Monitoring of Groundwater Quality for Small-scale Irrigation: Case Studies in the Southwest Sokoto-Rima Basin, Nigeria.

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ABSTRACT

Ground water from open-wells, tube-wells and boreholes were investigated to ascertain the current quality status and suitability for irrigation in the floodplains (*Fadama* lands) of the southwestern Sokoto-Rima basin in northern Nigeria. The water samples were slightly acid with pH values ranging from 5.7 to 6.1. In terms of salinity hazards measured as electrical conductivity (Ecw) and total dissolved solids (TDS), the water samples had very low salinity (Ecw 48-607 $uS.m^{-1}$, TDS 38-486$mg.l^{-1}$) with the exception of the tube-well samples from site C (Birnin Kebbi) with moderate salinity (Ecw 822 $uS.m^{-1}$ and TDS 657 $mg.l^{-1}$). With respect to sodicity hazards, the sodium adsorption ratio (SAR) values obtained for all the samples ranged from 0.2 to 1.4. This indicates a low risk of sodium buildup in the soils. However, irrigation water of very low salinity (<200$uS.m^{-1}$) and low SAR can lead to problems of water infiltration into the soils. The nitrate concentration in most of the samples was quite high ranging from 4.5 to >50$mg.l^{-1}$, possibly as a result of excess applications and leaching of nitrogen fertilizers.

Keywords: Groundwater quality, small-scale irrigation, management

1. INTRODUCTION

Irrigation has been practiced since antiquity. Unfortunately, the problems that contributed to the demise of several ancient civilizations are still present today (Graham *et al.* 2003a). According to El-Ashry (1993), 18 percent of the world's agricultural land is irrigated but it produces 33 percent of the total harvest. According to Rhoades (1993), it is of relatively recent recognition that salinization of water resources is a major and widespread phenomenon of possibly even greater concern to the sustainability of irrigation than is that of the salinization of soils, per se.

Although irrigation is useful for sustaining/increasing agricultural production, it is imperative that good quality water be used (Singh, 2000). Regardless of its source, soluble salts are always dissolved in irrigation water, which could affect the physical and chemical properties of soils (Landon, 1991).
The Sokoto and Rima rivers drain an area of 92,250 km^2, approximately 2% of the land area of Nigeria (Figure 1). The Sokoto-Rima Basin (SRB) lies roughly between latitudes 4° to 7°E and longitudes 11° to 14° N. Most large-scale irrigation projects within the basin such as the Bakolori, Goronyo and Wurno Irrigation Projects have deteriorated badly due to poor management, which has lead to salinity/sodicity development, soil erosion etc (Graham and Singh, 1997a; Graham and Singh, 1997b; Graham, 2000; Graham *et al.* 2003a). For example, less than 8,000ha of the 23,000ha Bakolori Irrigation Project is currently under irrigation (Graham and Singh, 1997b; Graham *et al.* 2003a). This

has lead to the emphasis currently being placed on small-scale *fadama* irrigation within the SRB. *Fadama* is a Hausa word which refers to low lying, relatively flat areas either in streamless depressions or adjacent to seasonally or perennially flowing streams (Kolawole and Scoones, 1994). They have been classified as Eutric/Dystric Fluvisols (FAO, 1990) by FDALR (1990). *Fadama* lands are more productive and have a greater agricultural potential than the surrounding uplands. They are also strikingly different from the uplands in their ecology and microclimate (Singh, 1999). They have a wide variety of medium to fine-textured soils with reasonably good hydraulic properties, which provide the farmers with a range of soil resource options suitable for different types of crops (Singh and Yacouba, 1998; Graham 2000). Groundwater tables in the *fadama* lands are usually close to the surface thereby making them easily exploitable for irrigation through open-wells and shallow tube-wells. The *fadama* lands support wet season rice production and a host of high value horticultural crops in the dry season through flood recession and irrigated agriculture. However, the high groundwater table and semi-arid weather conditions make the *fadama* soils prone to salinity/sodicity development (Singh, 1999). Regular monitoring of groundwater quality in the *fadama* lands is therefore imperative in order to detect any changes in quality so that changes in management can be planned. The objectives of this paper are to assess the present status of groundwater quality in the southwest Sokoto-Rima basin and then to suggest appropriate management strategies.

