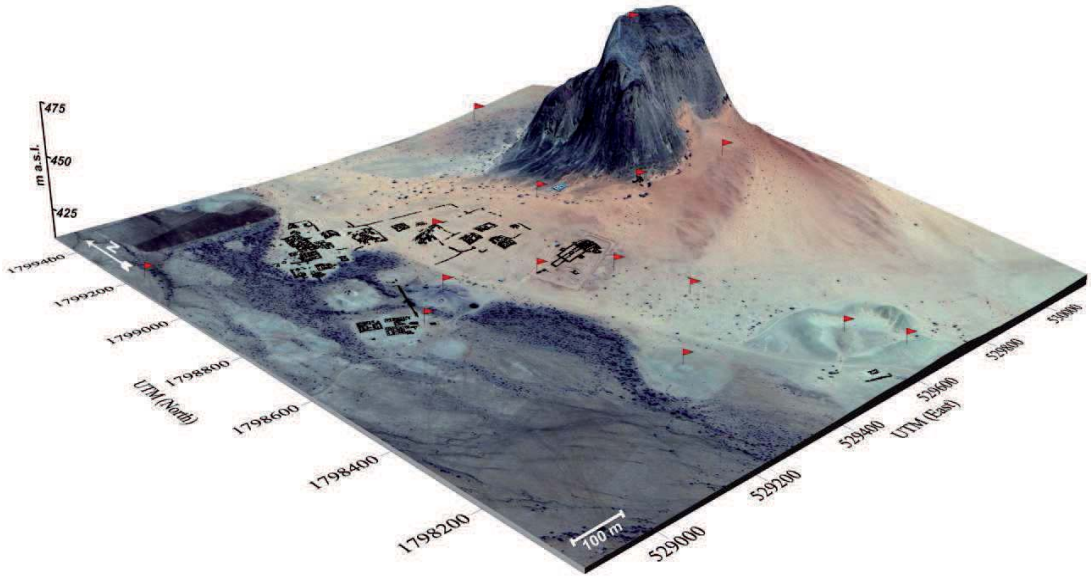
Dissertation of Jonas Berking

Geoarchaeology in Drylands

Palaeoenvironmental Reconstructions in the Vicinity of Naga, Central Sudan



Freie Universität Berlin • Fachbereich Geowissenschaften • Physische Geographie

Tag der Disputation 13. Juli 2011

Erstgutachterin: Prof. Dr. Brigitta Schütt
Institut für Geographische Wissenschaften
Fachbereich Geowissenschaften
Freie Universität Berlin

Zweitgutachter: Prof. Dr. Tilman Rost
Institut für Geographische Wissenschaften
Fachbereich Geowissenschaften
Freie Universität Berlin

Acknowledgements

This thesis was supported as part of the Cluster of Excellence Exc264 *Topoi* – The Formation and Transformation of Space and Knowledge in Ancient Civilizations – Research Area AI-7. My highest appreciation to *Prof. B. Schütt* for the establishment and realization of this project as well as this thesis, the conducted fieldwork and the preparation of the publications. For the last years *Prof. Schütt* has always been an excellent provider and manager of my research career not only in this very project, but also during other projects such as the one on the "Tibetan Plateau" and during numerous conferences and occasions. I'm also very grateful to Prof. T. Rost for his uncomplicated expert advice about this thesis.

Special thanks go to *Prof. D. Wildung* and *Dr. K. Kröper*, "Ägyptisches Museum Berlin"; who facilitated the field work. I want to continue thanking *Michael Schott* and *Julia Meister* for their assistance during fieldwork and their appraising work. To *Brian Beckers, Janina Körper, Sebastian Wagner, Burkhart Ullrich* and many others for an enlightening interdisciplinary research within the pleasant setting and support of Topoi. My expressed gratitude goes to the various scholars who gave me access to their laboratories or agreed on a cooperation: first of all there is *Prof. M. Frechen* and the LIAG in Hannover who enabled me to preprocess my OSL-samples and gave me the feeling of being part of the working group with their expert knowledge. To *Prof. M. Kaupenjohann* from the TU Berlin, who agreed on a cooperation to investigate the distinguished incrustations and discussing ways with my on how to get a grip on amorphous silica or iron oxides. To *Dr. H. Arz* for letting me open and analyze my sediment cores at the facilities of the GFZ Potsdam. To *Prof. M. Coffee* at the Purdue Rare Isotope Measurement Laboratory Indiana and his termless assistance with the cosmogenic nuclides dating. To *A. Riedel* and *U. Weferling* for providing the tachymetric survey data. To *A. Giribaldi* for the preparation of the thin sections. Thanks to *Prof. M. Edmunds* for the enlightening discussions about the fossil groundwaters in the Nubian aquifers and *E. Heyde* for the uncomplicated measurement of the water samples. To *Prof. H.-J. Pachur* for the discussions about the Holocene landscape evolution of the area and the possibilities of $CaCO_3$ precipitations. Thanks to *Dr. P. Wolf* and *Dr. C. Kleinitz* for their virtual and actual journeys throughout the north of Sudan and the Meroitic times. Thanks go to *Prof. K.-H- Pörtge*, *Prof. Prof. B. Meissner* and *Prof. B. Gabriel* for all the forwarded literature and photographs, which I gladly keep for any future scientist interested in the region. I also want to mention *Dr. T. Bauer* and the guys from Trigon Art as well as *J. Hamann* and his

conservation team, for not mentioning the thought of a pleasant and cool beer, when we had to cope with 47°C during the weeks of fieldworks.

Main thanks for the progression of this work go to the working group of Prof. Schütt, where at least *J. Krause*, *Dr. W. Bebermeier*, *S. Schneider* and *Dr. P. Hoelzmann* should be highlighted. Thanks for all the coffee and enlightening talk goes to *D. Wenske*.

Personally I want to thank my whole family for all their interest and support - I will have at least one copy of my thesis ready for them. And of course my girlfriend who never gave up on me and to whom I owe such a pleasant and harmonic life.

Summary

The scope of this study is the understanding of the natural and cultural landscape development in the vicinity of Naga in central Sudan since late Holocene. Investigations on the landscape history around Naga took place between 2008 and 2010. This ancient and now abandoned settlement had its heyday around 2000 years ago and is located in the hinterland of the Nile, in the semi-arid north of the Sudan. The study site is characterized by low annual precipitation ($\bar{x}$ = 95 mm a^{-1}) and high temperatures throughout the year ($\bar{x}$ = 29°C), with 95% of the rainfall occurring during the summer months (JUN-SEP). Only during this rainy season erratic flooding in the adjacent wadis occurs, which in due course can be used for irrigation measures.

Generally the rise and fall of ancient cultures in such drylands is controlled by the availability of water and therefore - where no perennial water sources are available - by effective rainfall and its reliability. Multi-proxy approaches and a detailed chronology are necessary, because palaeoclimatic proxy archives provide climatic information at most with annual or seasonal resolutions and hence are often not sufficient to account for the reactions or adaptations of societies to environmental shifts.

Different approaches are applied to get an idea about the structure of the settlement and how such an urban structure adapted to the (changing) environmental or climatic conditions and about the potential human or natural impact on the landscape. The landscape setting, its morphology and dynamics as well as the timing of the underlying processes is of high interest. Herein geomorphological patterns and landscape features were recorded and mapped during the field campaigns. A chronology was set up by various OSL- and ^{14}C-datings in different (sediment-) archives and received drilling cores. Data from the Sudanese weather stations as well as the output of paleoclimate models were evaluated to characterize the modern and past rainfall availability and variability. The application of surface characteristics and through the assessment of the hydrological situation, a rainfall-runoff model was set up. In combination with statistical analyses about the magnitude and frequency of rainfall- and runoff events these methods lead to the attempted environmental reconstructions.

One of the main geoarchaeological targets was an open water reservoir, the so called “Great Hafir of Naga”, which served the Meroitic citizens for water harvesting purposes some 2000 years ago. In this sense the citizens of Naga were adapted to the sensitive natural system and had to rely on the annual amount of runoff for water harvesting measures to ensure agricultural and domestically needs. The main results of the investigations show that fundamental

environmental changes did not take place in the area during the past 2000 years; where nevertheless subsystems may have varied significantly. The analyzed rainfall data for modern and past conditions implies that water harvesting in the regions would still be feasible today. However, due to human impact on the landscape coupled with a slight shift in the reliability and performance of annual rainfall the potential natural environment of Naga was disturbed - leading to the conclusion, that the Meroitic people experienced a time when the region was more comfortable and inhabitable than ever since.

Zusammenfassung

Die vorliegende Studie beschäftigt sich mit den natürlichen und anthropogenen Landschafts-veränderungen in der Umgebung von Naga, im zentralen Sudan, seit dem späten Holozän. Die Untersuchungen und Feldarbeiten fanden zwischen 2008 und 2010 statt. Die antike und später aufgegebene Stadt Naga erlebte ihre Blütezeit vor rund 2000 Jahren. Sie liegt im Hinterland des Nils am Rande des Wadi Awatib. Das Untersuchungsgebiet ist charakterisiert durch sehr niedrige jährliche Niederschläge ($\bar{x}$ = 95mm a^{-1}) und ganzjährig hohe Temperaturen ($\bar{x}$ = 29°C), wobei 95% des Niederschlags während der Regenzeit im Sommer fällt (JUN-SEP). Nur während dieser Regenzeit kommt es zu Oberflächenabfluss, welcher dann für Bewässerungsmaßnahmen verwendet werden kann. Grundsätzlich gilt die Verfügbarkeit von ausreichend Wasser, als eine Hauptvoraussetzung für (Hoch-)Kulturen. Wo keine ganzjährig schüttenden Wasserquellen oder sonstigen Gewässer vorkommen, sind Menschen auf so genannten wirksamen Niederschlag angewiesen. Da die meisten klimatischen Proxy nur eine zeitliche Auflösung von Jahren oder Jahreszeiten haben, sind sie häufig nicht geeignet kurzzeitige Schwankungen oder Veränderungen aufzuzeigen. Somit erscheinen Multi-Proxy Ansätze und eine hoch aufgelöste Chronologie unerlässlich. Die Untersuchungen fokussieren sich dabei auf die Landschaft rund um die Stadt Naga, die sowohl klimatischen als auch menschlichen Veränderungen unterlag. Die Erfassung dieser landschaftlichen Dynamik und ihre zeitliche Einordnung sind dabei von besonderem Interesse. Hierzu wurden geomorphologische und morphetrische Analysen und Kartierungen durchgeführt. Eine Chronologie wurde durch verschiedenen OSL- und ^{14}C-Datierungen in den untersuchten (Landschafts-) Archiven sowie erbohrten Sedimenten erstellt. Um Aussagen über die modernen und früheren Niederschlagsverhältnisse zu erhalten, wurden

die zur Verfügung stehenden modernen Wetterstationen sowie Paläo-Klimamodelle ausgewertet. Auf Grundlage der Oberflächeneigenschaften und der hydrologische Situation des Einzugsgebiets, wurde dann ein Niederschlags-Abfluss Modell erstellt, dass die damaligen und heutigen Zustände analysiert.

Die Hinzunahme verschiedener statistischer Analysen über die Magnitude und Frequenz der Niederschlags- bzw. Abflussereignisse, konnte dann für die Landschaftsrekonstruktion genutzt werden.

Aus den geoarchäologischen Untersuchungen ergab sich, dass ein großes Wasserauffangbecken, der sogenannte "Große Hafir von Naga", von den Meroitern, errichtet wurde, um die seltenen Niederschläge und Abflussereignisse zu sammeln und zu speichern.

Die Bewohner von Naga hatten sich also gut an dieses trockene Klima angepasst – und mussten sich dahingehend zu großen Teilen auf eine ausreichend ergiebige Regenzeit verlassen.

Die Hauptergebnisse dieser Untersuchungen zeigen, dass keine tiefgreifende Umweltveränderung im Gebiet während der letzten 2000 Jahre stattfand. So ergeben die analysierten Niederschlags-Abfluss-Daten, dass die Waterharvesting-Methoden von damals auch heute noch sinnvoll erscheinen.

Jedoch ist durch Eingriffe in den Landschaftshaushalt und durch eine Verschiebung in den klimatischen Gegebenheiten, die natürliche und potentielle Landschaft gestört. Dies führt zu der abschließenden Aussage, dass die Bewohner von Naga ihre Stadt zu einer Zeit bewohnten, in der das Klima stabiler und die Umweltverhältnisse angenehmer waren als seither.

Table of Contents

1 Introduction

The City of Naga was part of the Meroitic kingdom that existed between the 5th century BCE and the 5th century CE, with its dominion along the middle Nile reaches (Adams 1974). Naga was situated in an unfavorable and sensitive location at the fringe of the Sahara desert and about 40 km south of the Nile River, without any perennial water source (Berking et al. 2010).

The existence of the city for several hundred years and its later abandonment, the fragile dry environment and the climatic oscillations, which took place since Holocene times, are well known features frequently debated for the early civilizations from the Middle East and North Africa (Finné et al. 2011). Hence the key issues and problems of this thesis are concerning the climatic and environmental change or stability in the area since Late Holocene times.

The investigations can be condensed to the research questions:

- Did the hydrologic and climatic conditions at Naga change since late Holocene?
- To what extend did humans change the environment? And when did the transition from a natural landscape to a cultivated landscape took place?
- Why did the advanced Meroitic civilization found Naga at this location in a rather peripheral area?

A more theoretical approach to this setting is given in the next paragraph (1.1), the goals emerging from this background are given in paragraph 1.2., where paragraph 1.3 and 1.4 introduce the general structure and setting of the thesis.

1.1 Theoretical Background

Human – nature interactions state that human beings adapt to their surroundings and change their environments - the more and the longer the more irreversible - from natural to cultural landscapes.

Often, Earth scientists are interested in the controlling processes and thresholds affecting these changes. In this context environments that react fast on impacts are called sensitive or fragile. A crucial point herein is the climatic setting of a region. This in particular applies to the dry and semi-arid regions - covering more than one third (37%) of the Earth surfaces (FAO, 1993).

However, in such dryland areas some of the most advanced civilizations arose in ancient times - eminently the lands between the Euphrates and Tigris as well as the middle and lower Nile valley. In fact, the regions of the Middle East as well as the Nile valley served as the cradle for the European cultures and mark the transition from the Palaeolithic tribes towards advanced civilizations. This transition, as mentioned above, coincide in time and space with other transitions such as (i) the beginning of state building and urbanization as well as (ii) a climatic change from more humid Mid-Holocene conditions to dryer conditions since Late Holocene and (iii) the environmental change from natural to cultural environments (Fig. 1, Murphy 2007).

