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Topographic Wetness Index and Prehistoric Land Use

Abstract: A digital terrain model (DTM) of an area of approximately 100 km^2 in East Jutland, Denmark, has been created based on information from the oldest available topographic map from the second half of the 19th century. On the basis of this model, a topographic wetness index for a 10 x 10 m cell grid has been calculated. In this index a threshold value has been estimated, which corresponds to an arable / non-arable classification of the area. This was done with the help of information from economic maps dating about 1800 AD. Finally it is argued that DTM's generated on topographic maps drawn in 1:20,000 are too coarse for detailed modelling of land-use in large parts of prehistory. This conclusion has been achieved by comparing the modelled area with registered observations of archaeological finds and sites.

Introduction

From historical agriculture in temperate climates it is known that there is an intimate relationship between the amount of hay-production for winter-fodder and the number of domesticated herbivore. One cannot exceed the number of livestock beyond a certain threshold without getting fodder from an outside area. At the same time, the magnitude of the harvest is dependent on the amount of manure spread on the tilled fields. A proper balance between tilled fields and livestock maximizes the total outcome of a certain area and this is the main reason why mixed farming has been such a successful agricultural strategy. Adding to its success was the fact that it was a flexible agricultural strategy. To the land-user it left the options open to increase grassland for foddering livestock, to increase the tilled area, or to leave things unchanged. Whatever decision the farmer found to be appropriate, he had to choose and this is why the ratio of tilled area (the infield) versus grassland and meadows (the outfield) is a reflection of fundamental choices.

If we focus on a prehistoric situation, it is only in exceptional cases we have sufficient evidence to determine the area of the infield, and in most cases it will probably not be possible to determine the extent of the outfield. What we can do, however, is to model a prehistoric situation and relate this deductively achieved model to the archaeological record. Then we can draw our conclusions.

The three most vital parameters in models of prehistoric land-use are water drainage, soil-type, and topography (van Leusen 1993). We must not forget however, that these parameters are complex: they are inter-related and dynamic. In my opinion there has not been sufficient attention drawn to this fact. In intensively cultivated areas, like the Danish landscape for instance, water runoff has been managed for centuries with man-made constructions such as subsurface drainage-pipes, canals, dykes, and pumping stations. Available digital data on modern drainage systems is therefore not always the right choice in the modelling of prehistoric conditions. Artificial drainage has also dissolved many areas with high organic contents. The outcome is that the scale of available information on soil-types generally is too coarse to be usable. If we want to include information on soil-types in three dimensions in our studies, then modern data is not available.

Also modern data on topography is flawed, since we cannot regard the data as a direct representation of a prehistoric situation: intensive agriculture has altered the surface since local depressions and minor hills deliberately have been removed. Tilled areas simply have been also flattened by heavy agricultural machinery.

The physical geographer Kristian Dalsgaard has in a previous study demonstrated modern alterations of the oro-topographic surface (Dalsgaard 1985). With a dense net of core drillings he was able to prove that the prehistoric landscape was speckled with patches of wetland. Due to the annual rainfall and the lack of drainage, up to 25% of the area had to be classified as water logged. This area was not suitable for tilling since cereals, the dominating crop in European prehistory, cannot grow under these humid conditions. Dalsgaard's finding that the distribution of wetland matched the position of bogs, fens, and meadows on old economic maps from about 1800 AD was extremely interesting. These maps are highly detailed, as they were drawn in scale 1:4000. They were made as a part of agricultural reforms and for taxation purposes (Korsgaard 2006). Generally speaking the land was drained by natural hydrology at the time the maps were drawn. Basically Denmark was also divided into two extremes of the mixed farming strategy: in one extreme there was extensive agriculture with a maximum allocation of the area for grazing livestock with only small patches of tilled fields. This strategy was predominant on the sandy soils of Western Jutland. The other extreme on the loamy soils of eastern Denmark was an allocation of a maximum area for growing cereals. Dalsgaard's study area is located in the latter of the two extremes. What his core drillings confirm is the spatial distribution of potentially arable land. It was the choice of the land-user at any time to decide whether this land should be used for the growing of crops or whether to be used as wood or grassland.

