# Chemical quality of water at waterholes in the Etosha National Park

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ABSTRACT

Within the Etosha National Park major differences have been found in the chemical quality of water at waterholes. The waterholes in the West and South of the Park, described as alkaline earth – hydrogencarbonate water, provide water with low and constant electric conductivities. This water's overall chemical quality meets the guidelines (Department of Water Affairs 1991) for human consumption as well as for stockwatering. In contrast, the waterholes in the central region and the Eastern half of the Park supply alkali – saline water. This water mostly fails to meet the recommended guideline values for human consumption and in several cases exceeds even those for stockwatering. It undergoes distinct temporal water quality changes. The problematic parameters are electric conductivity, sodium, chloride and sulphate. Due to high correlations between the electric conductivity and the concentrations of sodium, chloride and sulphate, measurements of the electric conductivity serve as a simple measure for water quality inspection at these waterholes. A seasonal pattern of electric conductivity values is apparent, with a minimum after the rainy season (May – July), and a maximum at the end of the dry season (November – January) and water quality monitoring can therefore be reduced to twice a year.

## INTRODUCTION

Water is a key factor to all living forms in general. In semi-arid and arid climates natural surface water is scarce, therefore the actual occurrence of water is vital for humans as well as animals.

In the semi-arid ecosystem of the Etosha National Park numerous boreholes, contact springs and artesian springs supply the game with water throughout the year. During the dry season, when rain water puddles have dried up and the moisture content of the forage plants is at its lowest, the perennial waterholes are the centres of high animal concentrations. The daily movements of various water-dependent species, e.g. blue wildebeest *Connochaetes taurinus* and Burchell's zebra *Equus burchelli*, are then confined to a limited distance from the watering points (Berry 1980). Thus the availability of water, determined by the number and distribution of permanent watering points, restricts the size of the potential grazing area. In contrast, in the rainy season the animals are less dependent on the perennial waterholes, due to an abundance of rain water puddles. During this time the animals can forage in areas further away from the perennial waterholes and thus utilize the vegetation of a larger area.

In addition to the availability of water, the chemical quality may play an important role within the ecosystem of the ENP. Winter (1985) suggested that poor water quality may naturally have an adverse effect on the well-being of wildlife. Huyser (1979) tried to explain the preference for specific waterholes among elephants in terms of water quality aspects but could find no relation. Current research by the author addresses whether the chemical quality of water is influencing the utilization of waterholes by game.

## MATERIALS AND METHODS

Since 1964 the water quality at waterholes frequented by wildlife in the Etosha National Park has been monitored by the National Institute for Water Research (N.I.W.R.), now known as the Department of Water Affairs. Water samples were collected in plastic bottles without the addition of preservatives and transported to the laboratory of the N.I.W.R. in Windhoek. Between 1982 and 1984, however, two samples were taken at each waterhole, and one of them preserved by adding saturated $HgCl_2$–solution. In the laboratory chemical analyses were performed with standard methods following the AMERICAN PUBLIC HEALTH ASSOCIATION (APHA) (1980) on unfiltered samples. The main chemical parameters of interest were electric conductivity, sodium, calcium, magnesium, potassium, chloride, sulphate and fluoride.

This paper is based on data from 633 chemical water analyses from 92 waterholes, which have been sampled between 1975 and 1992. The 92 examined waterholes consist of 48 boreholes, 31 contact springs, 7 artesian springs, five pans and one omuramba. The locations of all relevant waterholes are illustrated in Figure 1. Only data from water sampled at troughs (concrete basins into which borehole water is pumped) and spring water pools are considered, because these are the localities where water is accessible to game.

The evaluation of the chemical water quality of waterholes in the Etosha National Park followed the guidelines of the Department of Water Affairs (1991) (Table 1). For animal usage the 'Livestock Drinking Water Standards' had to be taken as a guideline because no criteria are yet available to judge the suitability of the chemical quality of water that is utilized by wildlife.

