DFG/GTZ-Cooperation Project 'Soils and Environmental Change in the Etosha National Park/Namibia' (Az: Bu 659/4-1)

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A GUIDELINE FOR SOIL CLASSIFICATION IN THE ETOSHA NATIONAL PARK AND ADJACENT AREAS IN CENTRAL NORTHERN NAMIBIA

based on the FAO/UNESCO Legend of the Soil Map of the World and including a Methodology for a basic eco-pedological Hazard Assessment

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I. INTRODUCTION

This paper provides a tentative approach for an extended and regionally adapted soil classification system for Etosha/northern Namibia based on the updated FAO/UNESCO world soil map legend (FAO/UNESCO 1988).
The revised FAO system, which is designed up to a scale of 1:1 million, is a three level taxonomic system, where quantitative criteria of diagnostic soil horizons and properties serve as a basis for classification. Although the system is not as complete or flexible as the USDA Soil Taxonomy (Soil Survey Staff 1975, 1990), it is widely accepted and used as a framework for national and regional soil surveys due to its comprehensible nomenclature, easy applicability and its openness towards changes (Van Wambeke 1989:187).

The FAO soil classification system is based on a great number of regional and national soil surveys and maps and thus cannot be seen to represent adequately all soils in the different parts of the world at the same detail. Especially in regions, that are vast, sparsely populated and quite inaccessible for foreign researchers like the humid or semi-arid Tropics, the existing classification systems do not well represent the variety and diversity of soils due to a lack of information (Richter & Babbar 1991). To serve the specific needs of national and regional maps, a tentative third-level taxa is proposed, which allows the local application of the legend (FAO/UNESCO 1988:56). An example for a national application gives the Revised General Soil Legend of Botswana (Verbeek & Remmelzwaal 1990), where the FAO classification system has been extended and slightly modified to describe more adequately the range of soils present in Botswana.

II. A NEED FOR A REGIONAL ADOPTED SOIL CLASSIFICATION SYSTEM FOR NAMIBIA

Soil survey for the purpose of land evaluation and land use planning still is at the beginning in Namibia. Apart from a small number of more detailled studies on single (irrigation) development schemes (compiled by Schneider 1990, see also Buch 1993b), only framework has been done so far (Schneider 1989). Thus a comprehensive and regionally adapted system for soil survey on a medium to small scale is lacking in Namibia.

Starting in 1989, soil surveys on different scales and related eco-pedological as well as geomorphological-sedimentological studies were carried out in the Etosha National Park and adjacent areas in northern Namibia (Buch 1993a, Beugler & Buch 1993). This work was done within the frame of the present and foregoing cooperation projects between the

Etosha Ecological Institute and the University of Regensburg/ Germany. With the background of the collected experience and data and considering the lack of an adequate classification system in Namibia, there arises the need to outline a system that meets the following requirements:

- It should well be able to describe and classify the range and diversity of the soil types and properties in the semi-arid zone of northern Namibia at various levels, with the aim to allow statements on potential productivity and potential hazards of the different soil types or mapping units. Thus morphological or effective soil properties are preferable to genetical properties for classification, like clearly shown in the Soil Taxonomy (Soil Survey Staff 1975:7-11) or the FAO system, esp. at its lower levels. Although the separation of soil units in the the FAO classification relates to general principles of soil genesis, only the effects of soil forming processes are taken as identification criteria (FAO/UNESCO 1988:20).

- The nomenclature and definitions proposed by the FAO/UNESCO (1988) with only slight modifications have to be taken over, at least at the two highest levels; modifications and extensions, mainly at the third or lower levels, have to be defined in quantitative terms.

- The system has to be clearly structured and defined to avoid confusion and to allow a rapid and easy correlation with the USDA Soil Taxonomy (Soil Survey Staff 1975, 1988) or the South African Binomal System (Macvicar et al. 1977), as well as with other national soil classification systems in Southern Africa (SARCCUS 1984).

- Flexibility, i.e. applicability of the system on different scales (1:1.000.000 to 1:50.000 or even larger) and the possibility for an extension or change when necessary have to be required in order to allow its use in other parts of the country. As the classification of soils in northern Namibia is based on the present state of knowledge, modifications could be necessary with a growing database.

III. CLASSIFICATION STRUCTURE

The proposed classification partly follows the system developed by Petermann (1988) for arid soils in the Lybian part of the Sahara. He extended and partly modified the FAO classification up to seven hierarchical levels and made stronger adjustments to the USDA Soil Taxonomy in order to incorporate the different arid soil properties and to allow exact statements on large scale suitability of the soils for irrigation (Petermann 1988:66-85). Due to a less detailed spatial resolution of the soil observations and in order to maintain clearness and simplicity, Petermann's classification was simplified, esp. at the lower categories (from Groups downward).

Six hierarchial levels are proposed for the study area, where, depending on spatial resolution of soil informations, at least the three highest taxa are applied for soil mapping on a scale 1:50.000 or larger.
The taxa are from the highest level downward: MAJOR UNITS - UNITS - GROUPS - SUBGROUPS - FORMS - SERIES. Most Phases, describing limiting factors for land use (FAO/UNESCO 1988:60-63), are incorporated into the third or lower classification levels. Analogous to the phases, potential eco-pedological risks like erosion, salinization, alkalinization and flooding additionally are mapped as 'HAZARDS', taken into account the special ecological frame conditions and land use potential of the study area.

1. MAJOR UNITS

The Major Units are identical with the Major Soil Groupings of the revised FAO Legend. As mentioned above, they are identified by the presence or absence of diagnostic horizons and morphological properties, that express the kind and effects of dominant soil forming processes (FAO/UNESCO 1988:4; Petermann 1988:77; see also the definition of 'Orders' in Soil Survey Staff 1975:71). From the twenty-eight Major Soil Groupings (FAO/UNESCO 1988:14-15) ten could be identified in central northern Namibia, namely REGOSOLS, ARENOSOLS, FLUVISOLS, VERTISOLS, LEPTOSOLS, CAMBISOLS, CALCISOLS, PLANOSOLS, SOLONETZ and SOLONCHAKS. PARA-VERTISOLS were introduced and defined as the eleventh Major Unit in Etosha.

2. UNITS

Units represent soils with similar types and combinations of diagnostic horizons and properties. They represent a special soil dynamic and allow to classify soils by considering genetically and/or ecologically important properties (Petermann 1988:77). The units are exclusive to each other, i.e. they are not used in combinations.
Modification on the Unit level were necessary concerning the Regosols and Arenosols, where the Calcaric and Hypercalcaric Units were newly defined. The Hypersalic Unit was introduced for highly saline Fluvisols. The Chromic Unit was erased for Cambisols with

strong brown to red B-horizons without having ferralic properties. These Cambisols were more accurately differentiated at the third, the Group level.