Particularly in semi-arid, dry farming societies minor changes of the environmental conditions sometimes lead to severe reactions which can lead to the decline of a society. For most societal decay or abandonment of settlements multi-causal explanations are reasonable. For societies existing for longer periods, the stress of one single changed factor can generally be buffered. However, the change of one factor can already trigger system reactions, which then might lead to a collapse (Bintliff 1998, Figure 1).

The conditions which a society needs to dwell, are individually different and - at least concerning the societal factors – can hardly be quantified (Meze-Hausken 2008). A society that is existing over several centuries, has probably experienced several times with changing environmental conditions that threatened their well-being, but nevertheless survived. These bad conditions could either evolve from (i) ***cultural*** reasons like wars, economic problems, religious commotion or diseases; (ii) ***natural*** reasons like climatic stress, large fires or great floods or (iii) a ***combination*** of both. On short time scales, these impacts can be buffered; only, when such a factor is completely out of boundary conditions over a longer period, a collapse of the society might occur (Fig. 1; c.f. Bintliff 1998).

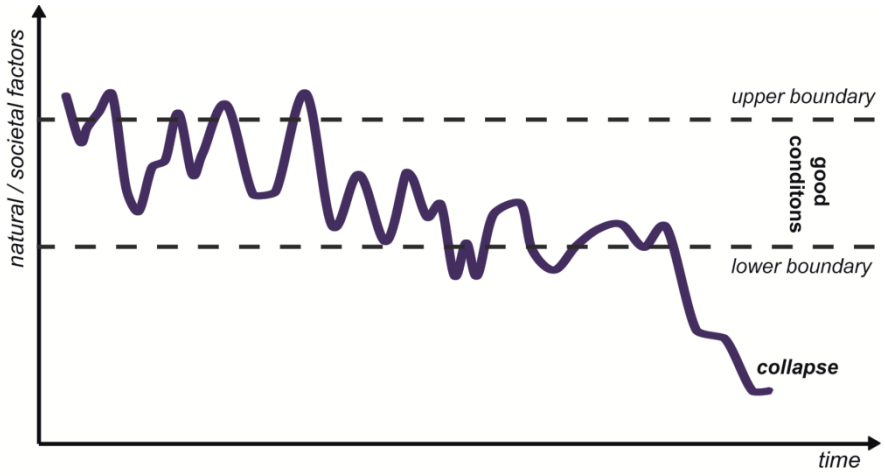


Figure 1 Conceptual progression of a society, that experiences changing natural or societal factors through time until the systems collapses.

In a simple process-response model we can state that societies always experience external forces of either natural or cultural origin, which leads to a specific feedback or even a transition. States in this sense are dynamic systems. As long as they are able to react on pressures, the state is stable. In other words the system is robust when it has the ability to absorb or solve any pressures inherently, where an imbalance of the system may lead to a reaction. The parameters can be simplified in a ratio given in the following (Formula 1).

Formula 1 The ratio of forces and feedback

The basic relation:

$$E = \frac{Ef}{If}$$

Where E = Dynamic Equilibrium, Ef = External forcing and If = Internal feedback.

Over a stable period this can be written as:

$$\frac{E}{\Delta t} = \frac{Ef}{If} \approx const.$$

For a normalized ratio this would intend:

E ≈ 0: well-being

E ≥ 1: reactions or measures are taken

E ≤ 1: reactions or measures are taken

E is much greater than ± 1: severe changes

Such ratios are frequently used for dynamic systems, to describe whether a reaction can take place and under which conditions – meaning the ability of a system to react (Jenkins 2005). The proceeding of the reaction can be described by an initial stage (educt) throughout a transition (tipping point) to a terminal stage (product) – where less energy has to be spent than in reverse and therefore the product is mostly persistent (Fig. 2).

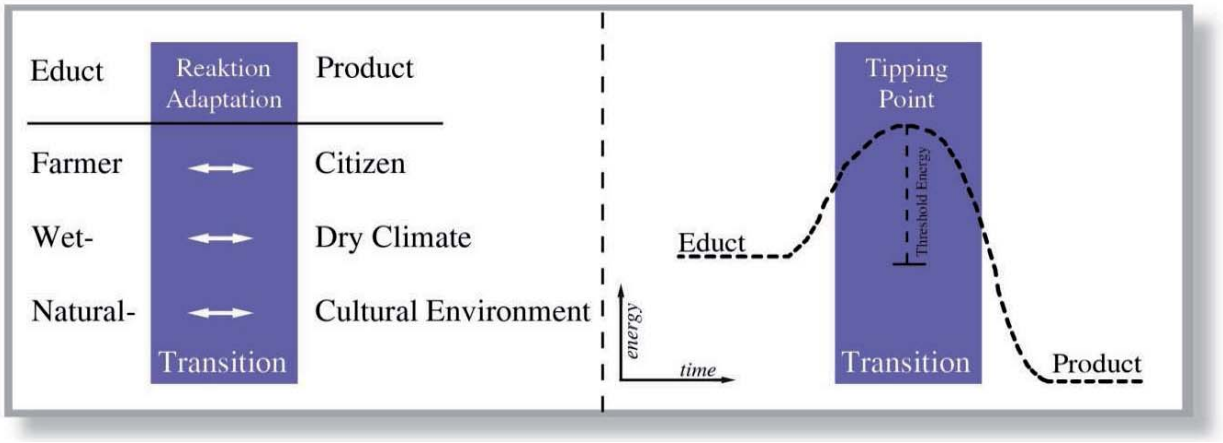


Figure 2 Energetic concept or process-response model for transitions in different systems through time and space

This implies, for instance, that once a natural environment, say a forested area (educt) which is used as a resource, experiences a tipping point (threshold), at which the forest could still be preserved. Here, after further cuttings or clearings, the only way to reinvigorate the wood is to take certain measures, such as planting new trees (energetic effort). If left alone, it will stay as a vast field, open to soil erosion (no energetic effort – persistent product). A simplified example for such an emerged cultural landscape, where woods would be expected but due to intensive clearings are almost gone and a new ecosystem is installed, is the Mediterranean Macchia (Hempel 1987).

This simple system- response model does not include many variables and as such is not including multiple pathways, as bifurcations, dynamic phases or any chaotic feedback or progression, as often accounted for such analysis. Here eco-system studies are necessary, looking for such system reactions of natural-cultural interactions and dependencies over time (Foley et al. 2005). Widely accepted is the progression of human-nature interactions, that lead from *stable*- to *instable*- and further to *restabilisation*-phases and in the end reaching again (a new) stability.

This ***resilience*** of a system - to react to internal forces or e.g. external extreme events is therefore not a simple system-response model but rather an idea of cyclic (anthropogenic-) landscape evolutions (c.f. Dotterweich 2008).

1.2 The main elements thesis

The Meroitic City of Naga existed between the 5th century BCE and the 5th century CE. The reasons for the decline of this state and the abandonment of the city still remain unclear, partly because appropriate archaeological research has only started in the last century and because the script and language (in contrast to the Egyptian hieroglyphs) is not yet understood. Geographically, Naga was situated in a physically vulnerable location, at the fringe of the Saharan desert, where mainly the alterations of orbital parameters directly lead to the absence of sufficient rainfalls (Berking et al. 2010). Moreover, the behavior of the rainfall itself is of great importance as well as the knowledge of how to harvest and store the rare runoff events, which also implies a cultural feedback.
Therefore the key issues and fields of activity concerning:

- *the climatic history*
- *the availability of water*
- *the dynamic of the natural and anthropogenic landscape development*
- *and the investigations on the ancient city and its facilities (mainly the 'Great Hafir')*

are addressed and investigated in this thesis.

1.3 Setting of the study

The research in Naga took place within the cluster of excellence Exc 264 TOPOI, which is an interdisciplinary project network between several institutions and universities localized in Berlin. Since April 2008 the Graduate Group Landscapes focuses in several projects on central places, their functions and impact on their surrounding environments. Most of these study sites are located in the drylands of the *Old World Desert Belt* like the Naga Project AI-7, which is the most southerly located site in the TOPOI Research group AI (Fig. 3).

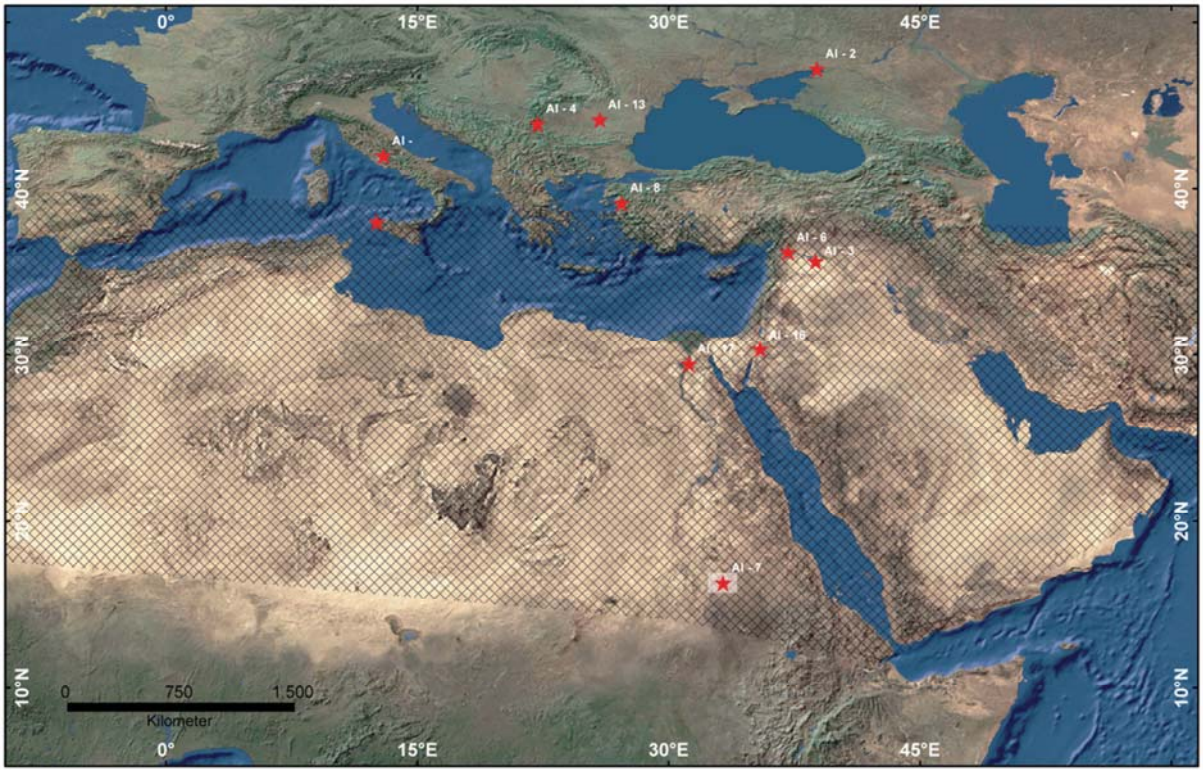


Figure 3 The sites of TOPOI Research Area A around the Mediterranean Sea and within the Old World Deserts Belt (black hatches). Highlighted in the south is AI-7: Naga.

1.4 The presented Thesis

Starting in *2008*, the first field campaign took place, followed by the major landscape-data analysis throughout the year. In *2009* the second field campaign took place and more specific work was done concerning investigations on geoarchaeological issues. In *2010* a third fieldtrip throughout the Northern Sudan was undertaken, but beside this, the year was nearly entirely reserved for the publication of the results. Since autumn *2010* the presented thesis has been compiled as a cumulative dissertation of the emerged international peer reviewed publications (Table 1).

Table 1 Progress of the Study

Winter 2008	*Fieldwork at Naga*
Autumn 2008	*Poster Presentation of preliminary results at the* 3. Mitteleuropäische Geomorphologentag, Salzburg.
Winter 2008	*Submitting a publication for the Special Issue for the* Journal: Zeitschrift für Geomorphologie.
Winter 2009	*Fieldwork at Naga*
Spring 2009	Oral Presentation of ongoing results at the "Geoarchaeology Meeting 2009. Sheffield, UK".[iii]
Autumn 2009	*Submitting a publication for the Special Issue to the* Journal: Geoarchaeology.
Winter 2010	*Fieldtrip to Sudan*
Summer 2010	*Submitting a publication for the Journal: Die Erde*[ii]*.*
Autumn 2010	*Preparation of and the dissertations and further publications.*
Winter 2011	*Submitting a publication for to the online Journal: eTopoi*[iv]*.*

The publications are ordered in a more logical context of a scientific thesis rather than their time of origin: Following the contents of (**i**) an "introduction to the study site and the geomorphological setting", (**ii**) "the applied geoarchaeological methods" and (**iii**) "the main geoarchaeological target in a competitive modelling approach" as well as (**iv**) a comprehensive review on the conducted research (Table 2, 3).

The guideline for this thesis is, that *chapter 1* (Introduction) and *chapter 3* (Synthesis) envelop the offered publications in *chapter 2* (State of the Art, Study Site, Methods, Results, Discussions and Conclusions). All publications are in original order, as they are submitted. But for a better readability, all references were assembled in *chapter 4*. In *chapter 5* (Appendix) the most relevant abstracts, as presented at various conferences, are collected.

