Human Impact on the Nile Basin: Past, Present, Future

Martin A.J. Williams

Abstract The gradual spread of plant and animal domestication throughout the Nile valley was associated with widespread deforestation, accelerated soil erosion and an exponential increase in the human population. The climate in the Nile basin during the first half of the Holocene was wetter than today. The advent of drier conditions began about 5,000 years ago and further accelerated the land degradation resulting from the spread of agriculture into the upland headwaters of the Blue and White Nile. A severe drought 4,200 years ago is evident in the strontium isotopic records from Lake Albert in Uganda as well as the Nile delta, and was associated with famine and severe social distress during Old Kingdom times. Deforestation in the Ethiopian highlands has led to accelerated soil loss from the Ethiopian headwaters of the Blue Nile/Abbai and Atbara/Tekezze rivers, with concomitant rapid rates of sedimentation in reservoirs downstream. By 1996, the capacity of the Roseires reservoir on the Blue Nile had been reduced by almost 60% through silt accumulation and that of the Khasm el Girba reservoir on the Atbara by nearly 40%. Historic fluctuations in Nile flood levels are in part related to El Niño Southern Oscillation (ENSO) events, with years of low flow often synchronous with years when the Southern Oscillation Index (SOI) is strongly negative. (The SOI is a measure of the surface atmospheric pressure difference between Darwin and Tahiti). Since over 300 million people will depend upon the waters of the Nile for their livelihood by the year 2020, a clear understanding of present land use and Nile flood history is essential for future planning.

1 Introduction

By the year 2020 over 300 million people will depend upon the waters of the Nile for their livelihood, so that a clear understanding of present land use and Nile flood history is essential for future planning (Hassan, 1981; Conway & Hulme, 1993;

M.A.J. Williams (✉)
Geographical & Environmental Studies, University of Adelaide, Adelaide 5005, Australia
e-mail: martin.williams@adelaide.edu.au

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Fraedrich et al., 1997; De Putter et al., 1998; Ayoub, 1999; Schumm, 2007, pp. 518–521; Wolman & Giegengack, 2007; Woodward et al., 2007). The lower Nile valley was one of the cradles of urban civilisation, totally dependent on floods from the upper Nile, just as Egypt is today. This great civilisation was based upon sedentary agriculture and a complex social structure (Said, 1997), in strong contrast to the hunter-gatherer communities of the Later Stone Age who occupied the Nile valley before the advent of Neolithic farming some 8,000 and more years ago (Arkell, 1949, 1953; Adamson et al., 1974; Clark, 1989). An interesting question is how these prehistoric communities might have interacted with the ever changing environments in the Nile basin, and what light this might shed upon present-day and possible future impacts.

2 The Neolithic Revolution

With the advent of forest clearing from Neolithic times onwards, and the exponential increase in the human population as a result of plant and animal domestication (Williams et al., 1998, pp. 239–241), there is widespread evidence of accelerated soil erosion in many parts of North Africa (Williams, 1988), including the Nile basin. One point to be borne in mind is that an impressive body of well dated evidence shows that the climate in the Nile basin and the adjacent Sahara during the Later Stone Age and early Neolithic was, in general, far wetter than today (Williams et al., 1974; Ritchie et al., 1985; Pachur & Kröpelin, 1987; Haynes et al., 1989; Pachur & Hoelzmann, 1991; Ayliffe et al., 1996; Gasse, 2000; Haynes, 2001; Nicoll, 2001, 2003; Schild & Wendorf, 2001; Hoelzmann et al., 2004; Jousse, 2004; Linstädter & Kröpelin, 2004; Smith et al., 2004; Kuper & Kröpelin, 2006; Kröpelin et al., 2008). It is also worth stressing that the later Neolithic and its associated clearing of woodland for agricultural purposes coincided with the progressive desiccation which followed nearly 10,000 years of higher rainfall over much of North Africa. The past 4,000–5,000 years were thus a time when human impact aggravated and accelerated the effects of the processes of desertification that were already in train. One particular extreme drought took place about 4,200 years ago and is evident in the strontium isotopic record in the Ugandan headwaters of the Nile (Williams et al., 2006) as well as in the Nile delta 7,000 km downstream (Stanley et al., 2003) and caused severe social distress in Old Kingdom times in Egypt and further afield.