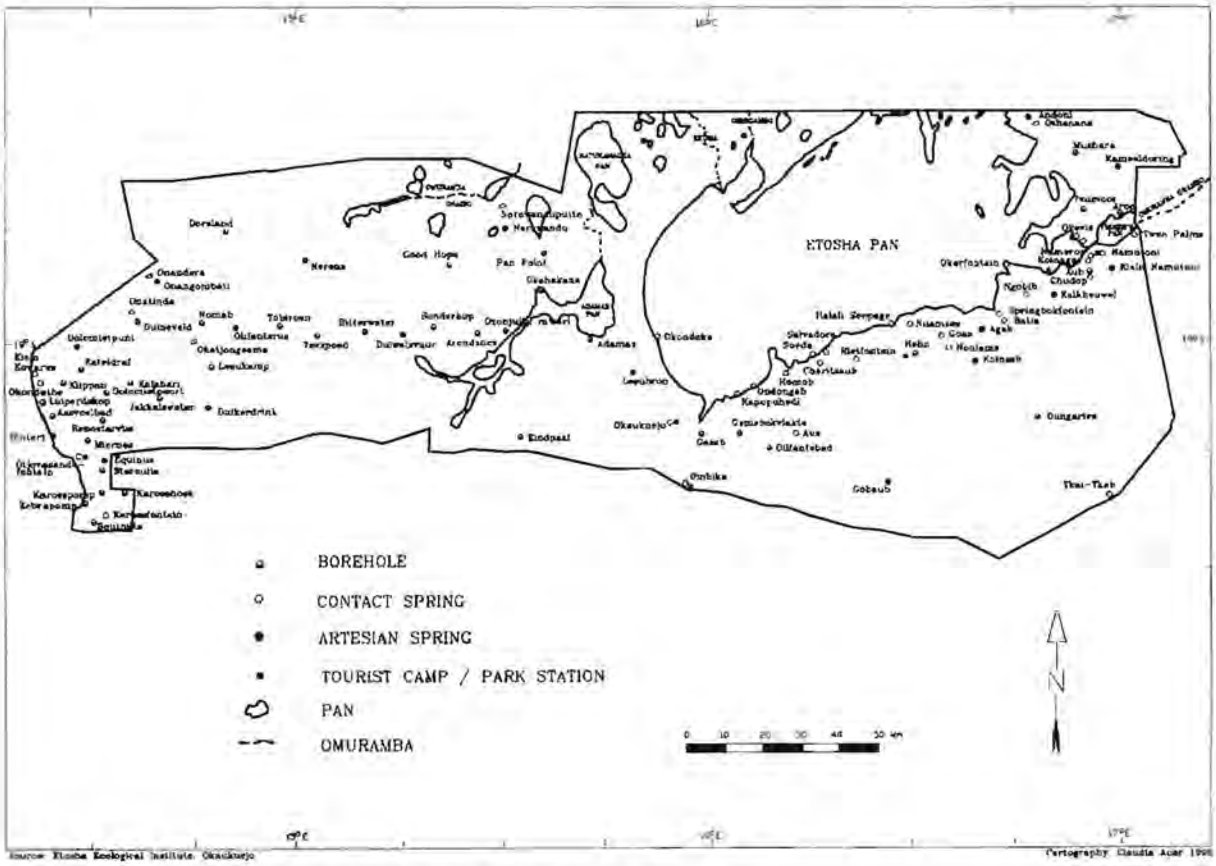


FIGURE 1: Locations of the examined waterholes in the Etosha National Park.

TABLE 1: Guidelines for the chemical evaluation of drinking water for human consumption and stockwatering according to the Department of Water Affairs (1991). Group A: excellent quality water / Group B: good quality water / Group C: low risk water; not yet critical, but attention should be given to those constituents over the B group limit / Group D: high risk or water unsuitable for human consumption; urgent and immediate attention is required to reduce the level of the problem constituent. The guidelines for stockwatering refer to domestic stock.

| | | HUMAN CONSUMPTION upper limit for group | | | | STOCK WATERING upper limit |
|---|---|---|---|---|---|---|
| CONSTITUENT | UNIT | A | B | C | D | |
| Conductivity | mS/m 25°C | 150 | 300 | 400 | >400 | 900 |
| Sodium | mg/l | 100 | 400 | 800 | >800 | 2000 |
| Calcium | mg/l | 150 | 200 | 400 | >400 | 1000 |
| Magnesium | mg/l | 70 | 100 | 200 | >200 | 500 |
| Potassium | mg/l | 200 | 400 | 800 | >800 | no comment |
| Chloride | mg/l | 250 | 600 | 1200 | >1200 | 3000 |
| Sulphate | mg/l | 200 | 600 | 1200 | >1200 | 1500 |
| Fluoride | mg/l | 1,5 | 2,0 | 3,0 | >3,0 | 6,0 |

TABLE 2: Overview of the mean chemical composition of water at waterholes in the Etosha National Park (Gammer 1993). (Based on 1029 water analyses from 100 waterholes between 1975 and 1992). MEAN: arithmetic mean / SD: standard deviation / MIN: minimum / MAX: maximum.

| | EC | TDS | PH | CATIONS | | | | ANIONS | | | | | | | SIO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | NA | CA | MG | K | CL | SO4 | HCO3 | CO3 | F | NO3 | NO2 | |
| | mS/m | mg/l | (pH) | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| MEAN | 497 | 3232 | 8 | 1002 | 60 | 83 | 35 | 1069 | 441 | 816 | 27 | 2 | 3.4 | 0.2 | 43 |
| SD | 689 | 4602 | 0.5 | 1632 | 51 | 94 | 174 | 1908 | 835 | 556 | 128 | 1 | 7.3 | 1.1 | 20 |
| MIN | 47 | 263 | 6.9 | 10 | 0 | 0 | 1 | 9 | 0 | 74 | 0 | 0 | 0 | 0 | 0 |
| MAX | 10093 | 66818 | 9.9 | 19800 | 679 | 1701 | 2700 | 23200 | 16000 | 6628 | 2311 | 32 | 55 | 17.5 | 98 |

This paper focuses on the parameter 'electric conductivity' (EC), because the electric conductivity is internationally accepted as a measure to determine the total ion concentration (Hem 1985). The undertaking of regular EC measurements serves as an indication of changes in the chemical quality of water (HEM 1982). The EC is measured in millisiemens per meter (mS $m^{-1}$, SI units) at 25°C.

