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Cover illustration: (*Top*) Figure 11.3 in book. Panorama of two Kaoko hunters posed against landscape. Courtesy National Archives of Namibia, A450 Hahn Collection, (*Bottom*) Figure 7.9 in book. Decoration over the gate of the inner façade of the temple of Esna, showing the nocturnal sun personified by the god Khnum (Photograph by Dagma Budde, Mainz).

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Chapter 2

Towards a Reconstruction of Land Use Potential: Case Studies from the Western Desert of Egypt

Andreas Bolten, Olaf Bubenzer, Frank Darius, and Karin Kindermann

This chapter is situated in the field among archaeology, geomorphology, and ecology. Two case studies from different east-Saharan landscape units classify and analyse archaeological, geoscientific, and remote-sensing data of Early and Mid-Holocene archaeological sites. The section combines the approaches of landscape ecology and landscape archaeology. The aim is a parameterisation of the research areas with respect to structural and ecological features. The data were used within a Geographical Information System (GIS), a hydromodelling, and statistical software. The analysis allows an indication of the observed landscape parameters that are essential for the location of the sites within each time slice. Therefore, the study broadens the understanding of the man–environment relationships.

With the help of this integral and autochthonous landscape inspection it is possible to reconstruct the past potential of the utilisation of such arid landscapes. Such an approach also helps in locating new archaeological sites within landscape units. At the end a first suggestion for a model of interacting key variables and the general landscape development of the Western Desert during the Early and Mid-Holocene is presented.

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2.1. INTRODUCTION

This chapter represents an attempt to generalise and calculate the available data for selected research areas of ACACIA[1] in the Western Desert of Egypt, which were collected on archaeological surveys between 1995 and 2002.

The research concentrated on the Early and Mid-Holocene of the Western Desert of Egypt when more humid climatic conditions allowed people to live in what is presently a hyperarid landscape. Outside the Nile Valley and the oases, the archaeological, botanical, and geoscientifical results of the research programs 'Besiedlungsgeschichte der Ostsahara' (B.O.S.) and ACACIA (both University of Cologne projects) show a complex picture regarding both the history of Holocene land use (Kindermann & Bubenzer, 2007; Kuper, 1989; Gehlen et al., 2002; Kuper, 2002, 2006; Kuper & Kröpelin, 2006; Riemer, this volume) and palaeoecological conditions (Besler, 2002; Bubenzer & Riemer, 2007; Bubenzer et al., 2007b; Kindermann et al., 2006; Riemer, 2006) in the timeframe approximately between 9000 and 5000 cal bc.

Within the Sahara, especially in Egypt, only macro- or mesoscalic palaeoecological studies relating to the recent or former land use potential exist (e.g., Adams & Faure, 1997; Alaily, 1993; Anhuf, 1997; Anhuf & Frankenberg, 2000; Bornkamm & Darius, 1999; de Noblet-Ducoudré et al., 2000; El Kady et al., 1995; Kehl & Bornkamm, 1993; Prentice et al., 2000; Schulz et al., 2001; Pachur & Altmann, 2006; Wendorf et al., 2001). Examples of archaeological reconstructions of ancient land use by use of GIS are given, for instance, by Spikins (2000, Northern England) and Farshad (2001, Iran). In contrast to the existent studies which often have the aim of reconstructing former landscapes and their use potential by an actualistic comparison with similar recent landscapes (e.g., Neumann, 1989), the attempt presented here works exclusively with the autochthonous data. The methods of data derivation and analysis of this new approach are described in detail in the appendix.

The archaeological and geomorphological field observations, generated during some 20 years of field research in the Western Desert of Egypt, were the starting point of this study. The spatial distribution of archaeological sites shows a distinct pattern over a wide range of spatial scale (Figure 2.1). It seems to be that Early and Mid-Holocene sites are mainly found in characteristic geomorphological positions, namely in association with drainage lines and depressions which supply a surplus of water (Bubenzer & Riemer, 2007). To prove this hypothesis an archaeological dataset from the two contrasting regions Djara (Egyptian Limestone Plateau) and Regenfeld (Great Sand Sea) were analysed in combination with environmental

[1] The results presented in this article chapter are based on the collaborating research of the projects A1 'Climatic Change and Human Settlement Between the Nile Valley and the Central Sahara' and E1 'GIS-Based Atlas of Holocene Land Use Potential for Selected Areas.' The archaeological database derives from the fieldwork of project A1, whereas the project E1 integrates the results of geoscientific disciplines with those of archaeology and social sciences (Bubenzer & Bolten, 2003; Bubenzer et al., 2007 a).

Figure 2.1. Archaeological sites within the Western Desert of Egypt recorded during archaeological surveys by B.O.S. and ACACIA (1980–2002). Displayed are three different spatial scale factors according to the scale discussion. 1: Landsat 5 image (30 m resolution); 2: ASTER image (15 m resolution); 3: Quickbird image (0.61 m resolution) (*See also Color Plates*)

information derived from topography, hydrography, and geology. A special focus was emphasised on the interrelationship between spatial configuration and the physical properties of the landscape. The scale of investigation (1:50,000) was predefined by the density of the archaeological evidence and the resolution of remote sensing data. An important advantage of this chorological scale[2] – which ranges approximately between 1:25,000 and 1:200,000 – is that it already generalises the complex reality and therefore represents a model of natural structures (Bastian, 1999).

The classification of the research areas according to structural and ecological features was an important step. For this aim, areawide detailed relief data, elevation models, and the (palaeo-) hydrography are fundamental (see contribution of Bubenzer, this volume). Due to the lack of topographic maps in these areas and point-specific field information, remote-sensing data had to be used in addition to field measurements. Particularly the distribution of archaeological artefacts and the geomorphological analysis of landforms were of crucial importance to establish an idea of the palaeolandscape.

This chapter proceeds along the following points of argumentation.

1. Definition of land use potential in terms of the project.
2. Methodology to derive parameters, which describe the land use potential; this includes the extraction of a digital elevation model from ASTER satellite data as a base for several steps of the analysis (see box).
3. Compilation and analysis of the derived dataset with statistical methods.
4. Brief conclusion with an outlook for further investigations.

2.2. FORMER LAND USE POTENTIAL

In general 'land use potential' can be defined as the capacity of land to sustain specific types of utilisation for a longer period of time without significantly degrading resources. In feasibility studies 'potential' means the capacity or the maximum productivity of a factor or a system of factors with regard to quantity and quality of output extraction in a defined acquisition period. According to the FAO Framework for Land Evaluation the present-day use potential of land depends on both biophysical and socioeconomic conditions (e.g., Kutter et al., 1997). Key elements are determined in the first place by climate, soil, and landforms, because, for example, the range and potential yield of crops are functions of these conditions. Beyond this, the degree to which the natural potential of a landscape can be tapped by the land users depends on technology, knowledge, and labor, as well as on people's aspirations (comp., e.g., Tress et al., 2003).

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[2] Within the investigation of whole landscapes the chorological scale is able to delimit or to order natural units. In the landscape ecology four aspects are distinguishable: the topological, chorological, regional, and geospherical dimensions (comp. Bubenzer, this volume).

