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Appraisal of Ground Water Quality and its Impact on Irrigated Soils in Khartoum State, Sudan

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Abstract: A study was undertaken to appraise the quality and impact of well waters on irrigated soils of fifty farms widely spread in Khartoum State, Sudan. Water quality indicators and pertinent soil properties were measured by standard procedures. The determinations were electrical conductivity of water (ECw) and soil saturation extracts (ECe) and soluble Na^+, K^+, Ca^{++}+ Mg^{++}, Cl^-, HCO_3^- and SO_4^{--}. Sodium adsorption ratio (SAR), residual sodium carbonate (RSC), theoretical pH (pHc) and Langeleir's saturation index (LSI) were computed. A questionnaire including pertinent well and farm data and information was filled. ECw ranged between 0.4 to 4.8 dS/m. According to the United States Salinity Laboratory (USSL) classification system, 30% of the water samples lied within the medium salinity class, 62% lied within the high salinity class and 8% within the very high salinity class. In agreement with USSL, highly significant linear correlations between ECw and total salt concentration of water expressed in $mmole^+/l$ or mg/l with 99% accountability were found. Ninety-eight percent of the water samples were non-sodic. Only one water sample gave a SAR value equal to 19.1 and the remaining waters had SAR ranging between 1.1 and 9.4. RSC was negative for all water samples with the exception of two samples (4%) that gave RSC values ≤ 0.6 and thus within the safe level. In general, LSI data agreed with RSC data. The well waters were predominantly Ca-Na/SO_4=Cl waters. The results showed that 70% of the top layer of the

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irrigated soil had ECe values that ranged between 0 and 2 dS/m, 14 ranged between 2 and 4 dS/m and 16% had ECe values greater than 4dS/m.Comparison between irrigated and non-irrigated top soil samples indicated that thirty-four (68%) soil samples were leached, thirteen (26%) management. were salinized and three (6%) were not affected by irrigation with ground water. The soils, which were salinized, had the following texture classes: four clays, two clay loams, five sandy clay loams, one sandy clay and one sandy loam. The leached soils also included different types of textures, which indicates that salinization resulted from poor soil and water management.

Key words: Salinity; sodicity; residual sodium carbonate; Langeleir's saturation index

INTRODUCTION

Salinization reduces the productive capacity of land. Because it is widely spread in arid and semi-arid areas and has great adverse impacts on crop productivity, it is considered a major desertification process. Salinizations of arid lands may be due to natural causes, e.g., weathering of rocks and minerals under the prevalent arid conditions where potential evapotranspiration is greater than rainfall in most months of the year. Salinization may also be due to human activities, e.g., irrigation of arid lands with medium to high salinity water under poor soil and water management (Mustafa 2007). Several large agricultural schemes are irrigated with good quality water of the River Nile and its tributaries (Mustafa 1973). However, the River Nile contains residual sodium carbonate which caused the development of sodic soils (Eaton 1950; Mustafa 1973). In Khartoum State, many private and cooperative farms use deep and surface borehole waters for irrigating vegetables, forage and fruit trees. In spite of the fact that these boreholes are close to the River Nile and its tributaries, they had higher salinity levels (Mustafa 1984). This is because the salinity of these ground waters is determined by other factors.

Salinization may reduce crop, range and forest production through its multiple adverse effects; namely, osmotic effect, specific-ion effects including nutritional imbalance and toxic effects and soil physical deterioration (Hamid and Mustafa 1975; Mustafa and Hamid 1977; Mohamed and Mustafa 2000; Mohamed and Mustafa 2001).

A previous study on the quality of many surface and deep borehole waters and their impact on irrigated soils showed that 70%, 28% and 2% were of medium, high and very high salinity level, respectively, according to the United States Salinity Laboratory water classification system (Mustafa 1984). About quarter of a century passed since that last survey was undertaken. Thus, it was envisaged that there is need to reappraise the quality and impact of the ground waters on irrigated soils of fifty farms widely spread in Khartoum State.

MATERIALS AND METHODS

Physical and Environmental Setting of the Study Area

This study was undertaken in Khartoum State, which lies between latitudes 15º8`- 16º39`N and 31º36`- 34º25`E in the semi-desert tropics. The State has an area of 5.2 million feddans (1 feddan = 0.42 ha). It is bordered by the River Nile State in the north, the Gezira State in the south, Al-Gadarif State in the east and north Kordofan State in the west.

The mean annual rainfall ranges between 75 mm and 150 mm and the rainy season extends between July and September. The average air temperature ranges between 21.6ºC and 37.7ºC. The mean annual evaporation rate is about 7.7 mm/day. Daily average relative humidity ranges between 21% and 38%.

The River Nile starts flowing northwards from Khartoum where the White Nile and the Blue Nile meet. The State is nearly a flat plain, gently sloping towards the River Nile and its two main tributaries; namely, the White Nile and the Blue Nile. However, there are some outcrops such as

Markhiat in Omdurman and Al Seleit in the eastern part of Khartoum North. The State is covered by three geological formations: the Nubian sandstone covering about two thirds of the State, the Gezira formation covering the area between the two tributaries of the Nile and basement complex covering a small area in the northern part of Khartoum North (Sabaloga).

The soils of the State are predominantly Aridisols with pockets of Vertisols formed on old alluvium deposits and Entisols on recent alluvium and Aeolian deposits. Most of the soils of the State are salt-affected (Mustafa 1986).

