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Spatial distribution of soil salinity: a GIS-based assessment at the Hardap irrigation scheme, Namibia

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ABSTRACT

Salinization is a worldwide problem that affects the physical and chemical properties of soils. It is the most common and widely recognized form of land degradation, particularly in arid and semi-arid regions, where evaporation surpasses precipitation. Namibia aims to grow the agricultural sector for food independence, economic growth and stability. As a result, it is of great importance to manage and protect crop farms from salinization in the country. This study assessed the spatial distribution of soil salinity at the Hardap Irrigation Scheme, one of the two largest and oldest schemes situated in a hot desert climate in Namibia. The grab sampling method was used to collect 59 surface soil samples from randomly selected sites in the study area. The sampling sites included both irrigated and non-irrigated areas. Samples were subsequently analysed in the laboratory for electrical conductivity (EC), using saturated paste EC1:5 method. Resultant measurements were then grouped into five salinity classes. The point data were interpolated using the Inverse Distance Weighted (IDW) method in ArcGIS. Salinity levels in the study area ranged between 0.004 and 1.97 dS/m ± 0.557 dS/m. Although high salinity levels were recorded, non- and slightly saline classes cover just over two-thirds of the study area. Soil salinity in the study area is thus generally low, but the hazard exists. The low salinity level in the study area may be due to hydropedological factors, the prevailing management system or both. Regular monitoring of soil salinity is recommended, especially when new management system is introduced.

Introduction

Salinization is a worldwide problem that affects the physical and chemical properties of soils (Dehaan & Taylor, 2002; Metternicht & Zinck, 2003). Soil salinity occurs naturally through processes such as mineral weathering or as a result of poor

The prevailing climatic conditions in the Hardap Region and the presence of a large-scale irrigation scheme at Mariental prompted this study to re-assess the spatial distribution of soil salinity at the scheme. The main objectives were to (i) measure the electrical conductivity (EC) of the topsoil at the past to have a low total dissolved salts content of about 180 g/L (Verster & van Rooyen, 1993).

Floods irrigation has been practiced at the scheme since inception (Agenbach & Theron, 2001). In recent years, some farmers switched to sprinkler irrigation systems. Currently, sprinkler irrigation is used mostly in the central parts of the scheme, whereas flood irrigation dominates in the northern and southern area. Wheat, maize and lucerne are the main cultivated crops.

The scheme is largely sited on the broad valleys of the Fish River consisting of level river terraces and gentle footslopes (Verster & van Rooyen, 1993). The area receives an average rainfall of about 215 mm per annum, which is ten times less than the average annual evaporation rate (Mendelsohn, et al., 2002). Verster and van Rooyen (1993) estimated that irrigation water to the soil system at the scheme is in excess of 1500 mm per annum. Average annual temperature is approximately 21 °C. Mean maximum temperature above 36 °C are common, and the area receives more than 10 hours of sunshine per day on average (Mendelsohn et al., 2002).

Verster and van Rooyen (1993) recognized at the scheme three soil classes*, Typic Haplargids, Typic Natrargids* and *arenic* Ustic Haplargids. The *typic* largely developed from colluvial material, while the *arenic* is fluvial in origin. The most common soil is a deep, reddish, weakly-structured, calcareous sandy clay loam occurring predominantly in the footslopes at the scheme. Heavy loam to clay soils, which are typically not recommended for irrigation because of factors such as restricted permeability and high salsodic content, also feature in the footslopes. Loamy fine sand to fine sandy loam are prevalent in the terraces of the Fish River.

Field data collection

The methodology (Figure 2) adopted in this study entailed a field data collection. Delineation of the irrigation scheme was onscreen digitized from a Sentinel 2A image, which was captured on August 11, 2016 and downloaded from the Sentinel Scientific Data Hub website. The resultant shapefile was then used to generate random sampling points using ArcGIS version 10.3; these points fell in both irrigated and non-irrigated areas. Subsequent to accessibility, 59 surface soil samples were collected using a grab sampling method between 16 and 23 August 2018; the topsoil sampling was collected to a depth of 10 cm. During fieldwork, a handheld Global Positioning System (GPS) Garmin-eTrex 10 was used to locate the exact position of the sampling points in Universal Transverse Mercator (UTM) projection system. Collected samples were stored in sealed labelled plastic bags. Soil texture of the samples was estimated through texture by feel (Ritchey, McGrath & Gehring, 2015).

