SUDAN & NUBIA

The Sudan Archaeological Research Society

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ASWAN
1st cataract
Hisn al-Bab
RED SEA
Egypt
Afyeh
Wadi el-Allaqi
Gebel Adda
2nd cataract
Wadi Gabgaba
Amara West
Sedeinga
Sai
3rd cataract
Tombos
Sudan
El-Ga'ab Basin
ABU HAMED
Nile
H29
5th cataract
Abu Sideir
KAREIMA
4th cataract
Napata
Wadi Abu Dom
Dangeil
ED-DEBBA
Gala Abu Ahmed
Wadi Howar
ATBARA
Meroe
Qalaat Shanan
Atbara
Wadi el-Melik
Wadi Muqaddam
6th cataract
Jebel Sabaloka
OMDURMAN
KHARTOUM
KASSALA
Eritrea
Blue Nile
MODERN TOWNS
Ancient sites
WAD MEDANI
White Nile
GEDAREF
SENNAR
KOSTI
N
Ethiopia
0
250 km
South Sudan
Azaza

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Contents

The Kirwan Memorial Lecture

Reports

Miscellaneous

Obituaries

Front cover: Excavations in progress in the *Kerma Ancien* cemetery at site H29 in the Northern Dongola Reach (photo D. A. Welsby).

Sudan & Nubia is a peer-reviewed journal

Aeolian sand landforms in parts of the Sudan and Nubia. Origins and impacts on past and present land use

R. Neil Munro, Mohammed Abdel Mahmoud Ibrahim, Hussien Abuzied and Babiker el-Hassan

A Modern Problem – Invasion of Sands into Agricultural Lands

In northern Sudan the impacts resulting from the perennial movements of aeolian sand dunes and sand sheets into irrigated agricultural lands and settlement infrastructure have long been considered a serious issue. Since the colonial days of the Anglo-Egyptian Sudan, national and local governments in the Provinces (now States), donor agencies and investors have tackled the problem. Whilst there have been a number of sand stabilisation success stories in recent decades, such as at Argi and Affad on the right bank of the Nile in Northern State, elsewhere the trees put in place to protect have run wild. In both ancient and modern times loss of natural woodlands by cutting and effects of drought has exacerbated the problem. The loss of land in Tokar Delta by sand dunes (Plate 1) , for example has long been a disaster. The relentless battles to stop vast quantities of aeolian sand overwhelming the valuable cropped lands on Nile alluvium will have to continue as long as the African deserts supply sand and an arid climate prevails.

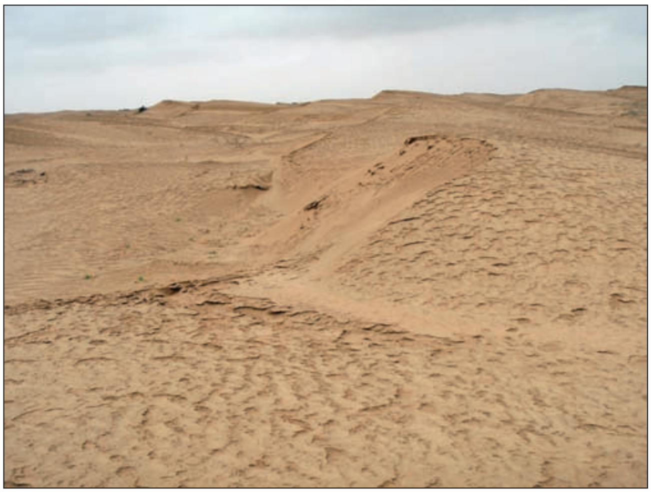

Plate 1. Dunes in the Tokar Delta stabilised by rainfall. The dunes are unusual and composed of quartz sand and also silt to sand-sized fragments of the silty alluvium that has been deflated by the extremely strong winds the area is notorious for. After rain the dunes are stabilised by a silt cap for a short time. They are a type of clay dune (Bowler 1973). (photo R. N. Munro, January 2010).

For conservation archaeology and heritage management in areas, such as along the Nile in Sudan, that are subject to drifting sand hazards – burial of sites and abrasion of monuments – it is important to understand in detail the nature and dynamics of sand movement affecting a site at different times of the year. As we shall illustrate in this paper there are many factors involved that need to be assessed first before one can prepare a site-specific management plan.

An Ancient Problem - Burial of Infrastructure along the Nile through the ages

During the early Holocene wet phase, when freshwater lakes existed over many parts of Nubia (Williams *et al*. 2010; Nicoll, 2004), it is likely that mobile sand dunes and sand sheets were much less in evidence. This all would have changed with the onset of regional dryness, at the end of the 1st millennium (Edwards 2004, 109), a period when weakly stabilised sandy materials would have been mobilised by winds. The historical records and archaeological surveys show that buildings and lands were being covered by sands during at least the past four millennia in Northern Sudan on the Nile: two sites, the left (west) bank New Kingdom (13th-11th century BC) site of Amara West and the 12th century church at Meinarti Island both suffered from aeolian sands (Welsby 2002, 117-118). At Amara West the site was located on an island in its heyday (Spencer *et al*. 2012, 37) but substantial amounts of aeolian sands now drift in from the north-north-east off undulating desert plains that stretch for hundreds of kilometres to the north.

The evidence of sand burial at numerous ancient sites along the Nile is in many ways similar, such as at the Kushite town of Kawa, where rooms were found party full of aeolian sand (Welsby 2000, 7) and some 1.47m of sand accumulated between excavation identified phases at Kawa, (Welsby 2011, 56-57). There is also fascinating epigraphic evidence found in the Temple of Taharqo, Kawa on an inscription of Irike-Amanote that records the clearing of sand from the processional way in the 2nd half of the 5th century BC:

> 'Then His Majesty found the road of this god after the sand had taken it in regnal year 42. Without the god having gone upon [his] road […..] this nome. [Th]en His Majesty brought a multitude of hands, to wit, men and women as well as royal children and chiefs to carry away the sand; and his Majesty was carrying away sand with his hand(s) himself, at the forefront of the multitude for many days …..'.
> (Trans. from Eide *et al* 1996, 412).

The build-up of sand to the west of Building A1 which engulfed the altar at Kawa was revealed during excavation (Welsby 2001a, 67).

At Old Dongola red aeolian sand is blowing in at present and burying the low-lying part of the excavated site. But the problem is an old one here, for after the destruction of the Cruciform Building the churches were filled with sand and dust. This was from the 15th century onwards and before the post-medieval dwellings were built over them (Godlewski 1990, 532).

At Faras, now deep beneath the surface of the Aswan reservoir, new buildings were established over aeolian sand-buried older ones (Welsby 2002, 117). The site was almost engulfed by sands in the 13th but survived until the late 15th century: they tried to counter the threat by blocking windows with *qawadis* (Welsby 2002, 118). Welsby (2002, 117) notes that Faras ceased to be on an island in the Medieval period and thus sand influx from the Western Desert would have increased: an analysis of sand samples from this site and others like it could tell us much about this apparent change: sands from the Nile are sub-angular and of mixed minerals commonly with Ethiopian volcanic rock minerals, whereas sands derived from the Sahara are mostly well rounded quartz grains. Desert sands also are reddish with Fe coatings, whilst fresh river sands are bluish grey though they do appear to yellow rapidly.

