Soils and soil erosion in the Etosha National Park, northern Namibia

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ABSTRACT

There is an urgent need in developing countries like Namibia for natural resources investigations in order to give a consolidated background for adequate management and future land use planning activities. Soil in particular, as the basis for plant and animal life, needs special attention and protection, both to guarantee human food supply as well as species diversity especiallly in protected areas like the Etosha National Park.

The soils of the Etosha National Park were mapped according to the FAO-system using a regionally adapted classification key. Their distribution and properties show a clear relation to either small-scale morphological position and geology. The Major Soil Units occuring are Arenosols, Regosols, Cambisols, Leptosols, Vertisols, Para-Vertisols, Fluvisols as well as Solonchaks and Solonetzs on the pans and in some shallow waterways and depressions. Relief-defined soil associations (catenas) are common. Wind and water erosion are natural processes in the semi-arid environment of northern Namibia and strongly influence soil profile genesis. Mainly due to fencing which restricts large-distance migration routes of the large game populations, regional high animal pressure and overgrazing occur in parts of the Etosha National Park, with the effect of accelerated soil erosion and subsequent environmental degradation. Especially in the intensively utilized grass plains at the southern and western margin of the Etosha Pan accelerated wind erosion and sheet erosion can be observed. In the more strongly dissected western park area also rill and gully erosion occur. Here, like in other parts of the Etosha National Park, permanent watering points are the focus of spreading land degradation. Especially at the end of the dry and the beginning of the wet season (September to December), when protection by vegetation cover reaches a minimum, both fluvial and aeolian erosion processes are highly active.

The observed types and intensities of soil erosion processes as well as the modelling of potential erosion hazard makes it possible to select regions inside the Etosha National Park with special climatic sensivity and high desertification potential. These are the grassplains at the western, southern and northeastern edges of the Etosha Pan and the strongly dissected Kaokoveld part of the Etosha National Park in the extreme south-west. Management decisions have to take account of the heterogenity of the ecosystems and their individual risk potential in order to allow a regeneration of already degraded areas or to avoid further degradation.

INTRODUCTION

Some seventy percent of Namibia's population are directly or indirectly dependend on the primary agricultural sector, especially in the north of the country, where climatic conditions are more favourable for agricultural production (Otzen 1990; Schneider 1991). Over the last few decades increasing human pressure, often in combination with unadequate agricultural techniques, led to the enhancement of desertification processes in large parts of the country (Seely *et al.* 1994), both in the communal farming areas (Adams *et al.* 1990; Marsh & Seely 1992) as well as in the commercial farming zone (Schneider 1991). This critical situation has been driven by a persistant drought since the beginning of the eighties (Engert 1997). In the 'semi-natural' ecosystem of the Etosha National Park (hereafter referred to as ENP), some areas also show severe environmental problems, especially soil erosion with all its negative effects. This is due to the indirect impact of man on the large game populations and their distribution, mostly by fencing and waterhole management. Keeping in mind the attractiveness of the ENP for tourism in Namibia, environmental degradation not only impairs ecosystem diversity, but indirectly does affect an important income source for the young country.

In order to develop an adequate response to these challenges (with the goals either maximizing agricultural productivity or maintaining plant and species diversity on a sustainable basis), there arises the fundamental need for intensive research on natural resources such as the actual status and dynamics of soils and vegetation, and the associated eco-pedological risk potential (= desertification potential). Only limited research has so far been done on soils and soil erosion in Namibia (e.g. Walter 1954; Ganssen 1963; Schneider 1989). Here, the ENP with its special position between the commercial farming zone in the south and the communal farming areas in the north and west (Owamboland, Kavangoland, Damaraland) serves as a useful model area for soil research and related environmental studies. From here the activities can spread out to the adjacent farming zones. This paper gives a brief summary of recent soil research done in the ENP during the last five years.

THE SOILS IN THE ETOSHA NATIONAL PARK

The first soil map of the ENP was published by Le Roux *et al.* (1988) using the South African Soil Classification (Macvicar *et al.* 1977). A strong correlation between the distribution of soils and vegetation in the park was documented. This shows, in relation to relief, the overall important role of soil properties, especially water and nutrient availability, on both small and large scale plant community variations in semi-arid savanna ecosystems (Huntley 1982; Frost *et al.* 1986).

Starting in 1989, the distribution and dynamics of the soils of the ENP were studied by Buch (1990a) in context with the Cainozoic geomorphological and palaeo-climatic evolution of the Etosha region (Buch 1990b; 1993; Buch & Trippner 1997). Additional work on soil erosion and soil erodibility together with semi-detailed soil mapping (scale 1:50.000) of chosen representative areas have also been done (Beugler 1991; Buch *et al.* 1993/94). As a preliminary result of the environmental studies in the ENP a parametric landscape ecological risk rating system, called LERIS (**L**andscape **E**cological **R**isk **I**nformation **S**ytem) (Buch *et al.* 1993) was developed and applied in the six model areas (Buch *et al.* 1993/94).

Soil profiles were described in the field according to FAO (1990) and AG Bodenkunde (1982) and after detailed laboratory analyses the soils were classified according to the FAO Soil Nomenclature (FAO/UNESCO 1990). In order to comprise the whole variety and properties of the soils in central northern Namibia, an extended classification key adopted to local conditions was developed on the basis of the FAO-system (Beugler-Bell *et al.* 1993). Field mapping was supported by air photo (appr. scale 1:50.000) and MSS-Landsat imagery interpretations. Twenty-six mapping units (thereafter referred to as MU) were identified and grouped into five classes, which reflect ecologically important properties like texture, substrate type and depth (Figure 1). Saline and sodic soils as well as soils from fluvial sediments were grouped into extra classes. Table 1 gives the area covered by each mapping unit in the ENP. The evaluation of important soil characteristics like nutrient status, drainage and available water-holding capacity (Table 2) was done according to international accepted standards (Landon 1984; AG Bodenkunde 1982).

The distribution of the 'Major Soil Units' (Soil Groupings according to FAO/UNESCO 1990) shows a clear relation to small-scale morphological position and geology (Buch 1993a). Soil associations dependent on relative relief position are common, even in only slightly undulating terrain. These soil associations demonstrate the validity of the 'catena'-concept in the semi-arid regions of Namibia (Ganssen 1963). Despite their genetical and morphological diversity the soils in the ENP generally show typical properties for arid and semi-arid regions (e.g. Dregne 1976, Skujins 1991) like a weak to moderate profile development, ochric A-horizons low in organic matter, slightly acid to alkaline reaction, high base saturation and low to moderate fertility (Figure 2). Partly, soluble salts and carbonates are accumulated in the lower topsoil or subsoil. The weathering rates of bedrock are very low in the semi-arid climate. Solum depths of 5 to 20 cm, weathered from compact limestone south of the Etosha Pan (MU C3) during the last 20.000 years suggest soil formation rates of 2.5 to 10 mm per 1000 years, which is equivalent to 0,04 to 0,16 metric tons/ha/year.