The research object of complex physical geography or landscape ecology (Troll, 1939, 1966; Bastian & Steinhardt, 2002) is the Earth's surface (v. Richthofen, 1877; Penck, 1894), understood as a three-dimensional layer including the lithosphere, atmosphere, and hydrosphere as well as the biosphere, which develops in relation to the former three (Gardner, 1977; Leser, 1997). A particular position is occupied by the anthroposphere or noosphere (from Greek *noos*, mind) because human beings live not only in the three-dimensional Euclidian physical-geographical space of land and water systems, but also in a conceptual sphere of the human mind and consciousness (Naveh, 1995). When reconstructing the land use potential of palaeolandscapes it is virtually impossible to access the latter. Therefore, the present study is mainly restricted to physical parameters. The first step, however, has to be an examination of recent landscape structures with their typical elements including evolution and thus their former function and change over time (Turner & Gardner, 1990; Haase, 1996). Synonyms for landscape elements are patch, ecotope, biotope, cell facies, habitat, or site. The landscape structure as the spatial mosaic of these elements is determined by their composition and configuration (Turner & Gardner, 1990; Syrbe, 2002).

During the Early and Mid-Holocene the more favorable climate of the northeastern Sahara was the most important factor with the growth of plants and that allowed people to live at least occasionally within an arid to periodically or episodically semiarid landscape. On the basis of precipitation amounts of 50–100 mm per annum (Neumann, 1989; Haynes, 2001; Schild & Wendorf, 2001), outside of the Nile Valley and of the oases, sufficient (fresh-)water occurred only in geomorphological positions with a surplus of run-off or seepage water (Bubenzer & Riemer, 2007). Therefore, the overall analysis of the georelief is a crucial point. The georelief is a product of landscape evolution. It conditions the redistribution of water and nutrients, and therefore dominates landscape structure directly and indirectly (e.g., Rohdenburg, 1989).

The soil is another important factor with its characteristic texture, thickness, salinity, and availability of nutrients. It becomes clear that the terrain characteristic (e.g., slope or exposition) also strongly influences the capability of land to support various types of vegetation (Barbour et al., 1999). In the region considered, most of these characteristics are strongly influenced by the geological setting, the georelief, and by the exogenous geomorphological processes, for example, the work of wind and water. Finally, the bedrock builds the basis for the landscape, is more or less resistant against weathering, and therefore influences evolution of landforms and soil generation and the availability of raw material for stone tools is a function of the geological setting (Kinderman et al., 2006).

A reconstruction of biomass production, food web structure, or biodiversity within former ecosystems is possible only by assessing the key factors, physical constraints as well as biotic requirements, which were active during different phases of landscape development.

2.3. STUDY AREAS

In particular, the present xeric (from Greek *xeri*, dry) landscape of the Western Desert of Egypt demonstrates an excellent test arrangement for research into the relation between man and environment. Both the onset of the Holocene humid phase and its termination are plumbable without larger disturbances by modern human activities. Taking into account that the archaeological sites are mostly located on the surface, an areawide detection is possible. Finally the sites are within restricted areas that allow an investigation in the chorological scale. For the purpose of this chapter two archaeological study areas with different geomorphological settings were chosen.

2.3.1. Djara

The Djara region (approximately 200 m a.s.l.; Figure 2.2) is part of the hyperarid Western Desert and lies in the center of the Egyptian Limestone Plateau (also named the Abu Muhariq Plateau). This plateau consists predominantly of Eocene marine carbonate rocks with minor shale intercalations. Its strata and surface dip gently to NNE.

The relief documents a karstic landscape with rounded hilltops, flat depressions, and drainage channels resulting from former wetter climate phases. The Pleistocene as well as modern hyperaridity led and leads to partly strong wind abrasion as well as dune formation (e.g., the famous ‘Abu Muhariq’ dune belt), serir, and hamada surfaces. The depressions and wadi channels are currently covered with sparse vegetation such as shrubs and a few tufts of grass and small herbs, which are independent of groundwater and depend on rare precipitation events that cause run-off. In the Early to Mid-Holocene humid phase (approximately from 9000 to 5000 cal bc) precipitation amounted to 50–100 mm per annum. This led to an accumulation of water and playa sediments in the depressions (Bubenzer & Hilgers, 2003). Until the present it was not clear whether the rains fell in winter or summer months but archaeobotanical findings support the idea of precipitation in both seasons (Kinderman et al., 2006).

The prehistoric settlement area of Djara embraces more than 150 archaeological sites, situated in a well-defined area of 10 by 5 km (Figure 2.2). Most of these sites were found and surveyed next to shallow depressions, often with living vegetation on playa sediments. The radiocarbon dates, taken from anthropogenic features, give – except for an Early Holocene unit (7700–6700 cal bc) – evidence for a main settlement duration between 6400 and 5300 cal bc. Stone tools establish the largest group of artefacts in all inventories, whereas ceramic are remarkably rare (Kindermann, 2004). On the base of diagnostic tool types and additional ^{14}C-dates two Mid-Holocene units, labelled as Djara A (6400–5900 cal bc) and Djara B (5800–5300 cal bc), are distinguishable. Neither vegetation nor fauna were abundant during the Mid-Holocene. Presumably these conditions supported highly mobile populations, with a predominant hunter-gatherer subsistence. After Djara B a distinct drop-off in the number of ^{14}C-dates marks the onset of modern hyperaridity (Gehlen et al., 2002; Kindermann, 2003, 2006; Kindermann et al., 2006).

