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Suitability Assessment of Shallow Groundwater of a Typical Coastal Aquifers for Irrigation Use; A Water Quality Index Model Approach.

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Abstract: *Shallow Groundwater of a coastal aquifer has been intensively used as a source of water for irrigation farming in the Niger Delta region of Nigeria. To assess the usability of this water for irrigation use, twenty locations at buguma city were mapped out and five water wells were sampled for each location using Simple random sampling technique. Each sample was analyzed for the cations(magnesium(Mg^{2+}), sodium(Na^+), potassium(K^+),calcium(Ca^{2+})),anion(nitrate ion($N0_3^-$)), trace elements(cadmium(Cd), iron(Fe), and zinc(Zn)and other phsico-chemical parameters(Salinity(SI), electric conductivity(EC) and pH) adopting standard methods. Based on the analyzed parameters, irrigation water quality parameters (RSC, SAR, %Na and %MR) and indexes(Kelly index(KI), Permeability Index(PI) and the Canadian water quality index(CWQI)) were calculated .To assess the usability of the shallow groundwater, results of the Water quality index models and other calculated irrigation parameters were compared with the standards. On the average, virtually all the sampling locations except Ombu, Igba and Jackreech were unsuitable for irrigation use.*

I. Introduction

Understanding water quality is a prerequisite to good irrigation design and management. The type of irrigation under design is always a function of quantity and qualityof water available . Thus, for an irrigation system to perform its functions maximally, that is ensuring release of adequate and good water quality, availability of good source ofwater is necessary. Vasanthiaviger (2008) observed that micro-irrigation performs excellently with water quality free of all but fine suspended solids and devoid of dissolved substances such as iron. These substances precipitate outof the solution and create plugging problems . Therefore, the usage of untreated source of water for irrigation is a common reason for micro-irrigation system failures(Quddus and Zaman, 1996.).Inthe aspects of plant diseases, toxicity problems occur due to plant uptake of constituents at concentrations high enough to cause crop damage, low yield and quality. In the light of these, series of measurements have been applied to classify the suitability of water for irrigation. This is based on the following parameters; Electrical conductivity (EC) which is a function of total dissolved solids (TDS), pH, calcium, iron, alkalinity and chloride(Naha et al 2013). (Rowe and Abdel-Magid 1995) enumerated other parameters that are required for proper suitability assessment of irrigation water to include; sodium, boron, potassium, manganese and nitrate.These measurements are not only necessary for the functionality of the system but also necessary for the quality and health of the crops. Crops take up these elements and accumulate them in roots, stem and leaves depending on the translocation factorof the substances (Subroto et al 2007). Hyper-accumulator crops take wide range of these substances and accumulate them in all parts of the crops (Sarma 2011).Concentrations of these substances beyond tolerable limits can cause toxic reactions in crops. For instance, crops grown in irrigation water excess of sulphatesalts experience cationic imbalance by limiting the calcium uptake and increasing the sodium and potassium adsorption(Harivandi 1999). During nutrition uptake and metabolism, excess bicarbonate in irrigation water harms mineral nutrition in crops(AL-Harbi 2009). The hazard which is expressed in terms of SAR (sodium Adsorption Ratio) is associated with the breakdown of soil structure(AL-Naeem 2011).It has been observed that SAR effects are measured in the ratio of sodium and magnesium. SAR effects are said to be high if the ratio is less than 1 (**Sandow et al 2011)**. This implies that the soil is likely to have high sodicity value, expressed as sodium hazards if sodium values are higher than that of the magnesium in irrigation water. SAR which is an index of measurement of sodium hazards in irrigated crop land, operates in consonant with the electrical conductivity(EC) of the irrigation water. EC measures the salinity values of the irrigation waters.Researchers in the past have utilized categorization scheme where SAR and sodium were compared in graphical plot with EC respectively to assess the irrigation water quality prior to irrigation scheme(Yidana 2010). Irrigation water enriched with nutrients such as nitrogen, phosphorus and organic carbons is liable to accelerate algeal growth which results to blockage of irrigation equipment with its attendant uneven water flow distribution in the irrigation system, reduction in crop yield and increase in overall maintenance cost (Cuena,1989).