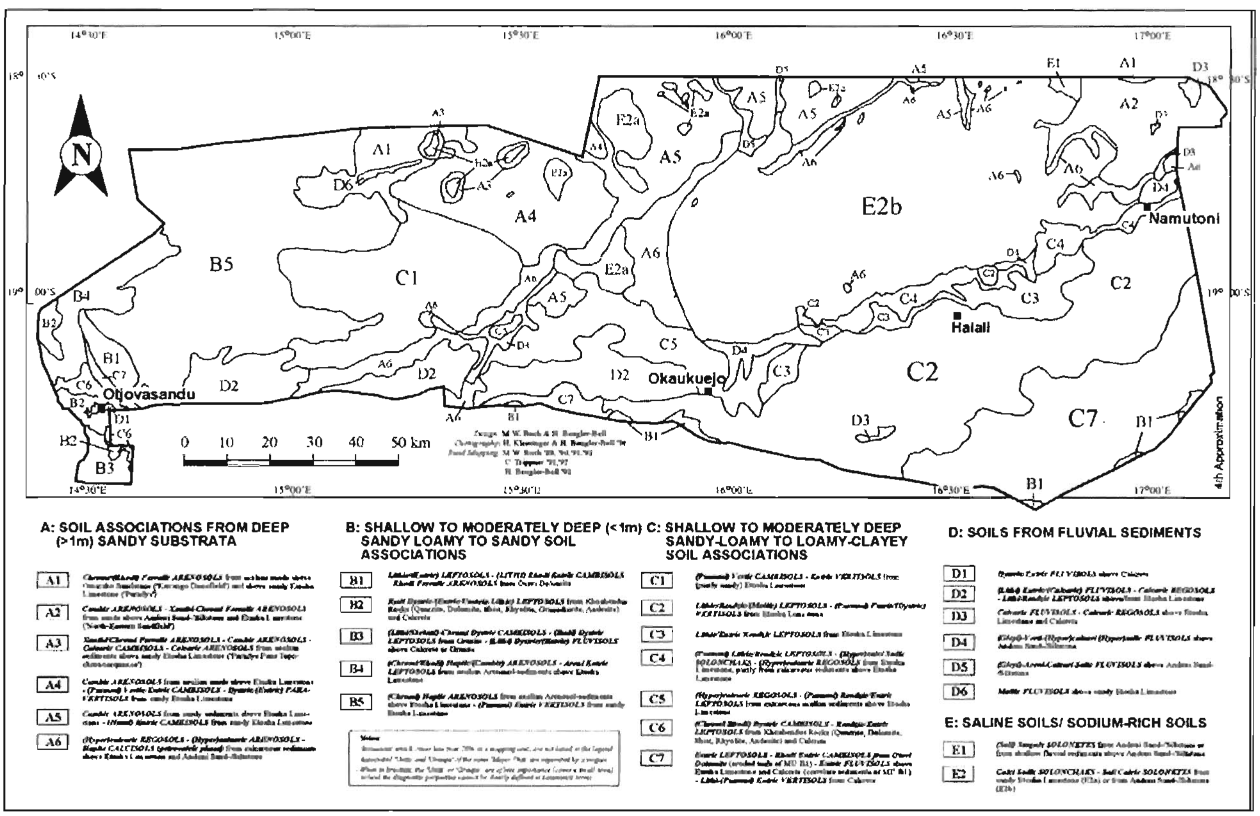


FIGURE 1: Soil map of the Etosha National Park

TABLE 1: Size of the soil mapping units in the Etosha National Park

MU	km²	%	MU	km²	%	MU	km²	%	MU	km²	%	MU	km²	%
A1	408	2	B1	336	2	C1	1349	6	D1	12	0.1	E1	36	0.2
A2	651	3	B2	142	0.6	C2	3320	15	D2	1101	5	E2a	443	20
A3	71	0,3	B3	118	0.5	C3	456	2	D3	112	0.6	E2b	4468	2
A4	994	5	B4	297	2	C4	367	2	D4	142	0.5			
A5	1219	6	B5	2687	12	C5	24	0.1	D5	59	0.3			
A6	959	4				C6	846	4	D6	18	0.1			
						C7	1534	7						
Σ	4302	19		3662	16		7896	36		1444	7		4947	22

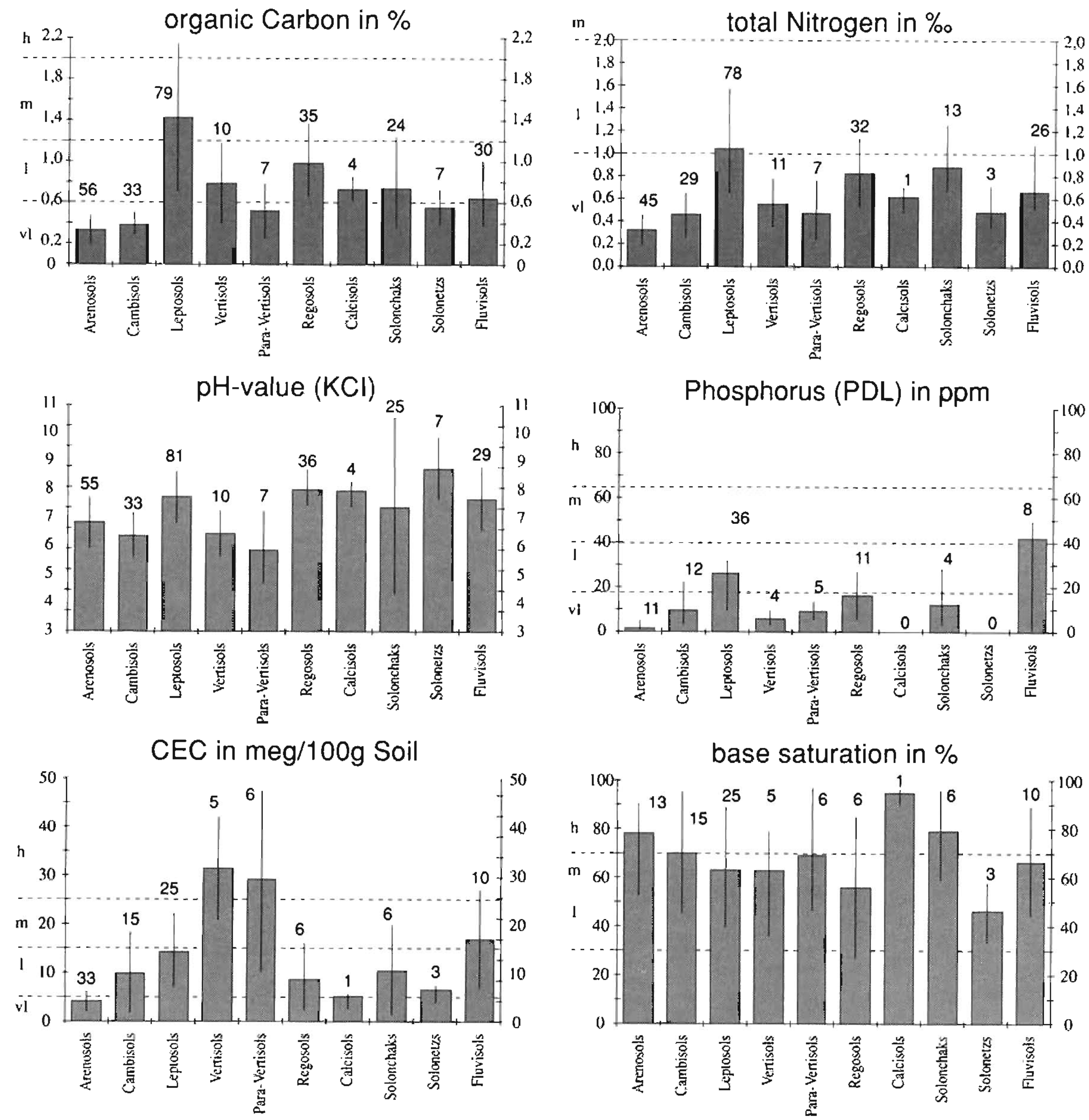
TABLE 2: General characteristics of the soils in the Etosha National Park

Mappiug Unit	Nutrient Status (Ferility)	Soil Depth	Internal Drainage (Infiltration capacity)	Water holding Capacity Topsoil (0-30cm)	Water holding Capacity Subsoil (30-200cm)	Soil Erodibility by Water	Soil Erodibility by Wind	Salinization Hazard	Alkalinization Hazard	Erosion Hazard Sheet Erosion	Erosion Hazard Wind Erosion	Erosion Hazard Gully Erosion
A1	1	5	5	2	5	1	5	1	1	1	5	1
A2	1	5	5	3	5	1	5	1	1	1	5	1
A3	1	5	4	2	5	1	4	1	1	1	5	1
A4	2	4	4	3	5	1	5	1	1	1	5	1
A5	2	4	5	4	4	2	4	1	1	1	4	1
A6	2-3	4	4	4	5	3	3	3	3	2	5	1
B1	1	1	4	1	-	3	2	1	1	1	5	2
B2	3	1	3	1	-	3	2	1	1	5	4	3
B3	1	2	4	3	2	3	3	1	1	2	4	2
B4	1	2	4	3	2	2	4	1	1	1	5	1
B5	1	2	5	3	2	1	5	1	1	1	5	1
C1	3	3	4	4	3	2	3	2	2	1	4	1
C2	4	1	3	1	-	2	2	2	3	1	4	1
C3	4	1	3	1	-	2	2	1	2	2	3	1
C4	3-4	1	3	2	-	3	3	4	4	4	5	1
C5	3	1	3	3	2	3	3	4	4	3	5	1
C6	2	3	3	3	3	4	3	1	1	2	4	1
C7	2	3	3	3	3	4	3	1	1	1	3	1
D1	3	3	3	5	4	4	3	1	1	4	5	3
D2	2-3	2	3	2	2	3	3	1	2	3	3	1
D3	2-3	3	4	3	3	3	3	2	2	1	5	1
D4	1	4	2	2	4	3	3	5	5	1	5	1
D5	1	3	5	4	3	1	5	5	5	1	5	1
D6	3	3	3	5	3	3	2	1	1	1	5	1
E1	1	1	1	1	-	3	4	5	5	1	5	1
E2a	1	5	2	2	4	3	3	5	5	1	5	1
E2b	1	4	2	2	4	3	3	5	5	1	5	1

1= very low, 2 = low, 3 = moderate, 4 = high, 5 = very high

Soil associations from deep sandy substrata

Cambic and Ferralic Arenosols developed in deep (>1 m) sandy substrata of aeolian and partly fluvial origin cover a wide area in the north-east (MU A2 and A1), north (MU A5) and north-west of the Etosha Pan (MU A1, A3 and A4) (Figure 1). Although very uniform in most properties, these carbonate-free soils with fine to medium sandy texture can be distinguished mainly by the colour of their B-horizon (e.g. 'Xanthi Groups' with hues of 7,5YR and 5YR with low chromas, 'Chromi Groups' with hues of 5YR and 'Rhodi Groups' with hues redder than 5YR). The colour variation (=redness intensity) reflects the relative age of soil formation in relation to medium-scale geomorphologic evolution and large-scale relief position, especially in the 'North Eastern Sandfield' (MU A2) and 'Paradys' (MU A1, A3 and A4). Mapping unit A4 shows a relief-defined soil association with Vertisol-like soils of partly sedimentary origin in small, closed depressions, classified as 'Para-Vertisols' according to Mückenhausen (1985). In mapping unit A5 the dominating decalcified Cambic Arenosols with relatively high contents of organic matter (>1 %) show transition to more finer-textured Eutric Cambisols according to the variation of the geology (fluvial carbonatic sands to sandy limestone).



