ELSEVIER

Journal of Arid Environments 62 (2005) 587–596

Journal of
Arid
Environments

www.elsevier.com/locate/jnlabr/yjare

Flood-borne sediment analysis of the Hoanib River, northwestern Namibia

K. Leggett*, J. Fennessy, S. Schneider

Namibian Elephant and Giraffe Trust, P.O. Box 527, Outjo, Namibia

Received 1 April 2003; received in revised form 13 December 2004; accepted 27 January 2005

Abstract

The suspended sediment contained in six flood events in the Hoanib River catchment during the wet season of 1999/2000 were analysed for volatile (or low molecular weight) fine particulate organic material (FPOM), higher molecular weight FPOM and the total organic carbon (TOC). Samples were evaporated to dryness at 80 °C, then heated in a high temperature oven to 250, 550 and 850 °C. The results show that the amount of sediment carried during the flood events varied between 1.54 and 31.27 g/L, with an average of 14.62 g/L. The amount of suspended sediment in the flood-waters (2.789–616.359 × 10^6 kg) was found to be dependent on the timing and duration of the flood event. The largest percentage of organic material was found in the volatile FPOM fraction (5.77 ± 6.26%), with lesser amounts being found in the higher molecular weight FPOM (3.36 ± 0.62%) and TOC (4.93 ± 1.86%) fractions.

Keywords: Ephemeral rivers; Flood-borne sediments; Organic carbon content

---

1. Introduction

There are 12 major westerly flowing ephemeral rivers of northwestern Namibia, including the Hoanib River (Fig. 1). According to Vogel and Rust (1987), the

---

*Corresponding author. Tel.: +264 67 313701
E-mail address: keal@iway.na (K. Leggett).

0140-1963/$ - see front matter
doi:10.1016/j.jaridenv.2005.01.020

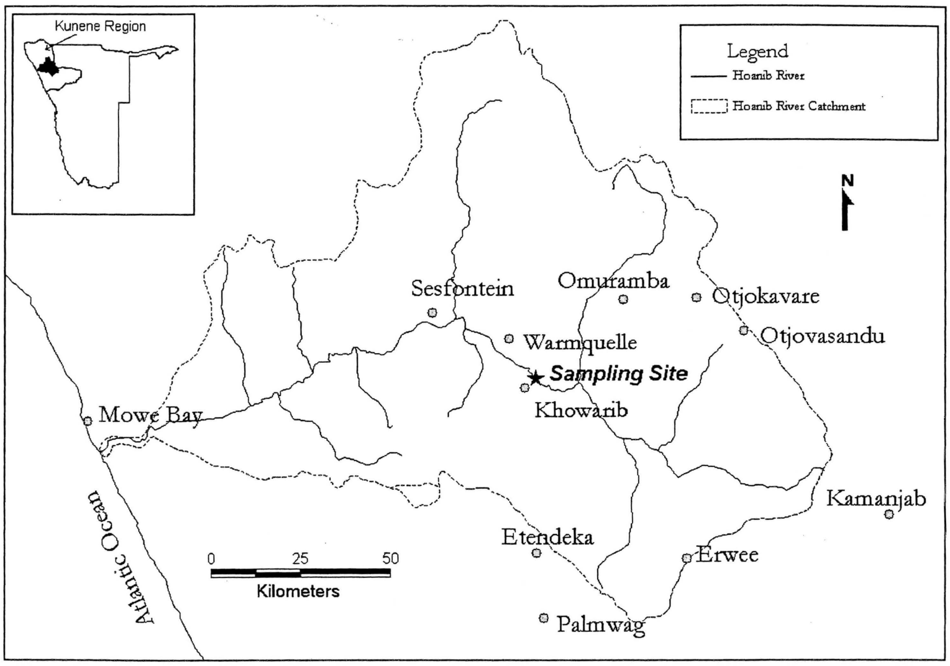

Fig. 1. Hoanib River catchment, northwestern Namibia, location map. Sampling site is indicated by a star.