In an attempt to achieve food sufficiency and to catch-up with the millennium goal, farmers in Nigeria have embark on all-year-round farming. In the light of this, farmers applythe irrigationfarming system to realize these objectives. A good number of farmers practice this scheme with little or no effort to ascertain the irrigation water quality in use. The reasons adduced to this unsafe practice were not far from to safe cost of crop production and absolute ignorance of the need to assess the suitability of irrigation water.The effects are long term on the consumers of these cropsand short term on the crops. Some of these effects include; manifestation of high salinity, crop toxicity and poor yield.People of Buguma are both subsistent and commercial farmers. They sufficiently adopt irrigation farming system to meet all year round and robust crop production for commercial needs. Farmers in Buguma city tap the water for irrigation from shallow wells located virtually in all households. The water is used directly from the wells to irrigate the crops without ascertaining its usability level. To this effect, groundwater of the coastal region of Bugumacity to assess its suitability for irrigation purposes will be under study. This study will put the famers in the knowof the level of usability of irrigation water and possible effects on the crops and consumers.

II. Materials and Methods

Buguma city is located longitude 4^o 44' 8 N and latitude 6^o 51'. 48E. People of Bugumacity are predominantly crop and fish famers. They practice irrigation farming to realize robust and all -year –round crop production. Shallow wells are their sources of water for irrigation .For effective sampling of those wells,Twenty locations within Bugumacity were mapped out for the study. Water samples from Seven boreholes were randomly sampled from each location making a total of one hundred and forty samples. Sampling was carried out once every month for seven months. Each sample was analyzed for Mg, Na, K, Ca, Salinity(SI), $N0_3^-$ and other phsico-chemical parameters adopting standard methods. pH and Electrical conductivity (EC) were measured in-situ using standard meters . The choice of variablesor parameters analyzed was informed by their roles during crop production. Other water quality parameters and indexes necessary for irrigation practice such as Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate(RSC), Permeability Index(PI), Kelly Index(KI), Magnesium Ratio(MR), and percentage Sodium(%Na) and the Canadian water quality index(CWQI) were evaluated with the following equations.

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

$$RSC = (HC03^- + C03^{2-}) - Ca^{2+} + Mg^{2+} \quad (2)$$

$$PI = \left[\frac{Na^+ + HC03^-}{Ca^{2+}+Mg^{2+}+Na^{2+}}\right] x100 \quad (3)$$

$$KI = \frac{Na^+}{Ca^{2+}+Mg^{2+}} (4)$$

$$MR = \left[\frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}}\right] x\ 100 \quad (5)$$

$$\%Na = \frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^+ +K^+}\ x100 \quad (6)$$

$$CWQI = 100 - \left(\frac{\sqrt{F_1{}^2+F_2{}^2+F_3{}^2}}{1.732}\right) \quad (7)$$

F1, F2 and F3 represent three factors that make the index model. F1 represents the failed variables(variables in the field samples that do not meet their objectives) relative to the total number of variables measured.

$$F_1 = \frac{\#Failed\ variables}{total\ variable} X\ 100 \quad (8)$$

$$F_2 = \frac{\#Failed\ test}{total\ test} X100 \quad (9)$$

$$F_3 = \frac{nse}{0.01nse + 0.01} \quad (10)$$

nse is the ratio of the summation of excursion of individual test to the total number of test

$$nse = \frac{\sum_{i=1}^{n} excursion\ _i}{\#of\ test} \quad (11)$$

Excursion is the number of times an individual concentration is greater than the objectives and this is expressed as

$$excursion = \frac{failed\ \ test\ \ value_{\,i}}{objective\ _{j}} - 1 \qquad (12)$$

CWQI is ranked between 0-100, where 0 and 100 values represent worst and best water qualities respectively. The values obtained were compared with the irrigation water quality parameters to ascertain its suitability. A weighted linear combination technique for each variable was adopted to further ascertaintheir suitability for irrigation water.

III. Results and Discussion

Table 1 shows average valuesof heavy metal analysis carried out on Water samples collected from all sampling locations. The results exhibited notable value differencesamong theanalyzed parameters. On the investigated heavy metals,(Cd, Fe and Zn)values,Cd and Zn were far below permissible limit for irrigation water(George 1983) in all the sampling points. Fe is not totally low but has varying concentration values between 1.07-5.64 mg/l. A good number of sampling sites exceeded the WHO minimum standard of 3mg/l for Fe. Withvarying severity problems(< 3mg/l=not a problem, 3-5mg/l=increasing problem, and >5mg/l= severe problem) well water from Abbi and Lawson study locationswill pose severe problem to crops,Okorosa, Bakubo, Ombu, Tariah, Johnbull, Warmate, Ombo and Horsefall will pose no problem while other locations will pose an increasing problem. The apparent high Fe concentration value was attributed to natural occurrence in soil, sediment and rocks especially in coastal regions(misstear et al 2006) as it is the case with the study area .previous accounts have attributed irrigation failure to high iron concentration. At highFe concentrationvalue and in the presence of oxygen,precipitation of reddish brown Fe_20_3flakes-off and clogs irrigation line nozzles, leading to blockages against free flow of water(El Kholy and Kandil 2004).