Rating (Buch *et al.* 1993):
vl = very low, l = low, m = moderate, h = high

Source: Buch (1993), Buch *et al.* (1993/94)

FIGURE 2: Chemical topsoil properties of the 'Major Soil Units' in the Etosha National Park

Along the Etosha Pan's western and north-western edges strong aeolian activity led to the deposition of calciumcarbonate-rich sediments. The most striking features are the two parallel running dune ridges along the western margin of the pan (Buch 1997). Here, the Middle Pleistocene to recent age of the sediments in combination with ongoing aeolian activity restrict a strong soil formation (MU A6). Vertical transport of salts and carbonates and formation of an initial cambic horizon are the only soil forming processes. The physical and chemical properties of the soils vary considerably in relation to their distance to the pan, e.g. carbonate content and grain size. Generally the deep sandy soils of class A are well to excessively drained, are very low in organic matter (<1 %) and have a very unfavourable nutrient status (Figure 2), except parts of mapping unit A6, which have medium CECpot-values (potential Cation Exchange Capacity at pH 7) (up to 20 meq/100 g soil) in the topsoil (Table 2). Although water holding capacities are low to moderate in the topsoil, these deep sandy soils have a high capacity to store moisture in the subsoil (Table 2).

Shallow to moderately deep sandy to sandy-loamy soil associations

In the Otavi Hills in the south-east and west of the park bare rock is exposed in many places and just some fine earth has accumulated in fissures and cracks of the hard dolimitic bedrock. In footslope positions intensively red coloured sandy remnants of very old Tertiary soil formations can be found (MU B1). In the more strongly dissected escarpment area around Otjovasandu only very shallow and rocky soils have developed from Khoabendus sedimentites and igneous rocks and partly from calcrete remnants (MU B2). The Leptosols and and rock outcrops on slopes are associated with silt-rich, partly carbonatic Eutric and Dystric Fluvisols in the V-shaped river valleys. In the Granite landscapes of Kaross (MU B3), the reddish-brown coloured Cambisols and Leptosols are coarse textured (gritty loamy sand) and show a moderate acid soil reaction. These soils are very poor in nutrients and organic matter (Table 2). With exception of some rocky soils from calcrete, the soils in the west have low base saturations (proportion of Ca, K, Mg and Na on the total amount of cations) of less than 50 %.

In the western part of the ENP large areas are covered by shallow to moderately deep aeolian Arenosol-sediments (MU B4 and B5) derived from short, longitudinal dunes in the 'Paradys' area (MU A1). These Arenosol-sediments above Etosha Limestone are associated locally with Eutric Vertisols and Para-Vertisols in shallow depressions (MU B5) ('red-black-catena'). Limestone outcrops are common. The nutrient status and content of organic matter of these Kalahari-type sedimentary soils is very low and drainage is less excessive compared to soil class A due to shallow profile depths and somewhat finer texture (Table 2).

Shallow to moderately deep loamy to loamy-clayey soils and soil associations

Between the Etosha Pan and the pediment zone of the Otavi Hills in the south extremely shallow to shallow clayey-loamy soils developed from limestone, cover a wide area of the so called 'Karstveld' (Le Roux *et al.* 1988), a smoothly northward tilted, flat to undulating plain. Because most superficial carbonatic rocks in Etosha are of sedimentary-evaporitic origin, they are referred to as limestone or 'Etosha Limestone' (see also Buch & Trippner 1997). The term calcrete is only used, when its genesis can be attributed to pedogenesis and/or related processes in the sense of Blümel (1982).

South of the Etosha Pan, soil associations of Lithic/Eutric/Rendzic Leptosols and Eutric Vertisols in depressions are common ('brown-black-catena'). This soil sequence represents the different stages of soil development in relation to micro-relief and time of soil formation (MU C2, C3 and C4). Towards the north, the Eutric Vertisols, whose properties (clay content, depth, clay mineralogy) vary considerably, dissappear with less pronounced microtopography and younger age of undisturbed weathering (MU C3) (see the contribution to the landscape evolution of the Etosha region, Buch 1997). At the pan's edge the shallow and rocky Leptosols of mapping unit C4 show higher contents of sand in the topsoil due to increasing aeolian deposition of pan-related sediments. Here, also strongly salt-affected soils (Solonchaks) can be found. The potential fertility of the shallow and rocky Karstveld soils regarding the contents of organic matter, nitrogen and available phosphoros is the most favourable of all soils in the whole park area (Table 2). Only the Vertisol-type soils and some Fluvisols show a higher cation exchanche capacitiy and high contents of phophorus (Figure 2). The slightly alkaline to neutral soil reaction is in accordance with the degree of decalcification. On the other hand the physical properties of these soils, especially total available water holding capacities and drainage conditions are very unfavourable depending to a great degree on the variation of bedrock characteristics (cracks, fissures) (Table 2).

The strongly weathered, moderately deep to deep (60-100 cm) Vertic Cambisols in the central western part of the ENP (MU C1) represent the climax stadium of Quaternary soil formation from Etosha Limestone in central northern Namibia. These soils show an increase of sand content in the topsoil (from sandy clay to sandy clay loam), which indicates enhanced recent to sub-recent aeolian activity in this area. In shallow depression the Cambisols are associated with clay-rich, dark grey-brown Eutric Vertisols. East, north and north-west of Okaukuejo shallow to medium, weakly developed, carbonate-rich silty loamy to sandy-loamy Regosols and Leptosols from mainly aeolian origin cover the limestone surface (MU C5). Despite high clay contents of the Leptosols, Vertic Cambisols and Vertisols the aeolian admixture of sand in the topsoils are responsible for medium basic infiltraton rates (4-20 cm/h), which indicate quite favourable drainage conditions (Table 2).

The oldest soils in the ENP with a genesis that probably goes back to the Middle Tertiary, are the intensively red coloured (hues 5YR to 2,5YR), shallow to moderately deep, slightly acid, sandy-loamy to clayey-loamy Dystric Cambisols developed from sedimentary and igneous Khoabendus rocks on the flat distal pediment zone of the Otavi Hills in the south-west of the ENP (MU C6). These polygenetic autochtonous soils are partly eroded and influenced by colluvial and aeolian redeposition. In the south-east and south the pediment zone of the Otavi Hills extends far north and shows a pronounced undulating topography. Otavi Dolomite forms the bedrock in this area. The sandy-loamy to clayey-loamy, reddish-brown erosion remnants of 'in situ' soils (Cambisols and Leptosols), which are comparable to those of MU C6, are associated with Eutric Vertisols from Calcrete in depressions ('red-gray/black-catena'). Also para-autochtonous and allochtonous fluvial sediments (correlate sediments to MU B1) are widespread in this area.

Soils from from fluvial sediments

The occurrence of Fluvisols in the ENP is either related to river valleys and basins (MU D1 and D5) or to less pronounced shallow drainage lines (omurambas) (D6, D4). Fluvial sediments are also deposited in some pan areas (MU D4) as well as in isolated shallow pan-like depressions within the Karstveld and the North-Eastern Sandveld (D3). Depending on the size and morpho-pedological characteristics of the catchment, the soils from fluvial sediments show pronounced differences in terms of their textural and chemical soil properties, thus providing a wide range of local eco-pedological site conditions. With exception of the soils of MU D2 the Fluvisols show favourable water holding capacities both in the topsoil and subsoil (Table 2).