3. GROUPS

At the group level pedological and ecological soil attributes are outlined, that have not been considered at any higher classification level, but are nevertheless important for soil ecology and management (e.g. texture, content of coarse fragments, color of B-horizon indicating different stages of weathering, organic matter content a.s.o.). Consequently most of the Phases, which represent limiting factors related to surface or subsurface features of the land (FAO 1988:60), are taken up into the Group category.

According to the concept of the Subunits, that were introduced in the revised FAO-classification to meet the specific needs at national and regional levels (FAO/UNESCO 1988:56-59), the Groups incorporate intergrades (for def. see Soil Survey Staff 1975:79) between Major Units and intergrades between different Units. Additionally new characteristics are marked or other higher level properties are specified to seperate extragrades (for def. see Soil Survey Staff 1975:80). Thus the groups represent the Great Group and Subgroup level of the Soil Taxonomy (Soil Survey Staff 1975:77-80) or the Group and Subgroup level of Petermann (1988:77). In contrast to Petermann (1988) and Soil Survey Staff (1975) climatic factors, i.e. moisture and temperature regimes, are not considered at this or higher levels.

Groups normally do not exclude each other and combinations within one Unit are possible, if not other stated. If combinations occur, more important properties should placed before less important (subjective choice).
Most of the modifications and extensions proposed in this paper are defined at the Group level.

4. SUBGROUPS

Deviating from the earlier version of the FAO/UNESCO Soil Map of the World (FAO/UNESCO 1974), all climatic criteria for classification, except permafrost, were eliminated from the revised FAO legend (FAO/UNESCO 1988:6). The reason for this is the difficulty of measuring soil temperature and soil moisture regimes and the problems of classification due to a lack of information. This trend, that is also followed by a number of national classifications (Van Wambeke 1988:181), goes opposite to the concept of the

Soil Taxonomy, where soil moisture and temperature regime are important factors of classification.

Especially in a semi-arid environment like in northern Namibia, the soil moisture regime is the most important ecological factor, that governs plant growth (= effective productivity of biomass) and the distribution, i.e. the spatial variation of vegetation. Besides the distribution and variability of rainfall (characterised by a E-W gradient of mean annual precipitation with high seasonal and spatial variability) (Engert 1993), soil morphological features like depth of solum, texture and structure or soil chemical properties as the presence of sweeling clay minerals (govern internal drainage and water holding capacity), as well as relief position and topography (govern external drainage) are crucial for the soil moisture regime at any site and its spatial variability.

Although the above mentioned difficulties of measuring soil climate are also existing in the study area, the soil moisture regimes were taken up into the soil classification as a own taxa: the Subgroup. This allows to drop the subgroup category without touching the three higher classification levels, if it is not possible to determine or estimate the soil moisture regime exactly by using standard climatic records (Newhall 1972; Van Wambeke 1982). Nevertheless it is important for future studies both to initiate soil climate measurements and experiments, and to interprete already existing records in order to get better informations on soil climatic properties. The integration of climatic data into the soil classification might be cancelled by combining soil informations with agro-ecological zone maps (Van Wambeke 1988:182), but these maps do not exist for the study area so far.
In central northern Namibia the aridic and ustic moisture regimes occur (for definition see Soil Survey Staff 1975:51-57).

5. FORMS

The Soil Form differentiates soils by their special site characteristics like relief position, slope, landscape unit, substrate, as well as additional soil properties like texture class, mineralogy and others. Thus the soils are grouped on similar physical and chemical properties, which affect their responses to management and manipulation for use (see the definitions of 'Families' in: Soil Survey Staff 1975:80,383-389). Additionally some special soil site characteristics like 'buried' (recent aeolian, fluvial or colluvial cover of >30 cm) or 'trunctated' (obvious removal of topsoil by soil erosion) may be outlined if possible. This is very difficult in the semi-arid area of northern Namibia, where aeolian, fluvial and colluvial redeposition are more or less normal features in soil profile genesis. The weak horizon differentiation and mostly low contents of organic matter in the epipedon normally inhibit clear statements concerning the extent of erosion and aggradation at a site.

6. SERIES

At the lowest level, the Series, locally observed ecological important properties like thickness and depth of diagnostic horizons, the nature of horizon boundaries or type of properties like the size of mottles or nodules are described. Soils from one Subgroup can be differentiated and classified according to one or more of their properties, which ranges are defined and restricted to a special Serie (Soil Survey Staff 1975:80-81). Lokal names are possible to separate soil Series. At a scale 1:50.000 or smaller the soils are normally not mapped at the Series level, except where the environmental conditions and the soils are very uniform over a large area, as it is the case in some regions of the ENP.

V. THE MODIFICATIONS

Table 8 shows the different Major Units, Units, Groups and Subgroups, that are mapped in central northern Namibia so far. The modifications and supplements, which are defined and discussed below, are printed in italic letters. If not other statet the diagnostic horizons and properties are defined after FAO (1988).

1) **Cambisols**: To have a proper separation from the Leptosols, the base of the cambic horizon has to be at least 30 cm below the surface instead of 25 cm recommended by the FAO (1988:24).

Due to less intensive weathering and high geomorphodynamic activity in the semi-arid climate, the soils often are quite shallow and rich in coarse (> 2mm) material, esp. on slopes. According to the requirements of the submitted classification (see chapter II), the relevant phases (FAO 1988:60-63) were partly redefined and classified into the Group level:

2) **Rudi**: 40% or more by volume of skeletic material > 2mm are present at the soil surface or within 20cm of the surface. The rudi-Group excludes the lithi-Group. Gravel (0.2 - 6cm) may be separated from stones and boulders (> 6cm) at the Forms level, as

