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HOANIB RIVER CATCHMENT STUDY, NORTHWESTERN NAMIBIA
Soil

May 2001

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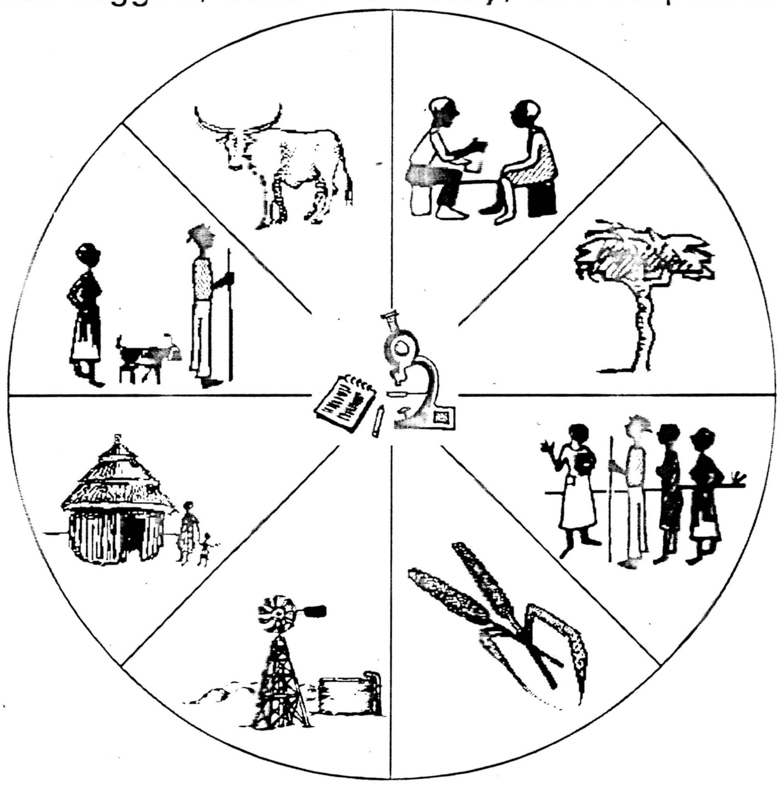

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GENERAL INTRODUCTION

This paper is a result of the research work carried out during the Hoanib River Catchment Study (HRCS) which began in 1998. The HRCS focused on appropriate basic socio-economic, biophysical and policy research on environmental issues important for sustainable use and development of natural resources in the Hoanib River catchment. The investigation examined present methods of lands and associated living conditions and highlighted potential alternatives to existing demands and expectations. Potential conflicts in the area revolve around the dynamics of different discourses and include: escalating, uncontrolled tourism; increasing aspirations and expectations of local residents often based upon popular misinformation; interactions between and among Non Government Organisations (NGOs), Government Ministries, and local people of different language groups; limited water availability and a relatively fragile environment.

This study has been a collaborative effort between relevant Government Ministries and Departments as well as local NGOs. The communities of the Hoanib River catchment are an integral part of the project, as a collaborative process has been used to identify problems, collect data and disseminate results.

As a result of the HRCS, four occasional papers have been published by the Desert Research Foundation (DRFN). These papers cover the general topics of soil, water, fauna, and vegetation in the Hoanib catchment, and are available for purchase through the DRFN library.

EROSION STUDIES AND SEDIMENT ANALYSIS IN THE HOANIB RIVER CATCHMENT, NORTHWESTERN NAMIBIA

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ABSTRACT

The erosion of topsoil from rural areas is a significant factor in limiting agricultural production as well as leading to land degradation. Research was carried out during this study to quantify the amount of sediment movement within the Hoanib River catchment area through the combined effects of wind and water erosion.

Experimental techniques are described and deficiencies of various measurement techniques are discussed. Several of the experiments were inconclusive due to wildlife, domestic stock, human interference or poor research design. The results obtained from suspended sediment analysis and characterisation of erosion types are presented.

The amount and type of suspended sediment carried by 6 flood events during the 1999-2000 wet season varied between 1.54 to 31.27g/L. The suspended sediment contained on average 14.06% carbon (organic) compounds and 85.94% inorganic compounds. In addition, it was possible to quantify the type of erosion occurring across the catchment by using a rapid appraisal technique along fixed transect lines. The results showed that sheet erosion was observed in 70% of all sites, while gully and wind erosion were observed in 50% and 25% of all sites, respectively.

KEY RESEARCH QUESTIONS

Erosion and sediment studies were undertaken in the Hoanib River catchment area to examine the following research questions:

(a) How much sediment is carried, either in a suspended form or swept along the riverbeds during flood events?

(b) What are the different forms of erosion occurring across the catchment and what is the extent of the erosion?

(c) Is the amount of erosion occurring across the catchment constant, or are some areas more subject to erosion than others?

BACKGROUND

Erosion affects more than 70% of Southern Africa's surface area and it has an immense impact on both local and regional level. It is generally regarded as the most widespread of all environmental problems (Hoffman *et al.*, 1999). It is estimated that human activities such as agriculture, forestry, construction and land clearing have, to date, degraded approximately 2 000 million ha across the world. A little over half of this degradation is as a result of human-induced water erosion and a third of it is due to wind erosion (IRIM, 2000; GCRIO, 2000).

Exact rates of erosion are virtually impossible to measure accurately and estimations are regarded as of little use (Hoffman *et al.*, 1999; Moore, 1988; Moon and Dardis, 1988). According to Hoffman et al. (1999), while erosion is considered not 'severe enough to destroy a country…its environmental, agricultural and economic consequences are certainly important enough to warrant detailed and thorough analysis'.

Three broad categories of soil degradation have been described in Southern Africa, including erosive and non-erosive forms (Hoffman *et al.*, 1999).

Erosive forms include:

(a)	Fluvial (water) erosion -	sheet and rill, gully and donga
(b)	Eolian (wind) erosion -	loss of topsoil, deflation hollows & dunes and overblowing

Non-Erosive forms include:

(a) Salinisation, acidification, water logging, pollution, soil mining and compaction and crusting.

The fluvial process in shaping the sedimentology of ephemeral rivers is well recorded (Picard and High, 1973; Baker *et al.*, 1988; Graf, 1988; Warner, 1988; Jacobson *et al.*, 2000a). The flood events in the westerly flowing ephemeral rivers of north-western Namibia are both episodic and aggradational. The sand-choked beds of the tributary rivers feeding the main channel tend to widen as a result of such episodes. This causes the typical steep valley sides or vertical erosion (Moore, 1988; Moon and Dardis, 1988). Studies have 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 (Moon and Dardis, 1988).

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 draining 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.

Within a highly variable rainfall environment, such as the Hoanib River catchment, a greater understanding of erosional events is required in order to assess whether or not sediments are being moved within, or lost entirely from, the system (MWTC, 1999).

Sediment, in particular suspended sediment carried by flood events, is comprised of both organic and inorganic particles of various sizes. The major classes of sediments, from the largest to the smallest size fractions are indicated in Table 1 below.

Table 1: Sediment classifications (after Friedman *et al.*, 1992)

Class	Size (mm)	Approx. size
Boulders	>256	Volleyball
Cobbles	>64	Tennis ball
Pebbles	>2	>Match head
Sand		
- V. Coarse	1.5	
- Medium	0.375	
- V. Fine	0.094	
Silt		
- V. Coarse	0.047	
- Medium	0.0117	No longer visible
- V. Fine	0.0049	

Clay	0.00195	

Sediments have been classified into four broad categories according to their origin with relation to the basin of water in which they are deposited: extrabasinal, carbonaceous, pyroclastic and intrabasinal (Friedman *et al.*, 1992).

Extrabasinal (terrigenous) particles

Terrigenous particles have been eroded from the land outside the body of water within which the deposition is taking place. Most terrigenous particles originate from bedrock. Particles are detached either by weathering, wind and water erosion, or catastrophic mass-wasting (landslides and glacial activity). During this process, particles either retain their chemical make-up or become chemically altered to clays and iron oxides (Friedman *et al.*, 1992). The Hoanib River sediments are predominantly terrigenous in origin.