West of Okaukuejo predominantly carbonate-free Eutric Fluvisols in shallow drainage lines interfinger with 'in situ' weathered Leptosols and sedimentary, aeolian Regosols of elevated positions (MU D2). Due to strong aeolian activity sand and silt contents in the topsoil are high. In the 'Otjovasandu Basin' moderately deep carbonate-free sediments are associated with deep silt-rich carbonatic sedimentary soils in the vicinity of the main river channel. The sediments are deposited above calcrete (MU D1). In the west, calcrete mainly is restricted to the river valleys and lower slope positions. In the wide shallow depression of 'Gobaubvlakte', 'Beisebvlakte' and 'Kameeldoring Pan' shallow to moderately deep, greyish-brown to brown Calcaric Fluvisols and Regosols (unconsolidated, weakly developed sedimentary soils of aeolian and/or colluvial origin) are found (MU D3). These soils partly show moderately to high soluble salt contents (EC5 2.0 mS/cm) at the rock contact. The Fluvisols in the periodically flooded drainage lines and depressions ('turfpan soils') at the southern edge of the Etosha Pan (MU D4) show considerably high soluble salt contents in the topsoil of up to 6.9 % and high alkalinity up to pH 10. These values are even higher for the Fluvisols deposited at the pans' surface (up to 12.9 % salt). The sandy sediments of the northern rivers (Ekuma and Oshingambo) (MU D5) also show moderately to high contents of soluble salts. In the 'Paradys' area, sediments rich in organic matter have accumulated in a shallow vegetated drainage line (MU D6).

Saline soils/sodium rich soils

Salt- and sodium-rich soils referred to as Solonchaks and Solonetzs according to FAO/UNESCO (1990) are strongly restricted to the actual surface of the pans or to revegetated former pan floors like the 'Andoni Bay' at the north-eastern edge of the Etosha Pan. High salt contents normally occur together with high alkalinity (*saline-alkali soils with and without structural B-horizon* after Szabolcs 1989). The formation of the Stagnic Solonetz (MU E1) of the 'Andonivlakte' is a result of the geomorphodynamical evolution of Etosha Pan during the Holocene (see also Buch 1997). The soil genesis of Solonetz-type with a structural B-horizon ('natric'-horizon) either superimposes a greenish-coloured clay-rich sandstone (Andoni Formation of the Kalahari Group) or a thin cover of fluvial sands over the parent bedrock of the former pan's surface at 1082 m a.s.l.. Solution and recristallisation as well as descending and ascending transport in a seasonal rhythm lead to an enrichment of soluble salts in the upper subsoil, similar to soil formation on slightly elevated parts of the recent pan surface. Here, EC5-values (electrical conductivity in a 1:5 soil/water solution) higher than 4.6 mS/cm can be reached. The dominance of sodium in the exchange complex is indicated by very high pH values (pH 9-10). A pronounced columnar structur with cutans of clay and organic matter in the Btn-horizon is the most characteristic feature of the Solonetz. This very dense horizon, which forms a hardpan when dry, acts as a lower limit of rooting depth and restricts drainage (Table 2). Consequently, large areas of the extremely flat 'Andonivlakte' are flooded after heavy rain showers. As typical for erosion levels of the former pan's floor, the above described soil formation is fossilized by 5 to 30 cm of slightly calciferous and partly salt-rich aeolian fine sands. In areas of high utilisation pressure by game, like around 'Andoni' waterhole or in the Owambo part of the Andonivlakte, this thin cover of aeolian sediments may be eroded. Due to the abundance of sodium ions, clay and organic matter particles become dispersed when moistened. This water-instable soil structure leads to the formation of a highly saline impermeable crust when the vegetation is destroyed and the erodible surface sands are blown out.

SOIL EROSION IN THE ETOSHA NATIONAL PARK

Soil erosion in an ecosystem context: introductory remarks

As known for other semi-arid environments in the world, the natural ecosystems of northern Namibia show an eminent resilience and regenerative capacity in relation to external impacts due to the highly variable climatic fluctuations (Frost *et al.* 1986; Mensching 1990). Although irregular, episodic events like severe droughts or bushfires may have a strong influence on animal population and vegetation dynamics on a smaller time-scale, the longterm stability within the amplitude of the natural system is not affected (Walker & Noy-Meir 1982; Coughley & Walker 1983; Buch 1993a).

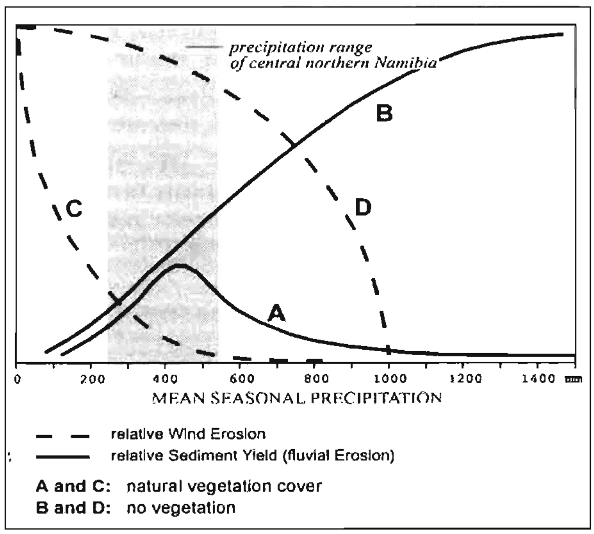


FIGURE 3: Water and wind erosion with increasing mean annual precipitation (after Verstraete & van Ypersele 1986).

Under the present conditions of semi-arid northern Namibia with annual rainfall between 250 and 550 mm/a, water and wind erosion processes are highly active within the annual rhythmic change of a rainy and a dry season (Verstraete & van Ypersele 1986) (Figure 3). The pedogenesis in large areas of the ENP reflects the basic fluctuation of the climate inherent to the system. Soil genesis is generally to a high degree influenced by deflation and erosion processes on one hand and aeolian/colluvial accumulation on the other hand. Thus the soils often do not exhibit a distinct undisturbed horizon differentiation typical for 'in situ' weathered soil profiles of

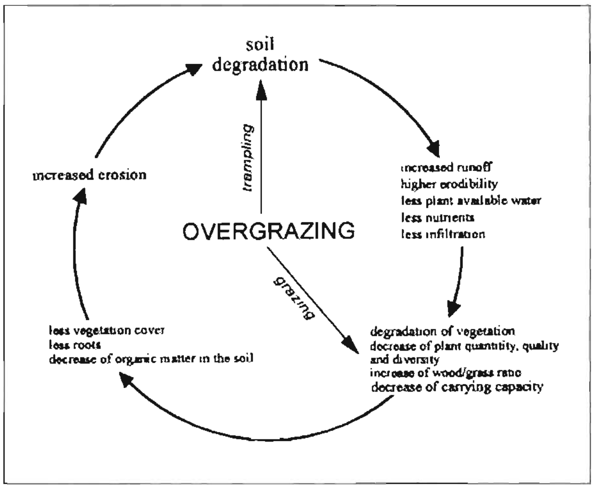


FIGURE 4: The overgrazing - erosion cycle (modified after Littleboy *et al.* 1992).

more humid areas. Besides that, the Late Quaternary sequence of several fossile soils and soil complexes within the sedimentary record of the western pan margin dunes give evidence for alternating phases of relative geomorphic stability and activity under prevailing semi-arid climatic conditions (Buch & Zöller 1992; Buch *et al.* 1992; Buch 1993a).

When a threshold value is passed, e.g. by proceeded destruction of the natural vegetation cover, the rate of soil erosion is accelerated by a number of positive feedbacks. Once soil erosion starts and recovery of vegetation is not possible (e.g. because of unadequate protection and/or climatic stress) factors like surface sealing, reduced infiltration capacities and increasing erodibility of the topsoil enhance runoff and erosion and further limit plant growth. The result is an ongoing deteriorating influence on soil and thus on the whole ecosystem (Figure 4). At a certain point this process of environmental degradation is irreversible and, when induced by human action, well known as 'desertification' (Seuffert 1987; Mensching 1990; Verstraete & Schwartz 1991; Helldén 1991; Mainguet 1991). In the following, the term 'soil erosion' consequently is used synonymously to accelerated erosion caused by direct or indirect human impact (Richter 1965). So far it has to be distiguished from 'natural' or 'geological erosion'.

