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Analysis of the Suitability of Surface Water for Irrigation Purposes: The Southwestern and Coastal River Systems in Ghana

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Abstract

Surface water basins all over the world are very crucial in irrigation industries. Irrigation schemes are particularly crucial in the agricultural economies due largely to the fact that global climate change has led to drastic changes in rainfall patterns. As a result, rain-fed agriculture alone is no more sustainable and irrigation schemes are being encouraged as poverty reduction/eradication strategies in the developing countries. This study was conducted to assess the overall controls on surface water resources in the coastal and south-western river basins in Ghana, and determine the suitability of these surface waters for irrigation activities. Multivariate statistical methods were applied to data on the physico-chemical parameters from the coastal and southwestern river basins. This study finds that the quality of surface water from these basins is controlled principally by leachate of chemicals from solid and mine wastes, the chemistry of rainfall, weathering of underlying silicate mineral-rich rocks and sediments, agricultural and domestic wastes. All the parameters are within the acceptable national concentration ranges for most domestic and industrial purposes. Sodium adsorption ratio (SAR) was used to assess the quality of water from the two basins for irrigation activities. The SAR values for all the months and years sampled are lower than 4 and the electrical conductivity values are equally low due to generally low ionic concentrations. When plotted on the Wilcox diagram, the data for all the months for the two years of the study, plot within the "excellent to good" category, suggesting that water from the area is of acceptable quality for irrigation activities.

Keywords: Coastal Basins, Southwestern Basins, Multivariate Analysis, Sodium Adsorption Ratio, Electrical Conductivity

1. Introduction

The role of irrigation programs in global food security can not be overemphasized. In the developing world where agriculture constitutes a significant stake in the national economies, irrigation schemes play pivotal roles in the delivery of both commercial and staple crops. In the so-called third world developing countries such as Ghana, the development of irrigation schemes has been identified as a strategy to reduce poverty and unemployment. Moreover, the recent erratic patterns in rainfall in Ghana and other countries, and the attendant crop failures have had telling effects on the annual grain and foreign exchange returns from commercial crops. In addition, the canker of rural-urban migration is on the ascen-

dancy as the teaming populations of the youth who hitherto made a living out of rain-fed agriculture now find solace in menial jobs in urban centers where they are engaged as porters with no proper accommodation or shelter.

Whilst acknowledging the role of irrigation schemes in global food security, it is imperative to assess the possible environmental effects of using poor quality irrigation waters for the sake of increasing crop productivity. Irrigation soils have been unduly affected by the use of high salinity, high sodicity soils for irrigation in some parts of the world including parts of China and India where irrigation is extensively carried out [1]. When this happens, the ability of the soil to hold and sustain productive irrigation is unduly affected, leading to massive crop fail-

ures. It is for this reason that the quality of irrigation waters need to be assessed prior to their use for irrigation schemes. Ideally, this assessment should be done against the specific soils that will be used for the planned irrigation schemes. In addition, since different crops have different tolerable limits for specific ions and the general salinity, it is imperative that the quality of irrigation waters be assessed against the type of crop that will be irrigated.