Sand encroachment at Meinarti (Adams 1965, 161; Welsby 2002, 118) led to its temporary abandonment in the 12th century. Adams (2000, 6) suggested that sand bars were exposed at low Nile levels during the later medieval period. At Amara West the site was on an island and the southerly flow of drifting sand would have been absorbed by the Nile channel on its north side, and as Spencer *et al* (2012) explain, when the channel silted up sands were able to cover the site, and to an extent probably help preserve it. This site today is one that suffers from seasonal re-burial since it lies downwind of sand drifting in from the Western Desert and Sahara – an endless supply.

Many ancient sites were placed on island or lee sites such as the massif of Jebel Barkal at Kareima, where the temples lie in a largely sand-free area downwind of the desert sand fetch: the surrounding terrain was not so protected. At other locations, such as Meroe pyramids, Nuri pyramids, Bakhit, and ez-Zuma, there appears to have been minimal sand drift at the time of construction, or as they were on ridges and sands of climbing dune were not developed there at that time the sand drift hazard was minimal. In the case of Meroe in particular, sand influx nowadays is considerable and appears to be related to a recent change in sand supply coming from the north; based on our studies along the Nile, it appears valid to say "sand on its way has arrived", rather than being an ancient problem (Plates 2 and 3).

At Meroe, Hinkel (2000, 16) attributed this increase to what he termed the observed desertification trend in northern Sudan. It is not clear though if *desertification* is the appropriate term for this sand surge. At Meroe, where quartz-rich sand is the culprit, it appears that the boundary fence to the north of the site is encouraging sand deposition. It is possible also that sands are moving south in some pattern of pulses in response to short-term dry episodes: more detailed analyses of climate and particularly wind data, and its relation to the threshold velocities observed by Abuzied (2009), may help elucidate this issue.

The ancients do seem to have been powerless to halt the inexorable drift of sands and were unable to establish sand stabilisation measures. It is possible local circumstances may have changed rapidly with time, and sands were deflated and drift initiated. Edwards (2004, 12,) notes that very low Nile levels occurred at intervals in medieval Nubia and much earlier dry episodes are known from Pharaonic times. These would have exposed significant areas of the sandy river bed to deflation that would become excessive as the Nile became lower during the dry season, throughout winter and well into the following dry season strong dry northerly winds would lift up sands and move them southwards. This was especially a problem on island sites that were free from sands of desert origin. How could one counter this? What is not clear yet is whether the deflating sand from sand banks at some of these sites was always a problem or one that occurred occasionally, perhaps due to human interference such as cutting of timber for construction or cooking, or natural such as these episodic dry periods with very low Nile phases: these

Plate 2. Meroe pyramids. Sands are accumulating around the pyramids (photo R. N. Munro, 2005).

Plate 3. Meroe. Sand encroachment at Meroe pyramids has steadily increased in recent years (photo R. N. Munro, 2005).

are topics for future study and correlation. The pattern was probably the same as today with the strongest winds occurring in the winter.

Whilst the inhabitants along the Nile could assemble huge monuments, wind-blown sand was difficult for them to control. The link between vegetation reducing wind speeds and hence limiting sand movement was probably just not recognised. The destruction of vegetation along the Nile must have been substantial. In Europe very similar tales of sand-buried churches and villages can be found, for example 15th to 17th century Scotland, and it was only gradually there that destruction of natural woodland on dunes, such as the Culbin sands, was banned by Act of Parliament, and 200 years later later by wholescale afforestation of coastal dunes, that an element of control over a serious problem was accomplished (Gimingham, 1964; The Moray Firth Partnership, 2007).

The sand bars near Kajbar illustrate the low water conditions, when exposed areas can deflate sand onto agricultural lands (Plate 4). Island sites offered some security from marauders, at Pharaonic settlements (e.g. Amara West), or Christian sites (e.g. Faras and Meinarti), or pillaging at cemeteries (e.g. Mograt Island). From our own observations, Kawa too was probably on a rocky island initially. At Mograt although there is abundant aeolian sand to the north from the Nubian Desert this does not appear to have crossed the Nile (Plate 5). The recorded silting up of the channel at Amara West (Spencer *et al.* 2012) would have allowed sand to drift in unimpeded from the north, with likely disastrous impacts for the settlement (Spencer *et al.* 2012, 41-2).

Plate 4. Sand banks on the Nile at Kajbar. View downstream from the right bank (photo R. N. Munro, 2008).

Modern Problems for Archaeology and Agriculture

At ancient sites sand influx was such that people were unable to cope with what was probably a steady accumulation of sand, but in modern times too it can be tough for the humble small holder who sees his farm overwhelmed. Just close to ancient Amara West we observed a few years ago a small irrigated farm that had been covered by drifting sand and abandoned: numerous other examples occur between Merowe and the Third Cataract. It appears that often insufficient thought is given to establishing wind breaks with planting of appropriate trees and shrubs. These have to be maintained by irrigation and if the pump fails then the vegetation will succumb too.

Plate 5. Mograt Island. View downstream. Sands blowing from the north (right) enter the Nile and are washed downstream. Mograt receives almost no aeolian sand. Existing and proposed dams could alter the dynamics of sand deposition and cause more siltation in the Nile (USAAF 1943 Trimetrogon oblique aerial photograph: Roll 107 R-1060-35. Sudan National Survey Authority archives).

At Kawa, at the present time, aeolian sands appear to be derived from sands blowing out of both the Selim basin to the north, and in a lesser amount to deflation of Nile sediments from sand bars. An oblique aerial photograph of the Nile and right bank area of the Wadi el-Khowi (Plate 6) shows dunes moving southwards over old Nile alluvium and palaeochannels that were active in the Neolithic (Woodward *et al.* 2001; 2007).

Together these sands bury excavations and also blast and degrade stonework and reliefs (Plate 7). In the past when Kawa may have been on an island the source would have been sand bars: the lowest levels at Kawa have yet to be excavated.

The increase of sand and dune accumulation at the Meroe Pyramids, north of Shendi, is one instance that has been reported by Sudanese and others familiar with the area since conservation and restoration began there, post 1970s (Plates 8 and 9). Hinkel (2000, 16) in particular, has reported on the increase of sands and sand abrasion at Meroe between 1966 and 1978, by comparing aerial photographs. He attributed this to what he termed the observed desertification trend in northern Sudan. At Meroe the dunes now partly cover the site, resulting in inability to access funerary chapels as

Plate 6. Barchan dunes moving southwards across the Wadi el-Khowi receive sand from the Nile and sandy lands in the Selim Basin. Kawa is in the centre on the right bank. Dongola is on the left bank. Oblique air photograph by R. N. Munro, 2004.

modern wooden doors are choked by sands, whilst saltating sand whipped up by winds is causing extensive damage to stonework and reliefs.

It is clear that there is a steady loss of shrub and tree vegetation in northern Sudan. A combination of felling, drought and lack of regeneration means that winds are unchecked and sand movement probably more widespread than say a century ago.