3 Deforestation

In the Ethiopian headwaters of the Blue Nile and Atbara/Tekazze rivers, the long-term rate of erosion in the forested highlands amounts to 10–15 m/Ma when averaged over the past 30 million years (McDougall et al., 1975; Talbot & Williams, this volume). The present rate is one to two orders of magnitude higher

(Hurni, 1999; Williams, 2000). A similar bleak picture is also true of the once densely forested uplands of Uganda, which have been extensively cleared for agriculture, construction and fuel, including charcoal burning. Indeed, land use change may now outweigh climate as a geomorphic agent in the more elevated parts of the Nile basin, especially the Ethiopian and Eritrean uplands (Nyssen et al., 2004).

Nevertheless, year-to-year variations in precipitation, and intermittent prolonged droughts, continue to exert a major influence upon plants, animals and human societies in the drier portions of the basin (Williams, 2003a, b). Seventeen years of monitoring vegetation cover along the southern margins of the Sahara using satellite imagery revealed considerable variation from year to year in response to annual variations in rainfall (Tucker & Nicholson, 1999). An earlier study by Tucker et al. (1991) extending from 1980 to 1990 concluded that at least 10 years of observations were needed to detect any possible trends in the vegetation cover in this region.

4 The Role of ENSO

We now recognise the role of El Niño Southern Oscillation (ENSO) events and of regional anomalies in sea surface temperature in controlling the incidence of major floods and droughts in widely scattered parts of the world (Adamson et al., 1987; Williams & Balling, 1996; Camberlin et al., 2001; Mo et al., 2001; Mo & Häkkinen, 2001; Giannini et al., 2003), including the Nile basin (Osman & Hastenrath, 1969; Whetton & Rutherfurd, 1994; Camberlin, 1997; Wang & Eltahir, 1999; Nicholson & Selato, 2000; Whetton et al., 2000; Osman & Shamseldin, 2002; Bergonzini et al., 2004).

Sir Gilbert Walker defined the Southern Oscillation in 1924 (Walker, 1924). The Southern Oscillation Index (SOI) is a measure of the surface atmospheric pressure difference between Darwin and Tahiti and, as noted above, is widely used today in predicting wet and dry years. Time series analysis shows a statistically significant correlation between years of low Nile flow, drought in Indonesia and years of weak summer monsoon rainfall in India and eastern China (Whetton et al., 1990; Whetton & Rutherfurd, 1994; Whitaker et al., 2001). The converse is equally true, with years of extreme flooding synchronous in each of these regions. Short periods of exceptionally heavy rainfall and flooding in the central Sudan (Hulme & Trilsbach, 1989; Davies & Walsh, 1997; Williams & Nottage, 2006) are often broadly synchronous with extreme downpours in regions outside the Nile basin, including Somalia and Inner Mongolia, as noted by Williams and Nottage (2006). On 16 August 1999, Khartoum received as much rain in 6 hours as it normally received in the entire year. In fact, the extreme rain that fell in only a few days in August 1999 filled the depressions between the dunes in the northern Gezira and created the tropical rain-pools so well described almost half a century ago by Julian Rzóska (1961). This extreme event also re-created the type of landscape familiar to the hunter-gatherer-fishing folk of the Early Khartoum Tradition (Williams & Nottage, 2006).

5 Erosion

Despite earlier claims to the contrary, overgrazing was not responsible for the prolonged drought that began in the Sahel region of western Africa and in the Sudan in 1968 (Williams, 1995, 2000, 2002; Williams & Balling, 1995; Zeng, 2003). However, drought can lead to local overgrazing which can in turn accelerate soil erosion by wind and water and re-activate previously stable vegetated dunes. The southern margins of the Sahara, including Kordofan Province west of the White Nile, are covered in sand dunes that have remained vegetated and relatively stable for the last 10,000 years. Recent severe droughts combined with tree clearing and over-stocking have led to remobilisation of the once stable desert dunes in this region. Aubréville (1949) documented the replacement of tropical African rainforest by secondary savanna and scrub as a result of tree clearing and burning associated with shifting cultivation and coined the term desertification to encapsulate this process. He concluded that humanly induced deserts were forming in Africa in areas receiving 750–1,500 mm of rain a year.