TABLE 1: Major Units, Units and Groups occuring in north central Namibia

MAJOR UNITS	UNITS	GROUPS	SUBGROUPS
CM CAMBISOLS1)	**e** Eutric **d** Dystric **v** Vertic **u** Humic **c** Calcaric	***w*** *Rudi*2) ***s*** *Skeleti*3) ***l*** *Lithi*4) ***p*** *Psammi*5) ***x*** *Chromi*6) ***o*** *Rhodi*7)	*ustic* *aridic*
LP LEPTOSOLS	**e** Eutric **u** Umbric **d** Dystric **k** Rendzic **m** Mollic **q** Lithic	***w*** *Rudi*8) ***p*** *Psammi* ***a*** *Areni*9) ***s*** *Skeleti*10)	
FL FLUVISOLS11)	**e** Eutric **m** Mollic **d** Dystric **u** Umbric **c** Calcaric **z** Salic12) *z! Hypersalic*13)	***a*** *Areni*14) ***l*** *Lithi* ***v*** *Verti*15) ***c*** *Calcari*16) ***c!*** *Hypercalcari*17) ***g*** *Gleyi*18)	
AR ARENOSOLS19)	**h** Haplic **b** Cambic **f** Ferralic20) *c Calcaric*21) *c! Hypercalcaric*22)	***t*** *Xanthi*23) ***x*** *Chromi*24) ***o*** *Rhodi*25) ***u*** *Humi*26) ***l*** *Lithi*	
RG REGOSOLS	*c Calcaric*27) *c! Hypercalcaric*28) **e** Eutric **d** Dystric	***w*** *Rudi* ***s*** *Skeleti* ***l*** *Lithi* ***p*** *Psammi*	
VR VERTISOLS	**e** Eutric **d** Dystric **c** Calcaric	***l*** *Lithi* ***p*** *Psammi*	
CL CALCISOLS29)	**h** Haplic **p** Petric	***z*** *Sali*30) ***w*** *Rudi* ***s*** *Skeleti* ***l*** *Lithi*	
SN SOLONETZS	**j** Stagnic31) **k** Calcic	***z*** *Sali*32) ***z!*** *Hypersali*33) ***k*** *Calci*34)	
SC SOLONCHAKS	**h** Haplic **k** Calcic **n** Sodic	***k*** *Calci*35) ***c!*** *Hypercalci*36)	
PL PLANOSOLS	**e** Eutric **d** Dystric	***k*** *Calcari*37) ***z*** *Sali*38) ***n*** *Natri*39) ***l*** *Lithi*40) ***a*** *Areni*41)	
*PV PARA-VERTISOLS*42)	**e** Eutric **d** Dystric **c** Calcaric **s** Salic	**l** Lithi **c** Calcari	

this is an important property for soil management purposes (note the differences to the 'rudic phase' in FAO 1988:62).

3) **Skeleti**: Same definition like the rudi-Group, but with a presence of 40% or more skeletic material occuring between 20 and 50cm below the surface. The skeleti-Group excludes the lithi-Group.

4) **Lithi**: Continuous hard rock (see definition FAO 1988:29), including a slowly permeable horizon (see Planosols), is occuring within 50cm of the surface.

5) **Psammi**: The psammi-Group is mapped for soils (Cambisols, Leptosols, Regosols, Vertisols, Para-Vertisols), which show a relative enrichment of sand and silt (10% or more) within the upper 50% of the soil depth due to high aeolian activity (accumulation). This property is mapped at the Group level, as it is an important eco-pedological attribute, that improves drainage, aeration and water holding capacity of the soils. Psammi-Groups are lacking signs of illuvial translocation of clay within the profile as well as the destruction or selective erosion of clay in the surface horizons (see the def. of argic B horizon in FAO 1988:22).

6) **Chromi**: Cambisols which reddish brown to red, partly strongly leached B horizon has the following color requirements, but does not show ferralic properties:
a Hue of 7,5YR with a Chroma of 8 or a Hue of 5YR with achroma of 6 or more.

6) **Rhodi**: Cambisols which reddish brown to red, partly strongly leached B horizon has the following color requirements, but does not show ferralic properties:
a Hue of 2,5YR, 10R, 7,5R or 5R

8) Within the Major Unit of the Leptosols, the **rudi**-Group is not used for Lithic Leptosols, as those soils normally have high contents of skeletic material.

9) **Areni**: Sandy Leptosols with a texture coarser than sandy loam.

10) **Skeleti**: Leptosols with a presence of 40% or more by volume of skeletic material at a depth at 10cm or deeper.

11) **Fluvisols**: As stated above and shown with the separation of psammi-Groups, most of the soils in semi-arid northern Namibia are influenced by erosion, accumulation and redeposition by water and wind due to the special ecological environment (extreme seasonality, convective type of rainfall, partly sparse vegetation cover, dry soil sur-

face). An accumulation of fresh material at regular intervals consequently cannot be used alone to describe fluvic properties (FAO 1988:29). Additionally a clear differentiation between in situ weathered soils and redeposited soils sometimes is not possible just by regarding their morphology or pedological properties. Many shallow soils of small, episodical drainage lines or depressions and colluvial soils at footslopes do not show a clear stratification in at least 25% of the soil volume within 125cm of the surface, as recommended by the FAO (1988:29) for Fluvisols. In this case, and in contrast to the normal classification principles (Chapter II), the relative relief position and the geomorphological principle of correlate sediments have to be used as an additional attribute for the classification of Fluvisols.

The great variety of pedological properties, which can be outlined for soils classified as Fluvisols offer a wide range of ecological site conditions. This fact has to be considered in the classification by defining a large number of Groups:

12) **Salic**: Salic properties refer to an electric conductivity of 1:5 soil/water$_{dest}$ solution at 25°C of more than 2mS/cm within the rooting zone to a maximum depth of 100cm or of more than 0.5mS/cm if pH exceeds 8.5. The minimum thickness of the required salt concentration (EC5 >2 / 0.5mS/cm) has to be at least 30cm (note the difference to the definition given by FAO/UNESCO 1988:33). Salic Fluvisols as Fluvisols having salic properties are classified in preference to calcaric properties (Ebenda 1988:36).

13) **Hypersalic**: Hypersalic properties refer to an electrical conductivity of 1:5 soil/water$_{dest}$ solution at 25°C of more than 4mS/cm within the rooting zone to a maximum depth of 100cm or more than 2mS/cm if pH exceeds 8,5. The thickness requirements are the same as for salic properties.

14) **Areni**: Eutric, Mollic, Calcaric and Salic Fluvisols having a texture which is coarser than sandy loam at least within 50cm of the surface.

15) **Verti**: Eutric, Mollic, Calcaric, Salic and Hypersalic Fluvisols having vertic properties at least within 50cm of the surface.

16) **Calcari**: Salic Fluvisols which are calcareous at least between 20 and 50cm from the surface.

17) **Hypercalcaric**: Fluvisols which contain more than 25% calcium carbonate equivalent at least throughout a depth between 20 and 50 cm.

18) **Gleyi**: Eutric, Mollic, Calcaric and Salic Fluvisols having gleyic properties (FAO 1988:30) with an upper boundary between 50 and 125cm from the surface.

19) **Arenosols** are sandy soils with a texture coarser than sandy loam and a depth of 30cm or more, exclusive of materials which show fluvic or andic properties. In correspondence with the classification of Arenosols in Botswana (Verbeek & Remmelzwaal 1990:15-16) and the changed definition in the 2nd reprint of the FAO/UNESCO Soil Map of the World (1990^2:39), gravelly soils having more than 35% rock fragments or other coarse fragments should be excluded. As the colour of the B horizon is an important feature for the distinction of Arenosols in Namibia, Cambic and Ferralic Arenosols are classified into Groups by their color. Also a differentiation into Calcaric and Hypercalcaric Arenosols seems to be useful. Like in Botswana, calcic and petrocalcic horizons should be permitted for Arenosols (Verbeek & Remmelzwaal 1990:16), in order to group all sandy soils into one Major Unit. Additionally the lithi-Group should be allowed.

