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Past and present desertification in the context of climate change – a case study from Jordan

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Abstract

Desertification is seen as a severe threat for the Mediterranean and the desert belts, which is accelerated by global warming. Both land use and climate variations may lead to an advance of the desert, and human and natural factors can be connected in feedback relationships. This makes it difficult to describe cause-and-effect relationships, and to predict the impact of global warming. A key is understanding historic desertification. Focusing on paleosols, these questions are investigated in the Decapolis region in northern Jordan in the transition area between the Arabian desert and the Mediterranean climate zone. It had been assumed that historic desertification in the Decapolis was connected with severe degradation of soils, and caused by agricultural mismanagement and deforestation. However, the greatest part of the erosion took place at the end of the last Ice Age and during the Younger Dryas. As it seems, climate change was previously understood too linearly: extreme rainfall events can be more devastating than drought, and it is the frequency and intensity of such events which is decisive for landscape change. It seems questionable whether reducing human pressure can compensate for stronger climatic forcing. The key for dealing with global warming is adaptation to climatic irregularities.

Kurzfassung

Desertifikation wird als ernste Bedrohung für den Mittelmeerraum und die Wüstengürtel gesehen, die durch die globale Erwärmung verschärft wird. Dabei können Mißmanagement und Klimaveränderungen identische Auswirkungen haben, und menschliche und natürliche Faktoren in Rückkoppelungen verbunden sein. Dies macht es schwierig, Ursachen und Wirkungen zu differenzieren und die Folgen der globalen Erwärmung vorauszusagen. Ein Schlüssel ist die Untersuchung historischer Desertifikation. Basierend auf der Analyse von Paläoböden werden diese Fragen in der Dekapolis-Region in Nordjordanien untersucht. Man nahm an, dass Desertifikation dort durch Misswirtschaft und Abholzung verursacht worden war. Jedoch fand der größte Teil der Erosion während der letzten Eiszeit und der jüngeren Dryas statt. Wie es scheint, werden die möglichen Auswirkungen von Klimaänderungen oft zu linear gesehen. Extreme Niederschlage und ungewöhnliche Witterungen können weit verheerender sein als z. B. eine Dürre, und die Häufigkeit und Intensität von Starkregenereignissen ist entscheidend für Landschaftsveränderungen. Es scheint fraglich ob eine Verringerung des menschlichen Nutzungsdrucks klimatische Veränderungen kompensieren kann. Der Schlüssel zur Anpassung an die globale Erwärmung liegt in der Vorbereitung auf klimatische Unregelmäßigkeiten.

1 Introduction

The United Nations recently issued a new desertification alert, warning that global warming may lead to expanding deserts (UN, 2007). While it is acknowledged that climate change is the trigger of the increasing desertification threat, member countries are advised to strengthen efforts reducing human pressure on the land. But can reduced human pressure compensate for increased climatic forcing? An answer might be given considering past examples of desertion, which played an important role for the evolution of the actual understanding of desertification[1]. In particular, the Mediterranean and its transition zones to the desert host impressive ruins from the Roman-Byzantine period, which raise the question why these once densely settled areas were abandoned. Three fundamental explanation approaches can be differentiated:

1. Population growth or conquest by uncivilized tribes caused over-exploitation of the land, leading to soil erosion and irreversible degradation of the agricultural potential. As well, it is discussed whether erosion and reduced vegetation may lead to decreased precipitation (LOWDERMILK, 1944). This is the prevailing theory and basis of many current measures combating desertification.
2. Natural climate variations determined settlement history. According to this model, phases of decline were connected with drought and bad harvests. This thesis gained attention recently due to new climate reconstructions and the increasingly obvious global warming (ISSAR and ZOHAR, 2004). Considering vegetation and soil erosion, climate change and mismanagement can have identical impacts.
3. Many archaeological studies found no evidence for environmental changes and concluded that political or economic developments were behind the ups and downs of settlement history (WALMSLEY, 1992). Authors who support this thesis do not exclude environmental changes, but consider their effect subordinate compared with the meaning of socio-economic factors. The limited area of an archaeological excavation also allows for only limited conclusions about environmental change.

