Evaluation of chloride mass balance and recharge in agricultural lands in Nigeria

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Abstract: Groundwater salinization studies and recharge estimation were carried out at the Irrigation Research Station, Kadawa, Nigeria. Groundwater samples from fifteen randomly selected piezometer locations were analyzed monthly for chloride using Mohr's method for three years while recharge was estimated using the chloride mass balance (CMB) method. Groundwater chloride range from 22 - 91.4 mg/L, seasonal trend was identified with the hot dry season (April – June) having higher values than the wet season (July – October). Correlation analysis revealed chloride status that is not associated with one another in all soil types while salt build up was observed at the south western tip of the farmland indicating potential reduction of agricultural productivity. CMB revealed a mean annual recharge of 869 mm; the method was found to underestimate recharge because it does not account for lateral flow contribution, hence should be discouraged as a stand-alone methodology for recharge studies. Salt build-up was exacerbated by the collapse of the drainage system. Reconstruction of the drainage systems using tile drains should be executed to control the rising water level in the area; conjunctive use of groundwater and surface water is recommended to maximally utilize available water in order to ensure ecological sustainability and free some water for other uses.

Keywords: irrigation, groundwater, chloride mass, recharge, water management, salinity

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1 Introduction

One of the problems of irrigated agriculture in arid and semi-arid regions is that of salt build up among others (Singh and Panda, 2012). A well designed irrigation scheme should have an accompanying land drainage system to ensure that excess water is not allowed to remain on the land after successive water application.As water level rises on a farmland, dissolved salts in the water move by capillary actionto the shallow subsurface, and when the water evaporates, salts areleft behind, causing degradation of the soil (Han, et al., 2011).All irrigation waterbrings salts even when the water is of good quality.

Literatures show that when irrigated landsare insufficiently drained, saltsespecially sodium chloride accumulates in the root zone (Chaniho, et al., 2010;Forkutsa et al.,2009; Russeniello et al.,2013; Sayel and Barlas, 2001; Velstra and De Jong, 2011).Heuperman et al. (2002) reports that more than 33%of the world's irrigated land is affected by secondarysalinisation and/or waterlogging; soil salinity refers to the presence of high concentrations of soluble saltsin the soil moisture of the root zone. These concentrations of soluble salts,through their high osmotic pressures, affect plant growth by restricting theuptake of water by the roots, butsensitivity to high osmotic pressures varies widely among plants species depending also on environmental conditions.Salinity can also affect plant growth because the high concentration of saltsin the soil solution

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interferes with a balanced absorption of essential nutrinets by the plants.

One of the problems identified in many public irrigation schemes in Nigeria is the collapsed infrastructure among others, especially the land drainage structures leading to serious waterlogging problems. This scenario is caused by institutional neglect as a result of dwindling funds for maintenance and adequate irrigation water management by the numerous government controlled river basin organizations. Semi-arid regions in Nigeria need irrigated agriculture to ensure food security and as an adaptation to climate change caused by reduction in rainfall amounts; the wet season in these areas is now limited to about four months in the year, annual rainfall is low in amount (350 mm – 780 mm), erratic and poorly distributed (Sobowale et al., 2010).The response of the government to these environmental challenges was massive investment in irrigation development in the region in the 1970s and 1980s; however, the investment was not matched with adequate funds for operation and maintenance of facilities and adequate institutional management strategy. The resultant effect in some of the irrigation schemes was low crop yield; increased waterlogging and salt build up.

The chloride mass balance (CMB) approach of estimating groundwater recharge is an inexpensive method which draws impetus from the fact that chloride is a stable environmental tracer and originates from precipitation and dry fallout as aerosol, it is transported into the subsurface with infiltrating water (Wood, 1999).Chloride concentrations in unsaturated and saturated zone pore water have been found to be inversely related to recharge (Gee, etal, 2005; Somaratne and Smetten,2014).High chloride concentrations in groundwater indicate low recharge rates because chloride accumulates in the subsurface as a result of evapotranspiration whereas low chloride concentrations indicate high recharge rates because chloride is flushed through the subsurface. Water fluxes and ages of pore water can be estimated using the CMB approach in which the mass of Cl into the system (precipitation and dry fallout) times the Cl concentration in precipitation and dry fallout is balanced by the mass out of the system (recharge) times the Cl concentration in recharge water in the unsaturated zone. The age of the pore water can also be estimated by dividing the cumulative mass of Cl from the surface to the depth of interest by the Cl input to the system (Bazuhair and Wood, 1996).In Sub – Saharan Africa (SSA), long term groundwater chloride data are rarely available, monitoring is usually done when needed; this makes analysis very problematic and prone to errors. Ideally, CMB method is best suited for application in areas with a minimum of data ranges of 5 – > 10,000 years (Beekman and Xu, 2003). With this limitation, it will be practically impossible to apply the method in SSA especially in Nigeria where the need to manage water sustainably has become an imperative in the face of the looming water scarcity in the semi – arid parts of the country.

