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• *Geoarchaeology – Fuzzy logic – Predictive modelling*

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Landscape Classification using Principal Component Analysis and Fuzzy Classification: Archaeological Sites and their Natural Surroundings in Central Mongolia

Landschaftsklassifikation mithilfe von Hauptkomponentenanalyse und Fuzzy-Klassifikation: Archäologische Fundstellen und ihr naturräumliches Umfeld in der zentralen Mongolei

With 9 Figures and 1 Table

The middle and upper Orkhon Valley in Central Mongolia (47.5°N, 102.5°E) hosts a multitude of diverse archaeological features. Most of them – including the well-known ancient cities of Karakorum and Karabalgasun – have only rarely been described in their geographical setups. The aim of this study is to describe, classify and analyse their surrounding landscapes and consequently characterise these sites geographically. This analysis is based on freely available raster datasets that offer information about topography, surface reflectance and derivatives. Principal component analysis is applied as a dimensional reduction technique. Subsequently, a fuzzy-logic approach leads to a classification scheme in which archaeological features are embedded and therefore distinguishable. A distinct difference in preferences regarding to choose a site location can be made and confirmed by semiautomatic analysis, comparing burial and ritual places and settlements. Walled enclosures and settlements are connected to planar steppe regions, whereas burial and ritual places are embedded in mountainous and hilly environments.

1. Introduction

Geoarchaeological research combines the analysis of present-day and past landscapes and spatial patterns of archaeological features. Hence, the approach aims at linking the analysis of site locations, their natural setups and lifestyles of cultures using archaeological and geographical methods (*Vita-Finzi* 1978, *Zabel* 2003). The middle and upper Orkhon Valley in central Mongolia (*Schwanghart* et al. 2010) is a perfect site for studying past environmental and human interactions. It hosts a multitude of archaeological features that indicate a diverse pre- and historical, cultural and environmental development in the steppe region and provide a crucial link for understanding the local and regional interaction between human activities and natural surroundings. Yet a detailed analysis of the natural surroundings and site characteristics of these archaeological sites in central Mongolia and their extensive steppe areas is still lacking. In addition, an environmental overview of the surroundings of archaeological sites will lay the foundation for predictive modelling approaches (*Verhagen* 2007) that will support the automatic identification of possible archaeological sites in this area. In this study we will present a description of the landscape classes surrounding the analysed sites in central Mongolia.

The identification and classification of shape, coverage and corresponding processes of the Earth's surface have played a fundamental role in many fields of geographical and geoarchaeological studies and provide the basis for many modelling approaches in environmental sciences (*Vita-Finzi* 1978, *Blankson* and *Green* 1991, *Bolongaro-Crevenna* et al. 2005, *Ehsani* 2008). Shape and coverage of Earth surface elements are inherent in the term "landscape" (*Ehsani* and *Quiel* 2009). In addition, landscape can be interpreted by an observer who should be taken into account when defining landscapes (*Linton* 1968). But there is also the objective approach: landscape as a repetition of similar forms and underlying clusters of interacting, naturally or culturally determined features on a broad scale (*Forman* and *Godron* 1981, *Meynen* and *Schmithüsen* 1953). Since a universal definition of landscape is lacking, we aim at incorporating both concepts in our approach.

The analysis presented in here is part of the BMBF-funded project "Geoarchaeology in the Steppe Region – Reconstruction of Cultural Landscapes in the Orkhon Valley, Central Mongolia". Its primary aim is to investigate the interrelation of human activity and environment in the Orkhon Valley as the certainly most important settlement area of the Mongolian steppe. The aim of this study is to assess the spatial patterns of archaeological sites and the relation between the function and actual natural setup of these localities. Our objectives are: (1) to extract basic elements that define landscape units, using principal component analysis (PCA), (2) to identify and describe landscape classes on a hillslope scale for the upper and middle Orkhon Valley, using a fuzzy classification algorithm, and (3) to analyse archaeological sites with respect to these landscape classes by distinguishing between surrounding and visual landscapes. The key question is whether subsets of the Orkhon Valley landscape promote preferential settlement and use due to their suitability for agriculture, their strategic potential, ritual value and protection from natural hazards. Answering this question will contribute to the reconstruction of historical landscape units.

2. Study Area

2.1 Natural aspects

The study area is located at the border zone between the eastern part of the Khangai Mountain Range and the central steppe zone of Mongolia (101.5°E, 47.5°N). Altitudes range between 1350 m in the northern and 2400 m in the south-western part. Owing to its location along the Mongolian-Uralian Lineament, bedrock is characterised by a variety of Mesozoic sedimentary, metamorphic and igneous rocks (*Badarch* et al. 2002, *Sladen* and *Traynor* 2000, *Traynor* and *Sladen* 1995).

The area's climate is highly continental, with an annual temperature range of 40 K and annual precipitation averaging 300 mm (Kharkhorin, 1974-2006). Under these conditions, *Kastanozems* are the predominant soils, associated with calcretes that developed on loess deposits in less-inclined areas (*Schwanghart* et al. 2009). Shallow *Entisols* predominate along ridges and steep slopes, and *Fluvisols* developed in flood-