Carbonaceous particles

These particles are organic in nature and are derived from either solid carbonaceous material (coal, amber, wax and kerogen) reworked from other geological formations, or from modern plant detritus (Friedman *et al.*, 1992).

Pyroclastic particles

These particles are derived during the explosive action of a volcano. Particles include rock fragments, single crystals and fragments of volcanic glass (Friedman et al., 1992).

Intrabasinal particles

These particles grow biochemically or chemically in the waters within which deposition is taking place. They include carbonate biocrystals, silica biocrystals, particles composed of evaporite minerals and minerals that grow at the water/sediment interface. Carbonate biocrystals are secreted by marine organisms such as foraminifers and molluscs. Sediment forms when these calcium carbonate skeletons are broken down physically or biologically. Diatoms, sponges and dinoflagellates form silica biocrystals. Diatoms are primary contributors to siliceous intrabasinal sediment in seawater and fresh water (Friedman *et al.*, 1992).

Sediments introduced into surface water are either deposited on the bed of the river or suspended in the water column (suspended load). The 'bed load' sediments consist of large particles that move by bouncing along the bottom. Generally, the suspended load in lotic (flowing) water consists of grains less than 0.5mm in diameter (Dunne and Leopold, 1978). A water body's suspended load is a component of the total turbidity that is made up of both inorganic and organic components.

In the twelve major westerly flowing ephemeral rivers of northwestern Namibia, including the Hoanib River, both the suspended loads and the bed load are carried at high velocities in the periodic floodwater events. The volume of these transported sediments depends primarily on the flow velocity of floodwaters. The higher the flood's flow velocity, the larger the particles that can be carried by the water. Any sediment transported by water is subject to deposition as flow velocity decreases (McCabe and Sandretto, 1985; Graf, 1988; Baker *et al.*, 1988; Jacobson *et al.*, 1995; and Jacobson *et al.*, 2000a).

SECTION I

INTRODUCTION

HOANIB RIVER CATCHMENT STUDY (HRCS) AREA

The Hoanib River catchment is one of twelve major ephemeral river catchments that occupy the semi-arid areas of northwestern Namibia. All twelve rivers flow into the Atlantic Ocean or end in the Namib Sand Sea. The Hoanib River originates in the western edge of the Etosha National Park (ENP), flowing through commercial and communal farming areas and, near its mouth, traverses the protected Skeleton Coast Park (SCP). The Hoanib River catchment occupies an area of 17 200 km^2, 3% of which lies in private farm lands, 91% in communal farm lands, and 6% is protected in both the Etosha National Park and Skeleton Coast Park (Jacobson *et al.*, 1995).

The Hoanib River constitutes the boundary between the former Damaraland and Kaokoland. Since Independence in 1990, these two areas have been incorporated into the Kunene and Erongo Regions (see Figure 1). The Hoanib River catchment can be divided into three broad geographic sections. The eastern section (east of the Khowarib Schlucht) that is dominated by a *Colophospermum mopane – Terminalia prunoides – Combretum apiculatum* vegetation type (Becker and Jurgens, 2000; Leggett *et al.*, 2001a). This becomes a *Colophospermum mopane – Terminalia prunoides* vegetation type as rainfall decreases, with annual grass (*Stipagrostis hirtigluma* and *Kaokocholoa nigrirostis*) dominating the plains (Becker and Jurgens, 2000; Leggett *et al.*, 2001a). The western section of the Hoanib River (from the Khowarib Schlucht to the Dubis wetlands) is dominated by *Colophospermum mopane* woodlands with seasonally dependent stands of perennial grasses (*Stipagrostis uniplumis* and *Stipagrostis hochstetterana*) (Becker and Jurgens, 2000; Leggett *et al.*, 2001a). In the extreme western section of the river - from the Dubis wetlands to the coast - virtually no vegetation exists outside the river course where *Faidherbia albida* trees are the dominant vegetation type with occasional seasonal grasses (mainly *Stipagrostis hochstetterana*) (Seely and Griffin, 1986; Nott, 1987; Viljoen and Bothma, 1990; Jacobson and Jacobson, 1998; Fennessy *et al.*, 2001). A broad flood plain (some 70km^2), in front of the moving dunes of the coast, offers substantial grazing for wildlife after flood events during the wet season (Leggett, 1998

The rainfall within the catchment is both varied and unpredictable, with a mean rainfall of approximately 350mm in the east of the catchment, to less than 15mm at Möwe Bay in the

Atlantic coast (Jacobson *et al.*, 1995; MWTC, 1999; Leggett *et al.*, 2001b). Drought is defined as two concurrent years where below average rainfall is recorded (Jacobson *et al.*, 1995). In many areas of Namibia rainfall is generally below average with occasional heavy rainfall years. In such an environment drought is normal. It is probably more accurate to refer to climatic cycles as either periods of aridity where below average rainfall occurs or wet periods when above average rainfall occurs (Jacobson *et al.*, 1995).

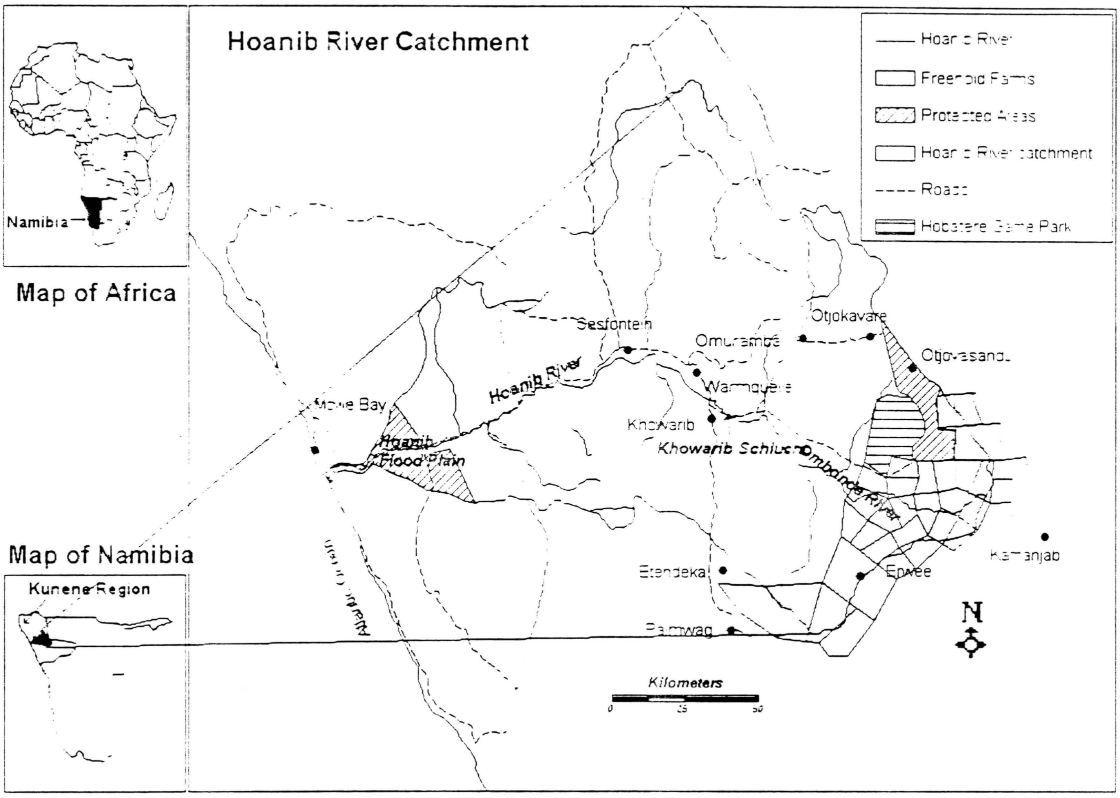

Figure 1: Hoanib River catchment location map.