Removal of forest in tropical uplands can alter the local hydrological balance through increased runoff and reduced infiltration. Accelerated loss of soil from highland catchments can lead to sedimentation in reservoirs far downstream and not always within the same country. By 1996, the capacity of the Roseires reservoir on the Blue Nile had been reduced by almost 60% through silt accumulation and that of the Khasm el Girba reservoir on the Atbara by nearly 40% (Swain, 1997). The silt was from the Ethiopian highlands. Hurni (1999) has monitored accelerated soil erosion in the Ethiopian uplands. In one region in Gojjam Province the area cultivated increased from 40% in 1957 to 77% in 1995, while the area under natural forest decreased from 27% to 0.3%. Annual rates of soil loss amount to about 2 mm/a) on mountain slopes, but attain rates of over 15 mm/a during cultivation years, or some 5–10 times more than in non-mountainous areas (Hurni, 1999). However, as Nyssen et al. (2004) point out so clearly, deforestation in the Ethiopian highlands during the last several thousand years has not been a linear process, with intervals of forest regrowth alternating with periods of forest removal, a view endorsed by Williams (2003b, pp. 38–41), who also noted that gully erosion in Ethiopia was sometimes triggered by earthquake activity and had nothing to do with human impact (Williams, 2003b, pp. 41–45).

6 Salt Accumulation

Further examples of adverse human impacts upon landscapes in the Nile basin include the progressive accumulation of salt in agricultural soils as a result of clearing of the native vegetation, poor canal maintenance and inadequate soil drainage. Salt accumulation is now a major problem in parts of Egypt irrigated from the main Nile and in sporadic patches along the White Nile (Williams, 1968; Williams et al., 1982). Fortunately for the peasant farmers of the Gezira irrigation area watered from the Blue Nile, both the water and the sediments from the Blue Nile are non-saline, so that the long-term prospects for farming on soils derived from Blue Nile – by far the majority, as noted by Tothill (1946) as long ago as 1946 – are reassuring.

This latter point brings us to the issue of sustainable land use in the Nile basin. As a broad generalisation, sustainable use of all natural resources depends upon two key principles or prerequisites (Robèrt, 1992; Williams, 1999, 2000, 2003). First, materials should not systematically be removed from any natural or humanly modified system, at a rate faster than the capacity of that system to produce a surplus. Second, materials should not systematically be added to any natural or humanly modified system at a rate faster than the capacity of the system to absorb and recycle such materials. Accelerated soil erosion breaches the first condition; excessive use of fertilizer, pesticide or herbicide breaches the second condition. On planet earth the only source of any *net increase* in primary productivity is through photosynthesis. All else is simply recycling what is already present on earth. Hence, great care must be taken to avoid undue deforestation and removal of the plant cover.

7 Conclusion

With a world population in excess of 6.5 billion, and an exponential increase in greenhouse gases, it is highly probable that current global warming trends are primarily anthropogenic (Menon et al., 2002; Meehl & Tebaldi, 2004). Among predicted outcomes are more extreme rainfall events and an increase in tropical summer rainfall, and an increase in the magnitude and frequency of droughts in semi-arid areas. The geomorphic consequences are likely to be greater runoff and sediment yield from tropical rivers. The interactions between land, ice, ocean, atmosphere and biosphere are complex and involve lags, thresholds and feedback processes, both positive and negative. It is possible that dust mobilisation from the southern margins of the Sahara may be both a cause and a consequence of drought in the Sahel region of Africa (Prospero & Lamb, 2003; Zeng, 2003).

