The Dynamic Nature of the Transition from the Nile Floodplain to the Desert in Central Egypt since the Mid-Holocene

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1. Introduction

The Nile and its floodplain played a crucial role in the development of the Egyptian civilizations. Being one of the most important allogenic rivers in the world, the Nile travels for more than 3000 km through an arid environment. The fertile floodplain, made up of silt and clay deposits through annual flooding events, and ranging in width between a few hundred meters and almost 20 km, thus stands in great contrast with the surrounding desert environment. The transition from the fertile floodplain to the sterile desert is not only an important geomorphologic and pedologic boundary, it also represented a religious and cultural limit in ancient Egypt between life and dead. However, this border between desert and floodplain is not a stable one. It changes through time through the interaction of fluvial processes operating in the floodplain of the Nile and geomorphic processes operating in the desert including aeolian processes and wadi activity. A correct understanding of the changing nature and location of the transition from the Nile floodplain to the desert is an important element in the reconstruction of the natural and cultural landscape of ancient Egypt. It not only determines the width of the floodplain, and thus indirectly also the maximum cultivable area, but also the location of settlements, cemeteries and harbors.

Here, we present some of our preliminary results of the geomorphic study of the desert-floodplain transition in Central Egypt (see figure 1). In this region, the floodplain is almost at its maximal width (± 15-20 km). The River Nile is flowing in the Eastern part of the floodplain and at several locations the river

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is actually eroding the eastern desert cliff, thus forming the border between floodplain and desert. The contemporary eastern course of the Nile has been suggested, for instance by Butzer,[1] to be the result of a gradual shift from west to east throughout the Holocene and this for the entire Egyptian Nile Valley. The dynastic Nile is thus suggested to have run more towards the centre of the floodplain. Also typical for this part of the floodplain is the Baḥr Yūsif, a side branch running parallel to the Nile for about 200 km before it enters the Fayyūm depression. Baḥr Yūsif runs in the western part of the floodplain, mostly at 2-4 km from the western desert edge, however, at a few locations it also comes directly in contact with the desert. The current morphology of the western and eastern deserts adjoining the floodplain is also different. Typical for the eastern desert edge is the limestone cliff with relative heights of 60-100 m: this cliff separates the limestone plateau (150-200 m a.s.l.) or higher desert from the pediments and wadi alluvial fans that form the lower desert (50-60 m a.s.l.) and the adjoining floodplain (45-50 m a.s.l.). At the western edge, the topography rises more gently: the width of the lower desert is much larger and the height of the plateau lower compared to the eastern side. Furthermore, not only limestone hills and cliffs form the western edge, also remnants of Pleistocene Nile terraces (gravel) as well as dunes from the Southern Rayyān Dune Field (SRDF) are present. In particular the SRDF plays a prominent role in the natural landscape of the western desert edge between Daljā in the south, and Sandafa in the north.

1 BUTZER, 1976, p. 134.

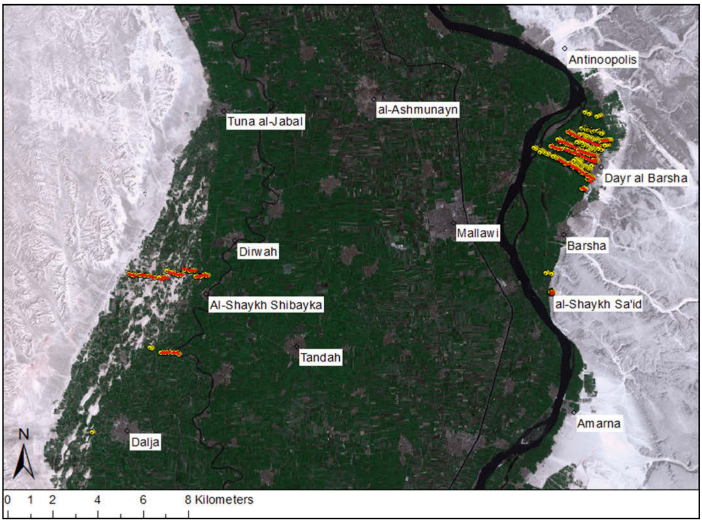

Figure 1. Aster satellite image of the Nile Valley in Central Egypt around Mallawi with indication of the main sites referred to in the text. The river channel in the western part of the valley is Baḥr Yūsif, whilst the River Nile is running near the eastern edge of the floodplain. Yellow dots indicate soil corings, whilst red lines show the location of the electrical resistivity imaging profiles.