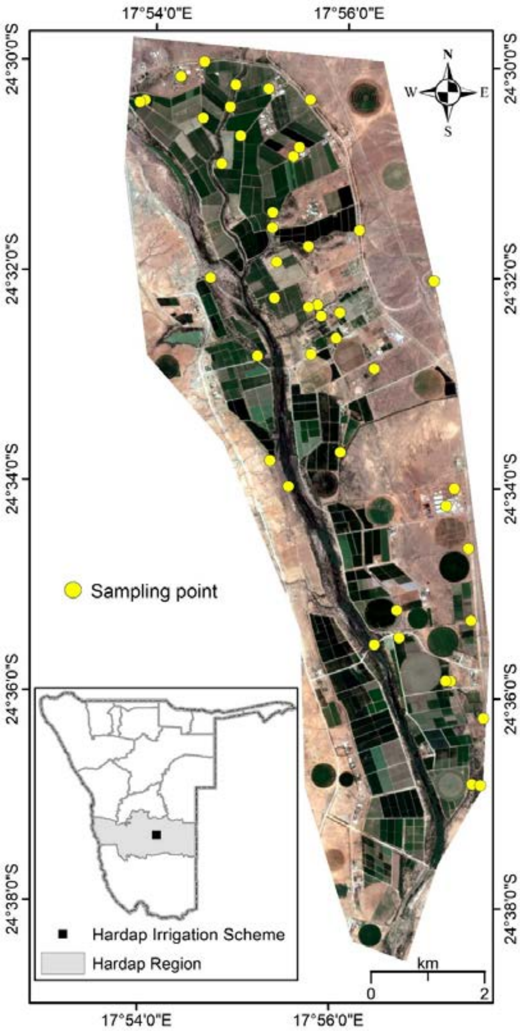

Figure 1: Location of the Hardap Irrigation Scheme and the distribution of soil sampling sites overlaid on a Sentinel 2 image of the study area

Laboratory analysis

Measurement for EC from samples was done using the saturated paste EC1:5 method (Rhoades, 1982). Each soil sample was first weighted and then dried in the oven set at 105 ^{0}C for 24 hours. The dried soil samples were weighted again, and weight loss was calculated to assess the moisture content. In the next step 1:5 ratio (1 soil: 5 deionized water) was prepared and left to equilibrate for an hour while shaking the contents every 15 minutes to allow dissolution of soluble salts.

Finally, the EC was measured using a Hach HQ14d meter with a CDC401 conductivity cell. The readings were recorded in µS/cm and converted to dS/m. Resultant measurement were classified according to methods described by the Grape and Wine Resource and Development Cooperation (GWRD, 2010; Table 1).

Table 1. Salinity classes for sandy loam, loam and clay soils of the top-soil samples in the study area. The classification scheme was adapted from GWRD (2010).

Saline class	Measured EC 1:5 (dS/m		
	Sandy Loam	Loam	Clay
Non-saline	<0.15	<0.17	<0.4
Slightly saline	0.16-0.3	0.18-0.35	0.41-0.8
Moderately saline	0.31-0.60	0.36-0.75	0.18-1.6
Very saline	0.61-1.2	0.76-1.45	1.6-3.2
Highly saline	>1.2	>1.45	>3.2

GIS Analysis

Results of the EC point data were interpolated in ArcMap 10.3 using the IDW technique. The interpolation method had an option of specifying the search distance for determining the interpolated value of each pixel. As such, we used a sample-based default search distance of 3520 m in both the major and minor semi-axis and a spatial resolution of 25 m. The search distance translated in a maximum of 15 and a minimum of 10 nearest sampling points employed in the interpolation for each pixel. A soil salinity map with five classes was derived following the methodology depicted in Figure 2 and classified according to GWRD (2010).