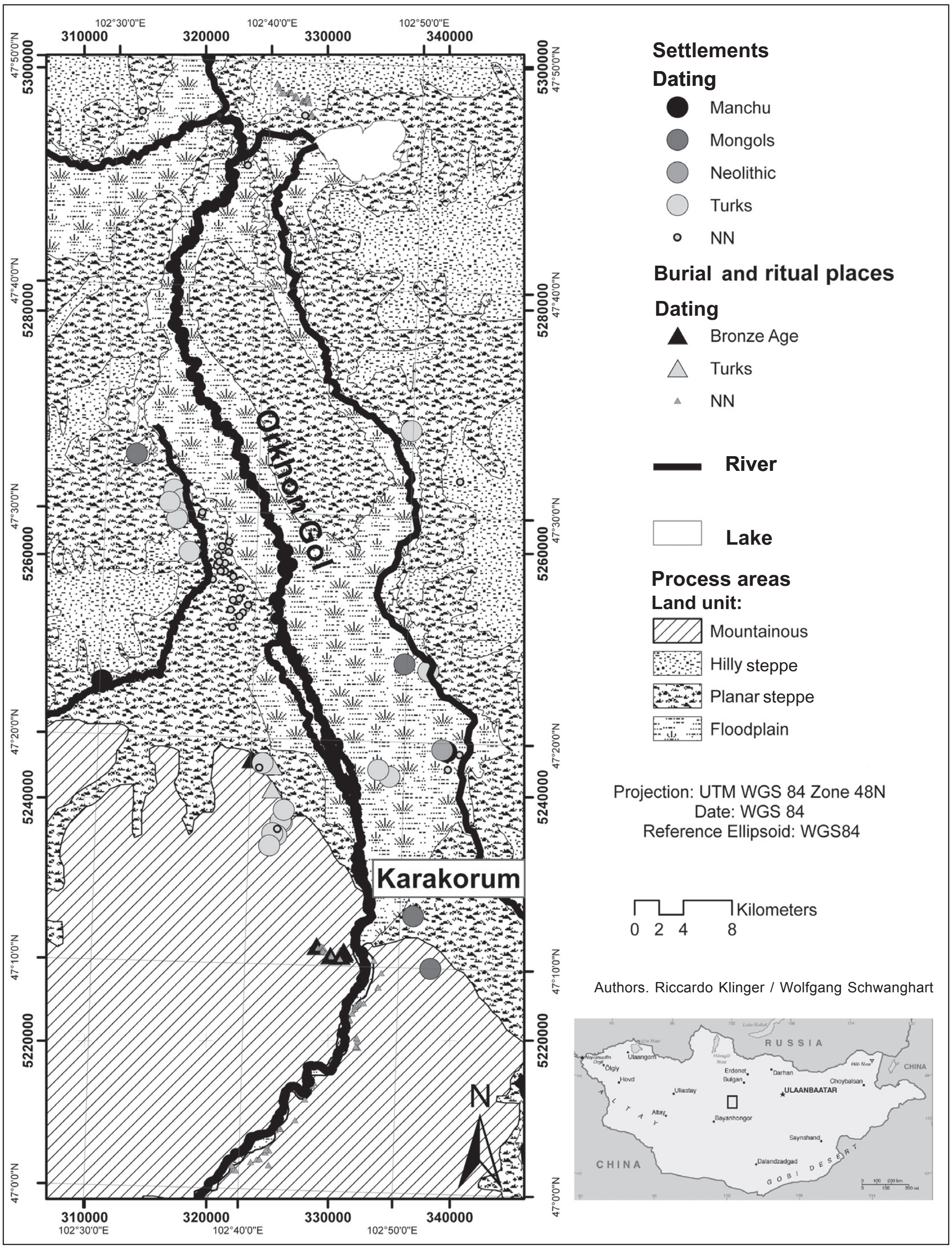

Fig. 1 Overview map of the investigation area and large-scale geomorphological process areas / *Übersichtskarte des Untersuchungsgebietes mit Ausweisung der großskaligen geomorphologischen Prozessbereiche*

plains locally associated with hummocks (*Barthel* 1983, *Haase* 1983). Plant cover consists mainly of steppe vegetation, such as *Karagana, Artemisia, Stipa* and *Allium*. The sparse forests are largely composed of *Larix Sibirica* and softwoods in ecological niches (*Hilbig* 1995). The area (approx. 3200 km²) comprises four major landscape units (*Fig. 1*): the floodplains of the Orkhon and Tamir Rivers, a lowland steppe area, a hilly steppe area, and an elevated mountainous area (*Bemmann* et al. 2010). Valleys are in general filled by fossil periglacial debris tongues. Hillslopes are covered by debris interlayered with loess strata and are strongly incised by first-order streams in headwater areas (*Schwanghart* et al. 2008, *Schwanghart* and *Schütt* 2008).

2.2 Cultural aspects

The ancient capitals of Karabalgasun (Uighurs) and Karakorum (Mongols) are located near the Orkhon. In addition, a variety of walled enclosures, burial sites and other sites can be identified in the area. Preliminary relative dating of the sites from surface finds and site typology provide evidence for human presence from Middle Palaeolithic to modern times (*Ahrens* et al. 2008). Eight cultural entities spanning the period from the 2nd mill. BC up to the 17th century AD are particularly relevant (*Bemmann* et al. 2010, *Drompp* 1999, *Drompp* 2005, *Wright* 2007). Two major groups of monuments can be distinguished for the Bronze and Early Iron Age: slab burials (2nd – c. 1st mill. BC) followed by Khirigsuurs (assemblages of stones used as ritual sites or grave mounds, see *Wright* 2007, *Allard* and *Erdenebaatar* 2005), and deer stones (1st mill. BC – 1st cent. BC). These were followed by six cultural entities spanning the period from the Iron Age to modern times: Xiongnu (c. 3rd cent. BC – c. 4th cent. AD), Gök-Turks (6th cent. AD – 8th cent. AD), Uighur Empire (765 AD – 847 AD), Khitan (Liao dynasty) (906 AD – 1125 AD), Mongol Empire (1206 AD – 1368 AD) and Manchu (17th – 20th cent.).

Most of these cultures, especially from the Iron Age onwards, are characterised as nomadic (*Weiers* 2005). The non-sedentary lifestyle is regarded as the main reason for the general scarcity of settlements in the area. Yet walled enclosures and the city remains are exceptions. Information about economic and cultural life and sometimes even settlement characteristics can be found in several historical sources. 'The Secret History of the Mongols' reports that the Mongols cultivated crops in the Orkhon Valley near Karakorum. This text, written in Uighur or h'Pags-pa by an unknown Mongolian author around 1240 AD, is one of the few written sources and the only one written by a Mongolian (*Cleaves* 1982). Pollen analysis also indicates agriculture around Karakorum (*Rösch* et al. 2005), and frequent findings of sheep bones suggest sheep rearing in the Orkhon Valley (*von den Driesch* et al. 2010). It can thus be concluded that sedentary and nomadic cultures in the Orkhon Valley were strongly dependent on goods and services supplied by the surrounding environment, and that the landscape, its functioning and its sensitivity were essential factors for viability in the relatively harsh environment of the steppe area. The severity of influence exerted by cultivation on landscape and vegetation coverage, however, is not fully understood. *Schlütz* et al. (2008) claim a naturally-induced steppe vegetation in central Mongolia. This is in contrast to findings by *Tarasov* et al. who show a strong human influence due to farming and animal breeding and the resulting effects on vegetation (*Hilbig* and *Opp* 2005, *Rösch* et al. 2005, *Tarasov* et al. 2006). Hence, a detailed and quantitative knowledge of the present landscape is essential for the understanding of the prehistorical and historical development of this area (*Shiraishi* 2004).

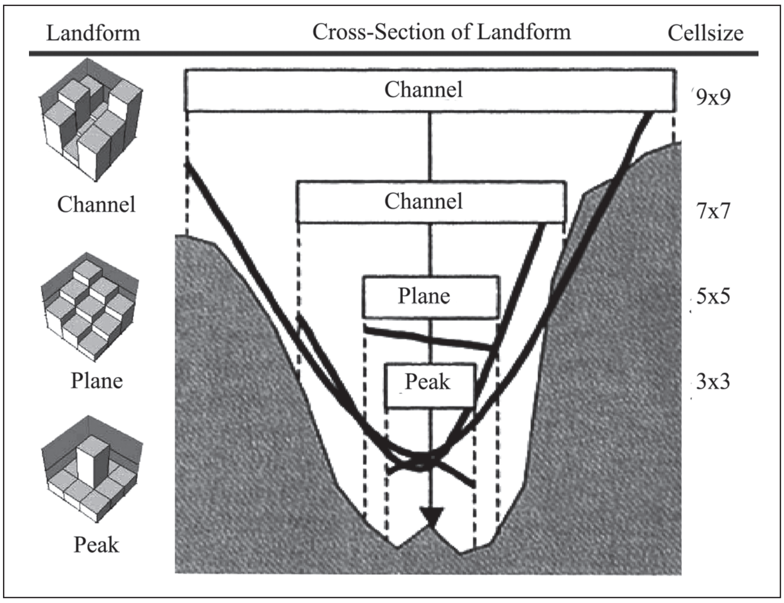

Fig. 2 Morphometric classes at scales ranging from 3 x 3 to 9 x 9 cells and corresponding 3-dimensional sketch (rearranged after *Fischer* et al. 2004, *Fischer* et al. 2005) / *Morphometrische Einheiten in unterschiedlichen Skalen mit 3 x 3 bis 9 x 9 Zellen und entsprechende 3-dimensionale Abbildung (verändert nach Fischer et al. 2004, Fischer et al. 2005)*

