Salt content as an eco-pedological limiting factor in soils of the Etosha National Park, northern Namibia

C. TRIPPNER

Faculty of Philosophy III - History, Social Sciences and Geography - at the University of Regensburg, Universitätsstr. 31, D-93040 Regensburg, Federal Republic of Germany

ABSTRACT

Soil salinization is a serious eco-pedological limiting factor, particularly for plants sensitive to even very low salt concentrations. In the Etosha National Park in northern Namibia eight soil types can be distinguished that show different levels of the electrical conductivity (EC5) and a typical vertical distribution of salts in the soil profile. The spatial configuration of salts and electrical conductivity values is controlled by the distance of the soils from the Etosha Pan and their location to the main wind direction as well as by the internal structural and textural characteristics of the soils.

National land use planning might be forced to extend agriculture land use in those areas in northern Namibia, which are today part of the Etosha National Park. Due to the great variability of rainfall and low mean annual precipitation in the study area, irrigation is necessary to tap the maximum agricultural potential. However, the use of regional extremely saline ground water in the study area will enhance the natural effects of salinization. As a consequence, irrigation will lead to soil salinization, a rapid decrease in crop yields, soil sealing, and enhanced soil erosion. A potential agricultural use of the central western parts of the Etosha National Park and similar areas in the adjacent southern Owambo region can only be successful if the landscape-ecological limitations and economical risks are thought to be acceptable. However, the 'soil/plant/irrigation water' interactions have to be investigated not only under the present-day environmental conditions but especially in the light of possible future global climatic change.

INTRODUCTION

Salinization is recognized as one of the most limiting factors for the agricultural and ecological potential of soils (Leser 1980; Landon 1984; FAO/UNESCO 1988; Scheffer & Schachtschabel 1989; Goudie 1990; Buch 1993a). This paper therefore describes salinization and related phenomena as a major *eco-pedological risk*. Intensified by human impact, *secondary salinization* leads to land and soil degradation and, consequently, to decreasing crop yields (Thomas & Middleton 1993). In contrast to most of the crop species, the natural vegetation as it appears in the Etosha National Park (thereafter refered as the Etosha N.P.), is generally far higher adapted to prevailing soil conditions (e.g. increased electrical conductivity values) and, as a rule, represents the climax or sub-climax vegetation of an undisturbed habitat. Therefore, it would be a fateful misinterpretation just as well, to deduce good crop growing and/or pasture conditions from a temporal and local dense vegetation cover (often grass species) in the Etosha N. P. at certain times of the year or after a good rainy season.

Inappropriate irrigation practises and subsequent salinization constitute a serious national hazard for a country of the so-called third world, particularly with the background of possible future global climatic change. Some serious socio-economic problems are already recognized in Namibia, such as rapid population growth (3% per year; Marsh & Seely 1992), misuse of land, inappropriate cultivation practises, overgrazing and increasing demands on groundwater resources. The just mentioned socio-economic issues combined with the semi-arid to arid climatic conditions in most regions of Namibia are accelerated by a continuos period of below-average rainfall since the eighties (Buch 1993a; Engert 1997). The northern regions of Namibia are presently in particular prone to desertification and economic decline. Sustainable land use by appropriate ecological techniques should be a major national goal. Hence, understanding the causes of increased salt content in soils and resultant effects on the ecosystem are of vital importance. Even the Etosha N. P. in northern Namibia is facing salinization hazards, and therefore seems to be an ideal test area to study the problem of soil salinization and related phenomena and their consequences.

The rapidly growing population in northern Namibia results in increasing demand for pastural and arable land. As a consequence, Namibian national land use planning is challenged in order to intensify the productivity in the communal areas in such a way that it still meets the requirements for an environmental sound and sustainable agriculture management. Futhermore, national land use planning might be forced to extend agriculture land use in those areas in northern Namibia, which are today part of the Etosha N.P. Here, in particular the central western part of the Etosha N.P. has become a matter of discussion. Due to the low average annual amount of rainfall of the area under discussion with 380 mm (Engert 1997), the highly variable nature of rainfalls and the high evaporation rates (see also Marsh & Seely 1992) it might be inevitable to establish irrigation schemes. Consequently, salinization problems will become a focal point of land use planning.

As a result of the first National Workshop to combat Desertification in Namibia in 1994 it was pointed out that soil salinization is a major environmental threat in northern Namibia that will expose these regions to soil degradation and desertification (Wolters 1994). Therefore it is of ultimate importance to investigate the soils in the concerned areas with regard to their potential salinization hazards.

As a first approach to the problem it is important to differentiate between natural and human induced salinization problems. This paper presents the first results of investigations between 1991 and 1992 on potential salinization hazards in four study areas in the Etosha N. P. (Fig. 1). Etosha N.P. represents a 'semi-natural' ecosystem of high biological diversity, where the natural soil conditions and the natural ecological potentials can be studied under the conditions of a minimized human impact. In terms of the basic landscape-ecological design, the four selected study areas within the present boundaries of the Etosha N.P. are representative for those areas in northern Namibia, which already today experience tremendous human pressure.

The management of Etosha N.P. is guided by the major aim to preserve the biodiversity of the ecosystem. Managements activities are therefore restricted, including the management of waterholes, the artifical burning of certain areas that have not experienced natural veld fires during a periode of ten years as well as the construction of roads for tourists. Nevertheless, all these activities have only local effects on the environment and are mainly concentrated on the surroundings of the tourist rest camps Okaukuejo, Halali and Namutoni.