Table 2 The order of presented publications

	Title	***1st Submitted***	***Journal***
i	Berking, J., Schütt, B.: Late Quaternary Morphodynamics in the Area of the Meroitic Settlement of Naga, Central Sudan.	2008	Zeitschrift für Geomorphologie Vol. 55, 3, pages 1-24.
ii	Berking, J., Kaufmann, G., Meister, J, Schott, M., Schütt, B., Ullrich, B.: Geoarchaeological Methods for Landscape Reconstruction at the Excavation site of Naga, Central Sudan.	2010	Die Erde, *accepted*.

iii	Berking, J., Beckers, B., Schütt, B.: Runoff in two semi-arid watersheds in a geoarchaeological context: A case study of Naga, Sudan, and Resafa, Syria.	2009	Geoarchaeology, 2010, Volume 25, Issue 6, pages 815–836.
iv	Geoarcheology and Chronostratigraphy in the Vicinity of Meroitic Naga in northern Sudan - a Review	2011	eTopoi, *in press.*

Table 3 The Authors contribution to the publications

	Own Contribution [%]
i	70
ii	30
iii	40
iv	80

Late Quaternary Morphodynamics in the Area of the Meroitic Settlement of Naga, Central Sudan

Jonas Berking and Brigitta Schütt

Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, Haus H, 12249 Berlin, Germany,

Including: 7 Figures & 4 Tables

Abstract

The Wadi Awatib discharges near the 6th Cataract into the River Nile and drains a catchment of 2360 km^2, an escarpment area. In this escarpment area, at the foot of the "Gebel Naga", the Meroitic settlement Naga was located. The relief is characterized by the Cretaceous Nubian Sandstone Formation, forming plateau areas with slightly inclining foot zones and downslope steplike changes, adjusted onto the level of the Nile river. Faults around the neighboring escarpments indicate tectonic activity. Massmovement desposits along the escarpment's steep indicate mass movements as a controlling process for escarpment shaping. OSL dating of overlying eolian deposits give a minimum age for the mass movements of 36 ka. Rock fall deposits around the archaelogical findings indicate, that mass movements have to be expected also in the most recent past.
Fluvial dynamics and eolian dynamics are the factors controlling present day shaping of the landscape in the Wadi Awatib and around the Naga excavation site, including the dissection of the footzone of the escarpment. Dunes occur predominantly as lee-dunes at the Gebel Naga. Sand-back fillings of the memorials at Naga excavation site attest strong eolian dynamics in most recent time.

Keywords: dryland geomorphology, palaeoenvironment, chronostratigraphy, geoarchaeology, OSL dating

The original Publication is available at :

http://dx.doi.org/10.1127/0372-8854/2011/0055S3-0049

If you can't get access, you can contact me for a copy: *Jonas.Berking@Fu-Berlin.de*

Geoarchaeological Methods for Landscape Reconstruction at the Excavation Site of Naga, Central Sudan

Berking, J.[1+3], Meister, J.[1], Ullrich, B.[2], Schott, M.[1], Kaufmann, G.[2], Schütt, B.[1]

[1]Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, 12249 Berlin, Germany

[2]Freie Universität Berlin, Department of Earth Sciences, Institute of Geological Sciences, Geophysics Section, Malteserstr. 74 – 100; 12249 Berlin, Germany

[3]Leibniz Institute for Applied Geosciences, Section S3: Geochronology and Isotope Hydrology, Stilleweg 2, 30655 Hannover, Germany

With 11 figures & 3 tables

Abstract

The archaeological excavation site of Naga, remains of a Meroitic city, is located in the semi-arid region along the fringe of the north-eastern Sahel and the south-eastern Sahara desert, in central Sudan, 150 km north of Khartoum and 40 km south of the Nile. During its heyday (from about 300 BCE to 300 CE) the city was a highly developed central place, with a large population and an economic culmination. Naga has been the object of archaeological research for several decades and of geoscientific investigations since 2008.
The first step for the investigation was to select adequate methods that combine the advantages of various subdisciplines and approaches. The study presented employs techniques from terrain modelling, geophysics and environmental analytics to evaluate field data with the aim of a comprehensive landscape reconstruction.

Keywords: Geophysical prospection, terrain modelling, 3-D visualization, arid environment, flood water harvesting

The original Publication will be available at :

http://die-erde.de/html/erde_online.html

If you can't get access, you can contact me for a copy: *Jonas.Berking@Fu-Berlin.de*

Runoff in two semi-arid watersheds in a geoarchaeological context – a case study of Naga, Sudan and Resafa, Syria

Berking, J., Beckers, B., Schütt, B.
Freie Universität Berlin, Department of Earth Sciences, Physical Geography,
Malteserstraße 74-100, 12249 Berlin, Germany

Abstract

This study is a geoarchaeological approach to compare two ancient cities, focusing on the relation of their present water availability to their past water-storage volumes. The first is the Meroitic city of Naga in the dry savanna of Sudan, where around the turn from BCE to CE the citizens built the "Great Hafir" with a capacity of 45×10^3 m^3 to collect surface runoff. The second city is Resafa in the desert steppe of Syria where, around 300 years CE, the Romans built large cisterns with a total capacity of 21×10^3 m^3 to store surface water. We aim to evaluate the physical catchment characters of two semi-arid watersheds and their present-day water availability by applying the rainfall-runoff model HEC HMS. The main input is contemporary rainfall data, classified through a magnitude-frequency analysis to determine rainfall intensity of 1-hour events. This analysis suggests that the water reservoirs of each now long-abandoned city would be completely filled by a 35.9 mm h^{-1} rain event in the Resafa Basin and a 39.1 mm h^{-1} rain event in the Basin of the Great Hafir. Such events occur nearly annually, which in turn implies that water harvesting in the two semi-arid regions would still be feasible today.

Keywords: HEC HMS, rainfall-runoff modelling, magnitude-frequency analysis, Mini Disk infiltrometer, water harvesting techniques

The original Publication is available at :

http://dx.doi.org/10.1002/gea.20333

If you can't get access, you can contact me for a copy: *Jonas.Berking@Fu-Berlin.de*

Geoarcheology and Chronostratigraphy in the Vicinity of Meroitic Naga in northern Sudan - a Review

Jonas Berking[1+2] & Brigitta Schütt[1]

[1]Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, 12249 Berlin, Germany

[2]Leibniz Institute for Applied Geosciences, Section S3: Geochronology and Isotope Hydrology, Stilleweg 2, 30655 Hannover, Germany

Abstract

The ancient and now abandoned settlement of Naga, which had its heyday around 2000 years ago, is located in the hinterland of a Nile tributary in the semi-arid north of the Sudan. Investigations on the landscape history in the vicinity of Naga took place between 2008 and 2010. Here we present 15 new OSL dates and four new radiocarbon ages (totaling 28 age determinations for the whole study site) and first results of a 6 m long drilling core from the centre of the ambient Wadi Awatib. A comprehensive interpretation of the processes at the excavation site is attempted. The age determinations range widely from very young ages (several decades) to very old ages (into the Eemian). Data show that fundamental environmental changes did not take place in the investigation area at least during the past 2000 years; nevertheless, subsystems may have varied significantly.

Keywords: OSL Dating, MIS Chronology, Desert Margins, Drylands, Climatic Oscillations, NE Africa, Sudan, Landscape Reconstruction, Landscape Evolution

The original Publication will be available at :

http://journal.topoi.org/index.php/etopoi

If you can't get access, you can contact me for a copy: *Jonas.Berking@Fu-Berlin.de*

3 Synthesis

The presented thesis is compiled of four publications all adding to a comprehensive understanding about the palaeoenvironmental situation in the area of Naga in central Sudan. The synthesis attempts to condense the results from *different perspectives* and gives an outlook beyond this integrated work. Several authors contributed to it.

The study in the vicinity of Naga presented in this dissertation were undertaken to understand the geoarchaeological setting, including the investigations on the:

- history of the climate
- availability of water
- environmental history
- dynamic of the landscape and its archives
- ancient city and its facilities (mainly the *Great Hafir*)

Due to these various fields of activity which require multiple methods and approaches, different perspectives in the following are presented to summarize and synthesize them.

The climatic perspective

Through the conducted investigations the characterization of the present and past climatic situation is of outstanding importance. This has three major reasons:

- Numerous authors state more humid and favorable climatic conditions throughout the Sahara and its neighboring areas, especially for Mid-Holocene times.
- The location of Naga directly at the fringe between the hyper-arid Sahara and the semi-arid Sahel-zone.
- The remote location of Naga about 40 km south of the Nile River without any perennial water source.

The present day climate is characterized by an annual average temperature of 29°C and annual rainfall amounts of ~95mm a^{-1}, with 95% of the rainfall occurring between June and August.

The main trigger for the appearance of the summery rainy season is the maximum northward extent of the ITCZ, which in due course is mainly triggered by orbital parameters (c.f. Milankovic-theory on millennial timescale). The maximum latitudinal extent of this low pressure zone is assumed to have influenced regions up to 17°N during Mid-Holocene times; whereas today, it influences the areas until about 15°N – the latitude of Naga (Berking et al., *submitted*).

The most pressing question prevailed whether such low annual precipitation amounts can form a sufficient basis for any agriculture- or domestic needs, where available water is a prerequisite for any settlement. Herein one of the main results of the conducted research is that not the annual sum of precipitation but rather its event-character is crucial. This is due to the fact that single high-intensity precipitation events may lead to runoff, which can then be used for water harvesting purposes. Through a broad analysis covering most of the weather data available for the region and by incorporating this data into a *rainfall-runoff model,* we concluded that the rainfall character at Naga is indeed dominated by erratic and probably high-intensity rainfall events with small spatial extensions.

This *rainfall-runoff model* was conducted not only for the study site of Naga, but also at the excavation site of Resafa in Syria, where similar climatic conditions prevail. One of the main assumptions herein is that *surface runoff* only occurs when the rainfall intensity surpasses a certain *threshold*. This *threshold* mainly depends on the infiltration capacity of the soils and the rainfall intensity. The excess of this *threshold* and, hence, the generation of runoff leads to the so-called *Hortonian overland flow* (Yair & Lavee, 1985). In this first approach modern weather data were used to feed the rainfall-runoff model for Naga and Resafa, revealing the fact that, still today, water harvesting-measures in both regions could be feasible. Whether the climatic conditions during the Meroitic period were also suitable for water harvesting measures can be answered in two ways. First of all, the climatic setting in the region was more humid during Mid-Holocene and the humidity slowly declined to the prevailing conditions. In consequence, higher or at least similar climatic conditions can be assumed for the Meroitic and modern times. In addition, comparison of the runoff as calculated by the application of the *rainfall-runoff model* with the storage volume of the “Great Hafir” confirms that this amount of collectable runoff was presumably also envisaged by the Meroitic engineers.

Ongoing work incorporates paleoclimatic model data, suggesting that the frequency of rainfall-events that exceed the aforementioned threshold changed significantly since the Mid-Holocene. Combining data of simulated and observed atmospheric conditions the probability of rainfall events has been estimated. The resulting main hypothesis is that the Meroitic city of Naga was founded in the hinterland of the middle Nile valley during a time when the interannual rainfall

availability was more stable and reliable than at present. Beyond that, model data confirm that the regional precipitation character has probably changed particularly since the time when the ancient and now-abandoned settlement of Naga was founded and the Meroitic engineers coped with the rare annually runoff events by building the “Great Hafir of Naga”.

Our results indicate that the abandonment of the city during the first centuries CE coincided with the reduced availability of surface runoff as a response to orbital forces, at least as one of the causes. Moreover, the regular summer rainy season does not consecutively imply sufficient rainfall for (agri-)cultural needs, because the intensity of rainfall is more crucial than its total amount. Effective precipitation and runoff are only available in such arid environments when a low pressure cell produces a convective storm with short and heavy rainfall.

Consequently, the Meroitic city of Naga was founded during a time when annual rainfall as well as storm events appeared more reliable and therefore flood water harvesting was more feasible (Berking et al., *submitted*).

The geomorphological perspective

For the overall aim of landscape reconstruction, the geomorphological investigations contributed in three major ways:

- The relief analysis - including implications from the geomorphological mapping and the assessment of the geomorphometric conditions and
- the assessment of the stability or instability of the conceived surface morphology and
- the lithostratigraphy and its chronology.

The relief of the study site can be characterized by typical landforms of the Saharan landscape. Dominating elements are contrasting steep slopes of the cretaceous escarpment areas, accompanied by some outliers, rising several decameters above the valley bottoms. Eolian deposits cover most parts of the escarpments’ footslopes.

These deposits are frequently incised by channels, which show at least marks of ephemeral runoff . The major receiving stream, the Wadi Awatib, can be characterized by an anatomizing and slightly incised wadi-system; the alluvial plain of the Wadi Awatib is locally up to 5 km wide, building a vast undulated plain with a distinct micro-relief. The channels are between several centimeters up to 6 m deep incised into the alluvial plain and are often followed by a riverine forest. The general orientation and dipping of the catchment towards the Nile is documented by

the innumerable headwater incisions and flow paths from the escarpment to the wadi system and its tributaries and finally into the Wadi Awatib. The characterizing sediments relocated and accumulated in this system are either flood deposits or eolian sands accumulated during times of accelerated sand-availability or -movement. Nearly all investigated sediment-archives show several hiatus, sometimes event-layers and discontinuous sedimentation.

One of the main results of the geomorphological research enhanced by chronostratigraphical analysis proves a continuous relief shaping dynamic in the area at least since the late Pleistocene ages. Sediments from the tube drillings and the analyzed dune sediments show several Pleistocene ages (MIS 4-2). Many dune sediments point to hyperarid presumably LGM conditions (MIS 2-1). Conclusively, adding to our idea of the *post-Meroitic* phases, are the late Holocene age determinations, undertaken in the slack water deposits of the Hafir and the eolian sands covering the Amun-Temple - all pointing to post-Meroitic processes after the abandonment of the city.

The environmental perspective

The environmental reconstructions are literally the sum or combination of all approaches focusing on the landscape history, including various archives and palaeoenvionmental proxies:

- The biological, geomorphological, physical and chemical parameters (mainly of the sediments samples)

The study site is located in the drylands, which are - due to their high temperature and unsteady precipitation regime - fragile regions, where, despite their unfavorable conditions, permanent settlements have existed since prehistoric times. It is agreed with Aktar-Schuster & Mensching (1993) that the natural environment of the region around Naga has been degraded, which is not only caused by the harsh exogenic conditions, but mainly due to human impact. The raising of sheep and goats as well as tree chopping and irrigation measures lead to the destabilization (or reactivation) of dunes or inhibits soil development, most likely also in the alluvium.

The application and interpretation of the various obtained proxies in terms of landscape change has proven to be rather complicated. This is mainly due to the fact that the geoarchaeological timeframe is hardly distinguishable in the sediment archives.

However, most of the obtained proxies from the sediment- archives point to an initial soil development, with low organic matter, sometimes high concentrations of alkaline (earth) metals

and hardly any stratification. Moreover, highly compacted layers were identified, which are affected by the ascending translocation of soil water and finally its evaporation. Residue of soil-water solutes leading to widespread formation of sub-surface incrustations with silcretes predominating in the area of Naga. These crusts have an effect on the vegetation, inhibiting a healthy grow, they can enhance the runoff (and interflow) by acting as a water aquiclude and the detorate the tilling possibilities. Whether these incrustations are relictic or still active was analyzed through an analysis of geochemical approaches (including amorphous silica and pedogenic iron), but could not be conclusively answered.