Plate 7. Kawa. Sand blasting is destroying monumental remains. Sites such as this require urgent protection from both sand influx and strong winds (photo R. N. Munro, January 2012).

Currently, while the issues are understood well enough the potential impacts are often not taken seriously by some developers in this very harsh and unforgiving hyper-arid environment. Even some large schemes are established without shelterbelt protection and if the sand supply is even moderate canals can be buried by sand overnight sometimes before a drop of irrigation water has flowed (Plate 10). Is it not surprising that the ancients could not cope?

Today in this area the location of aeolian dunes, sand sheets, and sand-free areas downwind of hills, are well known from soil and landform mapping studies (Ibrahim 1994, 1997; Bonifica 1986; Lahmeyer 2005; Williams *et al.* 2010).

One issue appears to be that planners considering opening up the old alluvial plains may have looked more at the obvious aeolian features – the huge sand dunes, such as occur on the right bank of the Nile on the Dongola Reach that march on towards the river, and neglected the sand sheets with their erratic though steady supply of sand. When working on soil surveys on both sides of the Nile in 2004-2005 it became clear to us that drifting sand sheets were one of the biggest hazards to irrigation schemes and settlements, but the estimates of how much sand was actually passing a point were at that time guesses. We had no idea of how much sand passed a particular point in a year. What was noticed was that on any given day on what were termed the *desert plains* on the left bank, lands that lie well above the level of the Nile's late Pleistocene terraces, there appeared to be almost no drifting sand. But 2m deep soil pits could be found half-filled after an overnight and seemingly 'ordinary' blow. Clearly something rapid in sand movement was happening whilst we slept. Similar rapid events in ancient times, and especially if they occurred at night (when storms often blow), would have very difficult to manage.

The impact of drifting sand on farms in recent years has been observed to be one of continuous struggle in most areas. On the right bank where sand is drifting off groups of barchan dunes the sand flow is clearly more rapid, and the requirement to protect lands, settlements, and archaeological sites more urgent.

For both development purposes and sand drift reduction at archaeological sites though, it is possible to apply tested and proven mitigation remedies (Watson 1985) that can reduce the sand drift hazard and its consequences, but it has to be recognised that such treatments will take time and great efforts, and will require long term commitments from all.

Sand abrasion of monuments, for example at Meroe, is a particular issue. The height to which saltating sand can reach, and thus cause abrasive damage to structures, is a factor of wind speed, grain size and surface characteristics (Wiggs 2011). It was recognized long ago that saltation was higher on rocky surfaces (Bagnold 1941) and that each saltating grain impacting the surface causes ejection of more grains in turn. On hard surfaces saltating grains may reach 3m in height and a mean height of more than 200mm (Pye and Tsoar 2009). In general up to 80% of saltation occurs within 20mm of the surface (Butterfield 1991, reported by Wiggs 2011).

At monumental sites being considered for conservation management though, the local characteristics need to be carefully examined at each site, and the problems quantified and rigorously assessed.

Methods for Sand Drift Measurement

To assess the actual amounts of drifting sands, rather than just make estimates based on meteorological data and sand particle sizes, it is fortunate that a programme of sand drift measurements has been completed by Hussien Abuzied of

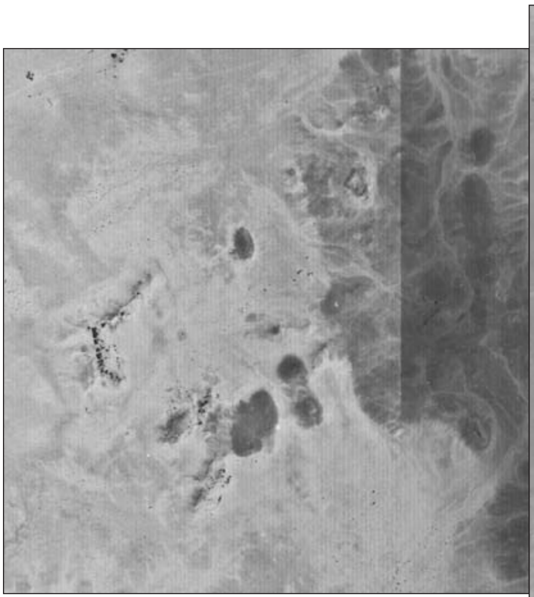

Plate 8. *Aerial Photograph of Meroe pyramids area. 1979. Sudan National Survey Authority archives.*

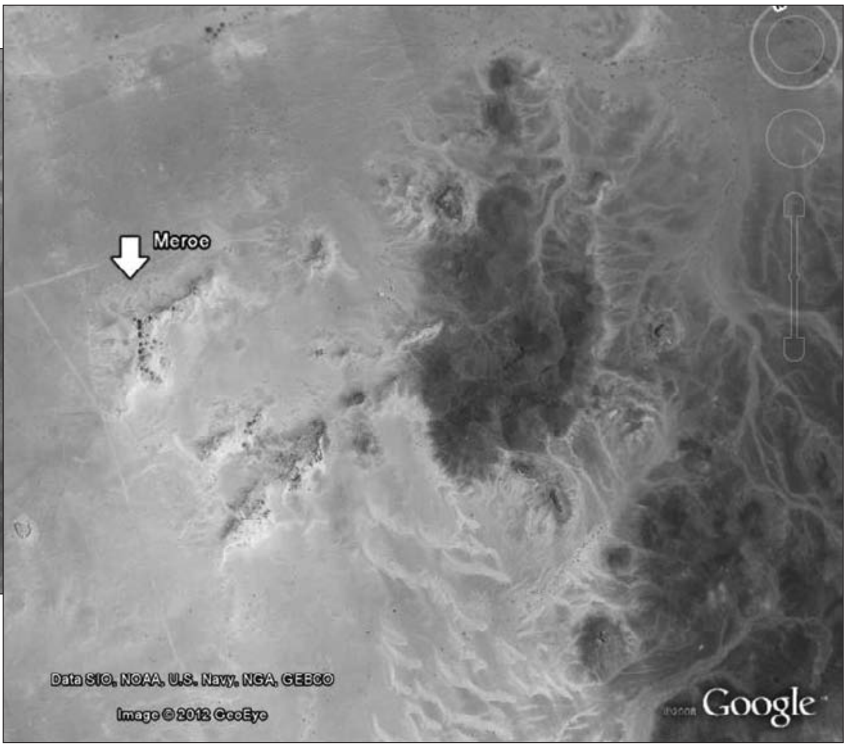

Plate 9. Meroe Pyramids. Google Earth image, converted to greyscale, Feb. 28th, 2010. © Google Earth 2012.