Causes, types and processes of soil erosion

The ENP has been surrounded by a 'game-proof' fence since 1973, both to ensure adequate protection of plant and animals inside the Park and to prevent damage in the adjacent farming areas, especially by elephants and predators. Unfortunately, this fence has also cut off the seasonal migration routes of the large game populations and has lead to the concentration of animals in areas with enough available water and high grazing capacities during the dry season. Especially the west of the ENP and the southern and eastern margin of the Etosha Pan are affected, as here important traditional migration routes to the Kaokoveld and the Lake Oponon area in Owambo have been cut by fencing (Figure 5). As a consequence, regional overstocking caused the destruction of the grass cover and the soil surface by excessive grazing and trampling. Thus the deteriorating effects of soil erosion,

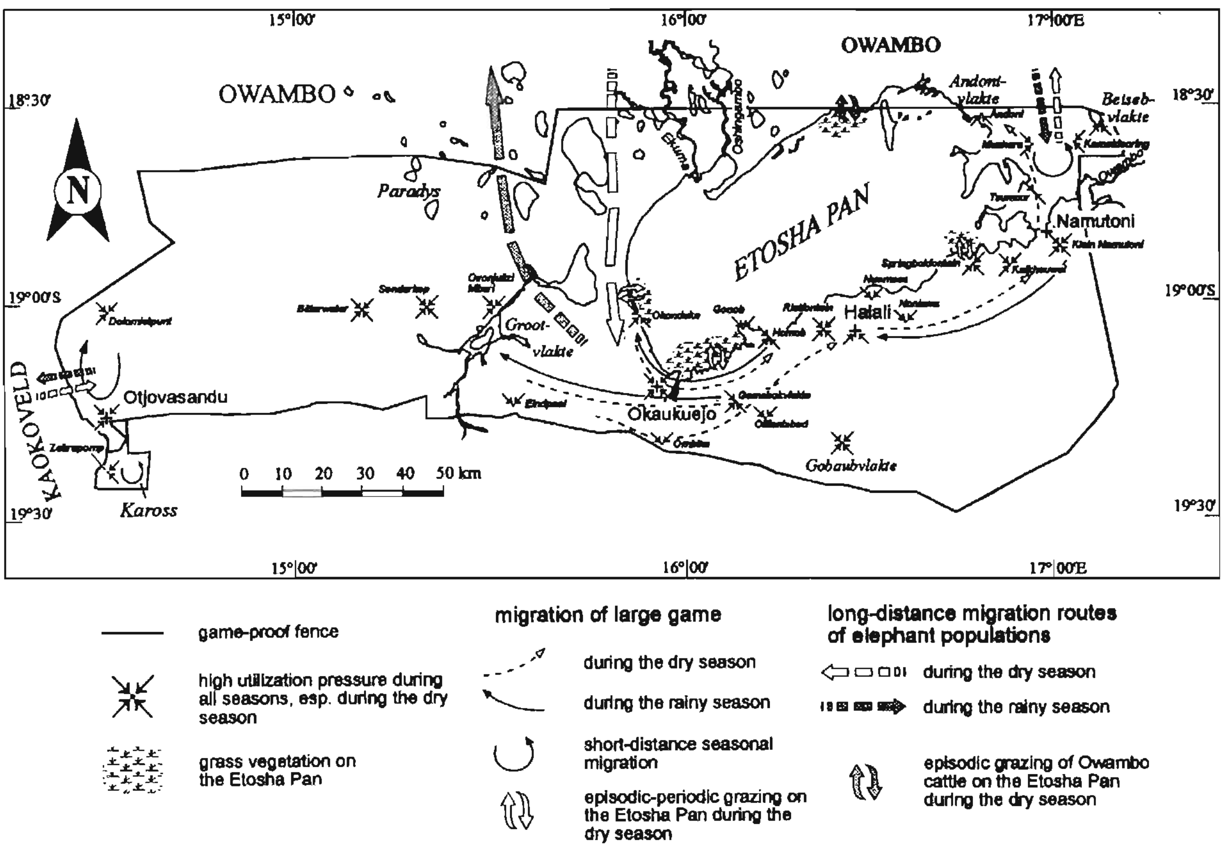


FIGURE 5: Seasonal game migration and utilization pressure in the Etosha National Park (modified after Buch 1993a).

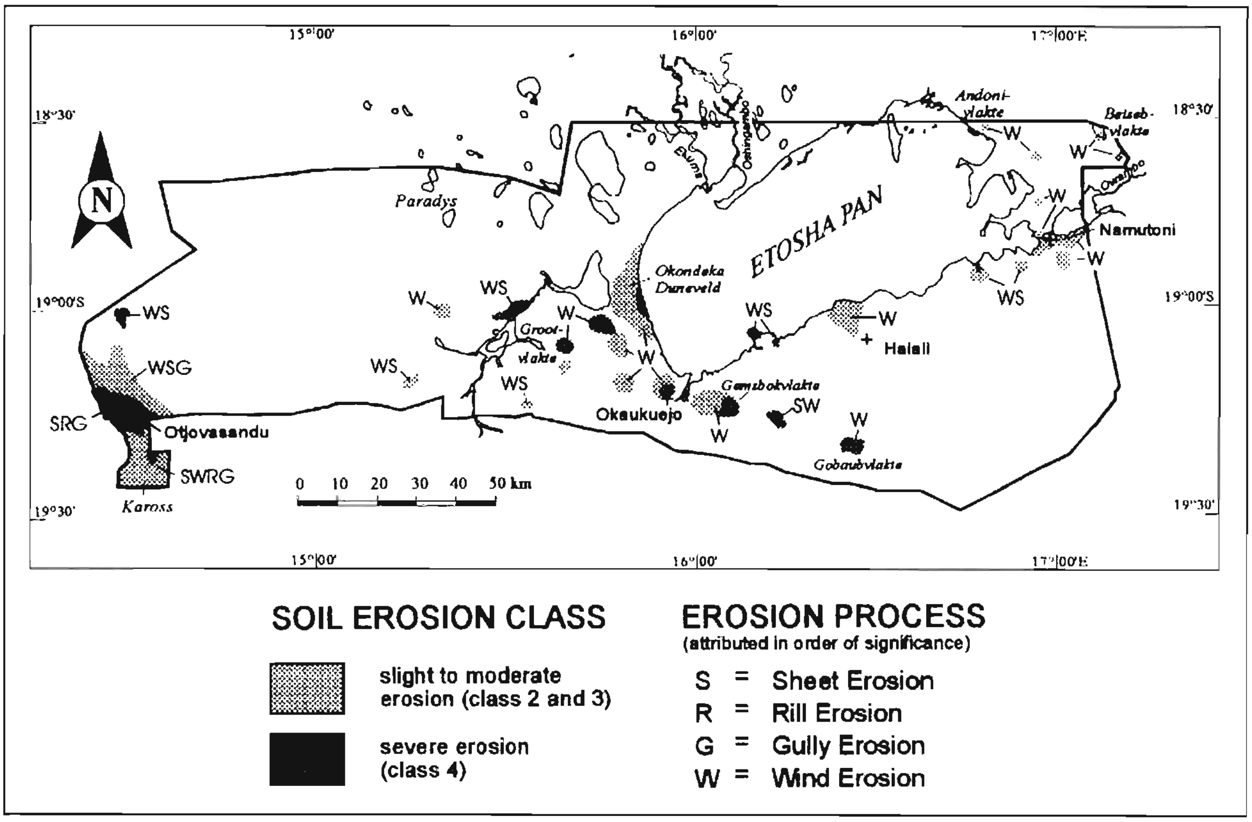


FIGURE 6: Soil erosion in the Etosha National Park (classified after SARCCUS 1981).

PLATE 1: Several cm-thick, fresh aeolian sediment cover after a thunderstorm in October 1992, 3 km west of Okondeka (Okondeka Duneveld). Photo: H. Beugler-Bell, Oct. '92

which are enhanced by climatic stress, are currently clearly visible after a long period of under-average rainfall in large areas of the ENP (Figure 6).

The main types of erosion in the ENP are sheet and wind erosion, whereas additionally rill and gully erosion occur in areas with more accentuated topography. While rills and gullies could clearly be identified in the field, the effects and degree of wind and sheet erosion had to be derived indirectly from soil profile characteristics (depth of A-horizon, content of organic matter, grain size distribution), from evidence of freshly deposited sediments, from veld condition (plant species composition and density) (Du Plessis 1992) and partly, by interpreting aerial photographs and satellite images. Soil erosion is most active at the end of the dry season and at the beginning of the wet season (September to December), when the topsoil is extremely dry and the least vegetation cover is present. High-energy tropical thunderstorms not only cause extreme runoff but also increase the aeolian activity due to high wind speeds and turbulences shortly before the rain starts (Plate 1). These observations are supported by wind erosion measurements at the southwestern edge of the Etosha Pan which show a clear relation between aeolian deposition and rain events, especially at the start of the rainy season (Figure 7).