2. Methodology

A wide range of techniques is being applied to reconstruct the floodplain-desert transition, including the analysis of current and historic topographic maps, multi-temporal remote sensing imagery, GPS measurements, soil coring, sediment dating and geophysics. The first three methods were used to describe the current landscape and to decipher sub-recent fluvial and desert dynamics. The oldest available satellite image is a CORONA image dating from May 1968, and together with the topographic map of 1945 produced by the Egyptian General Survey Authority, it provides a reference for the landscape before the closure of the Aswan High Dam, i.e. before the annual floods disappeared. Landsat TM 5 images from 1984 and 2003 with a spatial resolution of 30 m were used to detect and map the dynamics of the SRDF. A Quickbird image from 2005, GPS measurements taken in 2009 and Geoeye high satellite images available on Google Earth from 2011 further extended the time range.

More than 200 soil cores have been made with depths ranging in between 1 and 9 m. These cores were aligned on east-west running transects across the transition area and in the Nile floodplain. A genetic interpretation of the sediment stratigraphy was made mainly based on sediment texture and lithology. Coarse sands were interpreted as channel deposits, loamy sand and sandy loam deposits are typical for levees and crevasse splays, whereas silt loam, silty clay loam and clay deposits are representative for the more distal parts of the floodplain. Wadi material could be determined based on the presence of sub-angular limestone fragments and the high calcium carbonate content of the sediments. Discriminating dune sand from fluvial channel deposits was performed by combining sediment texture including sorting, grain morphometry determined under scanning electron microscope, geochemistry and mineralogy, as well as the presence of freshwater organisms (snails) typical for river channels. The genetic interpretation was further interpolated between coring locations using electrical resistivity imaging (ER). ER profiles were performed with a SAS 1000 Terrameter using a Wenner-Schlumberger protocol and electrode spacings of 2 to 5 m. Depth of the ER profiles ranges between 10 and 40 m, and profiles are oriented east-west with lengths varying between 200 and 1500 m. ER profile interpretations were validated using soil cores. High resistivity values were interpreted as coarse sand and gravel under groundwater level, and sand above groundwater, whereas low values were interpreted as silt loam to clay deposits. The combination of soil cores and ER images provide more insight into the longer-term dynamics of the transition area. At several locations, organic fragments within the sediment record were dated using AMS ^{14}C. Also a few optically stimulated luminescence dates were obtained on point bar deposits and dune sediments. Both radiocarbon and OSL ages provided an age control of the sediment stratigraphy.

3. The evolution of the eastern floodplain-desert transition

We analysed in particular the transition area between al-Shaykh Saʿīd (immediately north of Amarna) and Antinoopolis, with a focus on the surroundings of Dayr al-Barshā. Several now-inactive Nile channels can be seen on older topographic maps and CORONA and these are still visible in the field. These channels were still active before the closure of the Aswan High Dam but became inactive due to the reduced peak flow discharge (see figure 2). However, field observations as well as soil coring and ER mapping, did show that some of these channels have been bulldozed over the last few decades and turned into arable land. At many locations, wadi material is first being brought into the former channels. Next, former river banks are leveled and silt and sandy loam deposits are moved from the banks into the channel (see figure 3). The same operations take place in and along former irrigation and drainage canals running south to north along the border between the floodplain and the desert. These post-1970 leveling activities make it difficult to interpret the current landscape, be it through topographic analysis or through the use of remote sensing data, to infer palaeo-channels that became inactive well before the Aswan High Dam closure.

