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Suitability of Underground Water for Irrigated Agriculture in Some Parts of Botswana

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Abstract: The study was carried out to evaluate underground water quality of some parts of Botswana (Serowe, Molepolole, Tsabong 1, Tsabong 2 and Kanye 1 and Kanye 2) regarding its suitability for irrigation. Twenty four boreholes were sampled and the water was analysed for pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^-), carbonate (CO_3^{2-}) and chloride (Cl^-). Sodium Adsorption Ratio (SAR) was calculated. Tsabong water had significantly high TDS, EC, SAR, Na^+ and Cl^- compared to Serowe, Molepolole and Kanye and it was considered unsuitable for irrigation. Underground water from Molepole and Kanye 1 were found to be suitable for irrigation based on their TDS, EC, SAR, Na^+ and Cl^- contents. Kanye 2 water was not suitable for irrigation due to high EC and TDS.

Key words: Botswana, EC, irrigation, salinity, SAR, underground water

INTRODUCTION

Irrigation is important for successful crop production in semi-arid regions. The hot and dry climate of Botswana requires good quality irrigation water (low in soluble salts). Good quality water is usually not available in sufficient amounts. In determining water availability for irrigation, information is required on both its quality and quantity. It is quite common though to neglect the quality and concentrate on the quantity. Water quality should refer to how well a water supply fulfils the needs of its intended use. Given the prevailing conditions in Botswana, farmers are often forced to use bad quality water which contain high quantities of dissolved salts. Use of such waters leads to yield reductions and crop failures plus the formation of salt affected soils which are difficult and expensive to ameliorate[1,2]

Groundwater is an important source of water in Botswana, where surface water is relatively scarce. In some places, use of groundwater is limited due to the presence of high amounts of dissolved salts[1]. The quality of water for irrigation purposes is measured by such variables as pH, electrical conductivity (EC), total dissolved solids (TDS), the sodium adsorption ratio (SAR), bicarbonates and carbonates (HCO_3^- and CO_3^{2-}) and chlorides (Cl^-)[3,4]

The EC and TDS, measure the salt concentration in water and give an indication of how salts may affect crop water availability. The SAR is a ratio that provides an estimate of the relative amount of the Na^+ ion to the Ca^{2+} and Mg^{2+} ions according to the Eq. 1.

$$SAR = Na/[(Ca + Mg)/2]^{1/2} \quad (1)$$

$$SAR\text{-}adj = Na/[(Ca + Mg)/2]^{1/2} * (1 + (8.4\text{-}pHc) \quad (2)$$

Equation 2 takes into account the ability of the water to dissolve lime, where pHc is a pH of the irrigation water in contact with lime and in equilibrium with soil CO_2[3]. Poor quality irrigation water can cause soil salinity, reduce soil permeability and be toxic to some plants[5,6] .

The semi-arid nature of Botswana's climate which is characterised by low and unreliable rainfall, makes rainfed agriculture unprofitable. Irrigation could provide a solution in some areas, but there is shortage of good quality surface water, consequently, farmers are forced to use underground water for livestock and crop production. The quality of underground water for irrigation purposes from different parts of Botswana is not known. Therefore, the objective of this study was to evaluate underground water quality for irrigation purposes in different parts of Botswana.

MATERIALS AND METHODS

Underground water was sampled in Serowe, Molepolole, Tsabong (Tsabong 1 and 2), Kanye (Kanye

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1 and 2) as shown in Fig. 1. The water was sampled between June 2000 to July 2001. The sites were chosen to cover four agro-ecological zones of Botswana.

Tsabong 1 comprised of two boreholes in Tsabong town and one borehole each in the settlements of Segotlhola and Khubujagabojang. The boreholes in Tsabong 1 were located west of Tsabong, all within a radius of 50 km from the town centre. Tsabong 2 also had four boreholes, one in Bokspits, one in Magading and two in Khudungwane all located south of Tsabong. The boreholes in Tsabong 2 were within a 50 km radius from Tsabong town.

The Serowe boreholes were located around Setekwane settlement and were within a radius of 50 km from Serowe town.

The boreholes in Kanye 1 were located in Kgwakgwe, Ramonnedi, Matlhatsa and Kanye town , all within a radius of 20 km from the centre of Kanye town. Kanye 2 boreholes were located in Ramatlabama, Kanye dam (2 boreholes) and Mamokhasi dam, all within a radius of 50 km south of Kanye town centre.

In Molepolole, two of the boreholes were located in the Gaotlhobogwe valley. This valley is located about 10 km south of Molepolole town centre. One borehole was located in Newtown and one in Ratotoboro, all within the town of Molepolole. All the boreholes were within a radius of 20 km from the centre of Molepolole.