The objective of this research was to evaluate groundwater salinization and recharge to groundwater at the Irrigation Research Station within the Kano River Irrigation project (KRIP) using chloride mass balance method and GIS techniques. Estimating the level of salinization and groundwater recharge in irrigated farmland is very important to ensure sustainability of the project and the ecosystem; these will enable the development of conjunctive use of surface water and groundwater. The results will provide a decision support for irrigation water management and ecological sustainability in the area.

2 Materials and methods

2.1 Study location

The Irrigation Research Station, Kadawa is part of the Kano River Irrigation Project (KRIP) which was proposed to cover an estimated area of 620 km^2 (62, 000 ha). Itis located about 47 km south of Kano between longitudes 8^{o}25.45^1 and 8^{o}26.15^1 E. and latitudes 11^{o}38.29^1 and 11^{o}38.50^1 N. The area is situated within the

Sudan savannah agro-ecological zone of Nigeria with three distinct seasons; namely, wet season, cool dry season and hot dry season. The area is characterized by a mean annual rainfall of about 700 – 800 mm which falls from June to October each year, the mean daily temperature ranges from29°C to 38°C.The geology of the area is a dissected peneplain developed on the crystalline Precambrian rocks of the basement complex, the main rock types are granite, gneisses and schist, complex glimmer schist and quartzite. The top of the basement complex is deeply weathered and on this zone, a lateritic iron pan layer is developed; the soils are mostly moderately deep to deep and well drained with sandy loam textured surface and sandy clay loam textured subsoil (Jibrin et al., 2008). The pilot study was carried out in a selected 0.269 km^2 (26.9 ha) experimental farmland.

The location of sampling points and soil profile classification in each of the selected irrigation blocks(F-3.4, F-3.5, F-3.6 and F-3.7) are shown in Figure 1;each block is well laid out and intensively cropped with vegetables, wheat, onions, tomatoes, rice, etc. Soils of the experimental farm belong to the upland plain, about 60% are deep and well drained, and the remaining 40% are poorly drained and are underlain by an iron pan of Ferruginous Feldspar found at an average soil depth of 152 mm.