The frequency of El Niño events has decreased during the last 1,400 years (Moy et al., 2002), but we do not know what influence the general increase in global sea surface temperatures will have upon the magnitude and frequency of future El Niño events. In the Sudan – the largest country in the Nile basin and Africa – the distribution of tree species is closely allied to rainfall and soil type (Smith, 1949), so that any future changes in precipitation, if sustained, will have an as yet unforeseen effect upon animal habitats and human land use. It is too soon to argue that the severe drought that afflicted much of the Nile basin from 1968 onwards is linked to anthropogenic influences on climate, since there were, after all, prolonged historic droughts in East Africa (Verschuren et al., 2000) before the Industrial Revolution and its associated emissions of carbon dioxide, methane and nitrous oxides. However, we are entering uncertain times, where forecasting the impacts of future change is not easy. It is, for example, hard to predict the climatic consequences of the albedo changes linked to the decrease in polar ice, since the response may be non-linear. Human societies will need to learn to live with uncertainty in a time of rapid environmental change, just as our ancestors did in the past.

References

Adamson, D. A., J. D. Clark & M. A. J. Williams, 1974. Barbed bone points from Central Sudan and the age of the "Early Khartoum" tradition. Nature 249: 120–123.

Adamson, D. A., M. A. J. Williams & J. T. Baxter, 1987. Complex late Quaternary alluvial history in the Nile, Murray-Darling and Ganges basins: three river systems presently linked to the Southern Oscillation. In J. V. Gardiner (ed.), Proceedings of the First International Conference on Geomorphology, Part II, Manchester, September 1985. Wiley, Chichester, pp. 875–887.

Arkell, A. J., 1949. Early Khartoum. Oxford University Press, Oxford.

Arkell, A. J., 1953. Shaheinab. Oxford University Press, Oxford.

Aubréville, A., 1949. Climats, forêts et désertification de l'Afrique tropicale. Société d'Editions Géographiques, Maritimes et Coloniales, Paris.

Ayliffe, D., M. A. J. Williams & F. Sheldon, 1996. Stable carbon and oxygen isotopic composition of early – Holocene gastropods from Wadi Mansurub, north-central Sudan. The Holocene 6: 157–169.

Ayoub, A. T., 1999. Land degradation, rainfall variability and food production in the Sahelian zone of the Sudan. Land Degradation and Development 10: 489–500.

Bergonzini, L., Y. Richard, L. Petit & P. Camberlin, 2004. Zonal circulations over the Indian and Pacific Oceans and the level of Lakes Victoria and Tanganyika. International Journal of Climatology 24: 1613–1624.

Camberlin, 1997. Rainfall anomalies in the source region of the Nile and their connection with the Indian summer monsoon. Journal of Climate 10: 1380–1392.

Camberlin, P., S. Janicot & I. Poccard, 2001. Seasonality and atmospheric dynamics of the teleconnection between African rainfall and tropical sea-surface temperature: Atlantic vs. ENSO. International Journal of Climatology 21: 973–1005.

Clark, J. D., 1989. Shabona: an Early Khartoum settlement on the White Nile. In Krzyzaniak, L. & M. Kobusiewicz (eds), Late Prehistory of the Nile Basin and the Sahara. Studies in African Archaeology, Vol. 2. Poznan Archaeological Museum, Poznan, pp. 387–410.

Conway, D. & M. Hulme, 1993. Recent fluctuations in precipitation and runoff over the Nile sub-basins and their impact on Nile discharge. Climatic Change 25: 127–151.

Davies, H. R. J. & R. P. D. Walsh, 1997. Historical changes in the flood hazard at Khartoum, Sudan: lessons and warnings for the future. Singapore Journal of Tropical Geography 18: 123–140.

De Putter, T., M-F. Loutre & G. Wansard, 1998. Decadal periodicities of Nile River historical discharge (A.D. 622–1470) and climatic implications. Geophysical Research Letters 25: 3193–3196.

Fraedrich, K., J. Jiang, F-W. Gerstengarbe & P. C. Werner, 1997. Multiscale detection of abrupt climate changes: application to River Nile flood levels. International Journal of Climatology 17: 1301–1315.