20) **Ferralic**: Arenosols showing ferralic properties and a coloring of the B horizon expressed by Chromas of 5 or more or Hues redder than 10YR (FAO/UNESCO 1990^2:39). The Cation Exchange Capacity of 4mq per 100g soil is taken as the boundary of ferralic properties, as for sandy soils the calculation of CEC per 100g clay seems problematic (Verbeek & Remmelzwaal 1990:11).

21) **Calcaric**: Arenosols which contain 2 - 20% calcium carbonate equivalent at least throughout a depth between 20 and 50cm.

22) **Hypercalcaric**: Arenosols which contain more than 20% calcium carbonate equivalent at laeast throughout a depth between 20 and 50cm.

23) **Xanthi**: Cambic and Ferralic Arenosols which B horizon has the following colour requirements:
a Hue of 7,5YR with a Chroma smaller than 8 or a Hue of 5YR with a Chroma smaller than 6.

24) **Chromi**: Cambic and Ferralic Arenosols which B horizon has the following colour requirements:
a Hue of 7,5YR with a Chroma of 8 or a Hue of 5YR with a Chroma of 6 or more.

25) **Rhodi**: Cambic and Ferralic Arenosols which B horizon has the following colour requirements: a Hue of 2,5YR, 10R, 7,5R or 5R

26) **Humi**: Arenosols which have a content of 0.8% or more organic carbon in the epipedon.

27) **Calcaric**: Regosols which contain 2 - 25% calcium carbonate equivalent at least throughout a depth between 20 and 50cm.

28) **Hypercalcaric**: Regosols which contain more than 25% calcium carbonate equivalent at least throughout a depth between 20 and 50 cm.

29) **Calcisols**: As calcic and petrocalcic horizons are permitted in Arenosols, Calcisols are soils which have a texture of sandy loam or finer, a calcic or petrocalcic horizon or concretions of soft powdery lime within 125cm of the surface. In contrast to the definition of FAO/UNESCO (1988:43), salic properties are allowed.

30) **Sali**: Haplic and Petric Calcisols which have salic properties within the rooting zone.

31) **Stagnic**: Solonetzs which show stagnic properties within 100cm of the surface. In the case of a sandy epipedon with low contents of iron the signs of reduction and segregation of iron (FAO/UNESCO 1988:30-31) as the effect of water saturation are not clearly developed, although seasonal waterlogging due to a dense natric sub-surface horizon is evident. Stagnic Solonetzs show transitions to Natri-Dystric (Eutric) Planosols where the same restrictions concerning their stagnic properties have to be made.

32) **Sali**: Stagnic and Calcic Solonetz which show salic properties within the rooting zone.

33) **Sali**: Stagnic and Calcic Solonetz which show hypersalic properties within the rooting zone (see footnote No.13).

34) **Calci**: Stagnic Solonetz which have a calcic horizon or show an concentration of soft powdery lime within 125cm of the surface.

35) **Calci**: Sodic Solonchaks which have a calcic horizon or show an concetration of soft powdery lime within 125cm of the surface.

36) **Hypercalci**: Sodic Solonchaks with 25% or more calcium carbonate equivalent at least throughout a depth between 20 and 50cm or which have a calcic horizon with 25% or more calcium carbonate equivalent.

37) **Calcari**: Planosols which are calcareous within the rooting zone.

38) **Sali**: Planosols which have salic properties within the rooting zone.

39) **Natri**: Planosols which have natric properties in the slowly permeable subsurface horizon.

40) **Lithi**: Planosols with a slowly permeable horizon with an upper boundary within 50cm of the surface.

41) **Areni**: Planosols which have a texture coarser than sandy loam in the rooting zone.

42) **PARA-VERTISOLS**: In central northern Namibia in situ weathered Vertisols frequently occur in shallow circular depressions of different radius esp. in limestone (Beugler & Buch 1993, Buch 1993a). On the other hand, dark, clay-rich soils without marked horizontal differentiation can be observed in similar landscape positions, which do not show typical properties of Vertisols like well developed cracks, slickensides, wedge-shaped or parallelpiped structural aggregates or gilgai (FAO/UNESCO 1988:41). Additionally these soils often do not fulfill the textural requirements for Vertisols (> 30% clay) and normally show a high proportion of sand and silt.

It is necessary to classify the soils described above into the new Major Unit Para-Vertisols, a term proposed by Mückenhausen (1985^3:499), as a proper grouping into other Major Units (esp. Vertisols, Fluvisols and Cambisols) is not possible. The eco-pedological site conditions, i.e. the physical and chemical properties differ significantly from those of the Vertisols reflecting a different kind of genesis.

No regular distribution patterns can be recognized so far and soil formation might change from a Vertisol-type soil to a Para-Vertisol between one shallow depression to the other near by (Trippner, in prep.). Para-Vertisols seem to a greater degree be influenced by sediment intake from surrounding higher positions, although in situ weathering is dominant separating the Para-Vertisols from the Fluvisols.

Based on the present state of knowledge, the following definition is proposed for the identification of Para-Vertisols:

Para-Vertisols *are soils having, after the upper 18cm have been mixed, 20% or more clay in all horizons to a depth of at least 50cm. They have dark colors with avalue of 4 or less and a chroma of less than 4 in the upper 75% of the solum. The color requirements may be waved when finely devided calcium-carbonate is present. There is no or only weak horizon differentiation except aeolian accumulation of silt and sand in the topsoil (psammi Group) or an ochric, mollic or umbric A horizon or a calcic horizon or concentration of soft pwdery lime or salic properties within the rooting zone. Para-Vertisols have only weakly developed or no vertic properties like deep cracks, slicken-*

sides, wdge-shaped or parallelpiped structural aggregates or gilgai. The clay fraction is dominated by Illite-type minerals or Pallygorskite. Swelling clay minerals of the smectite-type are not present or play only a minor role.

V. HAZARDS

Keeping in mind the special background of the project 'Soils and Environmental Change in the Etosha National Park/ Namibia', emphasis is given on the determination and mapping of potential eco-pedological risks, their severity, their effects on present and future land use and their distribution. In the Etosha National Park and surrounding areas, the primary land use is wildlife management inside and extensive goat and cattle farming outside the park. These kinds of extensive and low input land use are highly dependent on the productivity of the natural savanna/grassland ecosystems, which is negatively affected mainly by the processes of erosion, salinization, alkalinization, and partly, flooding.

The Hazards have to be assessed based on their actual distribution, severity and dynamics and by considering the vulnerability of the different pedosystems (= soil mapping units or landscape units) towards the processes mentioned above. Data and informations for the Hazard assessment are either derived from qualitative observations, quantitative measurements and by using simply applicable models.

Although some of the relevant soil attributes like salinization or alkalinization are already considered in the soil classification (e.g. by 'salic' and 'natric' properties), their special performance on the soil maps should ease the interpretation of the informations for potential (non-soil scientist) users like wildlife management, environmental planners or lokal farmers. The definition of problem areas, as well as the type and degree of degradation and desertification risks are clearly outlined, which might act as a helpful tool for management desicions.