In addition to specific ion toxicities, it has been globally accepted that the proportion of the sodium ion against the major alkaline earth metals (calcium and magnesium) in irrigation waters play key roles in determining its quality for use on irrigation schemes. The sodium adsorption ratio, SAR, is an index which measures the relative proportions of the sodium ion on one hand and the sum of calcium and magnesium ions on the other. This index is used together with the electrical conductivity (EC) (which provides a quantitative measure of the salinity of irrigation waters), to comprehensively classify irrigation waters. One of the popular schemes used is that of the United States Salinity Laboratory's categorization scheme developed in 1954. This scheme plots the EC on a logarithmic axis against SAR on a linear axis, and divides the area of the graph into sections with ascribed irrigation quality. Another scheme is the Wilcox [2] diagram which is a plot of the percentage sodium against the EC. The Doneen's diagram plots the permeability index, calculated from the relative proportions of sodium and bicarbonate ions on one hand, and the sum of the major cations on the other hand, against the total ion content of the water in milliequivalents per liter. These categorization schemes have been used generally and widely to assess irrigation water quality prior to various irrigation schemes in the world [3].
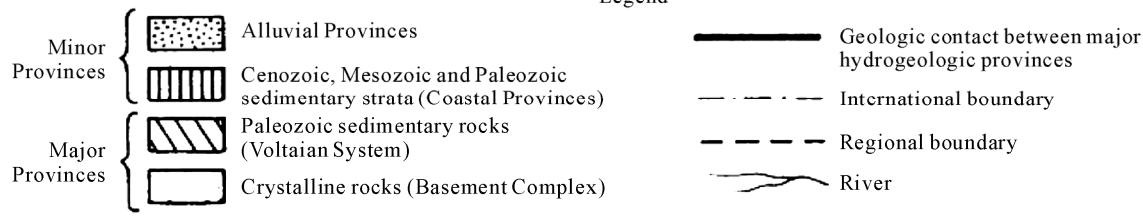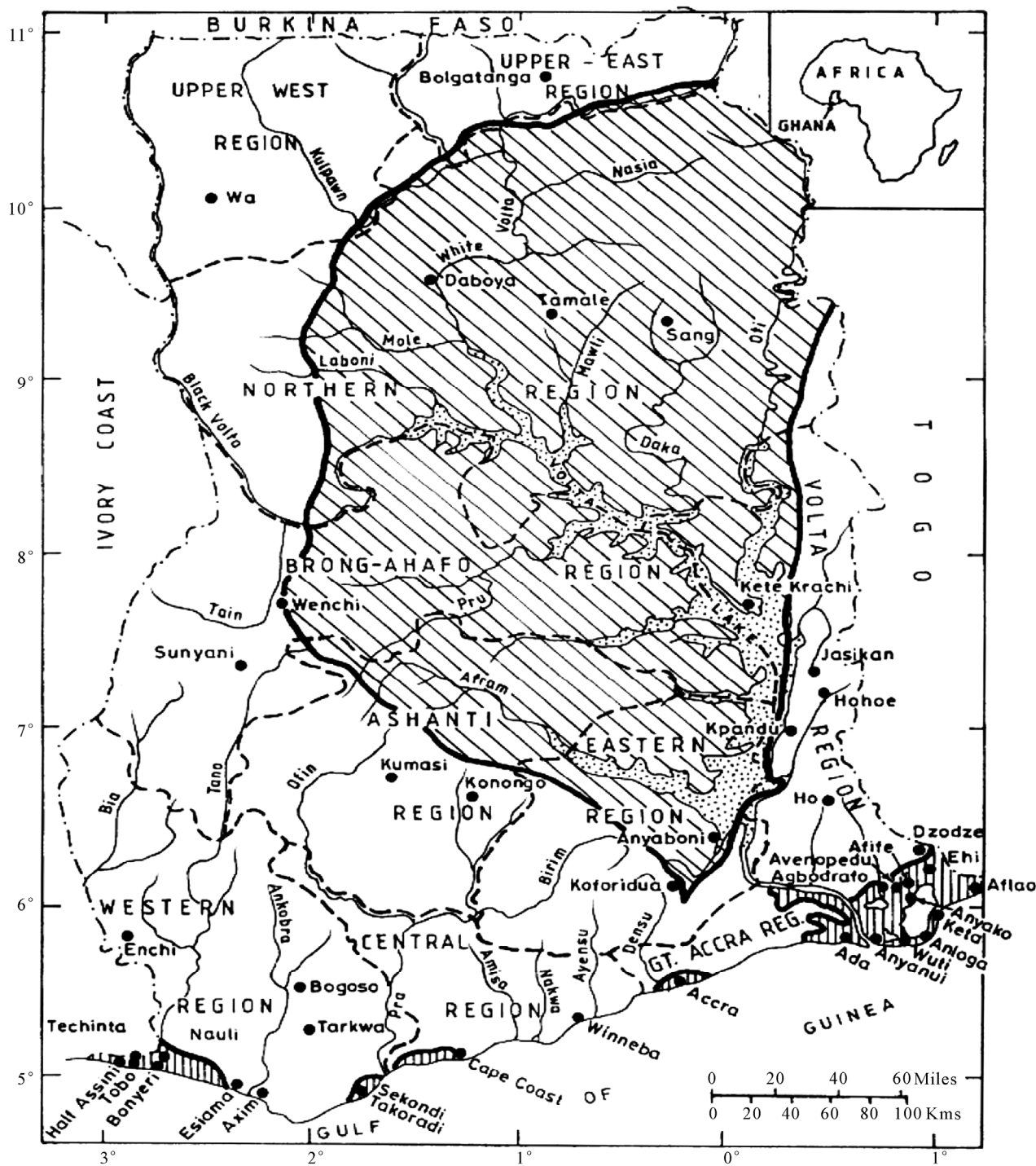
A thorough assessment of the irrigation quality of waters is based on the total ion content of the water as reflected in the EC, the SAR, the temporal variations in these parameters, as well as the specific toxic effects of individual ions such as boron. It has also been noted that the effects of high SAR values are slightly higher when the ratio of calcium to magnesium in irrigation waters is lower than 1 [4]. The soil is more likely to contain high sodicity values when the calcium content of the irrigation water is higher than the magnesium content.

In this study, the quality of surface water from two major river basins in southern Ghana is being assessed to determine their suitability for irrigation in a tropical setting. An attempt is being made to investigate the variations of the assessment parameters to seasonal changes and the spatial variations of these parameters. The coastal and southwestern river basins have been sampled to be used as a case study. In the literature, little is known about the irrigation quality of surface water bodies in Ghana. Yidana *et al*. [5] used water quality data from some portions (three locations) of the Ankobra River Basin in southern Ghana to determine the variations of SAR and EC with time, and the concomitant effects on the irrigation quality of water from these locations. Later, Yidana [6] carried out an assessment of the major parameters controlling surface water hydrochemistry in southern Ghana. He determined that the quality of rainfall as well as the weathering of the underlying rock is the major factor influencing the hydrochemistry at the basin scale. His study, however, did not comprehensively assess the variations of irrigation quality control parameters with season and location. Other studies have been conducted on groundwater quality for irrigation in Ghana [7,8]. The uniqueness of the current study lies in the incorporation of seasonal effects on the irrigation quality of surface water bodies in a typical tropical environment such as Ghana. Such an assessment is relevant because the irrigation quality of water is influenced by a gamut of factors which likely vary with season. Since such basins will be accessed for all year through irrigation schemes, it is crucial that an assessment of the quality of water they deliver for irrigation takes into account the effects of seasonal variations.

2. The Study Area

The drainage system in Ghana is divided into three main components: The Volta river system, the southwestern river system, and the coastal river system. The study area comprises the coastal basins and the southwestern river systems of Ghana (**Figure 1**). The southwestern river system covers about 22% of the drainage network in Ghana and consists of the Bia, Tano, Pra, and Ankobra Basins. It is located between latitudes 5˚N and 7.7˚N and longitudes 0.3˚W and 3.2˚W. The mean slope of the river basin ranges between 0.2% and 0.4% [9]. The southwestern river system receives recharge from numerous streams. The relief is relatively low, with the lowest elevation being about sea level [9], and very few high elevations. For instance in the basin, average elevations range between 150 - 300 m above sea level, although there are a few locations of elevations exceeding 600 m. In the Tano basin on the other hand, average elevation is about 225 m, and the highest elevation is about 580 m above mean sea level. The Ankobra basin has the lowest average elevation of 75 m, but most areas range from 0 m and 15 m above sea level in elevation. The mean annual rainfall in the southwestern river system ranges from 1136.7 mm to 2156.0 mm. There are two main rainy seasons peaking respectively in May/June and September/October of every year. Temperature ranges

Legend

Minor Provinces	▨ Alluvial Provinces
	⊞ Cenozoic, Mesozoic and Paleozoic sedimentary strata (Coastal Provinces)
Major Provinces	◨ Paleozoic sedimentary rocks (Voltaian System)
	☐ Crystalline rocks (Basement Complex)