3. State of the Art: Landscape Classification

The delineation of landscape facets that represent functional units of the Earth's surface is termed landscape or landform classification (*Burrough* et al. 2000). Landscape classification is challenging since different landforms and land covers exist at various spatial scales and may superimpose each other (*Bronstert* 1999). One approach to landscape classification is to use multiple datasets for topographic attributes such as gradient or curvature, from which so-called geochores are extracted, using multivariate statistical techniques (*Bastian* 2000, *Ehsani* and *Quiel* 2009). Most studies on landscape classification have concentrated on the classification of only topographic data, thereby disregarding the informative value of surface cover. Landforms are classified using fuzzy algorithms (*Bolongaro-Crevenna* et al. 2005; *Burrough* et al. 2000; *Dragut* and *Blaschke* 2006), self-organising maps and artificial neural networks (*Behrens* et al. 2005, *Ehsani* 2008) or relational neighbourhoods combined with descriptive statistics (*Dikau* 1989, *Dikau* 1990). The same procedures can also be found in approaches towards classifying remote-sensed spectral reflectance data that provide information about surface coverage. Classification approaches comprise unsupervised (e.g. ISODATA, *Lo* and *Choi* 2004) and supervised classification algorithms (*Keuchel* et al. 2003, *Knick* et al. 1997), Support Vector Machines (*Burges* 1998, *Kavzoglu* and *Colkesen* 2009) and fuzzy methods (*Owen* et al. 2006; *Yu* et al. 2008). Other approaches try to incorporate the advantages of several classification algorithms in one application using decision trees (*Kavzoglu* and *Colkesen* 2009).

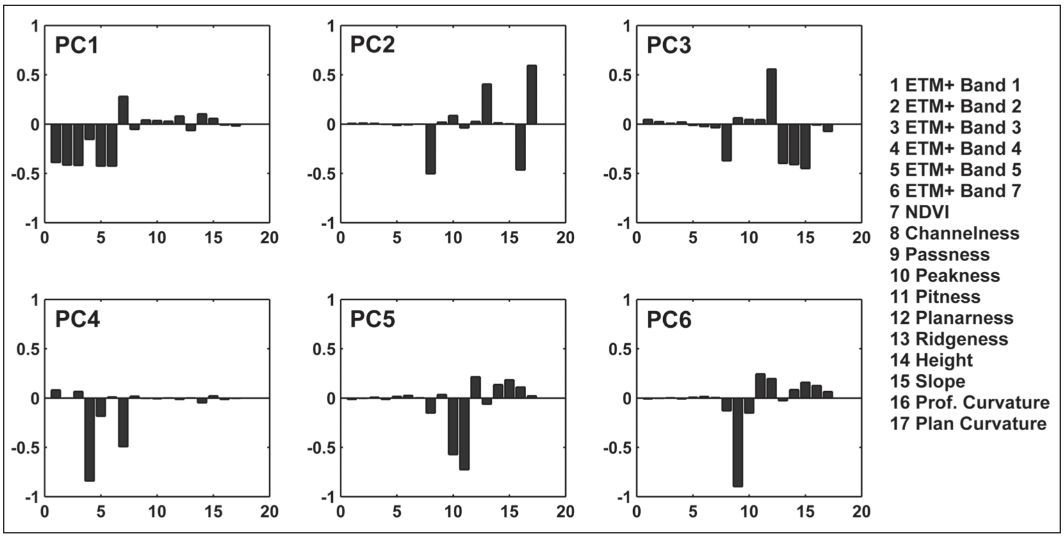

Fig. 3 Loadings (ordinates) of each variable (1-17; absissa) in the extracted principal components
Ladungen (Ordinate) jeder Variable (1-17; Abszisse) der extrahierten Hauptkomponenten

4. Data

An orthorectified ETM+ image (path 134 / row 27, 12th August 2001) provides the basis for surface-cover and land-use parameters. The scene covers the entire study area and captures a situation comparable to that found during field campaigns of 2008/09 since the image was taken at the end of the rainy season. Here we use the visible, near- and mid-infrared bands (bands 1 to 5 and 7) and calculate the normalised difference vegetation index (NDVI) as an indicator for the active vegetation coverage per cell.

Topographic information is obtained from elevation data gathered during the Shuttle Radar Topography Mission (SRTM3) with a resolution of three arc seconds (approx. 90 m). The digital elevation model (DEM) is rescaled to a cell size of 28.5 m. The slope along the steepest gradient (*Evans* 1980, *Moore* 1993, *Warren* et al. 2004) and the plan and profile curvature (*Jordan* 2003, *Moore* et al. 1993) are calculated using ESRI ArcGIS 9.2 (3D-Analyst Extension). Landserf is used to classify landforms (*Wood* 2009). The algorithm determines the probability of each pixel to represent one out of six major landforms using a moving-window classifier on the first and second order derivatives of the DEM. Seven different kernel sizes ranging between 85.5 m (three pixels) and 427.5 m are used (15 pixels, *Fig. 2*). As a result each pixel contains the probabilities (verbalised as peakness, pitness, planarness, ridgeness, passness and channelness) of representing each of six landform classes (peak, pit, plane, ridge, pass or channel, *Fisher* et al. 2004).

5. Methods

The resulting 17 matrices (or variables, see *Fig. 3*) – each contains approx. 4.5 million objects (pixel) – are z-standardised and reshaped to one matrix so that rows describe objects and columns are variables. A PCA is performed on the data matrix using Matlab (R14). For further analysis, only principal components (PCs) were used that fulfill the Kaiser criterion (*Sharma* 1996). The component loadings are rotated using Varimax rotation to facilitate a better distinction of each PC and hence interpretation (*Joliffe* and *Morgan* 1982). The scores of each pixel are extracted and z-standardised as well.

Fuzzy classification approaches try to incorporate and quantify uncertainties in classification schemes. In this analysis, the Gustafson-Kessel algorithm (gk-algorithm) is used (*Gustafson* and *Kessel* 1979). An advantage of this algorithm is the probability space belonging to each cluster centre, which is formed like an ellipsoid in dependence on A (*Babuska* et al. 2002). This algorithm is based on minimising Equation 1:

Gustafson-Kessel algorithm (gk-algorithm):

$$(1)\quad J(X;U,V,A)=\sum_{i=1}^{c}\sum_{k=1}^{N}(\mu_{ik})^{m}\,D_{ikA_i}^{2}$$

One important component in Equation (1) is the weighting exponent "m" which determines the fuzziness in the resulting classification. This value should be within the range of 1.5 and 3.5. Numerous analyses show that satisfying results are obtained for m = 2 (*Choe* and *Jordan* 1992, *Gath* and *Geva* 1989, *Jihong* et al. 2001).