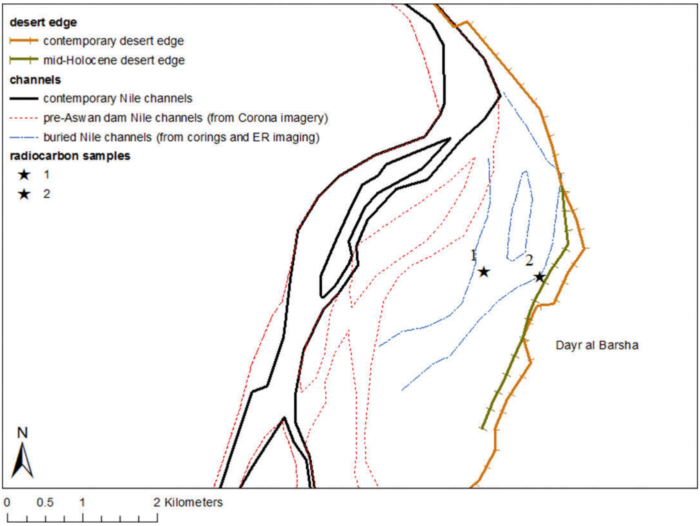

Figure 2. Indication of contemporary and ancient channels of the River Nile west of Dayr al Barshā based on Quickbird imagery (2011), Corona imagery, as well as coring and electrical resistivity imaging profiling. Contemporary and mid-Holocene desert edge (based on corings, see Figure 3) is also indicated. Stars denote sample location for AMS radiocarbon dating of fluvial point bar deposits (1: cal 650 – 780 A.D.; 2: cal B.C. 180 – 20 A.D.).

Figure 3. Wadi material is being used to level former Nile channels (left), whereas the banks of the former channels are being bulldozed (right) and the excavated Nile silts are being used as topsoil in the infilled channels. Pictures are taken 2 km south of Dayr al Barshā.

However, the field-based geomorphic approach provided evidence for ancient Nile channels that run further to the east compared to the twentieth century active channels. Both sediment corings and ER revealed the presence of a major channel in the form of meters thick sand deposits and high resistivity values, respectively. The width of the major palaeo-channel is approximately 250-300 m, which is similar to the main channel today. Further to the north, this channel bifurcates into two smaller channels of 100-150 m wide (see Figure 2). At the edge of these now buried channels, the top of the point bar deposits were characterized by high concentrations of micro-charcoal pointing towards deliberate firing activity along the banks of the river. Immediately on top of the charcoal, fine-grained sediment points to the infilling of an abandoned channel. At two locations, these micro-charcoal concentrations were used for AMS ^{14}C dating and returned an age of cal B.C. 180 – 20 A.D. and cal 660 – 780 A.D. This suggests that the activity of these Nile channels ceased around these dates. No indication for older or younger channels could be found. However, close to the desert edge near the village of Dayral-Barshā, no indications for channel activity could be found in the top 5 meters. At several locations close to the desert edge, charred plant material retrieved from the silt loam overbank sediments at 1.2 to 4.5 m depth returned radiocarbon ages ranging between cal B.C. 2890 – 2620 and cal B.C. 1400 – 1120. However, at a few locations, much more recent ages were obtained, i.e. cal 1210 – 1290 A.D. and cal 1420 – 1500 A.D. for material at 2.2 and 4.5 m depth, respectively. None of these dated samples were related to former channels. Hence, we conclude that at least for the last few thousand years, no major channel ran immediately next to the contemporary eastern floodplain-desert transition.

A more detailed coring dataset and ER profiling was made across the contemporary desert edge around the village of Dayral Barshā. Our results indicate that the location of the transition from desert to Nile floodplain did not change much over the last few thousand years, however, the morphology of this transition did change enormously. At present, there is a gentle grading of the alluvial fan at the mouth of the Wādī Nakhla towards the floodplain, with a small topographic step of ±1-2 m over a distance of 50-100 m. But the corings revealed a much more stepped and steeper desert edge. Over a distance of less than 40 m, the thickness of Nile silts covering wadi deposits increases from 0.5 m to more than 4.5 m, but locally probably much more (Figure 4 and 5). In dynastic times, the floodplain-desert transition thus must have been very abrupt. This is probably related to active undermining of the wadi pediment by the River Nile, which thus must have flown at the desert edge as is still the case between al-Shaykh Saʿīd and Amarna in the south and around Antinoopolis to the north of Dayr al Barshā (see Figure 6).

