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Predictive modeling; find site preferences; segmentation; Bronze Age.

The term "predictive modeling" comprises a range of GIS-based methodological approaches and statistical models that were developed in recent years from interdisciplinary projects and have been applied in archeological sciences to predict unknown archaeological sites. These predictions are based on the detailed analysis of the distribution and the characteristics from known discoveries.

The main goal of this research is to understand the dependency of such sites from natural environmental factors that together with their distribution pattern allow identification of causative determinants for their occurrence.

From these efforts, new models will be derived that will allow transfer and application towards broader, more exhaustive area-wide predictions.[1] The current limitations of 'predictive modeling' are the variable and broad distribution of sites and the diversities of available raw data, which require an individualistic approach for the analysis.[2]

In the field of archaeological research in Central Germany such predictive models do not exist.

The discovery of the Sky Disc of Nebra led to a closer investigation of the spatial relationships of such find sites and find situations of the Early Bronze Age throughout Central Germany. Therefore an interdisciplinary DFG research group ("FOR550") was found to investigate the significance of the entire "Aunjetitzer Verband" for the European Early Bronze Age.

A sub-goal of this project aims to develop a model to analyze the settlement preferences.

Firstly to characterize Early Bronze Age find locations in their natural environment and secondly to predict their potential distribution.

While previous studies refer to a small-scale and physiographically discrete area, this study covers various morphological zones as "Makroregionenebene"-specified territory, including several diverse landscape units.[3]

The basis for the study is formed by the archaeological findings that are dispersed over an area of 24,000km^2. For this reason, a direct applicability of existing methods is not possible.

Subsequently the question that needs to be answered is whether it is possible to derive a reliable and applicable predictive model for such a large area with different natural

1 Möller et al. 2010; Verhagen and Dragut 2012.
2 Graves 2011; Zwertvaegher et al. 2010.
3 e.g., Kunow and Müller 2004; Fletcher 2008; Jaroslaw and Hildebrandt-Radke 2009.

environments. The distinctive feature of this work consists primarily in the size of the investigated area.

The prerequisite for the development of a predictive modeling is a comprehensive database built on a precise characterization of corresponding find sites and their spatial distribution as well as possible preferences of natural environments. A number of studies are dedicated to the identification of influencing factors which identify appropriate geofactors and demonstrate their meaning.[4]

For database development, all available official and free geodata that detect dependencies in the distribution of archaeological find sites were compiled.

Essential data sets here are the SRTM Digital elevation model at a resolution of 90m together with topographical, geomorphologic and natural environmental basis data.

Because of the transregional context of this large research area covering several states, all input data needs to be homogenized and adapted beforehand. These are first of all differences regarding the geodesic fundamentals. In addition there are also divergent scale ranges, processing statuses and accuracies together with different notations, even in certain fields. After these preparatory steps, there was a spatial data basis available for the whole study area. This is necessary for the intersection of the archaeological information with the topographic and thematic basic data.

From all available data that went into the database used for the modeling process, 10 parameters were selected for testing the predictivity of the model. In a first step, the distance from river network, distance from loess and the distance from floodplain were calculated and edited comprehensively from geographic base data. Secondly, the agrarian number as a measure of earning capacity of soils was brought into the research. The four factors mentioned above are thematic base data and will be completed by 6 relief parameters derived from the digital SRTM-Elevation Model. These are slope (S), elevation (E), vertical distance to river network (VDN), vertical distance to culmination network (VDC), topographic wetness index (TWI) and mass balance index (MBI).

For further processing of such complex and diverse input data that include direct and indirect quality criteria, a data reduction was required. For this reason, a segmentation of the relief of the study area was performed. The transformed relief parameters f(E), f(MBI), f(S), f(TWI), f(VDN) and f(VDR) were used for the object extraction.[5]

The segmentation procedure reduced the set of data considerably. 2630×2545 Pixel were aggregated to 41,952 segments by local homogeneity relief criteria.