## RESULTS AND DISCUSSION

A first overview of the mean chemical composition of water at waterholes within the Etosha National Park is given in Table 2.

The average mass concentrations (in mg/l) of various cations show the order sodium > magnesium > calcium > potassium. The order for the dominant anions is chloride > hydrogencarbonate > sulphate (Gammer 1993). The high mean electric conductivity of 497 mS/m indicates that Etosha's average waterhole supplies water that is relatively rich in ions and belongs to group D (Table 1). However, the standard deviations as well as the minimum and maximum concentrations suggest that major deviations from the mean ion concentrations have to be expected at individual waterholes.

In respect of the dominant cations and anions two main categories of ground water can be recognized in the ENP (Figure 2), namely alkaline earth – hydrogencarbonate water and alkali – saline water (Auer 1993, Gammer 1993). The waterholes situated in the western region and some near the southern border of the Park contain alkaline earth - hydrogencarbonate water with the major cations being magnesium and calcium and the major anion being hydrogencarbonate. This type of water reflects the local geological milieu dominated by dolomites and limestones of the Damara Sequence (Buch 1993, Rahm & Buch 1997). On contrast, the waterholes in the central region and the entire eastern half of the Park provide water that is enriched in sodium, chloride and sulphate and thus is regarded as alkali - saline water. These ions originate from ion exchange and mixing processes during the contact of groundwater and saline sediments in sandstone/siltstone/clay layers of the Kalahari– Facies (Buch 1993, Rahm & Buch 1997).

An overall view of the chemical water quality is given by the mean electric conductivities at waterholes (Figure 3). Within the area of the Etosha N.P. a distinct spatial pattern of the electric conductivity could be identified. The waterholes that supply water with the lowest electric conductivities (under 300 mS/m) and thereafter are classified as excellent and good water (group A and B), are located in the South and West of the Park. It is water with generally low loads of ions of the chemical type of alkaline earth – hydrogencarbonate water. These low EC– waterholes in the West of the Park are situated on and closely to the west and east of the great water divine (Van der Merwe 1983). The short way of ground water flow and the nature of rock it penetrates, mainly calcrete, dolomites and quartzites, are considered responsible for the low electric conductivities in water extracted by boreholes in this region. The waterholes in the South of the Park with group A and B electric conductivities provide water from mainly calcrete and dolomite aquifers, that are recharged in the Karst areas south of the Park, so called 'Etosha Bogen' (Buch 1993).

In the direction from the West and South towards the Etosha Pan and the smaller pans in the northern centre of the Park, which is considered to be the general direction of groundwater flow (Rahm & Buch 1997), a distinct