FIELD AND LABORATORY METHODS

The investigation of the salinity hazards in the Etosha N.P. is based on 365 soil samples taken during the years 1991-1992 (Trippner 1993/94) with an Eijkelkamp drill auger set following standard soil science procedures. The soil samples were dried at 35°C in a drying oven and homogenized with a pestle and mortar, prior to chemical analyses. For the determination of the electrical conductivity 20 g of a subsample of the total soil sample (grain size < 2 mm) were mixed with 100 ml of demineralized water on a sample shaker for two hours and then centrifugated to separate the solution from the mineral soil. The resulting soil:water extract of the ratio 1:5 (EC5) is measured with a salinity meter, and the EC5 values are quoted in mS/cm at 25°C (Kretzschmar 1983, Landon 1984). The salt content of the soil samples is calculated by the formula

$$\% \text{ salt} / 100 \text{ g soil} = \frac{(\text{EC5} \cdot 0.064 \cdot 100)}{\text{mass of the sample}} \quad \text{(Kretzschmar 1983)}$$

RESULTS AND DISCUSSION

Effects of salinization on soils and plants

Increased salt content in soils hinders plant growth, reduces pore space and decreases productivity (Table 1), because the increased osmotic potential of the soil water affects the absorption of water and nutrients by the plants (Fink 1963; Scheffer & Schachtschabel 1989). Maize, sorghum and wheat, classified as medium tolerant to salt, show drastic (50%) yield reductions at an EC5 of 1,25 mS/cm in the soil (=0,40% salt/100g soil). Barley, date palm, sugarbeet and cotton, classified as highly tolerant to salts show yield reductions of 50% at electrical conductivities of 2,72 mS/cm corresponding to 0,87% salt/100g

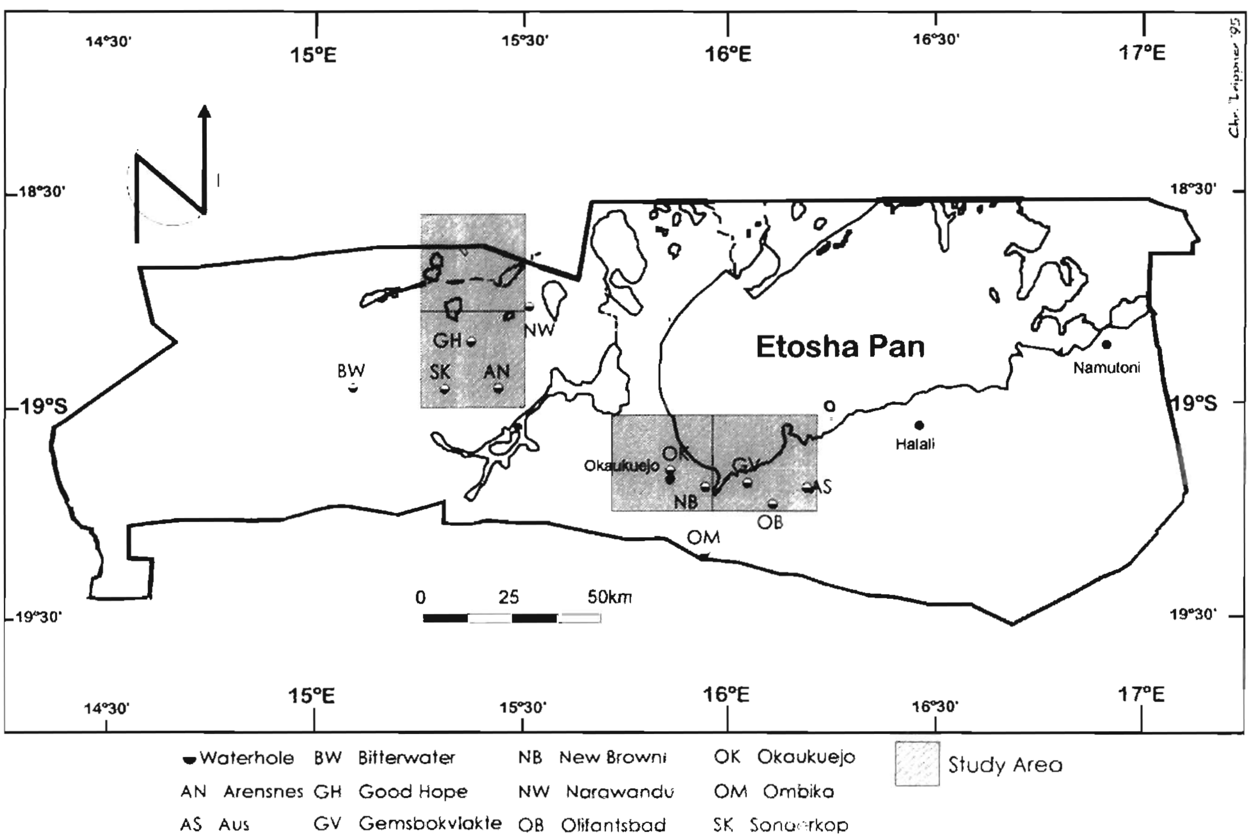

FIGURE 1: The location of study sites in the Etosha National Park, northern Namibia.