Hoanib River is 238 km long and has an average gradient of 0.48%. It normally ends in an extensive floodplain on the inland side of an approximately 10 km wide dune belt that run parallel to the coast and it is only during exceptional rainfall years (like the 1999/2000 wet season) that the river breaks through the dunes.

The fluvial processes involved in shaping the sedimentology of ephemeral rivers are well recorded (e.g. Baker et al., 1988, p. 96; Graf, 1988, p. 45; Jacobson et al., 2000a). The flood events in the westerly flowing ephemeral rivers of northwestern Namibia are both episodic and aggradational in nature. The sand-choked beds of the tributary rivers, which feed the main channel, tend to widen as a result of such episodes. This causes the typical steep valley sides or vertical erosion. Studies by Jacobson et al. (1995) ascribed the aggradation occurring in these environments as a result of highly variable rainfall conditions, loss and destruction of natural vegetation, agricultural and forestry practices and soil loss as a result of human-induced factors.

Ephemeral river flood events not only cause erosion or denuding of soil in an area, but also impact on the ecology of the linear oasis, providing essential water for the coming season (Jacobson et al., 1995; Hoffman et al., 1999). In addition, flood events transport essential nutrients, soil, organic matter and seeds (Ward and Aumen, 1986; Jacobson et al., 1999). As one area is affected by such a loss, others downstream may benefit with sediment deposition thus in turn enriching the soil, of providing food and habitats for small animals, as well as playing an important role in riparian forest ecology (Jacobson et al., 1995; Abrams et al., 1997). Within catchments, rivers that drain into a 'floodplain' environment, like that of the Hoanib, are always potential areas of high deposition (Vogel, 1989; Jacobson et al., 2000a). These environments are nutrient-rich (inorganic and organic) and provide relatively fertile soils to promote the growth of vegetation, which would otherwise not be feasible in the arid Pro-Namib.

Geomorophologically, the Hoanib River has undergone three main stages. Before the 10th century AD, the climate was more humid than the present and the river underwent autochthonous valley formation (humid incision). By the 16th century, the climate had become more arid and river underwent a shortening period (arid aggradation). Currently, the river is again lengthening (arid incision) (Vogel and Rust, 1987; Rust and Vogel, 1988). The sediment that is presently accumulating in the Hoanib River flood plain is fine grained river-end deposits, terrigenous in nature, being eroded throughout the catchment and composes of both inorganic and organic fractions (Vogel and Rust, 1987; Jacobson et al., 1999).

The volume of the suspended loads carried by the episodic flood events in the ephemeral rivers are primarily dependent on the flow velocity of floodwaters, which in turn are dependent on the duration and quantity of precipitation in the catchment area. A rainfall gradient exists from east to west across the Hoanib River catchment. The eastern section receives an annual average of 325 mm, while less than 15 mm is the annual average rainfall at Möwe Bay on the Atlantic coast (Jacobson et al., 1995, p. 127; Anon, 1999; Leggett et al., 2001). Precipitation also varies spatially and temporally within the catchment area (Jacobson et al., 1995, p. 18–21; Jacobson et al., 1999; Leggett et al., 2001).

In light of the importance of flood events to the ecology of the ephemeral rivers, this study was undertaken to examine the amount of organic material contained in the suspended sediments in the Hoanib River. Organic material is of particular importance to the biota providing the necessary nutrients to ensure growth (Jacobson et al., 1999). A further motivation for this work was that there is little data available in the literature on the organic material contained in suspended sediments of flood events in ephemeral rivers.

2. Material and methods

Water samples were collected during six different flood events in the Hoanib River upstream from the sand weir in the Khowarib Schlucht (−19°17′00″S, 13°54′36″E), during the 1999–2000 wet season. The organic fraction contained in the suspended sediment of a 2 L samples of floodwater were analysed (vide Jacobson et al., 2000b for method). Jacobson et al. (2000b), heated suspended sediment samples to 550 °C for 2 h to determine the fine organic particulate matter (FPOM).