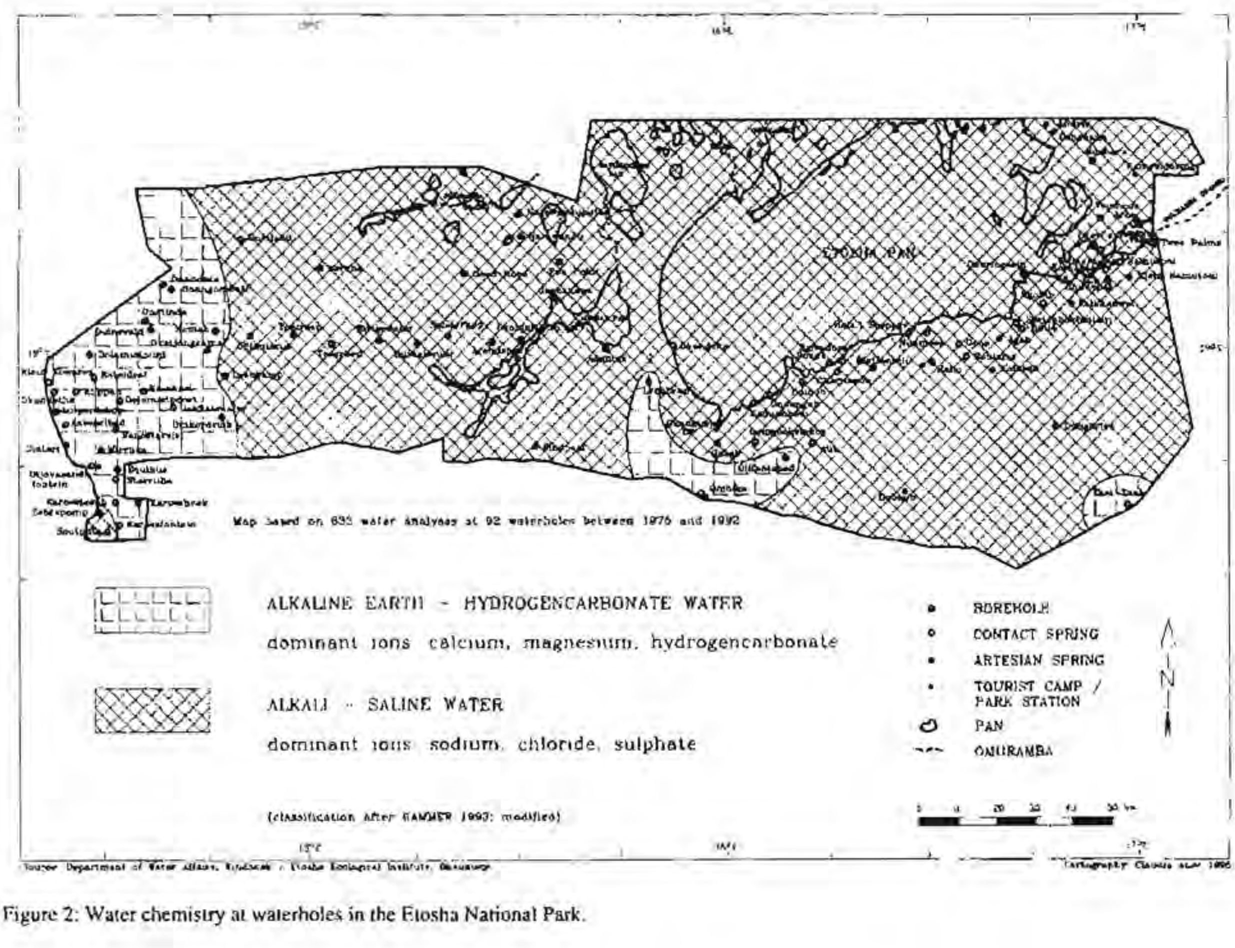


Figure 2: Water chemistry at waterholes in the Etosha National Park.

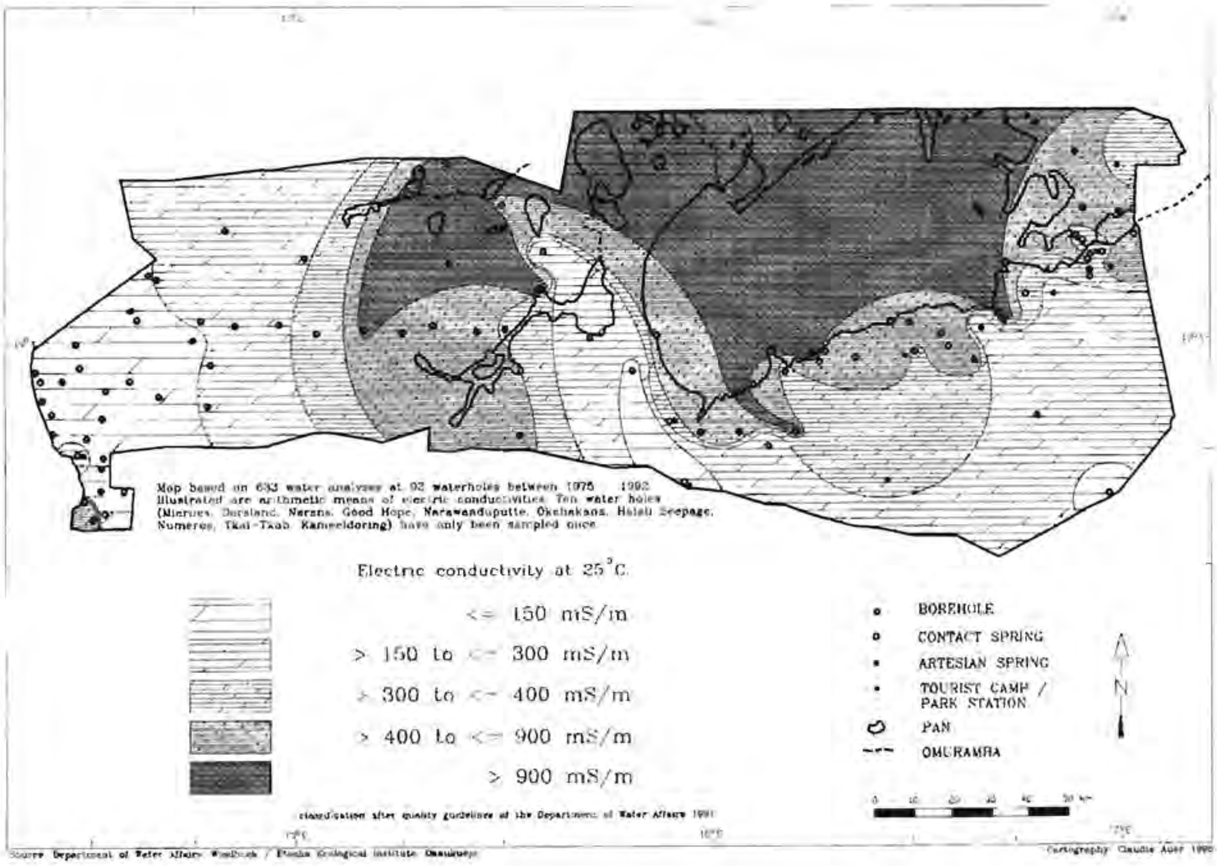


FIGURE 3: Mean electric conductivities at waterholes in the Etosha National Park.

increase in electric conductivities can be identified. The highest values that exceed even the recommendation of 900 mS/m for stockwatering, are found in the centre of the Park at the waterholes Bitterwater, Good Hope, Narawandu, Narawanduputte and Okahakana, as well as along the southern edge of the Etosha Pan at Kapupuhedi, Sueda, Batia, Aus and in the North–East at Oshanana and Andoni. In total 11% of all examined waterholes provide water with electric conductivities unsuitable for stockwatering.