The elevation of the Hoanib River catchment is neither gradual nor uniform, ranging from 0m at its mouth to approximately 1820m in the Etendeka/Grootberg ranges (Jacobson *et al.*, 1995). The erosion impact caused along these varied gradients is neither regular nor uniform, with high degrees of fluvial erosion caused by large episodic rainfall events and floods within the catchment (Picard and High, 1973; Baker *et al.*, 1988; Graf, 1988; Warner, 1988; Jacobson *et al.*, 2000a).

Sheet erosion, usually in combination with rill erosion, is predominant throughout the Hoanib catchment and is specifically pronounced in areas where the slope gradient is more acute i.e. Khowarib Schlucht (IRIM, 2000; GCRIO, 2000). Throughout the catchment the sediment yields have been seen to be directly correlated with slope, as mentioned, as well as the erodibility of the soils (Hoffman *et al.*, 1999). These fluvial processes result predominantly from mass precipitation, which, when combined with eolian (wind) erosion, are suggested to cause the greatest impact and loss of substrate in an arid and semi-arid environment (IRIM, 2000; GCRIO, 2000).

In both the communal and freehold farming areas, the processes involved in erosion have been enhanced by human activity. Furthermore, it is evident that the effect of rainfall on erosion in such an environment is markedly higher in an arid/semi-arid environment than it would be in others. Human-induced influences and activities in the catchment i.e. denudation of soil and vegetation around a village (piosphere effect), add to an already increasing problem. Not only does erosion inhibit crop or agricultural production, but it also impacts on surface water storage and has more recently been regarded as one of the most obvious indicators of desertification or land degradation (Hoffman *et al.*, 1999).

The often violent periodic flooding that occurs in the Hoanib River introduces large volumes of sediment into the river system annually (Jacobson *et al.*, 1995; Jacobson *et al.*, 1999). This sediment is terrigenous in nature, being eroded throughout the catchment area and is composed of both inorganic and organic fractions. In many seasons, the river flood volume is not sufficient to push the river through the coastal dune front to the sea. Under these circumstances, the floodwater banks up against the dunes causing a large floodplain where sediments are deposited (Vogel, 1989; Jacobson *et al.*, 1999).

This deposition process supplies relatively fertile alluvial soils to the floodplain and promotes the growth of nutritious grass species in an area where graze is a rarity. After such periods, large numbers of wildlife are attracted to these floodplain areas (Leggett *et al.*, 2001c). In years of high rainfall (e.g. the 1995 and 1999/2000 wet season), the flood events are sometimes large enough to break through the coastal dune system and push the river all the way to the coast. This deposits large volumes of nutrient rich terrigenous sediment into the coastal oceanic system, removing them from the terrestrial ecosystem. These events can contribute to the increased biological productivity of the coastal zone.

Erosion, with its effects, has important social, economic and environmental implications that require both understanding and assessment. Poor land and water management has resulted in erosion events that cannot be reversed. With a transitory population in the north-west, which is ever increasing, the need to undertake integrated monitoring and evaluation of indicators is of significant and increasing importance.

METHODS

SURFACE SOIL EROSION

Field sampling methods

Erosion transect lines were established at four different locations within the Hoanib River catchment. Each transect line was located within an area of different land use, terrain and soil type. The transect lines at each location were run along a distance gradient away from the river and were established to measure accretion or erosion of soil throughout the study period.

Geographic Positioning System (GPS) co-ordinates were taken from the middle of the river channel (see Figure 2). The following locations were chosen for the study:

- Serengeti Plains -19.41089°S, 14.11410°E
- Khowarib Schlucht -19.26869°S, 13.89108°E
- Khowarib Plains -19.22101°S, 13.49234°E
- Dubis Plains -19.22101°S, 13.49234°E

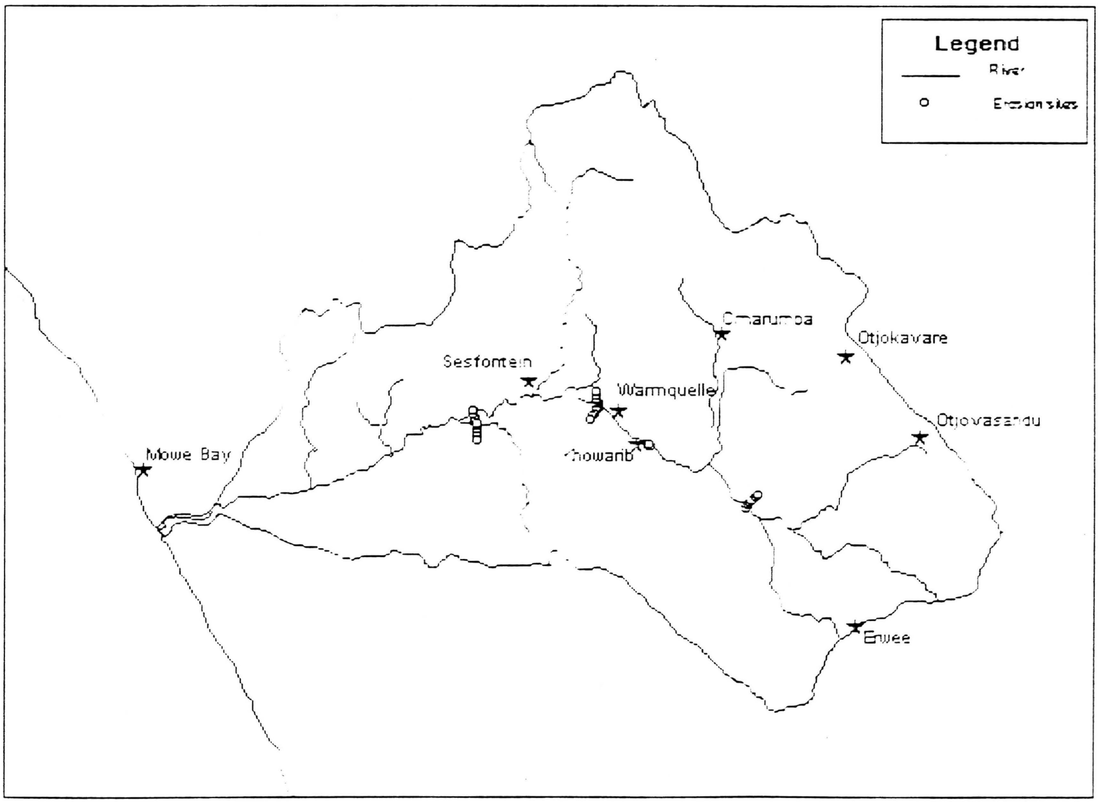

Figure 2: Hoanib River catchment erosion stake sites

Transects, two at each location, were then run in opposing directions and perpendicular from the Hoanib and Ombonde (extension of the Hoanib) River channel beds. 60cm erosion stakes were hammered into the ground until 30cm protruded at 25m, 50m, 75m, 100m, 150m, 200m, 350m, 400m, 500m, 1km, 2km, 3km and 4km distances from the river and across open plains. The top 30cm of the erosional stakes were painted white to increase their visibility and provide an accurate measuring point.

At each of the sites along the transect lines, GPS co-ordinates were recorded (Appendix A). A description of the terrain and soil type in the immediate environment of each site e.g rocky/shale or sandy soil, was also recorded.

Sites were only surveyed after a year and as it happened, after one of the highest seasonal rainfall periods in recent history. The accretion or erosion of soil was then recorded for each site along the transect lines. Measurements were taken based on the original 30cm protruding erosion stake buried at each of the sites.

SEDIMENT STUDIES

Flood-borne Sediments

A series of experiments was undertaken on water samples collected during six flood events in the Hoanib River 1999-2000. The water samples were analysed for sediment and basic chemical composition (inorganic and organic fractions). The method described is similar to that of Jacobson *et al.*, (2000b). However, a process of heating to 250°C, 550°C, 850°C was added to determine the volatile, bound and inorganic carbon (respectively) in the sediment samples. Jacobson *et al.*, (2000b) heated suspended sediment samples to 550°C for 2 hours to determine the fine particulate organic matter (FOPM).