In this study, suspended sediment samples were heated to 250, 550 and 850 °C. The percentage weight loss on heating to 250 °C was attributed to low molecular weight FPOM, similarly, percentage weight losses at 550 and 850 °C were attributed to higher molecular weight FPOM and TOC, respectively. It is noted that at 250 °C, some of the higher molecular weight FPOM will have volatilized, while at 850 °C it is possible that some inorganic carbon compounds may also have been volatilized.

Where possible, samples were collected at 0, 6, 12, 18, 24, 36, 48, 60 and 72 h intervals during flood events. Some flood events did not last for the 72 h of the sample collection, while other flood events were only initial floods that were later swamped by larger flood events. Community members (CM), trained by the researchers on how to read a standard 100 mL-graduated rain gauge, measured rainfall in the eastern section of the catchment at Otjokavare (−19° 05′02″S, 14° 20′38″E). Rainfall was recorded each morning after rain, volume noted and gauge emptied, throughout the 1999–2000 wet season. Outside of the wet season, no rain fell in the catchment area. Observations on the number of days of each flood event were made at the Khowarib Schlucht.

One liter of re-suspended floodwater was filtered through a Watman no. 1 filter, the resultant sediment was transferred to a beaker complete with washings (deionized water) and evaporated to dryness (at 60 °C). The samples were heated at 80 °C for a further 12 h to ensure dryness. The sediment was then weighed with a Mettler 1200 scale. Approximately 2 g sediment was weighed (Mettler AE100) into high temperature crucibles and fired in a high temperature furnace (Labcon REX-C100 Series muffle furnace) for 30 min at 250 °C and weighed again on a Mettler AE100 scale after cooling. The process was repeated with the same sample at 550 °C, and again at 850 °C.

3. Results

Sediment loads carried in the Hoanib River floodwater varied from 1.54 to 31.27 g/L, with an average sediment load of 14.62 g/L. The amount of suspended sediment carried by each flood event varied and was determined by the quantity and distribution of rainfall. With the exception of one sample, the amount of suspended sediment also contained in a flood event decreased over the sampling period. In the sample where increased suspended sediment was observed, an increase in the precipitation at Otjokavare (see Fig. 2) resulted in successive flood events, carrying with them an increased suspended sediment load. Rainfall of greater than 40 mm in the eastern section of the catchment (Otjokavare) (Fig. 2) was required for a flood event to be recorded at Khowarib. The duration and quantity of precipitation determined the length and volume of the flood event. As the catchment is large and the rainfall not evenly distributed, some flood events (30 November 2002, 5 January 2003, 16 April 2003) were recorded for which no rainfall was observed at Otjokavare.

The greatest percentage loss of weight (average of 5.77%, S.D. = ±6.26%, $n = 24$) was observed when the suspended sediment was initially heated to 250 °C. This fraction corresponded to the volatile (low molecular weight FPOM) organic material. Further heating of the suspended sediment samples resulted in an average loss of 3.36% (S.D. = ±0.62%, $n = 24$) at 550 °C and 4.93% (S.D. = ±1.86%,