Gasse, F., 2000. Hydrological changes in the African tropics since the Last Glacial Maximum. Quaternary Science Reviews 19: 189–211.

Giannini, A., R. Saravanan & P. Chang, 2003. Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. Science 302: 1027–1030.

Hassan, F. A., 1981. Historical Nile floods and their implications for climatic change. Science 212: 1142–1145.

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

Haynes, C. V., C. H. Eyles, L. A. Pavlish, J. C. Ritchie & M. Rybak, 1989. Holocene palaeoecology of the eastern Sahara: Selima Oasis. Quaternary Science Reviews 8: 109–136.

Hoelzmann, P., F. Gasse, L. M. Dupont, U. Salzmann, M. Staubwasser, D. C. Leuschner, & F. Sirocko, 2004. Palaeoenvironmental changes in the arid and subarid belt (Sahara-Sahel-Arabian Peninsula) from 150 ka to present. In R. W. Battarbee, F. Gasse & C. E. Stickley (eds), Past Climate Variability through Europe and Africa. Springer, Dordrecht, pp. 219–256.

Hulme, M. & A. Trilsbach, 1989. The August 1988 storm over Khartoum. Weather 44: 82–90.

Hurni, H., 1999. Sustainable management of natural resources in African and Asian mountains. Ambio 28: 382–389.

Jousse, H., 2004. Impact des variations environnementales sur la structure des communautés mammaliennes et l'anthropisation des milieux: exemple des faunes holocènes du Sahara occidental. Documents du Laboratoire de Géologie, Université Claude Bernard-Lyon 1, France, no. 160, 273 pp.

Kröpelin, S., D. Verschuren, A-M. Lezine, H. Eggermont, C. Cocquyt, P. Francus, J-P. Cazet, M. Fagot, B. Rumes, J. M. Russell, F. Darius, D. J. Conley, M. Schuster, H. von Suchodoletz & D. R. Engstrom, 2008. Climate-driven ecosystem succession in the Sahara: the past 6000 years. Science 320: 765–768.

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

Linstädter, J. & S. Kröpelin, 2004. Wadi Bakht revisited: Holocene climate change and prehistoric occupation in the Gilf Kebir region of the Eastern Sahara, SW Egypt. Geoarchaeology 19: 753–778.

McDougall, I., W. H. Morton & M. A. J. Williams, 1975. Age and rates of denudation of Trap Series basalts at Blue Nile gorge, Ethiopia. Nature 254: 207–209.

Meehl, G. A. & C. Tebaldi, 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305: 994–997.

Menon, S., J. Hansen, L. Nazarenko & Y. Luo, 2002. Climate effects of black carbon aerosols in China and India. Science 297: 2250–2253.

Mo, K. C. & S. Häkkinen, 2001. Interannual variability in the tropical Atlantic and linkages to the Pacific. Journal of Climate 14: 2742–2762.

Mo, K., G. D. Bell & W. M. Thiaw, 2001. Impact of sea surface temperature anomalies on the Atlantic tropical storm activity and West African rainfall. Journal of the Atmospheric Sciences 58: 3477–3496.

Moy, C. M., G. O. Seltzer, D. T. Rodbell & D. M. Anderson, 2002. Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. Nature 420: 162–165.

Nicholson, S. E. & J. C. Selato, 2000. The influence of La Niña on African rainfall. International Journal of Climatology 20: 1761–1776.

Nicoll, K., 2001. Radiocarbon chronologies for prehistoric human occupation and hydroclimatic change in Egypt and northern Sudan. Geoarchaeology 16: 47–64.

Nicoll, K., 2003. Recent environmental change and prehistoric human activity in Egypt and Northern Sudan. Quaternary Science Reviews 23: 561–580.

Nyssen, J., J. Poesen, J. Moeyersons, J. Deckers, M. Haile & A. Lang, 2004. Human impact on the environment in the Ethiopian and Eritrean highlands – a state of the art. Earth-Science Reviews 64: 273–320.