The historically recorded situation in the eastern part of Denmark thus constitutes an ideal workbench for modelling surface hydrology in a naturally drained situation (Dahlke 2003; Sørensen / Zinko / Seibert 2006). A study on this subject will be published elsewhere (Andresen in press). Another interesting subject, however, is the investigation of how the archaeological record relates to a modelled landscape classified in a bipartite arable / non-arable dichotomy. This will be examined at the end of this paper. Thus this study relates to previous suitability studies of farming communities in other landscapes (Dominguez / Kolm 2005).

Generating a Digital Terrain Model

The digital terrain model is the most important layer in analytical GIS studies, but it is not always realized how much attention one should pay to it. The quality of the DTM should ideally be as critically assessed as information on the position and date of archaeological sites – probably even more. The reason is that the DTM is the source and the object of many analytical procedures. I am not only referring to second derivatives such as slope and aspect, but also to cost-analysis, such as least cost paths. A quality assessment of a DTM is dependent on scale: one should not use a DTM on a smaller scale than recommended by its creator. Even if one wants to use a DTM on a larger scale than its sampling size, one must carefully consider the aggregation procedure.

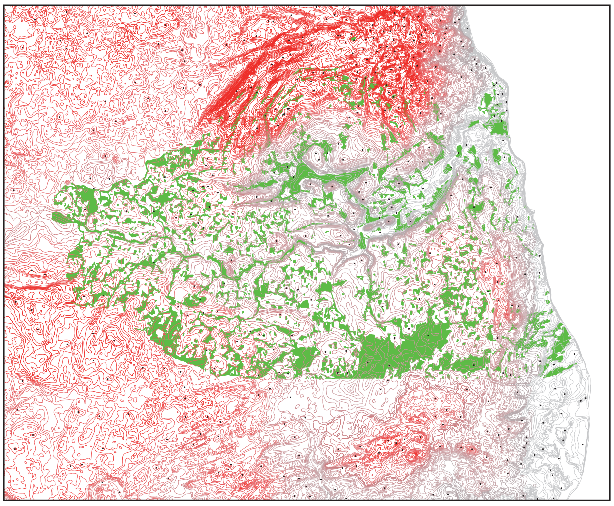

Fig. 1. The digitized contour curves from the military mapping of 1875 overlaid by wetland as recorded on economic maps from around 1800 AD.

It is expected from mapping agencies that their data is frequently updated and reflect the current situation. This applies in principle for the DTM too. Modern dams, roads, and other man-made constructions must therefore be carefully removed from the DTM if a situation previous to their creation is modelled. Until recently, the digital DTM with the finest resolution of the Danish landscape had a grid-size of 50 x 50 m. Obviously this is too coarse a grid-size for modelling prehistoric land-use. Instead of waiting for a digital DTM with a suitable resolution, I began digitizing contour curves from topographic maps.

Ad Fontes

Digitizing contour curves from topographic maps is tediously laborious involving long hours of work. In my opinion the time spent can be worthwhile because this way one is then in complete control of the data generating process, which enables one to obtain a very good grip of the modelled landscape. In the Danish case, all contour curves on all printed topographic maps can be traced back to sources from the second half of the 19th century. The military needed exact topographic information and therefore, the whole country was surveyed completely – some areas even twice (Korsgaard 2006, 59). From 1855 a dioptre was used, which is still regarded as a relatively precise instrument. It was the first to measure distance, direction, and vertical angle. This made it much easier to draw the contour curves in the field. The curves themselves were drawn on sheets in scale 1:20,000 with five feet equidistance. One can only admire the effort, energy, and precision,

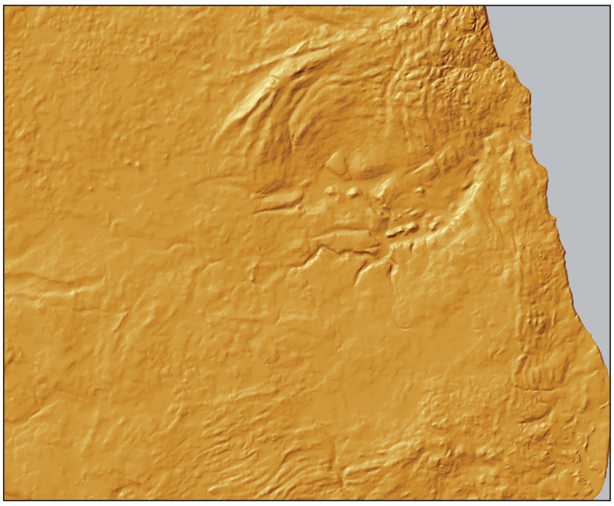

Fig. 2. The digital terrain model of the study area.