Five validation indices are employed to identify the best classification scheme and optimal number of clusters:

The Partition Coefficient (PC) – local maxima indicate good classification

$$(2)\quad PC(c)=\frac{1}{N}\sum_{i=1}^{c}\sum_{j=1}^{N}(\mu_{ij})^{2}$$

Classification Entropy Index (CE) – local maxima

$$(3)\quad CE(c)=-(\tfrac{1}{N})\sum_{i=1}^{c}\sum_{j=1}^{N}\mu_{ij}\log(\mu_{ij})$$

The Separation Index (SI) – local minima

$$(4)\quad SI(c)=\frac{\sum_{i=1}^{c}\sum_{j=1}^{N}(\mu_{ij})^{2}(\|x_j-v_i\|)^{2}}{N\,min_{i,k}(\|v_k-v_i\|)^{2}}$$

The Partition Index (PI) – local minima

$$(5)\quad PI\,(c)=\sum_{i=1}^{c}\frac{\sum_{j=1}^{N}(\mu_{ij})^{2}(\|x_j-v_i\|)^{2}}{N_i\sum_{k=1}^{c}(\|v_k-v_i\|)^{2}}$$

One index of Xie and Beni (IXB) – local minima

$$(6)\quad IXB(c)=\frac{\sum_{i=1}^{c}\sum_{j=1}^{N}(\mu_{ij})^{2}(\|x_j-v_i\|)^{2}}{N\,min_{i,k}(\|x_j-v_i\|)^{2}}$$

The use of several indices instead of only one was shown to indicate good classification schemes more reliably (*Kim* et al. 2004, *Xie* and *Beni* 1991, *Rezaee* 1998).

Based on Russian aerial photographs originating from 1972 and field surveys in summer 2006 and 2008, 195 potential archaeological sites were identified and located using GPS and geocoding in ArcGIS. Some of these archaeological sites were verified during the archaeological field campaign in 2008 (n=59, *Ahrens* et al. 2008). The site categories used are burial and ritual place (n=117) and settlement (n=78; *Fig. 1*). A temporal and cultural affiliation of these sites is not considered in the analysis since the data on the relevant ages of the sites are not available yet.

In a subsequent step, we derive and analyse spatial subsets of the raster dataset containing the classification results to obtain information on the perceptible and immediate natural surroundings of each archaeological site. The extent of the perceptible landscape is the viewshed of the respective location and is calculated in ArcGIS 9.2 (3D Analyst; viewshed subset). The immediate

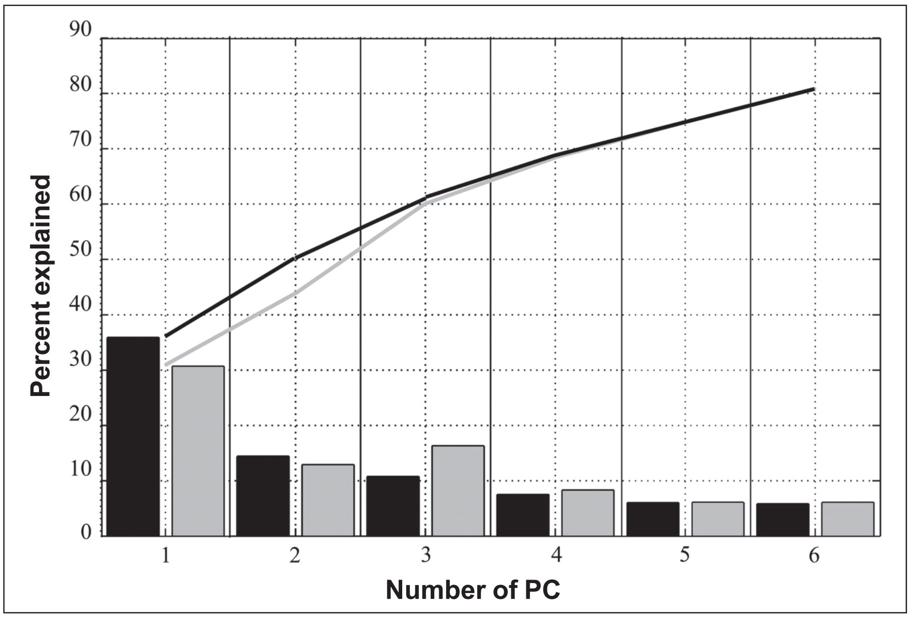

Fig. 4 Explained variances by each principal component before (black) and after Varimax rotation (grey) and corresponding summerised values (lines) / *Erklärte Varianz durch jede einzelne Hauptkomponente vor (schwarz) und nach Varimax-Rotation (grau) und zugehörige Summenkurven (Linien)*

natural surroundings of each location are represented by a quadratic buffer zone (10 x 10 km) around each site. This spatial extent provides a good compromise between computational efforts and spatial selectivity. Differences in the frequency distribution of landscape units within these subsets are tested using the Kolmogorov-Smirnov test (two-sided). First, we test the overall distribution of landscape classes against the quadratic subset for each feature to see whether the chosen location can be treated equally in its setup compared to the whole area. The alternative hypothesis is that there is a major difference, and therefore special landscape surroundings occur at one site compared to the overall landscape. Second, we ask if the surroundings (quadratic subsets) and the perceptible landscapes (viewshed subsets) are similar or indicate differences in usage and perception of surrounding space. Third, the distributions of pixels per classes belonging to settlements are tested against the distribution of classes regarding the burial sites and ritual places in viewshed subsets and quadratic subsets to see if the setup in these classes is comparable.

6. Results

The PCA extracts six PCs that explain 80.7 % of the variance of the input variables (*Fig. 4*). The interpretation of each PC is based on the rotated loadings matrix of the input variables (see *Fig. 3*). The first and fourth PC have highest loadings on variables obtained from Landsat imagery. The second PC correlates with channelness and planform and profile curvature. PC3 correlates positively with planarity and negatively with ridgeness, altitude and slope. PC5 has two high loadings on pitness and peakness, and PC6 correlates positively with passness and negatively with pitness and planarness.

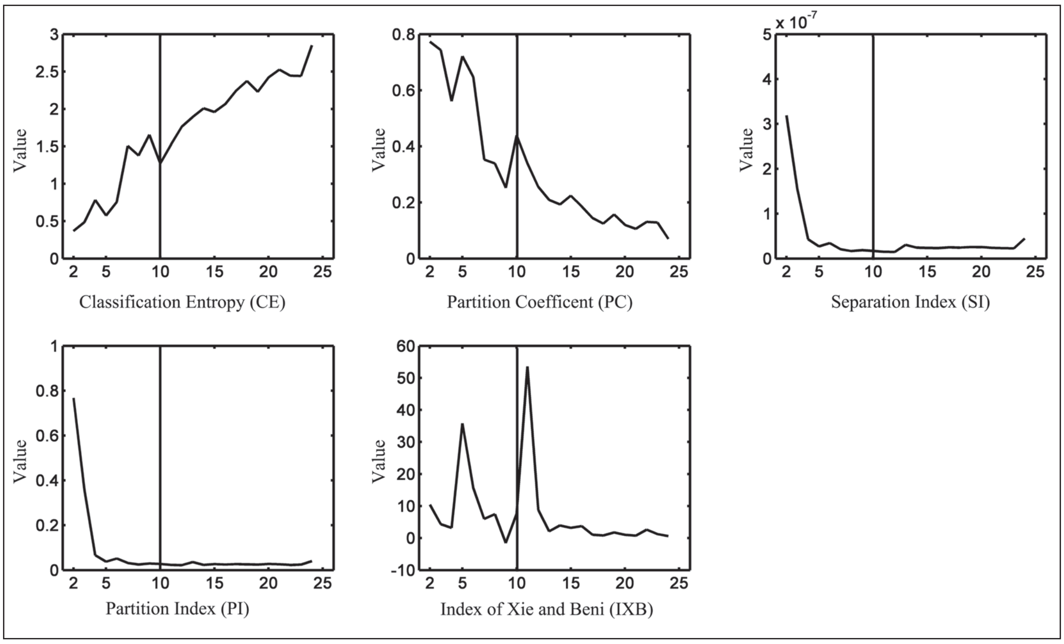

Fig. 5 The values of five validation indices for the solutions produced by the gk-algorithm
Werte von fünf Validierungsindices für die durch den gk-Algorithmus produzierte Lösung

The fuzzy classifications are calculated for the factor scores of each pixel using the gk-algorithm. The validity indices show detectable extremes. The classification with 15 and 19 classes is indicated by indices CE, PC and IXB. IXB shows low values covering the solutions of six up to ten classes as well. Comparing this minimum with other indices, the classification with ten clusters is suggested by two more indices (*Fig. 5*). Despite these classifications with numerous classes, CE, PC, SI and PI suggest a solution with five classes. This contradicts the IXB-value for five classes, which indicates a worse solution compared to ten classes. With this information, using more classes increases the complexity of interpretation. Additionally, there is an increasing problem of selectivity, and therefore the classification scheme with ten classes is used for further analysis (*Tab. 1*).