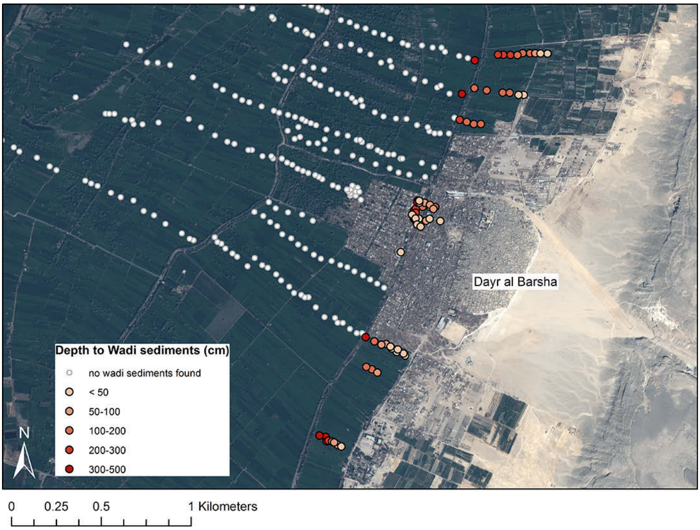

Figure 4. Depth to wadi sediments in the sediment corings performed in the surroundings of Dayr al Barshā. A gradual to abrupt thinning of the Nile flood sediments from west (> 5 m) to east (< 0.5 m) can be discerned over a distance of 100-200 m.

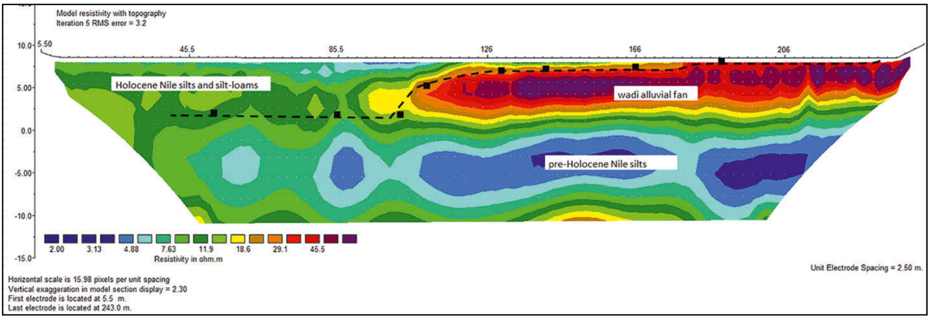

Figure 5. Results of the soil corings and electrical resistivity profile LRDB0813 located 300 m south of the village of Dayr al Barshā (southernmost set of corings indicated on Figure 4). High resistivity values correspond to relatively dry coarse-grained wadi deposits that can be related to the alluvial fans at the footslope of the limestone cliff. Low resistivity values refer to dry to wet alluvial Nile silts and silt loams. Black squares indicate the coring depth at which coarse-grained wadi material was found. The dotted black line corresponds to the interpreted topographic step in the landscape (height of approx. 5 m).

Figure 6. The left picture shows the sharp transition from the Nile channel to the desert near Antinoopolis. The height of the topographic step is approx. 8-10 meters. The right picture shows the gradual transition from the Nile floodplain (foreground) and the wadi fans whereby the boundary of the urbanized area corresponds to the desert edge. The profile shown in figure 5 is taken at this location. The major buried topographic step (5 m in height) shown on Figure 5 is located near the soil coring location in the foreground but is now completely buried under late-Holocene Nile silts.

For the eastern bank of the River Nile between Amarna and Antinoopolis, our data show that the Nile is shifting from east to west (see Figure 2), thus contrary to the generally accepted theory of Butzer.[2] This has important implications for a better understanding of the natural and cultural landscape of ancient Egypt as the position of the River Nile thus must not be looked for towards the central part of the floodplain, i.e. closer to al-Ashmūnayn. Furthermore, the important channel dynamics that occurred between the present-day course of the Nile and the eastern desert also implies that there was no continuous aggradation over time. Thus, sediment depth cannot be used for dating using the often used rule of thumb that 1 mm of silt corresponds to 1 year. Our results show a strong dependency of sedimentation rate to age. This effect, on geological timescales also known as the Saddler effect,[3] is typical when the lateral movement of channels is more important than the vertical aggradation.