One reason for the increase in salinity can be sought in an increasing distance between the areas of main recharge and the waterhole sites. With a longer way of ground water flow there is more time of contact between water and the rock it penetrates, and hence more opportunities of solution of minerals in water (Hem 1985). In addition, the geological underground changes from the West and South of the Park north– and eastwards. Calcrete and dolomite submerge under various layers of silt–, clay– and sandstone ('Kalahari sediments') which increase in thickness to over 250 m in the North–East of the Etosha N.P. (Buch 1993). These deposits of the so–called 'Etosha Basin' are rich in salts, predominately sodium chloride, due to alkali – saline conditions towards the end of the sedimentation of the Etosha Basin (Buch 1993). Ground water originating from these deposits is alkali–saline with generally high loads in ions and thus high electric conductivities. According to recent investigations by Hoad (1992) in the neighbouring Tsumeb District there is a dramatic change of chemical water quality at the 17° E longitude which can be regarded as the eastern boundary of the Etosha N.P.. East of this longitude the Kalahari aquifers yield fresh water, west of it, however, a saline zone occurs abruptly in the Kalahari aquifer. Hoad (1992) explains the cause of this salinity with the existence of an internal drainage basin which influences the ground water quality in most of the Kalahari sediments.

For the Park Management it is firstly of interest to identify which parameters are occurring in concentrations above the guidelines and secondly at which waterholes the chemical qualities are problematic. Table 3 gives the numbers and percentages of examined waterholes, at which mean ion concentrations of different water parameters occur above the recommended limits for human consumption and stockwatering.

A comparison with the guidelines for human consumption gives an indication of the poor chemical quality of water at numerous waterholes in the Etosha National Park. At over 50% of the examined waterholes the EC values and sodium and chloride concentrations are above the upper B–group limit. Fluoride concentrations are classified unfit for humans for about 25% of the waterholes, sulphate concentrations for 17.1% and magnesium concentrations for about 15%. Whereas excessive electric conductivity, sodium, chloride and magnesium mainly give an unpleasant and salty taste, high sodium levels can cause high blood pressure. High concentrations of fluoride causes mottling of teeth and skeletal fluorosis, excessive sulphate levels can have laxative effects, which are enhanced when consumed in combination with magnesium (Department of Water Affairs 1990–1995). The

TABLE 3: Number of water quality parameters and waterholes considered unfit for human consumption and stockwatering (Department of WaterAffairs 1991) in the Etosha National Park. Water qualities considered unfit for human consumption are group C and D water qualities.

| | | WATERHOLES (n=28)) WITH MEAN ION CONCENTRATIONS UNFIT FOR | |
|---|---|---|---|
| CONSTITUENT | UNIT | HUMAN CONSUMPTION | STOCKWATERING |
| Conductivity | mS/m 25°C | 46 (56.1%) | 9 (11.0%) |
| Sodium | mg/l | 49 (59.8%) | 10 (12.2%) |
| Calcium | mg/l | 2 (2.4%) | 0 |
| Magnesium | mg/l | 12 (14.6%) | 1 (1.2%) |
| Potassium | mg/l | 1 (1.2%) | no guideline |
| Chloride | mg/l | 43 (52.4%) | 7 (8.5%) |
| Sulphate | mg/l | 14 (17.1%) | 3 (3.7%) |
| Fluoride | mg/l | 21 (25.6%) | 1 (1.2%) |

chemical constituents, which generally occur within acceptable levels are calcium and potassium.

The comparison of the parameters' mean values with the guidelines for stockwatering (Table 3) show that at 9% of the waterholes the acceptable levels of electric conductivity are exceeded. The sodium concentrations lie above the guidelines at 12,2% of the waterholes, chloride concentrations at 8,5% and sulphate concentrations at 3,7%. Fluoride and magnesium as well as calcium are generally occurring in acceptable levels. Therefore the main problematic water quality parameters for the purpose of stockwatering are electric conductivity, sodium, chloride and sulphate.

According to Kincaid (1988) the excessive intake of salt causes severe anorexia, anhydremia, weight loss and collapse in cattle. High salt contents (above about 3000 mS/m) in the water will reduce performance of sheep. Peirce (1968) reported that grazing Australian Merino lambs treated with saline water of 10 g total dissolved solids per liter, which corresponds to an electric conductivity of approximately 1500 mS/m, showed increased incidences of diarrhoea, decreased body weights and reduced wool production. Higher mortality rates were also recorded.