▬▬▬ Geologic contact between major hydrogeologic provinces

—·—·— International boundary

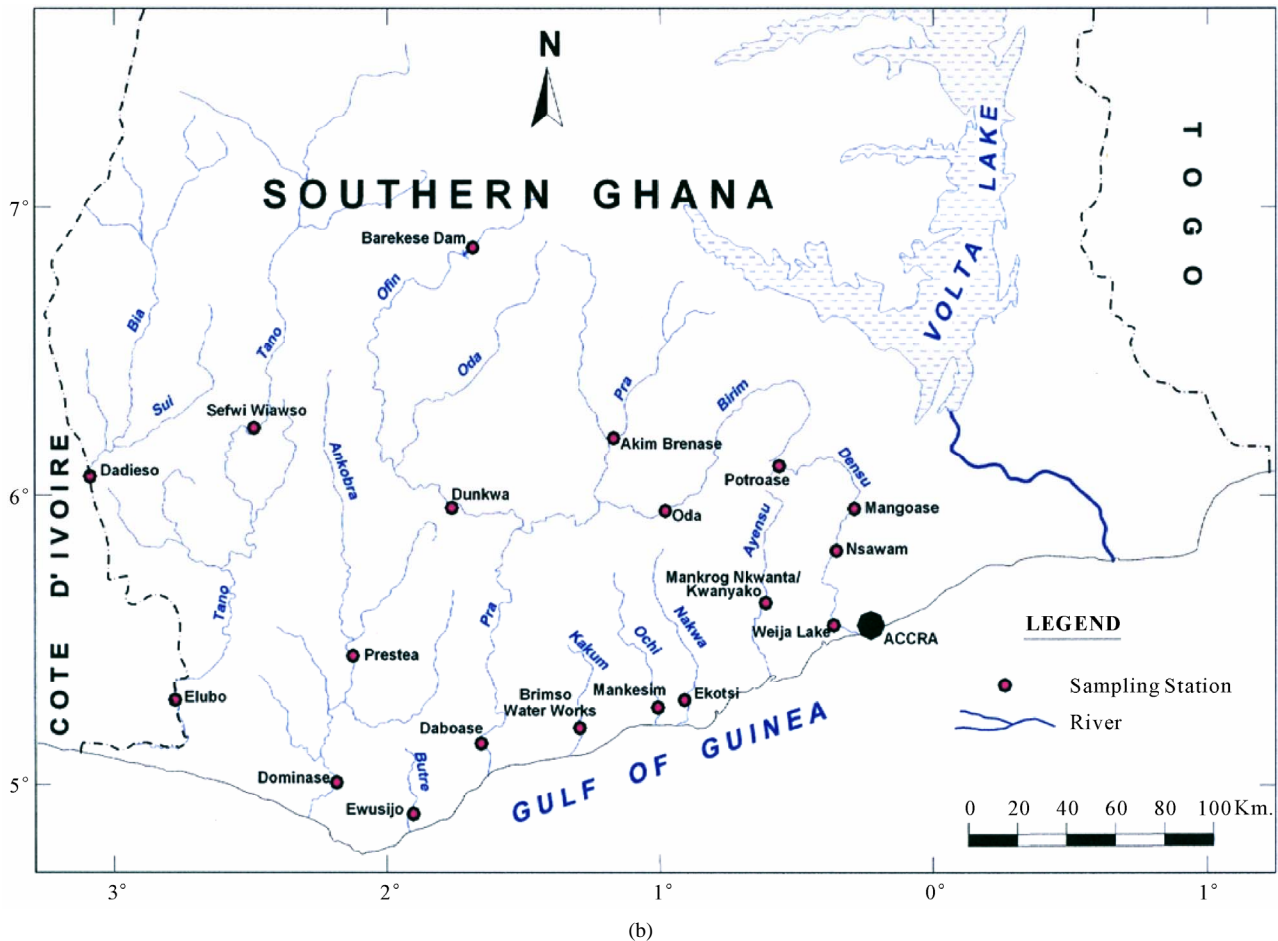— — — Regional boundary

〜〜 River

(a)

(b)

Figure 1. (a) A hydrogeological map of Ghana showing the underlying geology of the Coastal and Southwestern River Basins; (b) Drainage map of southern Ghana showing the Southwestern and Coastal River Basins.

between 25°C and 27°C. The annual relative humidity ranges between 58% and 96%.

The coastal river system is made of the Densu, Ochi-Amisa, Ochi-Nakwa, and Kakum River Basins and covers an estimated area of 8010 km^2 (Dickson and Benneh, 1995). The river system feeds several important water supply systems such as the Weija, Winneba, Kwanyaku, and Baafikrom. The lowest elevations in the area are about sea level, whilst elevations as high as 500 m above sea level are common. The coastal river basins are underlain by the Precambrian granites and granodiorites and associated gneisses. The Lower and Upper Birimian and Dahomeyan rocks, as well as some Tertiary sediments, also underlie some areas within the coastal river basins. Due to the vast size of the coastal river basins, the climate is greatly varied, and is characterized by highly variable high temperatures and annual rainfall. The average annual temperature is about 28.5°C. The hottest months in the basin are February to April when the mean monthly temperature is about 32°C. There are two distinct climatic zones in the area: the dry equatorial climate

and the wet equatorial climate zones [10]. There are two rainfall regimes with different intensities. Annual rainfall ranges between 900 mm and 1600 mm in the dry and wet equatorial zones respectively.

3. Methodology

Samples were taken from nineteen locations representative of the coastal and southwestern river basins in Ghana in the months of February, May, July, September, and November of 2006, and 2008. All sampling protocols were observed in the field and the samples were analyzed in the laboratories of the Council for Scientific and Industrial Research in Accra, for the concentrations of the major cations and anions, as well as silica. Other parameters determined include the total suspended solids (TSS), the biochemical oxygen demand (BOD), chemical oxygen demand (COD), NO$_3$-N, NO$_2$-N, NH$_3$-N, turbidity and dissolved oxygen content (DO). pH and electrical conductivity (EC) were measured in the field using standard meters properly calibrated for

such uses. The sampling and analyses were conducted by the staff of the Water Research Institute of the Center for Scientific and Industrial Research (CSIR) in Accra, contracted by the Ghana Water Resources Commission.