The vegetation cover consists of annual (75%) and perennial plants (25%), shrubs and some trees mainly Acacia trees.

The main water resources are the River Nile and its tributaries, seasonal water courses (wadies) and ground water in the three geological formations, mainly away from the River Nile system.

Sampling locations

Water and soil samples were collected from 50 randomly-selected farms widely spread in Khartoum State. The geographic position of each farm was geo-referenced using a Global Position System, for future monitoring. Twenty farms lie in Khartoum North: seven in Al-Halfaya, five in Al-Ailafoon, two in each of Al-Kadro, Al Khogalab and Al-Hag Yousif, and one in each of Karnos and Soba Sharg. Fifteen farms lie in Khartoum: four in each of Al-Sheta and Om Haraz, three in Al-Kalaka and two in each of Al-Geraif Garb and Al-Shegelab. Fifteen are in Omdurman: seven in Al-Moeleh, four in Dar Al—Salam and two in each of Al-Fetehab and Ombada.

Farm data

A questionnaire was formulated to obtain relevant information and data from the farm managers or superintendents. The information and data obtained included the geographic location of the farm, its area, age, crops grown and the adopted irrigation scheduling. Furthermore, the depth and age of wells of the farm were also recorded. These detailed data and information are reported elsewhere (Elsayed 2007).

The areas of the farms varied from 1 to 100 feddans (1 feddan = 0.42 ha) with a mean of 23 feddans and a coefficient of variation (C.V.) of 83%. Their age also varied widely from 2 to 47 years with a mean of 21 years and C.V. of 64%. In general, crops such as vegetables, forages (lucerne and Abu Sabaeen) and fruit trees are grown.

The depth of the wells varied widely from 10 to 150 m with a mean of 60 m, and a coefficient of variation (C.V.) of 70%. The age of the wells also varied greatly from 2 years to 37 years with a mean of 17 years and a C.V. of 58%.

Fifty water samples were taken from wells used for irrigating the crops in the fifty selected farms and saved in bottles for analysis. Soil samples from 0-30 cm depth were collected by an auger from the irrigated fields and from adjacent non-irrigated lands. In each farm, several soil samples were collected. They were then thoroughly mixed to form a composite soil sample. Similarly, a composite soil sample from the non-irrigated lands was formed. These composite samples were air dried in the laboratory, thoroughly mixed, crushed, passed through 2-mm sieve and saved in tagged bags.

Both water samples and soil saturation extracts were analyzed using the same standard analytical procedures (Page *et al.* 1986). Two to three replicate determinations were made. The electrical conductivity of water (EC) or that of the saturation extracts (ECe) was determined using a conductivity metre; pH was determined by a standard pH meter, Na and K were determined using a Flame photometer, Ca + Mg was determined by titration against EDTA (Diehl *et al.* 1950; Cheng and Bray 1951). The HCO_3 and Cl were determined by using Rietemeier (1943) titration method. Sulphates were calculated by difference. Sodium adsorption rate (SAR) was calculated from soluble Na^+, Ca^{++} and Mg^{++} salts ($mmole^+/l$) by the following relationship:

$$SAR = Na^{+} / \sqrt{[(Ca^{++} + Mg^{++})/2]}$$

Soil particle-size distribution was determined by the hydrometer method (Black 1965). Residual sodium carbonate (RSC) was calculated using the following equation (Eaton 1950):

$$RSC = (CO_3^{--} + HCO_3^{-}) – (Ca^{++} + Mg^{++})$$

All ions were expressed in mmole^{+}/l. The theoretical pH (pHc) was calculated from knowledge of Ca^{++}, HCO_3^{+} and the total salt concentration (C) of well water samples expressed in mmole^{+}/l using regression lines, which were developed by the authors from Bower *et al.* (1968) as presented in Bohn *et al.* (1979). $pK_2 – pK_c$ was plotted against C, pCa was plotted against Ca and $pHCO_3$ was plotted against HCO_3. These regression lines were used for calculating pHc by the following relationship:

$$pHc = pK_2 – pK_c + pHCO_3 + pCa$$

$pK_2 – pK_c$ was calculated from the following polynomial regression relationship:

$$pK_2 – pK_c = 5 \times 10^{-6} C^3 – 5 \times 10^{-4} C^2 + 0.0202 + 2.1152$$

The Langeleir's saturation index (LSI) is calculated by the following relationship:

$$LSI = pHa-pHc$$

where pHa is the actual pH of water. Positive LSI values indicate precipitation and negative values indicate dissolution of $CaCO_3$ from water.

RESULTS AND DISCUSSION

The detailed results of the water analyses were presented elsewhere (Elsayed 2007). Only summary statistics are presented in this paper.

Spatial distribution of the electrical conductivity

The mean electrical conductivity of the well water samples (ECw) ranged from 0.4 to 4.8 dS/m with a standard deviation (S.D.) of replicate measurements of individual wells ranging from 0.03 to 0.13 and C.V. ranging from 0.8 to 11.1%. The overall mean S.D. and C.V. were 0.10 and 5.8%, respectively. The spatial distribution of ECw in Khartoum State varied in the following order: Khartoum N. > Omdurman > Khartoum (Table 1). The relatively low overall C.V. of replicate ECw measurements indicated good precision of measurements and reliability of methods used.