Omdurman University. The drift rate measurements on the Dongola Reach were initiated in 2005 by Abuzied at the police checkpoint close to Baja and where the Wadi Howar reaches the Nile; a point notorious for loose sands before the asphalt road was constructed. Methods are reported more fully in Abuzeid (2009). At Baja an array of sand drift collectors was set up and made of two parts: one PVC tube 1m long and 51mm diameter closed at the base and buried in sand/soil, and inside this a movable metallic tube, 1m long and 38mm diameter, closed at the base with a plastic cover and with two slits 10mm wide and 300mm long cut on opposite sides. These collected sand creep at the surface. Similar traps were made so that they collected sand at heights up 0-300mm and 300-600mm above the ground. A sand trap, made according to the design of Jensen *et al.* (1984), was also installed at the Baja site: this collects sand at different heights up to 600mm. Designs of Leatherman (1978) were also used. An array is shown in Plate 11. The Baja location measured sand creep by placing plastic containers with a slit in the cap, vertically into the sands. These were orientated so that creeping sand could be collected from the north east through to north west. Two open pit sites at Baja (Baja 1 and

Plate 10. Wadi el-Khowi. In the Dongola Reach this irrigation canal was dug in the 1990s but was overwhelmed by sand sheets and then dunes, before an irrigation supply was provided (photo R. N. Munro, 2005).

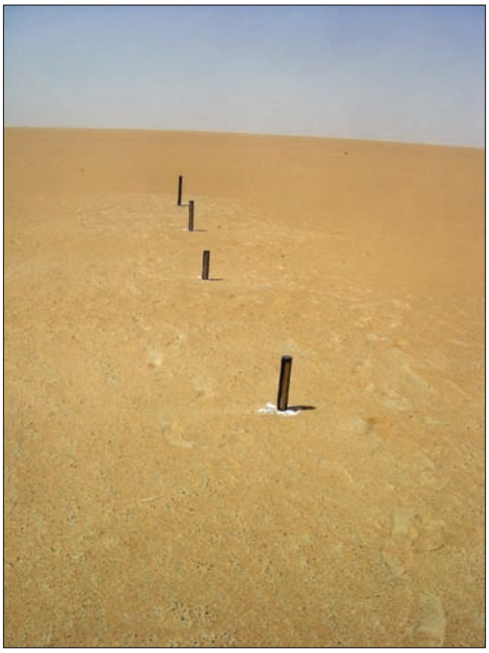

Plate 11. Baja. Array of vertical sand traps established by H. Abuzeid to measure sand drift (photo R. N. Munro October, 2004).

Plate 12. Goleid Plains, south west of Dongola. Sand trap of the type used to collect sand on the Goleid Plains and in the Wadi el-Khowi. The original pit is enlarged and a steel measuring rod inserted inside to assess volume change (photo R. N. Munro, March 2005).

2 respectively) were measured for some 639 and 709 days.

Open pit traps (Plate 12) were placed at three key locations: on the right bank situated on old Nile terrace alluvium downwind of barchan dune fields (sand trap sites 112 and 141); on the left bank on higher level old alluvial fans of the Goleid Plains area (sand trap sites 63 and 64); and further south on the Goleid Plains at sand trap sites 96 and 97. These were large open sand traps converted from old soil description pits (originally 2m long x 1m wide x 2m deep): that these pits had been filled with sand was the inspiration to find out how often this occurred, how much sand was involved, and from what direction it came.

The pits were enlarged on the downwind side to 2 x 2 x 2m and a steel reinforcing rod inserted in the centre to act as a measuring bar for the depth of sand. Flags were placed around the sites to assist in location, wind direction measurement and warn passing vehicles of a large hole in the otherwise featureless desert plains. The method adopted for measurement was simple: as sand accumulated in the pit the heap inside was flattened by a labourer and the accumulated volume measured by noting the depth on the steel rod. Periodically all sand was dug out and removed away from the site to maintain an open void and allow moving sand to drop in. Measurements at these sites were made for 885 days. At Baja the pits were modified into a round shape to take account of variable wind directions. Neither this nor any method will trap all sand, since in a fierce storm a proportion will saltate right over the pit, but we consider that it provides a good indication of accumulation and far improves on any guess.

Climatic data on the area was obtained from the Sudan Meteorological Department, part of the Ministry of Environment and Physical Development for Atbara, Dongola, Wadi Halfa and Karima. Dongola is the station nearest to the sites. In northern Sudan wind data is taken at airfields (Dongola, ed-Debba and Merowe) but at the moment this has restricted access. A hand held anemometer (Kestrel 1000) however, was used to take routine measurement of wind speeds at sites to measure threshold velocities.

Late Quaternary History, Sand Sources and Sand Movement

The Nile system cut a broad trench into this area in the Pleistocene, and the present flood plain is the lowest of a series of terraces that extend on either side of the river. These alluvial plains are bordered by the Nubian sandstone

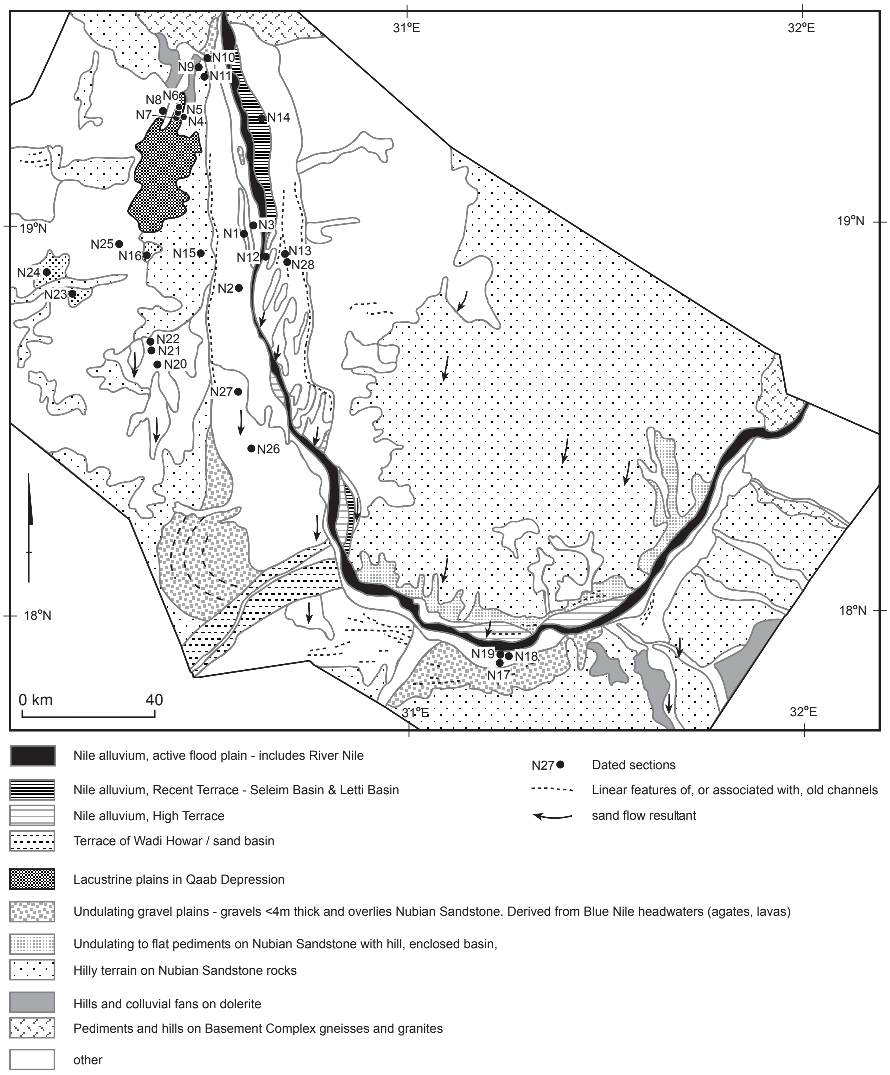

Figure 1. Geomorphic units and sand flow resultants of the Nile basin between Kareima and Kerma (reproduced with permission from Williams et al. *2010).*