The analysis of all flood-borne sediments was conducted at Gobabeb Training and Research Centre (GTRC) between the 28th May and the 2nd June 2000. The materials and equipment used in these experiments were obtained from the GTRC.

Field sampling methods

All samples were obtained from the Hoanib River and collected upstream from the sand weir in the Khowarib Schlucht (−19.26705°S, 13.89082°E). 2L samples of floodwater were collected from six different flood events between 18 November 1999 and 19 April 2000. Where possible, samples were collected at 0, 6, 12, 18, 24, 36, 48, 60 and 72 hr intervals during flood events. Due to the unpredictable nature of the flood events, it was not possible to collect samples during the entire timeline for most of the flood events. However, samples were gathered as close to these time intervals as possible. Some flood events did not last for the 72 hrs of the sample collection, while other flood events were only initial floods that were later swamped by larger flood events. Table 2 shows the duration and sample collection times during flood events.

Table 2: Occurrence, duration and sample collection times for flood events in the Hoanib River 1999-2000

1999-2000 wet season		
Date	**Duration of flood event (days)**	**Time of sampling (hrs)**
17/11/99	2	6, 12
30/11/99	2	0.16, 6, 12, 18
3/12/99	1	4, 10
16/12/99	5	0, 12, 36
5/1/00	2	1
23/3/00	12	2, 8 , 12, 18, 24, 36, 48, 50, 55, 60, 72
19/4/00	2	0

To assess the amount of sediment carried by a flood event, one litre of floodwater was evaporated to dryness and the remaining residue weighed.

Evaporating Flood Water Samples to Dryness

Steps:

(a) All evaporation beakers were washed in de-ionised water before being dried at 85°C.

(b) Once dried, the beakers were weighed on a Mettler P1200 top loading balance.

(c) Water samples were thoroughly shaken for 5 minutes to re-suspend all the sediment.

(d) Using a measuring cylinder, 1L of floodwater was measured and added to the beaker.

(e) Water samples were then evaporated to dryness at 85°C[1].

[[1]Note: After the sample had been evaporated for at least 12 hours, the supernatant liquid was filtered through a Watman No.1 filter paper. The sediment contained in the filter papers was washed back into the beakers with de-ionised water. In most cases this reduced the volume of liquid to be evaporated from 900mL to approx. 100mL. The samples were then allowed to evaporate to dryness overnight.]

(f) The dried samples were then weighed again on the Mettler P1200 to obtain the amount of sediment (g) contained in the water sample (L^{-1}).

The volatile organic, bound organic and total carbon fractions of the suspended sediment were determined by heating the solid residue (obtained from evaporation process outlined above) to 250°C, 550°C and 850°C, respectively. After heating to 850°C, the remaining residue was assumed to be the inorganic fraction.

High Temperature Furnace

Volatile Carbon:

(a) High temperature crucibles were cleaned with de-ionised water and dried at 85°C before being weighed. (All weighing was performed on a Mettler AE100 (4-decimal analytical balance).

(b) The crucibles were then washed in de-ionised water and pre-fired to 850°C in a Labcon REX-C100 Series muffle furnace to clean them of any impurities.

(c) Approximately 2g of dried sediment was transferred to the high temperature crucibles and weighed.

(d) Samples were fired to 250°C. After 30 minutes at this temperature, the samples were removed from the oven and allowed to cool in a desiccator. After cooling, the samples were weighed again to obtain the volatile organic fraction.

Bound Carbon:

(e) The samples were then returned to the muffle furnace and heated to 550°C and the process repeated to obtain the bound organic fraction.

Total Carbon:

(f) The above process was repeated with the remaining sample, which was heated to 850°C to obtain the total amount of carbon in the sediment sample.

RIVER-BORNE SEDIMENT

Field sampling methods

As described by Jacobson (pers.com., 1999), scour cords can assist in providing important information about sediment accretion or erosion and, in turn, channel changes as a result of a flood.

To measure the volume of sediment moving down the river in a flood event, six gauging points were established along the river. The gauges used in this study were similar to those described by Jacobson during his studies in the mid 1990s (pers.com., 1999), but differed slightly in that insulated red copper wire, as opposed to string, was used in this study. The wire was secured to a large bolt (70x20mm) and buried approximately 60cm deep in the riverbed. The wire was marked at the surface with a 3cm section of insulating plastic cut away from the copper wire core. Gauges were positioned at the following locations and GPS co-ordinates in the riverbed:

• Amspoort	-19.36189°S, 13.13870°E
• Khowarib	-19.25047°S, 13.84981°E
• Ombonde River	-19.31304°S, 14.01458°E
• Serengeti River confluence	-19.35638°S, 14.07813°E
• Ombonde River	-19.43760°S, 14.14263°E
• Ombonde and Otjovasandu River confluence	-19.46483°S, 14.23929°E
• Kamdescha	-19.42638°S, 14.32832°E

One more scour cord was to be added at the beginning the Hoanib Floodplain, but the early flooding of the Hoanib River on 16 November 1999 prevented this.

It was necessary to locate the sites near known or easily identifiable landform features so that they could be found after the floods. After seasonal flooding, the scour cord sample sites were revisited and excavated. As the channel bed was scoured, the cords, as described by Jacobson (pers.com., 1999), would bend downstream from the force of the flood. As the floods receded, fresh sediment would be deposited on top of the cords, making it difficult to locate them. The amount of sediment that had either been accreted or eroded from the riverbed could then be measured against the scour cord depth.

VEGETATION TRANSECT EROSION STUDIES

Field sampling methods

A rapid assessment of erosion was undertaken at vegetation sites along a distance gradient away from water sources as part of a greater vegetation study undertaken by the study team (see Leggett *et al.*, 2001d for more details). Eight different locations within the catchment, each with two transect lines 0-7km, were assessed for the type and degree of erosion.

Transects were undertaken at the following locations:

▪ Khowarib	-19.25601°S,	13.86680°E
▪ Sesfontein	-19.13543°S,	13.70391°E
▪ Omuramba	-19.02357°S,	14.09054°E
▪ Otjokavare	-19.06341°S,	14.34785°E
▪ Hobatere GP	-19.25325°S,	14.39414°E
▪ Serengeti	-19.41268°S,	14.11416°E
▪ Palmfontein	-19.65406°S,	14.22580°E
▪ Kaross (Etosha National Park)	-19.06341°S,	14.53519°E

The extent of erosion occurring within each plot was graded as low (1), medium (2) or high (3). For the purposes of this study, the types of erosion were defined by the following descriptions (R. Loutit pers.com., 1998):

- *Gully* where erosion was in the form of deep scars.
- *Sheet* where erosion occurred across a plain, exposing roots of trees and shrubs.
- *Wind* where erosion or accretion occurred around the roots of trees and shrubs, resulting in the vegetation appearing to be growing on mounds.