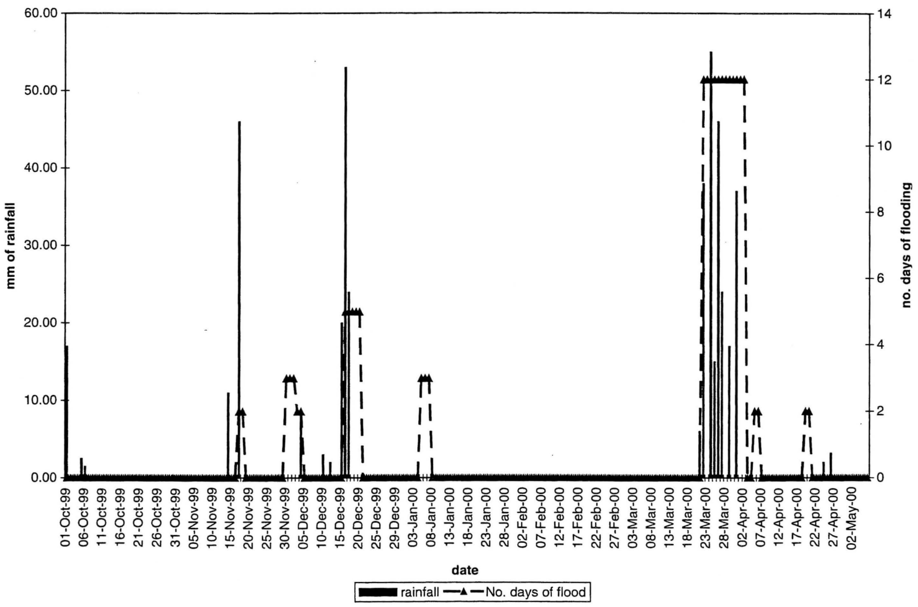

Fig. 2. Rainfall recorded at Otjokavare and length of flood events observed at Khowarib during the 1999–2000 wet season, Hoanib River catchment, northwestern Namibia.

$n = 22$) at 850 °C, which corresponded to the high molecular weight FPOM and TOC, respectively, Table 1.

The results show that the first flood (15–17th November 2003) contained the largest percentage of volatile organic material (22.51% and 23.81% for samples collected at 6 and 12 h, respectively). With the exception of the sample taken at 12 h on 24 March (18.40%), all additional floods carried a significant smaller percentage of volatile organic materials (3.52%, S.D. $= \pm 1.52$, $n = 21$). In comparison, the higher molecular weight FPOM remained similar. While the percentage of TOC varied, all samples exhibited losses on heating. This would infer that all the organic carbon in the suspended sediments had been volatilized at 850 °C. From the results it can be seen that the suspended sediment in floodwaters contained an average of 14.06% carbon component.

It was possible that the initial heating of sediment samples to dryness (at 60 °C), and then subsequent heating to 80 °C for 12 h, may not have completely dried the samples, with some water being trapped in pore spaces around the sediment molecules. If any water molecules were trapped around the sediment particles, heating to 250 °C could have liberated the water and the weight loss recorded as volatile organic material. To determine if there was any water remaining in the samples, three samples, two with a high percentage of volatile organic material (samples no. 1 and 15) and one with a relatively small amount of volatile organic material (sample no. 5) were heated as described, weighed after 12 h at 80 °C and

Table 1
Water samples collected during flood events in the Hoanib River (at Khowarib) during 1999–2000, the data includes date, time of collection, amount of sediment and percentage weight loss on heating (Con. = samples were either contaminated or lost during the heating procedure)