The areas that are severely affected by soil erosion are concentrated on the short and long grass plains and adjacent savannas surrounding the Etosha Pan, mainly at its' southern and the south-western margin (Figure 6). Here the game is concentrated due to the abundance of perennial waterholes (Figure 5). Frequently the Leptosols of mapping units C1, C2 and C3 are totally eroded around the waterholes, where bare limestone or limestone/calcrete 'hamada' cover the surface, e.g. at Okaukuejo, Gemsbokvlakte, Olifantsbad, Gonob, Klein Namutoni and Gobaubvlakte. Here wind erosion in combination with sparse vegetation cover and trampling effects of the

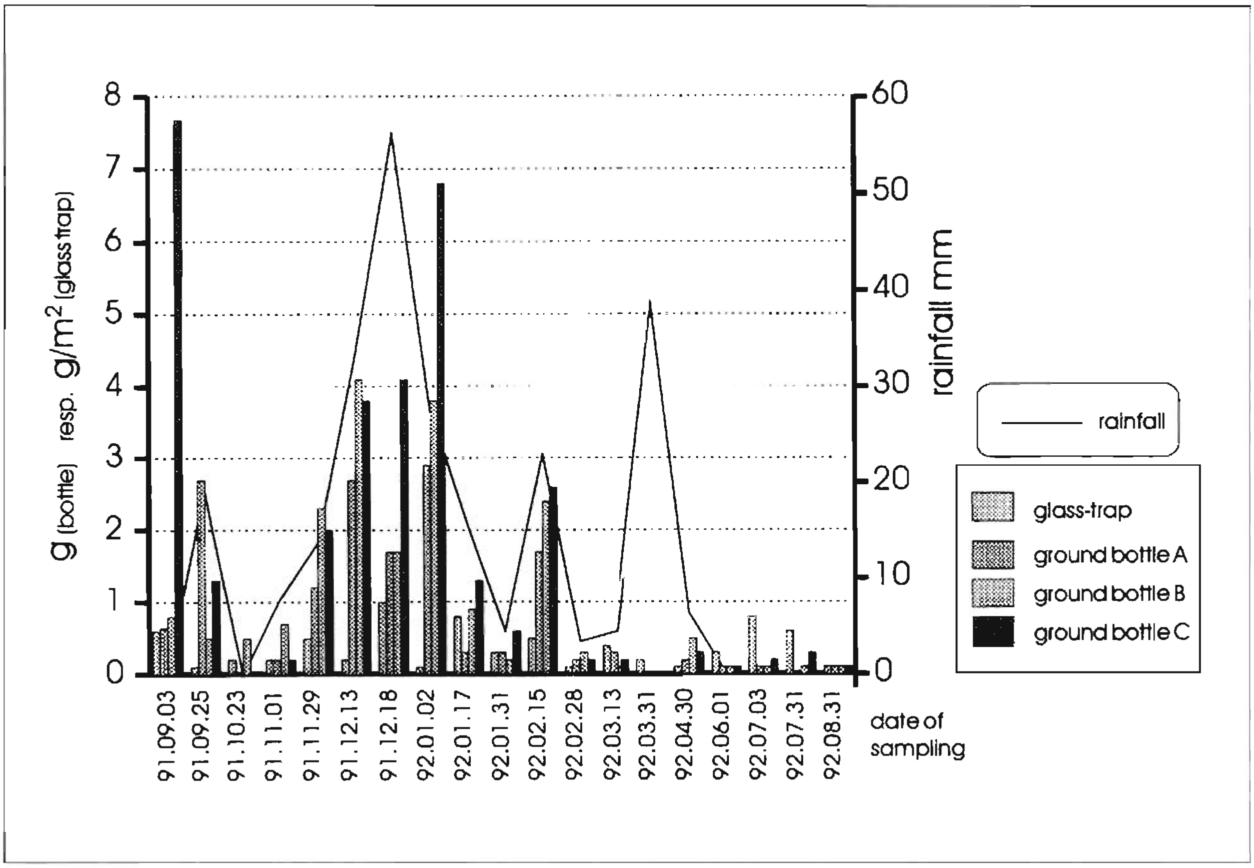


FIGURE 7: Airborne sedimentation at Okaukuejo Airfield (09/91-08/92).

animal populations seem to play a major role because of low relief energy minimizing superficial runoff. In the 'Okondeka Duneveld' (MU A6) sand sheets and sand accumulation around tussock grasses as well as traces of fluvial activity at the pan's edge are evidence for a high geomorphic activity in this area. South-west of Okondeka, the waterholes Natco, Grünewald, Adamax and Leeubron had to be closed in 1977 due to severe erosion damage, but few signs of recovery can be observed until now.

In the west of the ENP heavy overgrazing and accelerated erosion was also enhanced by the completion of the game proof fence, that inhibited the game's seasonal migration to the Kaokoveld in the west. The area around Otjovasandu especially is badly damaged (Figure 6), with sheet erosion on slopes (rock pavements) as well as rill and gully erosion on footslopes and in river valley sediments (Plate 2). As comparable to the situation in Kaross (MU B3), the origin of rills and gullies often can be attributed to road and/or animal tracks.

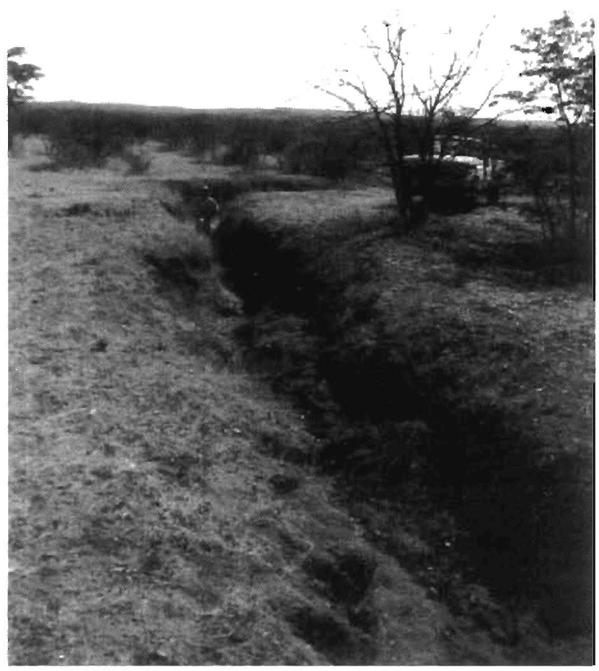


PLATE 2: 1.5 m deep erosion gully in a footslope colluvium 6 km south-east of Otjovasandu. Photo: H. Beugler-Bell, Nov. '92

Effects of soil erosion

The effects of soil erosion in the ENP are numerous and will be discussed briefly in order to get an idea of long term desertification potential of this area. Irreversible loss of soil negatively affects the most limiting ecological factors for plant growth in semi-arid environments, i.e. water holding capacity and nutrient status. Nutrient enriched topsoil (esp. with nitrogen and phosphorus) is blown out or washed away to low lying positions, which leads to net losses of plant available nutrients with increasing spatial heterogenity. Also pore space and rooting depth are reduced by soil removal and topsoil aridification is enhanced by increased runoff surface crust formation. With decreasing water holding capacities and aridification of the topsoil the fragile balance between the grass/wood components in savanna ecosystems (Walter & Breckle 1983) is shifted towards woody species. This leads to bush encroachment with negative effects on the veld's grazing capacitiy by reducing available herbaceous biomass and restricting accessability for large grazers (Kambatuku 1994). Prominent species associated with bush encroachment in the ENP are the stinkbush (*Petchual loeschea-leubnitchia*) spreading east of Ozonjuitzi Mbari and the in Homob area as well as *Acacia nebrownii*, *Dichrostachys cineria* (south of Namutoni), *Colophospermum mopane* (Kalkheuwel), *Acacia areanaria* (Andoni plains) and *Catophractes allexandri* in the pan's edge grassveld. The latter species also is common in the mopane shrubveld in the northwest of the Etosha Pan.

In the grassplains and open savannas of Etosha a decrease of more favourable perennial grass species (concerning nutritive value and erosion protection) can be related to environmental degradation and thus is an obvious effect of soil loss and overgrazing (LeRoux *et al.* 1988). In heavily utilized areas the zone of vegetation degradation extends several kilometers around the watering points, e.g. 5.5 km around Sonderkop or 4.5 km around Okaukuejo (Figure 5). In this area nearly no perennial grass species can be found (W. Du Plessis, pers. comm.). Close to the waterholes in the Karstveld where soil is nearly absent and the rocky limestone crops out at the surface, just well

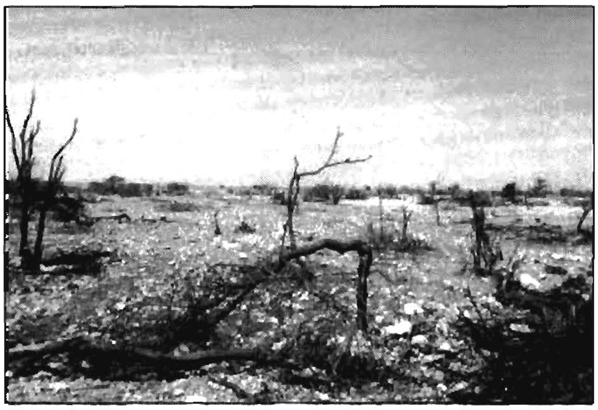


PLATE 3: Severe soil erosion damage and destruction of vegetation around Okaukuejo waterhole as the effect of high animal pressure. Photo: H. Beugler-Bell, Aug. '90

adapted woody species like *Colophospermum mopane* or *Acacia spp.*-thornshrubs are able to survive, if not additionally destroyed by an abundance of large mammals (e.g. elephants) (Plate 3). Such a degraded zone of anmimal impact around waterholes, called 'piosphere' (Andrew 1988), has often been attributed to domestic livestock (Valentin 1988; Perkins & Thomas 1993; Pickup & Chewings 1994), but also is a signal of severe veld overutilization and degradation by large wild herbivores (Thomas 1988; Thrash *et al.* 1995).

