Physico-chemical characteristics of soils at selected water-points in the Etosha National Park, Namibia

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Abstract

National parks are important systems for protecting biodiversity and ecosystems around the world. In Namibia, approximately 19% of the country's land surface is proclaimed for protected areas including Etosha National Park (ENP). Managing the protected areas effectively and sustainably requires a great understanding of various components of the park, including the soils. This study aimed to understand the soil properties at different water-points in ENP (at Mushara, Rietfontein, and Ombika water-points). Ten plots from each site were sampled, at different soil depths. Soil parameters such as soil texture, pH, electronic conductivity (EC), Cation Exchange Capacity (CEC), phosphorus (P), potassium (K), and organic matter content (OM) were measured and analysed. The results show that soils were poorer at Mushara than at Rietfontein and Ombika, in terms of OM, Zinc (Zn), EC, Iron (Fe), and CEC. Furthermore, Mushara had significantly more sand content than both Ombika and Rietfontein. However, there were no significant differences between Rietfontein and Ombika in terms of CEC, Zn, Calcium (Ca), pH, OM, iron, manganese, sodium (Na), and soil texture. All sites were largely dominated by sandy soil. However, Mushara had significantly more sand than both Ombika and Rietfontein and significantly lower clay and silt content than Ombika and Rietfontein. The study concludes that the soil properties at assessed water-points might be influenced by vegetation communities, soil type, and the total annual precipitation. Therefore, the results of this study can be used to refine conservation strategies and develop long-term monitoring programs. We recommend that future studies focus on the link between vegetation composition, above and below ground biomass, and soil properties in ENP.

Keywords: Etosha National Park, Namibia, Soil properties, Water-points

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1. Introduction

The National parks system is one of the most important ways of protecting and conserving the diverse ecological biodiversity and other aspects of the ecosystem worldwide. In Africa, there are more than 1,812 National Parks, covering approximately 3,112,027 km^2 of the total land of the continent while in Sub-Saharan Africa, they cover over 1 million km^2 of 23 million km^2 land (4%) (Colchester, 2003; Muhumuza and Balkwill, 2013). In Namibia, these areas cover around 19% of the country's land surface and are supported by various legislations, policies, and programmes that ensure the safeguarding of such systems for the benefit of both the current and future generations (MET, 2020). Long-term planning and the determination of effective and efficient management strategies for National Parks and other protected areas such as community-based conservancies, depend on the understanding of various components of the area, both biotic and abiotic components. Understanding such factors enables the managers to predict what the future is likely to bring, and act accordingly where necessary. Understanding soil properties is essential for directing conservation efforts in National Parks because the quality of the soil impacts directly water retention, nutrient availability, and overall plant health and growth, thereby influencing the entire food chain within the park. Soil processes and properties provide a wide range of functions in the ecosystem and communities (Blum, 1988; Rodríguez, et. al., 2014). The distribution and abundance of animals depend on the spatial diversity and variability of vegetation and its soil properties (Augustine et al., 2003). The high abundance of animals in one place can also affect the soil, depending on the density, the type of animals, and the totality of time that the animals stay at certain points. Animals can alter the soil surface, depending on the soil type and the amount of moisture content. Trampling, overgrazing, and deposition of the dung by larger animals can result in changes in soil properties (Owen-Smith, 1999; Mukura, 2009).

The soil in Etosha National Park (ENP) serves as a significant foundation on which the entire biodiversity and ecosystem depend to thrive, by supporting the vegetation, providing habitat, and nourishing a variety of countless organisms. ENP consists of diverse species, including 407 bird species, around 114 mammal species of which some are endangered, 110 reptile species, and 16 amphibians including elephants which number up to 2000 at times (Berry, 1997; Lindeque and Lindeque, 1997; Acacia is Africa, 2023,). These browsers often change the structure and composition of the vegetation (Beer et al., 2006). The browsers such as elephants are found to significantly impact the vegetation around water-points in ENP (de Beer et al., 2006; Nakanyala, 2012). This has the potential to impact the soil properties at water-points. Understanding the soil quality in the Park and conserving its health is paramount for the long-term preservation and maintenance of its unique biodiversity, ensuring ecological balance and the well-being of its inhabitants. Previous studies in the ENP on soil were mostly carried out in connection to tourism activities and their infrastructures (e.g. Nakanyala, 2012). This study aimed to assess the soil properties around three water-points across the rainfall gradient in the ENP (annual rainfall is approximately 500 mm in the north-east declining to less than 300 mm in the south-west). Additionally, the three chosen water-points (Mushara, Rietfontein, and Ombika) fall within different major vegetation communities (shrubland, woodland, and bushveld) within the Park.