Sample	Flood duration	Total volume of flood water $(\times 10^6\,m^3)$[a]	Sampling time (h)	Sed. (g/L)	% weight loss on heating to 250 °C	% weight loss on heating from 250 to 550 °C	% weight loss on heating from 550 to 850 °C
1	15–17/11/99	1896.47	6	13.27	22.51	2.40	3.25
2	15–17/11/99		12	1.54	23.81	3.35	5.92
3	30/11–1/12/99	N.M.	0	24.53	4.11	3.72	4.31
4	30/11–1/12/99		6	21.75	5.61	3.75	3.99
5	30/11–1/12/99		12	7.96	4.17	4.21	3.97
6	30/11–1/12/99		18	31.27	1.94	2.45	3.58
7	3/12/99	N.M.	4	9.87	2.71	3.33	10.08
8	3/12/99		10	14.46	5.31	5.11	4.44
9	17–20/12/99	4269.6	0	23.54	2.10	3.30	3.57
10	17–20/12/99		2	20.29	5.45	2.87	3.77
11	17–20/12/99		36	1.84	3.39	4.12	4.83
12	5/1/00	N.M.	1	20.58	2.60	3.00	3.62
13	23/3–6/4/00	42,158.61	2	13.61	3.83	3.26	Con.
14	23/3–6/4/00		8	11.4	2.64	2.95	Con.
15	23/3–6/4/00		12	17.71	18.40	2.75	10.01
16	23/3–6/4/00		18	13.03	4.55	3.34	4.43
17	23/3–6/4/00		24	22.79	3.46	2.71	5.78
18	23/3–6/4/00		36	15.29	3.28	3.36	6.57
19	23/3–6/4/00		48	9.6	5.33	3.58	5.09
20	23/3–6/4/00		50	9.86	3.22	2.80	4.03
21	23/3–6/4/00		55	7.9	3.33	3.80	5.24
22	23/3–6/4/00		60	13.63	3.70	3.20	4.12
23	23/3–6/4/00		72	13.53	1.78	3.21	3.78
24	16–18/4/00	191.43	0	11.72	1.40	4.04	4.01
Average				14.62±7.14	5.77±6.26	3.36±0.62	4.93±1.86

N.M.—not measured at Sesfontein weir. Flood failed to reach Sesfontein weir.

[a] Data obtained from the Department of Water Affairs, Ministry of Agriculture, Water and Rural Development measured at the Sesfontein Weir (35 km downstream from Khowarib).

then further heated to 110 °C for 1 h and weighed again; the results are presented as a percentage weight loss (Table 2). The data were compared to the percentage loses occurring when the same samples were heated to 250 °C. It can be observed that the two samples with high volatile organic carbon percentages on heating to 250 °C showed only a minimal loss on heating to 110 °C. While, sample no.5 showed a higher percentage loss on heating to 110 °C than either samples no. 1 or 15, but still less than the percentage observed on heating to 250 °C. This indicates that there was very little residual water in the samples. Therefore, the observed percentage weight loss on heating to 250 °C can be assumed to be due to volatile or low molecular weight FPOM.

Table 2
Percentage weight loss on suspended sediment samples heated to 110 °C and 250 °C, Hoanib River catchment, northwestern Namibia

Sample	% loss on heating to 110 °C	% loss on heating to 250 °C
1	2.88	22.51
5	4.44	5.61
15	2.60	18.40

Table 3
Amount of sediment, low molecular weight FPOM, high molecular weight FPOM and other organic compounds contained in flood events in the Hoanib River, northwest Namibia

Flood event	Volume of flood[a] ($\times 10^6 m^3$)	Total sediment[b] ($\times 10^6$ kg)	Low molecular weight FOPM ($\times 10^6$ kg)	High molecular weight FOPM ($\times 10^6$ kg)	Other organic carbon compounds ($\times 10^6$ kg)
15–17/11/99	1,896.47	27.3	1.6	0.92	1.3
17–20/11/99	4,269.6	62.4	3.6	2.1	3.1
23/3–6/4/00	42,158.61	616.4	35.6	20.7	30.4
16–18/4/00	191.43	2.8	0.16	0.09	0.14

[a] Data obtained from Department of Water Affairs, Ministry of Agriculture, Water and Rural Development measured at the Sesfontein Weir (35 km downstream from Khowarib).
[b] Assuming that the average amount of sediment per litre is 14.62 g.

Using the data collected during this study it is possible to calculate the approximate amount of suspended sediment carried in a flood event (Table 3). Assuming that the average amount of suspended sediment carried in a flood event is 14.62 g/L and a large flood event such as that observed between 23 March and 6 April 2003 involving a volume $42158.61 \times 10^6 m^3$ (measured at Sesfontein weir), this flood would therefore have deposited 616.4×10^6 kg of new sediment in the lower Hoanib River and floodplain. This sediment contained an average of 5.77% (or 35.6×10^6 kg) volatile or low molecular weight FPOM, 3.36% (or 20.7×10^6 kg) high molecular weight FPOM and a further 4.93% (or 30.4×10^6 kg) of other organic material. The amount of sediment carried by flood events varied from 2.8 to 616.4×10^6 kg and was dependent of the volume and duration of the flood.