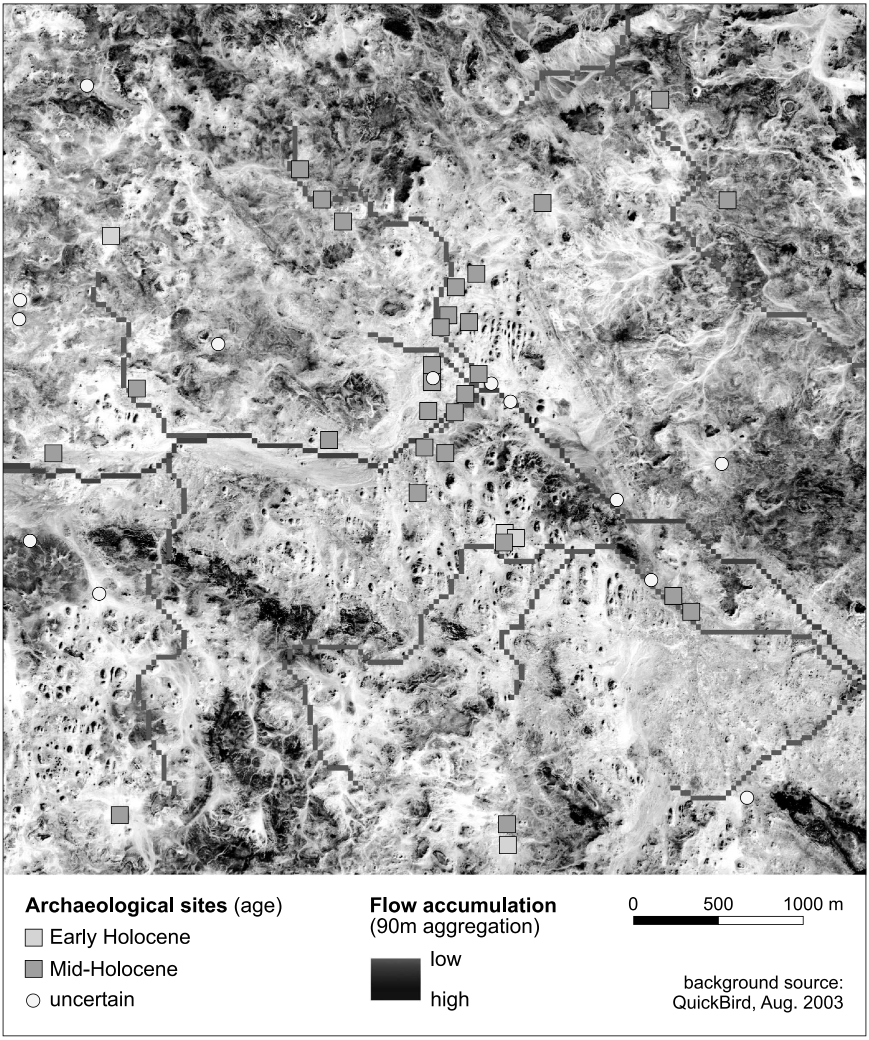

Figure 2.2. Archaeological sites and flow-accumulation in the Djara area. The flow-accumulation is derived from the digital elevation model. Clearly visible is the accumulation of sites along the main drainage line in the centre of the figure (*See also Color Plates*)

2.3.2. Regenfeld

The Regenfeld area (approximately 400 m a.s.l.; Figure 2.3) is located in the southern part of the Great Sand Sea, Western Desert of Egypt. The bedrock consists of Cretaceous shale, silt, and sandstones (Nubian Sandstone) dipping gently to the north. Besides the deflated Holocene playa remnants in the corridors, Pleistocene megadunes (draa with heights up to 70 m above the corridors) with riding modern longitudinal silk dune (height: approximately 15 m) are

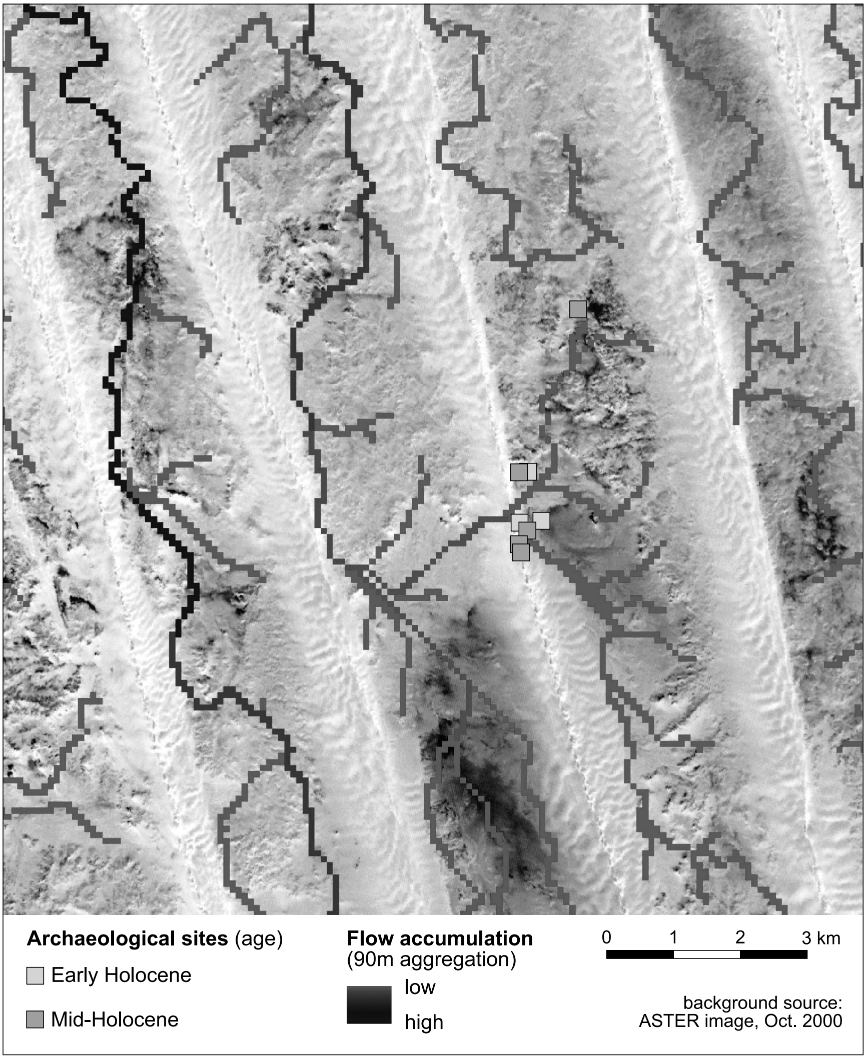

Figure 2.3. Archaeological sites and flow-accumulation in the Regenfeld area. The flow-accumulation is derived from the digital elevation model. For better understanding the flow-accumulation raster is aggregated from 30 to 90 m pixel resolution. Clearly visible is the incidence of archaeological sites at the calculated dune penetration point (*See also Color Plates*)

formative (Riemer, 2000; Besler, 2002). Actual vegetation (mostly *Stipagrostis* spp.) is restricted to the lower dune flanks. From the geomorphological point of view the favorable situation of the Regenfeld area in the Holocene humid phase is based on a surplus of water from the megadunes and from a small sand sheet which reaches from the south into this area (Bubenzer & Riemer, 2007).

These sand accumulations are able to store large quantities of water over a long time after a precipitation event. Because the megadunes are built of single grains a deep penetration of the water is possible. In addition the building of capillaries is prevented and therefore the evaporation is diminished. A reddening of the playa sediments (generation of hematite minerals) corroborates the assumption that a northward expansion of monsoonal summer rains occurred during the Holocene optimum. The annual amount of precipitation was approximately 100 mm (Bubenzer & Besler, 2005). The accumulation of playa sediments took place in the endorheic pans by sedimentation in seasonal or ephemeral lakes, which developed after surface run-off. For the Great Sand Sea groundwater was of no relevance for humans, thus the psammitic silicate deposits of the playas are the result of precipitation, run-off, and seeping water from the draa bodies during the Holocene humid phase.

After the mostly hyperarid Pleistocene, human occupation started in the Western Desert of Egypt around 8800–8700 cal bc with the beginning of the Holocene humid phase (Kröpelin, 1993; Kuper & Kröpelin, 2006). The Regenfeld area can be subdivided into four archaeological phases, three Early Holocene units (Regenfeld A–C) and a Mid-Holocene one, labelled Regenfeld D (Gehlen et al., 2002). Whereas units Regenfeld A–C are distinguished by different lithic-tool kits, one of the most important characteristics of unit D (approximately 6500–5400 cal bc) is the introduction of pottery and the abundance of grinding stones. All bones identified on the archaeological sites belong to wild animals and verify a hunter-gatherer subsistence.

2.4. DATA PREPARATION AND EXPLORATIVE STATISTICS

Although several basic structures within the spatial patterning of the archaeological sites can be discovered simply by visual inspection of overlays, an ordination analysis of site attributes and landscape features leads to a deeper understanding of the landscape and vegetation patterns as a driving factor of spatial occupation patterns.