2. Methods and materials

2.1 Study area

Etosha National Park is situated in the north of Namibia and straddles the 19^{o} south latitude between approximately 14^{o} and 16^{o} east longitude. It was proclaimed in 1907 and it stretches more than 350 km from east to west and covers an area of 22,912 square kilometres. The Etosha pan covers about 4,731 km^2, which is about 21% of the park area. Wildlife varies and includes larger mammals such as Elephants, Giraffe, Black and White Rhino, Lion, Leopard, Black- Faced Impala, Burchell's Zebra, Springbok, Blue Wildebeest, Gemsbok, Hyena, Oryx, Kudus and Elands among others. While smaller species include animals such as jackals, bat-eared foxes, warthogs, honey badgers, and ground squirrels. (Olivier and Olivier, 1993; de Beer et al., 2006; Nakanyala, 2012; Cossu, 2022; Luetkemeier et al., 2023; Naha et al., 2023).

Rainfall, which ultimately determines the primary production, is also highly variable across the Park, with an average annual rainfall of around 500 mm in the north-east declining to less than 300 mm in the south-west (Hipondoka and Versfeld 2003). Average rainfall: Namutoni 443 mm, Halali 429 mm, and Okaukuejo 412 mm (Figure 1). The total rainfall is highly variable over the years and can be very patchy in its distribution both within the seasons and over the Park. Generally, the hottest month is September/October, during which the average daily maximum temperature is 34–40°C. Winter in Etosha National Park is cool and dry and temperatures are moderate, with a minimum of 6°C in July (at night). The rainy season usually begins in November, whilst February is the wettest month in the year (Figure 2). Soils vary from Cambic and Ferralic arenosols sediments to Leptosols and Vertisols in depressions, and Solonchaz and Solonetz soils in the Pan (Beugler-Bell and Buch, 1997; Nakanyala, 2012). Ombika and Rietfontein are both seemingly dominated by the same tree species, *Terminalia pruniodies* and *Colophospermum mopane*, while Mushara mainly comprises *Albizia anthelmintica*, *Philenoptera nelsii* and *Dichrostachys cinereal (*Angombe et al., 2020*)*.

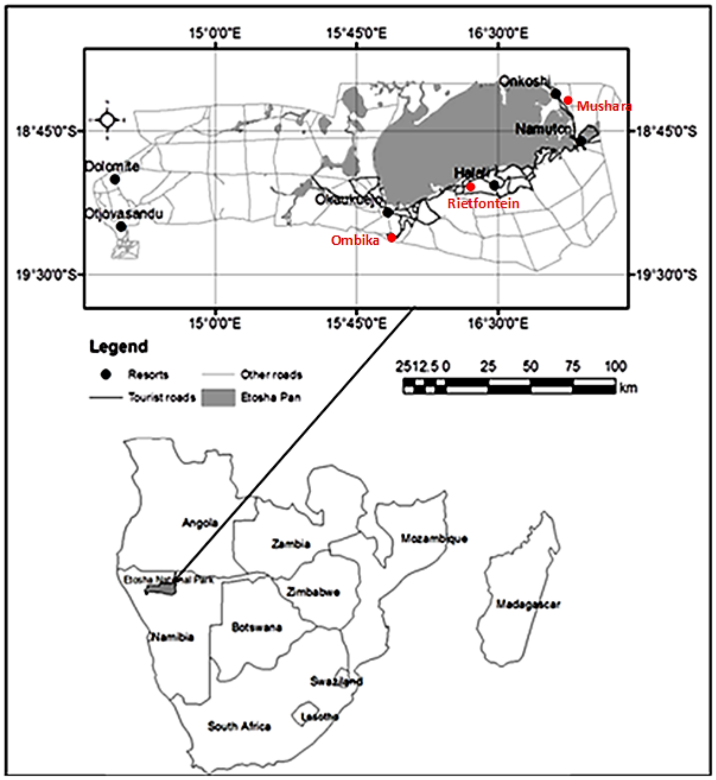

Figure 1: Etosha National Park and sampling sites (adapted from Nakanyala, 2012).