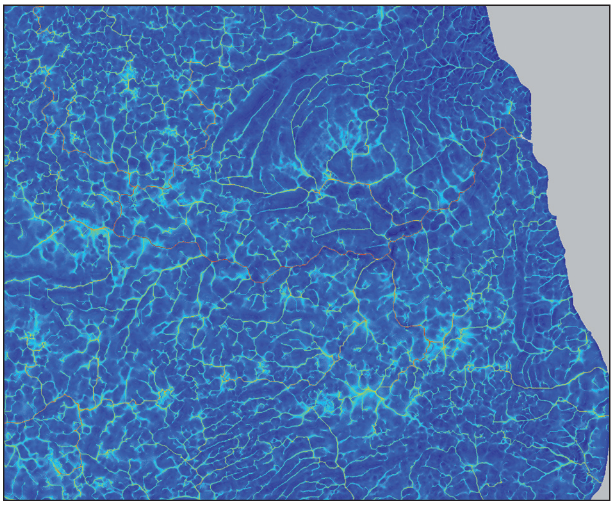

Fig. 3. The computed wetness index of the study area.

which were put into the map material. The maps still leave a present day user with a large amount of confidence in their credibility, and this may be one reason why the contour curves have been re-used for almost 150 years.

Shortly after the extensive fieldwork, the information was subsequently transferred to rectangular maps. These beautifully hand-coloured maps have lately been scanned and geo-referenced by the Danish Ordnance Survey (KMS) and were thus an easy choice as the basis of a digital DTM. The original maps were only consulted in specific areas.

The study area I picked was the parish in which I live – Maarslet south of Aarhus. I could easily solve uncertainties in the interpretation of the curves by downloading areas of the map from 1875 AD to a handheld PDA with a GPS and thus simply go out in the field and check the contour lines on the map. The other advantage was that the parish is located in "loam-Denmark" – the area where the historic agriculture around 1800 AD was directed towards a maximum production of cereals.

Also six economic maps covering the parish were scanned and geo-referenced. In this reference, I used the location of prominent edges in the cadastre. The error was estimated to be 20 m at most. Using MapInfo it was an easy job to digitize areas with the signatures of bog, fen or meadow. Also the overlay of the contour curves onto the digitized wetland is a standard procedure *(Fig. 1)*. A visual inspection of the two map layers confirmed that the mapped wetland was generally located in identifiable low-lying areas. In some areas, however, the signature on the economic maps did not seem convincing because they were placed on local topographic maxima. Therefore the decision was taken to perform an independent control of the mapped wetland signature by computing a topographic wetness index. To my knowledge, such a study has never been done before, at least not on a Danish material.

From Contour to Grid

The new perspective required a re-definition of the study area, which now expanded from 25 km^2 (the area of the parish) to 100 km^2 (the watershed boundaries of the local stream, the Giber). After digitizing the contour curves, their topology and z-order were checked with tools written in MapBasic by myself. When that was done, the interpolation process was hoped to transfer the contour lines to a smooth grid-representation of the study area. Initially, that was obtained, but cross-sections of the surface revealed that the grid looked like a representation of rice terraces from Indonesia (Conolly / Lake 2006, 105).