[1] "Desertification" in the first place did not mean an invasion of sand, but depopulation of an area (from Latin "desertere", the meaning of which is preserved in the German words "wüst fallen/Wüstung"). The term desertification as an expansion of deserts was coined in the 1930ies during the U. S. dust bowl.

For the current land use planning under global warming, it is most important which of the above mentioned theses is closest to reality. Does it make sense to conduct large-scale reforestation programs, or are these forests going to die anyway under continued warming? Does a rise of temperatures lead to drier conditions, or is the opposite going to happen? Is human action most relevant for landscape dynamics, or is climate? Many countries in semi-arid regions face a strong growth of population and industry while water resources are diminishing. The necessary expansion of water harvesting and general land use is increasingly risky, because it is unknown whether the environment will remain stable.

The look into the past is a key for dealing with the future, since what already happened may happen again. Past environmental systems are "closed" and cannot change any more, which allows improved understanding of causal relationships. In cooperation with several archaeological missions, these questions are currently investigated by the Chair of Environmental Planning in a project funded by German Research Foundation (DFG) on "Interactions of land use, climate and soil development in the context of settlement history in the Decapolis-Region (Northern Jordan)". The Decapolis region extends from the Jordan valley over a Mediterranean highland into the Arabian desert (fig. 1 and 2).

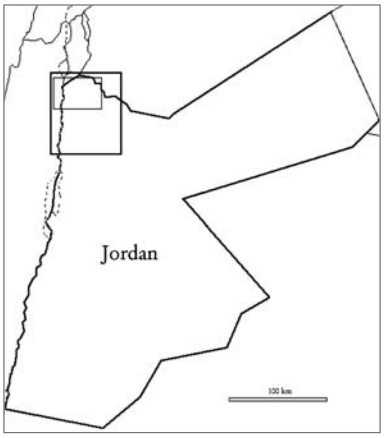

Figure 1:
Map showing the approximate location of the Decapolis region in Northern Jordan (big box) and the investigation area (small box).

Figure 2:
The ruins of the Decapolis cities are impressive and famous. This example shows Jerash. (Photo: B. Lucke).

2 Paleosols as archives of environmental change

In many areas in Jordan, paleosols were discovered which can contribute to reconstructions of past environments, and are in particular important for desertification studies since soils are indicators of land degradation. However, many paleosols in Jordan were only recently recognised as such because of their similarity to present soils, and because archaeological missions lacked the expertise to identify and examine them.

A soil is a paleosol when it is disconnected from ongoing soil-forming processes, for example after being built over by a town, or after being buried by a landslide which deposited enough material to put the soil out of reach for soil-turning animals. This preserves the status of soil-formation at the time of burial. But paleosols are not proxies for single parameters like annual precipitation, since many other variables like vegetation, human activity, dust deposition and temperature are involved in soil-forming processes. The challenge for the paleosol researcher is to understand which of the many factors changed. Regarding climate reconstruction, other proxies like e.g. speleothems or lake sediments deliver more precise and specific results (which can be combined with paleosol examination). The advantage of paleosols lies in their greater spatial distribution, and the need to consider various factors can turn out as a benefit since it delivers better clues about causal relationships.

A set of factors makes the Decapolis region the ideal investigation area for studying environmental history and differentiating the influence of humans from the effect of climatic changes. On the one hand, the situation in the transition zone to the desert permits the investigation of soils and colluvia along climatic gradients. On the other hand, historical dating of landscape changes and a comparison of soil development with reference to the source rock and relief are made possible by the good archaeological documentation and simple geological structure. In the Decapolis region, the geological structure consists of chalk limes and horizontally structured limestones shaped by Karst, which are at some places covered by basalt. The picture of the landscape is that of a high plateau incised by deep valleys (in Arabic wadis). While the plateau is covered by red soils (Terrae Rossae), the slopes show white-grey soils (Rendzinas).