4. Discussion

The mean amount of suspended sediment (14.62 ± 7.14 g/L) observed in the floodwaters of the Hoanib River was slightly less than the amount of suspended sediment reported in the Kuiseb River (35.5 ± 20.6 g/L) (Jacobson et al., 2000b). A possible reason for this difference was probably the position of the collection points in relation to the lengths of the rivers. Jacobson et al. (2000b) collected their samples from the lower section of the Kuiseb River, approximately 210 km from the rise of the river. While this study collected samples from a mid-way through the Hoanib River, approximately 140 km from the river's rise. As a river's carrying capacity increases with flood volume and the distance it flows (Jacobson et al., 2000b), the difference in collection distance could account for the observed differences in the amounts of suspended sediment carried by the rivers.

The amount of suspended sediment that a river can carry is proportional to the velocity and volume of water in the riverbed. This is in turn directly related to the amount, duration and distribution of rains in the catchment area (Jacobson et al., 1995). From the results obtained during this study, at least 40 mm of rain was required in the catchment area for the first flood event to occur. The first floods are not long events as a lot of the water infiltrates the deep sand and gravel beds associated with the river channel filling it with water decreasing the volume of flow, as the flood passes. However, subsequent floods in particular major flood events such as the one that occurred from 23 March to 6 April, are less affected by infiltration and evaporation and tend to result in a much higher volume of floodwater reaching the lower ends of the rivers.

The amount of sediment deposited in the lower Hoanib River varied with the volume and duration of the flood event. There was up to a 220 times difference in the amount of sediment contained in each of the flood events. No comparable data could be found in the literature.

Jacobson et al. (2000b) reported an average value for FPOM (which represents a combination of the volatile and bound organic fraction) of 11.8% (S.D. = ± 2.7, $n = 20$). This percentage is only slightly higher than the volatile (low molecular weight FPOM) and higher molecular weight FPOM of 9.13% (S.D. = ± 6.29, $n = 24$) measured during this study. Both the volatile (low molecular weight FPOM) and high molecular weight FPOM were assumed to be highly combustible organic materials, e.g. wood fragments, seedpods and roots. The probable source for a great deal of the organic material was *Faidherbia albida* (Delile) A.Chev. (Fabaceae) which is the most abundant tree in the riparian woodland of the Hoanib River and are abundant along the entire length of the river (Fennessy et al., 2001). According to Jacobson et al. (2000b), *F. albida* seed pods were a major source of organic material found in the ephemeral river floods. There was a large variation in the FPOM (both low and high molecular weight) in the suspended sediment, with samples collected from the first flood event containing much higher levels of volatile material (low molecular weight FPOM) than any subsequent flood event. This could be due to the first rains leaching most of the relatively lighter organic material from the soil and carrying them in the runoff. Subsequent rainfall and flood events contained relatively smaller amounts of organic materials.

Other organic materials measured in the TOC fraction of the study were of a more intractable nature of unknown origin. However, it is possible that some of this fraction consisted of inorganic carbon compounds volatilized at 850 °C, e.g. calcium carbonate ($CaCO_3$) compounds, which exists in natural systems in mineral form (limestone) or can originate from organisms (bone or shell fragments).