The experimental design was a completely randomised design with four replicates (boreholes). All water samples were analysed in triplicate at the Botswana College of Agriculture soil science laboratory. Water samples were drawn from the borehole by attaching a weight to the bottom of a sterilised polythene bottle. A string long enough for the depth of the specific borehole was attached to the neck of the polythene bottle. The opened bottle was slowly lowered into the borehole, making sure that it did not touch the sides and the bottom of the borehole. When full, the bottle was raised to the surface. Water samples were brought to the soil science laboratory at BCA and stored at 4°C and were analysed within 28 days of sampling.

The following chemical characteristics analysed were: pH, EC, Na^+, Ca^{2+}, Mg^{2+}, TDS and Cl^-. An electronic pH meter was used to measure the pH of the samples after calibrating with buffer solutions of pH 4, 7 and 9. A conductivity meter model EDT Instrument BA 380 measured the EC. A flame-photometer model Corning 410 was used for determining Na. An Atomic Absorption Spectrophotometer (AAS), Varian AA10, measured Ca and Mg. Chlorides were determined by titrimetry using the silver nitrate and potassium dichromate method. The total dissolved solids were analysed by the filtration and

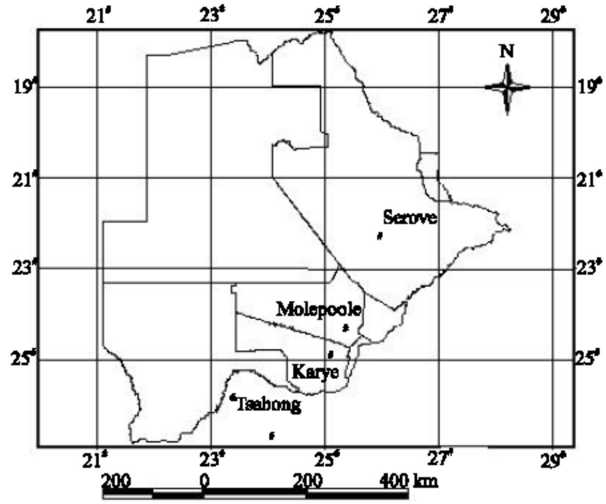

Fig. 1: Map of Botswana showing the towns around which the boreholes were located

evaporation method. The SAR was calculated according to the following equation:

$$SAR = Na/[(Ca + Mg)/2]^{1/2} * (1 + (8.4\text{-}pHc)$$

Analysis of Variance was performed on the data using the general linear models (PROC GLM) procedure of the Statistical Analysis System (SAS) (2003) program package. Treatment means were separated using the Least Significant Difference (LSD) method at $p = 0.05$.

RESULTS AND DISCUSSION

Underground water from Tsabong 1 had the highest EC, TDS, SAR compared to underground water from Serowe, Molepolole and Kanye (Table 1). The EC of underground water from Tsabong 1 was significantly higher than that of Tsabong 2, Serowe, Molepolole, Kanye 1 and Kanye 2. There were no significant differences among ECs of Serowe, Molepolole, Tsabong 2, Kanye 1 and Kanye 2, though Kanye 2 water had relatively high EC (12 dS m^{-1}). The TDS values followed a similar trend to the EC.

The difference in the EC and TDS of the different sites could be due to variation in the types of minerals which are found in the soils and hence in the water in the different areas. The Tsabong area, which is part of the Sandveld is characterised by deep sands. Such soils are usually highly leached as a result of their excessive drainage. The difference in EC and TDS can also be attributed to the low rainfall and high temperature. Low rainfall together with high temperatures leads to the

Table 1: Variation of EC, TDS and SAR among the different sites

Site	EC (dS m^{-1})	TDS (mg L^{-1})	SAR (mmol $L^{-1})^{1/2}$
FAO recommendation	< 3.0	< 2000	< 24
Serowe	0.56b	364b	7.23bc
Molepolole	0.79b	497b	1.37c
Tsabong 1	34.91a	24615a	61.98a
Tsabong 2	9.61b	3073b	25.06b
Kanye 1	0.64b	590c	0.60c
Kanye 2	12.00b	287b	0.80c
Significance	*	**	****
LSD	20.58	13783	21.06

*, **, **** significant at p=0.05, 0.01 and 0.0001, respectively. Means within columns followed by the same letter(s) are not significantly different

Table 2: Variation of pH, bicarbonate, carbonate and chloride ions among the different sites

Site	pH	HCO_3^- (cmol kg^{-1})	CO_3^{2-} (cmol kg^{-1})	Cl^- (cmol kg^{-1})
FAO recommendation	6.5-8.4	< 8.5	None	< 10
Serowe	7.98ab	3.52a	0.57a	1.8b
Molepolole	7.35ab	5.58a	0.44ab	1.8b
Tsabong 1	7.56ab	3.02a	0.00b	520.0a
Tsabong 2	7.26b	3.52a	0.00b	36.13b
Kanye 1	7.30ab	5.99a	0.19ab	0.90b
Kanye 2	8.43a	2.85a	0.55a	0.8b
Significance	*	ns	*	**
LSD	1.16	3.55	0.52	298.8

*, **, ns significant at p=0.05, 0.01 and not significant respectively. Means within columns followed by the same letter(s) are not significantly different