2. MATERIALS AND METHODS

The area of this study lies approximately within longitude 10° 45’ to 12° 30’N and latitude $5^0$00’ to 6° 30’E (Figure 1). Based on a climatic classification by Papadakis (1961), the basin has a Semi-arid Equatorial Tropical climate (Ojo, 1977). This consists of a long dry (October-May) and a short wet (June-September) season. Some characteristics of the sites chosen for the case studies are given in Table1. Some properties of the soils in the same areas are presented in Table 2.

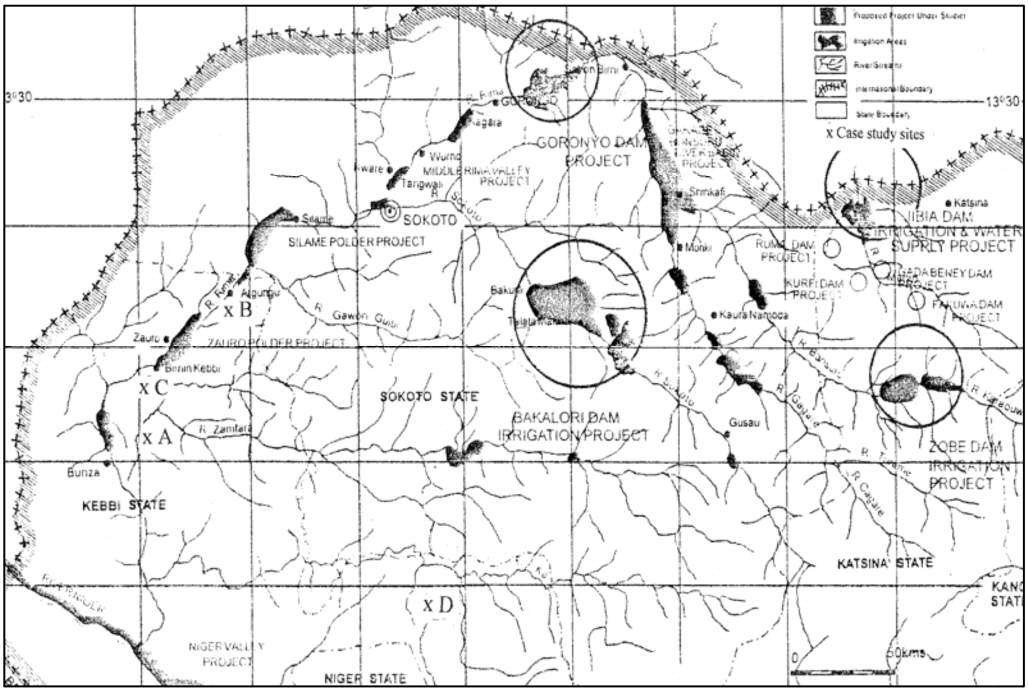

Figure 1. Map of the sokoto-rima basin indicating case study sites

2.1 Groundwater Sampling Methods

Four sites were selected for sample collection, Jega (A) (4^o23'E, 12^o15'N), Argungu (B) (4^o31'E, 12^o40'N) Birnin Kebbi (C) (4^o12E 12^o32N') and Zuru (D) (5^o12'E, 11^o27'N) (Figure 1). In each case study site, open-well, tube-well and borehole water samples were collected in replicate from ten different sites located at least 1000m from each other.

Table 1. Characteristics of the study area

Characteristic	Site A-C	Site D
Mean annual rainfall	700	1000
Rainfall range	534-941	612-1069
Temperature		
Minimum	26-42	34-39
Maximum	12-18	15-30
Bioclimate	Sudan Savanna	Northern Guinea Savanna
Physiognomy	Shrub woodland	Open savanna woodland
Geology	Sedimentary rocks	Basement complex rocks

Source: Graham (2004)

Table 2. Some properties of the *fadama* soils in the study sites.