Table 1: Average values of the heavy metals

Locations	Cd	Fe	Zn
Abbi	0.009	5.64	0.01
pepple	BDL	4	6.3
Okorosa	BDL	2.6	7.3
Bakubo	0.003	1.07	11.3
Ombu	0.001	2.52	0.1
Lawson	0.009	5.11	5.1
tyger	BDL	3.11	4.3
Tariah	0.001	2.98	0.12
Young-aney	BDL	3.19	0.3
Igba	BDL	3.99	0.9
Johnwest	0.003	3.04	1.4
Johnbull	0.002	1.9	3.9
Jeckreech	0.001	4.01	17.2
Wokoma	0.006	3.5	13.4
Warmate	0.007	2.7	11.5
Ombo	0.004	2.6	12.4
Ikpo	0.008	3.1	0.12
Edi	BDL	3.8	3.22
Horsefall	0.009	2.1	1.45
cottrell	0.003	1.8	1.1

At concentration value greater than 5mg/l, Fe could form coating on the leaves of the crops to inhibit photosynthesis(Akpan et al 2012)

Table 2 presented other physic-chemical parameters. A wide range of concentration values were observed in all sampling locations. Sodium adsorption ratio(SAR) expresses the presence of sodium in relation to calcium and magnesium. In this study, SAR concentrationwas within a range of between 27.3 to 84.2. The lowest and highest SARconcentrationvalues were recorded at Ombu and Wokoma wells respectively. Considering the SAR standard rankingfor irrigation water suitability, presented as follows;

Table 2: index values and other physicochemical parameters

Location	SAR	RSC	KI	PI	%Na	%MR	Sl	ph	$N0_3^-$ mg/l	Mg mg/l	Na mg/l	K mg/l	Ca mg/l	EC (dS/m)	WQI
Abbi	81.7	2.01	3.87	100.9	82	87.2	2400	5.11	45	70	311	49.9	10.3	4.2	5.15
pepple	59.37	2.45	4.57	97.1	83.4	97.2	8700	5.23	57	79	413	40.1	11.3	27.3	3.39
Okorosa	70.3	2.33	2.65	90.3	69.3	85.3	7100	6.51	34	64	201	29.7	11	17.3	9.01
Bakubo	41.01	1.89	3.56	94.3	90.3	63.9	290	5.81	49.1	61	340	37.11	34.4	0.8	14.90
Ombu	27.3	1.11	1.11	80.2	56.3	78.7	1600	6.23	79.1	67	110	22.6	36.1	1.20	60.98
Lawson	30.9	1.13	4.33	89.9	82	79.2	1400	6.7	78.1	69	377	20.01	18.1	8.3	29.45
tyger	42.33	1.24	5.1	114.7	84.4	81.3	4300	6.4	79.1	51	319	19.78	11.7	22.9	9.96
Tariah	55.8	2.01	2.98	114.7	76	84.8	2100	7.7	46.2	54	196	21.24	9.7	2.03	7.86
Young-aney	34.11	2.54	1.3	118.8	69.6	45.2	7200	5.9	40.3	31	89	35.11	37.7	21.5	7.49
Igba	48.31	2.46	3.04	78.6	77.6	69.4	200	6.3	33.8	66	289	40.23	29.1	0.5	54.23
Johnwest	54.8	1.8	2.13	99.7	71.5	86.5	440	5.9	50.1	89	219	39.1	13.9	0.3	15.98
Johnbull	63.5	2.3	4.17	95.3	83	83.4	4800	5.71	47.2	75	374	45.23	14.9	15.9	8.45
Jeckreech	42.1	1.1	2.75	99.9	73.1	85.5	6400	6.8	54	84	245	27	14.3	11.4	44.85
Wokoma	84.2	2.9	4.24	85.6	70.5	71.6	5100	6.24	78.3	93	275	35.3	36.9	13.5	3.43
Warmate	67.3	1.4	2.11	97.2	82.5	42.9	5800	6.1	89	73	412	45.7	24.11	14.1	2.22
Ombo	58.3	1.4	2.82	60	72	70.7	4000	5.74	78.5	78	235	39.1	32.4	13.4	4.65
Ikpo	42.6	1.67	4.73	86	76.8	68.2	8640	6.9	98	69	285	49.2	32.1	21.6	3,56
Edi	59.7	1.8	5.4	96	83.8	62.8	2220	6.52	86.8	48	361	32	28.4	5.3	27.67
Horsefall	74.2	1.3	2.71	103.2	85.5	95.2	3400	5.98	89.8	68	386	35.9	3.4	14.7	6.32
cottrell	83.2	1.6	3.12	95.6	75.8	79.4	4339	6.9	75.4	92	314	48.4	23.94	13.8	32.57