4. The evolution of the western floodplain-desert transition

For the western study site, our main focus was the interaction area between the floodplain and the SRDF between Ṭūna al-Jabal in the north, and the city of Daljā in the south. It extended from the western desert to the channel of Baḥr Yūsif. In this region, dunes with heights above 20 m are separated by nearly flat and cultivated interdune areas. In this study, we were particularly interested in reconstructing the evolution of this part of the floodplain so as to analyse 1) the past changes in dune and floodplain areas, and 2) the possibility that the dunes influenced the Nile hydrology. Interactions between rivers and sand dunes can have far-reaching consequences on fluvial and aeolian geomorphology,[4] and thus also on the landscape inhabited by humans. Evidence for invading dunes blocking the Nile, thereby creating lacustrine environments and influencing settlement patterns (e.g. the Makhadma lake behind a dune field at Naj ʿḤammādī region) has been demonstrated for Upper Egypt in the Late Pleistocene (±22-14 kacal BP)[5] but never for central Egypt nor for the Holocene period.

The multi-temporal analysis of the SRDF using Landsat TM data for 1984 and 2003 showed that all the dunes moved in SSE direction, thus towards the

2 Butzer, 1976, p. 134.

3 Saddler, 1981, v. 89, p. 569–584.

4 See e.g. Liu, Coulthard, 2015 for a global overview.

5 Vermeersch et al., 2006; Vermeersch/Van Neer, 2015.

Nile floodplain.[6] However, their study also revealed that once the dunes invaded the floodplain – and are surrounded by vegetated cultivated areas – the migration rate is strongly reduced. Mohamed also calculated an average migration rate for 43 barchan dunes in the desert of 4.4 m/year from NNW to SSE.[7] Within the floodplain, dunes migrate only at a speed of approx. 1 m/year. Instead of moving at high rates, dunes tend to increase in height once they reach the floodplain. The combination of the migration rates for the analysed dunes with a map of the entire dunefield made it possible to calculate the total amount of sand that is annually being transported by migrating dunes towards the Nile floodplain. It is estimated that 0.34 million tons (Mt) of dune sand is transported towards Baḥr Yūsif on an annual basis, and this for the entire SRDF region between Samalūṭ in the north and Daljā in the south. Unfortunately, few data on the bedload transport of the Baḥr Yūsif are available. For the Nile at Banī Suwayf and Banī Mazār, this is estimated at 0.23 and 0.33 Mt/year, respectively.[8] These values are underestimating the transport capacity, however, as the Nile after the closure of the Aswan High Dam transports less sediment than it potentially can. Based on transport capacity equations,[9] we estimated the pre-dam transport capacity of the Nile and Baḥr Yūsif at 2.8 and 0.25 Mt/year, respectively. Thus, the rates at which sand is being flown into the floodplain is much less compared to the ability of the River Nile to transport sand as bedload. Under these conditions, it is very unlikely that the SRDF would have been able to influence Nile hydrology. However, the situation for Baḥr Yūsif is different. Sand influx and transport capacity are of an equal magnitude. Furthermore, for the dry periods which reduced the Nile discharge with up to 80 % towards the end of African Humid Period (approx. 5.5 ka BP),[10] we estimate the transport capacity of Baḥr Yūsif to 0.02-0.03 Mt/year. Hence, in these periods of major climatic and environmental change, the advancing dunes indeed could have blocked the flow of Baḥr Yūsif, which represents a major impact on the local hydrology of the floodplain, and thus also on the local population.

6 MOHAMED/VERSTRAETEN, 2012.

7 MOHAMED, 2012.

8 GAWEESH/VANRIJN, 1994; ABDEL-FATTAH et al., 2004.

9 e.g. KALINSKE, 1947.