plateau, itself a complex region with largely inactive alluvial and colluvial fans on margins of bedrock jebels. There are also some ancient stabilised dunes - Qoz (Williams *et al.* 2010). Recent studies on the Nile, and its defunct tributary the Wadi Howar, are elucidating the complex history of this area, and showing it to be closely linked with prehistoric settlements and early agriculture (Kröpelin 1993; Macklin and Woodward 1998; 2001; Pachur and Kröpelin 1987; Welsby 2001b; 2002; Welsby *et al.* 2001; Williams and Talbot 2009; Williams *et al.* 2010; Woodward *et al.* 2001; 2007). In this area the principle geomorphic units of the region are shown in Figure 1 (from Williams *et al.* 2010).

In the sand drift study area of the Dongola Reach changes to the regime of the Nile in the middle Holocene (Woodward *et al.* 2007) led to the abandonment of broad flood plains and an onset of aridity. At this time sands perhaps already moving swiftly southwards from the Egyptian border and beyond, began to form clusters of barchan dunes on the Wadi el-Khowi plain. For some millennia since then, it is clear, sand sheets and mobile aeolian sand dunes have moved southwards on both banks of the Nile, threatening if not ruining farms and livelihoods of rural communities.

Plates 13 and 14 shows the pattern of dune movement over 50 years around Barquat Kuluf on the right bank plains of the Wadi el-Khowi. Dune movements were measured using 1960 photography and Google Earth imagery, and dune fronts moved south at rates ranging from 6.9m / y^{-1} over a 51 year period, to 7.2m / y^{-1} over a 43 years period.

The landscape that stretches away from each bank of the Nile at the latitude of the Third Cataract near Dongola, and indeed all the way to Abu Hamad, is in effect a hyper-arid region, mostly devoid of settlement and vegetation over a vast area with only a few oases (on the left bank) where groundwater comes close to or rarely to the surface with undulating to mountainous dissected terrains on the Nubian Sandstone Formation. The Pre-Nubian erosion surface on Pre-Cambrian Basement Complex emerges to the north on both banks: areas that are currently the subject of gold exploration, but it is likely that prospecting could be extended for seeking out gold-bearing rocks to the Basement that is beneath the Nubian cover, and recent sands. Mining in northern Sudan may be the source of dust plumes generated recently (Plate 15).

Plate 13. Dunes around Barquat Kuluf. Aerial photograph from 1960. Sudan National Survey Authority archives.

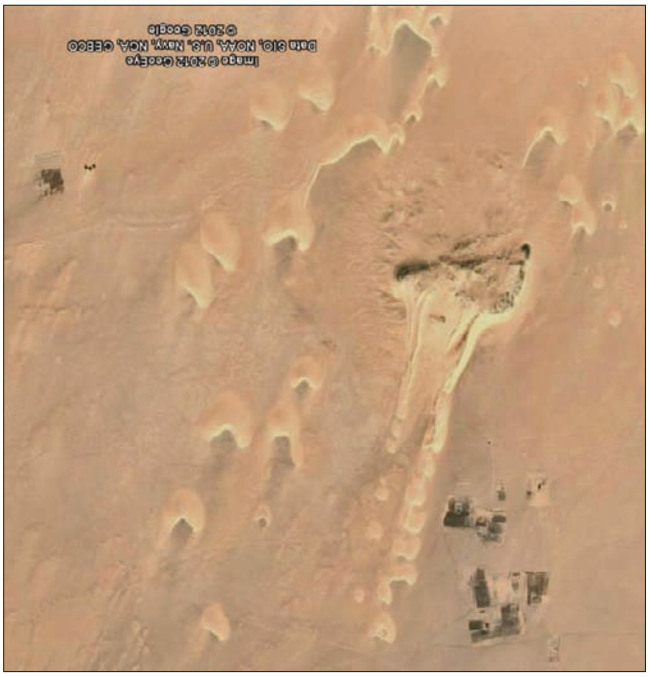

Plate 14. Barquat Kuluf area. Google Earth image, dated 16th November 2011. © Google Earth 2012.

On both banks of the Nile in this region aeolian sands appear to come partly from these Nubian Sandstone outcrops that flank the Nile, as suggested by Sandford (1935) and Edmonds (1942), and the Basement Complex granites that lie further north. A regional picture was given by Butzer (1980). Examination of satellite imagery shows an apparent greater amount of sands around the Nubian outcrops. Only a small amount of sand appears now to come out of the Nile from sandbanks at low water, and with the altered flood regulation of the Nile below Merowe dam this source may be further reduced. In addition rapid response of farmers to planting crops on the land exposed by annual drawdown of the Nile means that deflation from many areas is reduced. Where the exposed lands are extremely sandy though, planting is not practised, but spontaneous germination by indigenous plants, particularly *Tamerix aphylla*, can cover the exposed banks. It is not clear if such a pattern did or did not happen during Pharaonic to Medieval times. In years where exposed lands

Plate 15. *Dust plumes originating in northern Sudan. NASA Terra Modis Image. 25th February 2012. The dust movement, one plume originating from a single point in the Nubian desert, illustrates also the sand pathways over Sudan. Image: NASA, GSFC.*

were particularly sandy and dried out rapidly then colonisation by plants would likely have been minimal; in other years the drawdown may have had less serious consequences.

There is a steady flow of drifting sand that appears to have several origins and of different ages in northern Sudan and south-east Egypt:

Erosion by wind abrasion from Basement Complex granite and Nubian Sandstone landforms;

Deflation of these sands and movement southwards in form of sand sheets and dunes

Occasional, ephemeral, fluvial erosion of sandy landforms and deposition as loose unstable sands in wadis and plains, with deflation by wind of these to the south.

While very little sand is emerging along the shores of Lake Nasser/Nubia, sand drifting southwards from the Nubian Desert is approaching the new Merowe reservoir, as shown by a comparison of 1943 Trimetrogon photography and Google Earth imagery (Plates 16 and 17). Recent Google Earth imagery shows that the sand front is now well within the lake.

Plate 16. Trimetrogon oblique aerial photograph from 1943 of the area downstream from Abu Hamid shows the sand front advancing south. Compare with Google image Plate 17. USAAF 1943 Trimetrogon Photo: Roll 841 L-6412. Sudan National Survey Authority archives.