Site	Texture	pH	O.C.	T.N.	Ca	Mg	K	Na	CEC	ESP
A	LS-CL	5.3-6.8	0.2-0.6	0.16-0.47	1.8-5.3	1.6-7.3	0.1-0.5	0.1-0.2	4.0-31.0	0.6-5.0
A1	LS-SL	4.2-5.1	0.1-0.5	0.02-.0.09	0.6-6.3	0.2-1.8	0.1-0.5	0.3-1.0	0.4-2.0	6.2-33.3
B	LS-SL	4.8-6.9	0.2-1.4	0.01-0.002	1.8-4.6	2.3-8.1	0.1-2.5	0.2-1.5	5.0-26.4	1.4-22.4
B1	L-CL	4.6-6.0	0.2-0.3	0.02-0.04	0.6-1.3	0.2-0.3	0.1-0.2	0.5-0.9	1.9-2.9	14.0-35.0
C		6.1-6.4	0.6-1.9	0.01-0.002	1.8	2.2-4.9	0.1-0.2	0.2	1.8-5.0	4.0-11.1
C1		5.1-7.1	0.3-1.1	0.02-0.04	0.6-1.3	0.2-0.3	0.1-0.2	0.5-0.9	1.9-2.9	14.0-35.0
D		4.6-8.4	0.1-2.3	0.001-0.65	0.9-5.6	1.8-3.2	0.1-2.5	0.1-13.8	1.0-8.4	0.4-5.6
D1		4.2-6.1	0.5-1.4	0.01-0.09	0.6-4.8	1.0-2.1	0.1-0.4	0.5-1.3	0.1-2.4	5.0-26.0

Note: Organic carbon (O.C.) and total nitrogen (T.N.) are in percentage while exchangeable cations and CEC are presented in cmol (+) kg^{-1}. LS = loamy sand, SL = sandy loam, L = loam and
CL = clay loam.
Sources: A, B, C and D (Singh, 1999), A1, B1, C1 and D1 (Kebbi Agricultural and Rural Development Authority unpublished data 2005).

2.2 Analytical Methods

Groundwater samples were analyzed for the parameters included in Tables 4 to 6. Briefly, pH and electrical conductivity (Ecw) were read at 25^0 C with conductivity and pH meters, respectively. Total Dissolved Solids (TDS) was determined by the Evaporation-Drying Method. Sodium and K and Ca and Mg were determined using Flame Photometry and

Atomic Absorption Photometry, respectively. Nitrate was estimated by Colorimetry using phenol-disulfonic acid after removing NO_2 with sulfuric acid. Chloride was determined by titration against $AgNO_3$ with potassium dichromate as the indicator after neutralizing with $CaCO_3$. Sulfate was analyzed using the Gravimetric technique by precipitating barium sulfate in an acidified solution. Carbonate was determined by titration with 0.1M HCl while bicarbonate was estimated by titration to pH 4.5 with 0.1M HCl. These methods have been described in detail in FAO (1984). In addition, the sodium adsorption ratio (SAR) was calculated using the equation:

$$\mathrm{SAR} = \frac{Na^{+}}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}}$$

3. RESULTS AND DISCUSSION

Table 3 reports the pH, electrical conductivity (Ec), total dissolved solids and SAR results obtained in analysis of the water samples. The waters tended to be slightly acid with pH values falling within the narrow range of 5.7 to 6.1, which is below the normal range in irrigation water given by Ayers and Westcot (1985) and Landon (1991) as 6.5 to 8.4. The greatest direct hazard of an abnormal pH in water is the impact on irrigation equipment. As with any acid material, the low pH may cause damage to pipelines, sprinklers and other equipment. Abnormal pH in irrigation water may also cause nutrient imbalances and such waters may contain a toxic ion (Ayers and Westcot, 1985). Treatment of the water would be expensive and impractical. Irrigation management in this situation would involve careful choice of equipment and crop type/variety. This is particularly important with respect to borehole water used to irrigate orchards in the study area.