The classification results highlight the importance of topographic and morphometric information. The number of objects in each class varies strongly. The extremes of PC5 and PC6 are respected by the gk-algorithm by finding class centres. This leads to six classes with large numbers of objects around the mean of PC5 and PC6, but four classes covering the extreme values of PC5 and PC6 in the dataset. Only few pixels were grouped in these four classes (*Fig. 6*).

The landscape in the immediate surroundings of the sites is significantly different for settlements and burial sites. In a site category, more than 50 % of all possible pairs of distributions of landscape classes are treated equally in both possible subset types. In contrast, the comparison of both subset types of burial and ritual places with the subsets of settlements shows dissimilarities of 60 % and higher.

Comparison of the distribution of classes of the viewshed and quadratic subsets with the overall distribution of landscape units shows strong dif-

Tab. 1 Vectorcoordinates of cluster centres and their interpretation as a result of gk-algorithm with 10 classes / *Vektor-Koordinaten der Cluster-Zentren und ihre Interpretation als Ergebnis der gk-Algorithmen mit 10 Klassen*

#	PC1	PC2	PC3	PC4	PC5	PC6	Interpretation
1	0.50	-1.90	-1.58	-0.42	-0.40	-2.02	Vegetated channel and slope sections.
2	0.03	-1.18	0.47	-0.11	-13.47	4.15	Local topographic depressions
3	0.12	0.90	-0.91	0.14	0.04	0.07	Less vegetated lower slopes
4	0.60	1.72	-1.97	0.10	-0.05	0.03	Unvegetated ridges and upper slopes
5	0.12	0.71	-0.23	0.15	0.09	-11.23	Passes
6	0.98	-0.07	0.57	-0.64	-0.12	-0.07	Planar mountain forests and wetlands
7	-0.40	-0.03	0.05	0.19	-0.05	-0.05	Vegetated rolling hills
8	-0.42	-0.01	0.52	0.15	0.13	0.11	Planar, loosely vegetated steppe
9	0.66	-1.98	-1.61	-0.29	-0.39	-0.43	Grass-covered valley bottoms
10	-0.04	1.89	-0.47	0.12	-6.30	-1.89	Unvegetated mountaintops

ferences (see *Figs. 6* and *7*). Only few archaeological features show similar sets of classes. By comparing viewsheds with quadratic subsets, we derive similar results. On the basis of the Kolmogorov-Smirnov test, we reject the hypothesis that the distribution in perceptible landscapes and surrounding landscapes is equal (using a level of significance of $\alpha = 0.05$).

The distributions of landscape classes of the burial and ritual places and the settlements suggest that the differences between these two site categories are often greater than the differences to the overall dataset or subsets respectively (*Figs. 6* and *7*). Regarding the position of each archaeological feature, a major difference can be verified. Settlements are situated in dedicated landscapes. Burial and ritual places occur in all major landscape classes (*Fig. 8*).

7. Interpretation

The interpretation of the PCs is based on the loadings: PC1 represents albedo, and high values correspond to bare soils. PC2 relates to narrow valleys of headwater areas, and positive values indicate ridgelines (*Fig. 4*). Small-scale topographic variability is addressed by PC3. PC4 relates to the absence of photosynthetic active vegetation. PC5 shows high amplitudes in loadings on peakness and pitness; PC6 refers only to passness. Both PCs remain hardly interpretable, but the fifth PC can be described as an indicator of missing planarness. The lack of variance is also stated by the eigenvalue of these two PCs which are near to one before and after rotation. The lack of PCs that show a strong covariance of both reflectance values and topographic derivatives indicates that the information obtained from Landsat imagery and the DEM complement each other.

The different results of the validation indices employed to characterise the classification quality show the difficulties of interpreting these values. In this study, the indices tend to highlight partitioning results with a larger number of classes (*Fig. 5*). In order to facilitate interpretation of classes, results with a smaller number of class-

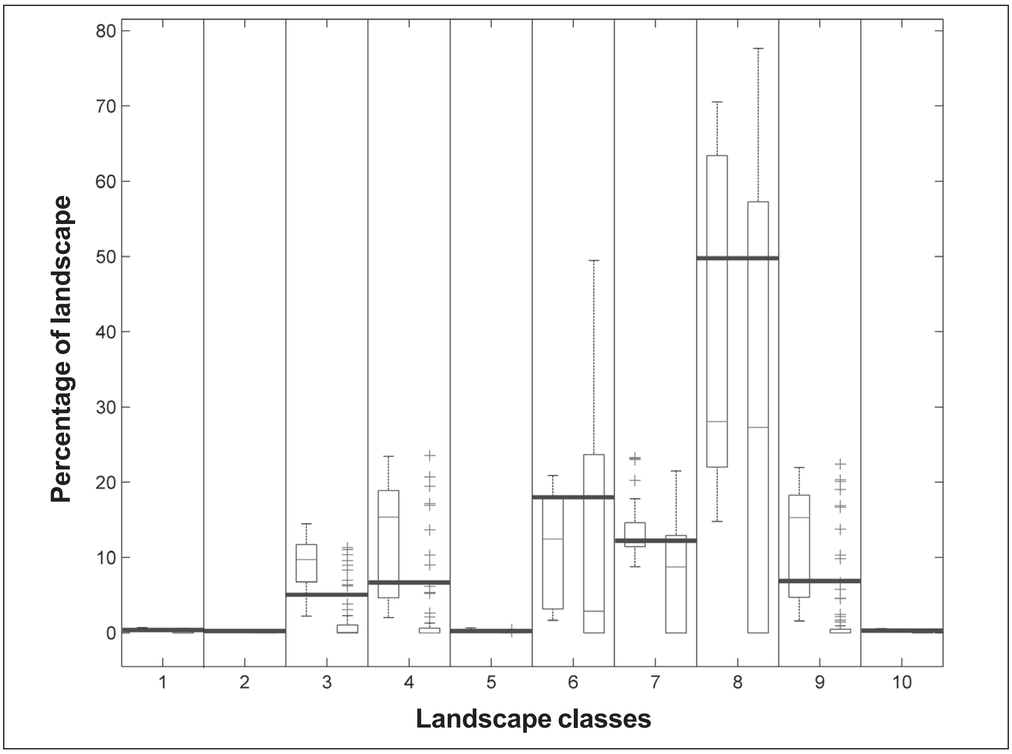

Fig. 6 Boxplots of percentages (ordinate) of landscape classes (abscissa) in quadratic subsets using the gk-algorithm around settlements (right columns) and burial and ritual places (left columns). The solid lines indicate the overall percentages of landscape units in the investigation area. / *Box-Plots der Anteile (%; Ordinate) der Landschaftsklassen (Abszisse) in quadratischen Subsets, unter Verwendung des gk-Algorithmus, im Umfeld von Siedlungen (rechte Darstellung) und Begräbnis- und Ritualplätzen (linke Darstellung). Die durchgezogenen Linien markieren den Verbreitungsanteil der jeweiligen Landschaftsklassen im Untersuchungsgebiet.*

es are preferred. The Partition index PC points to fewer numbers of classes. Here, maximum values for ten classes indicate a better separation and therefore more distinguishable classes.