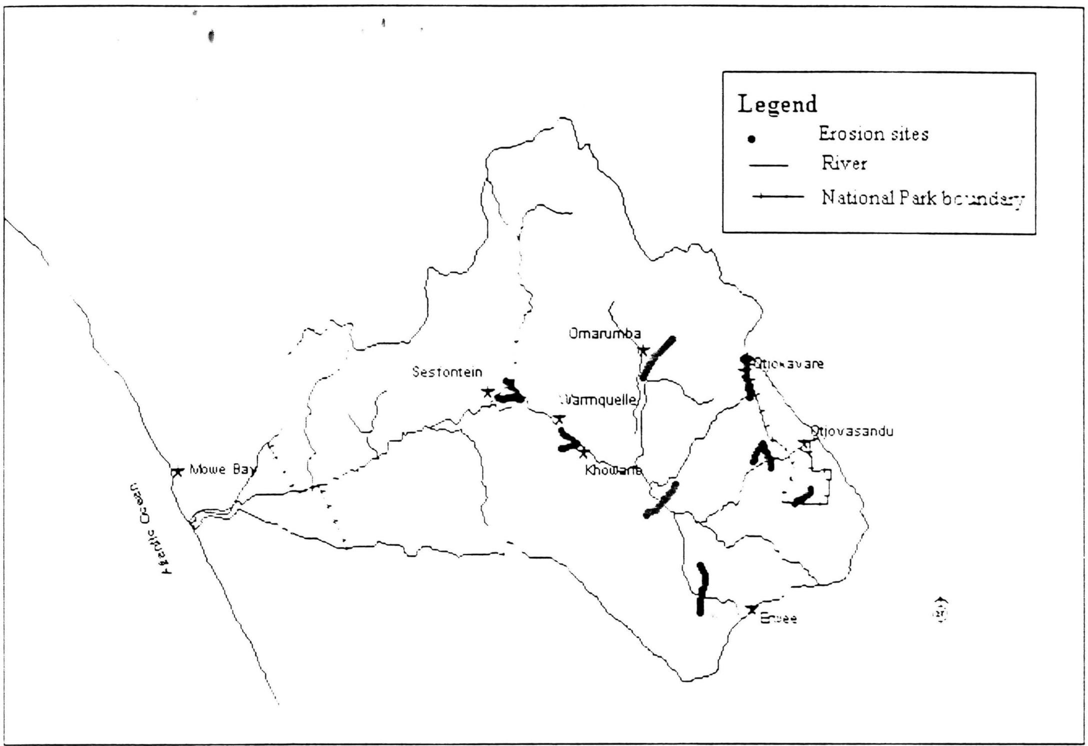

Figure 3: Hoanib River catchment vegetation erosion sites

RESULTS

Many of the erosional processes observed during this study are slow and only become significant, or even problematic, after several years. In a 2-year study it is often not possible to quantify a erosional process, however, it is possible to qualify the processes taking place.

SURFACE SOIL EROSION

Results obtained from the erosion transects are presented in Table 4. These results represent transects undertaken across different land use, terrain and soil types.

Table 4. Accretion or erosion (cms) at each site along the four transect gradients

	Serengeti plains		Khowarib Schlucht		Khowarib plains		Dubis plains	
Distance from river	North transect	South transect	North Transect	South Transect	North transect	South Transect	North Transect	South Transect
25m	2	B	L	L	1.2	4	1.5	-1
50m	0	5	L	L	1.2	0	-0.5	0.7
75m	1	-2	L	L	B	1.5	0.5	1.5
100m	-0.5	-2	L	L	0	1.2	1	0.5
150m	-4	24	L	L	3	0.5	3	0.2
200m	L	0	L	-0.5	1	1.2	B	0.1
350m	L	-2	L	1	4	3.5	3.5	-0.5
500m	L	L	L	1	0.2	1	0.5	-0.5
1km	L	L	B	1	2	-0.5	0.3	1.7
2km	L	L	L	L	-1	-7	2.5	0.2
3km	-1	L	L	L	0.5	T	11.5	1.7
4km	-1.5	L	L	L	-1	L	4	5

L (lost) - erosion stakes not found when surveyed.

B (broken) - the erosion stakes were found broken.

T (trampled) - the erosion stakes were found out of the original holes, though not broken.

Table 4 does not provide a complete data set for the erosion impact occurring throughout the different areas of the catchment. Several problems were encountered when the stakes were surveyed in 2000, as numerous stakes could not be found and others had been trampled or broken. The results showed that the erosion impact appeared to be random and most likely to be dependent on the substrate of the immediate area around the site. Areas containing hummocks, gullies and plains were more susceptible to erosional events (see Appendix A).

The Serengeti plains and Khowarib Schlucht transects provided no comparative data as the majority of stakes had been lost or removed from their original sites. The Khowarib plains and Dubis plains transects were compared for the erosion or accretion which occurred along the distance gradient – up to 500m away from the river, and then this compared to the total impact along the whole gradient. Interestingly, Khowarib plains sites (average of both the northern and southern transects) had both accretion and erosion with a range of between −7cm to +4 cm of topsoil removed or added. Overall there was an average accretion of 1.57 cm. A similar trend was observed at Dubis where again both accretion and erosion was observed across the transect in a range between −1cm to +11.5 cm, with an overall accretion of 0.7 cm. However, the Khowarib plains indicated an erosion impact in the sites 1 to 4km from the river with between −7cm and +2 cm of topsoil lost (average loss of 0.79 cm). The opposite effect was observed in the Dubis plains transects where an increased accretion rate of between 0.3cm to 11.5 cm (average accretion of 1.63 cm) was observed in the sites 1 to 4 km from the river.

FLOOD-BORNE SEDIMENTS

Samples were collected from flood events and analysed for the mass of sediment each flood was carrying and the organic and inorganic components of suspended material. The date, time of collection, amount of suspended material (sediment), and the weight loss on heating suspended solids to 250°C, then 550°C and finally 850°C are shown in Table 3.

Table 3: 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

Sample	Date	Time	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	18 11 99	6 hrs	13.27	22.51	2.40	3.25
2	18 11 99	12 hrs	1.54	23.81	3.35	5.92
3	30 11 99	10mins	24.53	4.11	3.72	4.31
4	1 12 99	6hrs	21.75	5.61	3.75	3.99
5	1 12 99	12hrs	7.96	4.17	4.21	3.97
6	1 12 99	18hrs	31.27	1.94	2.45	3.58
7	3 12 99	4hrs	9.87	2.71	3.33	10.08
8	3 12 99	10hrs	14.46	5.31	5.11	4.44
9	16 12 99	0hrs	23.54	2.10	3.30	3.57
10	16 12 99	2hrs	20.29	5.45	2.87	3.77
11	18 12 99	36hrs	1.84	3.39	4.12	4.83
12	5 1 00	1hr	20.58	2.60	3.00	3.62
13	23 3 00	2hrs	13.61	3.83	3.26	Con.
14	23 3 00	8hrs	11.4	2.64	2.95	Con.
15	24 3 00	12hrs	17.71	18.40	2.75	10.01
16	24 3 00	18hrs	13.03	4.55	3.34	4.43
17	24 3 00	24hrs	22.79	3.46	2.71	5.78
18	25 3 00	36hrs	15.29	3.28	3.36	6.57
19	26 3 00	48hrs	9.6	5.33	3.58	5.09
20	26 3 00	50hrs	9.86	3.22	2.80	4.03
21	26 3 00	55hrs	7.9	3.33	3.80	5.24
22	27 3 00	60hrs	13.63	3.70	3.20	4.12
23	27 3 00	72hrs	13.53	1.78	3.21	3.78
24	19 4 00	0hrs	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**

Con. – samples were either contaminated or lost during the heating procedure

The results from Table 3 show that the sediment carried in the flood events varied from one flood event to the next. In any one flood event there appeared to be a decrease in the amount of suspended material carried by the river over time. However, this varied significantly, though once rainfall had ceased in the catchment area, volume and velocity of the flood event also decreased.

The heating of the resulting suspended sediments to 250 °C, liberated the volatile organic carbon compounds from the sediment. Re-heating the same sediments to 550 °C liberated any organically bound compounds from the sediment. The final re-heating of the suspended sediments to 850°C liberated inorganically bound carbon, leaving only inorganic material in the heated material.

The highest percentage of volatile organic compounds appeared to be associated with the first flood event whereas the percentage of volatile carbon fraction decreased in subsequent flood events. The volatile carbon fraction also tended to decrease over time during a flood event, with the highest percentage of volatile carbon fraction being observed in the initial floodwaters. It appeared as though both organically and inorganically bound carbon fractions remained constant throughout all flood events. In addition, the percentages of both organically and inorganically bound carbon appeared not to vary significantly over the time interval of the flood. Inorganically bound carbon fraction showed a greater percentage variation in the suspended material than organically bound fraction.