Thus, the Hazards are kinds of special interpretations of soil data, but should not anticipate a land capability or suitability classification, where a wider range and the complex interactions of factors for land use potentialities and limitations are considered.

On the soil map, the Hazards are superimposed to the soil mapping units and printed as signature overprints. They may appear single or in combination. If the mass of information is too confusing, when showing the Hazards on the soil map, seperate maps should be printet! The classes and class limits proposed in this paper may be subject to change, if necessary (e.g. when applied to other areas with different landscape and different land use patterns).

1. EROSION HAZARD

Wind and water erosion probably are the most important factors, that affect ecosystem productivity and limit land use in the study area.

To get a realistic idea of the degree of erosion, the vegetation as protective agent has to be incorporated into the assessment. Vegetation cover, esp. the grass cover, which is the most important element influencing the degree and extent of erosion a site, is extremely dynamic and subject to interseasonal change. On the other hand vegetation is the factor, that is primarily, directly or indirectly influenced by management actions. If no data on mean annual interception by vegetation are available to incorporate into the soil loss model, the actual vegetation cover is not taken into account, when estimating water erosion. Then, an intermediate cover, ranging from 5-30% for grasslands and from 20-50% for open savannas and woodlands[1], is used to calculate mean sheetwash erosion. As no simple models for wind erosion do not exist so far, vegetation cover cannot be incorporated into the wind erosion hazard assessment.

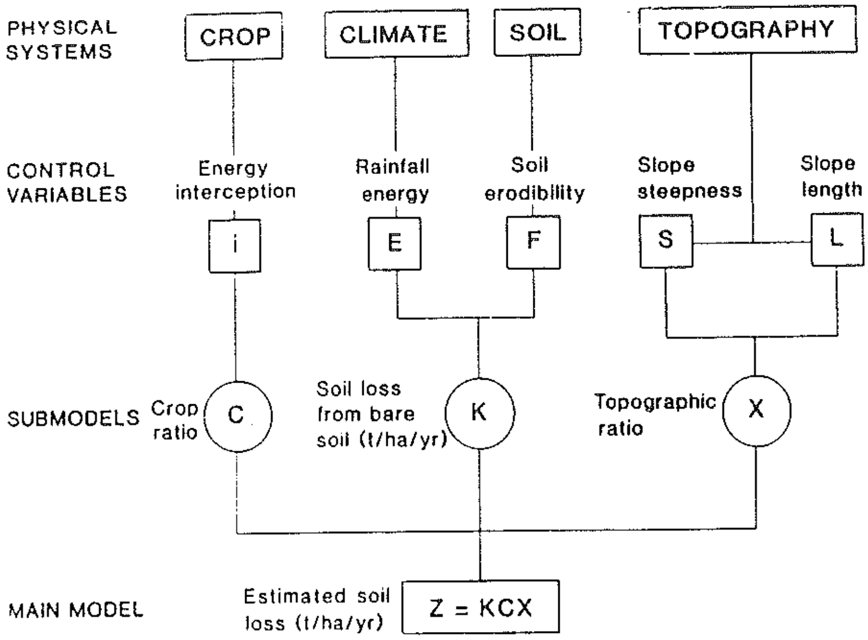

FIGURE 1: The SLEMSA Model (from: Stocking et al. 1988:171)

The **SLEMSA** model (Soil Loss Estimation for Southern Africa), an empirical model developed in Zimbabwe (Stocking & Elwell 1973), is used to estimate the degree of **water erosion** (sheetwash) expressed in 'Erosion Hazard Units' (EHU) (Stocking et al. 1988:170) (Fig.1). This takes into account the factors soil erodibility (Beugler & Buch

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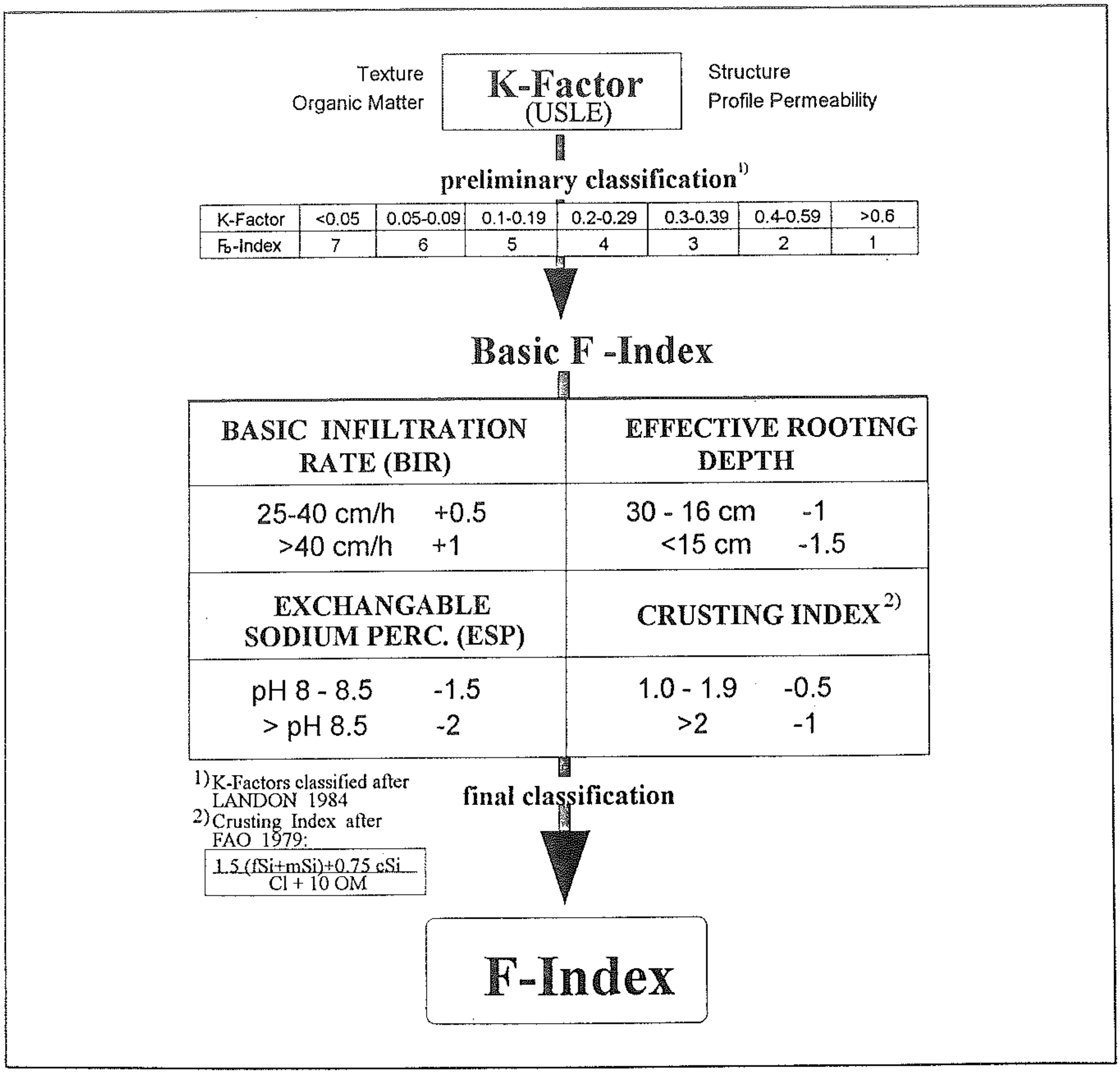
[1] The ranges of mean annual interception by vegetation given here are only valid for the Etosha National Park, where an estimation of mean cover was done for the main vegetation communities by Mr. Wynand du Plessis, Plant Ecologist at the Etosha Ecological Institute (W. du Plessis 1992, Pers. Comm.).