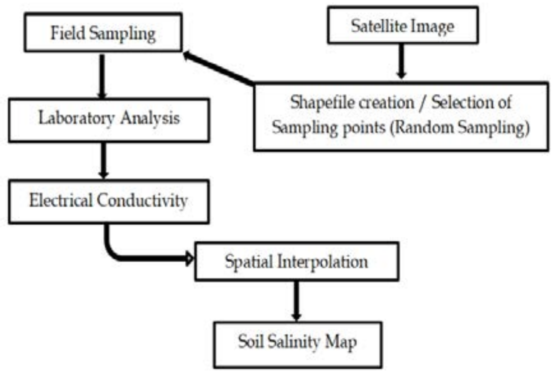

Figure 2: Approaches of the methodology employed in the study

RESULTS

Laboratory results

Subsequent measurements recorded 1.969 dS/m as the highest EC values, whereas the minimum was 0.003 dS/m with a median of 0.123 ± 0.428. EC values of less than 0.17 dS/m, which falls under non-saline levels, were obtained from 72.88% (n=43) of the analysed samples (Figure 3). Highly saline levels, above 1.45 dS/m, were measured from 5.0% of the samples. The overall results indicate that the study area is characterised by low salinity levels, averaging 0.235 ±0.557 dS/m. In general, non-irrigated sites (n=33) have mean (0.273 dS/m ±0.0.018) EC values higher than irrigated areas that have an EC value of 0.185 dS/m ±0.0.010 (n=26); both mean values fall under the slightly saline class. The highest moisture content recorded from the 59 samples was 6%.

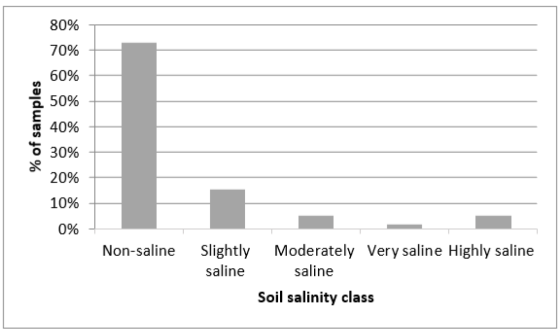

Figure 3: Frequency of salinity classes of top-soil samples in the study area

Figure 4 indicates the spatial distribution of soil salinity across the 5570 ha of the study area. The non-saline class covers the highest proportion (54.22% or 3020 ha) of the study area. This class dominates in the northern part of the irrigation scheme with few patches in the central and south-eastern areas. The moderately saline class comes a distant second. It covers 19.84% (1105 ha) of the study area. This salinity class mainly occurs in the southern and central areas. However, in the northern areas the moderately saline class can also be noticed as an isolated patch. The slightly saline class is in the third position and it is found in the central and south-eastern parts of the study area. This class covers 14.47% (806 ha) of the study area. The very saline class covers 10.60% (590 ha), while highly saline area extends over a 45 ha (0.81%) of the irrigation scheme. Areas under flood irrigation regime have the lowest salinity levels, whereas very and highly saline levels occur in the central parts where sprinkler irrigation is used.

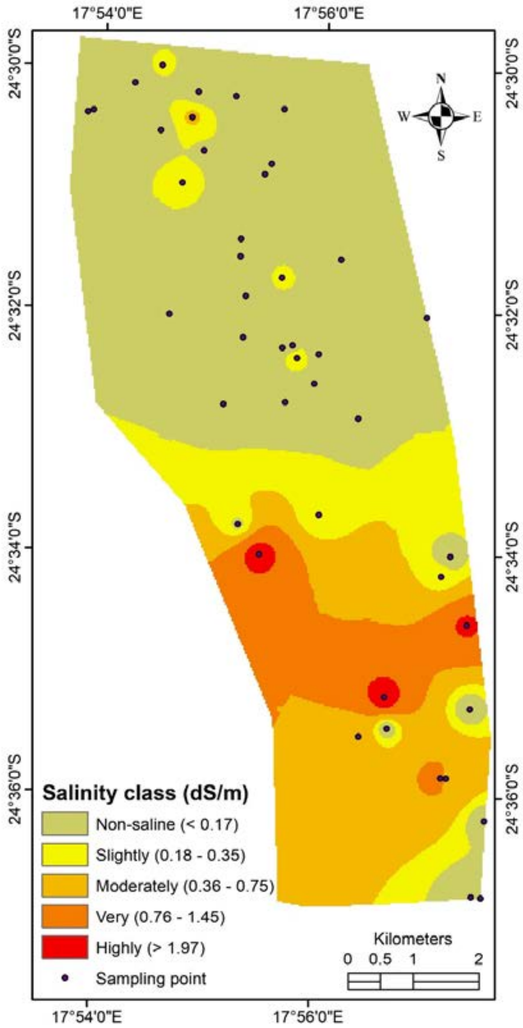

Figure 4: Spatial distribution of salinity classes for top-soil samples in the study area

DISCUSSIONS

The objectives of this study were effectively pegged to a two-stage approach in terms of the methodology and results. The first approach was to establish the extent of salinity levels from individual samples in the study area. In this regard, the study revealed that salinity is not a pressing edaphic issue at the scheme at present. Notwithstanding, high and very high salt content were measured in the study area.