Table 1. Spatial distribution of ECe (dS/m), SAR and some of the cations and anions (mmole$^+$/l) of the water samples in three localities of Khartoum State

Locality	ECw	SAR	Na^+	K^+	Ca^{++}+ Mg^{++}	Cl^-	HCO_3^-	$SO4^{--}$
Khartoum N..	1.5	3.9	7.6	0.11	7.4	7.1	2.1	5.8
Khartoum	0.8	3.5	4.3	0.12	2.9	3.6	1.7	1.9
Omdurman	1.2	5.7	7.7	0.19	3.5	5.7	1.8	3.8
Mean	1.2	4.3	6.6	0.14	4.9	5.6	1.9	4.0

According to the United States Salinity Laboratory (Richards 1954) classification system, 30% of the water samples lied within the medium salinity class, 62% within the high salinity class and 8% within the very high salinity class. Although the wells from which these water samples were collected were relatively close to the River Nile system, they had

ECw values greater than those of the Blue and White Nile rivers in all seasons (Mustafa 1973). This may be attributed to the geologic and chemical nature of the aquifers, the relatively higher withdrawal and limited recharge of water by the low rainfall and by the Nile. The C.V. of mean ECw among the fifty wells was 71%. This high variation may be attributed to depth and age of well, age of farm, irrigation interval, general soil and water management scenario, geologic nature of the aquifer and distance from the River Nile system. The last two variables were not measured. The questionnaire data yielded a significant ($P = 0.05$, $r = 0.286$) linear increase in ECw with increase in irrigation interval. The low accountability of irrigation interval was due to other interacting factors. Other considered variables; namely, age and depth of well and age of farm, had no significant impact on ECw. Multiple regression analyses did not yield significant correlation between ECw and the measured variables. If one is interested on the impact of one variable, other variables must be kept constant.

Fig.1 shows a highly significant linear correlation between the total salt concentration expressed in mmole$^+$/l ($r^2 = 0.9899$) or mg/l ($r^2 = 0.9861$) and ECw in dS/m. This finding is in agreement with those of the United States Salinity Laboratory, Riverside (Richards 1954). The two empirical relationships depicted on the figure may be used for conversion purposes, particularly in Khartoum State.

Spatial distribution of cations

The mean concentration of Na^+ ranged from 1.5 to 28.3 mmole$^+$/l, with S.D. of replicate measurements of individual wells ranging from 0.06 to 0.26 mmole$^+$/l and equivalent C.V. ranging from 0.2% to 6.8%. The overall mean S.D. and C.V. were 0.11 and 2.4%, respectively. The spatial distribution of Na concentration in Khartoum State varied in the following order: Omdurman > Khartoum N.. > Khartoum (Table 1).

The mean concentration of Ca^{++} plus Mg^{++} ranged from 2.0 to 24.5 mmole$^+$/l, with S.D. of replicate measurements of individual wells ranging from 0.00 to 0.76 mmole$^+$/l and C.V. ranging from 0.0 to 11.5%.

The overall mean S.D. and C.V. were 0.26 and 6.1%, respectively. The spatial distribution of Ca^{++} plus Ma^{++} concentration in Khartoum State varied in the following order (Table 1): Khartoum N. > Omdurman > Khartoum (Table 1).