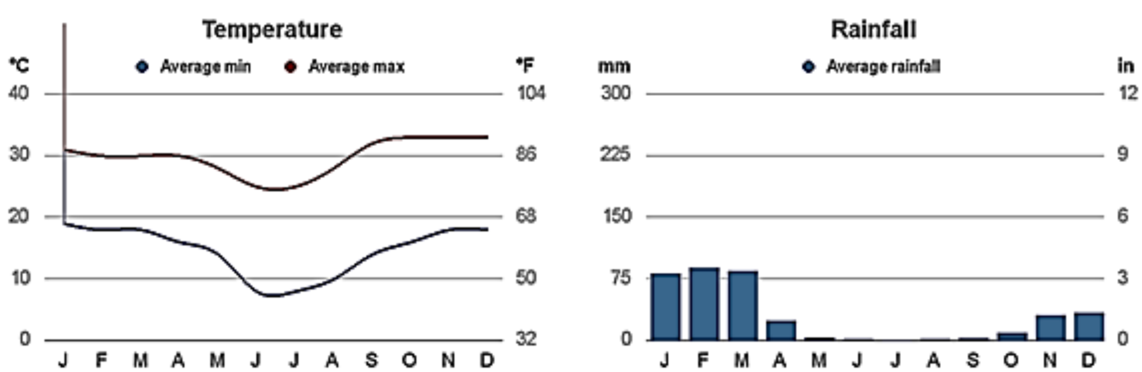

Figure 2: Etosha National Park average monthly climate, based on 50 years (Ham, 2020).

2.2 Data Collection

The study was conducted during the rain season, from November to February (2015). A total of twenty-four (24) sampling sites were established (10x10m), as follows: six (6) from Mushara, 11 from Ombika, and seven (7) from Rietfontein. Soil samples were collected at different soil depths, according to the horizons (A_1 and A_2). Soil parameters measured included soil texture, pH, electronic conductivity, salinity, phosphorus, potassium, sodium, and organic matter content. Materials used were GPS, soil auger, soil chart, diameter tape, and measuring tape.

2.3 Description of the methods used for soil analysis

The soil samples were analysed at the Ministry of Agriculture, Water, and Forestry analytical soil laboratory, following standard procedures: Soil samples were dried at a temperature of 35 ˚C. The Ohlsen method Extraction with sodium bicarbonate) was used to extract available phosphorus, and measured spectrophotometrically using the Phosphomolybdate blue method. The cations were extracted with 1M ammonium acetate at pH 7. Measurement of Calcium, Magnesium, Potassium, and Sodium were done by Inductively Coupled Plasma (ICP). Cation Exchangeable Capacity (CEC) was carried out with 50:50 Ammonium acetate (1M) and Ethanol at pH 7 if pH (H2O) >6.8 & EC >0.4mS/cm. Organic matter content was measured using the Walkley-Black method (Sulphuric acid-potassium Dichromate oxidation). Organic matter content was calculated as organic-C x 1.74. The electrical conductivity was measured in the supernatant of the 1:2.5 soil: water suspension before measurement of pH. The units of measurement used were mS/cm (1 mS=1000 uS).

2.4 Statistical Analysis

The soil data were analysed using the Statistical Package of Social Science (SPSS) software program IBM version 21. The data were tested for normality using the Shapiro-Wilk test. Variables that were normally distributed were analysed using a one-way analysis of variance (ANOVA) to test for significant differences in the levels of the selected soil properties, while the Kruskal-Wallis Test was used to test for differences in nonparametric data. Where significant differences in levels of soil properties were observed, a multiple comparison or pairwise comparison test was used to determine which sites significantly differed from each other.