Environmental variables, which have not been measured in the field, were prepared from remote-sensing datasets for the assessment of their strength as predictors for site distributions (see Appendix for details on the applied methods and resources).

The explanatory power of the derived environmental variables was assessed using Canonical Correspondence Analysis (CCA; ter Braak, 1986, 1994). This multivariate ordination technique is attractive here as it takes two related data matrices as input: the first (main) one typically consisting of incidences or abundances of attributes within a set of sites whereas the second matrix contains environmental variables measured in the same sample units. The ordination within attribute space is constrained by multiple regression on variables in the secondary matrix. CCA is implicitly based on the chi-squared distance and expects a unimodal relation of site attributes to the set of explanatory variables.

The result of the CCA is shown in a bi- or triplot. The resulting ordination is a product of the variability of both the environmental and the archaeological attribute data. Site scores and attribute scores are plotted on the same graph using different scales. The angle and length of the arrows show the direction and strength of the relationship between ordination scores and environmental variables. Its aim is to sort the variables and display their relations to identify dependencies between environmental and archaeological variables.

Our main matrix was set up to hold the information on artefacts from the field surveys, compiled and classified to binary variables by Karin Kindermann and Heiko Riemer (Table 2.1). In both study areas, Djara and Regenfeld, a multilevel strategy was applied. The investigations combined large-scale reconnaissance surveys, local systematic surveys within the areas of research, and detailed archaeological analysis of the sites. Field work comprised excavations and complete collections of artefacts spread out on the surface (Riemer, this volume). To systemise the survey data, a standard form was used for the registration of archaeological features. Excavations were established to separate relevant chronostratigraphic units and to reconstruct the site's spatial configuration and centers of activity using high-resolution excavation grids. The stone artefacts, included in the following statistical analysis, are material from surfaces as well as from excavations. Age categories were derived from typochronological classification of diagnostic artefacts and from ^{14}C-dates.

The second matrix contained the environmental information for the archaeological sites, represented by the remote-sensing and GIS-derived elements. Variables

Table 2.1. Archaeological attributes, which have been used for the main ordination matrix; abbreviations, categories, and number (*n*) of respective cases by region

Archaeological site descriptors			Djara	Regenfeld
Variable	*Explanation*	*Category*	(n=158)	(n=43)
AGE	Classified age	Early Hol.	11	5
		Mid-Hol.	77	38
		Uncertain	70	0
SIZE	Area of sites	Small	108	29
		Middle	45	11
		Large	5	3
DENS	Density of artefacts	Isolated	90	16
		Low	41	20
		High	27	7
BLANK	Blank production	Present	96	28
TOOL	Tools	Present	85	23
ARROW	Arrow heads	Present	16	10
ADZE	Adzes	Present	26	0
GRIND	Grinding stones	Present	44	30
HEARTH	Hearths	Present	117	10
OES	Ostrich egg shell artef.	Present	11	5

Table 2.2. Environmental variables, which have been used for the secondary ordination matrix; abbreviations, categories, and number (*n*) of all classified locations for the background

Environmental site descriptors:	Djara (n = 5,524), Regenfeld(r = 27,174)
Variable	*Explanation*
LAT	UTM Latitude position
LONG	UTM Longitude position
ALT	Altitude from DEM (m)
SLOPE	Inclination (deg)
EXP_180	Aspect (north–south: 1...0...-1)
EXP_090	Aspect east–west 1...0...-1)
TOPO index	Topographic position within 150 m neighborhood: TOPO = (H-min(HĐ))* $n(x < H)/24$
FLOAC	Flow accumulation through site pixel (30 m)
FLOACX	Flow accumulation through next channel pixel (30 m)
HYDRO index	Maximum flow accumulation through site neighborhood (210 m)
DIST	Low cost distance to next channel (m)
GEO$	Geological unit (from digitized map)

were log-transformed where necessary, and standardised to zero mean and unit variance (Table 2.2).

Frequency distributions of the environmental variables were calculated, which allowed a comparison of site attribute spectra with the respective regional background (neutral model). Differences would normally then be confirmed statistically by bootstrap techniques.

The spatial resolution of all data presented is 30 m. Although CCA is reported to be rather insensitive to autocorrelation, all analyses were repeated with a coarse-grained subset (resolution 210 m) in order to detect possible bias induced by the clumped distribution of the archaeological sites. Neither the frequency distributions nor the CCA results showed a marked difference to the original dataset.

All analyses were done using the programs SYSTAT 10 (Systat software Inc.), CANOCO 4 (ter Braak & Smilauer, 1998), and PC-ORD 4 (McCune & Mefford, 1999).

2.5. RESULTS AND DISCUSSION

Archaeological remains within the study areas are generally, more often than expected from the statistical background, located at lower positions (depression area or wadi) within the topological sequence, close to hydrological features receiving considerable run-off from surrounding terrain (Figure 2.4). Frequency distributions of sites dated as Mid-Holocene, which constitute the majority of the investigated places, show a tendency to bimodality in comparison to the regional background (e.g., arrowheads, ostrich egg shell artefacts (OES), adzes, and grinding stones).

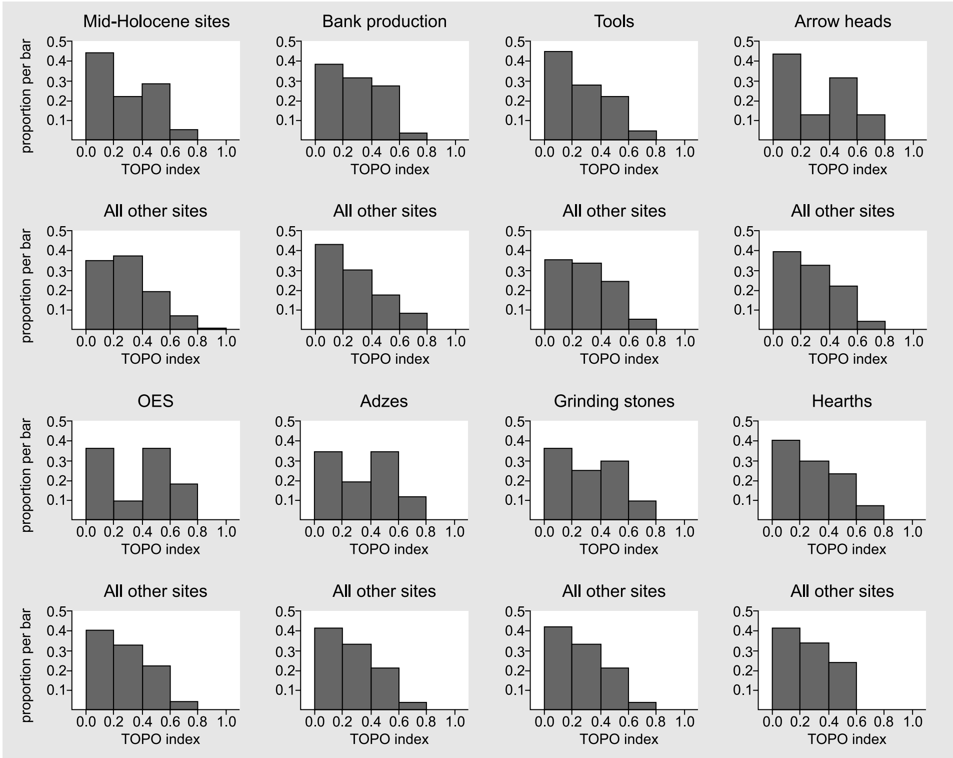

Figure 2.4. Histograms showing the distribution of the Topo-Index (see Table 2.2) values among sites with a certain age, or presence/absence of artefact types, against their background. OES – ostrich egg shell artefacts

Many assemblages could be found near hydrologically favored positions, however, there are also sites located on the higher and drier end of the spectrum. These sites seem to contain preferably signs of blank production and/or hearths. On the other hand, grinding stones and/or stone tools were found in great numbers near channels and flood plains (Figure 2.5).