Despite the mathematical similarity of IXB and SI, major differences in the resulting values exist: SI seems unsuitable for differentiation because it is near to zero (*Fig. 5*). IXB computes the differences of each pixel (vector) and the class centre to which it belongs, while SI compares the class centres and distances from each other. IXB therefore has well-detectable extremes for the gk-clustering. This results from the proposed structure of clusters in the gk-algorithm, but also the computation has to be considered. Extremes can be detected much better in the classification with the gk-algorithm as it would be covered by a more moderate class structure using a normal fuzzy c-mean algorithm (*Bezdek* et al. 1984).

The component scores were standardised prior to classification, so each class can be interpreted based on its statistical moments in the PC value

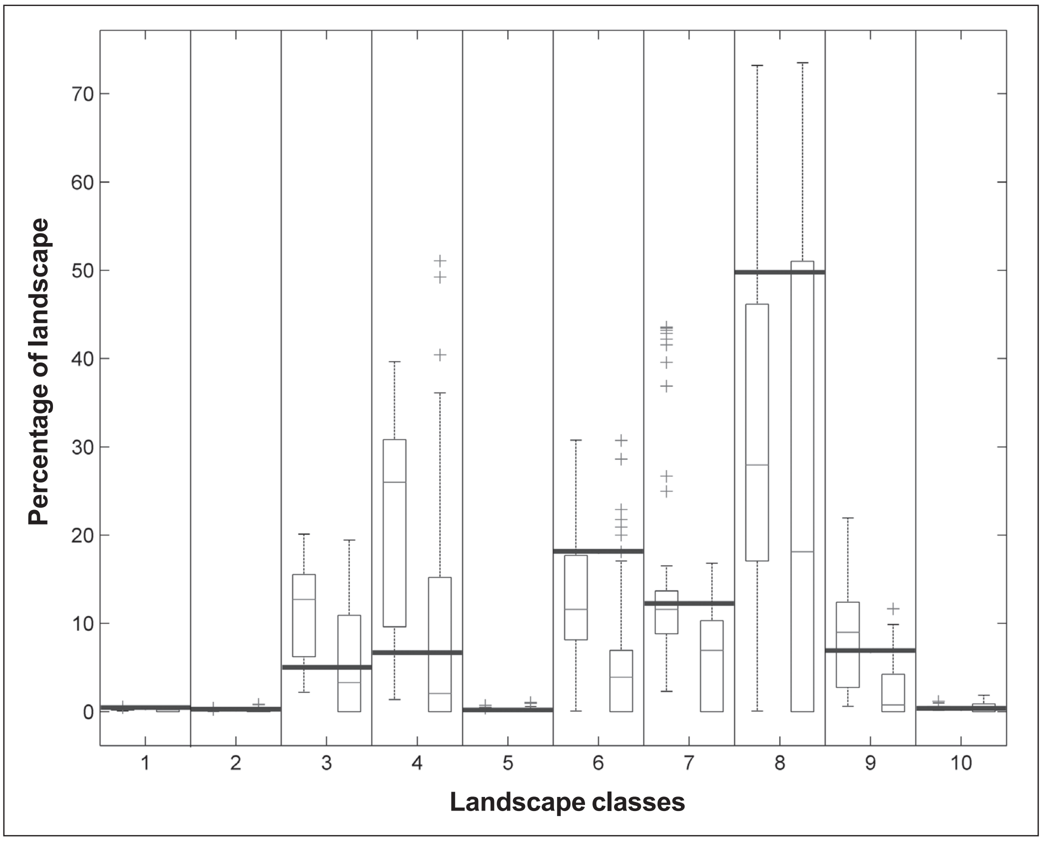

Fig. 7 Boxplots of percentages (ordinate) of landscape classes (abscissa) in viewshed subsets using the gk-algorithm around settlements (right columns) and burial and ritual places (left colums). The solid lines indicate the overall percentages of landscape units in the investigation area. / *Box-Plots der Anteile (%; Ordinate) der Landschaftsklassen (Abszisse) in Viewshed-Ausschnitten (Subsets) unter Verwendung des gk-Algorithmus im Umfeld von Siedlungen (rechte Darstellung) und Begräbnis- und Ritualplätzen (linke Darstellung). Die durchgezogenen Linien markieren den Verbreitungsanteil der jeweiligen Landschaftsklasse im Untersuchungsgebiet.*

space (*Tab. 1*). The gk-algorithm produced a set of major units: less-vegetated lower slopes, unvegetated upper slopes and ridgelines, hilly forests and wetlands, undulating steppe, flat steppe, and grass-covered valley bottoms (*Fig. 9*).

The classification algorithm returned classes with very few objects (steeply incised, grass-covered slopes, depressions, passes, and unvegetated mountaintops) (*Figs. 6* and *7*) where connected components comprise hardly more than three pixels. Yet, two of these classes represent key positions for understanding location selection: passes are preferred travel routes; peaks can act as lookouts and surveillance locations.

The specific locations of both burial and ritual places and settlements are confirmed by the analysis of quadratic subsets and viewshed subsets: burial and ritual places are located in landscape

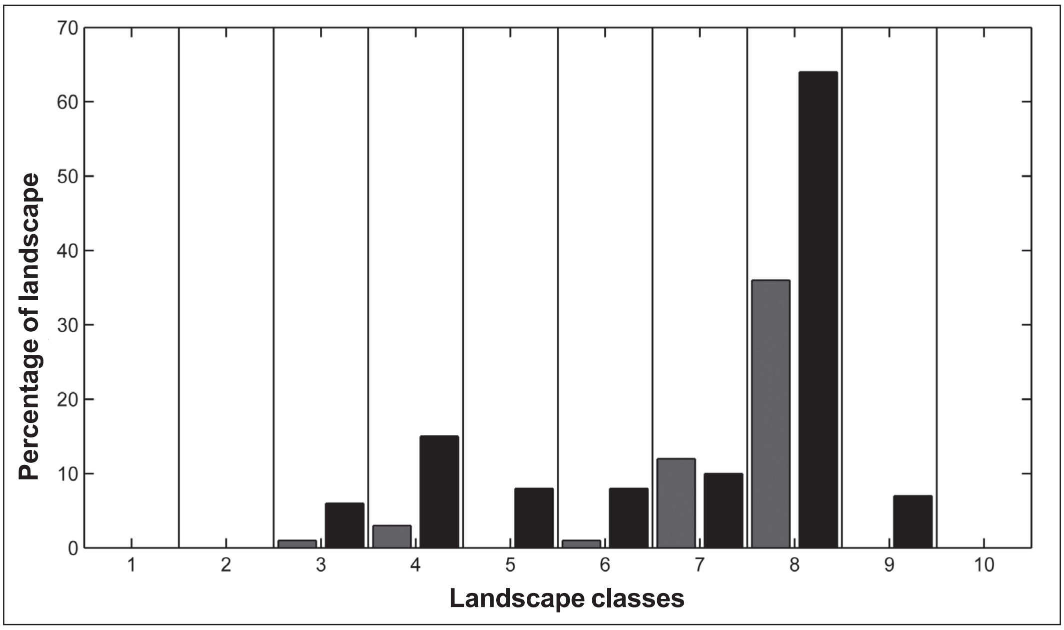

Fig. 8 Histogram of landscape classes at the feature positions. Burial and ritual places are shown in black, settlements in grey. / *Verteilung der Landschaftsklassen im Bereich archäologischer Fundstätten. Begräbnis- und Ritualplätze sind schwarz, Siedlungsplätze sind grau dargestellt.*