5. Summary

The flood-borne sediments of the Hoanib River were analysed for organic materials; volatile (low molecular weight) FPOM, high molecular weight FPOM, and TOC. Floodwaters carried an average of 14.62 g/L of sediment of which 14.06% volatile, high molecular weight FPOM and TOC. The volatile fraction (Av. = 5.77%, S.D. = ±6.26%) in floodwater was consistently higher than the higher molecular weight FPOM (Av. = 3.36, S.D. = ±0.62%) and TOC (Av. = 4.93%, S.D. = ±1.86%) fractions. The amount of sediment that was contained in each flood was dependent on the duration and intensity of the flood and varied from 2.8 to 616.4×10^6 kg.

Acknowledgements

The authors would like to thank Dr. Mary Seely, Dr. Joh Henschel, Mr. Bertus Kruger and the staff of the DRFN for their help and assistance throughout the study period. Also thanks to Dr. Mattius Raab for his comments on the final manuscript. In addition, we would like to thank the Ministry of Agriculture, Water and Rural Development for their continued support and the Ministry of Environment and Tourism for their permission to conduct the study in northwestern Namibia. We also give our appreciation to Sida for funding the study, and to the NGOs and line ministries who have provided us with invaluable time, experience and effort. Most importantly, we extend our gratitude to the communities of the Hoanib River catchment. The analysis of all flood-borne sediments was conducted at Gobabeb Training and Research Centre, Namibia.

References

Abrams, M.M., Jacobson, P.J., Jacobson, K.M., Seely, M.K., 1997. Survey of soil chemical properties across a landscape in the Namib Desert. Journal of Arid Environments 35, 29–38.

Anon, 1999. Rainfall Data. Department of Meteorological Services, Ministry of Works, Transport and Communication, Windhoek, Namibia, 8pp (unpublished report).

Baker, V.R., Kochel, R.C., Patton, R.C. (Eds.), 1988. Flood Geomorphology. Wiley, New York (528pp).

Fennessy, J., Leggett, K.E.A., Schneider, S., 2001. *Faidherbia albida*, distribution, density and impacts of wildlife in the Hoanib River catchment, northwestern Namibia. DRFN Occasional Paper (in press).

Graf, W.I., 1988. Fluvial Processes in Dry Lands. Springer, Berlin, Germany (346pp).

Hoffman, T., Todd, S., Ntshona, Z., Turner, S., 1999. Land degradation in South Africa—Final Report. Department of Environmental Affairs and Tourism, South Africa (41pp).

Jacobson, P.J., Jacobson, K.M., Seely, M.K., 1995. Ephemeral Rivers and their Catchments: Sustaining People and Development in Western Namibia. Desert Research Foundation of Namibia, Windhoek, Namibia (160pp).

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S., 1999. Transport, retention and ecological significance of woody debris within a large ephemeral river. Journal of the North American Benthological Society 18 (4), 429–444.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S., 2000a. Hydrologic influences on soil properties along ephemeral rivers in the Namib Desert. Journal of Arid Environments 45, 21–34.

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S., 2000b. Variation in material transport and water chemistry along a large ephemeral river in the Namib Desert. Freshwater Biology 44, 481–491.

Leggett, K.E.A., Fennessy, J., Schneider, S., 2001. Rainfall, water sources and water use in the Hoanib River catchment, northwestern Namibia. DRFN Occasional Paper.

Rust, U., Vogel, J.C., 1988. Late quaternary environmental changes in northern Namib Desert as evidenced by fluvial landforms. In: Heize, K. (Ed.), Palaeoecology of Africa and Surrounding Islands, vol. 19. pp. 127–137.

Vogel, J.C., 1989. Evidence of past climatic change in the Namibia Desert. Palaeogeorapgy, Palaeoclimatology and Palaeoecology 70, 355–366.

Vogel, J.C., Rust, U., 1987. Environmental changes in Kaokoland Namib Desert during the present millennium. Madoqua 15, 5–16.

Ward, G.M., Aumen, N.G., 1986. Woody debris as a source of fine particulate organic matter in coniferous forest stream ecosystems. Canadian Journal of Fisheries and Aquatic Sciences 43, 1635–1642.