The ordination results[3] support the general hypothesis. The CCA triplot shows the first two ordination axes to be correlated with the topographical and hydrological features derived from the digital elevation model (Figure 2.6). Attribute–environment correlations are significant (Monte Carlo test, 99 runs). The Topo-Index correlates with axis 1 (−0.943) and separates the two study regions, suggesting a different occupation pattern in response to landscape morphology. The Hydro-Index is correlated with axis 2 (−0.996), separating the Early from Mid-Holocene sites in Djara. One possible interpretation is that human exploitation in earlier phases of the Holocene optimum concentrated on the plains and highlands, where a diffuse vegetation of steppic character promised optimal hunting grounds. New and probably more profitable resources were found during later chronological units, when temporary wetlands came into existence and attracted people to settle on the deeper and more clayey soils along the shorelines. These were the places where seasonal inundation led to the vigorous growth of wild herbs and grasses, nutrient rich and worth being collected for their cereal products. If this activity was an autochthonous innovation or the result of interregional exchange remains one of the main archaeological problems to be solved for this region.

2.6. CONCLUSION

The study presented here focused on the three-dimensional physical aspects of landscape, emphasising its role as the ultimate basis of human livelihoods and life-supporting system, necessarily leaving aside all the cultural aspects of the environment. Nevertheless we acknowledge that people are more than passive recipients of climatic changes. However, it has to be borne in mind that during the Holocene humid optimum, the ecological situation already provided difficult conditions for the people in the Western Desert of Egypt. Neither vegetation nor fauna were abundant during the Mid-Holocene and therefore these conditions only supported mobile populations of predominant hunter-gatherers that were highly dependent on adequate rain, extremely vulnerable to climatic changes, and so reacted sensitively. That is just why arid zones, especially for the time slice examined, form an almost experimental situation, as key resources are limited factors, and

[3] To conclude the presentation of the results, some caution is warranted because the archaeological database is far from statistically ideal. The number of cases within categories varies over a wide range. There is also some ambiguity in the Topo-Index, which creates small values at valley positions, but also within level terrain.

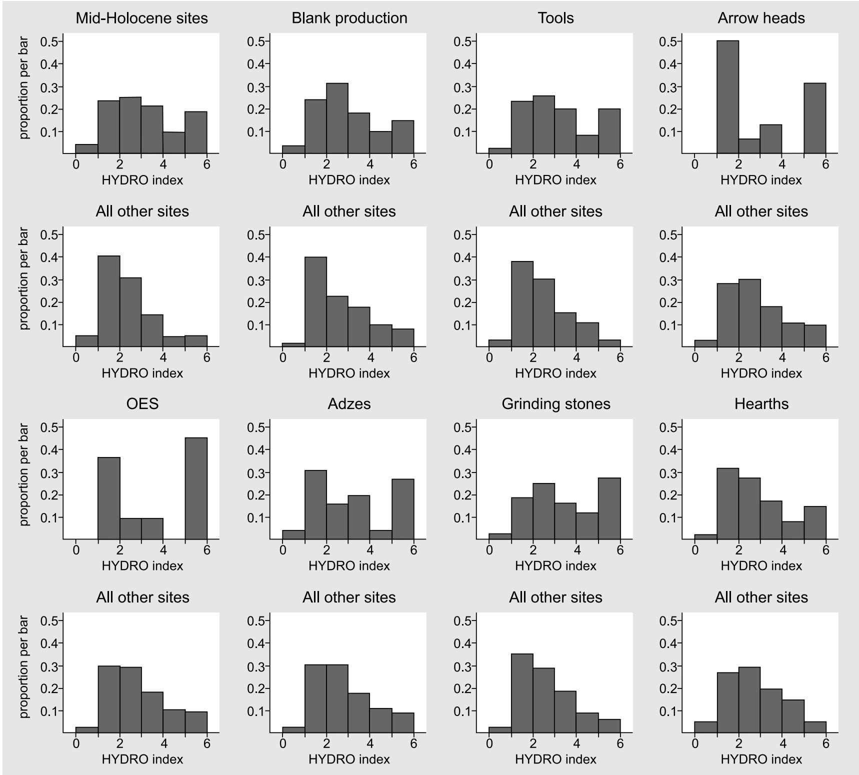

Figure 2.5. Histograms showing the distribution of the Hydro-Index (see Table 2.2) values among sites with a certain age and presence/absence of artefact types, against their background. OES – ostrich egg shell artefacts

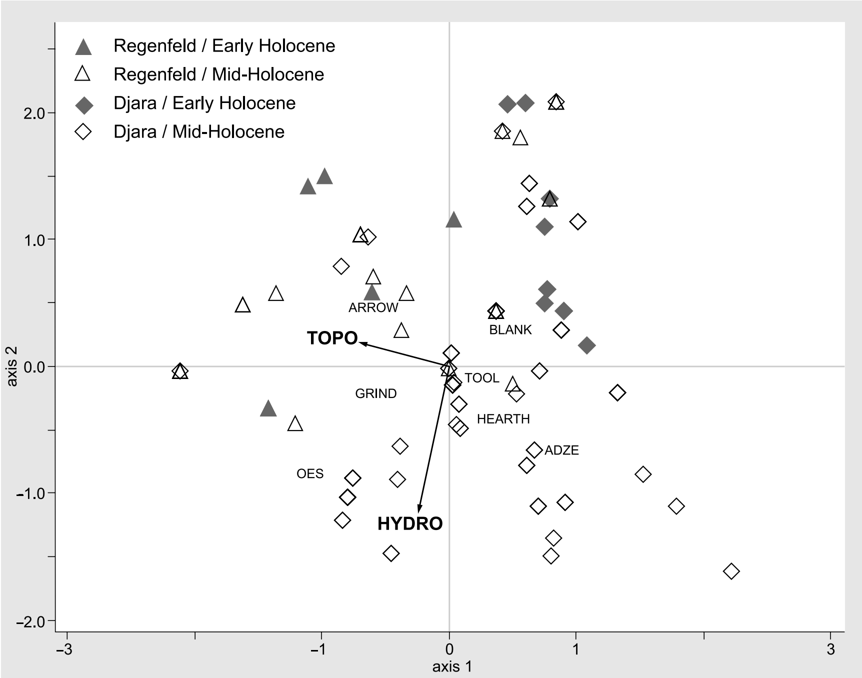

Figure 2.6. Triplot of the CCA, showing the ordination of prehistoric sites with respect to axes 1 and 2 from presence/absence of observations of archaeological remains. Artefact types are placed at their centroids in ordination space. Topo-Index is correlated with axis 1; Hydro-Index is correlated with axis 2. For details and abbreviations, see text

the environmental constraints of the arid landscape can be separated from other nonenvironmental factors

Starting from this point, our analysis of past patterns of adaptation was based mainly on a functional view, which sees landscape as a system composed of compartments and flows of energy and matter. In sum, by the coordination of scattered archaeological evidence and the establishment of relationships with their geographical background, we located places with ecologically favorable conditions for the prehistoric people and found reasonable explanations for site distributions in terms of environmental features.