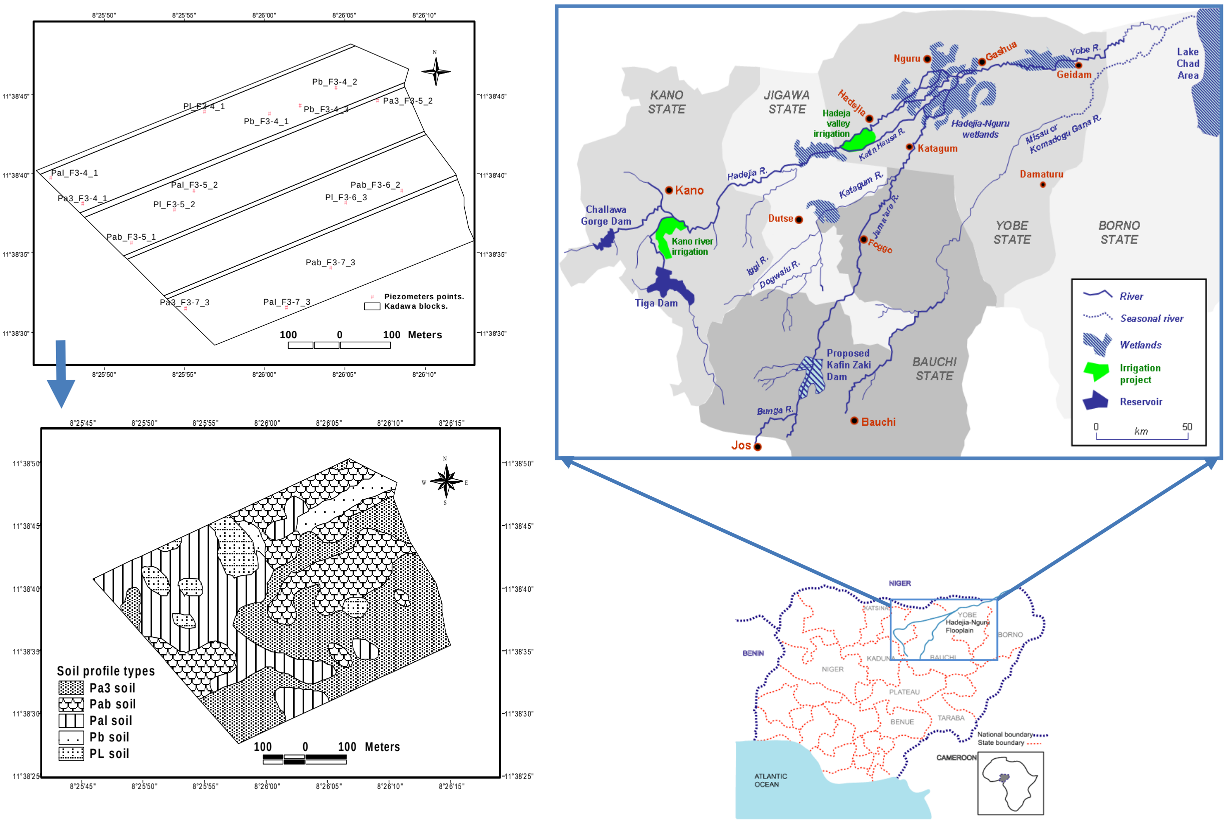

Figure 1 Location, sampling points and soil profile classification at the study site

2.2 Groundwater sampling and chloride mass balance analysis

Groundwater samples were collected and analyzed for a period of three years (2009–2012) using a monthly time step; to aid sample collection, fifteen (15) piezometers (50 mm Poly Vinyl Chloridepipes) with four evenly spaced 1 mm slots were installed in three replicates for each identified soil profile types (Pa3, Pal, Pl, Pab and Pb) on the farmland to an average depth of 1.5 m depending on depth to the underlying ferruginous hardpan. The soil profile types on the experimental farmland are the most dominant soil types found on the entire KRIP farmland, hence are representative of the irrigation project.

Soil samples at the piezometer points were obtained at an incremental depth of 50 cm and analyzed in the laboratory for pertinent soil mechanical and hydraulic properties (bulk density, particle density, void ratio, porosity, degree of saturation and specific yield) using standard methods. Groundwater chloride was determined on the field using Mohr's argentometric methods with Silver nitrate and Potassium chromate as reagents while chloride mass balance method was used to estimate groundwater recharge on the farmland based on the premise that chloride is a conservative natural tracer.

Water samples collected from the rain gauge and from piezometers were tested for chloride concentrations in the wet season while the irrigation water samples from field canals and groundwater samples from the piezometers were used in the dry season. Groundwater recharge, Re (mm) was estimated according to Beekman and Xu (2003) and Bazuhair and Wood (1996) as following Equation 1 and Equation 2:

$$R_e = P * {}^{C_p}\!/_{C_g} \ (1)$$

$$R_e = I_d * {}^{C_I}\!/_{C_g} \ (2)$$

where, P is the areal weighted precipitation (mm), C_p is the chloride concentration of precipitation (mg/L), C_g is the groundwater chloride concentration at the water table (mg/L), I_d is irrigation depth (mm), C_I is chloride concentration in irrigation water (mg/L). The CMB models were applied with some limiting assumptions in order to obtain a rapid estimate of recharge, they include:1) chloride mass flux into the experimental farmland will not change over time; 2) chloride input into the experimental farmland is from rainfall and irrigation water; 3) chloride isconservative in the system, hence, recycling or concentration of chloride within the phreatic aquifer doesnot occur;and 4) the system is atsteady state.

2.3 Spatial analysis of groundwater chloride

Tab delimited file format containing groundwater chloride data were imported into ArcGIS® 9.3 software by ESRI, U.S.A where the data values were extracted to geo-referenced sampling points. The points were treated as spot heights which were then interpolated using deterministic interpolation techniques to create surfaces from the measured points, based on the extent of similarity. The deterministic interpolation technique used was the local interpolator which calculated predictions from the measured points within neighborhoods, which have similar spatial areas within the larger study area. The spatial analyst extension of ArcGIS® 9.3 was used to generate Digital Elevation Models for ground water recharge on the farmland using the Inverse Distance Weighted (IDW) method for spatial interpolation as following Equation 3:

$$F(x,y) = \sum_{i=1}^{n} w_i f_i (3)$$

Where n is the number of scatter points in the set, f_i are the prescribed function values at the scatter points such as Recharge values and w_i are the weight functions assigned to each scatter point. See Equation 4.

$$w_i = \frac{h_i^{-p}}{\sum_{i=1}^{n} h_j^{-p}} (4)$$

Where p is an arbitrary positive real number called the power parameter (typically, p=2) and h_i is the distance from the scatter point to the interpolation point; see Equation 5.

$$h_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} (5)$$

where(x, y) are the coordinates of the interpolation point and (x_i, y_i) are the coordinates of each scatter point. The weight function varies from a value of unity at the scatter point to a value approaching zero as the distance from the scatter point increases. The analysis resulted in the development of a geo-spatial model of groundwater chloride on the farmland.