10 KROM, 2002.

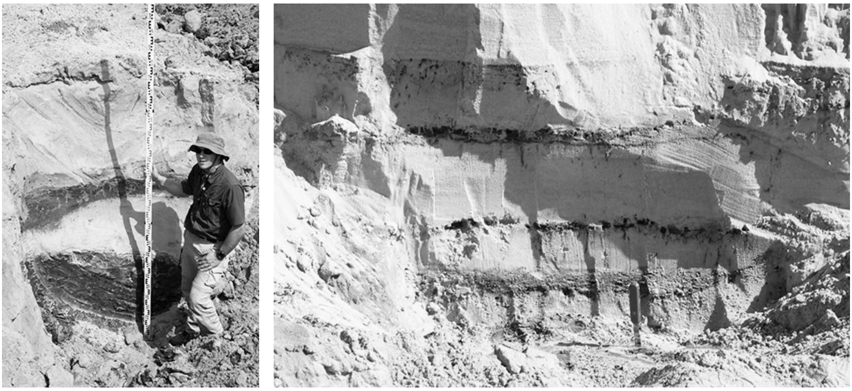

Figure 7. Nile silt and clay interfingering with dune sands in the eolian-fluvial interaction area between Dirwah and Dalja. The left picture shows thick clay-rich alluvial deposits at depth (> 3-4 m dune sand), whilst the right picture shows only cm thick Nile silts covered by 1-2 m of dune sand.

The long-term dynamics of the dune-floodplain interaction area was studied by ER and corings along a 3.5 km long west-east profile from the desert to Baḥr Yūsif near the village of Al-Shaykh Shibayka. The results show that close to the desert, the upper 5-10 meters are typical dune sands. However, at depth, some thin layers of clay deposits interfingered with the dune sands (see Figure 7). Often, these clay layers are only 1-5 cm thick. Further to the east, towards the Baḥr Yūsif, the thickness of the clay layers increases. In the most easterly part of the interaction area, the thickness of the dune sand deposits is less than 2 m and below it a continuous layer of several meters of Nile silts and clays was found (see Figure 7). In the central part of the interaction area, the clay layers interfingering with the dune sands are of variable thicknesses. However, this section is interesting for two other observations. First of all, remnants of a former river channel, nowadays buried under a few meters of dune sand, could be located, probably marking the location of an earlier channel of the Baḥr Yūsif. This indicates that the Baḥr Yūsif was forced further east by at least 900 m due to the advancing dunes. It also is in agreement with the quantification of the sand fluxes discussed above, which showed that the invading dunes were able to compete with the transport capacity of the Baḥr Yūsif. Next to the channel, we found in several detailed corings that the clay layers were mixed with the surrounding sand layers, with the presence of hoe marks. These indicate how these flooding deposits engaged agricultural practices in the interdune areas. Also at present, clay in the interdune areas is sometimes mixed with underlying sand to increase soil productivity (see Figure 8). One of the former cultivated layers at 7 m depth was dated at cal 2880-2620 B.C. (i.e. Early Dynastic Period to Old Kingdom) whereas the clay layer immediately below it is more than 2000 years older: this points towards a long period of stability which abruptly ended after the cultivation period by the invasion of the dunes. The cultivation period also falls shortly before the decrease in estimated Nile discharge[11] and a period of suggested contraction of Nile channels.[12] Although detailed datings are still missing, we interpret the advancement of the dunes after 2500 B.C. as the result of the ongoing mid-Holocene desertification typical for the Sahara.[13] Throughout the entire profile, the frequency and thickness of the clay layers also diminishes towards the top of the sequence, again showing how the influence of the fluvial processes is being reduced by the increasing intensity of aeolian processes. This increased intensity of aeolian processes during the last 4-5 ka is also reflected in the higher concentration of Saharan dust particles in Nile Delta sediments.[14]

Figure 8: Contemporary farming practices in the eolian-fluvial interaction area between Dalja and Dirwah (left). Farmers put silts and clays from Nile alluvial deposits atop new fields in the dune region (see soil heaps in the right picture) in order to make the sterile dune sand cultivable. Silts and clays are being mixed through farming practices: traces of such activities could be observed within the dune sands as well pointing to former agricultural practices in the area before the advancement of the dune system.