3. Results

All the variables except Iron, Manganese, Sodium, and Potassium were normally distributed according to the Shapiro-Wilk test. Consequently, the Analysis of variance Test was used to determine differences in soil properties for parametric data, and the Kruskal-Wallis Test was used for non-parametric data. Analysis of variance results revealed significant differences among the three sites for CEC, Zn, Cu, Ca, Mg, pH, EC, and OM. However, P did not significantly differ among the sites (Table 1).

Table 1: Analysis of Variance Results for parametric data

Parameter	p-value	significance
CEC	0.000	Significant
Zn	0.000	Significant
Cu	0.002	Significant
Ca	0.002	Significant
Mg	0.029	Significant
P	0.203	**Not significant**
PH	0.003	Significant
EC	0.000	Significant
OM	0.000	Significant

***The mean difference is significant at the 0.05 level**

The Kruskal-Wallis test revealed that Fe, Mn, Na, sand, clay, and silt significantly differed among the three sites (Table 2). However, K did not significantly differ among the sites.

Table 2: Results of the Kruskal-Wallis Test for the non-parametric data

Parameter	p-value	significance
Fe	0.002*	Significant
Mn	0.006*	Significant
Na	0.035*	Significant
K	0.567	**Not significant**
sand	0.001*	Significant
clay	0.007*	Significant
silt	0.001*	Significant

***The median difference is significant at the 0.05 level**

3.1 Soil texture

Mushara had significantly more sand than both Ombika ($p<0.00$) and Rietfontein ($p=0.009$). Mushara had significantly lower clay and silt content than Ombika ($p= 0.002$; $p<0.00$ respectively). Furthermore, Mushara had less silt content than Rietfontein ($p=0.005$). However, there was no significant difference between Rietfontein and Ombika in terms of silt, clay, and sand content (p=0.608; p=0.256; p=0.412 respectively).

Soils are largely dominated by sandy soil texture at all sites. Mushara had the highest sand proportions and the least silt and clay parts. Ombika had the highest proportions of silt and clay and the least sand proportion in comparison to Mushara and Rietfontein. Sandy soils decreased while clay soils increased with depth at all sites. However, silt decreased with depth at Mushara and Ombika (Table 3). Mushara had significantly more sand than both Ombika and Rietfontein and significantly lower clay and silt content than Ombika and Rietfontein. There was a significant association between area and soil texture (Chi-square 61.834 (4), p<0.00).

Table 3. Soil size particle contents (m_α, %)

Area study (n)	Horizon	Soil Size Particles		
		Sandy	Clay	Silt
Mushara	A_1	$93.40_{1.31}$	$4.97_{0.59}$	$1.60_{0.73}$
	A_2	$91.60_{2.10}$	$6.33_{1.79}$	$2.07_{0.32}$
Ombika	A_1	$46.90_{3.33}$	$10.50_{1.21}$	$42.58_{2.41}$
	A_2	$43.25_{2.36}$	$14.50_{1.81}$	$42.28_{1.58}$
Rietfontein	A_1	$50.28_{2.10}$	$7.58_{0.80}$	$42.16_{1.73}$
	A_2	$44.15_{4.55}$	$16.70_{1.30}$	$39.10_{3.30}$

3.2 Soil nutrients

The results showed that apart from phosphorus, the macronutrients are very low across the sites (Table 4a). Soil macronutrients, namely Potassium and Phosphorus did not differ significantly among the three sites. However, calcium differed significantly between Mushara and Ombika (p=0.003), as well as Ombika and Rietfontein (p=0.016). Potassium and Calcium did not differ between the topsoil and subsoil layers at Mushara. Generally, at Ombika the macronutrients decreased with depth except for potassium, which remained more or less the same. Interestingly, phosphorus increased with depth at Ombika and decreased with depth at Mushara and Reitfontein. In terms of micronutrients, the results show that the nutrients were poorer at Mushara than at