The second approach employed GIS to estimate the spatial distribution of salinity levels across the scheme. In that context, the study further suggests that the threat of soil salinity is not pervasive in the study area, as the non-saline class accounted for more than half of the area. Moreover, the combination of non- and slightly saline classes covered just over two-thirds of the study area. On the flip side, a third of the study area with moderately or higher salinity levels suggests that soil salinity is a menacing hazard at the scheme.

The combined use of these methods minimized the cost and time required for soil sampling and data analysis as recognised by Gorji, Sertel and Tanik, (2017). Admittedly, sampling points in the southern half of the study area were relatively fewer and dispersed, due to limited access.

Salinity is a vicious environmental factor limiting the productivity of crop plants since most of these plants are sensitive to high level exposure of salts in the soil. Low crop yields and unhealthy crops are usually associated with saline soil and vice versa (Houk, Frasier & Schuck, 2006; Pitman & Läuchli, 2002; Shrivastava & Kumar, 2015). During fieldwork it was observed that the central part where sprinkler irrigation is used had low yield as most of the crops were dead or unhealthy.

Unsurprisingly, very and highly saline levels recorded in this study were from the area with dull crops growth. In contrast, non- and slightly saline levels were recorded in the northern part of the irrigation scheme, where crops seemed much healthier and flourishing.

As mentioned in the description of the study area, flood irrigation is commonly used in the northern part of the scheme. Ironically, sprinkler irrigation that is commonly used in the central part of the scheme is water efficient when compared with flood irrigation (Herrero, Robinson & Noguésa, 2007). This is particularly critical for arid zones such as the Hardap Region, where evaporation is high, and water is often scarce. However, flood irrigation helps with reducing the levels of salt affected soil because large amounts of water flushes the salts that are in the soil. Thus, salts tend to accumulate in areas under sprinkler irrigation as the water applied is insufficient to flush down the salts as reported elsewhere (Darouich, Cameira, Gonçalves, Paredes & Pereira, 2017; Sustainable Agriculture Initiative Platform, 2009; Talukder & Shamsuddin, 2012). Moreover, sprinkler irrigation can be affected by wind speed, temperature and the permeability of the soil. High wind speeds result in uneven water distributions and most of the water gets lost to evapotranspiration.

The occurrence of impermeable soils in the study area is also a critical factor. Once water floods the surface, the effect of evaporation translates in salts accumulation (eg. Talukder & Shamsuddin, 2012). Under sprinkler irrigation system, such salts remain in the upper soil resulting in increasing soil salinity. Given these environmental conditions and results obtained in this study, sprinkler irrigation may thus be not suitable for the study area.

Results obtained in this study corroborate the findings of Verster and van Rooyen (1993) who evaluated the changes in soil salinity at the Hardap Irrigation Scheme some 25 years after it was established. In comparing their results with an earlier soil survey (Louw, 1957) predating the irrigation scheme, Verster and van Rooyen (1993) concluded that intensive cultivation had a positive impact on soil salinity at the Hardap Irrigation Scheme. This conclusion was based on the average EC values that decreased from 1410 mS/m in 1957 to 325 mS/m in 1992. In the same vein, our study recorded a lower mean EC average from areas under irrigation when compared with non-irrigated zones.

It should be noted, however, that the pre-irrigation study employed the electrical resistance of saturated paste, while Verster and van Rooyen (1993) used a saturated paste in a 1:2.5 soil:water extracts. The higher dilution of soil solutions EC values determined from soil over water mass rations typically result in lower than those obtained by saturated past extracts. As Kargas et al., (2018) cautioned, these types of measurements obtained from disparate extracts ought to be interpreted in terms of relative changes and not in absolute values. In that light our results, albeit relatively lower, are effectively similar to those of Verster and van Rooyen (1993), especially when considering the different dilution of solutions employed.

CONCLUSIONS

The level of salt affected soils as observed in the field and as predicted by IDW technique at the Hardap Irrigation Scheme is not as high or pervasive as anecdotally expressed by the local farmers. Although modern sprinkler irrigation systems save a significant quantity of irrigation water, flood irrigation appears to be more suitable for the Hardap Irrigation Scheme. Better yields were observed during fieldwork in the areas under flood irrigation compared to those irrigated by sprinkler irrigation, which was reported by farmers as an enhanced method introduced recently in the study area.

It is imperative that salinity at the Hardap Irrigation Scheme be monitored and assessed at regular intervals of about 10 to 15 years. During the intervening period, individual farmers can monitor salinity levels using inexpensive, handheld probes obtained commercially.

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