Osman, O. E. & S. L. Hastenrath, 1969. On the synoptic climatology of summer rainfall over central Sudan. Archiv fur Meteorologie Geophysik und Bioklimatologie B17: 297–324.

Osman, Y. Z. & A. Y. Shamseldin, 2002. Qualitative rainfall prediction models for central and southern Sudan using El Niño-Southern Oscillation and Indian Ocean sea-surface temperature indices. International Journal of Climatology 22: 1861–1878.

Pachur, H.-J. & P. Hoelzmann, 1991. Palaeoclimatic implications of Late Quaternary lacustrine sediments in western Nubia, Sudan. Quaternary Research 36: 257–276.

Pachur, H.-J. & S. Kröpelin, 1987. Wadi Howar: paleoclimatic evidence from an extinct river system in the southeastern Sahara. Science 237: 298–300.

Prospero, J. M. & P. J. Lamb, 2003. African droughts and dust transport to the Caribbean: climate change implications. Science 302: 1024–1027.

Ritchie, J. C., C. H. Eyles & C. V. Haynes, 1985. Sediment and pollen evidence for an early to mid-Holocene humid period in the eastern Sahara. Nature 314: 352–355.

Robèrt, K.-H., 1992. Det Nödvändiga Steget (The Natural Step). Falun, Sweden: Ekerlids forläg (in Swedish).

Rzóska, J., 1961. Observations on tropical rainpools and general remarks on temporary waters. Hydrobiologia 17: 265–286.

Said, R., 1997. The role of the desert in the rise and fall of Ancient Egypt. Sahara 9: 7–22.

Schumm, S. A., 2007. Rivers and humans – unintended consequences. In A.Gupta (ed.), Large Rivers: Geomorphology and Management. Wiley, Chichester, pp. 517–533.

Stanley, J.-D., M. D. Krom, R. A. Cliff & J. A. Woodward, 2003. Nile flow failure at the end of the Old Kingdom, Egypt: strontium isotopic and petrologic evidence. Geoarchaeology 18: 395–402.

Schild, R. & F. Wendorf, 2001. Geoarchaeology of the Holocene climatic optimum at Nabta Playa, Southwestern Desert, Egypt. Geoarchaeology 16: 7–28.

Smith, J., 1949. Distribution of tree species in the Sudan in relation to rainfall and soil texture, Bulletin No. 4. Sudan Government Ministry of Agriculture, Khartoum.

Smith, J. R., R. Giegengack, H. P. Schwarcz, M. M. A. McDonald, M. R. Kleindienst, A. L. Hawkins & C. S. Churcher, 2004. A reconstruction of Quaternary pluvial environments and human occupations using stratigraphy and geochronology of fossil-spring tufas, Kharga Oasis, Egypt. Geoarchaeology 19: 407–439.

Swain, A., 1997. Ethiopia, the Sudan and Egypt: The Nile River dispute. Journal of Modern African Studies 35: 674–694.

Tothill, J. D., 1946. The origin of the Sudan Gezira clay plain. Sudan Notes and Records 27: 153–183.

Tucker C. J. & S. E. Nicholson, 1999. Variations in the size of the Sahara Desert from 1980 to 1997. Ambio 28: 587–91.

Tucker, C. J., H. E. Dregne & W. W. Newcomb, 1991. Expansion and contraction of the Sahara Desert from 1980 to 1990. Science 253: 299–301.

Verschuren, D., K. R. Laird & B. F. Cumming, 2000. Rainfall and drought in equatorial east Africa during the past 1,100 years. Nature 403: 410–414.

Walker, G. T., 1924. Correlation in seasonal variations of weather IX: a further study of world weather. Memoirs of the Indian Meteorological Department 24: 275–332.

Wang, G. & E. A. B. Eltahir, 1999. Use of ENSO information in medium- and long-range forecasting of the Nile floods. Journal of Climate 12: 1726–1737.

Whetton, P. H. & I. Rutherfurd, 1994. Historical ENSO teleconnections in the Eastern Hemisphere. Climatic Change 28: 221–253.