Rietfontein and Ombika, in terms of Fe (Table 4b). Pairwise comparison Test revealed that Iron content significantly differed between Mushara and Ombika (p=0.001), as well as between Mushara and Rietfontein (p= 0.025), with Mushara having significantly lower iron content than both Ombika and Rietfontein. Mushara had significantly lower manganese and sodium than Ombika (p=0.002 and p=0.017 respectively). However, there was no significant difference between Rietfontein and Ombika in terms of iron, manganese, and sodium (p=0.932; p=0.43; p= 0.569 respectively). Sodium only differed significantly between Mushara and Ombika (p=0.017). There was no significant difference between Rietfontein and Ombika in terms of Zn, iron, and manganese. Copper significantly differed between Mushara and Rietfontein (p=0.002), as well as between Ombika and Rietfontein (p=0.016). However, Mushara and Ombika did not differ significantly in terms of copper content (p=0.345). Copper increased with depth at all sites and Manganese also increased with depth at Mushara but decreased at Ombika and Rietfontein, where at Ombika it decreased by more than half of the content in the topsoil. Fe only increased with depth at Ombika.

Table 4a: Macronutrients

Area	Horizon	Depth (cm)	K	P	Mg	Ca
			M_{σ}(ppm)			
Mushara	A_1	0-14	$0.01_{0.01}$	$1.10_{0.20}$	0.01_{-}	0.002_{-}
	A_2	14-16	$0.01_{0.01}$	$0.50_{0.12}$	0.006_{-}	0.002_{-}
Ombika	A_1	0-16	0.02_{-}	$4.50_{0.41}$	0.05_{-}	0.20_{-}
	A_2	16-45	0.02_{-}	$7.80_{5.09}$	0.045_{-}	0.10_{-}
Rietfontein	A_1	0-15	-	$7.56_{1.36}$	-	-
	A_2	15-35	0.01_{-}	$4.15_{0.85}$	0.045	0.12_{-}

Table 4b: Micronutrients

Area	Horizon	Depth (cm)	Mn	Cu	Fe	Zn	Na
			M_{σ}(ppm)				
Mushara	A_1	0-14	$1.43_{0.53}$	$0.29_{0.06}$	$0.34_{0.03}$	-	0.002_{-}
	A_2	14-16	$1.67_{0.48}$	$0.41_{0.03}$	$0.26_{0.06}$	-	0.002_{-}
Ombika	A_1	0-16	$25.60_{15.46}$	$0.25_{0.09}$	$3.37_{1.84}$	$0.13_{0.02}$	0.02_{-}
	A_2	16-45	$11.42_{5.56}$	$0.26_{0.07}$	$7.65_{6.32}$	$0.12_{0.02}$	0.03_{-}
Rietfontein	A_1	0-15	$2.35_{0.81}$	$0.05_{0.03}$	$0.638_{0.12}$	$0.13_{0.01}$	-
	A_2	15-35	$1.86_{0.04}$	$0.06_{0.06}$	$0.38_{0.04}$	$0.13_{0.01}$	0.03

3.3 Other soil content characteristics

The Tukey HSD, Multiple comparison test was used to establish the actual sites that significantly differ from each other. The results showed that Mushara and Ombika did not differ significantly in terms of copper content ($p=0.345$). Mushara had significantly less CEC, OM than Ombika (p-values: 0.000, 0.000, and 0.002 respectively) and Rietfontein ($p < 0.00$). Furthermore, Mushara had a significantly lower pH than Ombika ($p=0.002$). However, pH did not significantly between Mushara and Rietfontein ($p=0.172$). Ombika had significantly higher calcium than Mushara ($p= 0.003$) and Rietfontein ($p=0.016$). Mushara had significantly lower EC than both Ombika and Rietfontein ($p<0.00$). However, Rietfontein had significantly higher EC than Ombika ($p=0.006$). However, there was no significant difference between Rietfontein and Ombika in terms of CEC ($p=0.050$), pH ($p=0.162$), and OM ($p=0.063$).

The results showed that Mushara had virtually low organic matter contents, with 0.36 and 0.28% of organic matter at the top soil layer (A_1) and subsequent layer (A_2) (Table 5). In the two areas, organic matter decreases with increasing soil depth, while at Rietfontein, the organic matter content increases with soil depth. Ombika and Mushara areas, the topsoil layer has a relatively higher organic matter content than the subsoil horizons.