The ephemeral character of the moisture- and water availability and the equivocal location of Naga between the desert (without any rain) and the Sahel-zone (where rain-fed agriculture is possible) is crucial for the environmental history. The entire area is nowadays characterized by sparse drought-resistant vegetation, which is intensively modified by land use. While in the middle and lower course of Wadi Awatib the distribution of vegetation shows the typical contracted pattern of drylands, a dense savannah-vegetation cover occurs in its headwater areas.

This leads to the hypotheses that the environmental conditions in Naga changed throughout the last 2000 years primarily by human activity and impact and only secondarily due to climatic shifts.

The geoarchaeological perspective

At least since the middle of the 20th century geoarchaeological approaches, in the sense of archaeological issues analyzed and investigated by geoscientists, have become increasingly important for archaeological excavations. Various geoscientific methods are applied to answer the manifold specific questions at the particular study and excavation sites (Gladfelter 1977). In this sense, the presented thesis analyzes the palaeoenvironmental situation through the application of high resolved, spatially differentiated modeling approaches and analyses. The incorporation of the recorded terrain data as well as the analysis of terrestrial archives and their chronology enables us to reconstruct the paleoenvironment.

Crucial and widely acknowledged factors of landscape evolution such as climate variability, tectonic activities and surface shaping processes as well as direct and indirect human impact were recorded and evaluated. In order to enable a contextualization with the archaeological

timeframes and to analyze the landscape history it was essential to establish a robust chronology.

The most prominent feature evolving throughout the investigations was the “Great Hafir” of Naga. This water harvesting facility proved to be of high value and during its investigation various methods including *hydrological modeling, climatic reconstruction, geomorphological analysis, geophysical measures* and *archaeological connotation* were combined. It is herein the paramount geoarchaeological object that helped to get an idea of the advanced knowledge of the *Meroitic engineers*; it helped to evolve different techniques in terms of *surface modeling* and *subsurface geophysical investigations* –the implementation of the *morphological-* and *physical catchment character* and finally its combination with *climatic reconstructions*.

Retrospection

For the future it should be pointed out, that for palaeoenvironmental research in dryland areas, the investigations should mostly focus on the (paleo-)climate and (paleo-)hydrology of the respective study sites, rather than on other environmental features. This is mainly due to the fragmentary or inhibited evolution and succession of soils and vegetation. When, as it is the case for Naga, the environment is characterized by high dynamics and, moreover, the presence of continuous sediment archives is limited, a comprehensive environmental reconstruction is a challenging process. One way to cope with this problem is to aspire to a high quantity of samples rather than to a high quality, as, for example, by gaining many age-determinations.

4 Bibliography

Adams, W. Y. (1974): Sacred and Secular Polities in Ancient Nubia. World Archaeology. Political Systems, 6, 1, 39-51.

Adamson, D.A., Gasse, F., Street, F.A., Williams, M.A.J., (1980): Late Quaternary history of the Nile. Nature, 288, 50 – 55.

Ahnert, F. (1982): Untersuchungen über das Morphoklima und die Morphologie des Inselberggebietes von Machakos, Kenia. Catena Suppl.-Bd., 2, 1-72.

Ahnert, F. (2003): Einführung in die Geomorphologie. UTB, 440p.

Aktar-Schuster, M. and Mensching, H. (1993): Desertification in the Butana. GeoJournal, 31, 1, 41-50.

Aktar-Schuster, M., Kirk, M., Gerstengarbe, F.-W., Werner, P., C. (2000): Causes and Impacts of the Declining Resources in the Eastern Sahel. UNEP Desertification Control Bulletin, 36, 42-29.

Algarni, D. and El Hassan, I. (2001): Comparison of thin plate spline, polynomial, CI—function and Shepard's interpolation techniques with GPS-derived DEM. - International Journal of Applied Earth Observation and Geoinformation, 3, 2, 155-161.

Allison, R. (1997): Middle East and Arabia, in Thomas, D. (Ed) (1997). Arid Zone Geomorphology, Process Form and Change in Drylands (2nd ed). John Wiley and Sons.

Al-Qurashi, A., McIntyre N., Wheater H and Unkrich C. (2008): Application of the Kineros 2 rainfall–runoff model to an arid catchment in Oman. Journal of Hydrology 355, 1–4, 91–105.

Asfahani, J. and Radwan, Y. (2007): Tectonic Evolution and Hydrogeological Characteristics of the Khanaser Valley, Northern Syria, Derived from the Interpretation of Vertical Electrical Soundings. Pure Applied Geophysics, 164, 2291–2311.

Bahat, Y., Grodek, T., Lekach, J.and Morin, E. (2009): Rainfall–runoff modeling in a small hyper-arid catchment. Journal of Hydrology, 373, 1-2, 204-217.

Baird A. (1997): Overland flow generation and sediment mobilisation by water, in Thomas, M.S.T. (ed.):Arid Zone Geomorphology. John Wiley and Sons.

Bar-Matthews,M., Ayalon, A., Gilmour,M., Matthews,A., and Hawkesworth, C.J. (2003): Sea-land oxygen isotopic relationships from planktonic foraminifera and speleothems in the Eastern Mediterranean region and their implication for palaeorainfall during interglacial intervals. Geochimica et Cosmochimica Acta, 67, 17, 3181-3199.

Baumhauer R. and Hagedorn, H. (1990): Problems of ground water capture in the Kawar (Niger). Applied Geography and Development, 36, 99-109.

Baumhauer R. (1991): Palaeolakes of the South Central Sahara: problems of palaeoclimatological interpretation. Hydrobiologia, 214, 347-357.

Baumhauer R., Schulz E., Pomel S. (2004): Environmental changes in the Central Sahara during the Holocene - The Mid-Holocene transition from freshwater lake into sebkha in the Segedim depression, NE-Niger. Lecture Notes in Earth Sciences, 102, 33-47.

Baumhauer, R., Schütt, B. and Felix-Henningsen, P. (2009): Geomorphological Research in the South-Central Sahara in Review. Palaeoecology of Africa, 29, 1-21.

Berking, J. and Schütt, B. Late Quaternary Morphodynamics in the Area of the Meroitic Settlement of Naga, Central Sudan. Zeitschrift für Geomorphologie,Suppl.-Bd 3, 55, 1-24.

Berking, J., Beckers, B. and Schütt, B. (2010): Runoff in two semi-arid watersheds in a geoarchaeological context – a case study of Naga, Sudan and Resafa, Syria. – Geoarcheology 25, 6, 815-836.

Berking, J., Kaufmann, G., Meister, J., Schott, M., Schütt, B., Ullrich, B.: Geoarchaeological Methods for Landscape Reconstruction at the Excavation site of Naga, Central Sudan. Die Erde, in press.

Berking, J., Körper, J. Wagner, S., Cubasch, U., Schütt, B.: Heavy Rainfalls in a Desert(ed) City – A climate-archaeological case study from central Sudan. American Geophysical Union, in: Geophysical Monograph Series: "Climates, Past Landscapes, and Civilizations", submitted.

Beven, K. J. and Kirkby, M. J. (1979): A physically based, variable contributing area model of basin hydrology, Hydrol. Sci. Bull., 24, 43–69.

Beven, K.J. (2002): Runoff Generation in Semi-Arid Areas. In: Bull, L.J., and Kirkby M.J (eds): Dryland Rivers: Hydrology and Geomorphology of Semi-arid Channels. John Wiley, Chichester. Pp. 388.

Beven, K.J. (2003): Rainfall-Runoff Modelling: The Primer. Wiley-Interscience.

Bintliff, J.L. (1997) Catastrophe, chaos and complexity: the death, decay and rebirth of towns from Antiquity to today. Journal of European Archaeology, 5, 2, 67-90.

Birkhead, A. L. and James, C.S. (2002): Muskingum river routing with dynamic bank storage. Journal of Hydrology, 264, 1, 113-132.

Birot, P., Lhenaff, R. , Monteux, P. (1958): Recherches sur la limite septentrionale des glacis d'érosion en roches tendres. C.N.R.S. mem. & Doc.,6, 37-57.

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

Bork, H. and Ahrendt, I. (2006): Landschaftsentwicklung ohne Einfluss des Menschen? Die Nubische Wüste im Sudan. In: H.-R. Bork (ed.): Landschaften der Erde unter dem Einfluss des Menschen, 47-49.

Bowler, M. (1976): Aridity in Australia: Age, origins and expression in aeolian landforms and sediments. - Earth-Science Reviews, 12, 279-310.

Brinker, W. (1991): Zur Wasserversorgung von Resafa-Sergiupolis, Damaszener Mitteilungen 5.

Bubenzer, O., Bolten, A. and Ritter, M. (2007): Scale-specific geomorphometry of arid regions: Examples from the Eastern Sahara. - In: Bollig, M., Bubenzer, O., Vogelsang, R. and Wotzka, H.-P. (eds.): Aridity, Change and Conflict in Africa. - Proceedings of an International ACACIA Conference held at Königswinter, Germany October 1-3, 2003, Colloquium Africanum 2. Cologne, 17-34.

Bubenzer, O. and 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, 102, 221-231.

Burrough, P. A. (1986): Principles of geographical information systems for land resources assessment. - Oxford.

Burrough, P.A. and McDonnell, R.A. (1998): Principles of Geographical Information Systems. - New York.

Busche, D. (1983): Silcrete in der zentralen Sahara (Murzuk-Becken, Djado-Plateau und Kaouar, Süd-Libyen und Nord-Niger) Zeitschrift für Geomorphologie, N.F, 48, 35-49.

Busche, D. (1998a): Das Djado-Plateau: Genese einer zentralsaharischen Schichtstufen-Landschaft. In: H. Becker and W. Hütteroth (eds): 46. Deutscher Geographentag München, 46, 326-331.

Busche, D. (1998b): Die zentrale Sahara. Oberflächenformen im Wandel. 284pp.

Bussert, R. (1998): Die Entwicklung intrakontinentaler Becken im Nordsudan. Berliner Geowissenschaftliche Abhandlungen, A, 196. 329p.

Cammeraat, E. (2004): Scale dependent thresholds in hydrological and erosion response of a semi-arid catchment in southeast Spain. Agriculture, Ecosystems and Environment, 104, 2, 317-332.

Capra, A., Gandolfi, S., Laurencich, L., Mancini, F., Minelli, A., Orsini, C. and Rodríguez, A. (2002): Multidisciplinary approach for archeological survey: exploring GPS method in landscape archeology studies. - Journal of Cultural Heritage 3, 93–99.

Cardarelli, E. and Di Filippo, G. (2009): Integrated geophysical methods for the characterisation of an archaeological site (Massenzio Basilica -- Roman forum, Rome, Italy). - Journal of Applied Geophysics, 68, 4, 508-521.

Carol, P., Harden, P.and Delmas S. (2003). Infiltration on mountain slopes: a comparison of three environments, Geomorphology, 55, I1-4, 5-24.

Carsel, R.F., Parrish, R.S. (1988). Developing joint probability distributions of soil water retention characteristics. Water Resour. Res., 24, 755-769.

Chow, V.T., Maidment, D.R., and Mays, L.W. (1988). Applied Hydrology. McGraw-Hill, New York.

Claussen, M., and Gayler, V. (1997): The greening of Sahara during the mid-Holocene: results of an interactive atmosphere - biome model. Global Ecology and Biogeography, 6, 369-377.

Claussen, M., Kubatzki, C., Brovkin, V., Ganopolski, A., Hoelzmann, P., and Pachur, H.J. (1999): Simulation of an abrupt change in Saharan vegetation at the end of the mid-Holocene. Geophysical Research Letters, 24, 14, 2037-2040.

Coe, J.A., Kinner, D.A., and Godt, J.W. (2008), Initiation conditions for debris flows generated by runoff at Chalk Cliffs, central Colorado. Geomorphology, 96, 270-297.

Contreras, D. A. (2008): Reconstructing landscape at Chavin de Huantar, Peru: A GIS-based approach. - Journal of Archaeological Science, 36: 1006-1017.

Critchley, W., and Siegert K. (1991): Water harvesting. A manual for the design and construction of water harvesting schemes for plant production. FAO Paper No. AGUmisc. 17/91. FAO, Rome.

Damnati, B. (2000): Holocene lake records in northern Hemisphere of Africa. Journal of African Earth Sciences, 31, 2, 253-262.

Dane, J.H.. and Topp, G.C. (eds) (2002): Methods of Soil Analysis Part 4 - Physical Methods. Soil Science Society of America, Madison, WI.

Davis, C.A., Hellweger, F.L. and Maidment, D.R. (1997): HEC-PREPRO: A GIS Preprocessor for Lumped Parameter Hydrologic Modeling Programs. Center for Research in Water Resources, University of Texas at Austin.

De By, R. A. (Ed.) (2001): Principles of Geographic Information Systems: an introductory textbook. – Enschede.

Decagon Devices (2007): Mini Disk User's Manual, Ver. 6. Decagon Devices, Inc., 2365 NE Hopkins Court, Pullman, WA 99163.

DeMenocal, P., Ortiz, J., Guilderson, T., Adkins, J., Sarntheim, M., Baker, L. and Yaruskinsky, M., (2000): Abrupt Onset and Termination of the African Humid Period: Rapid Climate Response to Gradual Insolation Forcing. Quaternary Science Reviews, 19, 347-361.

Dennett,M.D., Keatinge,J.D.H.and Rodgers, J.A. (1984): A comparison of rainfall regimes at six sites in northern Syria. Agricultural and Forest Meteorology, 31, 3-4, 319-328.

Dotterweich, M. (2008): The history of soil erosion and fluvial deposits in small catchments of Central Europe: deciphering the long term interaction between human and the environment – a review. Geomorphology, 101, 192-208.

Drahor, M.G. (2006): Integrated geophysical studies in the upper part of Sardis archaeological site, Turkey. - Journal of Applied Geophysics, 59, 3, 205-223.

Dunne, T. (1978): Field studies of hillslope flow processes. In: Kirkby, M.J., and Chorley, R.J. (eds): Hillslope Hydrology. Wiley, Cichester, 227-293.