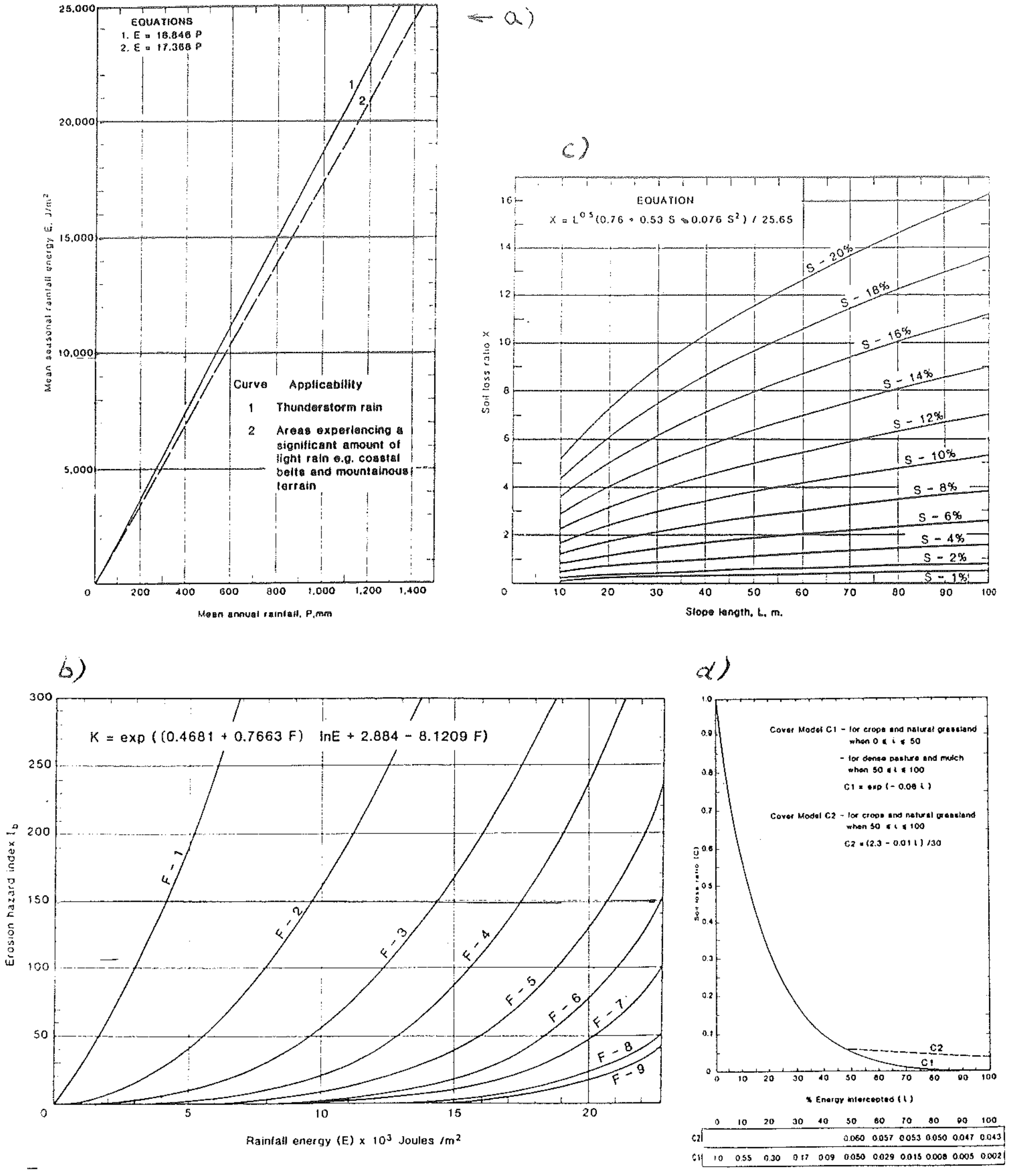
1993) (Fig.2), rainfall energy (Stocking et al. 1988:177) (Fig.3a), mean slope length and steepness (Ebenda:180) (Fig.3c). The impact of changing vegetation cover on soil loss, expressed as mean annual energy interception, has to be read from Figure 3d (Ebenda:179).

The 'Water Erosion Potential' (EP) class limits are kept low (Tab.2), keeping in mind the slow soil formation rates under semi-arid climatic conditions. The lower limit of EHU 4 is adjusted to the low rates of soil formation, reported by various authors for semi-arid climates (2 tons/ha/year in Botswana after Radcliffe 1992:3; even lower rates of < 0,3 tons/ha/year for semi-arid regions are cited by Morgan 1986:163):



K-Factor	<0.05	0.05-0.09	0.1-0.19	0.2-0.29	0.3-0.39	0.4-0.59	>0.6
F_b-Index	7	6	5	4	3	2	1

FIGURE 2: Estimating erodibility by water (from: Beugler & Buch 1993)



	0	10	20	30	40	50	60	70	80	90	100
C2						0.060	0.057	0.053	0.050	0.047	0.043
C1	1.0	0.55	0.30	0.17	0.09	0.050	0.029	0.015	0.008	0.005	0.002

FIGURE 3: Tables to determine rainfall energy (a) and the K- (b), X- (c) and C-submodels (d) of SLEMSA (from: Stocking et al. 1988)

TABLE 2: Classes of Water Erosion Potential (EP)

Class 1: PEHU = 4 - 8 (low=1)
Class 2: PEHU = 9 - 15 (medium=2)
Class 3: PEHU = > 16 (high=3)

When estimating potential **wind erosion**, only erodibility by wind can be considered, as other relevant factors and their interactions like wind speed, surface roughness and slope cannot be quantified so far. The effect of vegetation is similarily important to water erosion. The soils' susceptibility towards wind erosion is estimated from soil texture (Skidmore 1988:207) (Tab.3), which is an indicator for the percentage of dry aggregates bigger than 0,84 mm. The seven Wind Erodibility Groups (WEG) are grouped into three classes of Wind Erosion Potential (WP) (Tab.4).