11 BERNHARDT et al., 2012.

12 MACKLIN et al., 2015.

13 KUPER/KRÖPELIN, 2006.

14 BOX et al., 2011.

For the interaction area between Ṭūna al-Jabal and Daljā, multi-temporal analysis of CORONA (1968), Landsat TM (1984 and 2003), and Geoeye (2011) showed a major reduction in dune areas. In 1968, more than 1700 of the ±2600 ha large study region was covered by dune sand. In 1984 this was already reduced to 1123 ha, and in 2003 only 256 ha of dunes were left, i.e. only 15 % of the original dune area (see Figure 9). For 2011 no quantitative estimate is yet available but our qualitative analysis shows that the reduction is still continuing. The intensity at which the dunes are disappearing is quite in contrast to the rate at which the dunes are invading the floodplain. It is clear that this is not related to natural processes but rather to anthropogenic processes of land reclamation through bulldozing activities and the expansion of arable land. During several field campaigns, the authors have witnessed that dunes are being levelled and that the older Nile silts and clays preserved below the dunes are being quarried and brought on top of the dune sand to create new fields.This rapid transformation of the landscape has important implications for the preservation of the rich cultural and natural heritage which is preserved below the dunes.

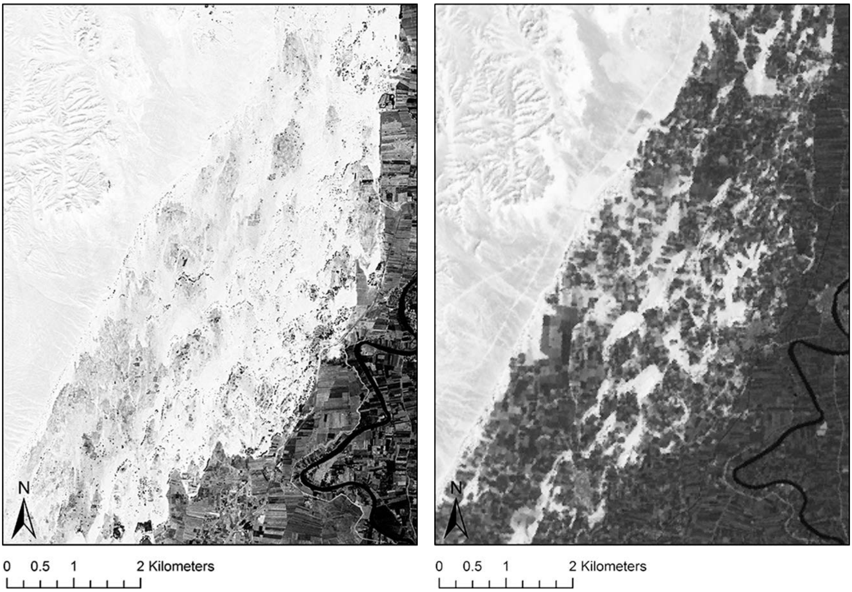

Figure 9: The Western floodplain-desert transition near Al-Shaykh Shibayka. Left: Corona image of 1968, right: ASTER image taken in 2003. Many dunes and interdune areas have been transformed to cultivated land.

5. Conclusions

The interaction area between the Nile floodplain and the desert is a highly dynamic and very variable environment. For the study area in central Egypt, the evolution along the western and eastern banks of the Nile is quite different. In the eastern part, the transition remained more or less at the same position throughout the last few thousand years, but the morphology drastically changed from a desert cliff eroded by the Nile to a more gently sloping surface. In the western part, the intensification of the dune migration into the floodplain following the mid-Holocene aridification of the Sahara meant that the areal extent of the floodplain decreased and that even the position of Baḥr Yūsif changed. Since the closure of the Aswan High Dam, human impact in the interaction area further increased whereby many of the dunes are being leveled thus destroying this unique interplay of dunes and Nile sediment dynamics. Also the cultural heritage preserved below the dunes in the floodplain deposits is nowadays threatened by the increase in cultivated land.

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