As indicated in Table 3, Ecw and TDS values varied widely. However, the salinity levels were generally low (Ecw 204-607, 88-822, and 87-188 $uS.m^{-1}$ and TDS 164-486, 71-657 and 38-201 $mg.l^{-1}$ for open-wells, tube-wells, and boreholes, respectively). The water samples collected from the tube-wells in B and D and the boreholes in B and C indicate severe restrictions in their use for irrigation due to Ecw values that might affect the soil infiltration rate. Low salinity water tends to leach surface soils free of soluble minerals and salts, especially calcium, reducing their strong stabilising influence on soil aggregates and soil structure. Without salts and without calcium, the soil disperses and the dispersed finer soil particles fill many of the smaller pore spaces, sealing the surface and greatly reducing the rate at which water infiltrates the soil surface. In fact, very low salinity water (<200 $uS.m^{-1}$) almost invariably results in water infiltration problems, regardless of the relative sodium ratio (Ayers and Westcot, 1985).

Table 3. pH, Ecw, TDS and SAR obtained for the water samples

SAMPLE/ LOCATION	PH	Ecw ($uS.cm^{-1}$)	TDS ($mg.l^{-1}$)	SAR
OPEN-WELL				
A	6.1a	607a	486a	1.1
B	5.7b	476b	380b	1.2
C	6.0a	204d	164d	0.8
D	5.9a	255c	203c	1.3
Standard Deviation	0.14	171	137	0.32
Coefficient of Variation (%)	2.3	44.4	44.3	29
F-LSD (0.05)	0.13	2.88	1.34	ns
TUBE-WELL				
A	5.9	244b	195b	1.6a
B	5.8	88d	71d	0.8c
C	5.8	822a	657a	1.4b
D	6	93c	75c	0.46d
Standard Deviation	0.12	314	251	0.49
Coefficient of Variation (%)	2.1	100	100	44.9
F-LSD (0.05)	ns	2.1	1.3	0.08
BOREHOLE				
A	5.8	188b	152b	1.2c
B	5.9	87c	70c	0.3c
C	6.0	48d	38d	0.2d
D	6.0	251a	201a	1.0b
Standard Deviation	0.14	84.00	68.00	0.44
Coefficient of Variation (%)	2.3	58.6	58.6	63.9
F-LSD (0.05)	ns	1.9	0.89	0.06

Note: mean values followed similar letters are statistically similar, ns = not significant

All the waters samples had very low levels of SAR with a range of 0.2-1.6, and would generally not pose any hazards with respect to Na build up in the soils. However, irrigation water with SAR 0-3 and Ecw<200 $uS.m^{-1}$, as is the case with the tube-well waters in site B (Ecw 88 $uS.m^{-1}$ and SAR 0.8) and D (Ecw 93 $uS.m^{-1}$ and SAR 0.46) and the borehole waters in A (Ecw 188 $uS.m^{-1}$ and SAR 1.2), B (Ecw 87 $uS.m^{-1}$ and SAR 1.2) and C (Ecw 48 $uS.m^{-1}$ and SAR 0.2) would pose severe restrictions to their use for irrigation due to their effect on soil infiltration rates. When such water is used for irrigation infiltration problems due to soil dispersion, plugging and sealing of the surface pores would occur and as a result problems such as soil crusting, poor seedling emergence, lack of aeration and plant/root diseases may further complicate crop management. If the soils become waterlogged and temporarily flooded due to the low infiltration rate for even short periods of a few days, much of the nitrate-nitrogen present may be quickly denitrified and lost from the soil to the atmosphere as N_2 gas due to poor aeration (Ayers and Westcot, 1985). Effective management of irrigated soils with infiltration problems include: applications of gypsum, which is available in the study area; cultivation and deep tillage; application of organic residues; more frequent irrigation and pre-plant irrigation.