TABLE 3: Estimating the erodibility by wind from soil texture (from: Lyles 1977:882).

WEG	Predominant Soil Texture Class of Surface Layer	Dry Soil Aggregates > 0,84 mm (%)	Wind Erodibility Index, I (Mg/ha)
1	Very fine sand, fine sand, or coarse sand	1 2 3 5 7	695 560 493 404 359
2	Loamy very fine sand, loamy fine sand, loamy Sand, loamy coarse sand, or sapric soil materials	10	300
3	Very fine sand loam, fine sandy loam, sandy loam, or coarse sandy loam	25	193
4	Clay, silty clay, noncalcareous clay loam, or silty clay loam (> 35% clay)	25	193
4L	Calcareous loam and silt loam or calcareous clay loam and silty clay loam	25	193
5	Noncalcareous loam and silt loam (< 20% clay) or sandy clay loam, sandy clay, and hemic organic soil materials	10	126
6	Noncalcareous loam and silt loam (> 20% clay) or noncalcareous clay loam (< 35% clay)	45	108
7	Silt, noncalcareous silty clay loam (< 35% clay), and fibric organic soil materials	50	85
8	soils not susceptible to wind	>80	0

TABLE 4: Classes of Wind Erosion Potential (WP)

Class 1: WEG 7 - 5 (low=1)
Class 2: WEG 4 - 3 (medium=2)
Class 3: WEG 2 - 1 (high=3)

The **Mean Potential Soil Erosion** (MPE) is calculated from the degree of potential water and wind erosion (Equation 1), weighted against the Effective Rooting Depth (ERD)[2] and expressed in three **Mean Potential Erosion Severity** classes (MPES) (Tab.5). To avoid underestimation of Mean Potential Soil Erosion (MEP), transitions between two classes are grouped into the higher class (e.g. MEP=1,5 → MEP=2 = medium).

$$(1)\quad (EP+WP)/2 = MPE$$

TABLE 5: Mean Potential Erosion Severity (MPES)

ERD	MPE 1	MPE 2	MPE 3
< 30 cm	2	3	3
30 -60 cm	2	2	3
60 - 100 cm	1	2	2
> 100 cm	-	1	1

MES classes: 1 = low, 2 = moderate, 3 = severe

It seems problematic to combine two factors with different content and accuracy of information (EP and WP) to calculate the Mean Potential Soil Erosion Severity. But as far as no better model to estimate the potential wind erosion exists, the proposed method should be adequate to allow generalized statements on the potential erosion hazard at a scale 1:50.000 or smaller.

It is clear, that with changing vegetation cover the Mean Erosion Severity of an area is changed towards a higher (decreasing vegetation cover) or lower (increasing vegetation cover) MPES class. In the case of water erosion the effects of changing cover can be deduced from tables (Fig.3c) or, after an adequate vegetation survey, can be incorporated to calculate the actual Erosion Hazard Units (EHU) of an area. On the other hand, by ma-

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[2] ERD = The Effective Rooting Depth or Rooting Zone is the part of the soil body, that plant roots are able to penetrate. Limitations for the rooting zone are either continuous hard rock, a strongly calcic or petrocalcic horizon, a duripan, or a horizon with high concentrations of salts or toxic elements (e.g. SHC4 or AHC 3). The maximum effective rooting depth is taken at 2m for deep sandy soils.

nipulating vegetation, the managemnet has the opportunity to reduce the Mean Potential Soil Erosion to a desired level.

2. SALINIZATION HAZARD

Contents of soluble salts are severe plant limiting factors, when exceeding a given level, as they contain ions beeing harmful to most plants and raise the osmotic pressure of the soil solution around the roots, thus limiting water uptake. In the semi-arid environment of northern Namibia low rainfall and high evaporation rates favour salt accumulation, esp. in fine-textured soils of low lying positions. Additionally the strong outblow of salt-bearing sediments from the bare floors of the Etosha Pan and other smaller pans enhance the risk of salinization (Trippner 1993), which could be worsened by direct or indirect human impact (e.g. by vegetation and climate change due to greenhouse warming, by irrigation agriculture).

Each individual plant reacts different to increasing contents of soluble salts (Landon 1984:159-162), but to allow general statements, the effects of salinity on crop yields have to be taken as representative to determine four salinity hazard classes (Tab.5) (Kretschmer 1983³:179). It has to be assumed, that grazing capacity is reduced with increasing salinization by limiting growth conditions for palatable species similar as for crop.

TABLE 5: Salinity hazard classes (SHC) (after Kretschmer 1983³:179; see also Landon 1984:158)

Class	**EC5 (mS/cm)**	**total salt content (in %)**[3]	**effects**
1 low	0,5 - 1,0	0,3 - 0,6	Yields of many crops restricted
2 moderate	1,1 - 2,0	0,7 - 1,3	Only tolerant crops yield satisfactorily
3 high	2,1 - 4,0	1,4 - 2,6	Only very tolerant crops yield satisfactorily
4 extremely high	> 4,0	> 2,6	Yields of all crops restricted

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[3] Mean values for horizons with a thickness of >15cm occuring in the rooting zone or mean value for the whole soil depth, when effective rooting depth is <15 cm.

3. ALKALINIZATION HAZARD

A high content of sodium in the exchange complex not only has a dispersing and deteriorating effect on soil structure, but also is toxic for most plants at high concentration. Alkalinization, i.e. an enrichment of sodium, is favoured by a changing ground water table with high salinity groundwater or by (aeolian) input of salts (mostly NaCl) with subsequent solution, transport and recristallisation in a seasonal rhythm. Obviously a semi-arid climate favoures alkalinization. A measure to classify the degree of alkalinization is the Exchangeable Sodium Percentage (ESP) or the pH-value (Tab.7). As the effect of the actual proportion of exchangeable sodium is differing from plant to plant and is depending on soil properties (e.g. salt content, amount and type of clay), only generalized values can be given here.

TABLE 7: Alkalinization hazard classes (AHC)

Class	**ESP**[4]	**approximate pH (KCl)**[5]
1 low	6 - 15	8,1 -8,5
2 moderate	15 - 25	> 8,5
3 high	> 25	> 8,5

4: FLOOD HAZARD

Land that is subject to seasonal or episodical flooding and induration during the growing season bears a high risk of crop damage. Normally flooding has no or only little effect on the range conditions (just a short time reduction of grazing area like in the Andonivlakte) and only has a meaning for cultivated agricultural areas. Thus the flood hazard has no importance for the area of the Etosha National Park. Regions that might be subject to flooding outside the ENP are situated at revier floodplaines in the mountainous area of the Great Escarpment (Damaraland, Kaokoland). Although no land suitability evaluation for irrigation agriculture has been done so far, there might exist some small areas, esp. on river floodplains, with good suitability for irrigation. Other areas subject to flooding with a potential for irrigation are situated north of the ENP in Owamboland.