The effects of excessive ion concentrations in water on wildlife species that are occurring in the Etosha N.P., has not been studied to the author's knowledge. It can be assumed that wildlife in Etosha has higher levels of tolerance to high concentrations of ions than domestic animals, as generally physiological adaptations occur in desert adapted mammals. However, there are no guide-

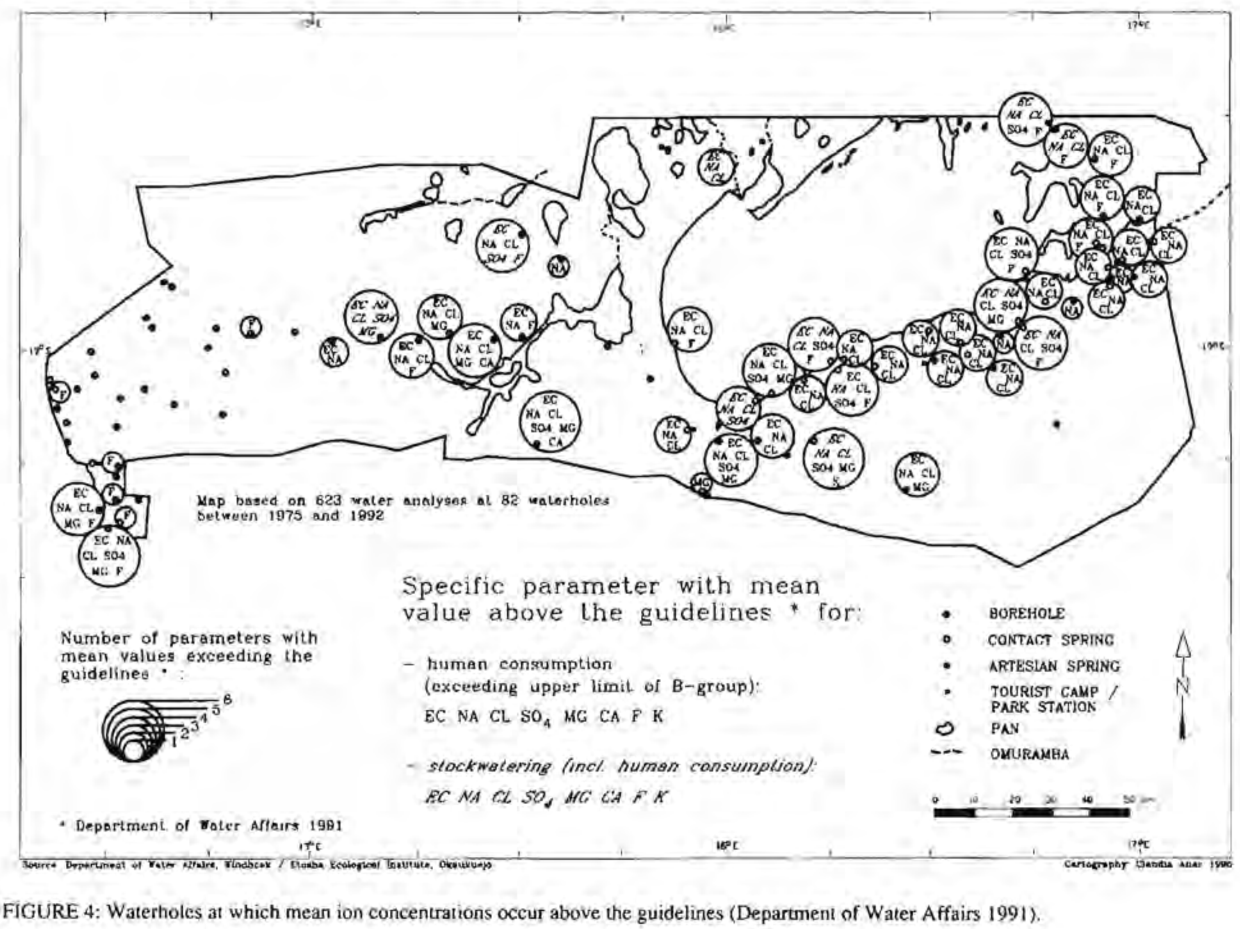


FIGURE 4: Waterholes at which mean ion concentrations occur above the guidelines (Department of Water Affairs 1991).