3 Results and discussion

3.1 Status of groundwater chloride

Table 1 presents some of the determined hydraulic characteristics of soil profiles on the farmland. All the identified soil profile types on the farmland revealed varying chloride concentration depending on period of the year. In Pa3 soil profile for example, groundwater chloride range from 23.3 mg/L– 52.6 mg/Lin August and April respectively, with a mean value of 31.6 mg/L. In Pal soil profile on the other hand, a maximum value of 91.4 mg/L was obtained in June while the minimum of 26.1 mg/L was observed in December. For the other soil profile types, a range of 22 mg/L– 33 mg/L, 24.2 mg/L– 48.3 mg/Land 30.5 mg/L– 60.9 mg/L were obtained for the Pl, Pab and Pb soil profiles, respectively. Results of correlation analysis presented in Table 2 show that each soil profile type has chloride concentration that is not associated with one another. This lack of association is indicative of the diverse cropping schedules and non-uniform irrigation on the experimental farmland, the farmland is also found to be subjected to non-uniform fertilizer application in terms of type and application rates. These was due to the fact that the farmland is an experimental farmland where irrigation research is being carried out since 1975; basically, there are only two types of fertilizer (Nitrogen – Phosphorus – Potassium (NPK) and Urea) being used in the area. It is very difficult to ascertain the level of fertilizer usage as varying experiments were usually set up on the farm every season with different types of crops being experimented.

Table 1 Hydraulic characteristics of soils at sampling points

Sn.	Piezometer Identifier	Soil Profile Description	Void Ratio	Porosity	Degree of Saturation	Specific Yield Sy
1	Pa3/F3-4/1	Deep soils, loamy sands over sandy clay loam, well drained with Aeolian drift over colluvial/alluvial soils as parent material.	0.187	0.829	0.987	0.158
2	Pa3/F3-5/2		0.206	0.821	0.993	0.171
3	Pa3/F3-7/3		0.204	0.809	0.978	0.169
4	Pal/F3-4/1	Moderately deep soils underlain by iron pan, loamy sand over sandy loam, well drained soils with Aeolian drift parent material.	0.179	0.846	0.998	0.153
5	Pal/F3-5/2		0.169	0.849	0.994	0.145
6	Pal/F3-7/3		0.203	0.826	0.995	0.169
7	Pl/F3-4/1	Shallow soils, loamy sands (30 mm to 100 mm depth) underlain by iron pan. Well drained with Aeolian drift parent material.	0.137	0.823	0.943	0.121
8	Pl/F3-5/2		0.179	0.843	0.995	0.152
9	Pl/F3-6/3		0.211	0.821	0.995	0.175
10	Pab/F3-5/1	Deep soils, loamy sands over sandy clay between 30–100 mm. Poorly drained with Aeolian drift over colluvial/alluvial soils as parent material.	0.200	0.829	0.997	0.167
11	Pab/F3-6/2		0.219	0.814	0.994	0.179
12	Pab/F3-7/3		0.135	0.879	0.998	0.119
13	Pb/F3-4/1	Loamy sands within 30 mm over sandy clay loams with colluvial/alluvial parent material.	0.100	0.854	0.945	0.091
14	Pb/F3-4/2		0.099	0.889	0.979	0.089
15	Pb/F3-4/3		0.150	0.861	0.991	0.131

The trend of chloride levels in groundwater on the farmland is shown in Figure 2; a seasonal trend can easily be identified as all the soils display higher chloride values in the hot dry season (April – June) while the values become lower towards the cessation of the rains between September and November, this is expected because of the dilution effect rainfall has on groundwater chloride. The groundwater chloride concentrations observed in the area are low when compared with those reported by Han et al. (2011) in a similar irrigation project in northwest, China where a mean concentration of 8.3 g/Lwas obtained. It should be noted that if the groundwater table rise is not ameliorated, increasing salt build up is imminent in the area which will lead to further reduction in crop productivity. See Table 2 please.