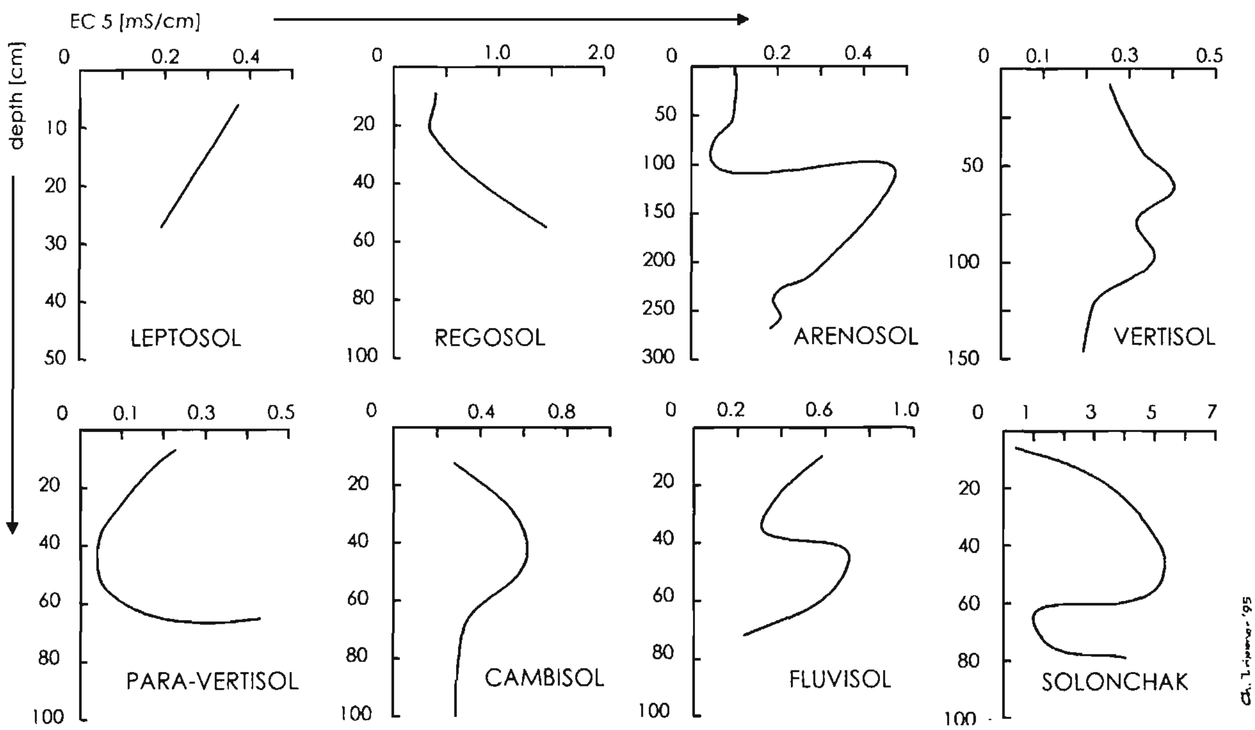

FIGURE 2: Typical vertical distribution of EC5 values of major soil types in the Etosha National Park.

soil (Acland 1971; Landon 1984; Russel 1973). High salt contents in soils cause nearly vegetation free areas so that erosion processes by wind and/or sheet floods will increase (FAO/UNESCO 1979). The accumulation of salts in soils causes interactions between the individual cations of the salts and the clay minerals in such a way that exchangeable cations like Ca, K, Mg (= plant nutrients) are replaced by phytotoxic sodium (Fink 1963). This effect raises the soil reaction (pH), destabilizes soil structure, reduces aggregate stability (Singer et al. 1982) under wet conditions, leading to surface sealing and crusting and in consequence to an increased soil erodibility (Werger & Coetzee 1978). Under dry semi-arid climatic conditions, as they are present in Namibia, all these effects together accelerate soil erosion (Russel 1973; Thomas & Middleton 1993).

TABLE 1: Interpretation of the Electrical Conductivities in Soils of the Etosha N. P. (modified after Kretzschmar 1983, Landon 1984).

Electrical Conductivity (EC5; mS/cm)	Salinization hazard	Crop reaction
0-1.0	low	Salinity effects are mostly negligible, except for the most sensitive plants
1.0-2.0	medium	yields of many crops restricted
2.0-4.0	strong	Only salt tolerant crops yield sufficiently
>4.0	extreme	Only very salt tolerant crops yield sufficiently

Another effect of soil salinization and/or high sodium (Na^+) contents may be a decreasing number of soil micro-organisms (Scheffer & Schachtschabel 1989). Furthermore in some strongly alkaline soil environments (pH > 8,5) with high contents of calcium carbonate ($CaCO_3$ > 25%), salinization provides a breeding ground for parasites and diseases, e.g. anthrax, particularly around waterholes (Seifert 1991).

Salt in the soils of the study area

Eight major soil types in the study areas in the Etosha National Park namely Cambisols, Arenosols, Leptosols, Regosols, Vertisols, Para-Vertisols, Fluvisols and Solonchaks can be distinguished and classified according to the revised legend of the FAO/UNESCO *Soil map of the world* (FAO/UNESCO 1988). The German part of the Etosha Research Group, i. e. Buch, Beugler-Bell & Trippner, modified the FAO nomenclature due to the special requirements of the soils in this semi-arid region of northern Namibia. A detailed description of the soil types mentioned above is given by Beugler-Bell & Buch (1997).

All the above mentioned soils types are influenced to a certain degree by the phenomenon of salinization related to the proximity to the Etosha Pan, to the textural characteristics and to the individual water infiltration characteristics. Figure 2 shows the vertical distribution of electrical conductivity as an indication of salt content in mS/cm in a soil dilution of 1:5 (EC5) in the studied soils in Etosha (Trippner 1993/94). The absolute level of the electrical conductivities (EC5) might vary within a certain mapping unit, but the typical distribution of salts in soil profiles as illustrated in Figure 2 is significant. Due to the varying EC5 values in the studied soils and the changing soil depths, the calibration of the abscissas and ordinates in Figure 2 is different.

Leptosols, which are the preferred locations of the *Mopane* tree (*Colophospermum mopane*), are characterized by a maximum soil depth of 30 cm (Fig. 2) and show variable salinization risks depending on their proximity to the Etosha Pan. Only soils within a distance of some 100 m to the Etosha Pan show an elevated salt content in the first five centimetres of the soil profile, this increase being

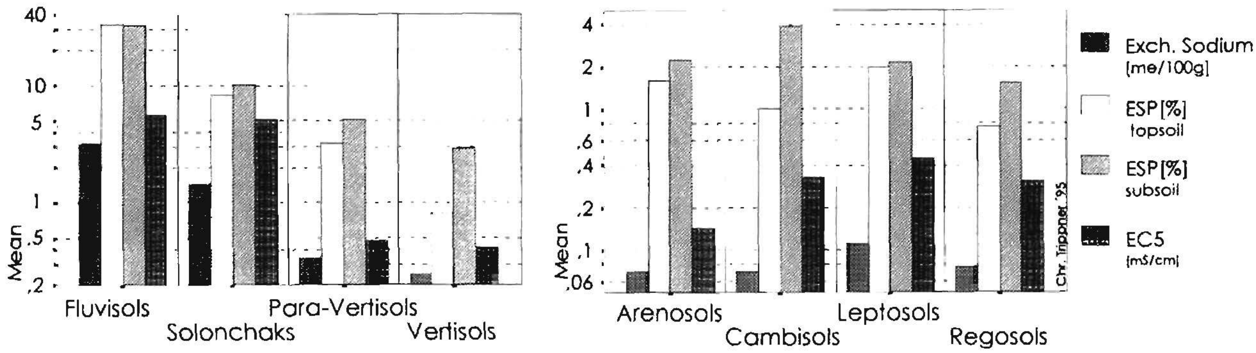

FIGURE 3: Salinity and sodicity parameters of major soil types in the Etosha N. P..