The resulting data for each parameter for the five months in each of the two years are summarized in **Table 1**. The data were standardized to their corresponding z-scores according to Equation (1), in order to meet the criteria for optimal multivariate analyses. The combined data for the five months of the two years were subjected to R-mode factor analysis and hierarchical cluster analysis (HCA). Data for the parameters for November 2008 were subjected to Q-mode HCA in order to produce spatial surface water associations in the study area. In both the R and Q-mode HCA, squared Euclidean distance was selected as the measure of similarity/dissimilarity, whilst the Ward's linkage method was used to link initial clusters. Several similarity/dissimilarity measures are available in the literature and statistical codes for HCA. However, in both modes of HCA, the combination of Euclidean distances and Ward's linkage method has been found to produce optimal results [5,11,12], and has been copiously used in multivariate classification schemes [3,5,13].

$$z = \frac{x - \bar{x}}{s} \qquad (1)$$

where z, x, $\bar{x}$, s are respectively the standardized values, the concentrations, mean and standard deviation of the parameters.

In the R-mode factor analysis, principal components analysis was selected as an extraction method whilst varimax rotation was selected as the rotation algorithm. Factor rotation is the application of an orthogonal matrix to the results of the factor analysis, and different matrices are applied based on the rotation type chosen. In this study, the varimax rotation was chosen to increase the variance among the resulting factors, thereby maximizing the ease of interpretation of the results. Naturally, it is possible to produce as many factors as there are variables in the dataset. However, this is usually avoided as much as possible since some of the factors produced in this fashion would not represent unique sources of variation in the dataset. For this reason, the Kaiser criterion is applied to ward off unnecessary factors in the final model. Kaiser criterion [14] requires that a unique factor worthy of inclusion in the final factor model must have an eigenvalue of not less than 1.

The irrigation quality of the water was assessed using the SAR (Equation (2)), the EC, and the sodium percent (Equation (3)). The Wilcox [2] and USSL [15] diagrams were therefore generated to characterize the irrigation quality of surface water from the study area.

$$SAR = \frac{m_{Na^+}}{\sqrt{\left(m_{Ca^{2+}} + m_{Mg^{2+}}\right)}} \qquad (2)$$

where the ionic concentrations are in mmol/L.

$$Na\% = \frac{m_{Na^+}}{m_{Na^+} + m_{Ca^{2+}} + m_{Mg^{2+}} + m_{K^+}} \qquad (3)$$

where the concentrations are in meq/L.

4. Results and Discussions

4.1. General Hydrochemistry and the Controls on Water Quality

Statistical summaries of the parameters analyzed for this study are presented in **Table 1**. The measures of the major parameters are generally low and show little variations from one season to the other. All parameters are within acceptable limits for most domestic uses, and could be attributed to natural causes. Since the river systems are generally flowing, there does not appear to be the cumulative enrichment of specific parameters from one season to the next.

Multivariate statistical methods have been copiously applied to a variety of geo-environmental studies throughout the globe. They have been used to delineate hydrochemical zones with definitive causative agents [8,13]. The method has also facilitated the delineation of groundwater recharge and discharge areas, and to characterize the general hydrochemistry of basins [5]. Usually factor analysis is applied together with cluster analysis, and the two are very useful in characterizing basins, thus providing clues of trends of environmental contamination. Factor analysis for instance is a data reduction multivariate statistical tool which reduces a large set of data of variables into a smaller number of uncorrelated, easily interpretable factors. Factor analysis is used in a similar fashion as piper trilinear diagrams, with the added advantage that it includes other parameters which are not usually used in piper trilinear diagrams. The result is a more robust hydrochemical classification model for basins.

R-mode factor analysis with varimax rotation resulted in five factors accounting for over 73% of the total variance in the hydrochemistry. **Table 2** presents the results of the factor analysis. Factor 1 loads highly and positively with all the major cations (except Na⁺), and BOD, and loads negatively against COD, accounting for about 22% of the total variance among the five factors. The biochemical oxygen demand provides an impression about the content of organic matter present in the system, and thus provides an indication of the degree of organic

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Table 1. Summary of the water quality data (February 2008).

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	26.716	639.202	202.684	12.000	5.568	23.593	0.030	0.642
Median	26.300	6.180	171.000	11.000	5.600	20.500	0.030	0.486
St.dev	1.652	1895.997	138.049	6.333	2.085	17.401	0.025	0.536

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na(mg/l)	K(mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	6.732	9.159	16.137	7.337	19.863	4.337	18.268	14.670
Median	6.800	4.100	13.600	7.300	13.200	4.200	13.900	12.800
St.dev	0.844	15.427	8.438	3.254	15.901	0.936	13.658	7.536

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F(mg/l)	PO$_4$-P (mg/l)	Hardness (mg/l)	NH$_3$-N (mg/l)	SiO$_2$ (mg/l)	
Mean	76.947	111.547	0.651	0.026	70.737	0.696	32.153	
Median	58.000	94.100	0.613	0.010	56.000	0.719	31.700	
St.dev	47.180	75.933	0.451	0.046	30.282	0.340	6.677	

May 2008

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	26.189	6.180	147.195	25.789	4.847	54.926	0.040	0.609
Median	26.200	6.200	123.000	16.000	5.100	47.800	0.040	0.439
St.dev	1.438	0.256	77.365	23.115	1.344	26.316	0.021	0.580

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	7.221	40.903	11.621	6.795	17.279	3.658	15.716	28.447
Median	7.300	32.500	9.600	5.800	14.400	3.300	9.900	28.800
St.dev	0.816	33.545	4.999	4.570	6.752	1.013	11.527	7.648