Edmunds,W.,M., Darling, W., G., Kinnburgh, D., G., Kotube, S., Mahgoub, S.(1992): Sources of recharge at Abu Delaig, Sudan. Journal of Hydrology, 131, 1-4, 1-24.

Eklundh, L. and Mårtensson, U. (1995): Rapid generation of Digital Elevation Models from topographic maps. - International journal of geographical information systems, 9, 3, 329-340.

Elagib N.A. and Mansell, G. (2000): Recent trends and anomalies in mean seasonal and annual temperatures over Sudan. Journal of Arid Environments, 45, 263–288.

Endreny, T., A., Kyle E.and Thomas, P.E (2009): Improving Estimates of Simulated Runoff Quality and Quantity Using Road-Enhanced Land Cover Data. Journal of Hydrologic Engineering. 14, 4, 346-351.

Eriksson, Mats - Olley, J.M. - Payton, R.W. (2000) Soil erosion history in central Tanzania based on OSL dating of colluvial and alluvial hillslope deposits. Geomorphology, 36, 1-2, 107-128.

Estigarribia, J. (2008): The Hafir as a water clarification Device. - Abstract on the 11th International Conference of Meroitic Studies.

Evenari, M., Shanan, L., Tadmor, N., Aharoni, Y. (1961): Ancient Agriculture in the Negev: Archeological studies and experimental farms show how agriculture was possible in Israel's famous desert. Science. 133, 3457, 979-996.

FAO (2003): Chapter 2. The world's drylands. (http://www.fao.org/docrep/007/y5738e/y5738e06.htm, April 2010)

Farrand, W. R. (1979): Chronology and Palaeoenvironment of Levantine Prehistoric Sites as Seen from Sediment Studies. Journal of Archaeoalogical Science, 6, 369 - 392.

Faure, H. (1966): Reconnaissance géologique des formations sédimentaires post-paléozoiques du Niger oriental. Mém. BRGM 47.

Felix-Henningsen, P. (1983): Zur Genese und Vergesellschaftung von Böden auf den Altdünen der nördlichen Goz-Region im Sudan. - Mitteilungen Deutsche Bodenkundliche Gesellschaft 38, 485 - 490.

Felix-Henningsen, P. (1999): Holocene and Pleistocene paleosols as indicators of palaeo-monsoon events in the Sahara desert of Central and East Niger. - INQUA XV International Congress, Book of Abstracts, 61, Durban, South Africa.

Felix-Henningsen, P. (2000): Paleosols on Pleistocene dunes as indicators of paleo-monsoon events in the Sahara of East Niger. CATENA, 41, 1-3, 43-60.

Felix-Hennigsen, P., Mauz, B. (2005): Paleoenvironemntal Significance of Soils on Ancient Dunes of the Northern Sahel and Southern Sahara of Chad. Die Erde, 135, 321-340.

Fernandez, V.M., Jimeno, A., Mendez, M., Lario, J. (2003): Archaeological survey in the Blue Nile area, Central Sudan. Complutum, 14, 201-272.

Finné, M., Holmgren, K., Sundqvist, H.S., Weiberg, E., Lindblom, M. (2011): Climate in the eastern Mediterranean, and adjacent regions, during the past 6000 years – A review. Journal of Archaeological Science, 38, 12, 3153-3173.

Flohn H., Nicholson S. (1980): Climatic fluctuations in the arid belt of the "Old World" since the last glacial maximum, possible causes and future implications. In: E. M. van Zinderen Bakker, J. A. Coetzee (Eds.), Palaeoecology of Africa and the surrounding islands. Sahara and surrounding seas.,12,Proc. Intern. Symposium, Mainz, 1-4. April 1979, 3-21.

Florinsky, I.V., Eilersc, R.G., Manninga, G.R., and Fullerd, L.G. (2002): Prediction of soil properties by digital terrain modeling. Environmental Modelling and Software, 17, 3, 295-311.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentince, I.C., Ramankutty, N., Snyder, P. K. (2005): Global Consequences of Land Use. Science, 309, 5734, 570-574.

Folk, R. and Ward, W. (1957): Brazos River bar: a study in the significance of grain size parameters. - Journal of Sedimentary Petrology, 27, 3-26.

Foody, G., Ghoneimm, E. Arnell, N. (2004): Predicting locations sensitive to flash flooding in an arid environment, Journal of Hydrology, 292, Issues 1-4.

Forte, M. (2000): Archaeology and virtual micro-topography: the creation of DEMs for reconstructing fossil landscapes by Remote Sensing and GIS applications. In: Lock, G. (ed.), Beyond the Map. Archaeology and Spatial Technologies, Amsterdam: 199-213.

Fowden, E. (1999). The Barbarian Plain: Saint Sergius between Rome and Iran. Berkeley and Los Angeles. University of California Press.

Fuchs, M. (2006): Mensch und Umwelt in der Antike Südgriechenlands. - Geographische Rundschau, 4, 4-11.

Furley, P. and Zouzou, R. (1989): The origin and nature of gypsiferous soils in the Syrian Mid-Euphrates, Scottish Geographical Magazine.

Gabriel, B (1997): Zur quartären Landschaftsentwicklung der nördlichen Butana (Sudan). Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin, 7, 23-30.

Gasse, F. (2000): Hydrological changes in the African tropics since the Last Glacial Maximum. Quat. Sci. Rev. 19 ,189–211.

Gasse, F. and Street, F. A. (1978): Late Quaternary Lake-Level Fluctuations and Environments of the Northern Rift Valley and Afar Region (Ethiopia and Djibouti). Palaeogeography, Palaeoclimatology, Palaeoecology, 24, 279 - 325.

Gasse, F. and Van Campo, E. (1994): Abrupt Post-Glacial Climate Events in West Asia and North Africa Monsoon Domains. Earth Planetary Science Letter, Vol. 126, pp. 435-456.

GHCN: Global Historical Climatology Networks.
http://iridl.ldeo.columbia.edu /docfind/databrief/cat-atmos.html

Giraud, B., Bussert, R., Schrank, E., (1992): A new Theacean wood from the Cretaceous of northern Sudan. Review of palaeobotany and palynology, 75, 3-4, 289-299.

Gladfelter, Bruce. (1977): Geoarchaeology: The Geomorphologist and Archaeology. American Antiquity, 42, 519-538.

Gläser, B. (1987): Altdünen und Limnite in der nördlichen Republik Sudan als morphogenetisch-paläoklimatischer Anzeiger. Hamburg, 193 p.

GLOBALSOD: Global Surface Summary of Day. May 2008.
(http://iridl.ldeo.columbia.edu /docfind/databrief/cat-atmos.html)

Gómez-Ortiz, D. (2007): Joint application of ground penetrating radar and electrical resistivity imaging to investigate volcanic materials and structures in Tenerife (Canary Islands, Spain). - Journal of Applied Geophysics, 62, 287-300.

Greenbaum, N., Ben-Zvi, A., Haviv, I., and Enzel, Y. (2006): The hydrology and palaeohydrology of the Dead Sea tributaries. In: Enzel, Y. , Agnon A., and Stein, M. (eds): New frontiers in Dead Sea palaeoenvironmental research. Geological Society of America, pp. 63–93.

Grove, A. T. - Warren, A. (1968): Quaternary Landforms and Climate on the South Side of the Sahara. The Geographical Journal, 134, 2, 194-208.

Gruen, A. (2008): Reality-based generation of virtual environments for digital earth. -International Journal of Digital Earth, 88, 106, 88-106.

Grunert, J. (1979): Fossil landslides in the central Sahara. - In: Van Zinderen Bakker, E.M. (ed.): Palaeoecology of Africa, 11, S. 47-49.

Grunert, J. (1983): Geomorphologie der Schichtstufen am Westrand des Murzuk-Beckens (Zentrale Sahara). Relief Boden Palaeoklima, 2.

Grunert, J. (1988): Klima- und Landschaftsentwicklung in Ost-Niger während des Jungpleistozäns und Holozäns. Würzburger Geogr. Arb., 69, 289-304.

Grunwald, S. and Barak, P. (2003): 3D Geographic Reconstruction and Visualization Techniques applied to Land Resource Management. - Transactions in GIS, 7, 231-241.

Günther, T., Rücker, C. and Spitzer, K. (2006): 3-d modeling and inversion of DC resistivity data incorporating topography - Part II: Inversion. - Geophysical Journal International, 166, 506-517.

Gvirtzman, G. and Wieder, M. (2001): Climate of the last 53,000 Years in the eastern Mediterranean, based on soil-sequence Stratigraphy in the coastal plain of Israel. Quaternary Science Reviews, 20, 1827 - 1849.

Haan, C.T., Barfield, B.J., and Hayes, J.C. (1994). Design Hydrology and Sedimentology for Small Catchments. Academic Pr. Inc.

Hassan, F.A. (1980): Prehistoric settlements along the Main Nile. - In: WILLIAMS, M.A.J.and FAURE, H.(Hrsg.):Sahara and the Nile. Rotterdam, 421 - 450.

HEC (2000): Hydrologic Modeling System: Technical Reference Manual. US Army Corps of Engineers Hydrologic Engineering Center.

Hecht, S. (2007): Sedimenttomographie für die Archäologie - Geoelektrische und refraktionsseismische Erkundungen für on-site und off-site studies. - In: Wagner, G. A. (Hrsg.), Einführung in die Archäometrie, Berlin, Heidelberg, 95-112.

Hempel, L. (1987): “The Mediterraneanization” of the climate in Mediterranean countries —a cause of the unstable ecobudget. GeoJournal, 14, 2, 163-173.

Hengl, T. and Evans, I.S. (2009): Mathematical and Digital Models of the Land Surface In: Hengl, T. and Reuter, H.I. (eds.), Geomorphometry-Concepts, Software, Applications. Developments in Soil Science, Amsterdam, 31-63.

Hillel, D. (1998): Environmental Soil Physics: Fundamentals, Applications, and Environmental Considerations. Elsevier.

Hinkel, M. (1991): Hafire im antiken Sudan. Zeitschrift für ägyptische Sprache und Altertumskunde, 118, 32-48.

Hoelzmann, P., Keding, B., Berke, H., Kröpelin, S. and Kruse, H., J. (2000): Environmental Change and Archaeology: Lake Eution and Human Occupation in the Eastem Sahara During the Holocene. Palaeogeography Palaeoclimatology Palaeoecology, 169, 193-217.

Hoelzmann, P. Keding, B., Berke, H., Kröpelin, S., Kruse H-J. (2001): Environmental change and archaeology: lake evolution and human occupation in the Eastern Sahara during the Holocene. Palaeogeography, Palaeoclimatology, Palaeoecology. 169, 3-4, 193-217.

Hoelzmann, P., Gasse, F., Dupont, L., M., Salzmann, U., Staubwasser, M., Leuschner, D., C, Sirocko, F. (2004): Palaeoenvironmental changes in the arid and subarid belt (Sahara—Sahel–Arabian peninsula) from 150 kyr to present. In: R.W. Batterbee, F. Gasse and C.E. Stickley, Editors, Past Climate Variability through Europe and Africa, Springer, 219–256.

Hulme M. (1992): The changing rainfall resources of Sudan. Transactions of the Institute of British Geographers, 15, No. 1, 21-34.

Hulme, M. (1989): Rainfall Changes in Africa: 1931-1960 to 1961-1990. International Journal of Climatology, 12, 685-699.

Hulme, M. (1996): Climate Change Within the period of Meteorological Records. - In: Adams, W.M., Goudie, A.S., Orme, A.R.: The Physical Geography of Africa, Oxford University Press,New York, 88-102.

Hutchinson, M.F. (1988): Calculation of hydrologically sound digital elevation models. - Third International Symposium on Spatial Data Handling at Sydney, Australia.

Hutchinson, M.F. (1989): A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. - Journal of Hydrology, 106, 211-232.

Imeson, A.C., and Prinsen, H.A.M. (2004): Vegetation patterns as biological indicators for identifying runoff and sediment source and sink areas for semi-arid landscapes in Spain. Agriculture, Ecosystems and Environment, 104, 2, 333-342.

Jäkel, D. (2004): Beobachtungen zur Dynamik und zu den Ursachen von Sand- und Staubstürmen in ariden Räumen, angestellt in Nordafrika und China. Die Erde, 3-4, 341-367.

Jarmer T., Schütt, B. (1998): Analysis of iron contents in carbonate bedrock by spectroradiometric detection based on experimentally designed substrates. In: Schaepmann, M., Schläpfer, D. and Itten, K. (eds), 1st EARSEL Workshop on Imaging Spectroscopy. Proceedings of the EARSEL workshop, Zürich, 6.-8.10.1998, 375-382.

Jenikins, A. D. (2005): Thermodynamics and economics. Ecological Economics, 1-23.

Johnston, K., Ver Hoef, J.M., Krivoruchko, K. Lucas, N. (1996): ArcGIS 9 Using ArcGIS® Geostatistical Analyst. ESRI.

Karnapp W. (1976): Die Stadtmauer von Resafa in Syrien. Denkmäler Antiker Architektur, 11.

Kellner-Heinkele, B. (1996): Rusafa in den Arabischen Quellen. In D. Sack: Die Große Moschee von Resafa - Rusafat Hisham. Resafa IV.

Kidron G., J. and Yair, A.. (2001): Runoff-induced sediment yield over dune slopes in the Negev Desert. 1: Quantity and variability. Earth Surface Processes and Landforms, 26, 461–474.

Kidron G., J. and Yair, A.. (1997): Rainfall-runoff relationship over encrusted dune surfaces, Nizzana, Western Negev, Israel. Earth Surface Processes and Landforms, 22, 1169–1184.

Kidron, G.J. (2007): Millimeter-scale microrelief affecting runoff yield over microbiotic crust in the Negev Desert. Catena, 70, 2, 266-273.

Kleinschroth, A. (1984): Wasserreservoirs im Sudan aus der Zeit der Antike. Mitteilungen aus Hydraulik und Gewaesserkunde der TUM, 41, 75-106.

Kleinschroth, A. (1986): Die Verwendung des Hafirs im meroitischen Reich. Beiträge zur Sudanforschung, 1, 79-96.

Kleinschroth, A. (1979): Das Reich Kusch und seine Wasserwirtschaftlichen Probleme. -Zeitschrift der Antike, 3, 23-30.