In terms of electronic conductivity, Rietfontein had the highest level of EC, followed by Ombika, then by Mushara. The soil conductivity at Mushara increases with the soil horizon. It is interesting to note that the EC at Rietfontein doubled that of Ombika and increased 10 times to Mushara. Rietfontein had a relatively higher CEC content of 38.42 me/100g in the topsoil, followed by Ombika (33.12), then by Mushara (2.77), making Rietfontein 13 times higher than Mushara. The pH is high in the same and top horizon (a) at Mushara. However, at Rietfontein and Ombika, the pH has increased with depth. Ombika had a slightly higher level of pH at both soil depths, compared to Mushara and Rietfontein. Overall, soil properties were poorer at Mushara than at Rietfontein and Ombika, in terms of OM, EC, and CEC (Table 5).

Table 5: Other soil characteristics

Area	Horizon	Depth (cm)	OM, %	EC, µS/cm	pH	CEC
			M_{σ}			
Mushara	A_1	0-14	$0.36_{0.05}$	$30.00_{12.50}$	$7.92_{0.23}$	$2.77_{0.88}$
	A_2	14-16	$0.28_{0.04}$	$35.33_{15.30}$	$7.713_{0.20}$	$2.45_{0.71}$
Ombika	A_1	0-16	$2.42_{0.38}$	$163.80_{24.07}$	$8.20_{0.06}$	$33.12_{2.65}$
	A_2	16-45	$1.74_{0.33}$	$175.33_{13.46}$	$8.34_{0.11}$	$32.76_{1.92}$
Rietfontein	A_1	0-15	$2.76_{0.50}$	$296.00_{40.89}$	$8.04_{0.07}$	$38.42_{0.64}$
	A_2	15-35	$3.82_{0.95}$	$199.50_{46.50}$	$8.12_{0.09}$	$36.17_{0.02}$

4. Discussion

Soil properties play a significant role in national parks such as Etosha National Park. The importance varies from providing a habitable place to the animals through determining the type of vegetation diversity of plant species to influencing water retention and nutrient content and hosting a diverse array of microorganisms crucial to nutrient cycling and decompositions. This paper serves as a benchmark to detect changes in soil properties over time.

4.1 Soil texture

Soil texture and mineral composition (e.g., sand, clay, silt) are inherent properties that evolve over geological timescales rather than years, making the results from 2015 applicable in understanding long-term ecological dynamics (Brady & Weil, 2010). Understanding the soil texture of ENP is crucial for wildlife management to implement appropriate strategies that can support a diverse range of soil types, to ensure that various habitats are available and can sustain a range of needs of different wildlife species. The distribution of the particles determines the structure of the soil and how porous it is, it is important to maintain a good structure. Wetting and drying, freezing and thawing, root growth, soil organisms, and cultivation are all actions that change the structure. Our findings show that soil textures at Ombika and Mushara study areas are more relatively homogeneous, with sand soil confined to Mushara, while loam soil was mostly found at Ombika. The higher sand content at Mushara creates a unique vegetation community and habitats. Wildlife such as Orycs, springboks, lions, elephants, Black rhinos, and some reptiles are likely to thrive in this area. Our findings can be used to draw up appropriate conservation strategies for those specific animals, that take into the function of specific habitat types while protecting the area from natural degradation and human disturbance. Alternatively, the results can be used to regulate the prevailing habitat conditions to improve the sites making them suitable for other species, depending on the Park's vision.

4.2 Soil nutrients

Soil nutrients directly impact the growth and development of plant species. Insufficient soil nutrition could easily lead to poor plant growth which would affect the overall health, and therefore the level of reproductive success of wildlife species. The results indicated that the sites have very poor nutrients, apart from phosphorus, and higher quantities of micronutrients of Manganese and Iron. Macronutrients are crucial for cellular components of the plants such as proteins and nucleic acids, and a deficiency in one of them could result in decreased plant productivity and/or fertility (Morgan and Connolly, 2013). Ombika and Rietfontein had very high amounts of phosphorus (Table 4a). This might be a disadvantage at these sites because the high level of phosphorus in the soil reduces the plant's ability to take up required micronutrients, especially iron, and zinc, even when the amounts of the two are highly adequate in the soil (Provin, and Pitt, 2022). Even though the pH was above neutral, sodium, calcium, and magnesium were very low, which can be attributed to the high amount of sand and low amount of clay soil in the soil structure. Furthermore, manganese availability did not decrease with an increase in pH but was approximately proportional to pH. This outcome is contrary to the results obtained by Schulte and Kelling (1999) probably because soils in our study areas are sandy and have very limited organic matter, especially at Mushara.