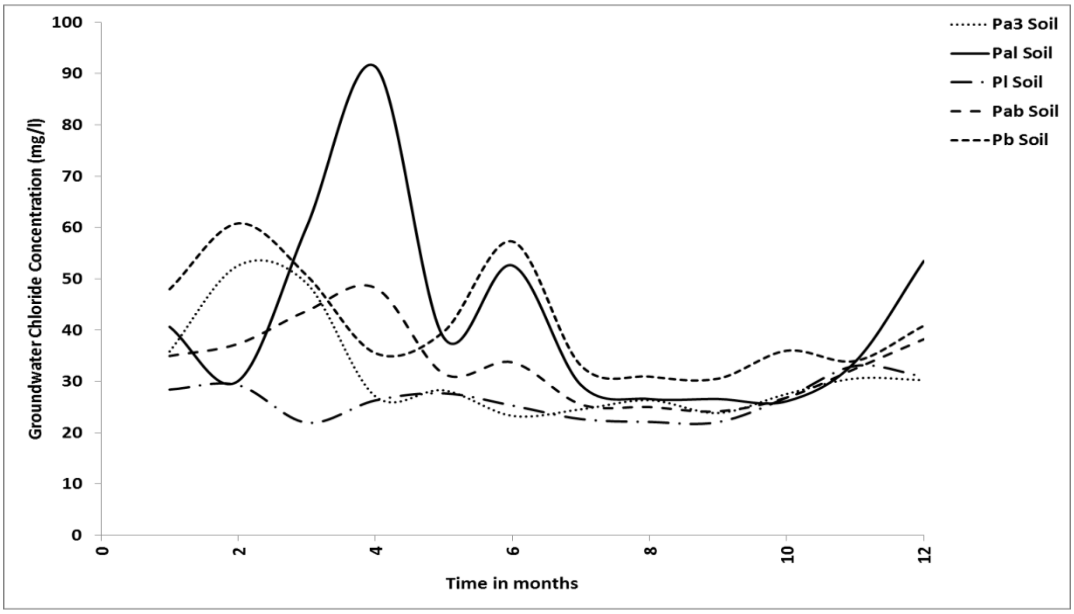

Figure 2 Trend of groundwater Chloride concentration on the farmland

Table 2 Correlation matrix of groundwater salinity on the farmland

	Pa3 Soil	Pal Soil	Pl Soil	Pab Soil	Pb Soil
Pa3 Soil	1				
Pal Soil	0.05	1			
Pl Soil	0.16	0.04	1		
Pab Soil	0.49	0.87*	0.26	1	
Pb Soil	0.66*	0.17	0.18	0.45	1

Note: * Significant

Geospatial model of groundwater chloride on the farmland presented in Figure 3 shows that even though the chloride values are generally low, areas of increasing salinity could be identified especially in the F3-4 block at the western tip of the farmland. Table 3 presents the summary of the chloride concentration in irrigation water and/or rain water, it ranges from 15.38 mg/L– 24.85 mg/L, 15.38 mg/L– 25.44 mg/Land 14.06 mg/L- 22.48 mg/Lin 2009/2010, 2010/2011 and 2011/2012 hydrological year, respectively. A pertinent observation in the data was that the chloride level in the irrigation/rainfall water was slightly lower than those observed in groundwater samples. See Table 3 please.