Klitzsch, E. (1970): Die Strukturgeschichte der Zentralsahara. Neue Erkenntnisse zum Bau und zur Paläogeographie eines Tafellandes. Geologische Rundschau, 59, 459–527.

Klitzsch, E., Sonntag, C., Weistroffer, K., El Shazly, E. M. (1976): Grundwasser der Zentralsahara: Fossile Vorräte. Geologische Rundschau, 65, 1, 264–287.

Knebla ,M.R., Yanga, Z.-L., Hutchison, K. and Maidment, D.R. (2005): Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the San Antonio River Basin Summer 2002 storm event. Journal of Environmental Management, 75, 325–336.

Kneisel, C. (2006): Assessment of subsurface lithology in mountain environments using 2D resistivity imaging. – Geomorphology, 80, 32-44

Knödel, K., Krummel, H., Lange, G. (1999): Handbuch zur Erkundung des Untergrundes von Deponien und Altlasten. – Berlin.

Konrad, M. (2001): Der spätrömische Limes in Syrien: Archäologische Untersuchungen an den Grenzkastellen von Sura, Tetrapyrgium, Cholle und in Resafa. Resafa, V.

Krause, J. and Schütt, B.: Fluvial geomorphology of the Achelouma valley, NE Niger. Palaeoecology of Africa, 29. (in press).

Kröpelin, S., Verschuren, D., Lézine, A.-M., Eggermont, H., Cocquyt, C., Francus, P., Cazet, J.-P., Fagot, M., Rumes, M., Russell, J. M., Darius, F., Conley, D. J., Schuster, M., von Suchodoletz, H., Engstrom, D. R. (2008): Climate-Driven Ecosystem Succession in the Sahara: The Past 6000 Years. Science, 320, 5877, 765 – 768.

Kröper, K. (2006-2007): The End of the Amun-Temple and beginning of Temple 200 – C14 dates from Naga. Cripel 26, 231-242.

Kuper R. and Kröpelin S. (2006): Climate-Controlled Holocene Occupation in the Sahara: Motor of Africa's Evolution. Science, 313, 803-807.

Ladoy, P., Lovejoy, S. and Schertzer, D., (1991): Extreme variability of climatological data: scaling and intermittency. In: Schertzer, D. and Lovejoy, S. Editors, 1991. Non-linear variability in geophysics: scaling and fractals, Kluwer Academic Publishers, The Netherlands, pp. 241–250.

Lange, J., Liebundgut, C., Schick, A. (2000): The Importance of Single Events in Arid Zone Rainfall-Runoff Modelling, 25 (7), 673-677.

Legutke, S., and Voss, R. (1999): The Hamburg Atmosphere-Ocean Coupled Circulation Model ECHO-G. DKRZ-Hamburg, Technical Report, 21.

Leopold, M., Plockl, T., Forstenaicher, G. and Volkel, J. (2010): Integrating pedological and geophysical methods to enhance the informative value of an archaeological prospection - The example of a Roman villa rustica near Regensburg, Germany. - Journal of Archaeological Science, 37, 7, 1731-1741

Leser, H. and Stäblein, G. (1975): Geomorphologische Kartierung - Richtlinien zur Herstellung geomorphologischer Karten 1: 25 000. - Berliner Geographische Abhandlungen, Sonderheft.

Li, X-Y., González, A., and Sole´-Benet, A. (2005): Laboratory methods for the estimation of infiltration rate of soil crusts in the Tabernas Desert badlands. Catena, 60, 255–266.

Lian, O.B. and Roberts, R.G. (2006): Dating the Quaternary: progress in luminescence dating of sediments. Quaternary Science Reviews, 25, 2449-2468.

Marquardt, Nicole - Krause, Jan - Schütt, Brigitta. Late quaternary spatiotemporal analysis of the palaeoclimate of North Africa and the Near East based on proxy-data. Quaternary Science Reviews, in preparation.

Martínez-Mena, M., Albaladejo, J., and Castillo, V. M. (1998): Factors influencing surface runoff generation in a Mediterranean semi-arid environment: Chicamo watershed, SE Spain. Hydrological Processes, 12, 5, 741-754.

Mauz, B. and Felix-Henningsen, P. (2005): Palaesols in Saharian and Sahelian Dunes of Chad: Archives of Holocene North African Climate Changes. The Holocene, 15, 453 – 458.

Mawson R. and Williams M.A.J. (1984): A wetter climate in eastern Sudan 2000 years ago? Nature, 309, 49-51.

McIntyre, N. and Al Qurashi, A. (2009): Performance of ten rainfall-runoff models applied to an arid catchment in Oman. Environmental Modelling and Software. 24, 726-738.

McLaren, S.J., Gilbertson ,D.D., Grattan ,J.P., Hunt ,Q., Duller , G. A. T. and Barker, G. A. (2004): Quaternary palaeogeomorphologic evolution of the Wadi Faynan area, southern Jordan. Palaeogeography, Palaeoclimatology, Palaeoecology. 205, 1-2, 131-154.

Mensching, H. (1958): Glacis - Fußfläche - Pediment. Zeitschrift Geomorphologie N.F,. 2, 1, 65-186.

Mensching, H. (1970): Flächenbildung in der Sudan- und Sahelzone. - Zeitschrift für Geomorphologie, 10, 1-29.

Mensching, H. (1973): Pediment und Glacis, ihre Morphogenese und Einordnung in das System der klimatischen Geomorphologie auf Grund von Beobachtungen im Trockengebiet Nordamerikas (USA und Nordmexiko). Zeitschrift für Geomorphologie N.F, 17, 133-155.

Meze-Hausken, E. (2008): On the (im-)possibilities of defining human climate thresholds. Climatic Change. 89, 299-324.

Michel, P. (1977): Reliefgenerationen in Westafrika. Würzburger Geographische Arbeiten, 45, 111-130.

Mitas, L. and Mitášová, H. (1999): Spatial interpolation. - In: Longley, P., Goodchild, M.F., Maguire D.J. and Rhind D.W. (eds.), Geographical Information Systems: Principles, Techniques, Management and Applications, Chichester, 481-492.

Mitášová, H. and Hofierka, J. (1993): Interpolation by regularized spline with tension, II Application to terrain modelling and surface geometry analysis. - Mathematical Geology, 25, 657-669.

Moore, I.D., Gessler, P.E., Nielsen, G.A., and Peterson, G.A. (1993). Soil attribute prediction using terrain analysis. Soil Science Society of America Journal, 57(2), 443–452.

Morin, E., Jacoby, Y., Navon S., and Bet-Halachmi E. (2008): Towards flash-flood prediction in the dry Dead Sea region utilizing radar rainfall information. Advances in Water Resources, 32, 7, 1066-1076.

Morisawa, M. (1968): Streams – their dynamics and morphology. McGraw Hill, New York. 175p.

Mousli, O.F. (1980): Methods of evaluation and classification of gypsiferous soils and suitability for irrigated agriculture. In: F.H. Beinroth and A. Osman (Eds.) (1980). Proceedings of the 3rd International Soil Classification Workshop. The Arab Center for Studies of the Arid Zones and Dry Lands (ACSAD), Damascus, Syria, 278-307.

Mulligan, M. (1998): Modelling the geomorphological impact of climatic variability and extreme events in a semi-arid environment, Geomorphology, 24, 1 , 59-78.

Murphy, D.J. (2007): People, plants and genes: the story of crops and humanity. Oxford Univ. Press, Oxford.

Murray, A.S. and Wintle, A.G. (2000): Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol. Radiation Measurements, 32, 1, 57-73.

Myers, L.E. (1975): Water Harvesting and Management for Food and Fiber Production in the Semi-arid Tropics. AR/USDA: Berkeley, CA.

Neal, A. (2004): Ground-penetrating radar and its use in sedimentology: principles, problems and progress. - Earth-Science Reviews, 66, 261-330.

Nichols, G. (1999): Sedimentology and Stratigraphy. – Oxford.

Nicholson S. E. (2001): Climatic and environmental change in Africa during the last two centuries. Climate Research, 17, 123–144.

Nicolau, J.,M., Sole-Benet, A., Puigdefabregas, J., and Gutierrez-Elorza, M. (1996): Effects of soil and vegetation on runoff along a catena in semi-arid Spain. Geomorphology, 14, 4, 297–309.

Nicoll, K. (2004): Recent environmental change and prehistoric human activity in Egypt and Northern Sudan. Quaternary Science Reviews, 23, 5-6, 561-580.

Nikolakopoulos, K., Kamaratakis, E. and Chrysoulakis, N. (2006): SRTM vs ASTER elevation products. Comparison for two regions in Crete, Greece. - International Journal of Remote Sensing, 27, 21, 4819-4838.

Omar, A. M. (1997): Compilation and Evaluation of solar and wind energy resources in Sudan. In: Renewable Energy, 12, 1.

Osman, O.E., Hastenrath, S.L. (1969): On the Synoptic Climatology of Summer Rainfall over Central Sudan. Arch. Met. Geoph. Biokl., Ser. B 17, 297-324.

Ostrovsky, V.N. (2007): Comparative analysis of groundwater formation in arid and super-arid deserts (with examples from Central Asia and northeastern Arabian Peninsula). Hydrogeology Journal, 15, 4, 759 -771.

Oweis, T., and Taimeh, A. (1996): Evaluation of a small basin water-harvesting system in the arid region of Jordan. Water Resource Management, 10, 1, 21-34.

Pachur H.-J. and Wünnemann, B. (1996): Reconstruction of the paleoclimate along 30°E in the eastern Sahara during the Pleistocene/Holocene transition. Palaeoecology of Africa 24, 1-32.

Pachur, H.J. and Hoelzmann, P., (1991): Paleoclimatic Implications of Late Quaternary Lacustrine Sediments in Western Nubia, Sudan. Quaternary Research, 36, 257-276.

Pachur, Hans-Joachim - Hoelzmann, Philipp. (2000): Late Quaternary palaeoecology and palaeoclimates of the eastern Sahara. Journal of African Earth Sciences, 30, 4, 929-939.

Parker, A., and Goudie, A. (2008): Geomorphological and palaeoenvironmental investigations in the southeastern Arabian Gulf region and the implication for the archaeology of the region. Geomorphology, 101, 3, 458-470.

Peckham, R.J. and Jordan, G. (ed.) (2007): Digital Terrain Modelling. - Berlin, Heidelberg, New York

Peeters, I., Rommens, T., Verstraeten, G., Govers, G., Van Rompaey, A., Poesen, J. and Van Oost, K. 2006: Reconstructing ancient topography through erosion modelling. – Geomorphology, 78, 250-264.

Pettijohn, F.J., Potter, P.E., Siever, R. (1973): Sand and Sandstone. Springer-Verlag, Berlin, New York. 553p.

Pflaumbaum, H. and Pörtge, K., Mensching, H. (1990): Hydrologische Steuerungsfaktoren morphologischer Prozesse in der Nil-Provinz (Rep. Sudan). In: Geoökodynamik, 11, 2/3, 241-256.

Pilgrim, H., Chapman, T.G., and Doran, D.G.D. (1998): Vegetation Problems of rainfall-runoff modelling in arid and semiarid regions. Hydrological Sciences. Journal des Sciences Hydrologiques, 33, 4.

Ponikarov, V. P. (ed.) (1966): The Geological Map of Syria, Scale 1:200000, Sheet I-37-XX (Salamiyeh).Moscow.

Rapp, G. and Hill, C.L. (2006): Geoarcheaology. The Earth-Science Approach to Archaeological Interpretation. – London.

Rehren, T. (1995): Meroe, Eisen und Afrika. Mitteilungen der Sudanarchäologische Gesellschaft zu Berlin, 3, 20-25.

Reid, I., Laronne, J.B., and Powell, M.D. (1998): Flash-flood and bedload dynamics of desert gravel-bed streams. Hydrological Processes, 12, 543–557.

Reimann, T., Naumann, M., Tsukamoto, S., and Frechen, M. (2011): Luminescence dating of coastal sediments from the Baltic Sea coastal barrier-spit Darss-Zingst, NE Germany, Geomorphology, in press.

Renssen, H., Brovkin, V., Fichefet, T., Goosse, H. (2006): Simulation of the Holocene climate evolution in Northern Africa: the termination of the African Human Period. Quaternary International 150, 95–102.

Reynolds, J. M. (1997): An Introduction to Applied and Environmental Geophysics. – Chichester.

Riehl, S., Bryson, R., and Pustovoytov, K. (2008): Changing growing conditions for crops during the Near Eastern Bronze Age (3000–1200 BC): the stable carbon isotope evidence. Journal of Archaeological Science, 35, 4, 1011-1022.

Rösner, U. (1995): Zur quartären Landschaftsentwicklung in den Trockengebieten Syriens. Relief Boden Paläoklima, 10.

Rowntree, K. M. (1988): Storm rainfall on the Njemps flats, baringo district, Kenya. International Journal of Climatology, 8, 3, 297-309.

Rücker, C., Günther, T. and Spitzer, K. (2006): 3-d modeling and inversion of DC resistivity data incorporating topography - Part I: Modeling. - Geophysical Journal International, 166, 495-505

Sack , D. (1996): Die Große Moschee von Resafa - Rusafat Hisham. Resafa IV.

Salzwedel, U. (1997): Bildungsbedingungen von Goz – und Ergsanden (Formational conditions of the Goz - and sandy sand sea). In Pörtge, K.-H. (Hg.). Forschungen im Sudan. Erfurter geographische Studien, 5, 33-48.

Sandmeier, R. (1997): Reflexw help notes, Sandmeier Software.
http://www.sandmeier-geo.de

Scheibner, T. (2004): Neue Erkenntnisse zur Wasserversorgung von Musawwarat es Sufra (I). Das übergeordnete Wasserversorgungssystem - Teil I: Wassergewinnung und -speicherung. - Mitteilungen der Sudanarchäologischen Gesellschaft zu Berlin e.V., 15, 39-65.

Schlumberger, D. (1950): La Palmyrene du Nord-Ouest. Recherches archaeologiques sur la mise en valeur d'une region du desert par las Palmyrens. Bibl. Archeol. Et Hist. Bd. 49. – Thése d´Etat, Paris.

Schmidt, R., (1998): Boden- und Landschaftsentwicklung im Gebiet der Tempel von Musawwarat es Sufra/Nordsudan . Mitteilungen der Sudanarchäologische Gesellschaft zu Berlin, 8, 68-76.