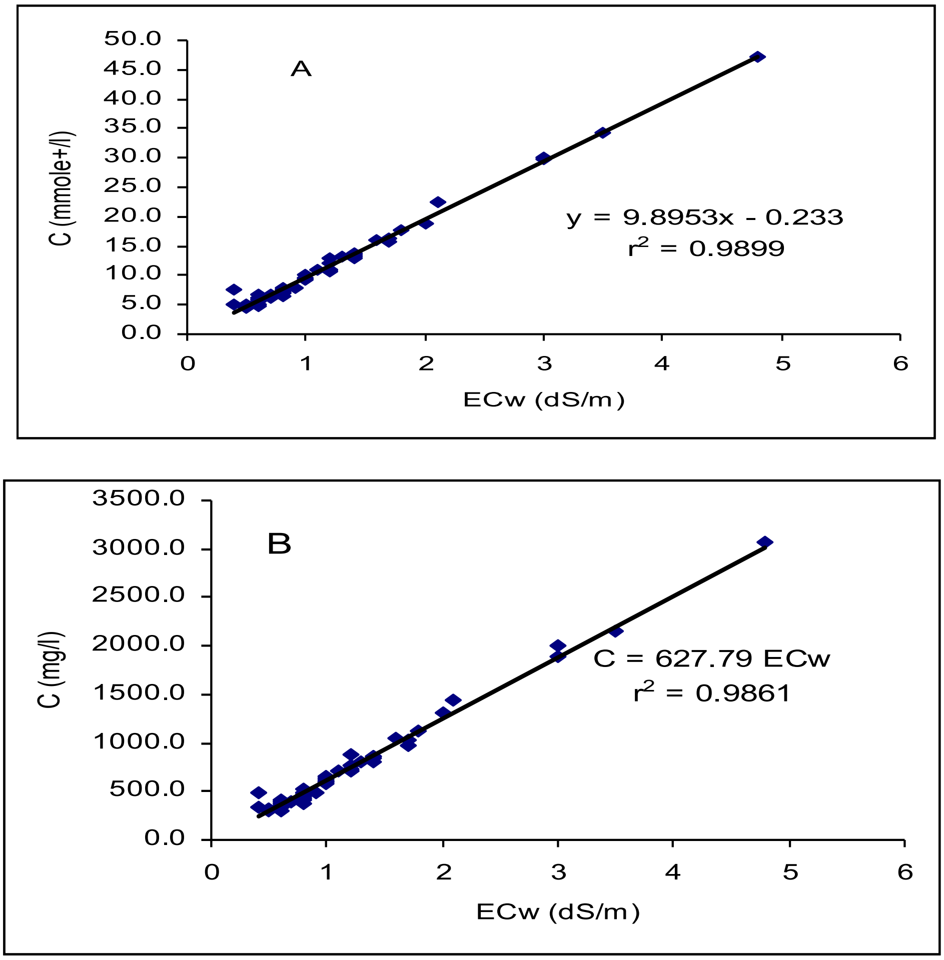

Fig.1. The relationships between Ecw and total salt concentration expressed in (A) mmole+/l and (B) mg/l

The mean concentration of K^+ ranged from 3.5 x 10^{-2} to 38.8 x 10^{-2} mmole$^+$/l, with S.D. of individual measurements ranging from 0.1 x 10^{-2} to 0.8 x 10^{-2} mmole$^+$/l and C.V. ranging from 0.2 and 7.9%. The overall mean S.D. and C.V. were 0.002 and 1.9%, respectively. The spatial distribution of K^+ concentration in Khartoum State varied in the following order: Omdurman > Khartoum > Khartoum N.. (Table 1).

Spatial distribution of sodium adsorption ratio (SAR)

The mean SAR values of the well water samples (ECw) ranged from 1.1 to 19.1 with a standard deviation (S.D.) of replicate measurements of individual wells ranging from 0.00 to 0.68 and C.V. ranging from 0.0 to 11%. The overall mean S.D. and C.V. were 0.2 and 3.9%, respectively. The very low overall C.V. of replicate measurements indicated precision and reliability of measurements. Ninety-eight percent of the water samples were non-sodic. Only one water sample gave a SAR value equal to 19.1 and the remaining waters had SAR ranging between 1.1 and 9.4. All water samples had SAR values greater than those of the River Nile system. The C.V. of the SAR values of the different well waters was 72%.

This very high value may be attributed to the multiple factors that affected the spatial variation of ECw. There was highly significant ($p < 0.001$, $r = 0.648$) increase in SAR with increase in ECw. The spatial distribution of SAR in Khartoum State varied in the following order: Omdurman > Khartoum > Khartoum N. (Table 1). This is because Na concentration was in the same order whereas the concentration of Ca+Mg was as follows: Khartoum N. > Omdurman > Khartoum.

Spatial distribution of anions

The mean concentration of Cl^- ranged from 1.5 to 17.5 mmole$^+$/l, with S.D. of replicate measurements of individual wells ranging from 0.00 to 0.52 mmole$^+$/l and C.V. ranging from 0.0 to 14.3%. The overall mean S.D. and C.V. were 0.22 and 5.0%, respectively. The spatial distribution of Cl^- concentration in Khartoum State varied in the following order: Khartoum N. > Omdurman > Khartoum (Table 1).

The mean concentration of HCO_3^- ranged from 0.5 to 4.2 mmole$^+$/l, with S.D. of individual measurements ranging from 0.00 to 0.40 mmole$^+$/l and C.V. ranging from 0.0 to 15.7%. The overall mean S.D. and C.V. were 0.11 and 5.5%, respectively. The spatial distribution of Cl^- concentration in Khartoum State varied in the following order: Khartoum N. > Omdurman > Khartoum (Table 1).

The mean concentration of SO_4^{--} ranged from 0.3 to 26.4 mmole$^+$/l, with S.D. of individual measurements ranging from 0.00 to 0.61 mmole$^+$/l and C.V. ranging from 0.0 to 43.0%. The overall mean S.D. and C.V. were 0.18 and 9.1%, respectively. The spatial distribution of Cl^- concentration in Khartoum State varied in the following order: Khartoum N. > Omdurman > Khartoum (Table 1).

Dominance of cations and anions

Szabolcs (1970) introduced a water classification system based on cation and anion dominance. Fig. 2 shows the cation and anion dominance of the studied water samples.

Spatial distribution of residual sodium carbonate

The results showed that the residual sodium carbonate (RSC) was negative for all water samples with the exception of two samples (4%) that gave RSC values ≤ 0.6 and thus within the safe level (Wilcox *et al.* 1954). This is due to the fact that the samples were predominantly sulphate and chloride waters (Fig. 2).

Langelier's index

Forty three water samples gave negative modified Langelier's saturation index (LSI), six gave positive values and one gave zero. These results indicated that $CaCO_3$ will dissolve in the soil when the waters with negative LSI are applied.

Classification of water samples

The U.S.A. classification system is based on the electrical conductivity of water (EC, μS/cm) indicative of the salinity hazard and SAR indicative of the sodicity hazard (Richards 1954). The following four salinity hazards were recognized: EC1 (low), EC2 (medium), EC3 (high) and EC4 (very high); and the following four sodicity hazards are recognized: S1 (low), S2 (medium), S3 (high) and S4 (very high). According to this system, 48% of the water samples belonged to EC3-S1, 30% to EC2-S1, 12% to EC3-S2 and 2% to each of the following classes: EC3-S3, EC4-S1, EC4-S2, EC4-S3 and EC4-S4. It is evident that these well waters had lower quality than those studied by Mustafa (1984). He found that 70% of the waters lied within EC2-S1 and 28% within EC3-S1. This may be attributed to the younger age of the wells, the lower withdrawal of water and the possible shorter distance to the River Nile system. Farah (1999) reported that the quality of well water decreased with increase of distance away from the River Nile system.

