of the carbon store. This is an important precondition for computing carbon credits, to provide further arguments for peatland protection.

Information on peat thickness in the tropics is limited and the example of Central Kalimantan is highlighted here. An early peat map, prepared by Sieffermann (1988) for ORSTOM, does not give details about peat depth, nor does the soil map published by BAKOSURTANAL in 1999. In a "Nationwide study of coastal and near-coastal swampland in Sumatra, Kalimantan and Irian Jaya" (1984) NEDECO Euroconsult carried out a number of measurements. Their transects of not more than 10 drillings each are relatively short, start at rivers or canals and, although dispersed throughout Central Kalimantan, they do not penetrate into the interior of the Katingan – Sebangau peat dome (today partially covered by the Sabangau National Park) or the Sabangau – Kahayan area (Block C, where the Ex Mega Rice Project (EMRP) was established). In 1995, Shepherd *et al.* (1997) carried out a detailed transect along a logging railway, 12 km into the Katingan-Sabangau peat dome. It provided a detailed cross section through the peat dome where, at the deepest point, peat layers more than 12 m thick were measured. However, this and other transects, such as Stahlhut's 20 km transect along the Mangkok canal in 2007, only cover relatively narrow strips and do not provide information on the entire peat dome. From 2000 to 2001, Jaya (2005) measured the thickness of the peat layer at more than 250 locations in Block C and Block B of the EMRP. These data have not yet been used for a systematic generation of a peat thickness map in these areas. To date, the only peat map that provides information about peat depth is that prepared by Wetlands International (WI) (Wahyunto *et al.,* 2004). It shows 5 classes of hemists/fibrists, from 0.5 to 1 m, 1.0 to 2.0, 2.0 to 4.0m, 4.0 to 8.0m and 8.0m to 12.0m thick.

### *Evaluation of the existing peat maps*

The BAKOSURTANAL map shows only one class of peat soils – Troposaprists, Tropohemists and Tropofibrists in Central Kalimantan; these cover 23,360 km$^2$. However, in the Katingan-Sebangau peatland and in Block C where BAKOSURTANAL describes podzolic and alluvial soils (Placorthod, Troporthod and Dystropept), Shepherd *et al.* (1997), Jaya and Stahlhut's found peat depths around 10 m. These peat thickness measurements are in better agreement with the Wetlands International map and its peat thickness classes. The problem with this map is that class labelling is not consistent – at several locations, peat thickness classes of 1.0 to 2.0 and 8.8 to 12.0 m are found adjacent to each other. A further shortcoming is the fact that it does not show the 3-m peat thickness demarcation line, and is thus of limited use for delineation of protected peatland.

In order to overcome these problems, existing peat thickness data were used to generate a peat thickness map that a) shows contiguous peat thickness classes, and b) defines the boundary between peat shallower and equal to or thicker than 3 m.

## MATERIALS AND METHODS

For this pilot study, only Block C of the Mega Rice Project was considered. The area investigated is delineated by the Sungai Sabangau in the East, the Kahayan in the West, the coast to the South and the Kalampangan canal to the North. Thus, an area of 4378 km$^2$ is encompassed. Peat thickness data from the following sources were used:

| Source | Date of survey(s) | No. of points |
|---|---|---|
| Shimada | 1999 | 16 |
| Jaya | 2000 - 2001 | 139 |
| Stahlhut | 2007 | 7 |

**Table 1 Sources of peat thickness survey data for the study area**

This results in an average sampling density of 1 data point per 26 km$^2$. However, the data points are distributed very irregularly, and large tracts of land are under-sampled. In particular, no information is available for the south of the study area, between approximately 3.12º S and the coast, an area of approximately 30% of the whole block.

Measurements were carried out using peat corers and soil augers. While Shimada and Jaya measured the peat thickness to centimetres, Stahlhut only recorded full dm; therefore, for this study, the figures of Shimada (2000) and Jaya (2005) were also rounded to full dm. This is not deemed to degrade the accuracy of the study, since on the uneven surface of the peat soil, height differences between hummocks and depressions often amount to several dm. As can be seen from the above table, an interval of 8 years lies between the earliest and the latest sampling. While the most extensive vegetation clearing and fires occurred before 1999, it needs to be taken into account that peat subsidence is likely to have taken place after this date. Less extensive fires occur to the present day.