There are quite a number of references on the contour-to-grid problem, and there are several applications which claim easy solutions (see http://www.vterrain.org/Elevation/contour.html). Trials demonstrated that these are claims. No interpolation algorithm can escape from the fact that elevation data from contour curves is not randomly, evenly, or regularly spread. On the contrary, elevation data from contour curves are much more densely distributed along the curves than between the curves. This is the reason why they produce very bad results, if they are not re-sampled prior to interpolation and the choice of a proper cell-size of the resulting grid. (Asserup / Eklöf 2000; Conolly / Lake 2006, 106). A rule-of-thumb is that the resulting cell-size should be set to half of the horizontal distance between curves. As contour curves are not evenly spaced, however, the mean distance was computed, which was close to 20 meters. Inside each of the 1 million 10 x 10 m cells the average altitude of the digitized points was computed. Subsequently, a variogram analysis was performed using VerticalMapper. This analysis produced the parameters for an ordinary Kriging interpolation, which was done in SAGA-GIS 1.0 (http://www.saga-gis.uni-goettingen.de). The resulting DTM was satisfactory *(Fig. 2)*.

Computing Topographic Wetness Index and Defining Threshold Value of Wetland

A smooth DTM is a pre-condition for reliable computation of the topographic wetness index. The index is assigned to each cell and is a real number spanning from very dry (0) to open water (24 in the study). The algorithm used in this study is based on combined parameters, which relate the flow-accumulation to the slope of a given cell (Beven / Kirkby 1979). Flow-accumulation is basically the size of the contributing area, so if the contributing area to a given cell is large and that cell has neighbouring cells of similar altitude, then the cell will get a high index score. If the contributing area is small and neighbouring cells are located in lower altitudes, then the cell will get a low index score (see also Wilson / Western / Grayson 2005; Hjerdt McDonell / Rodhe 2004; Sørensen / Zinko / Seibert 2006).

No information on soil-type is used in this study. One can take into account the permeability of the soil in the computation, but the available data on soils cannot be down-scaled to 10 x 10 m cells. Available soil data is based on core drillings with a distance of about 1 km, which means that a down-scaling to the spatial resolution of this study is a hazardous choice. One might argue that ignoring soil-data implies a comparable risk but since the study area according to the soil maps is pretty homogenous the decision was taken to ignore soil texture.