caused by airborne sedimentation from the Pan. As the result of their silty loam to sandy loam texture, the internal drainage of these soils is sufficiently high so that there are usually no higher concentrations of salt in the lower parts or at the basis of the soil profile. Figure 3 characterizes the Leptosols in the study area by very low contents of exchangeable sodium (Na^+) and ESP values (exchangeable sodium percentage) as well as by low electrical conductivities of around 0,4 mS/cm. Therefore the Leptosols show no or only modest eco-pedological limitations by salinization respectively and the main limiting factors in this soil type are high contents in skeleton (up to 75 Vol.-%) and the shallow profile depth (3-30 cm).

As a consequence of water percolation and the related processes of solution and precipitation of salts (Landon 1984; Petermann 1988; Scheffer & Schachtschabel 1989) the Regosols in Etosha, showing a maximum profile depth of around 80 cm, often have their highest electrical conductivity values (and therefore salt contents) at a contact zone between the mineral soil and the parent limestone bedrock (Fig. 2). As demonstrated in Figure 3 the salt contents of the Regosols average lower than those of the Leptosols but may reach values up to 1,2 %/100 g soil (= 3,8 mS/cm). These extreme values are severely limiting to toxic for most plants (Landon 1984; Russell 1973).

A very common soil type in Etosha, especially in the central western parts, are the Arenosols, which support predominately grasses and shrub species. Because of their coarse-grained texture (sandy loam or coarser) they are well drained and, if the profiles are deep enough, show a very typical distribution of salts (Fig. 2). As a result of episodical heavy rainfalls, salts are washed down to the lower part of the soil by percolation and then are precipitated in the B-horizon by evaporation under seasonally hyperarid conditions, because the transport of water in the top soil only takes place in the gaseous phase (Petermann 1988; Scheffer & Schachtschabel 1989). The electrical conductivity of most of the Arenosols is very low, in average 0,15 mS/cm (Fig. 3), but near the western margin of the Etosha Pan (soil mapping unit A6 'Okondeka Duneveld', Beugler & Buch 1997) values of 3,5 mS/cm can be reached, indicating limiting conditions for plant growth. Generally the Arenosols in the studied areas show no pedological limitations by salinization and/or increased sodium contents.

Associated with Leptosols that occur on slightly elevated relief positions, the Vertisols in Etosha appear only in depressions. They represent an 'in situ' soil formation from limestone, but also incorporating sediments that are washed in from the adjacent Leptosols. The Vertisols show a mean electrical conductivity of 0,45 mS/cm with maxima up to 4,0 mS/cm (Fig. 3). Such electrical conductivity values in general indicate only little limitations in relation to the vegetation (Table 1), although the maximum EC5 values are severely limiting to most plants. Due to their clay content up to 80 % and related phenomena (cracks, gilgai relief, extremely hard when dry/very muddy when wet), the Vertisols might be either free of vegetation and only support a grass vegetation that is adapted to these specific conditions. Thus, salinization is not a major limiting factor in Vertisols compared to the extreme soil physical characteristics of this soil type. The distribution of salts in the soil profile (Fig. 2) is not very differentiated due to the mixing (self-mulching) effects in this soil type (Scheffer & Schachtschabel 1989).

Closely related to the Vertisols are the Para-Vertisols (see Beugler & Buch 1997). According to their textural and hydrological conditions the Para-Vertisols show a distribution of salts as described in Figure 2. As an effect of atmospheric airborne input (Goudie 1990), the upper profile zones show slightly increased salt contents. Due to the coarser-grained matrix and, in most, due to the existence of a compacted horizon in the deeper profile zones, soluble salts are percolating downward with the rainwater and concentrating above the layer with the highest bulk density. As displayed in Figure 3, the average EC5 of a Para-Vertisol was determined at 0,48 mS/cm, but maximum conductivity values of nearly 2,0 mS/cm will restrict the growth of many plants and/or crops. Eco-pedological limitations for extremely sodium sensitive plants like deciduous fruit, nuts, cassava or citrus are expected for ESP-values in the subsoil of around 5% (Landon 1984). As already mentioned above, the effects of low to medium sodium contents and/or increased salt concentrations on the natural vegetation are far less severe than on cultivated plants (Dye & Walker 1980).

The Cambisols in Etosha can be characterized by a typical vertical distribution of the electrical conductivity with maximum values between 35-70 cm of the soil profile (Fig. 2). Increased clay contents and thereby higher bulk densities in this zone cause a concentration of percolated soluble salts. Although the EC5 values of this soil type indicate only very slight salinization problems (in average 0,35 mS/cm), the accumulation of salts above this extremely compacted horizon with electrical conductivities up to 1,2 mS/cm and sodium concentrations (ESP) of around 4%, together with an increased bulk density act as serious limiting elements for the plant growth at such locations (Russell 1973; Scheffer & Schachtschabel 1989). Consequently, the natural vegetation on Cambisols in the central western parts of the Etosha N. P. is a community dominated by *Colophospermum mopane* shrubs with a mean height of 30-40 cm and various annual grasses like *Aristida spp., Chloris virgata, Schmidtia kalahariensis.*

The electrical conductivities of the remaining soil types Fluvisols and Solonchaks vary according to their geographical positions. The content of exchangeable sodium between 1,5 and 3 me/100 g soil as well as ESP values ranging from 10-40% indicates extreme sodicity in these soils (Table 3).