The data resolution and thereby the degree of homogeneity were adapted to the size of the area.[6]

As a result, an object data set was generated that was diluted with available raster data.

In the process, all information of the 10 geofactors were integrated in the data set for the entire area. Afterwards, segments that contain find sites were extracted and the spatial values were diluted with the find sites.

Based on this method, the study area was analyzed both area-wide and for each find site.

The first interest is on the characterization of the region by geofactors.

The importance of the value distribution of all 10 geofactors, their dependencies with regards to the extensive distribution and their effect on the find site distribution can be viewed by a correlation analysis.

Representative selected results regarding the parameter TWI (topographic wetness index) should be shown in the following.

4 e.g., Poluschny 2002; Mischka 2007; Pankau 2007.
5 See Möller et al. 2010.
6 See Leukert 2002.

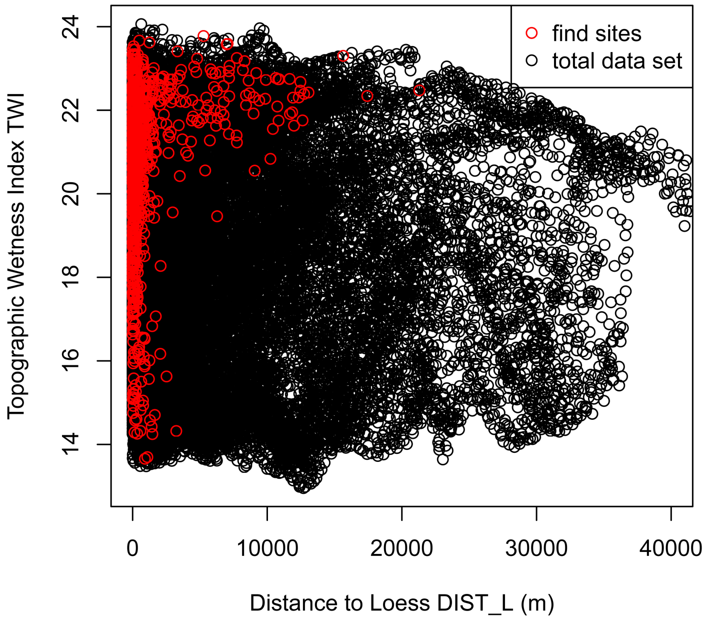

Fig. 1 | Comparison of the correlation between TWI and DIST_L of all segments and segments including find sites (highlighted red).

An important factor to recognize potential favorable areas is the TWI that identifies the relief-controlled distribution of ground humidity.

The following illustration shows the relations of the TWI with distance from loess (DIST_L).

The correlation of the combination of these factors for the study area is shown in Figure 1.

The correlation dependent on the find sites is highlighted in red.

For the total area there is a balanced distribution of the value range of both factors. There are both loess areas nearby and loess-distant areas with all levels of TWI. In relation to find sites containing segments, it is obvious that the density of find sites decreases with growing distance to loess. This tendency of the relief-controlled distribution of ground is compensated by increasing ground humidity.

A cluster analysis of all find-site related values follows after analysis of the relations of all geofactors to each other. This method allows the transfer of data into a format that is applicable for multifactor testing. The classification of the geofactors values at the find sites was performed by a k-means cluster analysis. The cluster signifies the preference extent according to the density distribution over the whole spectrum of values.

In the process, 10 target groups were defined. With an increasing number of find sites, the cluster were sorted from 1–10 (Fig. 2).

The TWI positively correlates with the site density. However, the maximal TWI does not represent the highest site density. Therefore, it is concluded that the TWI has a specific influence within the scope of the predictive model. The small variance of TWI within cluster 10 is noticeable which suggests the presence of a preferable range. From this data it is evident that the distribution of the archeological find sites is influenced by the TWI.