classes that reflect mountainous characteristics, while settlements are dominantly located in the monotonous, sparsely vegetated, flat terrain of the floodplain (*Figs. 6-8*).

7.1 *Burial and ritual places*

Especially the areas of divides and ridges can be seen from burial and ritual places (viewshed subsets). These features restrict the possible view, which leads to an overrepresentation of these classes compared to the quadratic subsets. In contrast, valley bottoms are underrepresented in the viewshed subsets. The results show that burial and ritual places have restricted visibility due to their preferred location in headwater areas and first order catchments.

Burial and ritual places are found on poorly vegetated slopes and along watershed divides (*Tab. 1, Fig. 8*). This implies a safe position, protected from water erosion and water logging that may damage graves located at the valley bottoms. The positions of burial and ritual places have a better visibility compared to locations near valley bottoms. This could also be an important fact because Khirigsuurs play important roles in shamanistic rites in historical and recent times (*Wright* 2007). The location of burial and ritual sites supports the notion that their choice is and was motivated by shamanistic beliefs since water, sky and rocks are central elements of shamanism for the nomadic people inhabiting the middle and upper Orkhon Valley (*Bezertinov* 2000).

7.2 *Settlements*

The differences between settlement locations and the locations of burial and ritual places are

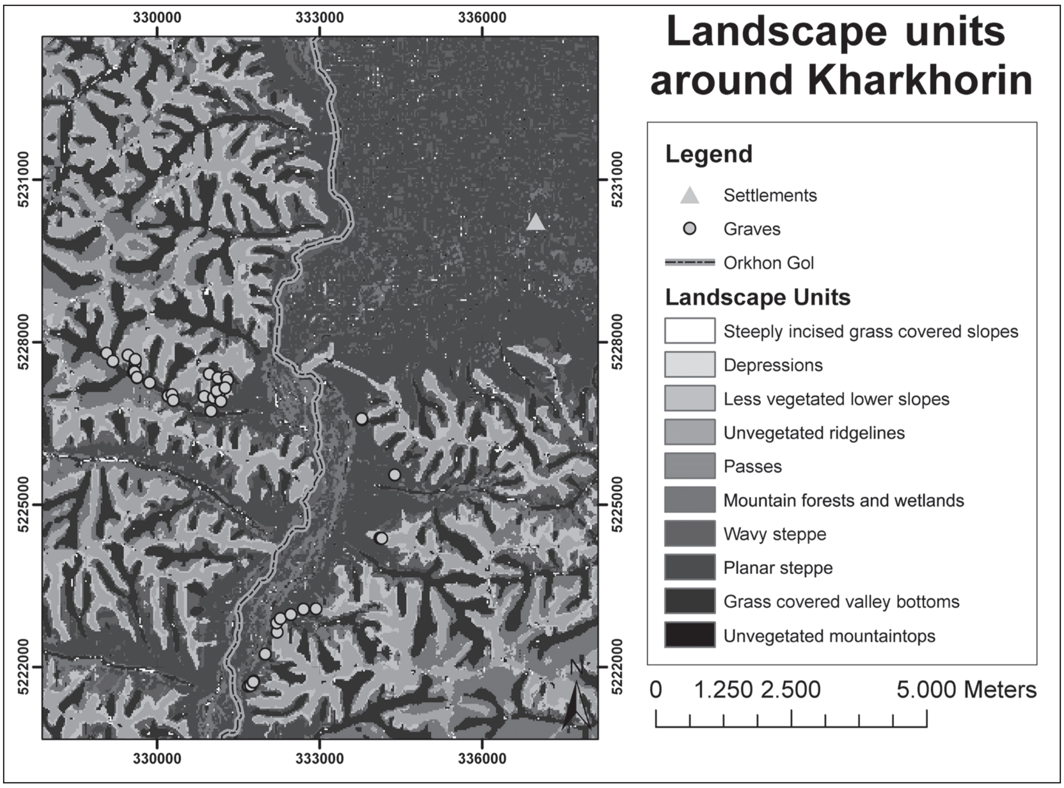

Fig. 9 Detailed map showing landscape classes around Kharkhorin (Karakorum, centre of map) derived with the gk-algorithm. / *Detailkarte der über den gk- Algorithmus abgeleiteten Landschaftsklassen in der Region von Kharkhorin (Karakorum, Kartenmitte)*

shown in *Figure 8*. The classes of planar steppe have much higher values in areas of the quadratic subsets and the viewshed subsets than burial and ritual places. These values are reduced in the viewshed subsets compared to the quadratic subsets due to sight confinement owing to Earth curvature. This causes an overestimation of slopes and watershed divides which are seen in the distance and are not part of surrounding landscapes. Nevertheless, visibility is a key to controlling landscape and major pathways of movement and is better than in a mountainous environment. The relatively high values of visible areas confirm this hypothesis (*Honeychurch* and *Amartuvshin* 2006).

The location of settlements in the surroundings of Karabalgasun and also along the main travelling direction through the north-to-south oriented Orkhon Valley is a further interpretational context. The former settlement sites are also preferred summer settlement locations in recent times. Yet the building of walls and interior elements such as roofed buildings suggests a continuous usage throughout the year. The Orkhon floodplain provides a good basis to gather hay for the harsh winters. Nevertheless, the locations on the planar steppe in a broad valley experience harsher winter conditions due to thermal inversions (*Barthel* 1983). Either the inhabitants of these settlements practiced pastoralism or farming throughout the year in the Orkhon floodplain and adjacent hills, as mentioned for Egiin-Gol and its Uighur sites (most settlements in the Orkhon valley are of Uighur origin, *Honeychurch* and *Amartuvshin* 2006), or the settlements were mainly used for trade or providing services for the central settlement of Karabalgasun. Besides these cultural interpretations of the results, it needs to be considered that all settlement sites are located close to the main river to ensure access to fresh water (*Kolbas* 2005*, Honeychurch* and *Amartuvshin* 2006).