In Sudan, local lore states that on the left bank reaches between ed-Debba and Merowe, sand dunes on the left bank of the Nile have resulted from transportation across the Nile. This seems unlikely as any study of imagery will show the startling differences between banks (Plate 16). Sudanese dust storms, *haboob*, clearly can move enormous quantities of silt and clay sized materials to a great height but mobility of sand in this way would be limited. We examined this theory recently near ed-Debba where a farmer told us that the dunes there were mostly derived from the south west in the *khareef*, but also receive some sand from the Nile. Did he think sand was blown across the river? He was not sure. An examination of imagery does not support the idea of sand hopping across the

Plate 17. Google Earth image of the same areas as Plate 16 showing that the sand front has advanced several km towards the south south west. This sand front now debauches directly into the Merowe reservoir. This image is from 2003. © Google Earth 2012.

Nile. Indeed, Google Earth images show dunes entering the Nile but no trace of sand egression onto the opposite bank. In a few locations though, where the wind direction is at right angles to the river, some linear aeolian features are apparent and appear to continue across the river, so we feel that the matter is not quite resolved yet. One should note though that in this region the summer winds move sand northwards for a few months. Thus, sand can actually move back to the river and might appear to have come from the other side. Does all this debate matter though? Well, if sand is moving backwards and forwards, as H. Abuzeid found, and even jumping over the Nile, then sand stabilisation programmes need to consider the various seasonal movements in planning shelterbelts on the windward edges. The jury must remain out on this one, until empirical studies at key sites can resolve it.

Huge areas of Kordofan and Darfur are covered by *qoz* stabilised sand plains and transverse dunes (Warren 1970) that were stabilised at intervals in the Pleistocene and early Holocene (Wickens and Parry 1981). The *qoz* of western Sudan have a higher silt+clay content (over 10%) than mobile aeolian sands and stabilisation almost certainly was a product of soil formation on sands that had accumulated dust during more climatically stable period. These *qoz* remain stabilised even in modern arid climates, but are often said to be remobilising: in fact degradation of the *qoz* surface from rainfall erosion and land pressure causes a thin upper layer to be washed out or deflated respectively, and these sands, reworked aeolian, can become mobile again, as they lack any soil binding properties, and will flow over the older dune formations. We consider that the bulk of the stabilised *qoz* dune as a landscape feature remains stable.

There are relatively few patches of *qoz* found elsewhere along the Nile: relic dune fields occur south of the Bayuda hills, and north of Qoz Rageb in the Atbara – Gash inter-riverine plain (see Plate 18); other older fixed (stabilised) aeolian sand dunes appear to be sparse north of Khartoum marginal to the Nile: on the left bank west of Dongola traces of an older stabilised aeolian sand plain *qoz* were found in 2005 (dated at 6.5± 2.1 ka, Williams *et al.* 2010), and on the north-facing side of the Sabaloka massif, 90km north of Khartoum, a small relict *qoz* with an active surface was visited by R. N. Munro and M. A. J. Williams in February 2010 for OSL dating purposes (Williams 2010). Other *qoz* may have been more extensive and largely eroded away, but one might expect to observe more relict patches.

There is a lesson here of course for modern stabilisation attempts: that vegetating dunes and sand sheets with shelterbelts will not only lead to soil formation from biological and chemical processes but permit accumulation of dust, prodigious amounts of which fall in Sudan during the *haboob* season. Occasional dust fall observations made by the writer in Khartoum show up to 0.5mm per year accumulation in secluded traps, equivalent to about 1m of (unconsolidated) dust per 2000 years. Single storms (usually dust and rain combined) though can drop large amounts of dust on dunes, as seen south of Khartoum (Plate 19).

Plate 18. Stabilised relic aeolian sand dune in the old Gash delta area, 10km north east of Qoz Rageb. The surface is littered with stone tools. Subsurface soil has $CaCO_3$ rhizo-concretions. Age of dunes likely Pleistocene with stabilization in the early Holocene (photo R. N. Munro, 2011).

Lessons from Sand Stabilisation Projects applied to Archaeological Sites

The problem of sand encroachment has not diminished

Plate 19. Dust fall on an active sand dune 50 km south of Khartoum towards Geteina after rainfall. Rainfall consolidated the dust into a hard layer. Such layers can be preserved in dunes and form basis of a soil surface that stabilises the dune (photo R. N. Munro, 2010).

over the centuries, and there are many instances visible to the curious observer where lack of protection against strong winds and drifting sands has led to infilling of canals with temporary or complete failure of irrigation schemes.

Sand accumulation and movement at archaeological sites is both a blessing and a curse! On the one hand, the blessing, rapid burial of man-made structures placed, for whatever reason, in areas where sands were accumulating, meant that the underlying buried layers were often preserved.

On the other hand is the curse, where sand accumulates at a site that is under excavation. Usually this is after the field seasons (though it can be during or at the end and make life difficult). The increment of sand, perhaps several metres thick, has to be dug out again at the start of a new season: a task, which in the absence of labour, volunteer field staff may find themselves detailed to work at!

More recently, the seriousness and magnitude of the problem of sand movement in Sudan triggered many studies during the past 60 years that have aimed to identify the issues and make suggestions of remedial measures (Smith 1949; Hunting Technical Services *et al*. 1963; MacDonald, Hunting Technical Services and Gibb 1979; Agrar und Hydrotechnik 1986; 1989). Smith (1949) made the first scientific assessment of sand stabilisation and tree species in Sudan, and noted that the most northerly location of indigenous species in Sudan is on sandy soils, not the clays. Roots penetrate moist sandy soils rapidly and can then gain entry to the more nutrient-rich clays below. The Butana grass patterns (Worrall 1959; Wickens and Collier 1971) have their origins partly as vegetation germinating on sand stripes formed across the slope by runoff.

Implementation of programmes to limit sand incursion into farmlands on the Nile in northern Sudan, was initiated in northern Sudan from the 1970s onwards in the Wadi el-Kowi, the Seleim Basin, the Letti Basin, and the Affad, Argi and Tenges areas. The United Nations Sahelian Office (UNSO) funded projects in the Letti Basin; Agrar und Hydrotechnik (AHT) was involved in the Seleim and Affad areas; and SOS Sahel UK at Affad, Argi and other locations in Northern State, with the Forests National Corporation (FNC) (COWI Consult, 1991 and 1993; Jensen 1993; Intermediate Technology 1996; Ibrahim 1997; and SOS Sahel 1998). SOS Sahel International (UK) planted and managed shelter belts in the 1980s. Dunes and *mesquite* together have grown up to a height of 20m or more adjacent to farmland, and here the farmers do control it (Plate 20), and livestock are either barred from entering the forested dunes or kept inside them to avoid spreading seeds after foraging on the palatable and nutritious pods.

*Plate 20. Sand stabilisation, right bank of the Nile opposite ed-Debba. Sand dunes encroaching onto Nile terrace alluvium were stabilised using mesquite (*Prosopis juliflora*) in the 1980s and continue to protect the farmlands. The trees root down to groundwater and farmers rigorously control any spread of mesquite. This degree of self management by the communities is commendable (photo R. N. Munro, 2005).*

These projects used, in part, *mesquite (Prosopis chilensis and P. juliflora*) a multipurpose exotic from South America that was favoured at the time, but it is now banned except for limited dispensation for controlled sand stabilisation in Northern State due to its habit of spreading into farmland as livestock droppings spread the seeds. As a result huge areas of productive farmland, particularly in the Gash and Tokar (Plate 21) deltas of eastern Sudan, have been infested by *mesquite*.