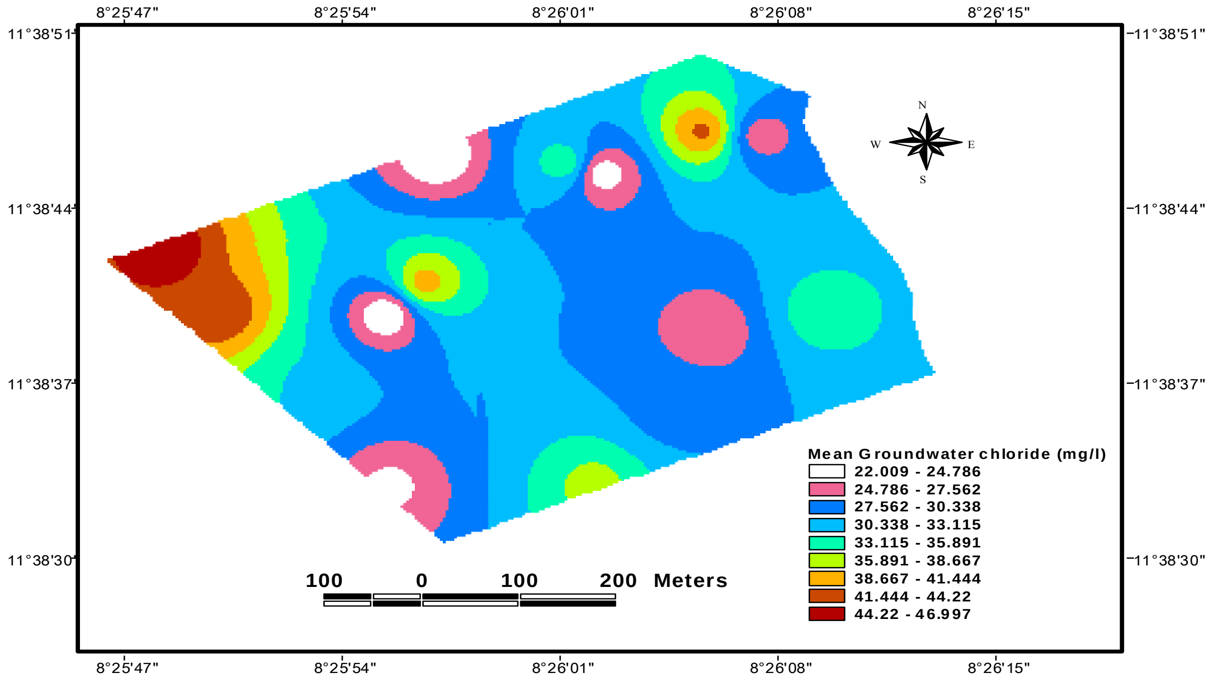

Figure 3 Geospatial model of groundwater chloride on the farmland

Table 3 Summary of chloride concentration in irrigation/rain water

	2009/2010		**2010/2011**		**2011/2012**	
Month	**Conc., mg/L**	**Remarks**	**Conc. , mg/L**	**Remarks**	**Conc. , mg/L**	**Remarks**
MAR	23.03	IRR*	21.89	IRR	21.45	IRR
APRIL	17.45	IRR	17.23	IRR	19.16	IRR
MAY	16.49	IRR	17.68	IRR	15.53	RAIN
JUNE	23.44	IRR	21.37	IRR	20.63	RAIN
JULY	24.04	IRR	17.75	RAIN	15.98	RAIN
AUG	24.85	RAIN*	25.44	RAIN	22.48	RAIN
SEPT	19.59	RAIN	15.38	RAIN	15.98	RAIN
OCT	15.38	RAIN	21.3	RAIN	19.82	RAIN
NOV	19.38	IRR	19.38	IRR	20.04	IRR
DEC	21.67	IRR	16.12	IRR	20.12	IRR
JAN	21.89	IRR	19.75	IRR	15.38	IRR
FEB	22.78	IRR	21.45	IRR	14.05	IRR
MIN	15.38		15.38		14.05	
MAX	24.85		25.44		22.48	
RANGE	9.47		10.06		8.43	

Note: * IRR connotes irrigation was applied while RAIN connotes rainfall

Fipps (1996) recommends the use of sub-surface drainage systems for areas with shallow water tables in order to control salt build up. As at present, this system of drainage is not in practice at KRIP; the existing surface drainage canals have collapsed with no hope of reconstruction due to dwindling funds. One of the observations made was that farmers have converted the drainage area for permanent rice cropping; this is inimical to the productivity of the farmland, the shallow water table will restrict the downward leaching of salts. It is recommended that perforated PVC pipes be used to drain excess irrigation water from the farmland; this will require adequate design in terms of pipe spacing and installation depth and slope. The observed change in the cropping pattern on the farmland is reflective of declining productivity in the area. The study revealed that the farmland is waterlogged in the month of July, August, September and some part of October making the area only suitable for lowland rice production in the wet season.

3.2 Groundwater recharge at the study site

The summary groundwater recharge values obtained from chloride mass balance analysis represented in Table 4, a mean annual total of 980mm, 740mm, 1070 mm, 880mm and 680mm of water was found to be recharged to the underlying phreatic aquifer via the Pa3, Pal, Pl, Pab and Pb soil profile types, respectively in the three years of study. A minimum recharge of24 mm was obtained in Pa3 soil for the month of April; at this period, the wheat crop is being harvested on the field with no irrigation on the land. The month of June recorded the least recharge in Pal soil with a value of 34 mm.