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	PO$_4$-P (mg/l)	Hardness (mg/l)	NH$_3$-N (mg/l)	SiO$_2$ (mg/l)	
Mean	45.684	80.947	0.647	0.048	56.632	0.450	19.042	
Median	38.000	67.700	0.470	0.037	48.000	0.275	18.600	
St.dev	25.796	42.529	0.580	0.038	26.825	0.356	4.050	

July 2008

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	26.047	6.933	146.011	35.421	7.163	3.400	0.009	0.714
Median	26.200	6.940	119.000	27.000	7.200	3.400	0.011	0.306
St.dev	0.964	0.275	67.591	28.161	0.579	0.720	0.005	0.797

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	7.163	28.282	10.695	4.521	15.484	5.111	12.842	16.765
Median	7.200	25.700	8.800	3.900	14.000	4.600	11.900	16.800
St.dev	0.579	16.361	5.381	2.180	7.158	1.985	5.983	4.889

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	SAR	PO$_4$-P (mg/l)	Hardness (mg/l)	NH3-N (mg/l)	SiO$_2$ (mg/l)
Mean	55.579	80.326	0.179	1.046243	0.076	45.053	0.529	19.253
Median	46.000	65.500	0.111	1.082983	0.054	38.000	0.510	18.800
St.dev	24.364	37.192	0.147	0.415987	0.052	21.327	0.283	3.820

September 2008

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	26.779	7.324	552.579	40.579	3.853	39.411	0.018	0.597
Median	26.600	7.300	110.000	27.000	4.200	38.600	0.010	0.448
St. dev	1.082	0.554	1830.134	30.848	0.875	13.082	0.023	0.415

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	6.932	28.753	9.432	4.505	21.095	4.263	11.479	22.447
Median	6.700	20.700	8.000	3.900	20.000	4.300	9.900	20.900
St. dev	1.044	25.545	4.246	2.735	8.905	0.833	6.036	8.169

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	SAR	PO$_4$-P (mg/l)	Hardness (mg/l)	NH3-N (mg/l)	SiO$_2$ (mg/l)
Mean	50.211	71.626	0.156	1.464	0.056	46.842	0.463	11.207
Median	44.000	60.500	0.118	1.249	0.044	36.000	0.412	10.800
St. dev	22.479	29.501	0.124	0.618	0.046	22.334	0.263	4.321

November 2008

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	28.842	6.596	169.126	24.053	6.911	3.821	0.055	0.310
Median	28.900	6.460	157.000	20.000	7.000	3.400	0.032	0.272
St. dev	1.484	0.555	71.641	18.085	0.934	1.401	0.098	0.202

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	6.911	19.364	11.747	5.037	23.821	5.163	13.732	29.674
Median	7.000	14.400	10.400	4.400	25.500	5.100	11.900	29.300
St. dev	0.934	14.375	5.294	2.315	8.122	2.070	7.003	11.254

Parameter	Alkalinity (mg/l)	TDS (mg/l)	PO$_4$-P (mg/l)	Hardness (mg/l)	NH$_3$-N(mg/l)	SiO$_2$ (mg/l)
Mean	59.158	93.032	0.026	49.789	0.405	18.879
Median	54.000	86.400	0.007	40.000	0.366	17.400
St. dev	28.785	39.402	0.056	21.867	0.143	3.736

February 2006

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	29.005	7.076	186.763	30.842	4.847	24.843	0.008	0.461
Median	29.300	7.000	175.000	26.000	4.800	27.000	0.003	0.333
St. dev	1.723	0.329	91.601	26.344	1.391	15.568	0.014	0.348

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	6.884	29.089	11.832	4.926	24.032	3.397	20.211	25.642
Median	7.000	17.400	12.000	3.900	19.800	3.500	14.900	20.700
St. dev	1.062	32.668	5.310	2.701	9.794	1.359	13.381	14.282

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	NH$_3$-N (mg/l)	PO$_4$-P (mg/l)	SiO$_2$ (mg/l)	Hardness (mg/l)
Mean	64.947	102.189	0.516	0.599	0.239	17.721	50.105
Median	66.000	96.300	0.538	0.573	0.187	17.900	46.000
St. dev	21.472	50.943	0.229	0.312	0.151	5.794	21.863

May 2006

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	26.374	6.681	143.489	39.222	3.242	68.632	0.052	0.316
Median	26.100	6.670	110.000	34.000	2.900	64.000	0.038	0.313
St. dev	1.632	0.377	90.087	31.506	1.737	18.536	0.052	0.181

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl(mg/l)	SO$_4$ (mg/l)
Mean	5.421	42.359	8.800	2.353	17.916	3.126	10.768	20.579
Median	5.300	44.800	5.600	1.000	18.000	3.300	7.900	20.800
St. dev	2.011	30.332	5.787	2.412	7.608	0.597	11.023	8.919

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	NH3-N (mg/l)	PO$_4$-P (mg/l)	SiO$_2$ (mg/l)	Hardness (mg/l)	
Mean	45.400	78.932	0.410	1.239	0.253	23.005	31.474	
Median	38.000	60.500	0.396	1.130	0.216	23.500	18.000	
St. dev	26.047	49.558	0.194	0.761	0.270	4.890	23.092	

July 2006

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	25.637	6.704	154.526	18.316	4.163	34.842	0.013	0.243
Median	25.400	6.580	128.000	16.000	4.000	31.000	0.008	0.224
St. dev	1.253	0.399	69.664	11.111	1.381	18.449	0.015	0.109

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	7.237	33.105	9.979	1.547	22.679	3.158	11.389	22.433
Median	6.900	39.000	8.000	1.000	23.000	2.880	8.900	23.000
St. dev	1.198	18.227	5.322	1.164	8.353	1.044	6.872	6.305

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	NH$_3$-N (mg/l)	PO$_4$-P (mg/l)	SiO$_2$ (mg/l)	Hardness (mg/l)	
Mean	55.474	85.000	0.433	0.923	0.100	15.021	31.263	
Median	44.000	70.400	0.446	0.958	0.126	14.500	24.000	
St. dev	29.521	38.301	0.123	0.415	0.063	2.680	17.464	