3 Results: climate and geology as landscape-forming factors

The Decapolis region was counted a classic example for the narrative of man's destructive impact on the land. In this context, it seemed to be out of question that the designers of the impressive monuments from the Roman-Byzantine era could not have been responsible for the degradation. That was attributed to the Muslim conquerors who supposedly allowed nomads to take over, neglect terraces, cut the forests, and overgraze the land. In essence, the immigration of uncivilized tribesmen was seen as the prime reason of desertification, and only their education by more civilized powers could turn things to the better (LOWDERMILK, 1944; HILLEL, 1991).

However first doubts about this paradigm arose when development aid projects could not achieve their goals. Such a project was conducted in the Zarqa valley close to the city Jerash, where sediment deposition into the King-Talal dam should be decreased and soils be stabilized by construction of terraces and stone walls (GTZ, 1991). It was even hoped to exert a positive impact on local climate by large-scale reforestation. However, a heavy rainstorm in February 1992 led to dramatic sedimentation into the dam in form of landslides, despite the construction of the terraces (AL-SHERIADEH and AL-HAMDAN, 1999). Besides, no general positive effect of the forest could be determined so far. Newer studies point to the opposite, showing that the monoculture afforestation with pine leads to a very high forest fire risk, may move the grazing pressure to ecologically more sensitive areas, and reduce groundwater formation (VAN DER LEEUW, 2004).

Investigations of paleosols and archaeological archives brought further insight. They show that the erosion of the Terra Rossa occurred mainly at the end of the last Ice Age and during the Younger Dryas (CORDOVA, 2005; MAHER, 2005 and LUCKE, 2007). The colluvia found in the wadis show that sedimentation since the Neolithic constitutes a very small portion of the entire deposits. No Neolithic site was found to be covered by red soil: erosion of the Terra Rossa in the Decapolis region had mainly come to end when agriculture was invented. But the sediment record also revealed that dramatic landscape changes with massive landslides and erosion of Terra Rossa took place at the end of the last Ice Age, during the Younger Dryas (CORDOVA, 2005, MAHER, 2005), and during the "Yarmoukian landslides" 8200 BP (WENINGER et al., 2005, LUCKE, 2007). At the end of the Byzantine period (~650 AD), and possibly at the end of the Mamluk period (~1500 AD), these phases of landscape instability may have resumed to a minor extent. Nevertheless no Terra Rossa was eroded any more, which is probably due to the fact that the landscape is in the stable state of completed erosion since the Neolithic period (NSM&LUP, 1993).

In general, the soil pattern points to a dominant role of local factors in soil formation (LUCKE, 2007). The deepest soils are located in the east, where wadis are least incised and drainage is minimal. In this context, long-term erosion seems not so much a matter of average annual rainfall, but relief. Soil variations are strongest on the deeply incised Mediterranean limestone plateau, the level appearance of which seems to be the outcome of considerable soil movement. As indicated by a profile close to the Yarmouk river, one of these movement processes might have taken place around 6880 BC, which lets a connection with the regional "Yarmoukian landslides"-event seem possible. Basalt soils are characterised by a strongly contrasting uniformity. This illustrates that not only the relief, but also the source rock played an important role for the formation of the soils. The uniformity of the basalt soils might be related to mixing processes that obliterate horizons as visible in the limestone soils, indicated by the drought cracks and slickensides. Even though the deep limestone soils show slickensides, too, their vertic behaviour seems not so pronounced which might be related to different sets of clay minerals (LUCKE, 2007).

The large-scale pattern repeats in the small scale. Soil distribution in the Wadi el-Arab supports the conclusion that soil development took place in a geological time scale. Soil properties are again related to the underlying rocks and relief, with red colluvia in the depressions, exposed chalk ridges, and grey soils covering the natural terraces of harder rocks. The latter might once have carried red soils, as still present on the adjacent high plateau, but there is so far no reason to attribute their erosion to historical periods. If they had been eroded recently, much more red colluvium should be visible in the Wadi el-Arab (e. g., at the foot of a hill formed by ruins (Tell) as a sediment obstacle), and not only in depressions between the chalk ridges. Although the lower wadi terraces give evidence of recent soil movements, no red colluvia could be observed there. Especially interesting is the paelosol which MAHER and BANNING found in Wadi Ziqlab, suggesting that the Terrae Rossae were eroded before 11,000 BC (MAHER, 2005), but that some red colluvia in the wadi bottom were not yet covered by Rendzinas until the late Byzantine period (fig. 3).