Fig. 2 shows that the well waters were predominantly Ca-Na/SO_4=Cl waters (Szabolcs 1970). Thirty percent of the well waters were sulphate = chloride, 27% of which were found in the upper aquifer of Omdurman. This is in agreement with the vision of Farah *et al*. (1997).

The spatial variability of the water quality based on the EC hazard only was classified according to the U. S. salinity laboratory system and mapped using GIS (Fig. 3). The map clearly illustrates that Khartoum N.is dominated by high (0.750-2.250 dS/m) and very high (> 2.250dS/m) salinity water, whereas Khartoum and Omdurman are dominated by low salinity water.

Irrigated soils

The detailed results of the soil analyses were presented elsewhere (Elsayed 2007). Only summary statistics are presented in this paper. Ten of the irrigated top soils were clay, five were sandy clay, five were clay loam, twenty-nine were sandy clay loam, and one was sandy loam.

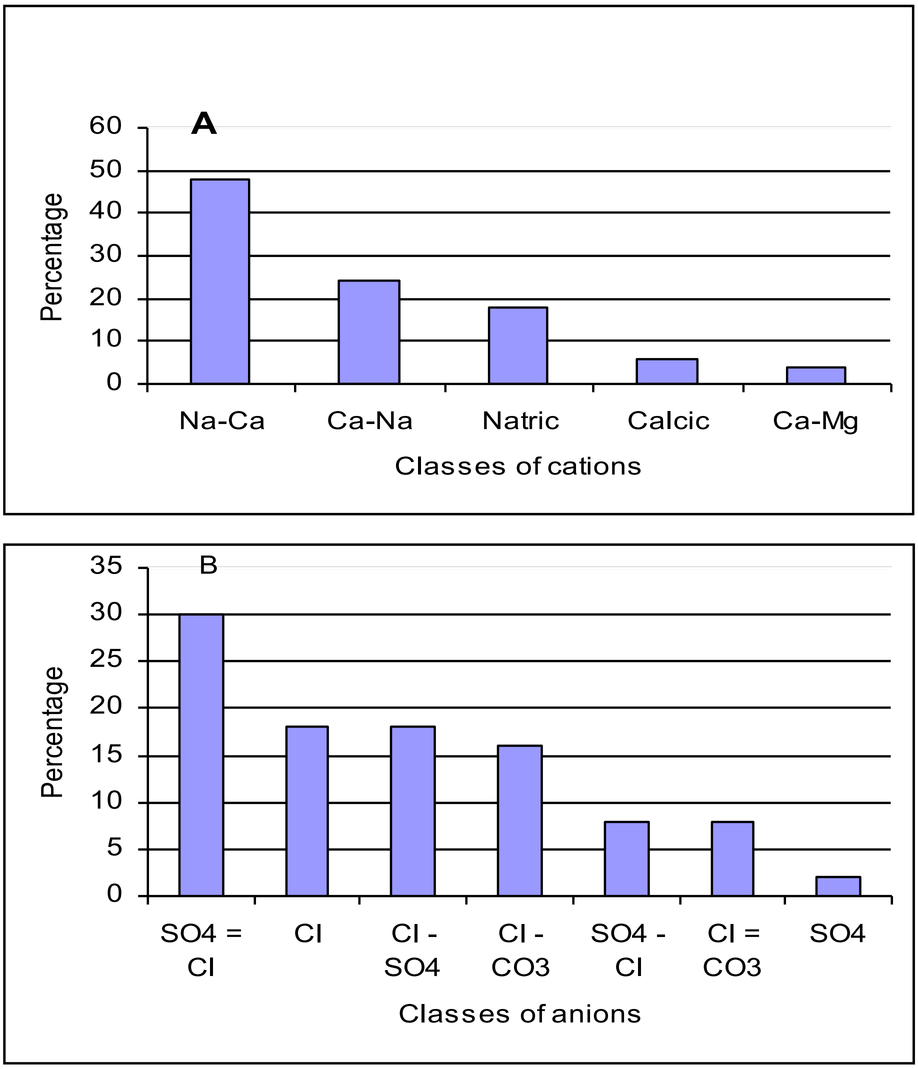

Fig.2. Classification of water according to dominance of (A) cations and (anions

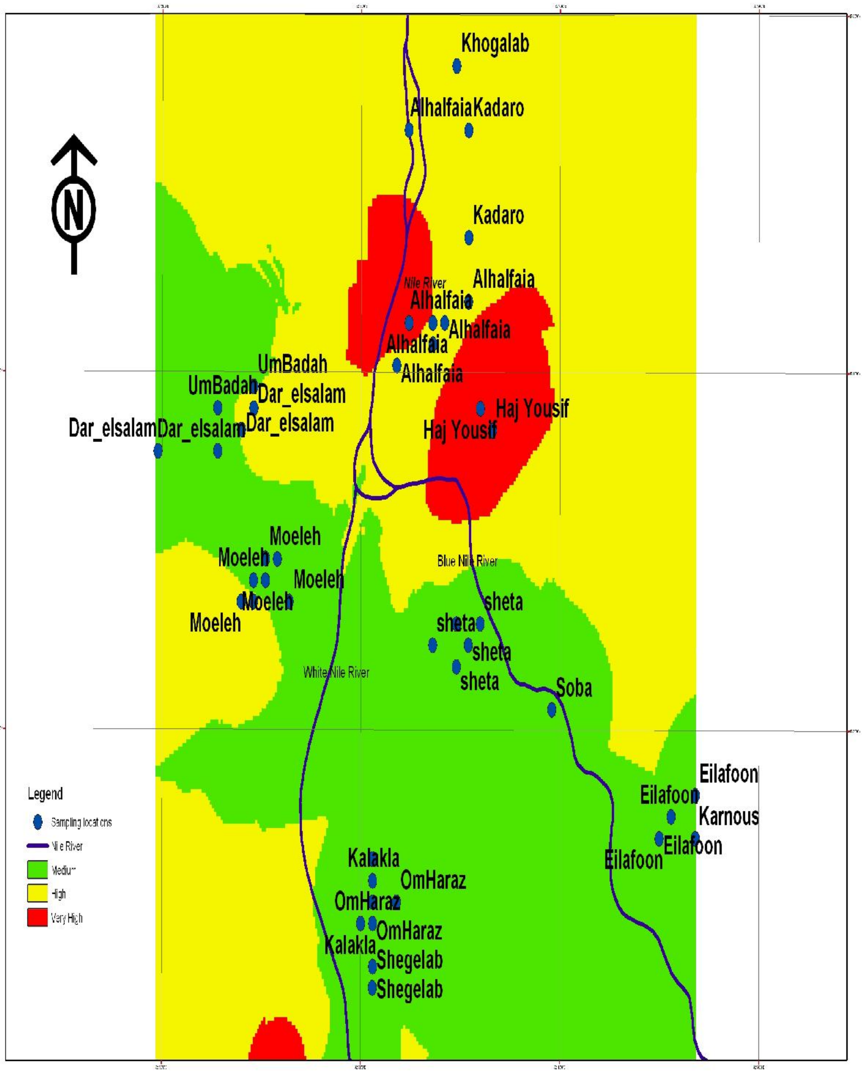

Fig. 3. Spatial variability of water EC in Khartoum State

In general, the low overall C.V. of the replicate measurements of ECe and all cations and anions and SAR indicated good precision of the measurement in question and reliability of the method used.

Spatial distribution of ECe

The mean electrical conductivity of the saturation extracts of the soil samples ranged from 0.3 to 21.1 dS/m with S.D. of replicate measurements of the various farms ranging from 0.00 to 0.11 and C.V. ranging from 0.0 to 11.8%. The overall mean of S.D. and C.V. for all measurements were 0.03 and 3.0%, respectively.

The results showed that 70% of the top layer of the irrigated soil had ECe values that ranged between 0 and 2 dS/m, 14% ranged between 2 and 4 dS/m and 16% had ECe values greater than 4 dS/m. Thus, 84% of these soil samples were non-saline according to U.S.A. classification system. The mean ECe values in the State varied in the following order: Khartoum N. > Omdurman > Khartoum (Table 2). This order was similar to that of the water samples.

The spatial variability of ECe was classified according to the U. S. salinity laboratory system and mapped using GIS (Fig. 4). The map clearly illustrates that Khartoum N. is dominated by high (2 - 4 dS/m) and very high (> 4 dS/m) top soils, whereas Khartoum and Omdurman are dominated by low salinity top soils. In general, this variation reflects the variability of the salinity water.