In many schemes the established shelterbelts are being maintained (Ibrahim 1997), though often with great difficulty due to lack of funding by the State or Federal agencies once an internationally funded programme ceases: the large volume of sands moving towards the Nile on the right bank of course does not cease. The successful examples seen nowadays are the result of continued community dedication and commitment as direct beneficiaries.

Winds and Weather in Northern Sudan

Wind data were analysed for Atbara, Karima and Dongola measured at a height of 15.2m. At Dongola, located 55-70km

Plate 21. Tokar Delta. Mesquite infested irrigated lands at the Iron Bridge area, Tokar. The spread of mesquite in Tokar area is being reversed by an EU funded programme (SPCRP Model Projects) to clear the mesquite jungle, develop high quality charcoal, and mill dried seed pods into medicinal quality food and health supplement. Replication elsewhere is possible (photo R. N. Munro, Jan. 2010).

north of the four Goleid Plains sand drift sites, and 100km north of the Baja sand drift sites, winds are mostly unidirectional from the north all year with a mean wind speed of 4.1-5m/s. Atbara, 370km east of the Baja survey area, has winds from the north between October and end of June, but in July through September winds are from the west/south west and south south west reflecting the influence of the *khareef*, the summer south-west monsoon.

At Karima, close to the Merowe dam and 130km north north east of the Baja site, the winds are from the north for almost all the year, but in June and July are from the north north west, reflecting an influence of the Inter-Tropical Convergence Zone's movement, modified in all likelihood by the mountainous terrain of the Bayuda desert within the bend of the Nile. The sand drift sites showed that northerly drift of sand is common in the *khareef* season, but there is also a northerly drift that the basic data from the meteorological stations, rather surprisingly, do not show. Further analysis of this data is required as this will be important in any assessment for protecting sites from drifting sand, and the planning of wind and shelter breaks.

At Dongola airport (data provided from the Meteorological Dept.) over a two year period from April 2005 – end March 2007, climate data showed the following:

a total of 14.2mm of rainfall was recorded, all but 0.8mm was in one year;

average wind speeds ranged from 4m/s to 6m/s with maximum gusts ranging between 14m/s and 19m/s and highest in July;

wind directions were north to north north west and do not show the southerly (west to south south west) *khareef* winds that are more common at Atbara and Khartoum but are seen at ed-Debba;

days with severe sand storms and with visibility of 1km or less amounted to 17 and 20 in 2005-6 and 2006-07 respectively;

days with good visibility and no strong gusts amounted to 193 and 237 days in 2005-2006 and 2006-2007 respectively.

Dune Movements

Measurements by H. Abuzeid in the Wadi el-Khowi using pegs showed a movement of 11.16m to the south over a 634 day period, or 6.33m / y^{-1}. Without a reference point downwind or some adjacent point it is difficult to measure progress, but a few sites showed results using multi-temporal photography: individual dune movements ranged from 6m/ y^{-1} for large dunes and 23m/ y^{-1} for small dunes. Ibrahim (1994) showed that in northern Sudan small barchans move up to 30m/yr. Using sequential aerial photography, starting in 1943 with Trimetrogon, we have been able to monitor dune movement of the Wadi el-Khowi barchans. The group of dunes shown in the comparative images of 1960 and Google Earth show similar positions (Plates 13 and 14) and characteristically dunes had moved together southwards as if one organic unit. In the Wadi el-Khowi it is apparent that in addition numerous other small southward-moving barchans have been forming that were not there in the 1960s. The rapid movement of dunes too, whilst uncovering some archaeological sites for the first time in decades and necessitating re-survey, is covering up others.

Sand Drift Data Results

The sand drift data measured by Abuzied (2009) in Northern State of Sudan provided planners with clear and unquestionable proof of the amounts of sand that drift across the northern plains of Sudan. The research also showed that sands drift in different directions. Earlier studies in the region examined sand sheet movement and estimated advances of more than 55m/year (SOS Sahel records 1988-98). Results from the recent research are summarised in Table 1, and include:

In the Wadi el-Khowi area of the right bank of Nile south east of Dongola, a range of 15.7 – 17.4m^3/linear m^{-1} width/ yr^{-1}, or an average of 16.6m^3. Here, sands are deflated off barchan dune fields that are moving slowly southwards. These amounts represent the 'top end' of the drift rates. Most of the sand comes off these dunes but a significant amount is a counter-drift northwards. During the *khareef* season of south westerly winds up to 12% of the sand was moving from the south, south west, and west. The study showed that at one site with total sand drift of 16.62m^3/linear m^{-1} width/ yr^{-1} some 12% or 1.94m^3/linear m^{-1} width/ yr^{-1} were from the south. The right bank sands taken on an adjacent dune have a mean grain size of 0.29mm.

The average from Goleid and Baja areas showed a total sand drift of 2.9m^3/linear m^{-1} width/ yr^{-1} of which 1.07m^3 or 37% was from the south in the *khareef* season. It was known that there was a counter drift but not to what extent: this has implications for design of shelterbelts along canals. Source areas for the *khareef* sands are in the southerly moving el-Ghaba dune field that lies on the right bank of the Wadi Howar, and the el-Baba dune field in the Qa'ab depression.

At Baja, the drift rates were 3.65 and 3.6m^3/linear m^{-1} width/ yr^{-1}, for Baja 1 and Baja 2 respectively. Most (80%) of this was found to be within the 0-300mm height zone, with much smaller amounts at 300-600mm and as creep. The average grain sizes of drifting sand were 0.35mm.

These drift rates are minimum values since the sand trapping mechanisms used almost certainly did not capture all passing sands as they affect wind velocities around the site and some material will saltate over the site at higher wind speeds. The vertical tubes at Baja measured creep, sand at 0-300mm and 300-600mm. Most sand saltates below 300mm, and field observations show a fine mist-like stream of sand moving across the plains under modest wind velocities.

Threshold velocities for the region were calculated from wind speed measurement at 0.15m and 1m height at the Baja area in April 2006 (Abuzied, 2009). On average, sand movement was initiated at 5.6m/s. At 5.4m/s there was no discernible movement.

Table 1. Data from H. Abuzeid Sand Drift Measurement Sites (source: Abuzied, 2009).

Site No	Region	Easting UTM	Northing UTM	Start Date	End date	Accumulated sand drift rate m^3	Drift Rate $m^3/lmw^{-1}/yr^{-1}$
63	Goleid plains	0228230	2068292	22 Feb 2005	8 Aug 2007	9.82	4.1
64	Goleid plains	0223900	2068393	22 Feb 2005	8 Aug 2007	10.27	4.2
97	Goleid plains	0225710	2053202	22 Feb 2005	8 Aug 2007	10.98	4.53
96	Goleid plains	0232218	2051127	22 Feb 2005	8 Aug 2007	9.17	3.78
Baja 1	Baja	0256931	2016741	1 Feb 2005	8 Aug 2007	6.93	3.57
Baja 2	Baja	0257011	2016811	9 Nov 2005	8 Aug 2007	6.16	3.52
112	Wadi el-Khowi	0237107	2090079	18 Mar 2005	7 Aug 2007	41.53	17.4
141	Wadi el-Khowi	0237390	2092343	18 Mar 2005	7 Aug 2007	37.5	15.7

Notes
Drift rate is given as $m^3/lm\ w^{-1}/yr^{-1}$ which is: m^3 per linear metre width per year
Site 112 lies 3.8km south of source dunes

Choice of Species in shelterbelts

The establishment of a shelterbelt that is going to be drip or surface irrigated requires a substantial investment. The key issue is to ascertain the availability of Nile or groundwater to allow seedlings to survive (BGS 1990) and become established for the long-term without further irrigation.