Both soil types sometimes show extremely high conductivities with maximum values at 28,7 mS/cm (Fluvisol) and 30 mS/cm (Solonchaks) and average values around 5 mS/cm (Fig. 3), which render such soils completely unsuitable as plant habitats. Even halophytic plants such as the saltbush (*Salsola etoshensis*) use these soil types only in some places. The vertical distribution of salts in the soil profiles of Fluvisols and Solonchaks is mainly determined by increased bulk density of distinct horizons and capillary processes due to evaporation.

The spatial distribution of electrical conductivity values

The spatial distribution of the electrical conductivity values of soils in the Etosha N.P. is shown in Figure 4. The distribution is based on the present soil map of the Etosha N.P. (4th approximation by Beugler-Bell & Buch 1997) and represents the average maximum EC5 values measured in individual profiles of the mapping units. Apart from specific soil properties, salinization of a certain site depends on its proximity to the Etosha Pan and its orientation in relation of the leeward site of the Pan. The soils west of the pan, located in the main wind direction from north-east (Engert 1992), on average show higher salt contents than the soils south of the Etosha Pan (Fig. 4). The highest EC5 values occur in the soils along the immediate margin of the Etosha Pan.

The salinization hazards of the other soil units need a more detailed interpretation. The narrow strip with low soil salinity values between the zones of high and medium salinization in the south of the Etosha N.P reflects well-drained soils ((Psammi) Lithic/Rendzic Leptosols) and an already reduced airborne sedimentation. The again elevated (medium) electrical conductivitiy values further south are of statistical origin because the Vertisols in this region sometimes show extremely high electrical conductivity values, which raise the regional average. In contrast to the soils west of the large Etosha Pan (see above), soil salinization west of the smaller pans in the central western part of the Etosha N. P. (Sonderkop Pan, Paradys Pan, Onaiso Pan) is only medium. The reasons for this observation are seen in the lower aeolian input from these pans with a smaller blowout area and the good drainage of the mainly sandy soils in these locations. Soils presently still showing low salt contents occur in central western Etosha, but associated ground water in this region is known to have high salt contents up to 10,6 g/l, indicating a potentially extremely high salinization risk when used for irrigation purposes (see below).

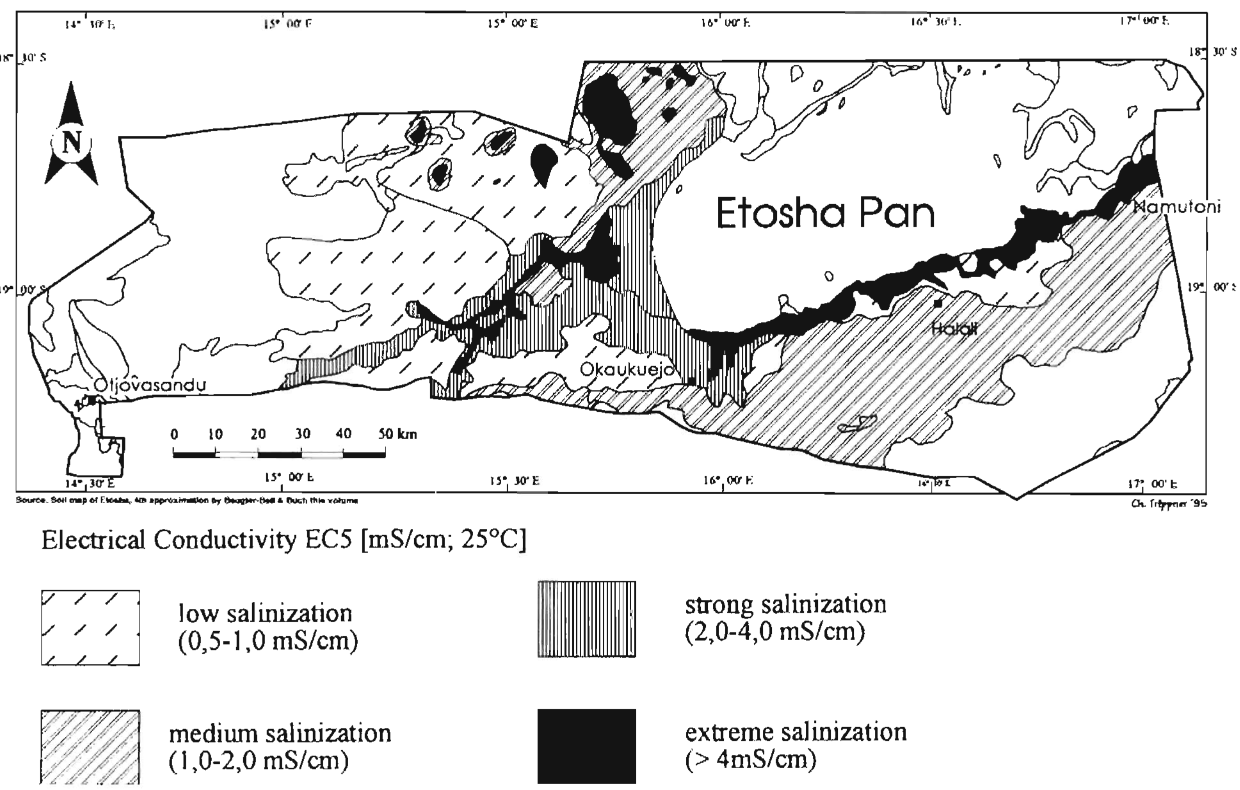

FIGURE 4: Spatial configuration of soil salinization in the study areas of the Etosha N. P.