September 2006

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	25.763	6.275	147.163	80.921	4.616	61.374	5.386	0.397
Median	25.600	6.230	141.000	77.600	4.600	62.100	0.062	0.404
St. dev	0.965	0.549	63.646	34.959	0.932	33.741	15.980	0.097

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	7.505	45.488	7.916	2.142	20.132	3.101	9.589	41.962
Median	7.600	31.400	5.600	1.900	17.800	2.960	6.000	18.800
St. dev	0.806	38.583	4.725	2.067	8.492	0.614	8.575	75.291

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	NH$_3$-N (mg/l)	PO$_4$-P (mg/l)	SiO$_2$ (mg/l)	Hardness (mg/l)	
Mean	42.632	80.921	0.288	1.326	0.083	24.497	28.632	
Median	36.000	77.600	0.233	1.270	0.063	23.500	18.000	
St. dev	19.345	34.959	0.200	0.726	0.089	8.178	17.864	

November 2006

Parameter	Temp	pH	EC (uS/cm)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	NO$_2$-N (mg/l)	NO$_3$-N (mg/l)
Mean	26.874	6.582	142.453	25.737	4.716	33.421	0.016	1.713
Median	26.700	6.540	128.000	22.000	4.600	25.600	0.012	1.710
St. dev	1.282	0.367	68.350	16.248	1.213	26.928	0.012	0.848

Parameter	DO (mg/l)	Turb (NTU)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO$_4$ (mg/l)
Mean	7.205	53.326	9.879	4.926	19.463	2.238	11.532	16.537
Median	7.000	42.200	8.000	3.900	19.200	2.200	8.900	15.200
St. dev	1.353	34.034	5.526	3.124	4.304	0.604	6.682	6.143

Parameter	Alkalinity (mg/l)	TDS (mg/l)	F (mg/l)	NH$_3$-N (mg/l)	PO$_4$-P (mg/l)	SiO$_2$ (mg/l)	Hardness (mg/l)	
Mean	48.526	78.342	0.309	1.271	0.052	21.397	46.737	
Median	38.000	70.400	0.211	1.300	0.052	21.400	38.000	
St. dev	27.975	37.626	0.180	0.700	0.037	5.943	24.732	

Table 2. Rotated factor model for the coastal and south-western river basins.

	Component				
	1	2	3	4	5
TSS (mg/l)	0.091	–0.241	0.844	0.178	–0.024
Sechi (cm)	–0.201	–0.231	–0.523	0.446	–0.091
BOD (mg/l)	0.654	0.202	–0.055	–0.024	0.257
COD (mg/l)	–0.628	0.184	0.208	0.049	–0.294
NO$_3$-N (mg/l)	0.143	0.040	0.046	–0.099	0.757
DO (mg/l)	–0.490	0.344	–0.261	0.053	0.318
Turb (NTU)	–0.440	0.041	0.757	0.028	0.093
Ca (mg/l)	0.790	0.060	0.235	–0.037	–0.237
Mg (mg/l)	0.616	0.254	–0.233	–0.019	–0.114
Na (mg/l)	–0.172	0.903	0.088	0.118	0.179
K (mg/l)	0.720	–0.219	–0.006	0.263	0.092
Cl (mg/l)	–0.023	0.882	–0.073	–0.160	–0.057
SO$_4$ (mg/l)	–0.338	0.428	0.299	0.261	0.502
SiO$_2$ (mg/l)	0.096	0.116	–0.087	–0.860	–0.107
Alkalinity (mg/l)	0.340	0.844	–0.136	–0.054	0.043
pH	0.268	0.137	0.039	0.796	–0.187

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization.

contamination. Factor 1 also loads negatively with DO, suggesting that this factor is associated with processes which consume the dissolved oxygen content of the water. The oxidation of organic carbon from various contamination sources, will certainly involve a reduction in the DO content of the water since raw oxygen is the most powerful oxidant of organic matter. This suggests that factor 1 represents contamination from solid waste disposal, which apparently is the source of the major cations in the hydrochemistry. Factor 1 represents the effects of the improper disposal of solid waste with significant metal content in the area. Refuse dumps are rampant in the vicinities of these river systems, and as runoff from rainfall is the major recharge, leachates from these dumps find their way into the flows.

Factor 2 loads positively with Na$^+$ and Cl$^-$ ions and obviously represents the contribution of the chemistry of rainfall, and the dissolution of halite in the soils, to the hydrochemistry of the river basins in the area. This is the second most important process controlling surface water hydrochemistry in the area. There is a reasonably strong relationship between Na$^+$ and Cl$^-$ ions in the hydrochemistry (**Figure 2**). Such strong relationships are characteristics of the contribution of recharging rainwater, and /or the weathering of halite in the underlying sediments. Earlier studies [5,6] suggest rainfall and the weathering of underlying bedrock and sediments as the major sources of variation in the hydrochemistry of the Ankobra River and surrounding areas. Such studies were based on the major ion content and silica, and did not include the BOD, COD, and DO contents. The role of solid waste disposal in the hydrochemistry may have been shielded because these parameters were not included in the overall assessment of the quality control parameters.

The third factor loads positively with total suspended solids (TSS) and turbidity, and obviously loads nega-
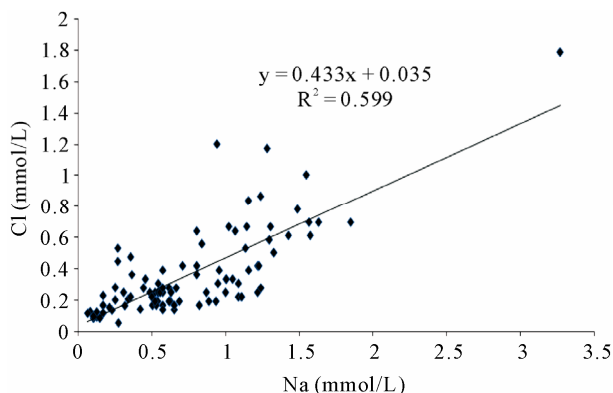
Figure 2. The relationship between Na and Cl ions in the area.