Table 4 Summary of monthly groundwater recharge on the farmland*

MONTH	Pa3 Soil, mm	Pal Soil, mm	Pl Soil, mm	Pab Soil, mm	Pb Soil, mm	MEAN, mm
MAR	42	37	53	43	31	**41**
APRIL	24	42	44	34	21	**33**
MAY	53	43	119	60	51	**65**
JUNE	55	34	39	43	37	**42**
JULY	98	72	100	88	70	**85**
AUG	253	112	233	175	103	**175**
SEPT	83	70	90	80	62	**77**
OCT	101	100	120	106	86	**103**
NOV	56	50	60	55	44	**53**
DEC	79	83	81	81	60	**77**
JAN	59	54	55	56	53	**55**
FEB	77	43	75	61	57	**63**
ANNUAL	980	740	1069	882	675	**869**

Note: * 2009 – 2012

Groundwater recharge was also lowest in Pl soil in the month of June with a value 39 mm; while recharge is also least in April for Pab and Pb soils in April respectively. The monthly trend of recharge to groundwater on the farmland in the three years of study is presented in Figure 4.

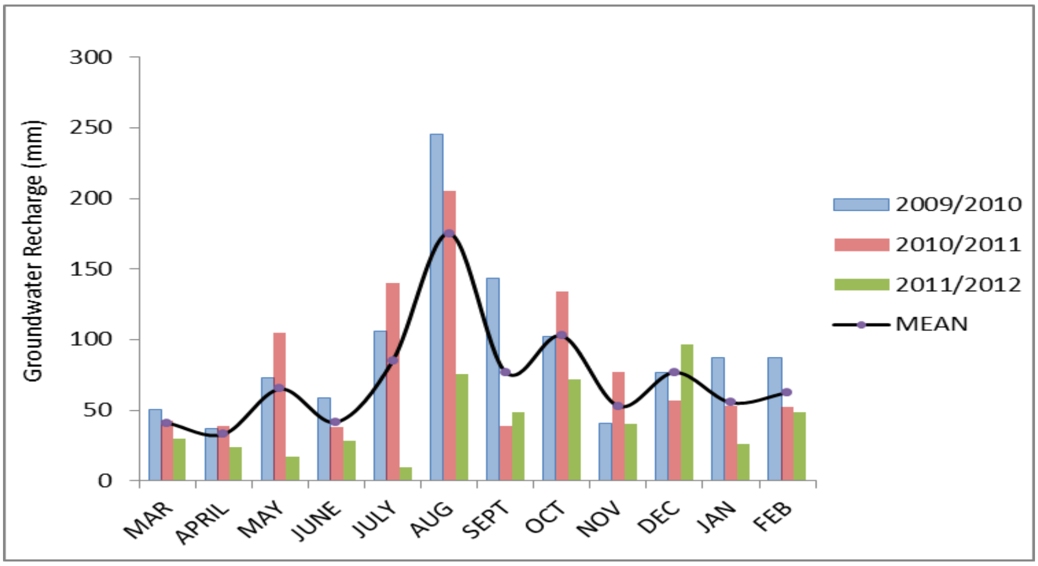

Figure 4 Trend of monthly groundwater recharge in the three years of study

The month with the highest recharge is clearly visible while the mean value across the entire area is equally shown. Annual areal mean of groundwater recharge on the experimental farmland was 869 mm which shows that an enormous amount of water is available on the farmland which could be drained and reused in order to maintain the salt balance on the farmland especially within the root zone depth. Incessant rising of the water table to the surface especially in the raining season and its decline in the dry season is responsible for the salt build up. At present, there seems to be no harm as the geospatial model of salt build up presented earlier shows that the crops being cultivated on the farmland are still sustainable for the time being. The amount of water recharged can support a conjunctive use of groundwater for irrigation on the farmland reducing the surface water draft from Tiga dam. Further analysis revealed that the annual recharge is in excess of the annual rainfall in the area, the balance being from irrigation water application. The year 2011 was obviously a low rainfall year in the area, heavy supplementation with irrigation was evident to sustain the rice on the field during the wet season. The gross irrigation water application on the farmland was 705 mm, 915 mm and 654 mm in 2009, 2010 and 2011 respectively showing that irrigation is the largest contributor to recharge in the area. It should be noted that lateral flow contribution could not accounted for by chloride mass balance method, it is the belief of the authors that cross flows from adjacent lands do occur in the area which will definitely contribute diffuse chloride into groundwater. Such contribution should be considered at a regional scale so that a more accurate estimation of recharge could be obtained. The implication of these is that the CMB method cannot adequately give an accurate estimate of groundwater recharge as a stand-alone method; according to Healy and Cook (2002),it is extremely difficult to assess the accuracy of any method. For this reason, it is highly beneficial to apply multiple methods of estimation and hope for some consistency in results – even though consistency, by itself, should not be taken as an indication of accuracy.