The high level of organic carbon and phosphorus in the sites could be attributed to recurrent floods, which resulted in the sedimentation and nutrient enrichment of soil by further addition of organic matter (Nath and Sarma, 2008). Potassium was found to be very low at all sites. This could be attributed to the fact that Potassium requires plant decaying and soil moisture to be replenished the soil (Wright, 2017). Etosha National Park falls under a semi-arid environment where both soil moisture and plant decaying are likely to be low most of the time. The decomposition of organic matter by soil microorganisms is needed to release the essential nutrients back into the soil, sustaining herbivores and omnivores in the park and, in turn also supporting the entire food web within the ecosystem.

The poor micronutrient content at Mushara compared to Reitfontein and Ombika could have been due to the low CEC at the site. Ombika had the highest levels of Mn, Cu, and Fe than the other sites. This could also be attributed to the woodland type of vegetation which increased the OM at the site. In addition, Rietfontein's underlying horizon had more humus than the upper horizons. This is unlikely in a normal condition of soils where organic matter decreases with depth (Chibsa and Ta'a, 2009; Du Preez, Van Huyssteen, and Mnkeni, 2011, Voltr et al., 2021; Xing et al., 2021). Overall, balanced nutrient levels are needed to ensure healthy vegetation and provide stability to the ecosystem. This would prevent other types of degradation such as soil erosion and have better-equipped ecosystems that can support a diverse array of wildlife species.

4.3 Variation in other soil properties

Our results indicated that Rietfontein and Ombika had higher EC, compared to Mushara. This is a clear indication that soil saltiness content increases toward the centre and the south-west part of Etosha National Park. The significant increase in EC might be attributed to the following factors as described by (Doerge, 2001): Firstly, mineral soils containing high levels of OM or more clay minerals have a much higher ability to retain positively charged ions, such as Ca, Mg, potassium (K), sodium (Na), than soils lacking these constituents. The presence of these ions in the moisture-filled soil pores will enhance soil EC in the same way that salinity does. Secondly, soils with water-filled pore spaces tend to conduct electricity more easily. Soils with high clay content have numerous, small water-filled pores that are quite continuous and usually conduct electricity better than sandier soils. Thirdly, dry soils are much lower in conductivity than moist soils. Fourthly, increasing the concentration of electrolytes (salts) in soil water will dramatically increase soil EC. Saline soils are known for hindering plant growth, limiting the available food sources for animals, reducing the freshwater for plants and animals through poor water retention, and impacting the ecosystem by affecting the soil organisms (Safdar et al., 2019; Gavrilescu, 2021; Naorem et al., 2023). Moreover, such a significantly high salinity level might force certain species to alter their migration routes or change their behaviour as an adaptation strategy, and this could lead to additional stress and potential population decline. The ENP managers would need to employ strategies such as habitat restoration, and planting salt-tolerant species to reduce the salinity impacts. These would depend on the degree of salinity, the wildlife in the area, and the specific ecosystem at each place.