Whetton, P., D. A. Adamson & M. A. J. Williams, 1990. Rainfall and river flow variability in Africa, Australia and East Asia linked to El Niño – Southern Oscillation events. In P. Bishop (ed.), Lessons for Human Survival: Nature's record from the Quaternary. Geological Society of Australia Symposium Proceedings 1, pp. 71–82.

Whitaker, D. W., S. A. Wasimi & S. Islam, 2001. The El Niño-Southern Oscillation and long-range forecasting of flows in the Ganges. International Journal of Climatology 21: 77–87.

Williams, M. A. J., 1968. Soil salinity in the west central Gezira, Republic of the Sudan. Soil Science 106: 451–464.

Williams, M. A. J., 1988. After the deluge: The Neolithic landscape in North Africa. In J. Bower & D. Lubell (eds), Prehistoric Cultures and Environments in the Late Quaternary of Africa. Cambridge Monographs in African Archaeology 26, BAR International Series 405, pp. 43–60.

Williams, M. A. J., 1995. Interactions of desertification and climate: present understanding and future research imperatives. Proceedings of the International Planning Workshop for a Desert Margins Initiative. Nairobi, January 1995, pp. 161–169. Reprinted in Arid Lands Newsletter (2001).

Williams, M. A. J., 1999. Desertification and sustainable development in Africa, Asia and Australia. Proceedings, International Conference on Desertification and Soil Degradation, Moscow, November 11–15, 1999, pp. 107–124.

Williams, M. A. J., 2000. Desertification: general debates explored through local studies', Progress in Environmental Science 2: 229–251.

Williams, M. A. J., 2002. Desertification. In I. Douglas (ed.), Encyclopedia of Global Environmental Change, Volume 3: Causes and consequences of global environmental change. Wiley, Chichester, pp. 282–290.

Williams, M. A. J. & R. C. Balling Jr, 1995. Interactions of desertification and climate: an overview. Desertification Control Bulletin 26: 8–16.

Williams, M. A. J. & R. C. Balling Jr, 1996. Interactions of Desertification and Climate. London, Arnold, 270 pp.

Williams, M. A. J., Medani, A. H., J. A. Talent & R. Mawson, 1974. A note on Upper Quaternary sub-fossil mollusca west of Jebel Aulia. Sudan Notes and Records 54: 168–172.

Williams, M. A. J., D. A. Adamson & H. H. Abdulla, 1982. Landforms and soils of the Gezira: A Quaternary legacy of the Blue and White Nile rivers. In M. A. J. Williams & D. A. Adamson (eds), A Land between Two Niles. Balkema, Rotterdam, pp. 111–142.

Williams, M., 2003a. Desertification in Africa, Asia and Australia: human impact or climatic variability? Annals of Arid Zone 42: 213–230.

Williams, M., 2003b. Changing land use and environmental fluctuations in the African savanna. In T. J. Bassett & D. Crummey (eds), African Savannas: Global Narratives and Local Knowledge of Environmental Change. James Currey, Oxford, pp. 31–52.

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

Williams, M., D. Dunkerley, P. De Deckker, P. Kershaw & J. Chappell, 1998. Quaternary Environments. Second Edition. London, Arnold, 329 pp.

Williams, M., M. Talbot, P. Aharon, Y. Abdl Salaam, F. Williams & K. I. Brendeland, 2006. Abrupt return of the summer monsoon 15, 000 years ago: new supporting evidence from the lower White Nile valley and Lake Albert. Quaternary Science Reviews 25: 2651–2665.

Wolman, M. G. & R. F. Giegengack, 2007. The Nile River: Geology, hydrology, hydraulic society. In A. Gupta (ed.), Large Rivers: Geomorphology and Management. Wiley, Chichester, pp. 471–490.

Woodward, J. C., M. G. Macklin, M. D. Krom & M. A. J. Williams, 2007. The Nile: evolution, Quaternary river environments and material fluxes. In A. Gupta (ed.), Large Rivers: Geomorphology and Management. Wiley, Chichester, pp. 261–292.

Zeng, N., 2003. Drought in the Sahel. Science 302: 999–1000.