APPENDIX

Steps of Deriving Environmental Parameters

At the beginning of the project the source of digital elevation model data and the necessary grid resolutions were discussed. Free available elevation data (e.g., GTOPO 30 model) is unsuited to the question described, because its resolution is too coarse. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) onboard the National Aeronautics and Space Administration's (NASA's) TERRA spacecraft (launched in 1999) provides digital stereo data at 15 m resolution (Yamaguchi et al., 1998). ASTER's spectral and geometric capabilities include 14 bands in different wavelengths. A comparison of ASTER and the well-known LANDSAT ETM+ spectral bands is given in Figure 2.A1.

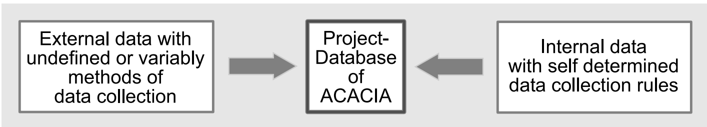

Figure 2.A1. ASTER spectral bands (top) compared to Landsat ETM+ (bottom). The rectangular boxes indicate the sensor channel with the respective spatial resolution on the top of the boxes. VNIR – visible and near infrared; SWIR – short-wave infrared; TIR – thermal infrared.

For generating DEMs the L1A raw data (available at the EOS DG, 2007) with the two stereo bands (3b and n) are in use (Fujisada, 1998; Abrams, 2000). The orientation is set by the same tie points because of the lack of exact ground control points in the unsurveyed region. It is for this reason that only relative DEMs can be extracted. In very smooth terrain, as well as under problematic conditions (cloud cover) the generation and the quality of DEMs are imprecise. However, the comparison between generated DEMs by the ASTER team and the generated DEM of the same scene by our project shows particular agreement. Another problem concerns the mosaicing of several generated elevation models, because artefacts might arise from small absolute elevation differences in the models between to track rows. However, the problems described are quite rare and most often attributed to errors in the raw data (Bolten & Bubenzer, 2006; Bubenzer & Bolten, 2008). Remarkable is the enormous calculation time for a DEM extraction (about 30 min calculation time without setup work for one dataset), so a generation of a wide-range elevation model could only be done with up-to-date computer power.

(continued)

Figure 2.A2 shows a flowchart starting with the extracted DEM. Thence-forward there are two directions of analysis.

Firstly the determination of surface data with a GIS and secondly the extraction of hydrologic parameters in a watershed modelling software (TOPAZ, Garbrecht, 2000). Then, secondary combinational parameters (e.g., a topographic valley index [Myburgh, 1974]) in combination with the external data could be extracted as an origin for a statistical processing.

The part 'surface data' means the distribution of altitude, slope, and aspect for the entire DEM area. After this the data of specific points – defined by archaeological sites (external data) – can be extracted and transferred into a database. The determination of slope and aspect, as simple primary geomorphometric parameters (Schmidt & Dikau, 1999), are part of most raster-based GIS systems.

The part 'hydrology data' contains the determination of flow-direction, flow-accumulation, and watershed basins, called complex primary geomorphometric parameters (Schmidt & Dikau, 1999). With these parameters a quantitative calculation of a hypothetical drainage system is possible. The quality of the drainage system is checked by comparison with a ground-checked drainage system analysis by Jäkel and Rückert (1998). The extracted drainage system shows good correspondence, except in flat playa areas, when the error noise of the DEM is more important and higher than the elevation variety (Bubenzer et al., 2007c).

Another derived vector parameter is the favorable path to the drainage system in dependency of the surface slope.

The derived parameters from the statistical software can be used to identify different landscape characteristics regarding the land use potential. At a sufficient number of investigated regions an areal interpolation is possible.

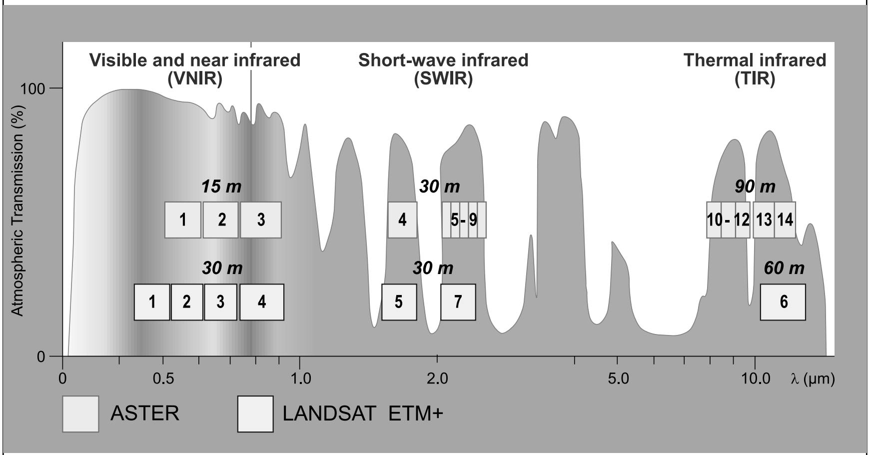

Figure 2.A2. Flow chart for further calculation (*See also Color Plates*)

(continued)

REFERENCES

Abrams, M. (2000). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER): Data products for the high spatial resolution imager on NASA's Terra platform. *International Journal of Remote Sensing*, 21, 847–859.

Adams, J.M. & Faure, H. (Eds.) (1997). QEN members. Review and atlas of palaeovegetation: Preliminary land ecosystem maps of the world since the Last Glacial Maximum. Oak Ridge National Laboratory, TN, 1999 (http://www.esd.ornl.gov/projects/qen/adams1.html).

Alaily, F. (1993). Soil association and land suitability maps of the Western Desert, SW Egypt. *Catena Suppl.*, 26, 123–153.

Anhuf, D. (1997). Paleovegetation in West Africa for 18.000 B.P. and 8.500 B.P. *Eiszeitalter und Gegenwart*, 47, 112–119.

Anhuf, D. & Frankenberg, P. (2000). Die mittelholozäne Feuchtphase 5000 BP – Eine Vegetationsrekonstruktion für Afrika. *Regensburger Geogr. Schriften*, 33, 99–126.

Barbour, M.G., Burk, J.H., Pitts, W.D., Gilliam, F.& Schwartz, M. (1999). *Terrestrial Plant Ecology*. Menlo Park, CA: Addison Wesley/Longman.

Bastian, O. (1999). Landschaftsbewertung und Leitbildentwicklung auf der Basis von Mikrogeochoren. In U. Steinhardt & M. Volk (Eds.), *Regionalisierung in der Landschaftsökologie* (pp. 287–298). Stuttgart, Leipzig: Teubner.