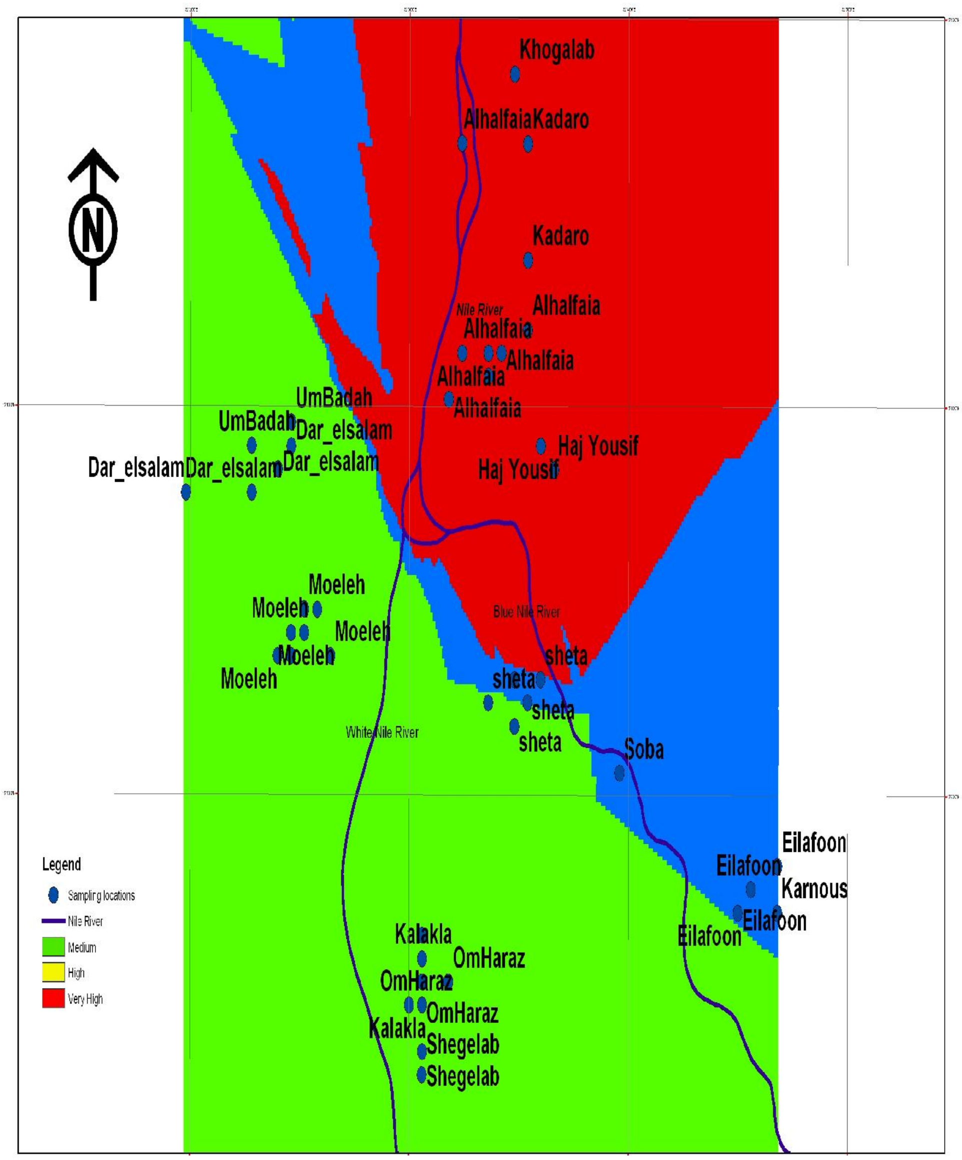

Fig 4. Spatial variability of ECe of soils irrigated with well waters in Khartoum State

Spatial distribution of cations

The mean Na^+ concentration of the saturation extracts of the irrigated soil samples ranged from 1.3 to 165.2 mmole$^+$/l with S.D. of replicate measurements of farms ranging from 0.00 to 0.60 mmole$^+$/l and C.V. ranging from 0.0 to 8.3%. The overall mean S.D. and C.V. were 0.15 and 1.8%, respectively. The spatial distribution of Na^+ in the State was in the following order: Khartoum > Khartoum N. > Omdurman (Table 2).

The mean $Ca^{++}+Mg^{++}$ concentration of the saturation extracts of the irrigated soil samples ranged from 1.8 to 69.3 mmole$^+$/l with S.D. of replicate measurements of farms ranging from 0.00 to 2.5 mmole$^+$/l and C.V. ranging from 0.0 to 20.2%. The overall mean S.D. and C.V. were 0.6 and 6.8%, respectively. The spatial distribution of Na^+ in the State was in the following order: Khartoum N. > Khartoum > Omdurman (Table 2).

Table 2. Spatial distribution of ECe (dS/m), SAR and some of the cations (mmole$^+$/l) of the irrigated and non-irrigated soil samples in three localities of Khartoum State

Locality	ECe	SAR	Na^+	$Ca^{++}+Mg^{++}$
		Irrigated		
Khartoum N..	4.2	11.4	26.6	14.6
Khartoum	1.1	13.7	18.2	6.1
Omdurman	1.3	4.7	6.9	6.2
Mean	2.4	9.8	18.2	9.5
		Non- irrigated		
Khartoum N..	5.4	8.1	27.2	25.3
Khartoum	4.1	12.3	28.4	13.9
Omdurman	3.4	4.4	13.7	20.2
Mean	4.4	8.2	23.5	20.2

Spatial distribution SAR of irrigated soils

The mean SAR values ranged from 0.8 to 96.0 with S.D. of replicate measurements of farms ranging from 0.00 to 9.8 mmole$^+$/l and C.V. ranging from 0.0 to 15.9%. The overall mean S.D. and C.V. were 0.6 and 4.3%, respectively. The spatial distribution of Na^+ in the State was in the following order: Khartoum > Khartoum N. > Omdurman (Table 2).

Non-irrigated soils

The detailed results of the soil analyses were presented elsewhere (Elsayed 2007). Only summary statistics are presented in this paper.

Spatial distribution of ECe

The mean electrical conductivity of the saturation extracts of the soil samples ranged from 0.6 to 29.7 dS/m with S.D. of replicate measurements of the various farms ranging from 0.00 to 0.20 dS/m and C.V. ranging from 0.0 to 7.9%. The overall mean of S.D. and C.V. for all measurements were 0.05 and 2.0%, respectively.

The results showed that 38% of the top layer of the irrigated soil had ECe values that ranged between 0 and 2 dS/m, 22% ranged between 2 and 4 dS/m and 40% had ECe values greater than 4 dS/m. Thus, 60% of these soil samples are non-saline according to U.S.A. classification system. The mean ECe values in the State varied in the following order: Khartoum N. > Khartoum > Omdurman (Table 2).