Table 3: Average annual rainfall, mean maximum temperature and potential evapo-transpiration rates for the study sites

Location	Average annual rainfall (mm) (65 year averages)	Evapotranspiration rates (mm) (40 year averages)
Serowe	455.5	1550
Molepolole	495.1	1654
Kanye	516.6	1781
Tsabong	290.4	1806

Source: Bhalotra[11,12]

concentration of salts in both in the soil and the underground water because water movement is upwards in response to high evapo-transpiration rates. From Table 3, it is evident that rainfall in Tsabong area is relatively low while temperatures and the potential evapo-transpiration rates are much higher. Because of the low rainfall, the aquifers are not charged regularly, concentration of salts arise, leading to high EC and TDS. The lower ECs and TDS from the other areas could be a direct reflection of the aquifer recharges since they receive higher rainfall amounts and evapo-transpiration rates are lower. The mineral content of groundwater is also known to vary with location[7]. In the present study, there were large variations in EC and TDS within the same location, suggesting differences in acquifers and underlying rocks within a location. This therefore, suggests that although rainfall or lack of it could be a major contributor to the quality of underground water, it may not be the only one. Tsabong (1 and 2) water was not suitable for use in irrigated agriculture for most crops due to its salinity[3]. EC values greater than 3 dS m^{-1} and/or TDS greater than 2000 mg L^{-1} cause severe salinity problems for crops[3]. Irrigation water with an EC of less than 0.7 dS m^{-1} is considered safe and suitable for use on most soils and agricultural crops while irrigation water with an EC range of 0.7 to 3 dS m^{-1} may cause slight to moderate salinity problems[3]. The salinity hazard of water is directly related to the quantity of salts dissolved in it. All irrigation water contains potentially injurious salts and nearly all the dissolved salts are left in the soil after the applied water is lost by evaporation from the soil or through transpiration by plants[8]. In semi-arid to arid places such as Botswana where the evapo-transpiration rate is much higher than precipitation (Table 3), this problem is more pronounced. Salts accumulate in the root zone of plants and besides being toxic to plants, the salts resist the capability of plants to extract sufficient water from the soil.

Tsabong 1 underground water had a significantly higher SAR value than Tsabong 2, Serowe, Molepolole, Kanye 1 and Kanye 2 (Table 1). Tsabong 2 underground water had a significantly higher SAR value than Serowe, Molepolole, Kanye 1 and Kanye 2 (Table 1). High SAR values reflect the high concentration of the Na^+ ion relative to that of Ca^{2+} and Mg^{2+}. In Tsabong, the high SAR values could be due to the mineralogy of the area. The surface and groundwater in contact with the underlying rock is known to easily attain high salts[9]. The high SAR could also be due to the low rainfall and high temperature conditions of the area. Water with a SAR of >24 $(mmol)^{1/2}$ is not suitable for irrigation because it will cause permeability problems[3]. High SAR values causes clay dispersion, leading to slaking of soil aggregates and hence the collapse of soil structure[10]. A combination of EC of > 0.5 dS m^{-1} and SAR of < 16 $(mmol)^{1/2}$ is suitable for irrigation while 0.5-0.2 dSm^{-1} and 16-24 $(mmol)^{1/2}$ will pose slight to moderate problems and < 0.2 dS m^{-1} and >24 $(mmol)^{1/2}$ will cause severe problems[3]. Following this classification, Serowe underground water is moderately suitable for irrigation, Molepolole and Kanye 1 have suitable water, while Kanye 2 is moderately suitable. High SAR values translate into high Na^+ ion concentration. The danger with a high Na^+ concentration in irrigation water is that in soils containing high amounts of colloidal materials, Na^+ ion will occupy most of the exchange sites. Soils that have high exchangeable Na^+ slake and have generally poor physical properties.

There were no significant differences in the pH of underground water from Serowe, Molepolole, Tsabong 1 and Kanye 1 (Table 2). The pH of underground water at Kanye 2 was significantly different from that of Tsabong 2 (Table 2). There were no significant differences among the HCO_3^- concentration at the sites under study. Serowe and Kanye 2 ground water contained relatively high HCO_3^- than ground water from Tsabong (Table 2). Tsabong water contained no carbonates.

Specific solutes affect the quality of irrigation water by being toxic and affecting the nutritional balance of the crop. High concentration of chloride ions in irrigation water causes leaf burn and defoliation. Tsabong 1 and 2 ground water contained more than 10 meq L^{-1} of the Cl^- ion (Table 2), which can cause problems of toxicity[3]. Ground water from Serowe, Molepolole and Kanye did not contain toxic amounts of the Cl^- ions.

In conclusion, the underground water from the Serowe, Molepolole, Tsabong and Kanye regions of Botswana differed significantly in their physico-chemical properties. The underground water from the sampled boreholes in Tsabong (1 and 2) and Kanye 2 was found to be not suitable for irrigation while underground water from Molepolole and Kanye 1 was found to be suitable for irrigation purposes.

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