The greatest percentage weight loss appeared to be on heating the samples to 250 °C. As the samples were evaporated to dryness at 80°C to avoid the loss of volatile organic carbon compounds, it was possible that some water molecules were trapped in the dried sediment. To eliminate the possibility that water evaporating from the dried samples contributed significantly to the fraction assumed to be the volatile organic fraction, selected samples were heated 110°C for an hour before being heated to 250°C. The method followed here is the same as already outlined for sediment analysis. The results of this experiment are shown in Table 4.

Table 4: Percentage weight loss on samples heated to 110°C and 250°C

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

The results from Table 4 show that in two of the samples tested, only a small percentage of the total volatile carbon fraction was liberated at 110°C. These two samples showed significantly greater weight loss when heated to 250°C. This showed that water or very volatile organic compounds made up only a small fraction of these samples. In the remaining sample, a significant percentage of the fraction was attributed either to volatile organic carbon or to water trapped in the sediment pores.

SEDIMENT SCOUR CORDS

After the above average rains of the 1999/2000 season, no scour cords were found at any of the locations in the riverbed. A lesson that can be learnt from this method is: prepare for the worst possible flood events, then use the precautionary principle and add a little more just in case. These results indicate that either the erosion of the sediment in the riverbed was exceeded 60cm, or so much sediment was deposited that it was impossible to find the cords through normal excavation methods.

VEGETATION TRANSECT EROSION

Figure 3 presents data collected from rapid erosion assessments conducted along the vegetation transect lines (see Leggett *et al.*, 2001d for details) at eight locations within the catchment. The data provided an indication of the varying erosion types and degrees along transect lines away from the water source (point of origin and taken as 0 metres).

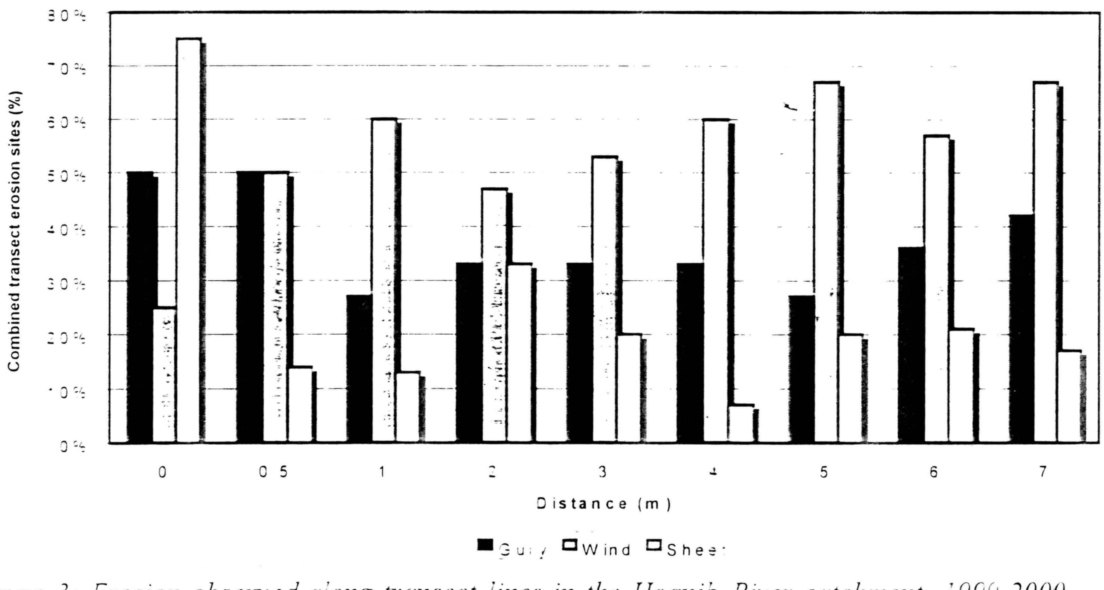

Figure 3: Erosion observed along transect lines in the Hoanib River catchment, 1999-2000 (as percentage)

The data obtained from all transect lines showed that erosion was occurring over the entire most prevalent around water points. Gully erosion varied from 27% to 50% and appeared to be uniform across the catchment, while wind erosion varied between 25% to 67% and was most prevalent on sites further away from the water sources.

DISCUSSION

EROSION STAKES

Accelerated erosion caused by human influence throughout the Hoanib River catchment can be observed when travelling across the catchment. Due to the loss of stakes because of flood events, human behaviour, wildlife or domestic stock, the processes involved in erosion are no closer to being documented for this environment. The observed results from the Khowarib plains and Dubis plains area indicate an accretion occurring in these two environments. Because both areas are plains environments, the deposition of sediments was more likely to be observed than in a hilly, steep or rocky area due to the reduced slope and broader deposition zone. Erosion appeared to be occurring at distances greater than 1km from the riverbed, which can probably be attributed to the substrate type of these sites. The predominant substrate type of these more distant sites was sand and/or gravel which would lend themselves more easily to being eroded than the rock/shale environments of the sites nearer the river (for more details see Appendix 2). This shows that the substrate type may play an important factor with relation to the stability and erosional nature of an area. At Dubis plains, however, substrate appeared to play a lesser role, where an accretion of material was observed at sites more than a kilometre from the river. The substrate types of some sites after the 1km point also differed slightly from those previously observed in the transect.

These results showed that substrate type was not the only major factor determining accretion or erosion rates. In any one environment, substrate type, combined with factors such as the amount of local rainfall, slope gradients, agricultural practices (overgrazing and compaction) and immediate geological environment, must first be understood and monitored before any erosion potential of an area can be determined.

FLOOD-BORNE SEDIMENT

Sediment loads observed from the results indicated that the amounts carried in the Hoanib River floodwater varied from 1.54g/L to 31.27g/L. The average sediment load from the analysed samples was 14.62g/L. This mean value is less than that reported by Jacobson *et al.* (2000b) of 35.5 g/L, but well within the range that would be expected as a standard deviation of 20.6 g/L which was reported for the samples. In addition, Jacobson *et al.* (2000b) reported that the sediment load increased with the length of flow of the river. Khowarib is only mid-way through the catchment, while samples by Jacobson *et al.* (1999) were taken from the lower Kuiseb River. Within the Hoanib River catchment the sediment loads varied with the amount of and intensity of rainfall, and hence flood events. There also appeared to be a decline in the sediment carried in the floodwater over time e.g. samples collected 18/11/99. This was most probably due to a decrease in the velocity of the floodwater. As rainfall ceased, the volume of the floodwater decreased as did the velocity of the flood. Consequently, the sediment carrying capacity of the water decreased proportionally.

The results also indicate that in a big flood event - as occurred from 23 to 27 March 2000 - the sediment carrying capacity of the floodwater varied over the 4-day period and did not appear to decline with time. This was most probably due to additional storm events occurring throughout the upper Hoanib River catchment, causing surges in the floodwater in the river and hence the periodic increases in sediment loads.

Organic and inorganic fractions in the sediment

By heating the sediment samples to 250°C, 550°C and 850°C it was possible to determine the volatile organic, bound organic and inorganic carbon fractions (total carbon) respectively. The residue after heating to 850°C was assumed to be the inorganic fraction. The volatile organic fraction was assumed to be low molecular weight organic compounds and highly combustible carbon compound e.g. wood fragments and roots. The bound organic fraction, however, was assumed to be that fraction held within the soil, including inorganically bound carbon.

The results indicate that the sediment in floodwaters contained an average of 14.06% carbon compounds and 85.94 % inorganic compounds.