Another source of subsidence is the dense network of major and minor drainage canals, more than 400 km of which could be identified on a LandSat imagery of 30 m resolution taken in July 2000. Owing to the difficulty of terrain and vegetation, the majority of peat depth drilling was carried out alongside these linear canals that run either in North - East or South - West directions. In addition to subsidence, such sampling, according to Zöhrer (1980), is prone to cause biased results, particularly where the transects run parallel to spatial trends present in the sampled parameter. Since it is not possible to account for differences in subsidence at the various locations, it is assumed here that it was uniform in the entire area of investigation.

Another source of uncertainty is the peat thickness at the perimeter of the study area, which is 460 km long. It is generally assumed (Moore & Bellamy, 1974) that ombrotrophic mire accumulates peat faster in the centre, while towards its fringes, the peat accumulation rate decreases to 0; this leads to a characteristic dome shape. In the project area, those transects that run in East - West direction, support this assumption – with peat thickness decreasing towards the Sabangau and the Kahayan Rivers. Also, a North-South transect shows a gradient towards the South, with the peat depth decreasing to 0 near the coast. Therefore, 916 points were digitised at the boundary of the peat dome, along the Kahayan, the coastline and the Sabangau, and assigned a peat thickness of 0.0 m. This ensures that during the interpolation, the peat will not extend over the rivers and into the Java Sea.

In order to generate a continuous surface from point measurements, a wide range of techniques is available. They can be divided into global and local techniques.

An example of the former is the trend surface, where all available points are used to create the surface. For this study, a 2nd order polynomial was chosen – a coarse but rapid way to gain an overall impression of the peat thickness in the study area. It is based on the assumption that the location is the independent variable and determines the dependent variable, in this case the peat thickness, which is expected to vary continuously throughout the area. This is justified by the preliminary interpretation of the available data that the peat thickness generally increases with distance from the rivers and from South to North. A disadvantage of trend surfaces (Burrough & McDonnell, 1998) is the influence of outliers on the entire surface.

Local interpolators only consider measurements in the vicinity of the point to be interpolated. A method used for this study is Inverse Distance Weighting (IDW). In order to interpolate the peat thickness at a location where no data are available, only measurements in the vicinity are used. IDW weighs the values of these measurements according to the distance from the point to be interpolated, i.e. the values farther away exert a weaker influence on the interpolated point than close ones. A minimum of 8 points was used. Similar to trend surfaces, IDW-generated surfaces are susceptible to extreme values; however, they do not affect the entire surface, but merely create local holes or peaks.

Geostatistical methods are a special case of local interpolators, known under the name Kriging. These analyze the variance of the difference between measurements, and its relationship to the distance. The approximation by a curve provides the variogram, which allows the estimation of the three components: the general trend in the data, spatially correlated variation and spatially uncorrelated noise. Unlike the deterministic IDW, the predicted surface produced by Kriging is an estimate, for which a standard error is provided. For this study, Ordinary Kriging was chosen since a Gaussian curve was felt to best represent the variance/distance distribution. In order to estimate the peat thickness at unsampled locations, a circular search radius with 8 neighbours was used.

To assess the accuracy of the interpolation, 75% of the available data points were used for the computation of the surface (training data), and the remaining 25% to compare peat thickness prediction and actual measurements (test data). The selection of training and test data was done randomly. The accuracy of the surfaces was then determined by visual comparison of the test data plotted against the predicted surface data at this location, and the computation of the coefficient of correlation (linear) between these pairs. The Student ‘t’ test was applied to determine if test and actual data represent the same population.

For the determination of the boundaries defining peat – 0.5 m - and peat to be protected – >3.0 m -, as well as for the computation of the peat volume, the following peat thickness classes were distinguished: 0.0 – 0.5 m (histosol and no peat), 0.5 – 1.5 m, 1.5 – 2.5 m, 2.5 – 3.0 m, 3.0 – 3.5 m, 3.5 – 4.5 m, etc. As average peat thickness per class, 1.0 m, 2.0 m, 2.75 m, 3.0 m, 4.0 m etc., were taken.

In the study area, the Wetlands International map distinguishes four peat depth classes – no peat (i.e. peat less than 0.5 m deep), 0.5 – 1.0 m, 1.0 – 2.0 m, and 2.0 – 4.0 m. The peat volume estimate was based on an average peat thickness of 0.0 m (class “no peat”), 0.75 m (class 0.5 – 1.0 m peat depth), 1.5 m (class 1.0 – 2.0 m peat depth) and 6.0 m (class 4.0 – 8.0 m peat depth). There is no peat depth class 2.0 – 4.0 m.