3.3 Influence of limiting assumptions on recharge estimates

Studies of this nature are rarely conducted in SSA especially in Nigeria, most irrigation schemes are experiencing declining productivity as a result of lack of integrated approach to their management; more worrisome is the absolute lack of pertinent data that could be used as a decision support for planners and managers of such schemes. These lack of data made the present study a very daunting challenge to the authors, hence the need to impose some limiting assumptions on the application of the CMB method which is usually the case for several previous studies in different parts of the world as reported in literature.

The first of these assumptions is that chloride mass flux into the experimental farmland will not change over time; literature shows that the time period represented by the recharged water and the variability of chloride input during that time span must be delineated. Groundwater sampled for this study has not been dated, and considering the fact that irrigation takes place on the farmland daily, fresh irrigation water of differing chloride content is being recharged to groundwater every day. Results from the study show that irrigation water which is the principal source of recharge water on the farmland has a chloride concentration which ranges from 16.49 mg/L– 24.04 mg/L, 16.12 mg/L – 21.89 mg/L and 14.05 mg/L - 21.43 mg/L in 2009/2010, 2010/2011 and 2011/2012 hydrological years, respectively. Similar variation was also observed with groundwater chloride as shown in Figure 2; these salt concentrations are low in comparison to results from other similar irrigation schemes in other parts of the world, the rate of change within the three years of study is very small and will not significantly affect the recharge estimate obtained from the study.

The major sources of chloride input into the experimental farmland is from rainfall and irrigation water, literature however show that dry deposition of chloride do occur on the ground surface (Scanlon et al.,2002); Beekman and Xu, 2003) apart from the wet deposition through rainfall. This has however been found to be dependent on the distance to the sea shore. The study site is located some 1, 200 km from the Atlantic Ocean which is a primary source of chloride and the area is also at an elevation of 648 m above mean sea level (amsl) point to the fact that dry deposition of chloride will be low and may not have any significant influence on the recharge estimate; this however does not negate the need to evaluate dry deposition of chloride in the area. Eriksson and Khunakasem (1969) estimated chloride catch by impingement to be 30% above that measured from precipitation collectors from studies conducted at Israeli coastal area; this shows how serious dry deposition should be considered when applying the method in coastal areas.

Literature show that chloride is conservative in most hydro geologic systems, this conservative behavior of chloride (Cl^-) arises from its stable outer electron configuration which results in low susceptibility to: oxidation or reduction reactions, formation of solute complexes, formation of less soluble salts and adsorption onto mineral surfaces. However, evaporative loss of ground water within the farmland may constitute recycling of chloride in the system as reported by Bazuhair and Wood (1996); the phreatic aquifer beneath the farmland is very shallow and sometimes, the groundwater level which ranges between 0 – and 19 mm below ground level (b.g.l.) in the month of July, August, September and some parts of October (Sobowale et al., 2015) causes groundwater evaporation which will cause chloride deposition in the soil profile. This is expected to add some uncertainties to the estimated recharge.

The assumption that the phreatic aquifer system is at a steady state implies that there was no pumping of any sort in the vicinity and hence no turbulent flow of any sort is generated that could lead to drawdown and lateral flow within the aquifer. The nearest well fitted with a motorized pump is located about 5 km away from the study site and was found to be drawing water from the fractured basement rocks, 20 m below the phreatic aquifer being studied. Other existing wells within the vicinity are fitted with manual hand pumps which are not expected to create a hydraulic gradient that could induce lateral flow within the aquifer. The study did not consider the possibility of interactions between the two systems, and with the area being devoted to irrigation from surface water only, possible mixing of chloride is not expected to take place because of the presence of a lateritic hard pan above the weathered basement complex and hence will not significantly affect the recharge estimates from the CMB method.

4 Conclusions

A pilot study of groundwater chloride distribution and recharge at the Irrigation Research Station within the Kano River Irrigation Project, Kadawa, Nigeria was carried out using CMB method. Results show gradual salt build up in the southwestern part of the experimental farmland with water logging problems observed in the wet months, this necessitated a change in the cropping pattern designed for project due to declining crop productivity. Mean annual recharge of 869 mm estimated for the farmland was found to be largely contributed by irrigation and reveals the enormity of water available in the area which could be drained and reused in order to maintain the salt balance on the farmland. Lateral flow contributions to recharge were however not accounted for by the method which shows its limitation to adequately estimate recharge as a stand-alone method. The study should be extended to a regional scale so that a more accurate estimation of recharge could be obtained.

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