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[4] see Footnote 3

[5] pH Values for non-saline soils, values for saline-sodic soils are normally lower.

We have not got much knowledge of the time, duration, variability and extent of flooding or induration so far. Therefore the proposed three flood hazard classes are more or less arbitrary (Tab.8) and exact informations should be collected from the lokal population like farmers or rangers, before the flood hazard is mapped in a special area.

TABLE 8: Flood hazard classes (FHC)

Class	**Type**	**Description**
1 low	ephermal	flooding occurs once in five years (statistical mean) during the growing period with a duration of at least five days
2 moderate	episodical	flooding occurs at least in two of five years during the growing period with a duration of at least five days or once in five years with aduration of at least ten days
3 high	periodical	flooding occurs once every year during the growing period with a duration of at least five days

REFERENCES

BEUGLER H. (in prep.): Semi-detailed soil mapping in the south-east and north-west of the Etosha National Park and adjacent areas: Sheet 1816DB Andoni and parts of Sheets 1914AB Kowares, 1914BA Otjovasandu, 1914AD Swartskamp and 1914BC Kaross. Report submitted to the research project 'Soils and environmental change in Etosha/ Namibia' (Az.: Bu 659/4-1).

BEUGLER H. & M.W. BUCH (1993): Soils, Soil Erosion and Soil Erodibility in the Etosha National Park/ Namibia. *Madoqua* : in print..

BUCH M.W. (1993a): Känozoischer Klima- und Umweltwandel in Etoscha/Nord-Namibia - Untersuchungen zur Klimasensibilität und Geomorphodynamik eines semi-ariden Landschaftsraumes im südlichen Afrika. -Habilitationsschrift, Institut für Geographie der Universität Regensburg, Teil I/II, unpubl: 284pp. + Figures.

BUCH M.W. (1993b):Klima und Boden als limitierende Faktoren landwirtschaftlicher Nutzung in Namibia. *Frankfurter Wirtschafts- und sozialgeographische Studien*; in print.

ENGERT S. (1993): Rainfall Periodicity and Spatial Variability in the Etosha National Park and Surrounding Areas of Northern Namibia. *Madoqua*: in print.

FAO/UNESCO (1988): Soil Map of the World - Revised Legend. World Soil Resources Report No. 60, Rome: 119pp.

KRETSCHMER (1983^3): Kulturtechnisch-bodenkundliches Praktikum. Ausgewählte Laboratoriumsmethoden - Eine Anleitung zum selbstständigen Arbeiten an Böden. Chr. Albrechts Universität Kiel, Selbstverlag; 466pp.

LANDON J.R. (ed.)(1984): Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman Inc., New York: 450pp.

LYLES L. (1977): Wind Erosion: Processes and Effect on Soil Productivity. *Trans ASAE* 20: 880-884.

MACVICAR C.N., LOXTON R.F., LAMBRECHTS J.J.N., LE ROUX J., DE VILLIERSJ.M., VERSTER E., MERRYWEATHER F.R., VAN ROOYEN T.H. & VON M. HARMSE H.J. (1977): Soil Classification. A binomal system for South Africa. Dept. of Agricultural Technical Services, Pretoria: 150pp.

MORGAN R.P.C. (1986): Soil erosion and conservation. Longman, UK: 298pp.

MÜCKENHAUSEN E. (1985^3): Die Bodenkunde und ihre geologischen, geomorphologischen, mineralogischen und petrologischen Grundlagen. VLG-Verl., Frankfurt a.M.: 579pp.

NEWHALL F. (1972): Calculation of soil moisture regimes from the climatic record. Soil Conservation Service. USDA, Revision 4, Washington, DC.

PETERMANN TH. (1988): Böden des Fezzan/Südwestlybien - Studie zur Klassifikation, Vergesellschaftung, Ökologie und Nutzungseignung von Böden einer Großregion der Sahara. Schriftenreihe Institut für Pflanzenernährung und Bodenkunde, Universität Kiel: 439pp.

RADCLIFFE D.J. (1992): An approach to the assessment of sheet erosion hazard on cropland in Botswana. FAO - Min. of Agric. Botswana: TCP/BOT/0053. Field Document 4: 24pp. + map.

RICHTER D.D. & L.I. BABBAR (1991): Soil diversity in the Tropics. *Advances in Ecological Research*, Vol.21: 315-389.

SARCCUS (1984): A correlation of the systems used by the SARCCUS member countries for the classification of their soils. SARCCUS Tech. Publ., Dept. of Agriculture and Water Supply, Pretoria: 36pp.

SCHNEIDER M.B. (1989): Böden und Bodenklassifikation in SWA/Namibia. *Agriinfo* 2,1: 10-12.

SCHNEIDER M.B. (1990): Bewässerungslandwirtschaft in Namibia und ihre Grundlagen in der Kolonialzeit. -Dissertation, Fachbereich Geographie der Johann Wolfgang Goethe-Universität zu Frankfurt a.M.. Wissenschaftliche Forschung in Namibia 19, Windhoek (Namibia Wissenschaftliche Geselschaft): 179pp.

SOIL SURVEY STAFF (1975): A basic system of soil classification for making and interpreting soil surveys. Soil Cons. Serv., US Dept. Agr., Agriculture Handbook No. 436: 746pp.

SOIL SURVEY STAFF (1988): Keys to Soil Taxonomy (fourth printing). SMSS technical monograph no. 6. Cornell University. Ithaca, New York; 280pp.

STOCKING M.A: & H.A. ELWELL (1973): Soil loss erosion hazard in Rhodesia. In: *Rhod. Agric. Journ.*, Vol.70(4):93-101.

STOCKING M, CHAKELA Q. & H. ELWELL (1988): An improved methodology for erosion hazard assessment - Part I: The Technique. *Geografiska Annaler* 70A: 169-180.

TRIPPNER CH. (1993): Salt Content as an Eco-Pedological Limiting Factor in Soils of the Etosha N.P/ Namibia. *Madoqua*: in print.

TRIPPNER CH. (in prep): Semi-detailed soil mapping in the central western part of the Etosha National Park and adjacent areas and the south-eastern edge of the Etosha Pan: Sheets 1915BB Okaukuejo, 1916AA Ondongab, 1815CD Sonderkop and 1815CB Ngandjela. Report submitted to the research project 'Soils and environmental change in Etosha/ Namibia' (Az.: Bu 659/4-1).

VAN WAMBEKE A. (1989): Tropical soils and soil classification updates. *Advances in Soil Science*, Vol.10: 171-193.

VAN WAMBEKE A. (1982): Soil moisture and temperature regimes. Africa SMSS Techn. Monograph No. 3; Ithaca, New York.

VERBEEK K. & A. REMMELZWAAL (1990): Revised General Soil Legend of Botswana. FAO/UNDP/Government of Botswana. Soil Mapping and Advisory Services Project. AG: BOT/85/011. Field Document 32: 75pp.