The peat volume estimates of the three interpolation methods, and the results of the peat depth estimate based on the Wetlands International map, were then compared.

## RESULTS AND DISCUSSION

For the 2nd Order Polynomial interpolation, the comparison of measured data with interpolated value at a specific location shows virtually no correlation. Also, at 0.05 significance level, the high t value of 3.6 lies far above the critical value of 2.02 (for a significance level of 0.05), suggesting that the interpolation generated ‘artificial’ values that do not represent ‘reality’ as measured in the field. This is most likely owing to peat thickness measurements which, in the study area, vary considerably over a short distance. This interpolation method obviously does not represent such variation appropriately.

The interpolated surfaces generated by IDW and Ordinary Kriging match considerably better with the measured values. The geostatistical method even achieves a significant, though not high correlation, but like IDW, measured and computed values represent the same population (t value for IDW = 1.45, for Kriging = 0.47 and thus considerably below the critical value).

| Interpolation method | $R^2$ | t* | Peat deeper > 0.5 m | Peat deeper > 3.0 m | Peat volume |
|---|---|---|---|---|---|
| 2nd order Polynomial | 0.17 | 3.62 | 2808 $km^2$ | 906 $km^2$ | 6.71 $km^3$ |
| Inverse Distance Weighting | 0.55 | 1.45 | 2116 $km^2$ | 745 $km^2$ | 5.38 $km^3$ |
| Ordinary Kriging | 0.69 | 0.47 | 2667 $km^2$<br>(1473 $km^2$ with 0.95 probability) | 1113 $km^2$<br>(555 $km^2$ with 0.95 probability) | 7.65 $km^3$<br>(5.5 – 9.9 $km^3$) |
| Wetlands International | | | 2928 $km^2$ | n.a. | 13.6 $km^3$ |

* critical value 2.02 for 0.05 significance level

**Table 2 Accuracy assessment and estimated peat depth and volume for three interpolation methods, and data derived from the Wetlands International map**