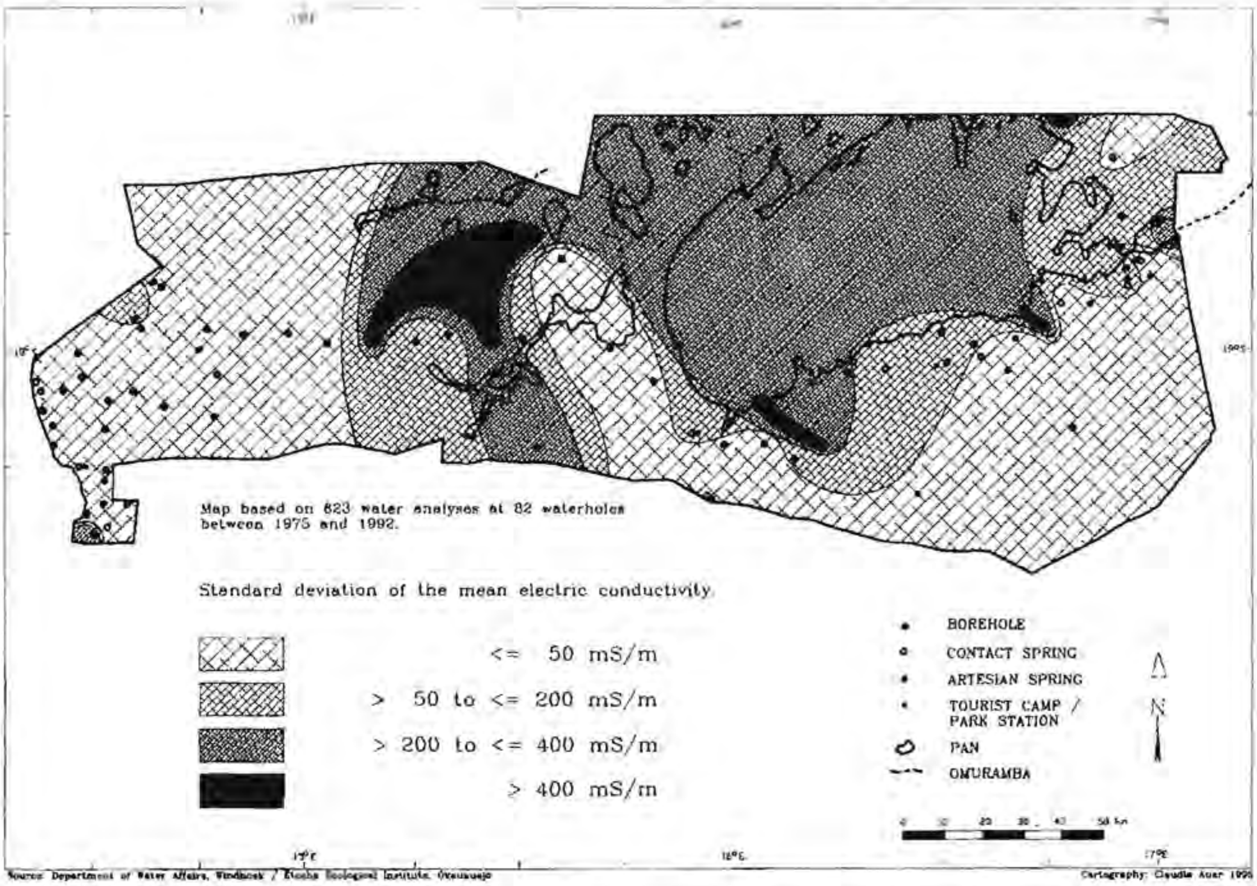


FIGURE 5: Standard deviation of the mean electric conductivity at waterholes in the Etosha National Park.

lines regarding concentration levels for various ions in forage or water, which may result in negative physiological effects in wildlife. Current research by the author is examining the influence of water quality on the utilization of waterholes by game. This approach tries to reveal the acceptance limits of wildlife for water quality by observing the animals' behaviour at different water quality waterholes.

Gammer (1993) has revealed very close correlations between the electric conductivity and the concentrations of sodium and chloride (both: $r = 0{,}98$; $p < 0{,}05$) and between the electric conductivity and sulphate concentrations ($r = 0{,}85$ $p < 0{,}05$) for the waterholes in the Etosha National Park. Therefore the measurement of the electric conductivity, even with a field conductivity meter at the waterholes themselves, serves as a quick and simple measure to identify critical concentrations of any of the problematic parameters sodium, chloride and sulphate.

The waterholes at which mean concentrations of different parameters exceed the recommended values are highlighted in Figure 4. The chemical water quality is mainly critical at waterholes in the extreme South–West and the central and eastern parts of the Park. The stockwatering limits for any of the parameters are exceeded at two waterholes in the Park centre and at nine waterholes in the East of the Park along the Etosha Pan. These are waterholes, which exclusively provide alkali – saline water and on which management activities, such as monitoring and improving of the water quality, should focus.

The arithmetic means of ion concentrations at waterholes, as illustrated in Table 3 and Figure 3 and 4, however, do not entirely present the real water quality situation. Temporal variation is likely to be expected between different water samples taken at a waterhole at different times. The standard deviation of the mean electric conductivity at each waterhole describes the variability of the total load of ions (Figure 5). Standard deviations under 50 mS/m are interpreted as constant electric conductivities, because field measurements revealed, that deviations of up to 50 mS/m can occur between various measurements at different points around one waterhole at a time (Auer 1993). Therefore, relatively constant chemical qualities occur at waterholes in the West and South of the ENP. Generally, the variabilities increase in the direction towards the central areas and the Etosha Pan. The highest standard deviations within the Park of more that 400 mS/m, which indicate significant temporal variations of the chemical quality, occur at Arendsnes, Bitterwater, Narawandu, Kapupuhedi, Aus, Springbokfontein, Batia, Oshanana and Andoni. For the Park Management this means that water quality monitoring can be reduced to a minimum at the relatively constant waterholes and instead should be focused on waterholes with higher quality variations.

Visually, a comparison of Figure 5 with Figure 3 shows that the waterholes with highly variable electric conductivities are in general those that have high mean electric conductivities. This has statistically been confirmed by a correlation coefficient of $r = 0{,}87$ ($p < 0{,}05$). Furthermore, it is exclusively alkali – saline water that shows distinct temporal quality changes.