The strong deflation of sediments from the nearly unvegetated Etosha Pan by mainly easterly and northeasterly winds is responsible for a relative accumulation of soluble salts in the soils west and south-west of the Pan (Trippner 1997). As the salts mainly are composed of halite (NaCl) the threat of salinization maybe accompanied by an increased alkalinization of the soils in these areas (Table 2). Slight to moderate subsoil salinization as a limiting factor for plant growth is partly compensated by a higher available water-holding capacity and more favourable infiltration characteristics due to the aeolian admixture of sand, esp. in the clay-rich soils of mapping units C1 and C4 (Table 2). Although the above mentioned effects have to be attributed to natural erosion, on which man has no direct or indirect influence, climatic changes expected from greenhouse warming (e.g. reduced and/or more accentuated rainfall, stronger winds) (Dregne 1990) could enhance wind erosion from the pan (Buch 1993a) and thus increase the risk of salinization.

Finally a positive, although exceptional aspects of soil erosion and its effect on ecosystem diversity in the ENP should be mentioned here. In parts of the dense woodlands south of Klein Namutoni (*community 14* according to Le Roux *et al.* 1988) the soils are nearly totally eroded due to high animal pressure over decades and bare limestone covers the surface. This environment with low to absent grass cover and a high diversity of shrub and tree species provides an ecological niche for a small browser species, the Damara Dik Dik *Madoqua Kirki*, which is well adapted to rocky environments.

Modelling erosion hazard in the Etosha National Park

The assessment of erosion hazard by using erosion models is a useful and valuable technique of land resource and landscape ecological risk evaluation. With this methodology it is possible to classify areas according to the type and intensity of soil erosion as a basis for land management decisions and soil conservation work (Morgan 1986). Model application was found necessary in the ENP, as field mapping was unpracticable because of limited time and money and because of the large dimensions and the unaccessability of the area. Also recent medium to large scale aerial photographs (scale + 1:25.000) were not available for a mixed field/air survey of erosion features (Williams & Morgan 1976).

Several erosion models were applicated to estimate soil erosion at exploratory to reconnaissance level (scale 1:1.000.000 - 1: 50.000) (Table 3). These are an integrated part of the LERIS land evaluation system (Buch *et al.* 1993). For potential wind and gully erosion two simple models were developed in order to identify areas of high erosion hazard on the basis of land, vegetation and substrate properties. The SLEMSA model (Soil Loss Estimation Model for Southern Africa) (Elwell 1981; Stocking *et al.* 1988) with a locally adjusted soil erodibility index F was used to define sheet erosion hazard.

Due to the low mean vegetation cover and the sandy nature of the topsoils wide areas inside the ENP bear a high to very high risk of wind erosion (Table 2). Especially the Sandveld areas (soil classes A and B), the actual pan floors (MU E2a, E2b and D4) and the pan's edge grassveld (MU A6, C4, C5 and E1) show a very high potential wind erosion hazard. On the pan and the marginal grassplains wind erosion hazard additionally is enhanced by the flat terrain and the nearly absence of trees or larger shrubs, which allows high wind speeds at the soil surface. Especially wind erosion increases manyfold in

TABLE 3: Soil erosion model application in the Etosha National Park

Erosion Type	Model Type	Factors	Results
Sheet Erosion	empirical (SLEMSA)	* soil erodibility (including land use) * rainfall erosivity * vegetation cover (mean rainfall interception * slope inclination and length	quantitative: * *t/ha/yr at field scale* * *EHU (Erosion Hazard Units) at medium to small scale*
Wind Erosion	deductive	* soil erodibility (Wind Erodibility Group) * vegetation cover and structure	qualitative: *5 erosion classes*
Gully Erosion	deductive	* depth of erosive material * basic infiltration rate * slope inclination * morphological position	qualitative: *5 erosion classes*

semi-arid areas, when the natural vegetation cover is disturbed or removed (Figure 3).

On the other hand sheet erosion risk is neglectable in large parts of the park, as the terrain of the Etosha Basin generally is very flat and the soils' susceptibility towards water erosion is limited by their moderate to high infiltration capacities combined with coarse texture, especially when situated in exposed positions (Table 2). Again, the marginal areas of the Etosha Pan are subject to moderate (MU D2) and high (MU C4) sheet erosion hazard. Like wind erosion, sheet erosion in this area is enhanced by high animal pressure, which negatively affects the factors soil erodibility and vegetation cover. With the exception of some areas with strongly undulating terrain (e.g. the Olifantsbad area), the shallow Karstveld soils are only slightly affected by sheet erosion due to their high content of surface rock material. However, in the strongly dissected Kaokoveld parts of the ENP in the west, sheet erosion hazard is high to very high in sloping terrain (MU B2) and in the Otjovasandu Basin (MU D1) (Table 2). Besides that this area is moderately threatened by gully erosion, especially in river valley alluvia and footslope sediments. Also the Kaross Granite Areas (MU B3) and the immediate footslopes of the Otavi Hills (MU B1) show a weak potential for gullying.

CONCLUSIONS

The ecosystems of central northern Namibia are characterized by a high spatial variability of the pedological site conditions, influencing physico-chemical processes as well as the resilience and vulnerability of the individual systems. This diversity has to be kept in mind when dealing with environmental problems (Buch 1993b). The monitoring of actual soil erosion damage as well as the determination of potential erosion hazard of the different mapping units and associated soil types in the ENP makes it possible to define special environments with high sensitivity towards external pressure and thus high desertification potential. These are the heavily grazed grassplains around the Etosha Pan of mapping units C4, A6 and E1, to a lower degree C3 and C5 (Figure 1), where relatively highly erodible soils, seasonally low or absent vegetation cover and high animal pressure may, or have already caused considerable damage on the ecosystem. The grassplains, which are in a stable dis-climax-stage due to intensive game performance (Le Roux *et al.* 1988), exhibit a high amplitude of primary production in relation to rainfall and grazing. However, when a threshold value is passed (e.g. soil depth, wood/grass ratio) and the enormous regenerative capacity of the system is exceeded, irreversible ecosystem changes and degradation will follow. The other area of special attention is situated in the west of the park (Kaross and the Otjovasandu area), where the pronounced relief, lower amounts of rainfall with extreme variabilities and the intrinsic vulnerabilities of the soils towards erosion (esp. mapping units D1, C6 and B3) show a high degradation potential.

Especially in regions where the soils are extremely shallow or restricted by a hardpan, e.g. in the Koakoveld (MU B2 and B3), in parts of the Karstveld (MU C2 and C3) and on the Andoni plains (MU E1) further removal of fine earth definitely will cause an *irreversible* negative change of soil and vegetation characteristics, thus leading towards desertification. Here, the threshold of transition to a further qualitative ecosystem state is very low. Parts of the park environment are already affected by this process actually spreading out from permanent waterholes (e.g. Okaukuejo, Gobaubvlakte, Otjovasandu area, Namutoni area).

The highly dynamic and erratic nature of savanna ecosystems and the danger of irreversible environmental degradation has to be considered in National Park management decisions concerning waterhole management, fire policy or the extension of tourist facilities (Westoby *et al.* 1989; Mentis & Bailey 1990). Areas of high degradation potential, which are chracterized by highly erodible and/or shallow soils, steep slopes, high rainfall variability and high erosion hazard, have to be managed very carefully. Where larger impacts in the environment are planned (e.g. drilling of new boreholes, building of new tourist camps or roads), a detailed landscape ecological risk assessment of the area of interest is necessary in order to guarantee the sustainability of wildlife and related ecosystems. Changes of fencing policy in some areas, e.g. in the Kaokoveld and at the north-eastern edge of the Etosha Pan should be considered and integrated into regional development plans in order to allow further game migration and to take away pressure from highly utilized regions like the Otjovasandu area or the pan's edge grassveld.

Although subject to great uncertainty, the threat of global warming has to be kept in mind when dealing with environmental problems, as its effects are thought to exacerbate the degradation of semi-arid lands in particular (Verstraete & Schwartz 1991). Land management should consider the potential implications of climatic change for environmental planning in order to achieve sustainable agricultural production or guarantee sustainable wildlife in Namibia in the future. Environmental research is required to monitore the quality and land capability potentials, and to analyse the sensitivity of resource systems in relation to climatic change and human impact (Riebsame 1991). As changes in soil properties can be seen as a general measure of the changes in ecosystem functions (Schlesinger *et al.* 1990), soil related research efforts have to be intensified.