The results of the cluster analysis can be transferred to the segments of the whole study area from which prognosis maps on every single geofactor can be derived (Fig. 3).

A comprehensive multifactorial prognosis of settlement sites for the study area was generated by analyzing all parameters, the weighting of single natural environmental variables and the combination of factors. The development of an archaeological predictive model based on prior analysis of environmental features has been demonstrated by the example of the Early Bronze Age in Central Germany and shown to be comprehensive

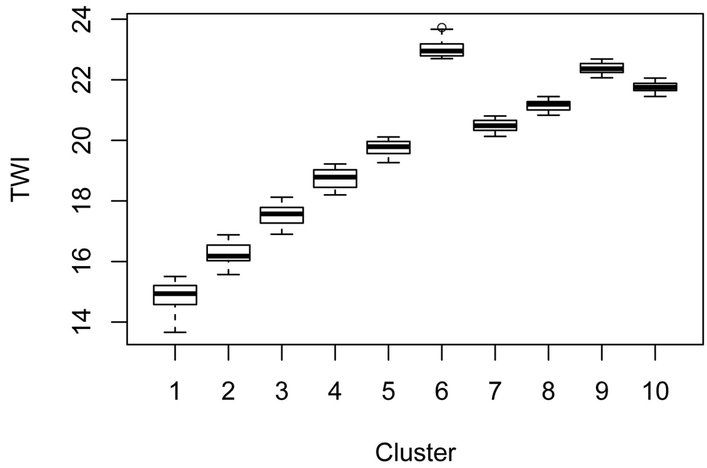

Fig. 2 | Box plots of sorted TWI-Cluster from 1–10.

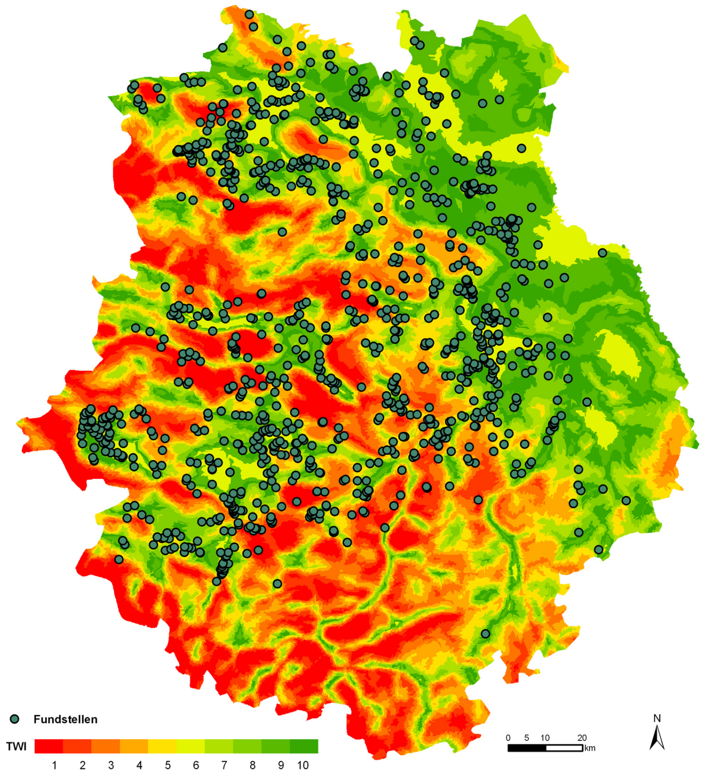

Fig. 3 | Prognosis map for TWI, avoided (red) preferred (green).

and transferable. The data volume has been reduced successful by the segmentation of the area needing to be analyzed without loss of spatial information. For the first time, this methodology has been successfully applied in this regional context. These results demonstrate that analysis of large study areas with different natural environmental features and geomorphologic characteristics is possible. In summary, this work provided the basis for further archaeological interpretations of find site distributions of the Early Bronze Age throughout Central Germany.

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