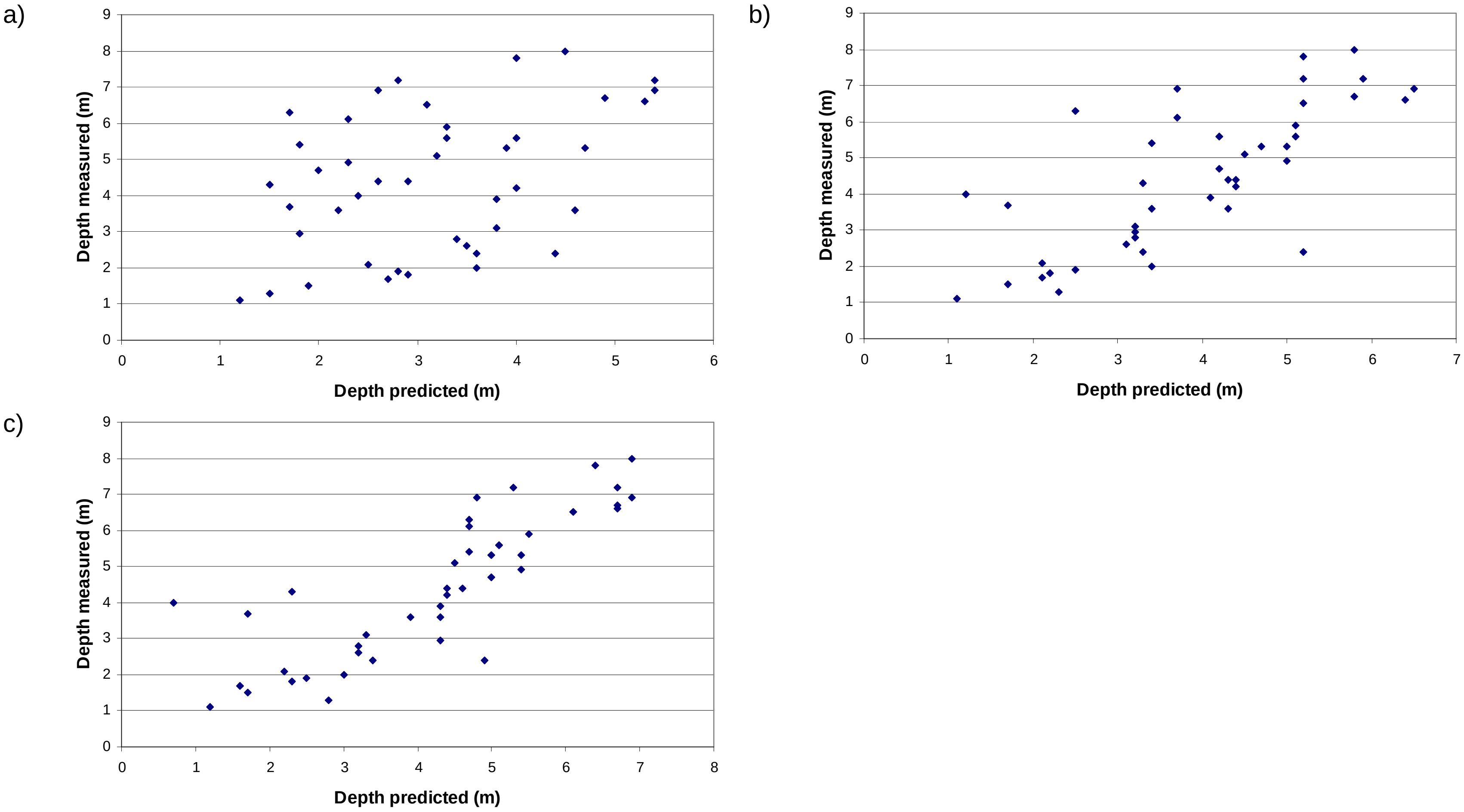
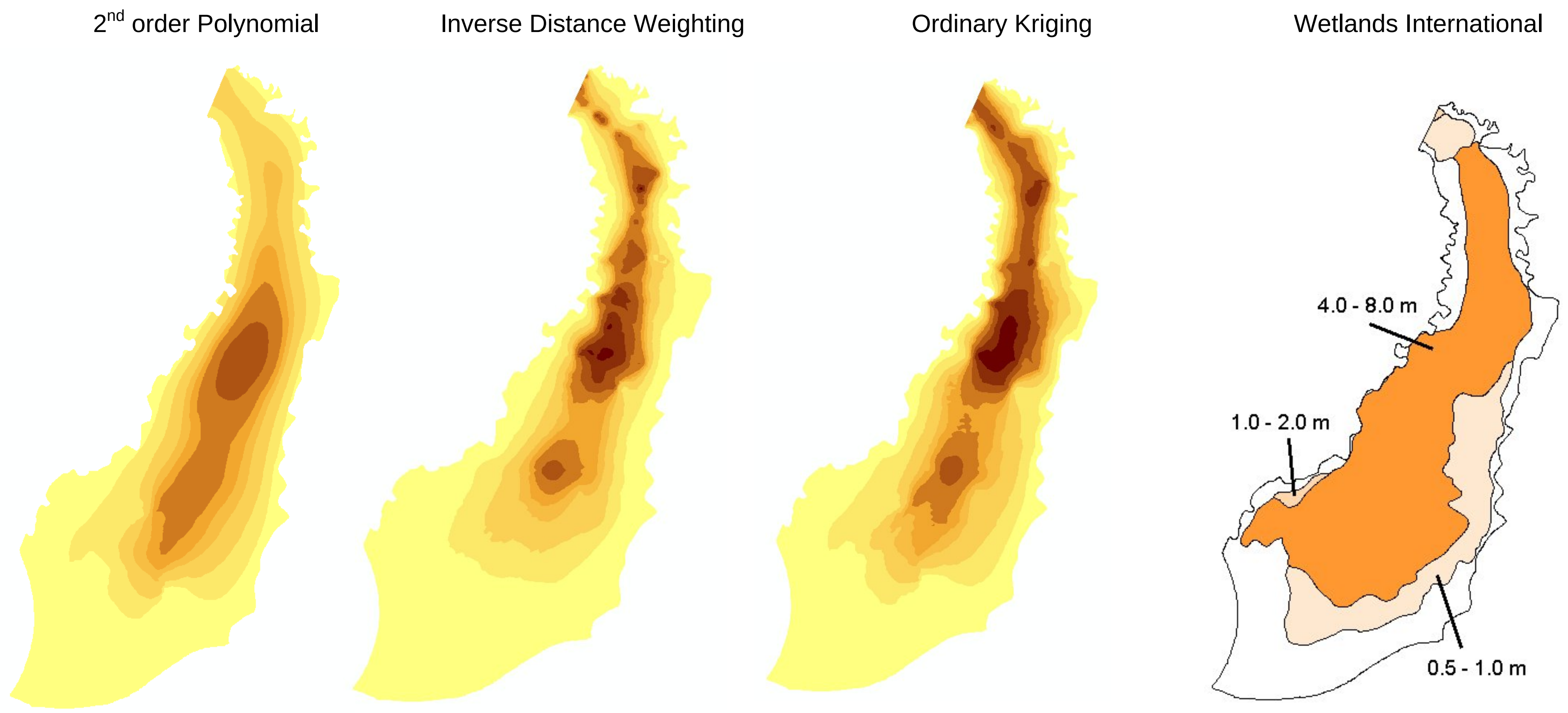