SAR=10.18; Good, SAR=18.26; Fair and SAR > 30 ;Poor(Hanson et al 1999), the water samples observed for SAR, have high concentration values and therefore not suitable for irrigation purposes. SAR is a measure of tendency of sodium(Na) ion to displace Ca ion in the irrigation water soil (Al-Tabbal and Al-Zboon 2012) due to its high position on the table of electrochemical series. This implies that more of sodium ions is readily available in the water as considerable amount of calcium is displaced. The importof high SAR value observed in the study locations wasan increase in Na ion . This condition produces adverse effects on the soil physical conditions and consequently on the crops, leading to a situation reported by previous researchers as sodicity or sodium hazards(Ayers and Westcot 1985).WithHigh SAR and sodium values in the irrigation waters, the soil then becomes hard, compact and impervious to water penetration (George 1983). The condition leads to apparent difficulty in pore water distribution through the entire soil matrix. With this scenario, the soil on which the irrigated water is applied will experience waterlogging and related plant diseases(Misstear et al 2006) which include; stunted plant and leave burnt.

Carbonate hazards in water were also measured with respect to concentration of Residue sodium carbonate(RSC) . Values of residual sodium carbonate measured in the study area varied in all sampling locations. Previous researches adjudged water sample with RSC value of 1.25 meq/L as been safe for irrigation.Also, RSC values between 1.25 to 2.5 meq/L was moderate whileRSC above 2.5 meq/L was not suitable for irrigation (Cuena 1989). in this respect, results of the study area showed that Omobu and jeckreech sampling locations were suitable for irrigation while other locations fall between moderate and not suitable ranges. With the prevailing RSC values, the crop irrigated with waterfrom the afore-mentioned sampling points stands the risk of carbonate hazard.

pH values for irrigation water are at normal range at between 6.5 to 8.4(Misstear et al 2006). The pH levels of the wells under study were between 5.11at Abbi water wells and 8.7 at Tariah water wells. The prevalent pH range of the wells describes the water as being slightly acidic and slightly alkaline . Although slightly higherthan normal pH range for suitable irrigation water, the prevailing pH values will have minimal side effects on the crops as observed by previous researchers(Sarma 2011).

Wide salinity concentration range of 200-8700 mg/l was observed in the water samples of the study area. The lowest and highest salinity values were observed at Igba and Pepple wells respectively. Salinity rating is usually carried out with respect to values of the electric conductivity. Previous researchers described electric conductivity of water as the ability of salt ions to conduct electric current within the water body, implying that the two parameters have direct relationship. The present study corroborated this observation. . From table 2 , high salinity with corresponding high electric conductivity values was virtually observed in all the wells. Values of electrical conductivity in relation to water salinity rating presented on table3 by Debel et al 2005 equally validated the present study.

Table 3 electric conductivity and salinity rating(After Debel et al 2005)

EC(Ds/m)	Water Salinity rating
<0.65	Very low
0.65-1.3	Low
1.3-2.9	Medium
2.9-5.2	High
5.2-8.1	Very high
>8.1	Extreme