An estimation of a threshold value discriminating

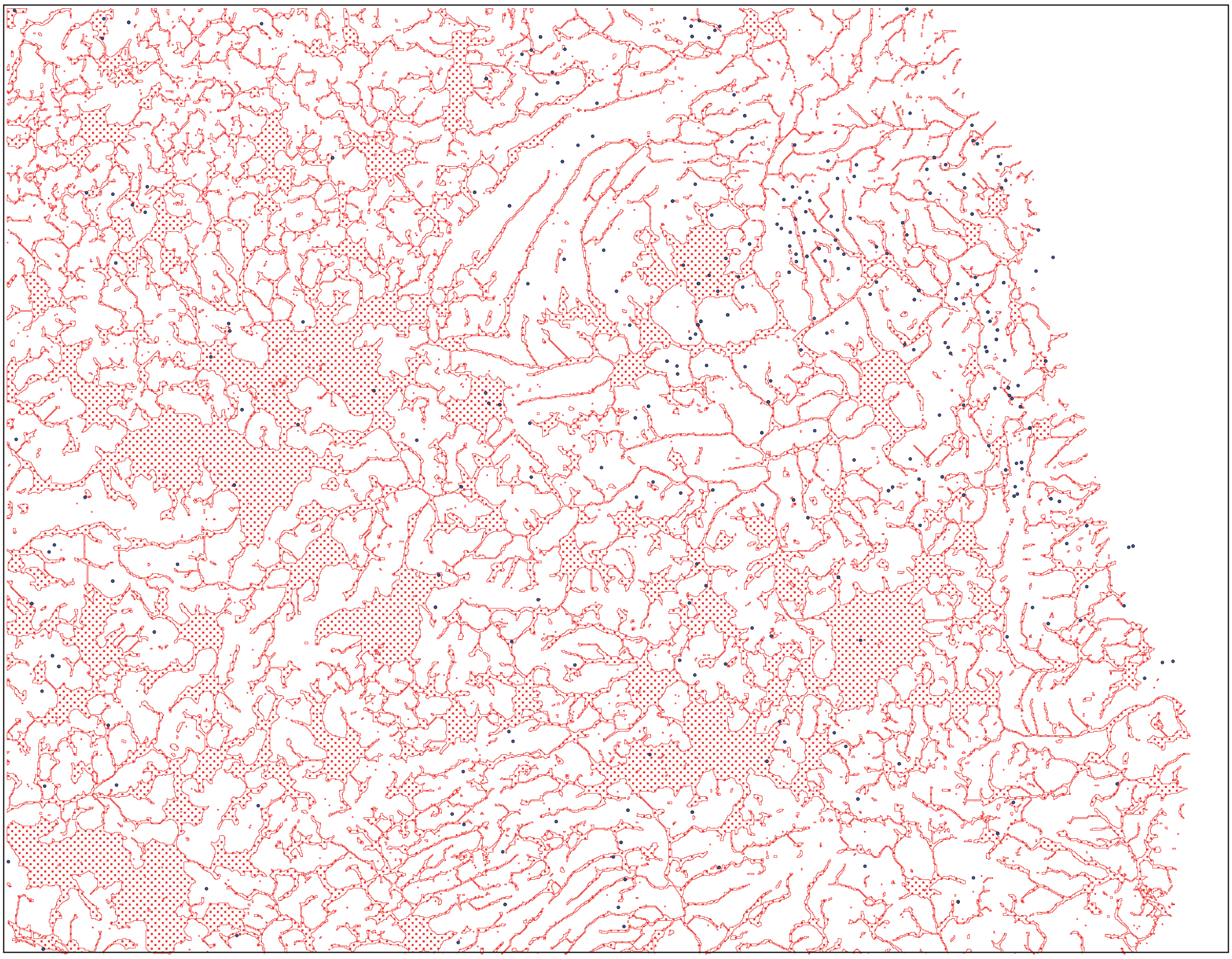

Fig. 4. The arable/non arable dichotomy of the study area overlaid by the observations of archaeological finds and sites as recorded in the national sites and monuments register.

between potentially arable and non-arable land was done by further analysis (ANDRESEN IN PRESS). It was based on the frequency distributions of the cells (N=23,144,298) on locations, which were assigned as wetland on the old economic maps. This distribution was then statistically compared to the frequency distribution of the cells (N=70,695,702) on locations which were assigned as arable.

Correlation with SMR-Data

The recordings of archaeological findings in Denmark dates back for centuries. Yet no spectacular archaeological findings have ever been made in the study area, despite the fact that two archaeological institutes and a museum are located in it. The sites and monuments record displays very common structures, such as megalithic tombs, Bronze Age mounds, flint scatters and Iron Age pits. The observations are stored in a national digital register of archaeological finds and monuments, the DKC (http://www.dkconline.dk). The precision of the find spots must be considered as being relatively precise but the uncertainty is higher than the 10 x 10 m cell size.

A spatial query combining the modelled arable / non arable classification with the find spots resulted in interesting results. Of 385 find spots, 60 were recorded on modelled non-arable land. 325 were located on modelled dry land. 95 respectively 290 would be expected if the find-spots were randomly distributed. This is obviously not the case. A Chi-square test returns very small probabilities for the observed distribution ($p=4*10^{-5}$). Of the 60 find-spots on modelled non-arable land were 30 recorded as being found in wood- or wetland and many of the finds were types of finds you might expect in wet conditions, such as complete Neolithic axes, iron age pots, and medieval wells for the production of flax. So at first sight prehistoric land-use seems to be properly modelled and the method should be considered as a success.

Discussion

Nevertheless, warning bells rang. In an intensively surveyed forest with extremely good conditions of preservation of ancient monuments, several megalithic tombs are found on areas which were modelled as being "wet" (LAURSEN 1982). From other investigations we know that tombs were erected on or closely nearby Neolithic habitation, and these findings therefore may indicate that the arable / non arable dichotomy is not sufficiently precise enough to locate the tiny farming clearances from the Neolithic and probably Bronze Age. We believe that a refinement of the model on the basis of a DTM of locally higher resolution may lead to a better prediction of the location of sites from these prehistoric periods (THOMPSON / BELL / BUTLER 2001). A natural next step therefore is to obtain a high precision LiDAR-scan of the forested area, since this area has not been cultivated as intensively as the surrounding areas and therefore represents a more accurate reflection of ancient topography. Data from the LiDAR-scan could subsequently be patched into the existing DTM and constitute a better source for the assessment of prehistoric land-use.

Acknowledgements

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