Schön, J. (1983): Petrophysik, Physikalische Eigenschaften von Gesteinen und Mineralen. –Stuttgart

Schöwer, R. 2007: Das Baustellenhandbuch für Aufmaß und Mengenermittlung. – Merching

Schütt, B. and Krause, J.: Comparison of proxy-based palaeoenvironmental reconstructions and hindcast-modelled annual precipitation – a review of Holocene palaeoenvironmental research in the central Sahara. Palaeoecology of Africa 29, in press.

Schütt, B., Berking, J., Frechen, F., Frenzel, P., Schwalb, A. and Wrozyna, C. (2010): Late Quaternary transition from lacustrine to a fluvio-lacustrine environment in the north-western Nam Co, Tibetan Plateau, China. - Quaternary International, 218, 104-117.

Shaaban, F.F. and Shaaban, F.A. (2001): Use of two-dimensional electric resistivity and ground penetrating radar for archaeological prospecting at the ancient capital of Egypt. - Journal of African Earth Sciences, 33, 3-4, 661-671

Sharma, K., D. (1998): The hydrological indicators of desertification. Journal of Arid Environments, 39, 2, 121-132.

Sharon, D. (1972): The spottiness of rainfall in a desert area. Journal of Hydrology, 17, 161–175.

Siart, C., Eitel, B. and Panagiotopoulos, D. (2008): Investigation of past archaeological landscapes using remote sensing and GIS: a multi-method case study from Mount Ida, Crete. - Journal of Archaeological Science, 35, 2918-2926.

Siart, C., Bubenzer, O. and Eitel, B. (2009): Combining digital elevation data (SRTM/ASTER), high resolution satellite imagery (Quickbird) and GIS for geomorphological mapping: A multi-component case study on Mediterranean karst in Central Crete. - Geomorphology, 112, 106-121.

Siart, C., Hecht, S., Holzhauer, I., Altherr, R., Meyer, H.P., Schukraft, G., Eitel, B., Bubenzer, O. and Panagiotopoulos, D. (2010): Karst depressions as geoarchaeological archives: The palaeoenvironmental reconstruction of Zominthos (Central Crete), based on geophysical prospection, sedimentological investigations and GIS. - Quaternary International, 216, 1-2, 75-92.

Sirocko, F., Sarnthein, M., Erleneuser, H., Lange, H., Arnold, M., and Duplessy, J. C. (1993): Century-scale events in monsoonal climate over the past 24,000 years. Nature, 364, 322–324.

Sirocko, F. - Claussen, M. – Sanchez, G., - Litt, T. (2007): The climate of past Interglacials. In Van der Meer, Jaap (Series Ed). Developments in Quaternary Science. Elsevier, London, Vol. 7.

Soil Survey staff (2006): Keys to Soil Taxonomy, Tenth Edition. USDA-NRCS. Washington, DC. http://soils.usda.gov/technical/classification/tax_keys/

Stuiver, M., Reimer, P. and Braziunas, T. (1998): High-precision radiocarbon age calibration for terrestrial and marine samples. Radiocarbon, 40, 3, 1127–1151

Sugar, C. and James, G. (2003): Finding the number of clusters in a data set: an information theoretic approach. Journal American.Statistic Association, 98,750 – 763.

Sultan. B., Baron, C., Dingkuhn, M., Sarr, B., Janicot, S. (2005): Agricultural impacts of large-scale variability of the West African monsoon. Agricultural and forest meteorology, 128, 1-2, 93-110.

Sutherland, R. and Brian, R. B. (1990): Runoff and erosion from a small semiarid catchment, Baringo district, Kenya. Applied Geography, 10, 2, 91-109.

Tagil, S. and Jenness, J. (2008): GIS-Based Automated Landform Classification and Topographic, Landcover and Geologic Attributes of Landforms Around the Yazoren Polje, Turkey. Journal of Applied Sciences 8, 6, 910-921.

Telford, W. M., Geldart, L. P, Sheriff, R. E. (1990): Applied Geophysics. – Cambridge.

Thales Navigation (2004): ProMark 2 System - User Guide. http://www.thalesnavigation.com

Tonini, A., Guastaldi, E., Massa, G. and Conti, P. (2008): 3-D geo-mapping based on surface data for preliminary study of underground works: A case study in Val Topina (Central Italy). - Engineering Geology, 99, 1-2, 61-69.

Tooth, S. (2000): Process, form and change in dryland rivers: a review of recent research: Earth-Science Reviews, 51, 67-107.

Tsubo, M., Walker, S., Hensley, M. (2005): Quantifying risk for water harvesting under semi-arid conditions: Part I. Rainfall intensity generation. Agricultural Water Management, 76, 2, 77-93.

Ulbert T. (1986): Die Basilika des Heiligen Kreuzes in Resafa-Sergiupolis. Resafa II. Zabern. Pp. 230.

Ullrich, B., Meyer, C., Weller, A. (2007): Geoelektrik und Georadar in der archäologischen Forschung: geophysikalische 3-D-Untersuchungen in Munigua (Spanien). - In: Wagner, G. A. (Hrsg.): Einführung in die Archäometrie. - Berlin, Heidelberg, 75-93.

USDA–NRCS (ed.) (2005): US Department of Agriculture Natural Resources and Conservation Service, National Engineering Handbook. National Technical Information Service, Washington, DC.

Vogel, S. and Märker, M. (2009): Reconstructing the Roman topography and environmental features of the Sarno River Plan (Italy) before the AD 79 eruption of Somma-Vesivius. - Geomorphology, 115, 1-2, 67-77.

Wagstaff, K. (2001): Constrained K-means Clustering with Background Knowledge. Proceedings of the Eighteenth International Conference on Machine Learning. 577 - 584.

Wainwright, J. and Mulligan, M. 2004: Environmental Modelling. – Oxford.

Walsh R.P.D., Hulme M. and Campbell M.D. (1988): Recent rainfall changes and their impact on hydrology and water supply in the semi-arid zone of the Sudan. The Geographical Journal 154, 2, 181–198.

Weinstein-Evron, M., Beck, A., and Ezersky, M. (2003): Geophysical investigations in the service of Mount Carmel (Israel) prehistoric research. - Journal of Archaeological Science, 30, 10, 1331-1341

Weiss, A. (2001): Topographic Position and Landforms Analysis. Poster presentation, ESRI User Conference, San Diego, CA.

Wenske, D., Böse, M., Frechen, M., and Lüthgens, C.: Late Holocene mobilisation of loess-like sediments in Hohuan Shan, high mountains of Taiwan. - Quaternary International, in press.

Wheater, H., Sorooshian, S. and Sharma, K. D. (2007): Hydrological Modelling in Arid and Semi-arid Areas. Cambridge University Press, Cambridge. 195 pages.

Whitehead, P., Smith, S., Wade, a., Mithen, S., Finlayson, B. and Sellwood, B., (2008): Modelling of hydrology and potential population levels at Bronze Age Jawa, Northern Jordan: a Monte Carlo approach to cope with uncertainty. Journal of Archaeological Science, 35, 3, 517-529.

WIGGS, Giles (2001): Desert dune processes and dynamics. Progress in Physical Geography, 25, 1, 53-79.

Wikander, O. (ed.) (1999): Handbook of Ancient Water Technology. Brill Academic Publishers, Leiden.

Wildung, D. and Kröper, K. (2006): Naga, Royal City of Ancient Sudan. Staatliche Museen zu Berlin – Stiftung preußischer Kulturbesitz.

Wildung, D. (1998): Sudan – Antike Königreiche am Nil. Ernst Wasmuth Verlag, Tübingen.

Williams, M. A. J. and Adamson, D.A. (1980): Late Quaternary depositional history of the Blue and White Nile rivers in central Sudan. In: Williams, M.A.J. and Faure, H.: Sahara and the Nile, 281-304.

Williams, M., and Nottage, J. (2006): Impact of extreme rainfall in the central Sudan during 1999 as a partial analogue for reconstructing early Holocene prehistoric environments. Quaternary International, 150, 1, 82-94.

Wilson, J. P. and Gallant, J.C. (2000): Secondary Topographic Attributes. Terrain Analysis: Principles and Applications. John Wiley and Sons. New York.

Wintle, A.G., Murray, A.S. (2006): A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols. Radiation Measurements, 41, 4, 369-391.

Wirth, E. (1971): Syrien, Eine Geographische Landeskunde. Wissenschaftliche Buchgesellschaft Darmstadt.

Wolf, S., Wolf, P., Onasch, H.U., Hof, C. and Nowotnick, U. (2008): Meroë und Hamadab - Zwei Städte im Mittleren Niltal in den Jahrhunderten um die Zeitenwende: Bericht über die Arbeiten zwischen 1999 und 2007 = Meroe and Hamadab-Two Cities in the Middle Nile Valley in the Centuries around the Beginning of Common Era. Report on Activities between 1999 and 2007. - Archäologischer Anzeiger, 2, 157-230.

Wolmann, M.G. and Miller, J.P. (1964): Fluvial processes in geomorphology. W.H. Freeman, San Francisco.

Wun, S., Lib, J. and Huang, G.H. (2008): A study on DEM-derived primary topographic attributes for hydrologic applications: Sensitivity to elevation data resolution . Applied Geography, 28, 3, 210-223.

Yair, A. and Raz-Yassif, N. (2004): Hydrological processes in a small arid catchment: scale effects of rainfall and slope length. Geomorphology, 61, 155–169.

Yair, A. and Lavee, H. (1985): Runoff Generation in arid and semi-arid zones. In: Anderson, M.G. and Burt, T.P. (eds): Hydrological Forecasting. Wiley Chichester, pp. 183 – 220.

Zech, W. and Hintermaier-Erhard, G. (2002): Böden der Welt: Ein Bildatlas. Spektrum Akademischer Verlag. 120p.

Zhang, R. (1997): Determination of soil sorptivity and hydraulic conductivity from the disk infiltrometer. Soil Science Society of America Journal, 61, 1024-1030.

Zhou, Q., Lees, B. and Tang, G. (ed.) (2008): Advances in Digital Terrain Analysis. - Berlin, Heidelberg.

Zielhofer, C., Faust, D., Diaz del Olmo , F., Baena Escudero, R. (2002): Sedimentation and soil formation phases in the Ghardimaou Basin (northern Tunisia) during the Holocene. Quaternary International, 109-125.

5 Appendix

3. Mitteleuropäische Geomorphologietagung, Salzburg. 2008, Poster.

Geoarchaeological Investigations around Naga, Central-Sudan

BERKING Jonas, SCHÜTT Brigitta

Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, Haus H, 12249 Berlin, Germany, Jonas.Berking@FU-Berlin.de

The remains of a Meroitic city called Naga, are located in central Sudan, 150 km north of Karthoum and 50 km south of the Nile. The archaeological excavation site is located in this semi-arid region along the fringe of the north-eastern Sahel and the eastern Sahara desert. During its heydays the city has been a highly developed central place, with a high population and an economic culmination from 300 BCE to 300 CE. Naga is the target of archaeological research since several decades and since 2008 of geoscientific investigations.

The recent climate is characterised by an insufficient precipitation/runoff ratio for a perennial discharge in ambient wadis. One goal of the project is therefore to answer the questions: How was the water supply of the city organised? Was there a higher water availability in ancient times due to a different climatic setting in the region - or were the inhabitants able to compensat the water deficit by using high sophisticated water harvesting techniques?

To distinguish between these possibilities different geomorphological and hydrological methods, coupled with geophysical- as well as high precision terrain data were applied and moreover the analysis of sedimentary records and a broad analysis of modern climate and hydrological data was performed. The results are used as input for high resolution modelling of the (palaeo-)drainage and landscape-evolution. We will present first results of geomorphic evidence of the investigated archives, as well as geomorphic processes.

Altogether palaeoenvironmental reconstructions provide crucial information for archaeological purposes, as they play a key role for answering questions about living conditions and natural resources.

Geoarchaeology Meeting 2009. Sheffield, Poster.

Comparison of two ancient central places in Syria and Sudan in a geoarchaeological context

Beckers, B., Berking, J., Schütt, B:

Freie Universität Berlin, Department of Earth Sciences, Physical Geography,
Malteserstraße 74-100, 12249 Berlin, Germany

Jonas.Berking@Fu-Berlin.de

Two ancient cities, Resafa in Syria and Naga in Sudan, are part of geoarchaeological investigations.
Both are located in a semi-arid environment next to a major wadi which has been the main source of water supply and both are within the vicinity of two big rivers: the Euphrates and the Nile. The cities have been highly developed central places, with a high population and economic culmination about 2000 years ago at Naga and 1500 years ago at Resafa they both had central importance concerning religion and trade.
In both cases, the modern precipitation/runoff ratio leads to insufficient and sparse water availability.
Higher water availability in ancient times might be due to climatic change in the regions, or might have also been compensated by ancient water harvesting techniques, which both, the Romans in Resafa and the Meroitics in Naga seem to have been sophistically engineered.
Therefore for both sites the following questions arise:

- How were the environmental conditions during the settlement of the cities
- Why did they settle at such remote places?
- How did the population cope with their environment?

A comparison in climatic history as well as an analysis of past water balance is required. The information will be derived from palaeoenvironmental proxies as provided by landforms and geoarchives. Due to the long tradition of water harvesting in these areas, also an inventory of past water harvesting techniques is necessary, to integrate these data into the analysis.
High resolution modelling focusing the (palaeo-)drainage - and landscape-evolution should than be applied to show if distinct similarities for both sites are also reflected in numeric applications.
The problems of different scales are the main focus of our comparison, concerning the utilized datasets. These are especially characterized by the resolution and quality of the remote sensing datasets and the herefrom derived geometric catchment-characteristics. The finally identified problems are hopefully leading to a compromising and representative research.

Jahrestagung der Afrikagruppe deutscher Geowissenschaftler (AdG), Beuth Hochschule für Technik Berlin, 2010.

Geoarchaeological Survey in Naga, Central-Sudan

Berking, J. & Schütt, B.

Freie Universität Berlin, Department of Earth Sciences, Physical Geography,
Malteserstraße 74-100, 12249 Berlin, Germany

Jonas.Berking@Fu-Berlin.de

The ancient Meroitic city of Naga in central Sudan is the target of archaeological and since 2008 of geoscientific investigations. The city is located 150 km north of Karthoum in 50 km distance to the River Nile. The city has been a highly developed central place, with a high population and an economic culmination from about 300 BC to 300 AD.