The results indicated that Mushara has a relatively low Cation Exchange capacity (CEC) of less than three milligram equivalents per 100 grams of soil (Table 5). This could be associated with the high content of sand soils (Gaines and Gaines, 1994; Ketterings et al., 2007; Table 3). CEC is largely defined by the types of clay minerals present and the humus content and is an indication of the capacity of the soil to hold and retain nutrients against leaching (Brady and Weil, 2010). Low CEC is indicative of sandy textured soils that are prone to high levels of leaching and to drought which invariably need more organic matter to improve water holding capacity but have open grainy structures that resist compaction. Mushara's sandy soils are prone to leaching, and its low CEC implies that any increase in rainfall could exacerbate nutrient loss while Ombika and Rietfontein, with higher clay and organic matter, provide better buffering against nutrient depletion. This understanding supports adaptive conservation strategies even a decade later. A study by Hamarashid et al. (2010) emphasized that soil microbial activity and nutrient dynamics, especially in sandy soils like those in Mushara, depend on external inputs like organic matter and rainfall variability, but the broader texture remains unchanged. The areas at the centre of the Etosha Pan, Rietfontein, have relatively high CEC content, 38.42 me/100g on. Soil texture in the Rietfontein and Ombika are more clayish, which correlates to the CEC. This is good for the ENP as clay soils retain water for longer periods for plants and animals, promoting a healthy ecosystem by providing stable soil and habitats. Furthermore, the high CEC holds and exchanges nutrients effectively, thereby supporting diverse vegetation, aiding in water and nutrient retention while also contributing to a balanced biodiversity and ecological niches for a wide range of wildlife species.

The pH showed that the park had weak alkaline (7.7 – 8.3) soils. The topsoil Horizon A_1 had weaker alkaline at Mushara, compared to other study sites where the pH slightly increased with depth (Table 5). The relatively high pH of the soils may be due to the more soil organic matter content and High microbial activity could have resulted in high organic acid production (Nath and Sarma, 2008). Neutral to weak alkaline is good for vegetation growth because acidic pH can be detrimental to plant growth and can only be survived by tolerant species while highly alkaline soils can bind essential nutrients, making them less available for plant uptake, hence less nutrient available. It can also lead to soil compaction which limits oxygen availability for roots and makes elements such as aluminium and boron more soluble and toxic to plants, among others. Therefore, for Etosha, our findings show it to be in good condition to promote a healthy natural environment at the moment. However, regular monitoring might be needed to ensure that it does not increase further.

5. Conclusion

Soil properties were found to be poorest at the Mushara waterhole compared to Ombika and Rietfontein water-points. The Mushara area is characterized by deep sands soil type while Ombika and Rietfontein are dominated by loamy soils. Rietfontein had the highest OM, EC, and CEC followed by Ombika, while Mushara had the lowest, including the pH level in comparison to others. The study therefore concludes that factors such as types of soil and vegetation might have played a significant role in the current status of the soil properties.

The soil types and major vegetation communities might have played a great role in the current soil properties. Rietfontein falls within a woodland, Mushara falls within the shrubland, and Ombika falls within the bushveld vegetation community. The most biomass would be from the woodland, hence a combination of the loam soil and the potentially high level of biomass in Rietfontein can be a good combination for the retention of the chemical content levels while a combination of deep sandy soils with shrubland vegetation holds the opposite for Mushara water point. Furthermore, there is a higher amount of annual rainfall at Mushara (500mm) than at Rietfontein (420mm) and Ombika (300mm). This could mean a high amount and rate of nutrients leaching from the deep sandy soils at Mushara, leaving little chemical properties. Soil with low CEC is susceptible to high leaching and is likely to develop a deficiency of other chemicals. The study recommends research on the relationship between above and below-ground biomass and soil properties. The study further recommends research on the underlying causes of the high pH and OM in the second horizon (A_2) at Rietfontein.

The study recommends regular monitoring to compare against the outcomes of this study. While no immediate re-sampling has been conducted, the recommendation underscores the importance of establishing a regular monitoring program for ongoing ecosystem management. The interval for monitoring can be 15 years, hence the next sampling campaign will take place in 2030. This is because the National Parks are not like cropland where soils could easily be changed in their chemical, physical or biological properties through agricultural activities such as cultivation, tillage, weeding, terracing, subsoiling, deep ploughing, manure, and fertilizer addition, liming, draining and irrigation. Furthermore, we recommend that the management of ENP use this data to adapt and refine conservation strategies in these three areas and develop a long-term monitoring program that can be used to assess changes in soil quality and the effectiveness of interventions. The management can also use these findings to create awareness among visitors, on the significance of the habitat and the importance of minimal disturbances in specific sites. Furthermore, the findings can be used to foster collaborations with for example research institutions, governmental agencies, and local communities to support comprehensive soil conservation and wildlife management initiatives for ENP while also advocating for policies that prioritize soil conservation within protected areas in Namibia.

6. References

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