The cationic concentrations in the waters sampled are presented in Table 4. The respective ranges for Na^+, K^+, Ca^{2+} and Mg^{2+} (in mg.l^{-1}) were 1.4-4.0, 0.3-4.0, 2.5-7.2 and 2.8-11.3 for the open-wells, 0.8-5.1, 0.2-8.1, 0.8-9.5 and 1.2-7.5 for the tube-wells, and 0.3-2.7, 0.2-1.5, 1.4-6.2 and 1.2-3.7 for the boreholes. Calcium and Mg were the predominant cations. The Ca: Mg and Ca: Total cations (TC) ranged respectively, from 0.51-0.88 and 0.26-0.32 for the open-wells, 0.41-1.28 and 0.1-0.4 for the tube-wells and 0.83-1.36 and 0.30-0.42 for the boreholes. With the exception of the tube-well waters from site C and the borehole waters from C and D, all the Ca: Mg values fell below 1. In a magnesium-dominated water (ratio of Ca: Mg < 1), the potential effect of sodium may be slightly increased (Ayers and Westcot, 1985). Research findings show that at a given SAR of the applied water, a higher soil ESP than normal will result when using water with a Ca: Mg ratio less than 1 (Rahman and Rowell 1979). This might explain the rather high ESP levels in reported in Table 2 even though the water used for irrigation has low SAR values. In fact Table 2 shows a significant increase in the soil ESP levels over a period of five years.

Table 4. Cationic concentrations (in mg.l^{-1}) obtained for the water samples

SAMPLE/ LOCATION	Na	K	Ca	Mg	Ca: Mg	Ca: T.C.
OPEN-WELL						
A	4.0a	4.0a	7.2a	11.3	0.64c	0.27b
B	3.8b	0.9c	5.9b	11.2	0.74b	0.32a
C	1.4d	3.3b	2.5d	2.8	0.88a	0.27b
D	2.5c	0.3d	3.3c	6.4	0.51d	0.26c
Standard Deviation	1.1	1.5	2.0	3.2	0.15	0.02
Coefficient of Variation (%)	36.8	80.0	42.2	44.5	30.0	8.5
F-LSD (0.05)	0.21	0.08	0.17	ns	0.04	0.01
TUBE-WELL						
A	2.1b	1.1b	0.8d	1.9c	0.41d	0.1c
B	1.3c	0.2c	1.3c	1.2d	0.59c	0.3b
C	5.1a	8.1a	9.5a	7.5a	1.28a	0.3b
D	0.8d	0.2c	2.1b	2.2b	0.96b	0.4a
Standard Deviation	1.8	3.4	3.7	2.4	0.35	0.10
Coefficient of Variation (%)	75.0	142.0	108.0	70.5	43.6	36.5
F-LSD (0.05)	0.14	0.14	0.2	0.17	0.11	0.03
BOREHOLE						
A	2.5b	0.6b	2.7c	3.3	0.83c	0.30b
B	1.1c	0.2d	6.2a	1.2	0.83c	0.42a
C	0.3d	0.3c	1.4b	1.3	1.08b	0.42a
D	2.7a	1.5a	5.0d	3.7	1.36a	0.42a
Standard Deviation	1.04	0.16	1.99	2.36	0.23	0.06
Coefficient of Variation (%)	63.0	39.6	52.0	60.0	22.7	14.2
F-LSD (0.05)	0.15	0.02	0.15	ns	0.09	0.01

Note: mean values followed similar letters are statistically similar, ns = not significant