tively with Sechi which measures the degree of transparency of the water. Factor 3 therefore represents the enrichment of the suspended load of the river basins in the area. Turbidity and TSS content of water are directly related to each other and therefore have a common source. The effects of surface mining activities, especially the illegal activities of artisanal miners, popularly called "galamsey" operators in the Western Region have been blamed for the increasing suspended load of the river basins. Factor 3, the turbidity factor, therefore represents the effects of surface mining activities on surface water quality in the study area. Pollution of water bodies by illegal surface mining activities and its deleterious effects on aquatic life and terrestrial ecosystem in the Western Region and other parts of the country represent a major environmental issue that has been the cause for concern over the years. In addition to the problems of turbidity, some heavy and toxic metals sometimes find their way into the water bodies leading to the poisoning of the aquatic organisms. High turbidity in water hampers the smooth movement of aquatic organisms and can cause death. The position of surface mining activities in the scheme of factors influencing surface water hydrochemistry is significant, in that it ranks after solid waste contamination and the contribution of rainfall hydrochemistry. This study did not include the conventional contaminants such as mercury and other heavy metals which are usually associated with mining operations in the area. Since the inception of mining activities in the Western Region, there have been reports of contamination of surface water bodies in the area. These range from increases in turbidity which hampers aquatic life and renders the water unattractive for human consumption, to chemical spills [16].

Factor 4 has high positive loading with pH, and loads negatively with SiO_2 suggesting that the processes controlling these parameters are divergent or orthogonal. This factor represents the weathering of silicate minerals

in the underlying lithology. The incongruent weathering of silicate minerals requires acid medium to be effective. As the pH of the medium increases, the propensity of these silicate weathering processes reduces. It is on account of this fact that these parameters load negatively with each other in the hydrochemistry. Silicate weathering is certainly not a major process controlling surface water hydrochemistry in the area. This finding is not surprising due to the fact that silicate weathering processes play significant roles only when the residence time of the water over the underlying sediment and basement rock is long enough. For silicate mineral weathering to contribute significantly to the hydrochemistry, residence times as long as a couple of millions of years will be necessary. In the case of river basins, the residence time is rather short, resulting in shorter periods of contact between rocks and the water. This is contrary to the findings with respect to the major controls on groundwater hydrochemistry at most of the basins in Ghana, where general mineral weathering processes have been determined to be the major sources of variation in the hydrochemistry [3,7].

The final factor in the factor model has high positive loadings for NO_3-N, and SO_4^{2-} and represents the contribution of agricultural chemicals to the hydrochemistry of these surface water basins. Nitrate- and sulfate-rich fertilizers and manures are extensively used in farms and backyard irrigation schemes. Some of the irrigation schemes involve the use of surface water from some of the river basins under study. The excess fertilizer is washed into the river systems, thus raising the nitrate and sulfate levels beyond their natural concentrations. Obviously, the raw concentrations of these parameters and the results of the factor analyses do not ascribe any significance to these processes in the hydrochemistry of surface water basins in the study area. The critical national standard for NO_3-N in portable water is 10 mg/l. Nitrate-N concentrations in the area over the period of the analyses are largely lower than 1.00 mg/l, and the highest concentration is a little over 3 mg/l. The critical maximum permissible concentration of SO_4^{2-} in potable water is 200 mg/l. Sulfate concentrations in the area over the period of the analyses, are lower than 50 mg/l in most cases, suggesting that contamination from agricultural chemicals are not significant enough to cause any health hazards.

The results of the R-mode HCA reproduced the results of the factor analysis (**Figure 3**). The dendrogram is the visual product of the HCA and in the case of the R-mode, the parameters (hydrochemical variables) are grouped into associations based on similarities/dissimilarities in the trends of their levels/concentrations in the field. Parameters which trend similarly in the field will be linked

to each other at closer linkage distances than those that are dissimilar in the field. **Figure 3** is the dendrogram for the R-mode HCA. A phenon line is drawn across the dendrogram at a preferred linkage distance in order to separate and distinguish the resulting clusters. Five clusters (groups) have been differentiated. Group 1 members are the most similar amongst all the groups. This group contains Na^+, Cl^-, TDS, hardness and alkalinity. Sodium and Cl^- ions are connected at a linkage distance of about 2, suggesting that the relationship between these two ions in the field is close and they vary in tandem. Alkalinity and TDS are also joined at a distance of about 2, and connected to the Na-Cl sub-cluster and hardness at a distance of about 3. Total dissolved solids and EC were both rejected in the R-mode factor analysis due to low communalities after the first trial of the analysis. They were therefore not part of the final factor model. The TDS appears to vary with Na^+ and Cl^- ion enrichment.

Group 2 contains BOD, K, Ca, and Mg, and mirrors factor 1 of the factor analysis. The connecting distances further suggest that K^+ and Ca^{2+} are more closely related to the BOD content of the water than does the Mg^{2+} ion. Groups 3, 4, and 5 respectively mirror factors 3, 4, and 5 of the final factor model. The dendrogram includes some more parameters than could be included in the factor model. Most of such factors were excluded from the factor model on account of low communalities. Their inclu-

sion on the dendrogram assists in the explanation of the trends represented by each of the water associations reproduced by the HCA and when compared to the factor model, the probable sources of some of these parameters can be deduced. For instance both total phosphorus (TotP) content and PO_4^{3-} concentrations are linked to the turbidity, which suggests that there is some component of the turbidity which is attributable to domestic waste. It is, however imperative to state that some of the associations may not necessarily be causative since statistical associations do not necessarily suggest causative relationships. For instance NH_3-N, and total nitrogen are in the same group as SiO_2. Whereas this may suggest that some component of the silica content of the water may be of organic origin, it does not necessarily indicate that the two parameters have a common source. In the study area, the relationship between SiO_2 and NH_3-N might be more complex. It might be related to the conditions that accompany their production. Silicate mineral weathering requires acid media to be effective, and the effect on the medium is an increase in pH. NH_3-N is also associated with high pH.