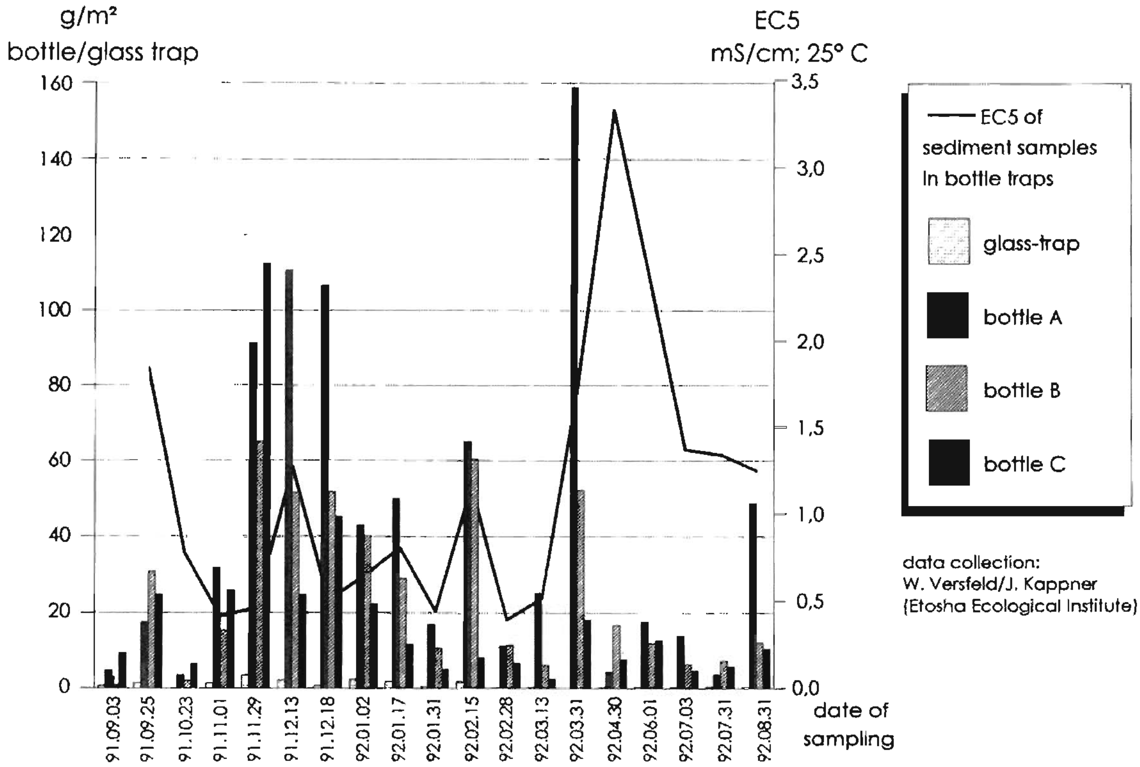

FIGURE 5: Aeolian sedimentation and electrical conductivity values of the airborne sediments at the Okaukuejo Airfield (Etosha N. P.) between August 1991 and August 1992.

Reasons for the salinization of soils in Etosha

Salinization of soils can be the result of different mechanisms. In arid and semi-arid environments salinization is mainly caused by the aeolian input (airborne sedimentation), capillary rise of ground water, and precipitation from episodic heavy rains (Thomas & Middleton 1993). These heavy rains in combination with enhanced evaporation might lead to salt accumulations in the central part of a soil profile, rather than on the soil surface (Petermann 1988; Scheffer & Schachtschabel 1989). As demonstrated for the Etosha region of northern Namibia, the variation in salt content of the soils is furthermore controlled by the soil type with its individual soil texture and bulk density characteristics of specific horizons that influence the internal drainage of the solum (see also Landon 1984).

Under natural conditions Goudie (1990) identified aeolian input and/or salt accumulations by evaporation as the most prominent cause for salinization processes. In the 'semi-natural' ecosystem of the Etosha N.P. the large flat area of the mostly unvegetated Etosha Pan in the eastern part of the park is undoubtly a major source for aeolian redeposition (Buch 1993a). Although Etosha Pan is not a typical salt pan (Buch 1997), salty enriched airborne sediments blown out from the Etosha Pan cause an elevated salt content in soils in the vicinity of the source area.

In order to test this hypothesis and to stimulate more sophisticated experiments in future, the annual distribution of aeolian salts and sediments were collected in simple constructed wind erosion traps (Buch 1990) at the three locations along the western margin of the Etosha Pan. Figure 5 displays the results of the experiment at the Okaukuejo Airfield between August 1991 and August 1992.

During the onset of the rainy season (the so-called 'early rainy season' between September and December) as well as during the major part of rainy season between January and March, the electrical conductivity values of sediment samples (sandy sediments of the ground bottle traps) fluctuate between 0,5 mS/cm and 1,3 mS/cm. Although sediment redeposition was excellerated during November and the first part of Dezember 1991, EC5 values never exceeded 1,3 mS/cm. Corresponding to a higher sedimentation rate (bottle A and B) during the second part of March, EC5 values start to increase respectively. The comparatively low rate of aeolian redeposition in April contrasts with the electrical conductivity peak (3,5 mS/cm) of this cycle, showing clearly that the highest electrical conductivity values occur at the end of the main rainy season (March/April).

These observations contrast considerable to an expected direct correlation between airborne sedimentation and salt content of these sediments. During the rainy season at least parts of the total floor of the Etosha Pan (formed in clay-rich sediments of the Andoni Formation) experience shallow surface water inundation (Buch 1993a). Surface water inundation as well as local rainfall on the pan leads to a descending transport of soluble salts to the deeper parts of the pan's profile. This mechanism is well reflected in the vertical distribution of the electrical conductivity of the Solonchaks of the Etosha Pan with maximum EC5 values around 50 cm and 80 cm below the surface (Fig. 2). With the onset of the dry season, when the pan's surface is drying up, capillary rise causes an accumulation of soluble salts in a thin layer on the surface. This thin surface crust (or 'salt impregnation') is rapidly eroded by wind action. Consequently, EC5 values of the aeolian sediments at the Okaukuejo Airfield in 1992 reached a maximum during April (Fig. 5). After the thin salt crust is eroded in the source areas of the Etosha Pan, the EC5 values decline, although during August (the 'windy month' at Okaukuejo) the redeposition rate increased. The described mechanism of the formation and erosion of a thin salt crust at the end of the rainy season is also identified during the early rainy season when the pan dries up between individual rainstorm events.

Another source of salt accumulation in the Etosha N.P. originates from lateral sediment supply and concentration in shallow channels mainly directed to the Etosha Pan. Commonly saline soils of the Fluvisol type (Hyper) Salic Fluvisols of mapping unit D4 (Beugler-Bell & Buch 1997) occur in these channels and watercourses. In the south-western corner of the Etosha Pan Hypersalic Fluvisols reach the pan floor (Fig. 4), where the salts are washed out and precipitate.