According to Jacobson *et al.* (2000b), a major source of organic material to be found in the ephemeral rivers are *Faidherbia albida* seed pods. *Faiherbia albida* are the most abundant tree in the riparian woodland of the Hoanib River (Jacobson and Jacobson, 1998; Fennessy *et al.*, 2001). The greatest percentage fraction of organic compounds was the volatile organic compounds where an average of 5.77% (SD = 6.26%, n=24) was contained in the samples. There was a large variation in this, with samples collected from the first flood event containing much higher levels of volatile organic compounds than any subsequent flood event. In addition, the initial flood observed on 18 November 1999 carried a higher total inorganic bound fraction than any other subsequent flood. This could be due to the first rains leaching most of the relatively lighter organic material from the soil and carrying them in the first flood.

From the results it appears that there was an average loss of 3.36% (SD = 0.62%, n =24) and 4.93% (SD = 1.86%, n =22) upon heating the samples to 550°C and 850°C respectively. Jacobson *et al.* (2000b) reported an average value for FPOM (which represents a combination of the volatile and bound organic fraction) of 11.8% (SD = 2.7, n=20). This percentage is only slightly higher than the combined volatile and bound fraction measured during this project of 9.13% (SD = 6.29, n =24). There appeared to be little variation in these percentage losses, regardless of when the samples were collected, thus indicating that these organic fractions were present in each flood event and at levels that were constant. The higher percentage observed in some samples heated to 850°C would most likely correspond to inorganically bound carbon particles e.g. the compound calcium carbonate, which exists in natural systems in mineral form (limestone) or can originate from organisms (bone or shell fragments).

The initial heating of sediment samples to dryness at only 80°C could possibly have resulted in 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 would have liberated them and the weight loss would have been recorded as volatile organic compounds. Only a minor decrease in the weight of each sample was observed on heating to 110°C for an hour, in comparison to when heated to 250°C. This indicates that there was very little residual water in the samples after they had been initially evaporated to dryness. Therefore, the observed percentage weight loss on heating to 250°C can be assumed as a volatile organic fraction.

SEDIMENT SCOUR CORDS

Unfortunately for the sediment study, the rainy season of 1999/2000 was an above average rainfall season with the best observed catchment wide rainfalls since 1976. The Hoanib River and its tributaries carried excessive run-off throughout this period and one of the implications of this was the loss of all the scour cords for the study. Each site was visited in May 2000 in an attempt to recover the cords, though this proved futile. The possibility of using a metal detector to locate the bolts securing the cords was considered, though after searching the broader area around each sample site and in turn, finding nothing, it was decided that this might be excessive and would demand more time than yield usable results.

With such a high water volume experienced throughout this study period, it can be inferred that the scouring impact was greater than the depth at which the cords were buried (60cm). This finding itself indicates the excessive movement of water and sediments within the Hoanib River catchment system. In the years in which the rainfall was 'locally' high e.g. 1995/96 and 1999/2000, a proportion of the nutrients contained within sediment movement was lost from the catchment system as they were deposited in the coastal environment. However, during years with lesser floods, sediments would not be completely lost from the system, as environments downstream e.g. the Hoanib River Floodplain, act as a reservoir for them. This in turn provides nutrients for vegetation growth in an area that would usually be devoid of vegetation.

VEGETATION TRANSECT EROSION STUDIES

The arid and semi-arid environment of the Hoanib River catchment is prone to various forms of erosion, run-off and sediment loss. The rapid erosion assessment methods conducted throughout the study provided a simple yet informative understanding of the erosion problems that can or may impact on this environment in the future. Erosional processes take place catchment wide and if left unchecked could result in the environment being increasingly eroded, with lesser amounts of fertile topsoil remaining. The culmination of the three erosion forms assessed (sheet, gully and eolian) indicated that the Hoanib River catchment, as a system, is significantly affected by erosion.

Interestingly, all three erosion forms occurred at all distances along the gradient, thus indicating a combined impact throughout the Hoanib River catchment. The fluvial erosion seems to have the greatest impact through all forms of erosion prevalent in an arid environment (Hoffman *et al.*, 1999).

The deposition of suspended and river-borne sediments occurs in locations where the velocity of the running water is reduced e.g. floodplain, alluvial plains and streambeds, as the velocity of the floodwaters decrease. Villages situated throughout the Hoanib River catchment, and in particular in the middle sections of the catchment, lie in environments where hardly any deposition of eroded topsoil takes place. Without the deposition of the eroded material, little benefit can be derived for vegetation growth and agricultural production.

Wind erosion has also been exacerbated by human influences in the catchment e.g. cultivation and over-grazing (compaction), which in turn results in reduced ground vegetation cover. Its impact on a larger scale is hard to quantify but was readily observed along the transects. How this affects the entire catchment system is unknown and the potential loss of topsoil in terms of social and economic benefits will only become apparent over time.

CONCLUSION

This study observed that there is a lack of knowledge of the erosional depositional systems operating in the Hoanib River catchment. A better understanding of these processes can only be achieved through appropriate information and long-term monitoring of soil erosion rates.

While several of the experiments conducted during this study did not achieve any conclusive data, the following was observed:

(a) Significant erosion is occurring in the catchment;
(b) In high rainfall years, large amounts of sediment are being moved along the riverbeds;
(c) Significant amounts of organic materials are carried in the floodwaters;
(d) The greater the volume of the flood, the greater the amount of suspended and river-borne sediment carried by the floodwaters; and
(e) The first floods carry more volatile organic compound than the later floods.

The overall movement of sediments and nutrients throughout the Hoanib River catchment system are unknown and this may have detrimental impacts on current and future agricultural initiatives. However, this study has shown that erosion, and the associated processes, alter the dynamics of the catchment system annually. Whether it be via natural weathering or leaching which further enriches environments downstream, or as a result of over-grazing and compaction around villages, human influences increase the rate at which these processes occur.

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APPENDIX A

(Erosion Stake GPS Co-ordinates and Site Descriptions)

Table A1: Location and description of erosion sites at Dubis

Location: Dubis Plains (North transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	25/05 99	25	-19.22101	13.49234	Rocky/Shale/Plain
2	25/05 99	50	-19.22048	13.49164	Rocky/Shale/Plain
3	25/05 99	75	-19.21999	13.49192	Rocky/Shale/Plain
4	25/05 99	100	-19.21989	13.49173	Rocky/Shale/Plain
5	25/05 99	150	-19.21968	13.49147	Sandy/Pebbles/Gully
6	25/05 99	200	-19.21919	13.19119	Sandy/Pebbles
7	25/05 99	350	-19.21805	13.49052	Trees/Sandy/Pebbles
8	25/05 99	500	-19.21669	13.49109	Sandy/Pebbles
9	25/05 99	1000	-19.2125	13.48969	Sandy/Gravel
10	25/05 99	2000	-19.20403	13.48728	Sandy/Gravel
11	25/05 99	3000	-19.19524	13.48566	Sandy
12	25/05 99	4000	-19.18678	13.48382	Sandy
Location: Dubis Plains (South transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	25/05 99	25	-19.22221	13.49257	Rocky, Pebbles on Sandy mounds
					(Mopane/Salvadora persica)
2	25/05/99	50	-19.22246	13.49223	Rocky, Pebbles on Sandy mounds
					(Mopane/Salvadora persica)
3	25/05 99	75	-19.22263	13.49218	Rocky, Pebbles on Sandy mounds
					(Mopane/Salvadora persica)
4	25/05 99	100	-19.22308	13.49192	Sandy depression - Gravel, Pebbles
5	25/05/99	150	-19.22351	13.49218	Sandy depression - Gravel, Pebbles
6	25/05/99	200	-19.22382	13.49212	Plain - Gravel, Pebbles, Grass cover
7	25/05/99	350	-19.22511	13.49229	Plain - Gravel, Pebbles, Grass cover
8	25/05 99	500	-19.22654	13.49218	Plain - Gravel, Pebbles, Grass cover
9	25/05/99	1000	-19.23102	13.4924	Plain - Gravel, Pebbles, Grass cover
10	25/05/99	2000	-19.23961	13.49272	Plain - Gravel, Pebbles, Grass cover
11	25/05/99	3000	-19.24875	13.49322	Plain - Gravel, Pebbles, Grass cover, Gully/run-off area
12	25/05 99	4000	-19.25588	13.4931	Gravel plain - Rocky between mountains, Gully/run-off area