**Figure 1 Scatter plots for predicted against measured peat depths using a) 2nd order Polynomial. $R^2$ = 0.17, b) Inverse Distance Weighting. $R^2$ = 0.56 and c) Ordinary Kriging. $R^2$ = 0.69**



| | |
|---|---|
| peat > 0.5 m | 2808 km$^2$ |
| peat > 3 m | 906 km$^2$ |
| av. peat depth | 1.53 m |
| peat volume | 6.71 km$^3$ |

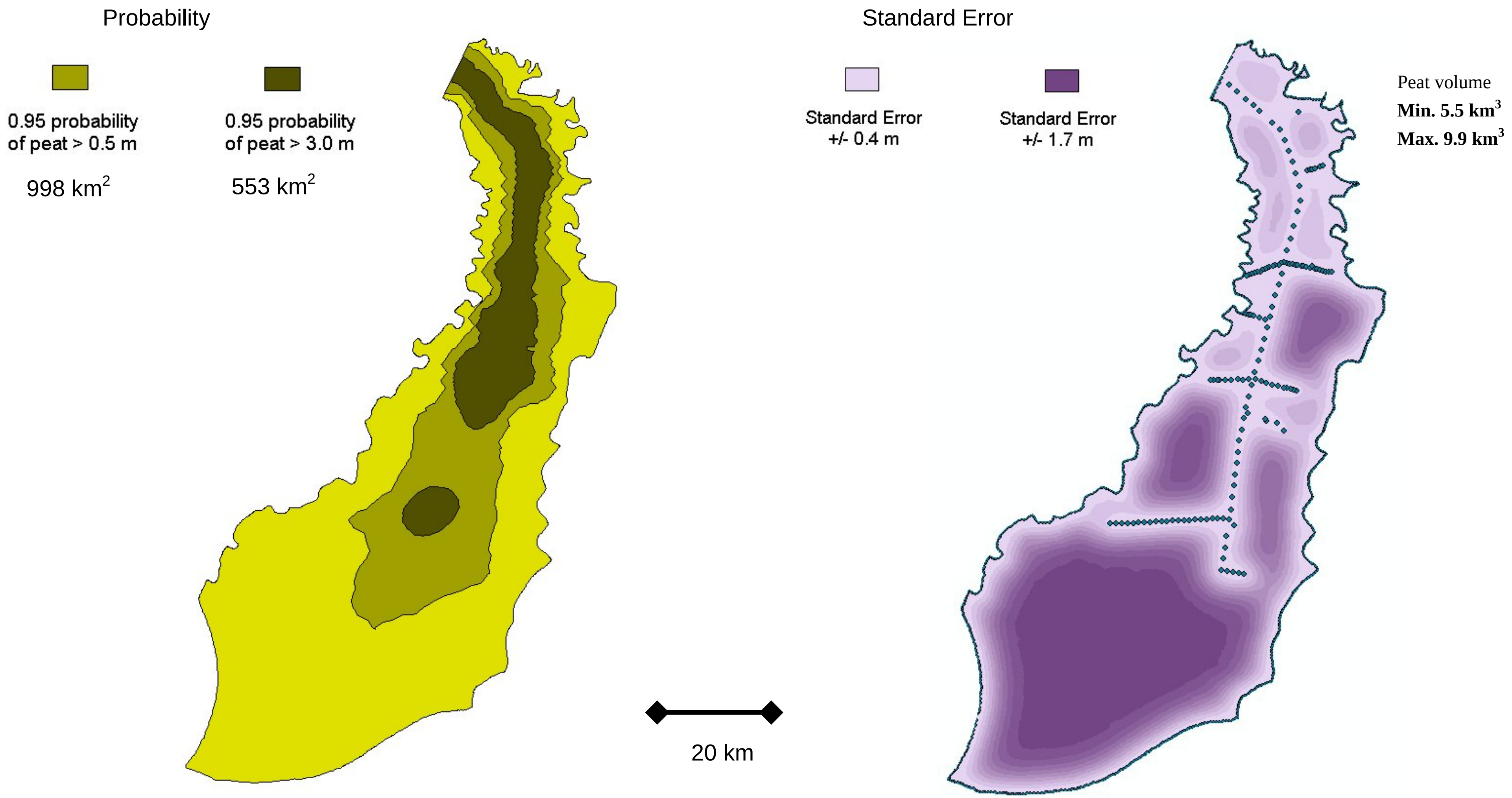
| | |
|---|---|
| peat > 0.5 m | 2116 km$^2$ |
| peat > 3 m | 745 km$^2$ |
| av. peat depth | 1.23 m |
| peat volume | 5.38 km$^3$ |