The next stage is to establish a fence or ideally a checkerboard framework of fences (usually date palm frond fences) of 4 x 4m up to 20 x 20m dimensions. Into the checkerboard box are transplanted six-month old and sun hardened seedlings: these will form the future shelterbelt.

A wide range of appropriate indigenous species exists in Sudan and respond well to irrigation (Plate 22) and with proximity to the Nile (Plate 23). The consensus amongst Sudanese sand stabilisation foresters now is that, with a few tested exceptions, adoption of indigenous plants, rather than *mesquite* and other fast growing exotics, is more appropriate, especially for external shelterbelts where there is a very harsh arid environment. At archaeological sites it may be desirable to plant species that were growing there in the past, if this is known. Despite the usefulness of *mesquite* as shown in the Tokar Delta it is perhaps wise that it is not included in any programme for shelterbelts at archaeological sites: its roots spread laterally and downwards rapidly and could disrupt unexcavated remains.

Plate 22. Irrigated shelterbelt trail using Acacia mellifera (kitr)*, New Hamdab scheme. Indigenous species like* kitr *grow well with irrigation, and are hardier than many introduced exotic species (photo R. N. Munro, January 2012).*

Plate 23. Indigenous Acacia nilotica *and halfa grass along the Nile at Kawa. These trap sands emerging from Nile sand banks (in background). It is not clear yet to what extent these species had colonised the Nile in Kushitic times (photo: R. N. Munro, January 2012).*

On active dunes, field practice and applied research made by SOS Sahel in the ed-Debba area (SOS Sahel, 1988-98) successfully stabilised dunes. They found that to establish trees on the top of a dune, the dune must not be more than 4m high. All planting above that height failed. The number of rows on the dunes depends entirely on the number of mechanical fence lines. Generally, tree spacing on dunes should not be less than 5 x 5m. In the sandy soils, soil conditioners such as farm yard manure, and filling pits with loamy fertile soil, were found to be essential for improving physical and chemical properties of the sandy soil.

Benefits

The potential long-term benefits from making protective measures on a development or conservation project where drifting sands cause problems are various:

Monumental Archaeology

Protection of monumental sites subject to an influx of aeolian sands that are scouring and abrading stonework and decorative features;

Downwind protection of the site from the strong winds that bring in wind-blown sand into monuments areas (a certain amount of sand will always drift through);

Planting trees within the archaeological areas contributes to amenity and micro-climate for the tourists and visitors in an otherwise bare and harsh areas (almost all the pyramids and archaeological areas in Sudan are notorious with harsh conditions not favourable to visitors and tourists).

Generation of employment opportunities and income improvement amongst villagers who live near the site and are maintaining the shelterbelts;

By sensible planning and management the shelterbelts can be used for protection and also help contribute towards the availability of fuel wood and animal fodder from use of multi-purpose trees and shrubs.

Agricultural Development

Protection of significant areas of supply canals and agricultural land from mobile sands.

Downwind protection of the livelihoods of villagers and farming families facing this danger.

Generation of employment opportunities and income improvement amongst forestry workers.

Contribution towards availability of fuel wood and animal fodder from use of multi-purpose trees and shrubs.

Other products from scattered shelter belt trees and shrubs suggest *dates, citrus, dom* and *hinna* as possibilities. These could be grown at intervals in the belt and the irrigation staff responsible for a particular stretch of a shelterbelt would have an added incentive to manage it. The harvesting potential of these tree crops though must be secondary to the initial purpose of shelterbelt planting.

Creation of a sense of security among the communities of the project.

Reclamation of land lost by burial under sands, or reclamation of unused desert lands.

To contribute towards increasing the vegetation cover in the region, to help reduce global gas emissions and ultimately global warming.

Monitoring of Winds and Sand Drift

It is important to observe the diurnal and annual patterns of winds in an area. R. N. Munro and Babiker el-Hassan installed five instruments in the Yemen Tihama (Huntington Technical Services 1999; IFAD 2002), and were able to monitor shelterbelt growth against wind directions and strengths. The movement of sand through a belt is best done by routine monitoring on the ground. In northern Sudan it would be useful if similar climate stations could be installed at proposed sand stabilisation shelterbelt projects, whether for agriculture or archaeology: the accurate measurement of wind speeds and directions will help in the design of shelterbelts and monitoring their impact on reducing sand drift into infrastructure. If stations are placed in front of a proposed shelterbelt on the windward side this can show the *without project* situation. A second instrument in a site downwind of the same shelterbelt can assess the impact over several years (the *with-project* situation). These would be automatic stations with data loggers for periodic downloading, and also have the ability to send data in real-time through a mobile phone network to a database.

Conclusions

For several millennia, sand sheets and mobile aeolian sand dunes have moved into arid northern Sudan, threatening if not ruining farms and livelihoods of rural communities (Plate 24). In the past, Neolithic palaeochannels and settlements that had been located beside these Nile river courses were covered by sands in the Wadi el-Khowi. Pharaonic sites, Kushite Kawa and medieval churches elsewhere were buried by sands. The problem has not diminished over the centuries, and there are many instances visible to the curious observer where lack of protection against strong winds and drifting sands has led to infilling of canals, with resulting temporary or complete failure of irrigation schemes. Archaeological sites too have suffered from abrasion of stonework and burial of remains that could be on view. The data collected so far from the sand movement assessment has given planners, developers, farm managers and conservationists the unavoidable truth - sand drift in these regions is variable in amount and can come from several directions at different times of the year. From the drift rate data, planners can be advised that the issue is not just about the large, visually spectacular but slow-moving sand dunes, but it is much more to do with drifting sand sheets that may have their source areas from either large visible dunes, or far to the north over the horizon.

The sand sheets appear innocuous, yet can build up enormous volumes in a year, as demonstrated above. Importantly,

Plate 24. The burial of a house by a dune advancing over old Nile alluvium at Nawa, north of the Letti Basin, Dongola Reach (photo D. A. Welsby).

irrigation planners are now using these data and assessments to design canal alignments; developers in turn will be wise to pay heed to these issues and establish structured windbreaks upwind of canals (external shelterbelts), within fields (internal belts), settlements and infrastructure, and around monumental archaeological remains in need of conservation, to protect all these from drifting sands. Any stabilisation programme requires a supreme effort, with motivation within the communities and the responsible government agencies. Sufficient funds are needed to initiate any one project, maintain it, and monitor the effectiveness of the protective measures. These things can be done but will always be a challenge.

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