As it is apparent for many soil types (except Fluvisols and Solonchaks) in the study areas of the Etosha N.P., the mean electrical conductivitiy values today do not reach a level which indicates really serious, eco-pedological limiting salt concentrations. Saline aeolian sediment input to the soils is a natural process operating during the entire periode of the Quaternary (the last 2 million years), when Etosha Pan was excavated as an erosion form (Buch 1993a). Thus, the natural vegetation communities of the Etosha N.P. seems to be in equilibrium with the seasonal rhythm of salty aeolian sediment input to the soils and the percolation by rainfall. Specific vegetation communities are well adapted to the locally limiting salt conditions.

In general, the main controlling factors of saline sediment input from the Etosha Pan into soils in the surrounding areas are the supply of lateral saline water and the variable moisture conditions on the floor of the Etosha Pan. A change in the total amount and/or salinity of sediment output from the Etosha Pan will be initiated by every process that supports or hinders lateral salt accumulation and that prolongs or reduces the availability of readily soluble surface salts. Future global climatic change could be the motor of those variations in the saline sediment output of the Pan and consequently influences the salinization of the soils affected by the Etosha Pan. Even though it is not yet possible to give an exact prediction of the effects of a worldwide climatic change, most likely there will be an temporal accentuation of precipitation and increased wind velocities (Buch 1993a). As a consequence the process of saline sediment blowout from the Etosha Pan may intensify. Together with a possibly increased evaporation due to global warming, the redeposition of pan sediments and the related salt input into the solum might enhance the salinization hazards of the soils in Etosha.

Salinization can also be caused by the use of irrigation water with high total salt content (>0,75 mS/cm = 0,05 % salt; Russell 1973; Scheffer & Schachtschabel 1989), but this problem is not present in Etosha yet, because no areas outside the tourist camps are being irrigated. The irrigation of uncultivated land with 300 mm water/a that shows a low salt content of 0,3 g/l (= 0,47 mS/cm) causes an accumulation of 90 g salts per year per m^2. Most of the boreholes in Etosha yield water with salt contents that are much higher (extreme value 10,6 g/l = 1660 mS/m) than those in the example above (Auer 1997). Thus, potential new agricultural areas in the future in the central western part of the Etosha N.P., which are designed as irrigation schemes, involve high eco-pedological risks and must therefore be considered very critical. The use of irrigation water from the boreholes Arendsnes and Sonderkop (EC 400-900 mS/m i. e. 2,6-5,7 g/l; Rahm & Buch 1997) or Good Hope, Bitterwater and Narawandu that all show conductivities of more than 900 mS/m (>5,7 g/l), will lead to rapid soil salinization within a few years. Even good water qualities as they occur around Okaukuejo (150-300 mS/m; 0,9-1,9 g/l) create considerable salinization hazards, when used as irrigation water.

CONCLUSIONS

Figure 4 illustrates that large areas of the Etosha National Park show medium to high electrical conductivity values that in principle indicate limitations on plant growth and increased risks of accelerated soil erosion and soil degradation under inappropriate land management. Under the conditions of the present day 'semi-natural' ecosystem of the Etosha N.P., this type of eco-pedological risk is not yet relevant, as the vegetation communities are well adapted to the soil conditions.

However, any kind of land use change must consider the already elevated salinization status of many soils in the study area. The medium to extremely high electrical conductivity values of the ground water of the region in mind, and due to their soil physical characteristics as well as their natural salt contents, nearly all soil types under discussion are completely unsuitable for irrigation purposes. The only exception are the Arenosols that usually show very low salt concentrations, only little accumulation of sodium in the soil profile and reasonable soil physical properties (high plant available field capacity, good internal drainage).

In order to ensure a downward water movement which avoids capillary rise of salt enriched water due to evaporation processes, flood irrigation practises might be recommended for Arenosols. However, for coarse textured soils like Arenosols with high infiltration rates of 20-30 cm/h this irrigation method must be disregarded as being ecologically ineffective and/or economically unsuitable (Petermann 1988). Under the semi-arid climate conditions of northern Namibia, flood irrigation practises would require the substraction of groundwater in a dimension that can in no way be justified. Alternatively, drip irrigation practises first of all require major investments and an appropriate management but might be still impracticable because of the high salt and mineral content of irrigation water that would block up the irrigation pipes within shortest time.

Apart from the above mentioned risks of soil salinization by irrigation water, it must be stated in general that water with such an enrichment of sodium, sulphate and chloride, as it occurs at many boreholes in the Etosha N.P. and particularly in the central regions of the park, will directly damage cultivated plants and reduce crop yields to a great extent. In contrast, the present natural vegetation is far higher adapted to prevailing soil conditions than any crop species (Acland 1977; Dye & Walker 1980; Landon 1984; Thomas & Middleton 1993). Most of the plants in the 'semi-natural' ecosystem Etosha are well adapted to even medium salt contents. As far as salinization risks already exist, the use of saline irrigation water will definitely increase the salinization hazard of the soils. Especially in the central western regions of the Etosha N.P., which are considered to be potential new agricultural areas for the rapidly growing population of the communal areas of northern Namibia, the soils will be affected by salinization if the extremely saline ground water is used for irrigation. In this case it must be expected that the crop yields will drop dramatically within some years with all the negative consequences for feeding and prosperity of people in this region.

ACKNOWLEDGEMENTS

The author likes to thank Dr. M. Lindeque, W. du Plessis and W. Versfeld (Etosha Ecological Institute, Okaukuejo/ Namibia) for technical assistance during the field work and the Ministry of Environment and Tourism for the permission to carry out field work in Etosha National Park/Namibia. Special thanks are due to A. Berié for analyses in the laboratory of the University of Regensburg. The author appreciated the very constructive comments of the referees. Financial support was granted by the German Research Foundation (DFG), the German Agency for Technical Assistance (GTZ) and the University of Regensburg (all Federal Republic of Germany).