Spatial distribution of cations

The mean Na^+ concentration of the saturation extracts of the irrigated soil samples ranged from 1.3 to 165.2 mmole$^+$/l with S.D. of replicate measurements of farms ranging from 0.00 to 0.60 mmole$^+$/l and C.V. ranging from 0.0 to 8.3%. The overall mean S.D. and C.V. were 0.15 and 1.8%, respectively. The spatial distribution of Na^+ in the State was in the following order: Khartoum > Khartoum N. > Omdurman (Table 2).

The mean Ca^{++}+Mg^{++} concentration of the saturation extracts of the irrigated soil samples ranged from 2.0 to 143.7 mmole$^+$/l with S.D. of replicate measurements of farms ranging from 0.00 to 10.97 mmole$^+$/l and C.V. ranging from 0.0 to 28.3%. The overall mean S.D. and C.V. were 1.1 and 7.2%, respectively. The spatial distribution of Na^+ in the State was in the following order: Khartoum N. > Khartoum > Omdurman (Table 2).

Spatial distribution of SAR of non-irrigated soils

The mean SAR values ranged from 0.6 to 33.6 with S.D. of replicate measurements of farms ranging from 0.01 to 2.9 mmole$^+$/l and C.V. ranging from 0.6 to 13.4%. The overall mean S.D. and C.V. were 0.4 and 4.1%, respectively. The spatial distribution of Na^+ in the State was in the following order: Khartoum > Khartoum N. > Omdurman (Table 2).

Impact on irrigated soils

Comparison between irrigated and non-irrigated top soil samples indicated that thirty-four (68%) soil samples were leached, thirteen (26%) were salinized and three (6%) were not affected by irrigation with ground water. The salinized soils have the following texture classes: four clay, two clay loams, five sandy clay loams, one sandy clay and one sandy loam. The leached soils have all types of textures. Thus, the impact may be due to inappropriate soil water management. Use of medium to high salinity water is expected to enhance salinization in medium to heavy-textured soils under the prevalent dry conditions of Khartoum State (Mustafa 1984). The presence of a layer of low permeability may impede salt leaching and thus encourage salinization. Salt stress depresses crop yield by adverse osmotic effect, specific ion effects including nutritional imbalance and toxicity of specific ions to some crops and physical deterioration (Bernstein and Hayward 1958, Mustafa 2007).

An appropriate technological soil and water management package must be adopted to improve crop productivity in these farms. The package must include planting of salt-tolerant crops, more frequent irrigations and application of additional water for salt leaching (AbdelMagid *et al.* 1982, Mustafa and AbdelMagid 1982).

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تقويم نوعيه المياه الجوفية وتأثيرها على الترب المروية فى ولاية الخرطوم- السودان

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موجز البحث: أجريت دراسة لتقويم نوعية مياه الآبار وتأثيرها على الترب المروية فى خمسين مزرعة بمناطق مختلفة في ولاية الخرطوم . تم قياس مؤشرات نوعية المياه وخواص التربة ذات العلاقة باستخدام طرق قياسية . وشملت التقديرات التوصيل الكهربائى للماء (ECw) و لمستخلص عجينة التربة المشبعة (ECe) والأيونات الذائبة التالية: Na^+ و K^+ و Ca^{++} +Mg^{++} و Cl^- و HCO_3^- و SO_4. وحسبت نسبة الصوديوم المدمص (SAR)، وكربونات الصوديوم المتبقى (RSC)، والرقم الهيدروجينى النظرى (pHc)، ودليل تشبع "لانقلير" (LSI). وقد تم ملىء استبانة البيانات والمعلومات الخاصة بالمزارع المختلفة. ولقد تراوحت ECw بين 0.4 و 4.8 ديسيسيمن/م حسب تصنيف معمل الولايات المتحدة للملوحة وج د أن 30% من المياه متوسطة الملوحة و 62% عالية الملوحة و8% ذات ملوحة عالية جداً . و لقد وجدت علاقتا ارتباط خطيتان معنويتان بين ECw والتركيز الكلى للاملاح في الماء بالمليمول $^+$/ل أو بالمليجرام/ل مماثلتان لمعادلتى معمل الولايات المتحدة للملوحة ولهما معامل تقدير يساوى 99%. وجدت عينة لها SAR يساوى 19.1 وبقية العينات لها SAR تراوح بين 1.1 و 9.4. وكانت RSC

سالبة لكل عينات الماء فيما عدا عينتينن (4%)، كانت لهما RSC > 0.6 مليمول$^{+}$/ل ولذلك فى المستوى الآمن. وعموما اتفقت بيانات دليل تشبع "الانقلير " مع تلك ل RSC. ولقد سادت املاح $Na\text{-}Ca/Cl{=}SO_4$ فى عينات المياه. أوضحت النتائج أن 70% من الطبقات العليا للترب المروية لها ECe تراوح بين صفر و 2 ديسيسيمن/م، و 14% لها ECe تراوح بين 2 و ديسيسيمن/م و 16% لها ECe > 4 ديسيسيمن/م. دلت المقارنة بين الطبقات العليا للترب المروية وغير المروية على أن 34 (68%) منها قد تم غسيل بعض املاحها، و ثلاث عشرة عينة (26%) قد تملحت وثلاث عينات لم تتأثر بالرى لجوفية. واشتملت لتى تمّلحت على القوامات التالية: اربعة طين، وإثنان طين طمى، وخمسة طمى طينى رملى. كما اشتملت الترب التى غسلت على نفس نوع القوامات ، مما يدل على ان التملح نتج عن سوء ادارة التربة والماء في بعض أجزاء المزرعة.