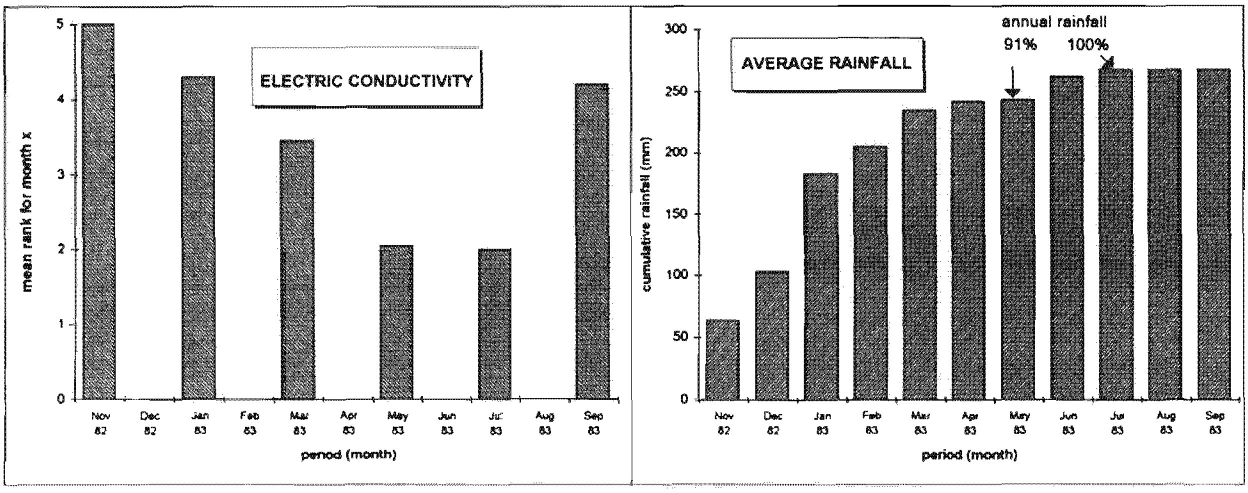


FIGURE 6: Comparison of electric conductivity values (n=10 waterholes) and cumulative rainfall between November 1982 and September 1983. High electric conductivity (EC) rank = relatively high EC; low electric conductivity rank = relatively low EC. The average rainfall was calculated for Okaukuejo, Halali and Namutoni camps.

Quality changes can be caused by a variety of factors, e.g. the amount of ground water recharge, the change of yield at a borehole or the change of flow of a spring, the size of the water surface as well as the depth of a water pool. Furthermore the climatic factors 'evaporation' and 'rainfall' are influencing the quality of water that is exposed (Hem 1985).

The effect of rainfall on water quality was examined by Auer (1993) by comparing the changes of the electric conductivity, measured every second month at ten selected waterholes, with the amounts of cumulative rainfall. Due to non-normal distribution and therefore possible distortion of arithmetic means, the electric conductivity values were statistically transformed into ranks. The different months were given different ranks according to their EC values. This was undertaken for each waterhole separately. The month with the lowest EC value obtained rank 1, the month with the highest EC value was given rank 6. Finally mean ranks were calculated for each month.

The comparison of the EC–ranks of each month with the cumulative amount of rainfall (Figure 6) indicates that during the period from November 1982 until September 1983 the electric conductivity was highest in the months November and January at the beginning of the rainy season. During the rainy season the EC consistently decreased and reached its lowest values in the months May and July 1983 when 91% and 100% of the yearly rain had fallen. A similar pattern has been observed by Moore (1987) at ion – rich lakes in the South-West of Australia, where the salinities reached the lowest values when 80% of the yearly amount of rain had fallen. These results suggest that water quality improves with the relative diluting effect of rainwater during the rainy season and deteriorates in the dry season due to a relative concentration through evaporation (Moore 1987, Auer 1993).

If generalized, these results give evidence that water analyses from samples collected twice a year, once between November– January and once between May–July, reveal the complete range of water quality variations within the year. However, I would like to stress that deviations from this general pattern might occur at different waterholes as well as in different years with other rainfall patterns. A recent study of the author is reviewing the universality of this seasonal pattern of water quality changes in the Park.

## CONCLUSION

At the waterholes of the Etosha National Park the main problematic water quality parameters for the purpose of providing water to wildlife are electric conductivity, sodium, chloride and sulphate. The guidelines for stockwatering as recommended by the Department of Water Affairs (1991) are currently used for the assessment of the suitability of water for wildlife, because of a lack of guidelines concerning wildlife. Realistic and relevant guidelines will have to be developed in order to assess the chemical water quality in Etosha with regard to the watering of wildlife.

Though wildlife in Etosha might tolerate higher ion concentrations in water than domestic stock, extremely poor water qualities might have negative physiological effects even to wildlife. Therefore waterholes with excessive ion concentrations, as found in the central areas of the Park and along the edge of the Etosha Pan, may need to be closed in future, or their water qualities may have to be improved. Regular measurements of the electric conductivity can serve as an effective tool for water quality monitoring in the Etosha N.P. because of close correlations between the electric conductivity and the concentrations of sodium, chloride and sulphate. Generally, monitoring of the chemical water quality can be reduced to twice a year since a seasonal pattern of electric conductivity values is apparent, with a minimum after the rainy season (May to July) and a maximum at the end of the dry season (November to January).

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