The anionic concentrations of the waters sampled are presented in Table 5. Available literature suggests that irrigation waters with (in mg.l^{-1}) 5 NO_3^-, 300, 960 SO_4^{2-}, 4 Cl^-, 3 CO_3^{2-} and HCO_3^- are considered safe for irrigation (Ayers and Wescot, 1985; Landon, 1991). The mean SO_4^{2-}, Cl^-, CO_3^{2-} and HCO_3^-, values for all samples fell within the safe limits, respectively ranging from (in mg.l^{-1}) 5.5-23.5, 1.9-3.7, 0.00-6.0 and 5.4-12.2 for the open-wells, 6.4-87.9, 2.0-3.5, 0.0-3.0 and 4.1-24.0 for the tube-wells and 3.8-19.5, 1.6-3.7, 0.0-3.5 and 8.5-10.9 for the boreholes. Of most concern however, is their nitrate content. Only borehole water from site A fell within the safe limits for irrigation. The other samples gave results ranging from 5 to in excess of 50mg.l^{-1}. In fact tube-well waters from D gave rather excessive (mean 52.8 mg.l^{-1}) nitrate values. This may be attributed to excess applications of nitrogen and the leaching of these fertilisers down the soil profile. Nitrogen in the irrigation water has much the same effect as soil-applied fertilizer nitrogen. In excess it may lead to the over-stimulation of crop growth, delayed maturity and poor quality of harvest. Its effect on irrigation canals through excess growth of algae and aquatic plants is however, irrelevant in this situation, as small-scale *fadama* irrigation does not involve the use of canals. The high nitrate content of the groundwater do not seem to have influenced the nitrogen content of the soils as indicated in Table 2. This apparently means that most of the applied nitrogen is leached out of the root zone. With effective soil management, the farmers can make use of this unusual fertilizer source. This can be done through prudent water management, mulching and applications of organic matter.

Table 5. Anionic concentrations (in mg.l^{-1}) obtained for the water samples

SAMPLES /LOCATION	NO_3	SO_4	Cl	CO_3	HCO_3
OPEN-WELL					
A	12.2	23.5	3.7a	4.4b	6.4a
B	6.4	11.2	1.9d	0.0c	8.3b
C	8.9	5.5	2.3c	0.0c	5.4d
D	10.2	16.8	2.7b	6.0a	12.2a
Standard Deviation	2.21	7.57	0.70	2.76	2.71
Coefficient of Variation (%)	23.5	56.4	26.3	107.0	33.6
F-LSD (0.05)	ns	ns	0.19	0.15	0.27
TUBE-WELL					
A	8.3c	6.4b	3.5a	1.2c	13.3b
B	5.3d	6.4b	2.0d	0.0d	24.0a
C	13.8b	10.3b	2.3c	3.0a	5.3c
D	52.8a	87.9a	2.8b	1.7b	4.1d
Standard Deviation	20.0	36.3	0.58	1.13	8.31
Coefficient of Variation (%)	100.0	131.0	21.8	76.4	71.0
F-LSD (0.05)	0.31	6.00	0.22	0.13	0.23
BOREHOLE					
A	4.5	3.8	3.7a	2.1b	10.9a
B	6.3	18.3	1.7c	0.0c	8.5c
C	5.5	7.7	1.6c	0.0c	10.3b
D	11.3	19.5	2.1b	3.5a	10.4b
Standard Deviation	2.80	6.99	0.91	1.56	0.97
Coefficient of Variation (%)	41.2	56.8	40.0	110.4	9.7
F-LSD (0.05)	ns	ns	0.20	0.11	0.24

Note: mean values followed similar letters are statistically similar, ns = not significant

4. CONCLUSION

Generally, analysis of the groundwater samples showed that they were slightly acid (pH 5.7-6.0), and appears not to have salinity and sodicity hazards (Ecw 48-822 uScm^{-1} and SAR 0.2-1.6). However, due to their low salinity and sodicity, problems with respect to water infiltration into the soils present itself. Their Ca: Mg ratios were generally less than 1 and continued use of such waters for irrigation might lead to nutrient imbalances in the soils. This may also be the cause of the rather high ESP levels reported for the soils. Applications of organic matter and gypsum and deep tillage may ameliorate the effects of high soil ESP. Furthermore; the waters sampled showed rather high nitrate contents. One may speculate that is as a result of excess fertiliser applications. With efficient soil management, such as proper water management mulching and applications of organic materials, the farmers can make use of the irrigation water as a nitrogen fertilizer source.

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6. ACKNOWLEDGEMENT

The authors would like to acknowledge the contributions of D. Manu and A.A. Jega, final year (2004/05) Higher National Diploma students of the Department of Agricultural Engineering, Waziri Umar Polytechnic, Birnin Kebbi, Nigeria in sample collection.