Also, the salinity of the study area was rated based on the standards provided on table3; salinity rating for Bakubo and Ombu wells was very Low while that of Igba and Johnwest was low. Salinity rating of Tariah and Abbi water wells was medium and high respectively, while the water samples of other wells recorded extreme high water salinity rating. The apparent high salinity level observed in most study locations could primarily be attributed to sea water intrusion and leaching of fertilizer chemicals to the aquifer(Chigor et al 2011).With respect to saline suitability, Bakubo, Ombu, Igba, JohnwestTariah and Abbi water wells were between Good and permissible for irrigation use while other wells were unsuitable. Variations were also observed on the Nitrate ion ($N0_3^-$) concentration among all the sampled wells of the study area. Nitrate ion ($N0_3^-$) concentration range was between 33.8 to 89.8mg/l .With the maximum allowable concentration of 50mg/l ,stipulated by WHO 2006 and NWQS 2007, $N0_3^-$ concentration was high in all the locations except Abbi, Okorosa, Bakubo, Tariah, Young-aney, Igba and Johnbull. The high concentration level observed in those areas could be attributed to heavy application of artificial fertilizer and solid municipal waste dump due to intensive farming activity and high cluster of people. Magnesium ion concentration beyond WHO 2006 and NWQS 2007 standards of 30mg/l was observed in all the sampling locations. The high level may not necessarily be linked to anthropogenic activity but could be as a result of natural deposition of carbonate rock(limestone) which is typical of the study area. Carbonate rock is usually a source of magnesium ion especially on dissolution (Dara et al 2012).

Applications of indexes

Kelly Index(KI) was applied to assess the suitability of water for irrigation . KI water value has a range of values between >1 and 1< . KI values of greater and less than unitydescribes the sampled water as being not suitable and suitable for irrigation respectively (Sundaray et al 2009). Values ofcomputed KI (1.11-4.73 meq/l)in water samples of the study locations were much more than unity, suggesting non -suitability for irrigation purposes.

As a criteria to measure the usability of water for irrigation, Permeability index(PI) was also applied to assess the usability of groundwater in Buguma city for irrigation . PI of water is a function of sodium, calcium, Magnesium and carbonate in the soil (Vasanthaiviger 2010, stewart and Hielsen 1990). This index divided Waterinto three classes(classes I, II and III) . Classes I and II water are categorized as good for irrigation with 75% maximum permeability while class III which has 25% maximum permeability was adjudged to be unsuitable for irrigation (Nagaraju et al 2006 and Ishaku et al 2011). Based on this assessment, the water samples from all the locations have good permeability index and therefore suitable for irrigation.

High presence of sodium in water results to sodium ion absorption on the clay and its exchange for Ca^{2+} and Mg^{2+} with permeability reduction and poor internal drainage(Vasanthiaviger 2010). Consequently, it was used as a tool for irrigation water classification. Previous researchers observed the following water classification for irrigation purposes based on the %Na;<20;excellent, 20-40; Good, 40-6-; permissible, 60-80 ; Doubtful, and >80; unsuitable. With this classification, water sample from the study area was onthe range of between doubtful and unsuitable.

Presence of magnesium in irrigation water is assessed using %Mg. the index for computing magnesium hazard in irrigation water is expressed in equation 5. From the guideline for interpretation of water quality for irrigation which stipulates that %Mg greater than 50% describes the water as unsuitable and vice versa(Misstear et al 2006),% Mg values of all the wells in the study area except Warmate and young-aney were greater than 50%, making the water from those wells unsuitable for irrigation purpose. It was observed that high value of %Mg increases soil alkalinity thereby adversely affecting its quality.

In order to reduce the multivariate nature of the water quality data and to provide general and readily description of water, a water quality index model which mathematically combine all quality parameters was adopted. This model was applied on the sampled water quality parameters in all the wells. It was observed that values of WQI were between 2.22 to 60.98 . Specifically, WQI of all the wells except ombu, igba and jeckreech were less than 44 and hence of poor quality. Judging from the observations of the previous researchers and provisions of the water quality index standard,water quality of those wellswas adjudged not suitable for irrigation(**El Kholy and Kandil 2004 , Tanji 1990**).Giving the values of QWIs values ofombu, igba and jeckreech wells as 60.98, 54.24 and 44.85 respectively, their water wells are suitable for irrigation use.

IV. Conclusion

Usability assessment of groundwater for irrigation in a typical coastal region of Niger delta of Nigeria has been studied. Values of the investigated trace elements(Zn, Cd and Fe) were below the permissible limit in all the study locations except Fe. Form other irrigation water parameters, SAR, salinity and RSC were high in all the sampling locations and these portend hazards to the crops. The WQI and other indexes also confirmed non-suitability of groundwater of virtually the study locations for irrigation use.

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