Some progress could be achieved regarding the methods of soil analysis. Soils rich in $CaCO_3$ as present in the Decapolis region are an analytical challenge since pre-weathered iron and clay is bound in the calcium carbonate in varying degrees. It was found that the "classic" soil investigation methods of iron oxide ratios and texture provide no meaningful results (LUCKE, 2007). But manganese oxides, magnetic susceptibility and $CaCO_3$-content show very clear tendencies, indicating that the overall soil development decreased since the end of the last Ice Age (Tab. 1). Especially the wadis seem to have changed from densely vegetated places with periodic waterlogging to traps of chalk accumulation.

Figure 3:
Paleosol with excavated surface from the Kebaran (11.000 BC). Further upwards is a Byzantine field border wall (on top of the meter scale) which was covered by a weakly developed Rendzina and chalk from the slopes. Wadi Ziqlab, northern Jordan, excavation by E. BANNING and L. MAHER. Photo: B. Lucke

Table 1:
Iron oxide ratios pretend intense soil development of the chalk, but $CaCO_3$-content, magnetic susceptibility and manganese oxides show clearly how the paleosol in Wadi Ziqlab is more developed than the sediments covering it.

Samp le No.	$CaCO_3$ %	Mn(d)/ Mn(t)*10	Fe(d)/ Fe(t)	Magnetic susceptibility χ (1/kg) *E-3
TZ 54 (chalk)	74	0,04	0,51	15,83
Ziq 1 (10 cm)	65	0,05	0,16	36,1
Ziq 2 (40 cm)	63	0,11	0,78	49,7
Ziq 3 (70 cm)	50	0,35	0,42	214,1
Ziq 4 (100 cm)	45	0,63	0,38	287,8

The additional analysis of air photos and historic travel reports indicates that old field patterns can be traced according to remains of field borders, and possibly weak differences of soil development, which again indicates that historic desertification in the sense of massive erosion did not take place (LUCKE, 2007). Evaluating the descriptions of 19th-century travel reports, the landscape changed much less in the recent past than previously assumed. For example, oak forests are still present where they were reported 200 years ago, and the remains of Byzantine field systems under the trees make clear that the Muslim conquest led to a natural reforestation. The overall picture is that of a very stable landscape, but the productivity of which is determined by water availability.

4 Conclusions

Our results from the Decapolis region let many current actions of combating desertification seem questionable. This is not to say that reducing human pressure on the land would not be desirable, but the impact of climatic changes dwarfs the impact of man in the environmental record of the soils of Jordan. There is no indication that Terra Rossa was eroded during history. Younger colluvia since the mid-Holocene consist of weakly developed chalk from the wadi slopes. In this context, manganese oxides and magnetic susceptibility point to much moister conditions in the past, possibly connected with periodic waterlogging. While man may locally have altered soils, and probably contributed to additions of calcareous dust, climate and the geological pre-disposition were decisive for landscape development.

It is important to note that the last period of major global warming, which is the end of the last Ice Age, and the last major global cooling, which is the Younger Dryas, led to dramatic landscape instability in Jordan. The sediment record indicates massive erosion in form of land slides, and possibly strongly reduced vegetation cover. The most likely explanation for this pattern is an increased frequency and intensity of heavy rainfall events. Global warming may not linearly lead to drier or warmer conditions, but to a switch from one climatic equilibrium to another, with a transition phase characterised by extreme and unusual weather. If confronted with instabilities as documented from the end of the Ice Age in the sediment record, it is likely that none of the present land use systems will survive (LUCKE, 2007).

Further research is planned to better understand the time-frames and occurrence of periods of landscape instability, feedbacks between land cover and climate, and to assess whether local or regional forcing was behind changes. With regard to present programs of combating desertification, the best strategy seems to prepare for extremely heavy rainstorms and unusual weather. It is so far not possible to say how land suitability will look like in 2100, but a careful cost-benefit analysis in the light of the environmental history seems imperative before conducting large-scale land recovery programs.

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