Bastian, O. & Steinhardt, U. (Eds.) (2002). *Development and Perspectives of Landscape Ecology*. Boston: Kluwer.

Besler, H. (2002). The Great Sand (Egypt) during the late Pleistocene and the Holocene. *Zeitschrift für Geomorphologie,* Suppl.-Bd. 127, 1–19.

Bolten, A. & Bubenzer, O. (2006). New elevation data (SRTM/ASTER) for geomorphological and geoarchaeological research in arid regions. *Zeitschrift für Geomorphologie*, Suppl. 142, 265–279.

Bornkamm, R. & Darius, F. (1999). Probleme der Landnutzungsplanung in der Extremwüste Süd-Ägypteus. *TU International*, 46/47, 39–42.

ter Braak, C.J.F. (1986). Canonical correspondence analysis: A new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67, 1167–1179.

ter Braak, C.J.F. (1994). Canonical community ordination. Part I: Basic theory and linear methods. *Ecoscience*, 1, 127–140.

ter Braak, C.J.F. & Smilauer, P. (1998). *CANOCO Reference Manual and User's Guide to CANOCO for Windows: Software for Canonical Community Ordination (Version 4)*. Wageningen: Centre for Biometry.

Bubenzer, O. & Besler, H. (2005). Human occupation of Sand Seas during the Early and Mid-Holocene. Examples from Egypt. *Zeitschrift für Geomorphologie*, Suppl. 138, 153–165.

Bubenzer, O. & Bolten, A. (2003). Detecting areas with different land use potential in Egypt, Sudan, and Namibia, GIS helps compare human strategies of coping with arid habitats. *ArcNews*, 25, 2.

Bubenzer, O. & Bolten, A. (2008): The use of new elevation data (SRTM/ASTER) for the detection and morphometric quantification of Pleistocene megadunes (draa) in the eastern Sahara and the southern Namib. *Geomorphology* (in press, available online).

Bubenzer, O. & Hilgers, A. (2003). Luminescence dating of Holocene playa deposits of the Egyptian Plateau, Western Desert, Egypt. *Quaternary Science Reviews*, 22, 1077–1084.

Bubenzer, O. & Riemer, H. (2007). Holocene climatic change and human settlement between the central Sahara and the Nile Valley: Archaeological and geomorphological results. *Geoarchaeology*, 22, 607–620.

Bubenzer, O., Besler, H. & Hilgers, H. (2007b). Filling the gap: OSL data expanding ^{14}C chronologies of Late Quaternary environmental change in the Libyan Desert. *Quaternary International*, 175, 41–52.

Bubenzer, O., Bolten, A. & Darius, F. (Eds.) (2007a). *Atlas of Cultural and Environmental Change in Arid Africa. Africa Praehistorica*, 21, 240 p. Cologne: Heinrich-Barth-Institut e.V.

Bubenzer, O., Bolten, A. & Ritter, M. (2007c). Scale-specific geomorphometry of arid regions – Examples from the eastern Sahara. *Proceedings of an International ACACIA Conference* held at Königswinter, Germany, October 1–3, 2003. *Colloquium Africanum*, 2: 17–34. Cologne: Heinrich-Barth-Institut e.V.

Bubenzer, O., Hilgers, A. & Riemer, H. (2006). Luminescence dating and archaeology of Holocene fluvio-lacustrine sediments of Abu Tartur, Eastern Sahara. *Quaternary Geochronology*, 2, 314–321.

El Kady, H.F., Ayyad, M.A. & Bornkamm, R. (1995). Vegetation and recent land-use history in the desert of Maktala, Egypt. In H.-P. Blume & S. Berkowicz (Eds.), *Arid Ecosystems* (pp. 109–123). Cremlingen-Destedt: Catena.

EOS DG (2007): Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/).

Farshad, A. (2001). Reconstruction of the evolution of the past agrarian landscape as a clue for assessing sustainability: A case study of Iran. In D. Van der Zee & I.S. Zonneveld (Eds.), *Landscape Ecology Applied in Land Evaluation, Development and Conservation. Some Worldwide Selected Examples* (pp. 1–48.) ITC publication, 81. International Institute for Aerospace Survey and Earth Sciences, Enschede.

Fujisada, H. (1998). ASTER level-1 data processing algorithm. *IEEE Transactions and Remote Sensing*, 36, 1101–1112.

Garbrecht, J. (2000). *TOPAZ User Manual* (http://grl.ars.usda.gov/topaz/USERMAN/PAGE1.htm).

Gardner, I.S. (1977). *Physical Geography*. New York: Harper's College Press.

Gehlen, B., Kindermann, K., Linstädter, J. & Riemer, H. (2002). The Holocene occupation of the Eastern Sahara: Regional chronologies and supra-regional developments in four areas of the Absolute Desert. In:Jennerstr. 8 (Eds.), *Tides of the Desert – Gezeiten der Wüste. Contributions to the Archaeology and Environmental History of Africa in Honour of Rudolph Kuper*. *Africa Praehistorica* (Vol. 14, pp. 85–116). Cologne: Heinrich-Barth-Institut.

Haase, G. (1996). Geotopologie und geochorologie – Die Leipzig-Dresdener Schule der Landschaftsökologie. In G. Haase & E. Eichler (Eds.), *Wege und Fortschritte der Wissenschaft; Sächsische Akademie der Wissenschaften zu Leipzig* (pp. 201–229). Berlin: Akademie-Verlag Berlin.

Haynes, V.C. (2001). Geochronology and climate change of the Pleistocene-Holocene transition in the Darb el Arba´in Desert, Eastern Sahara. *Geoarchaeology*, 16, 119–141.

Jäkel, D. & Rückert, H. (1998). Recent rainfall distribution patterns of the Republic of Sudan as a model for rainfall variations in the past and climate induced geomorphological processes in Sahelian countries. *Paleoecology of Africa*, 25, 101–120.

Kääb, A., Huggel, C., Paul, F., Wessels, R., Raup, B., Kieffer, H. & Kargel, J. (2002). Glacier monitoring from ASTER imagery: Accuracy and applications. *Proceedings LIS-SIG* Workshop Berne, March 11–13, 2002.

Kehl, H.& Bornkamm, R. (1993). Landscape ecology and vegetation units of the Western Desert of Egypt. *Catena*, 26, 155–178.

Kindermann, K. (2003). Djara: Prehistoric links between the Desert and the Nile. In Z. Hawass & L. Pich Brock (Eds.), *Egyptology at the Dawn of the Twenty-First Century. Proceedings of the Eighth International Congress of Egyptologists* (pp. 272–279). Cairo.

Kindermann, K. (2004). Djara: Excavations and surveys of the 1998–2002 seasons. *Archéo-Nil*, 14, 31–50.

Kindermann, K. (2006). Djara. Zur mittelholozänen Besiedlungsgeschichte zwischen Niltal und Oasen (Abu-Muhariq-Plateau, Ägypten). (Unpublished Ph.D. thesis, Köln 2006).

Kindermann, K. & Bubenzer, O. (2007). Djara – Humans and their environment on the Egyptian limestone plateau around 8,000 years ago. In O. Bubenzer, A. Bolten & F. Darius (Eds.), Atlas of Cultural and Environmental Change in Arid Africa *Africa Praehistorica* (Vol. 21, pp. 26–29). Cologne: Heinrich-Barth-Institut e.V.