| | |
|---|---|
| peat > 0.5 m | 2667 km$^2$ |
| peat > 3 m | 1113 km$^2$ |
| av. peat depth | 1.70 m |
| peat volume | 7.65 km$^3$ |

| | |
|---|---|
| peat > 0.5 m | 2928 km$^2$ |
| peat > 3.0 m | n.a. |
| av. peat depth | 3.1 m |
| peat volume | 13.6 km$^3$ |

| ▇ | ▇ | ▇ | ▇ | ▇ | ▇ | ▇ | ▇ | ▇ |
|---|---|---|---|---|---|---|---|---|
| 0 m - 0.5 m | 0.5 m - 1.5 m | 1.5 m - 2.5 m | 2.5 m - 3.0 m | 3.0 m - 3.5 m | 3.5 m - 4.5 m | 4.5 m - 5.5 m | 5.5 m - 6.5 m | 6.5 m - 7.5 m |

**Figure 2 Comparison of peat depth and volume estimates**



Probability

Standard Error

Peat volume

**Min. 5.5 $km^3$**

**Max. 9.9 $km^3$**

**Figure 3 Probability and standard error of the Kriging surface interpolation**

With regards to the peat volume estimate, it is obvious that an estimate based on the Wetlands International map – which was not intended for such purpose – leads to too large figures. Not only is the peat depth class 2.0 m – 4.0 m omitted and largely covered by the class 4.0 m – 8.0 m but the latter covers areas that, on all three interpolation attempts, show much lower peat depth values.

Despite its inaccuracy regarding the peat thickness at a specific location, the polynomial trend surface produced similar values for the peat volume estimates as Ordinary Kriging. As can be seen from figure 2, this is the result of the smoothing effect of the global interpolation, leading to under- as well as overestimates. Conversely, the IDW-based map bears much closer resemblance to the Ordinary Kriging interpolation, but nevertheless leads to peat volume estimates that lie below the minimum figures of Ordinary Kriging. The "hole and spikes" effect caused by this local interpolation method is clearly visible at figure 2, in particular, in areas where thick peat was recorded. Ordinary Kriging not only produced a smoother output, it also identified and compensated for outliers.

Of particular importance is the capability of Kriging to calculate the standard error of the interpolated surface, thus providing a minimum-maximum range of its predictions. Although this range is considerable, owing to the large tracts of land without measurements, the peat volume figures derived from IDW and the Wetlands International map both lie outside.

## SUMMARY AND CONCLUSIONS

The BAKOSURTANAL map is unsuitable for land use planning and computation of carbon storage in the study area because it does not contain any peat thickness information. Also, there are major discrepancies in using the Wetlands International map and associated ground data. Contradictions were not found between the ground data and the WI peat map, but the WI map does not show the 3-m peat thickness boundary and is thus of limited use if protection zones are to be declared, based on peat thickness.

Amongst the 3 surface interpolation techniques investigated, the 2nd order polynomial produced the least useful – because it is too general – output. In particular, it does not show small scale variation. It cannot be recommended for future peat thickness estimates. The surfaces interpolated by Inverse Distance Weighting and Ordinary Kriging are relatively similar, but IDW underestimated peat area and volume in comparison to Ordinary Kriging. The advantage of the geostatistical method is not only its higher accuracy, as shown by comparison of training and test data, but it also allowed an assessment of the reliability of its predictions. Furthermore, it identified areas of high standard error of the predictions indicating where there is a need for further peat depth sampling. This can help to avoid unnecessary sampling in areas where a sufficient density of peat depth drillings, in relation to the variability of the results, has been achieved.

However, Kriging required a number of input parameters which had to be chosen freely, and, as the literature (Oliver *et al.* 1989, Burrough & McDonnell 1998) shows, these choices can influence the output. Nevertheless, it is recommended here as a useful tool for future peat thickness estimates.

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