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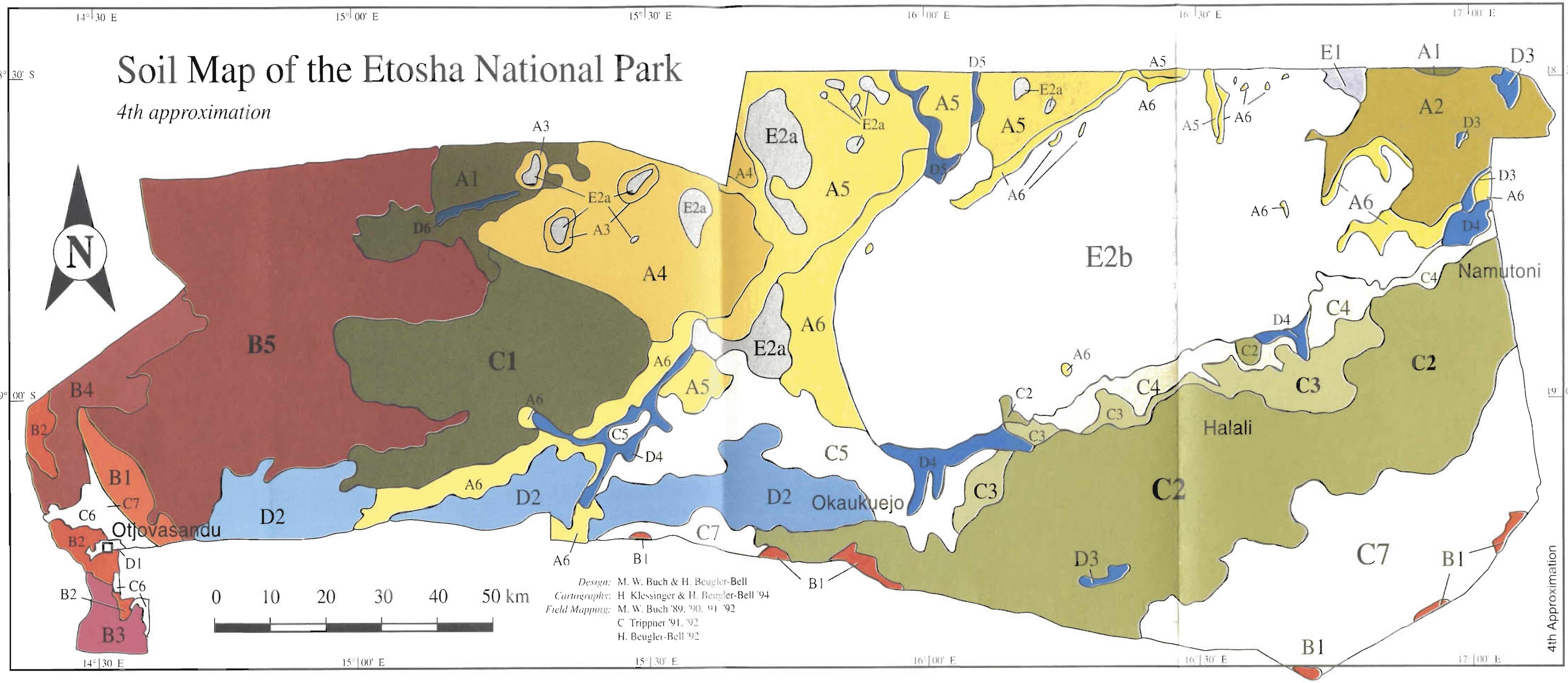

A: SOIL ASSOCIATIONS FROM DEEP (> 1 m) SANDY SUBSTRATA

- **A1** Chromi/(Rhodi) Ferralic ARENOSOLS from aeolian sands above Omatako Sandstone ('Kavango Dunefield') and above sandy Etosha Limestone ('Paradys')
- **A2** Cambic ARENOSOLS - Xanthi/Chromi Ferralic ARENOSOLS from sands above Andoni Sand-/Siltstone and Etosha Limestone (North-Eastern Samdfield')
- **A3** Xanthi/Chromi Ferralic ARENOSOLS - Cambic ARENOSOLS Calcaric CAMBISOLS - Calcaric ARENOSOLS from aeolian sediments above sandy Etosha Limestone ('Paradys Pans topo-chronosequence')
- **A4** Cambic ARENOSOLS from aeolian sands above Etosha Limestone - (Psammi) Veffic/Eutric CAMBISOLS - Dystric/(Eutric) PARA VERTISOLS from sandy Etosha Limestone
- **A5** Cambic ARENOSOLS from sandy sediments above Etosha Lime stone - (Humi) Eutric CAMBISOLS from sandy Etosha Limestone
- **A6** (Hyper)calcaric REGOSOLS - (Hyper)calcaric ARENOSOLS aplic CALCISOLS (petrocalcic phase) from calcareous sediments above Etosha Limestone and Andoni Sand-/Siltstone

B: SHALLOW TO MODERATELY DEEP (< 1 m) SANDY LOAMY TO SANDY SOIL ASSOCIATIONS

- **B1** Lithic/(Eutric) LEPTOSOLS - (LITHI) Rhodi Eutric CAMBISOLS Rhodi Ferralic ARENOSOLS from Otavi Dolomite
- **B2** Rudi Dystric/(Eutric/Umbric/Lithic) LEPTOSOLS from Khoabendus Rocks (Quarzite, Dolomite, Shist, Rhyolite, Granodiorite, Andesite) and Calcrete
- **B3** (Lithi/Skeletti)-Chromi Dystric CAMBISOLS - (Rudi) Dystric LEPTOSOLS from Granite - (Lithi) Dystric/(Eutric) FLUVISOLS above Calcrete or Granite
- **B4** (Chromi/Rhodi) Haplic/(Cambic) ARENOSOLS - Areni Eutric LEPTOSOLS from aeolian Arenosol-sediments above Etosha Limestone
- **B5** (Chromi) Haplic ARENOSOLS from aeolian Arenosol-sediments above Etosha Limestone - (Psammi) Eutric VERTISOLS from sandy Etosha Limestone

Notes:
- 'Inclusions' which cover less than 20% in a mapping unit, are not listed in the legend
- Associated 'Units' and 'Groups' of the same 'Major Unit' are seperated by a virgule
- When in brackets, the 'Units' or 'Groups' are of less importance (cover a small area) or/and the diagnostic properties cannot be clearly defined in taxonomic terms

C: SHALLOW TO MODERATELY DEEP SANDY-LOAMY TO LOAMY-CLAYEY SOIL ASSOCIATIONS

- **C1** (Psammi) Vertic CAMBISOLS - Eutric VERTISOLS from (partly sandy) Etosha Limestone
- **C2** Lithic/Rendzic/(Mollic) LEPTOSOLS- (Psammi) Eutric/(Dystric) VERTISOLS from Etosha Limestone
- **C3** Lithic/Eutric/Rendzic LEPTOSOLS from Etosha Limestone
- **C4** (Psammi) Lithic/Rendzic LEPTOSOLS - (Hyper)calci Sodic SOLONCHAKS - (Hyper)calcaric REGOSOLS from Etosha Limestone, partly from calcareous sediments above Etosha Limestone
- **C5** (Hyper)calcaric REGOSOLS - (Psammi) Rendzic/Eutric LEPTOSOLS from calcareous aeolian sediments above Etosha Limestone
- **C6** (Chromi/Rhodi) Dystric CAMBISOLS - Rendzic/Eutric LEPTOSOLS from Khoabendus Rocks (Quarzite, Dolomite, Shist, Rhyolite, Andesite) and Calcrete
- **C7** Eutric LEPTOSOLS - Rhodi Eutric CAMBISOLSfrom Otavi Dolomite (eroded soils of MU B1) - Eutric FLUVISOLS above Etosha Limestone and Calcrete (correlate sediments of MU B1) - Lithi-(Psammi) Eutric I ERTISOLS from Calcrete

D: SOILS FROM FLUVIAL SEDIMENTS

- **D1** Dystric/Eutric FLUVISOLS above Calcrete
- **D2** (Lithi) Eutric/(Calcaric) FLUVISOLS - Calcaric REGOSOLS - Lithi/Rendzic LEPTOSOLS above/from Etosha Limestone
- **D3** Calcaric FLUVISOLS - Calcaric REGOSOLS above Etosha Limestone and Calcrete
- **D4** (Gleyi)-Verti-(Hyper)calcari (Hyper)salic FLUVISOLS above Andoni Sand-/Siltstone
- **D5** (Gleyi)-Areni-Calcari Salic FLUVISOLS above Andoni Sand-/ Siltstone
- **D6** Mollic FLUVISOLS above sandy Etosha Limestone

E: SALINE SOILS/ SODIUM-RICH SOILS

- **E1** (Sali) Stagnic SOLONETZS from Andoni Sand-/Siltstone or from shallow fluvial sediments above Andoni Sand-/Siltstone
- **E2 (a/b)** Calci Sodic SOLONCHAKS - Sali Calcic SOLONETZS from sandy Etosha Limestone (E2a) or from Andoni Sand-/Siltstone (E2b)