REFERENCES

ACLAND, J. D. 1977. East African Crops. An introduction to the production of field and plantation crops in Kenya, Tanzania and Uganda. London: Longman.

AUER, C. 1997. Chemical water quality at waterholes in the Etosha National Park. *Madoqua* 20: 121-128.

BEUGLER-BELL, H. & BUCH, M.W. 1997. Soils and soil erosion in the Etosha N.P., northern Namibia. *Madoqua* 20: 91-104.

BUCH, M.W. 1990. Soils, soil erosion and vegetation in the Etosha National Park/Northern Namibia. Unpubl. field and laboratory results of the investigations of the year 1989 (Part I and II).

BUCH, M.W. 1993a. Känozoischer Klima- und Umweltwandel in Etoscha/Nord-Namibia - Untersuchungen zur Klimasensibilität und Geomorphodynamik eines semi-ariden Landschaftsraumes im südlichen Afrika. Unveröffentl. Habilitationsschrift, Inst. f. Geogr. Univ. Regensburg.

BUCH, M.W. 1993b. Klima und Boden als limitierende Faktoren landwirtschaftlicher Nutzung in Namibia. *Frankfurter Wirtschafts- und Sozialgeographische Schriften* 64: 139-172.

BUCH, M.W. 1997. Etosha Pan – the third largest lake in the world? *Madoqua* 20(1): 49-64.

BUCH, M.W., LINDEQUE, M., BEUGLER-BELL, H., DU PLESSIS, W. & TRIPPNER, C. (eds.) 1993/94. Environmental Change in the Etosha National Park/ Northern Namibia. Aims, Activities and First Results. Unpubl. report submitted to the 'Deutsche Forschungsgemeinschaft' (DFG) and the 'Gesellschaft für Technische Zusammenarbeit (GTZ)', Part I-V. Regensburg and Okaukuejo.

DYE, P. J. & WALKER, B.H. 1980. Vegetation - environmental relations on sodic soils of Zimbabwe Rhodesia. *J. Ecol.* 68: 589-606.

ENGERT, S. 1997. Spatial variability and temporal periodicity of rainfall in the Etosha National Park and surrounding areas in northern Namibia. *Madoqua* 20: 115-120.

FAO/UNESCO 1979. Tropical grazing land ecosystems. Rome.

FAO/UNESCO 1988. Soil map of the world. Revised legend. Rome.

FINK, A. 1963. Tropische Böden.- Einführung in die bodenkundlichen Grundlagen tropischer und subtopischer Landwirtschaft. Hamburg und Berlin: Paul Parey.

GOUDIE, A. 1990. The human impact on the natural environment.- 3rd edition. Oxford: Basil Blackwell.

KRETZSCHMAR, R. 1983. Kulturtechnisch-bodenkundliches Praktikum - ausgewählte Laboratoriumsmethoden. 3. Auflage. Kiel: Institut für Wasserwirtschaft und Meloriationswesen der Universität Kiel.

LANDON, J.R. 1984. Booker Tropical Soil Manual: A handbook for soil survey and agricultural land evaluation in the Tropics and Subtropics. London: Booker Agr. Ltd..

LESER, H. 1980. Natürliches Potential und Raumnutzungsprobleme im Südlichen Afrika. *Geoökodynamik* 1: 37-64.

MARSH, A. & SEELY, M. (eds.) 1992. Oshanas - sustaining people, environment and development in central Owambo, Namibia. Windhoek Typoprint.

PETERMANN, T. 1988. Böden des Fezzan/ Südwestlibyen - Studie zur Klassifikation, Vergesellschaftung, Ökologie und Nutzungseignung von Böden einer Großregion der Sahara. Schriftenreihe Inst. f. Pflanzenernährung und Bodenkunde Universität Kiel 1: Kiel: Eigenverlag.

RAHM, L. & BUCH, M.W. 1997. Groundwater flow in the southern part of the Etosha Basin indicated by the chemical composition of water. *Madoqua* 20: 129-135.

RUSSELL, E.W. 1973. Soil Conditions and Plant Growth. 10th edition. London, Beccles and Colchester: Longman..

SCHEFFER, F & SCHACHTSCHABEL, P. 1989. Lehrbuch der Bodenkunde. Stuttgart: Enke.

SEIFERT, H.S.H. 1991. Bodenseuchen als Indikator für Überstockung und Umweltzerstörung. In: MENSCHING, H. G. & SEIFERT, H.S.H. (Hrsg.). Göttinger Forschungsprojekte im Sudan. Göttingen: 125-135.

SINGER, M.J., JANITZKY, P. & BLACKARD, J. 1982. The influence of exchangeable sodium percentage on soil erodibility. *Soil Sci. Soc. Am. J.* 46: 117-121.

THOMAS, D.S.G. & MIDDLETON, N.J. 1993. Salinization: new perspectives on a major desertification issue. *J. Ar. Envir.* 24: 95-105.

TRIPPNER, C. 1993/94. Semi-detailed soil survey and evaluation of the eco-pedological and landscape-ecological risks in the south-western and central-western parts of the Etosha National Park/northern Namibia. In: BUCH, M.W., LINDEQUE, M., BEUGLER-BELL, H., DU PLESSIS, W. & TRIPPNER, C. (eds.). Environmental Change in the Etosha National Park/Northern Namibia. Aims, Activities and First Results. Unpubl. report submitted to the 'Deutsche Forschungsgemeinschaft' (DFG) and the 'Gesellschaft für Technische Zusammenarbeit (GTZ)', Part III and V. Regensburg and Okaukuejo.

WEGER, M. J. A. & COETZEE, B. J. 1978. The Sudano-Zambezian region. In: WERGER, M.J.A. (ed.). Biogeography and ecology of southern Africa. *Monographiae Biologicae* 31(1): 301-462.

WOLTERS, S. (ed.) 1994. Proceedings of Namibia's National Workshop to combat Desertification. Report from a National Workshop Windhoek, Namibia 4 - 7 July 1994. Windhoek: Desert Research Foundation of Namibia.