8. Discussion

PCA is a robust and parameter-free method of dimensional reduction (*Gustafson* 1998, *Griffith* et al. 2000, *Richard* and *Poccard* 1998, *Zhou* et al. 1991). Despite the large number of objects, this method is computationally fast and results are reproducible. The major disadvantage is the often loosely based choice of the number of PCs. The Kaiser criterion often leads to an increased number of PCs that are difficult to interpret (*Lance* et al. 2006). Other approaches often require strong parameterisation and are computationally intensive (*Watkins* 2006). The overestimation of the number of PCs also affects the results of gk-classification. Only two of the resulting clusters have vector entries that reproduce the influence of PC5 and PC6 except their mean values; these clusters are also small in their numbers of connected pixels. Regarding the noted broad scale of a landscape and with respect to the aim of this study, nearly half (four out of ten) of the resulting classes must be seen as side products in this study due to their minor occurrences. Still, gk-algorithm produces easily interpretable units that correspond with real environments: The major classes can be interpreted, and both land covers and surface forms are rendered by the algorithm. The differentiation between quadratic subsets and viewshed subsets represents an effective way to distinguish between natural surroundings and perceptible environments. Owing to advances in GIS soft- and hardware, the computational time of producing these subsets is negligible and results can be interpreted and compared (*Fry* et al. 2004, *Lake* et al. 1998).

Geochores are identified and described by interpreting the centre coordinates of each landscape class. The establishment of settlements in an area of planar steppe with poor vegetation coverage on the border to adjacent slopes has many advantages. Increased viewsheds provide security; yet the possibility of water harvesting techniques to assure water supply is not excluded since less inclined slopes and steeply inclined slopes are in the direct vicinity.

The presented approach assumes that the present-day geographical setup as represented by Landsat imagery and DEM reflects past conditions, both regarding environmental conditions and human activity. Recent pollen analysis suggests that grazing pressure in Uighur times was less than today, and there is also evidence of decreased forest area compared to today (personal communication: *Dr. Frank Schlütz*). In contrast, *von den Driesch* et al. 2010 infer high livestock density around Karakorum during the Mongol Empire. Results obtained from sediment analysis of Lake Ugii Nuur indicate relatively stable climatological conditions during the past 3000 years (*Rösch* et al. 2005; *Schwanghart* et al. 2009). Despite many uncertainties arising from the usage of present-day data to infer past environmental conditions, we think that the approach is appropriate as long as environmental changes in the investigated timeframe were incapable of changing the patterns observable today. At our current state of knowledge, this prerequisite is true for the study site.

9. Conclusion

The major advantage of this study is its user independency in deriving quantitative results that delineate landscape units. Nevertheless, interpretations of PCs and landscape classes are needed. It is still advisable to connect the automated mappings with the mappings obtained from fieldwork and the visual interpretation of air photography. But the manual mapping procedure is labour-intensive and usually restricted to smaller areas. Landscape classifications can be incorporated into a predictive modelling of potential archaeological sites, but additional factors such as upslope area, distance to the next water source, least-cost paths and many more should be included in future (*Dahlke* et al. 2005, *Mitasova* et al. 1996, *Siart* et al. 2008). Furthermore, a predictive model needs further calibration and validation using archaeological data that are still incomplete since huge areas have not yet been surveyed.

The landscape classification and subsequent analysis presented here show that settlements are embedded in a flat to slightly inclined steppe plains, covered only slightly by vegetation. These surroundings provide enhanced visibility towards the floodplains. In contrast, burial and ritual places are located in diverse landscapes, primarily in mountainous and hilly terrain. Their position in the transition zone between valley bottoms and steeply incised upper slopes gives an increased visibility. Our results agree with results of several archaeological surveys in Mongolia. However, ours is the first study to provide quantitative results and present a reconstructable analysis of landscape patterns (*Ahrens* et al. 2008).

With respect to the lifestyles and behaviour patterns of nomadic cultures, this analysis may also contribute to the identification of as yet unidentified sites. The possibilities of a statistical categorisation of sites regarding their natural surroundings can be another ongoing approach. Especially compared to time-consuming and expensive field work, the statistical approach chosen in this study can be suitable for a pre-field campaign. Nevertheless, the understanding of lifestyle, centrality of ancient capitals, cult of the dead, diet and interaction with neighbouring cultures is needed to make a predictive modelling approach reliable in the future. Furthermore, the key question is the spatio-temporal development of the floodplain of the Orkhon River. Information about the positions of meanders in archaeologically relevant time slices is needed for calculating distances to possible water supplies and has to be included in further studies.

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Summary: Landscape Classification using Principal Component Analysis and Fuzzy Classification: Archaeological Sites and their Natural Surroundings in Central Mongolia

The middle and upper Orkhon Valley in central Mongolia (47.5° N, 102.5° E) hosts a multitude of diverse archaeological features. Most of them – including the well-known ancient cities of Karakorum and Karabalgasun – have only rarely been described in their geographical setups. The aim of this study is to describe, classify and analyse their surrounding landscapes and consequently characterise these sites geographically. This analysis is based on freely available raster datasets that offer information about topography, surface reflectance and derivatives. Principal component analysis is applied as a dimensional reduction technique. Subsequently a fuzzy-logic approach leads to a classification scheme in which archaeological features are embedded and therefore distinguishable. A distinct difference in preferences regarding to choose a site location can be made and confirmed by semiautomatic analysis, comparing burial and ritual places and settlements. Walled enclosures and settlements are connected to planar steppe regions, whereas burial and ritual places are embedded in mountainous and hilly environments.

Zusammenfassung: Landschaftsklassifikation mithilfe von Hauptkomponentenanalyse und Fuzzy-Klassifikation: Archäologische Fundstellen und ihr naturräumliches Umfeld in der zentralen Mongolei

Das mittlere und obere Orchontal (zentrale Mongolei; 47,5° N, 102,5° O) beheimatet eine Vielzahl an archäologischen Stätten. Neben den bereits vielfach untersuchten Hauptstädten Karabalgasun und Karakorum sind diese bisher geographisch kaum beschrieben worden. Die Ziele dieser Studie sind eine Beschreibung, Klassifizierung und Analyse der sie umgebenden Landschaften und demnach eine Charakterisierung dieser. Die Analyse basiert auf frei verfügbaren Rasterdaten bezüglich der Topographie, Ableitungen der Topographie und Reflektanz (Landsat). Eine Hauptkomponentenanalyse dient der Dimensionsreduktion. Anschließend werden mit Hilfe einer Fuzzy-Klassifizierung Landschaftsklassen gebildet, nach denen die archäologischen Einheiten unterscheidbar sind. Unterschiede in der Lage im Landschaftsbild werden herausgearbeitet: Siedlungen und umwallte Anlagen sind an flache bis leichthügelige Steppengebiete gekoppelt, Grabanlagen hingegen sind in ein montanes Umfeld eingebunden.

Résumé: Classification du paysage en utilisant une analyse en composantes principales et la logique floue: des sites archéologiques et leurs milieux naturels en Mongolie centrale

Dans la vallée de l'Orhon, au cours moyen et supérieur de la rivière, se trouve un grand nombre de sites archéologiques. A part les sites connus comme Karabalgasun et Karakorum ils y en existent d'autres qui ne sont guère décrits dans la littérature géographique. Le présent travail cherche à décrire, à classifier et à analyser les paysages aux environs de ces sites archéologiques méconnus auparavant. L'analyse se fonde sur un modèle numérique de terrain (SRTM) et ses dérivées ainsi que sur des données de télédétection Landsat. A l'aide d'une logique floue, le paysage est classifié dans le but de distinguer les sites archéologiques. Ensuite, leur position en relation avec les caractéristiques du paysage est déterminée. Il se révèle ainsi que les cités et les remparts sont couplés aux terrains plats et légèrement vallonnés, tandis que les édifices funéraires se situent en terrain montagneux.

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