Kindermann, K., Bubenzer, O., Nussbaum, S., Riemer, H., Darius, F., Pöllath, N. & Smettan, U. (2006). Palaeoenvironment and Holocene land use of Djara, Western Desert of Egypt. *Quaternary Science Reviews*, 25, 1619–1637.

Kröpelin, S. (1993). Geomorphology, landscape evolution and paleoclimates of Southwest Egypt. *Catena*, Suppl. 26, 31–65.

Kuper, R. (1989). The Eastern Sahara from north to south: Data and dates from the B.O.S. Project. In L. Krzyżaniak & M. Kobusiewicz (Eds.), *Late Prehistory of the Nile Basin and the Sahara. Studies in African Archaeology* (pp. 197–203). Poznan: Poznan Archaological Museum.

Kuper, R. (2002). Routes and roots in Egypt's Western Desert: The Early Holocene resettlement of the Eastern Sahara. In R. Friedman (Ed.), *Egypt and Nubia. Gifts of the Desert* (pp. 1–12 (pl. 1–24)). London: The British Museum Press.

Kuper, R. (2006). After 5000 BC: The Libyan desert in transition. *C.R. Palevol*, 5, 409–419.

Kuper, R. & Kröpelin, S. (2006). Climate-controlled Holocene occupation in the Sahara: Motor of Africa's evolution. *Science*, 313, 803–807.

Kutter, A., Nachtergaele, F.O. & Verheye, W.H. (1997). The new FAO approach to land use planning and management, and its application in Sierra Leone. *ITC Journal*, 3/4, 278–283.

Leser, H. (1997). *Landschaftsökologie. Ansatz, Modelle, Methodik, Anwendung*. Stuttgart: Ulmer.

McCune, B .& Mefford, M.J. (1999). *PC-ORD. Multivariate Analysis of Ecological Data. Version 4.0.* Gleneden Beach, OR: MjM Software.

Myburgh, J. (1974). An index to relate local topography to mean minimum temperatures. *Agrochemophysica*, 6, 73–78.

Naveh, Z. (1995). Interactions of landscapes and cultures. *Landscape and Urban Planning*, 32, 43–54.

Neumann, K. (1989). Holocene vegetation of the Eastern Sahara: Charcoals from prehistoric sites. *African Archaeological Review*, 7, 97–116.

de Noblet-Ducoudré, N., Claussen, M. & Prentice, C. (2000). Mid-Holocene greening of the Sahara: First results of the GAIM 6000 year BP experiment with two asynchronously coupled atmosphere/biome models. *Climate Dynamics*, 16, 643–659.

Pachur, H.-J. & Altmann, N. (2006). *Die Ostsahara im Spätquartär. Ökosystemwandel im größten hyperariden Raum der Erde*. Berlin: Springer.

Penck, A. (1894). *Morphologie der Erdoberfläche*. Stuttgart: J. Engelhorn.

Prentice, I.C., Jolly, D. & BIOME 6000 participants (2000). Mid-Holocene and glacial-maximum vegetation geography of the northern continents and Africa. *Journal of Biogeography*, 27, 507–519.

Richthofen, F.v. (1877). Die heutigen Aufgaben der wissenschaftlichen Geographie. In F.v. Richthofen (Ed.), *China, Bd. 1* (pp. 729–733). Berlin: D. Reimer.

Riemer, H. (2000). Regenfeld 96/1 – Great Sand Sea and the question of human settlement on whaleback dunes. In L. Krzyżaniak, K. Kroeper & M. Kobusiewicz (Eds.), *Recent Research into the Stone Age of Northeastern Africa. Studies in African Archaeology* (pp. 21–31). Poznan: Poznan Archaological Museum.

Riemer, H. (2006). Archaeology and environment of the Western Desert of Egypt: ^{14}C-based human occupation history as an archive for Holocene palaeoclimatic reconstruction. In Youssef & El-Sayed, A.A. (Eds.), *Geology of the Tethys. Proceedings of the First International Conference on the Geology of the Tethys* (pp. 553–564). Cairo: Cairo University 2005, The Tethys Geological Society.

Rohdenburg, H. (1989). *Landschaftsökologie – Geomorphologie*. Cremlingen: Catena Verlag.

Schild, R. & Wendorf, F. (2001). Geoarchaeology of the Holocene climatic optimum at Nabta Playa, Southwest Desert, Egypt. *Geoarchaeology*, 16, 7–28.

Schmidt, J. & Dikau, R. (1999). Extracting geomorphometric attributes and objects from digital elevation models – Semantics, methods, future needs. In R. Dikau & H. Saurer (Eds.), *GIS for Earth Surface Systems* (pp. 153–174). Stuttgart: Gebrüder Borntraeger.

Schulz, E., Akhtar-Schuster, M., Agwu, Ch., Beck, C., Dupont, L., Jahns, S., Niedermeyer, M., Ousseini, I. & Salzmann, U. (2001). *The Holocene Landscape and Vegetation History of Northern and Western Africa – A Palaeoecological Atlas* (http://www.uni-wuerzburg.de/geographie/fachi/pal_atlas_afrika/index_atlas.htm).

Spikins, P. (2000). GIS models of past vegetation: An example from Northern England, 10000–15000 BP. *Journal of Archaeological Science*, 27, 219–234.

Syrbe, R.-U. (2002). Entwicklung von Struktur und Funktionsweise in der Landschaft. In G. Haase & K. Mannsfeld (Hrsg.), *Naturraumeinheiten, Landschaftsfunktionen und Leitbilder am Beispiel von Sachsen. Forschungen zur deutschen Landeskunde*, 250 (pp. 19–26). Flensburg: Academy Publication.

Tress, B., Tress, G. & Fry, G. (2003). Potential and limitations of interdisciplinary and transdisciplinary landscape studies. In B. Tress, G. Tress, A. van der Valk & G. Fry (Eds.), *Interdisciplinary and Transdisciplinary Landscape Studies: Potential and Limitations. Delta series*, 2 (pp. 182–192). Wageningen: Alterra Green World Research.

Troll, C. (1939). Luftbildplan und ökologische Bodenforschung (Aerial photography and ecological studies of the earth). *Zeitschrift der Gesellschaft für Erdkunde*, 241–298.

Troll, C. (1966). Landschaftsökologie als geographisch-synoptische Naturbetrachtung. In: ökologische Landschaftsforschung und vergleichende Hochgebirgsforschung. *Erdkundliches Wissen*, 11, 1–13.

Turner, M.G. & Gardner, R.H. (Eds.) (1990). *Quantitative Methods in Landscape Ecology*. *Ecological Studies*, 82. New York: Springer.

Wendorf, F., Schild, R. & Associates (Eds.) (2001). *Holocene Settlement of the Egyptian Sahara. The Archaeology of Nabta Playa, 1*. New York: Kluwer/Plenum.

Yamaguchi, Y., Kahle, A.B., Tsu, H., Kawakami, T. & Pniel, M. (1998). Overview of Advanced Spaceborn Thermal Emission and Reflection Radiometer (ASTER). *IEEE Transactions on Geoscience and Remote Sensing*, 36, 1062–1071.