Table A2: Location and description of erosion sites at Khowarib

Location: Khowarib Plains (North transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	26/05/99	25	-19.17678	13.77372	Rocky/Shale - Plain between hummocks
2	26/05/99	50	-19.17656	13.77367	Rocky/Shale - Plain between hummocks
3	26/05/99	75	-19.17632	13.77362	Rocky/Shale - Plain between hummocks
4	26/05/99	100	-19.17608	13.77358	Rocky/Shale - Plain between hummocks
5	26/05/99	150	-19.17559	13.77349	Sandy/Pebbles - On hummock between plain
6	26/05/99	200	-19.17501	13.77342	Sandy/Pebbles - Plain between hummocks
7	26/05/99	350	-19.17383	13.77324	Trees/Sandy/Pebbles
8	26/05/99	500	-19.17251	13.77298	Sandy/Pebbles - Plain between gully
9	26/05/99	1000	-19.16802	13.77193	Sandy/Gravel - Gully
10	26/05/99	2000	-19.15983	13.77031	Sandy/Gravel - Gully
11	26/05/99	3000	-19.15121	13.76865	Sandy - On hummock between plain
12	26/05/99	4000	-19.14299	13.76805	Sandy - Within erosion gully
Location: Khowarib Plains (South transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	26/05/99	25	-19.17809	13.77368	Rocky. Pebbles on Sandy mounds. Mopane/ Salvadora persica
2	26/05/99	50	-19.17837	13.77358	Rocky. Pebbles on Sandy mounds. Mopane/ Salvadora persica
3	26/05/99	75	-19.17864	13.7735	Rocky. Pebbles on Sandy mounds. Mopane/ Salvadora persica
4	26/05/99	100	-19.17899	13.77335	Sandy depression - Gravel. Pebbles
5	26/05/99	150	-19.17938	13.77317	Sandy depression - Gravel. Pebbles
6	26/05/99	200	-19.17989	13.77293	Plain - Gravel. Pebbles. Grass cover
7	26/05/99	350	-19.18119	13.7719	Plain - Gravel. Pebbles. Grass cover. on Hummock
8	26/05/99	500	-19.18208	13.77093	Plain - Gravel. Pebbles. Grass cover. Hummock area
9	26/05/99	1000	-19.18606	13.76815	Plain - Gravel. Pebbles. Grass cover
10	26/05/99	2000	-19.19382	13.76389	Plain - Gravel. Pebbles. Grass cover on Hummock
11	26/05/99	3000	-19.20114	13.75769	Plain - Gravel. Pebbles. Grass cover
12	26/05/99	4000	-19.20901	13.75471	Gravel plain - Rocky between mountains

Table A3: Location and description of erosion sites on the Serengeti plains

Location: Ombonde-Serengeti Plains (North transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	26/05/99	25	-19.41111	14.1142	Sandy Soil/Grassy Plain with Bare patch
					Coarse top Layer/Semi-Open/Level Area
2	26/05/99	50	-19.41085	14.11444	Sandy Soil/Grassy Plain with Bare patch
					Coarse top Layer/Semi-Open/Level Area
3	26/05/99	75	-19.41048	14.11462	Fine Sandy Soil/Grassy Plain/Semi-Open/Level Area
4	26/05/99	100	-19.41043	14.11487	Fine Sandy Soil/Grassy Plain with Bare patch
					Semi-Open/Level Area
5	26/05/99	150	-19.41008	14.11508	Sandy Soil/Grassy Plain with Bare patch
					Coarse top Layer/Semi-Open/Level Area
6	26/05/99	200	-19.41003	14.11515	Fine Sandy Soil/Grassy Plain/Semi-Open/Level Area
7	26/05/99	350	-19.40863	14.11569	Fine Sandy Soil/Grassy Plain/Semi-Open/Level Area
8	26/05/99	500	-19.40766	14.11677	Sandy Soil/Grassy Plain
					Coarse top Layer/Semi-Open/Level Area
9	26/05/99	1000	-19.40377	14.11956	Sandy Soil/Aluvium Plain/Open/Level Area
10	26/05/99	2000	-19.39773	14.12498	Clay Soil/Open/Level Area
11	26/05/99	3000	-19.3914	14.1315	Clay Soil/No Vegetation/Open/Level area
12	26/05/99	4000	-19.38546	14.13797	Clay Soil/Semi-Open/Mopani
Location: Ombonde-Serengeti Plains (South transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	26/05/99	25	-19.4111	14.1142	Sandy Soil/Grassy Plain/Aluvium/Open
2	26/05/99	50	-19.41085	14.11444	Sandy Soil/Grassy Plain/Aluvium/Open
3	26/05/99	75	-19.41048	14.11462	Sandy Soil/Grassy Plain/Aluvium/Open
4	26/05/99	100	-19.41043	14.11487	Sandy Soil/Grassy Plain/Aluvium/Open
5	26/05/99	150	-19.4135	14.11424	Rocky Soil Surface/Coarse Sandy Soil
					Gentle Gully/Open
6	26/05/99	200	-19.41444	14.11008	Rocky Soil Surface/Undulating Plain/Semi-Open
7	26/05/99	350	-19.40863	14.11569	Sandy Soil/Grassy Plain/Semi-Closed
8	26/05/99	500	-19.40766	14.11677	Sandy Soil/Grassy Plain/Semi-Closed
9	26/05/99	1000	-19.40377	14.11956	Sandy Soil/Grassy Plain/Semi-Closed
10	26/05/99	2000	-19.39773	14.12498	Sandy Soil/Grassy Plain/Semi-Closed
11	26/05/99	3000	-19.39145	14.1315	Sandy Soil/Grassy Plain/Open
12	26/05/99	4000	-19.38456	14.13797	

Table A4: Location and description of erosion sites at the Khowarib Schlucht

Location: Khowarib Schlucht (North transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	25/05/99	25	-19.26869	13.89108	Sandy Soil/ Calcite /Plain /Aluvium /Open /Level Area
2	25/05/99	50	-19.26893	13.8912	Sandy Soil/ Calcite/ Plain/ Aluvium/ Open/ Level Area
3	25/05/99	75	-19.26947	13.89084	Sandy Soil/ Calcite/ Plain/ Aluvium/ Open/ Level Area
4	25/05/99	100	-19.2693	13.89102	Sandy Soil/ Calcite/ Plain/ Aluvium/ Open/ Level Area
5	25/05/99	150	-19.26931	13.8916	Sandy Soil/Calcite/Aluvium/Open. Top of Rise
6	25/05/99	200	-19.26918	13.89236	Sandy Soil/Calcite/Aluvium/Open. Moderate Gully Side
7	25/05/99	350	-19.26923	13.89317	Sandy Soil/Calcite/Aluvium/Open Shallow Gully (Left side of Road)
8	25/05/99	400	-19.26928	13.89412	Sandy Soil/Plain/Aluvium/Open/ Level Area
9	25/05/99	500	-19.26922	13.89499	Sandy Soil/Plain/Aluvium/Open/Level Area
Location: Khowarib Schlucht (South transect)					
Stake No.	**Date Established**	**Distance from river (m)**	**GPS**		**Terrain description**
			°S	°E	
1	25/05/99	25			Sandy Soil/Calcite/Plain/Aluvium/Open Level area
2	25/05/99	75			Calcite Pan/Aluvium/Open/Moderate Slope
3	25/05/99	125			Calcite Pan/Aluvium/Open/Level Area
4	25/05/99	225			Hard Calcite Pan/Aluvium/Open/Level Area
5	25/05/99	375			Sandy Soil/Open/Level Area
6	25/05/99	575			Sandy Soil/Calcite Pan/Open/Gentle Slope
7	25/05/99	925	-19.26728	13.89289	Sandy Soil/Closed/Level Area
8	25/05/99	1225			Rocky Surface/Closed/Level Area