The surrounding Wadi Awatib is located in the semi-arid region along the fringe of the north-eastern Sahel and the eastern Sahara desert, recently characterised by an insufficient precipitation/runoff ratio for a perennial discharge in the wadi. One goal of the project is to answer the question: How the water supply of the city was organised. Was there a higher water availability in ancient times due to a different climatic setting in the region - or were the inhabitants able to compensated the water deficit by using high sophisticated water harvesting techniques?

To distinguish between these possibilities different geomorphological and hydrological methods were applied: including the mapping of geomorphology, channel geometry and topology as well as the analysis of sedimentary records and a broad analysis of modern climate and hydrological data.

The results are used as input for high resolution modelling of the (palaeo-)drainage and landscape-evolution. We will present first results of geomorphic evidence of the investigated archives, as well as geomorphic processes.

Altogether palaeoenvironmental reconstructions provide crucial information for archeological purposes, as they play a key role for answering questions about living conditions and natural resources.

LAC, Amsterdam 2010, Poster.

Geoarchaeological Survey in Naga, Central-Sudan with special focus on the Reconstruction of the Great Hafir

Meister, Julia; Berking, Jonas; Schütt, Brigitta

The Meroitic city of Naga in central Sudan is the target of archaeological and since 2008 of geoscientific investigations. The remains of the city are located 150 km north of Karthoum and 50 km south to the River Nile. During its heydays the city has been a highly developed central place, with a high population and an economic culmination from about 300 BCE to 300 CE. The surrounding Wadi Awatib is located in the semi-arid region along the fringe of the north-eastern Sahel and the eastern Sahara desert, recently characterized by an insufficient precipitation/runoff ratio for any perennial discharge in the wadi.

One aim of the palaeoenvironmental and geoarchaeological investigations is to answer the question, how the water supply of the city was organized: Was there a higher water availability in former times - due to a different climatic setting in the region? Or were the inhabitants able to compensate the water deficit by using high sophisticated water harvesting techniques? To distinguish between these possibilities this study is focused on the “Great Hafir”, the main water reservoir of Meroitic Naga, which was built to collect surface runoff and to store surface water.

Different geophysical and geomorphological methods were applied to reconstruct the today silted up basin: including geoelectrics, ground penetrating radar, relief-analysis as well as the analysis of sedimentary records. Here we present first results, about the size, volume, position and hydrologic setting of the Great Hafir.

This palaeoenvironmental reconstruction provides crucial information for archeological purposes, as it plays a key role for answering questions about living conditions and the use of water resources in Naga.

LAC, Amsterdam 2010, Oral Presentation.

A comparative approach to estimate the (palaeo-)runoff of two semi-arid watersheds in a geoarchaeological context –case studies of Naga (Sudan) and Resafa (Syria)

Beckers, Brian; Berking, Jonas; Schütt, Brigitta

Two ancient cities, late Roman-early Islamic Resafa in the desert steppe of Syria and Meroitic Naga in the dry savanna of Sudan, have been under archaeological investigation for several decades. Both are located in a semi-arid environment next to major wadi systems which have been the main source of water supply and both are within the vicinity of two big streams: the Euphrates and the Nile.

Since 2008 archaeological research has broadened to include geoarchaeological objectives concerning the palaeoenvironment and landscape history. This study is an approach to compare the two ancient cities, focusing on the relation of their present water availability to their past water storage capacity and constructions. In Meroitic Naga, around the turn from BCE to CE the citizens built the “Great Hafir” to collect surface runoff; in Resafa, around 500 years CE, the Romans built large cisterns to store surface water. We aim to evaluate present-day water availability by a rainfall-runoff model, mainly utilizing HEC HMS. The main input is modern rainfall data, which is filtered through a magnitude-frequency analysis to determine rainfall intensity as input for event-based rainfall-runoff model.

Work on hydrological and climatological questions in the two regions involves typical problems of drylands: the catchments of the wadis are ungauged, climate data are spatially and temporally fragmentary, and information on the physical characteristics of the catchments is either scant or coarsely resolved. Moreover, rainfall and runoff are spatially and temporally highly variable in semi-arid and arid areas, so that quantitative estimations of present and, to an even greater extent, past climatological and hydrological processes are problematic. The contribution aims to present the concept, background and first results of an approach to cope with these challenges and to model the catchments' rainfall-runoff relationships including the behaviour of the water supply systems of the two ancient cities of Resafa and Naga.

International Colloquium on Geoacheaology. Cairo, 2010, Poster.

BERKING Jonas, SCHÜTT Brigitta

Geoarchaeological Survey in Naga, Central-Sudan

Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, Haus H, 12249 Berlin, Germany

In the semi-arid region along the fringe of the north-eastern Sahel and the eastern Sahara desert, the archaeological excavation site of Naga is located. The remains of this Meroitic city are located in central Sudan, 150 km north of Karthoum and 50 km south of the Nile. During its heydays the city has been a highly developed central place, with a high population and an economic culmination from about 300 BCE to 300 CE. Naga is the target of archaeological research since several decades and since 2008 of geoscientific investigations.

The recent climate is characterised by an insufficient precipitation/runoff ratio for a perennial discharge in the wadi. One goal of the project is therefore to answer the question: How the water supply of the city was organised. Was there a higher water availability in ancient times due to a different climatic setting in the region - or were the inhabitants able to compensated the water deficit by using high sophisticated water harvesting techniques?

To distinguish between these possibilities different geomorphological and hydrological methods, coupled with geophysical- as well as high precision terrain data, were applied and moreover the analysis of sedimentary records and a broad analysis of modern climate and hydrological data was performed. The results are used as input for high resolution modelling of the (palaeo-)drainage and landscape-evolution. We will present first results of geomorphic evidence of the investigated archives, as well as geomorphic processes.

Altogether palaeoenvironmental reconstructions provide crucial information for archaeological purposes, as they play a key role for answering questions about living conditions and natural resources.

International Meeting on Statistical Climatology, Edinburgh 2010, Oral Presenation.

Statistical downscaling of precipitation of two transient Holocene AOGCM simulations for central Sudan

Sebastian Wagner[1,4], Janina Koerper[2,4], Jonas Berking[3,4]

[1]GKSS Research Center, Institute for Coastal Research, Geeshacht, Germany, e-mail: sebastian.wagner@gkss.de
[2]Free University of Berlin, Department of Meteorology, Berlin, Germany
[3]Free University of Berlin, Department of Physical Geography, Berlin, Germany
[4]TOPOI Excellence Cluster, Free University of Berlin, Germany

In the present analysis a statistical downscaling of the large scale circulation of two transient simulations of the global coupled climate model ECHO-G for the Holocene for a region in central Sudan [Naga, Nubic desert] is carried out to assess precipitation. Results will help colleagues from historical sciences investigating the rise and fall of ancient cultures in this region.
In the first part of the presentation the basic climatological features of the region under investigation and the calibration and validation of the statistical downscaling models are presented. An important part forms the physical plausibility of the statistical downscaling models calibrated with recent observational data. It will be shown that using principal component regression it is possible to investigate physical processes in the climate-circulation ship that are implicitly used by the statistical model.
The second part will present results based on these models for precipitation. An interesting result pertains to the added value of the application of statistical downscaling compared to the raw model precipitation output on centennial-to-millennial timescales. For instance, the downscaled model results show a non-linear decrease in precipitation in the Nubian desert during July in the course of the Holocene. This decrease, also evident in many proxy data time series and with climate models using interactive vegetation, can be reproduced by the downscaling model despite i) constant vegetation patterns used in the transient Holocene simulations and ii) the absence of the decline in precipitation in the raw model output.
Finally potential driving mechanisms controlling precipitation variability in the Nubian desert during the Holocene based on changes in external forcings [orbital, solar, greenhouse gases] are discussed.

Deutscher Arbeitskreis für Geomorphologie. Schmitten, 2010, Poster.

Geoarchaeological Survey in Naga, Central-Sudan

Jonas BERKING & Brigitta SCHÜTT

Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, Haus H, 12249 Berlin, Germany, JonasBerking@FU-Berlin.de

Keywords: Palaeoenvironment, Hafirs, Chronology, East Africa

In the semi-arid region along the fringe of the north-eastern Sahel and the eastern Sahara desert, the archeological excavation site Naga is located. 150 km north of Karthoum and in 50 km distance from the River Nile around 2000 years ago the Meroitic civilization which had an own language and script developed settled here in cities, including large temple- and palace complexes. Supplementary geoarchaeological investigation started in winter 2008. Geoarchaeological investigations are aiming on a reconstruction of the Holocene palaeonvironment, focussing the palaeohydrology and water balance in this at present only sparsely settled area where availability of water is the limiting factor for settlement.
Palaeoenvironmental reconstructions provide crucial information for archeological purposes, where they play the key role for answering questions about living conditions, natural resources and mainly water availability for ancient cultures. Hence geomorphic evidence and information of the investigated archives, as well as geomorphic process measurements of morphometry, channel geometry and topology might help to answer these questions.
Fieldwork included intensive geomorphologic mapping of the site. Additional detailed geodetic survey was necessary to generate a high resolution Digital Elevation Model. At geomorphological key sites sediments were sampled at outcrops and by probing. Special interest was also given to the traditional water harvesting techniques of collecting surface water in so-called Hafirs, which are partly used also at present and have most likely a history going back to the ancient times.
Here we present first results from the field work, focusing on the geomorphology and the water harvesting.

AGU 2011 Chapman Conference on Climates, Past Landscapes, and Civilizations, Santa Fe, Poster.

Application of paleoclimatic simulations in a geoarchaeological framework – two case studies along the Nile

Janina Körper[1], Jonas Berking[2], Wiebke Bebermeier[2], Maria Slaby[1], Sebastian Wagner[3], Ulrich Cubasch[1] Nicole Alexanian[4] & Stephan Seidlmayer[4]
[1]Institute for Meteorology, Freie Universität Berlin, Germany
[2]Institute of Physical Geography, Freie Universität Berlin, Germany
[3]Helmholtz Zentrum Geesthacht, , Germany
[4]German Archaeological Institut, Cairo and Freie Universität Berlin

Within the framework of an interdisciplinary research cluster focusing on space and knowledge of ancient civilizations the interactions of man and environment are investigated using a multimethodological approach including archaeological and geographical field work as well as modeling of environmental processes. Goals of the research cluster are to gain knowledge of how civilizations reacted to changing environmental conditions and to explain the processes leading to environmental changes. Two case studies from the arid to hyperarid Eastern Saharan landscapes of Egypt and Sudan will be presented. The first case study deals with environmental changes in Egypt. The agriculture of the Ancient Egyptian civilization depended almost entirely on the Nile waters and floods and therefore on the climatic conditions in the Ethiopian highlands, where the Nile floods mainly origin. In the late Old Kingdom and after the Old Kingdom (approx. 4,300-4,000 BP) agricultural land and settlements were covered by meter thick eolian sand sheets, pointing to changing environmental conditions, affecting the local population. A transient simulation of the last 6000 years with the coupled ocean-atmosphere model ECHO-G provides the basis for the comparative analysis of mid to late Holocene drought conditions in the Memphitic region and the Ethiopian highlands. Drought indices based on simulated monthly mean precipitation and potential evaporation reveal a trend towards drier conditions in the whole catchment area of the Nile. This trend is more pronounced in the Ethiopian Highland than in the Memphite region and explained by less moisture availability in the respective rainy seasons due to geographical shifts of the main precipitation regimes.
The second case study deals with environmental changes in central Sudan. The ancient Meroitic city of Naga is located 40 km south of the river Nile. The global general circulation model ECHAM5 is employed to investigate climatic shifts that may affect the rainwater availability. Time-slice experiments with a spectral horizontal resolution of T106, corresponding to a 1.1°x1.1° longitudinal and latitudinal grid, were implemented to investigate the statistics of the intensity of rainfall events. Here, the reoccurrence times of rainfall events passing a certain threshold derived from a rainfall-runoff model is investigated. The results show that the frequency of the reoccurrence of rainfall events sufficient for water harvesting and irrigation purposes was significantly higher 3000 years ago than for the last 2000 years. These case studies show that especially the investigation of changes in the seasonal cycle or daily rainfall statistics based on paleoclimatic model simulations provides an added value for geoarchaeological projects.

INQUA 2011, Bern, Oral presentation, accepted.

BERKING Jonas, SCHÜTT Brigitta

Geoarchaeological and Chronostratigraphical Targets around Naga, Central-Sudan

Freie Universität Berlin, Department of Earth Sciences, Physical Geography, Malteserstraße 74-100, Haus H, 12249 Berlin, Germany, Jonas.Berking@FU-Berlin.de

In the semi-arid region along the fringe of the north-eastern Sahel and the eastern Sahara desert, about 150 km north of Karthoum and 40 km south of the Nile, the remains of this Meroitic city Naga are located,. During its heydays the city has been a highly developed central place, with a high population and an economic culmination from about 300 BCE to 300 CE. Naga is the target of archaeological research since several decades and since 2008 of geoscientific investigations.

The present day climate of the region is characterised by the ephemeral character of available precipitation due to an insufficient precipitation-runoff-ratio for perennial discharge in the wadi. One goal of the project is therefore to answer the questions: How the water supply of the city was organised? Was there a higher water availability in ancient times due to a different climatic setting in the region - or were the inhabitants able to compensated the water deficit by using high sophisticated water harvesting techniques?

To distinguish between these possibilities different geomorphological and hydrological methods, coupled with geophysical- and high precision terrain data, were applied. The analysis of sedimentary records and the upset of a chronostratigraphy revealed new insights into the environmental-evolution during Holocene. This chronology enables for a contextualization with the archaeological targets. We will present final results of geomorphic evidence of the investigated archives, as well as geomorphic processes.

Altogether palaeoenvironmental reconstructions provide crucial information for archaeological purposes, as they play a key role for answering questions about living conditions and natural resources.

Erklärung

Hiermit erkläre ich, dass ich die Dissertation '**Geoarchaeology in Drylands - Palaeoenvironmental reconstructions in the vicinity of Naga, Central Sudan**' selbständig angefertigt und keine anderen als die von mir angegebenen Quellen und Hilfsmittel verwendet habe.

Ich erkläre weiterhin, dass die Dissertation bisher nicht in dieser oder anderer Form in einem anderen Prüfungsverfahren vorgelegen hat.

Berlin, den 30. Mai 2011