The Q-mode HCA is presented in **Figure 4**. The water associations generally go along the lines of the river basins being studied. Two surface water associations have been distinguished in **Figure 4**. Group 1 members are mainly from the southwestern river basins, whilst group 2 members are drawn from the coastal river systems.
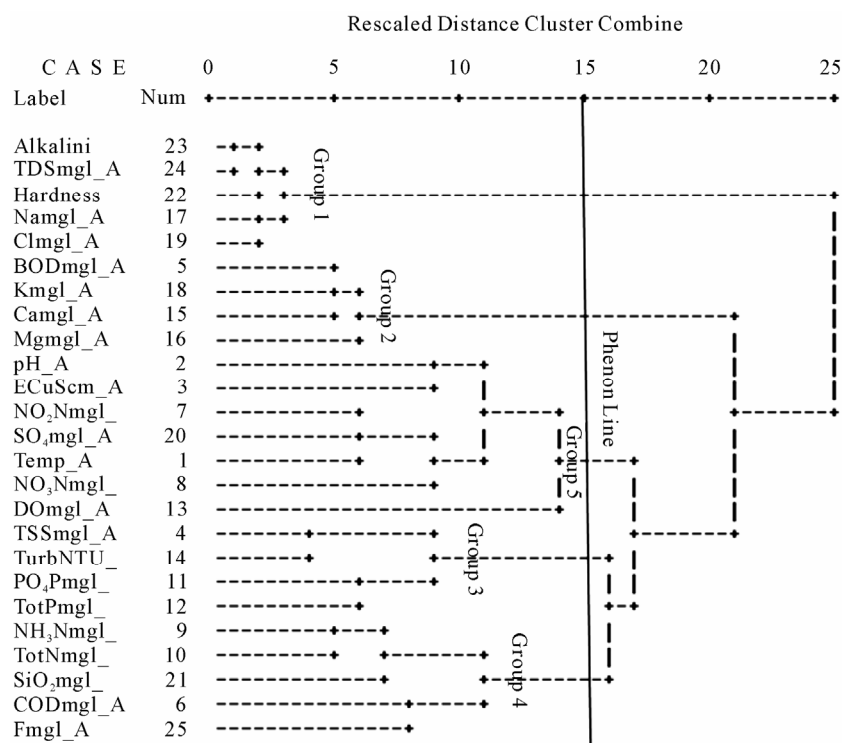

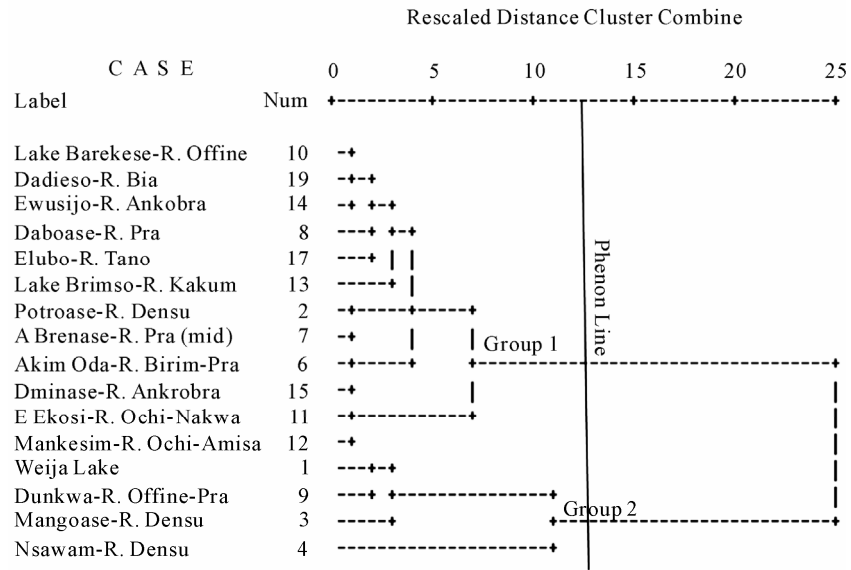**Figure 3. Dendrogram showing the results of the R-mode HCA**

Figure 4. Dendrogram from the Q-mode HCA.

Summaries of the parameters in each group are presented in **Figure 5**. In general, mean and median concentrations of the parameters in group 1 are higher than those of group 2. Both surface water associations are Na-K-HCO$_3$ water types (**Figure 6**). It appears that the southwestern river basins are much more enriched in terms of all the parameters than the coastal river basins. The significant finding from the Q-mode HCA is the clear differentiation of the two river systems in the area, which provides once again, another helpful use of HCA in environmental data analyses. The apparently higher concentrations of the major parameters in the southwestern river basins is attributed to the effects of surface mining activities in the Western Region, which are responsible for a significant proportion of the major ions in the water.

4.2. Irrigation Quality of Water from the Study Area

The assessment of the quality of water from the study area for irrigation is based on the salinity and sodium content relative to the concentrations of the other major cations in the water system. Extremely high salinities in irrigation waters have several adverse effects on both the irrigation soil and the crops being irrigated. High salinities affect plants both physically and chemically. High salinity waters reduce the osmotic ability of plants and thus interfere with the capacity of plants to absorb water from the soils and transport it to the branches and leaves [17]. This leads to a physiological drought of the plant although there may be a lot of water in the soil. This condition can cause the wilting of plants leading to death.

In addition to the salinity effects, high concentrations of specific ions such as sodium, bicarbonate, and boron can be lethal to irrigation crops. Even if the salinity is low, high concentrations of these ions can interfere with the ability of plants to absorb water from soils. The long term effects of using high salinity waters for irrigation is the accumulation of salts in soils, leading to a reduction in the hydraulic properties of irrigation soils with time. When this happens, the ability of such soils to support optimum plant growth and development is greatly affected.

Figure 7 illustrates the variability of SAR values from one location to the other, and from one season to the next. Although the SAR values are generally low (below 4), the highest values for all seasons were recorded in September 2006 in Ekosi. The lowest seasonal variations were recorded in Lake Barekese. The low values in these areas are attributed to the relatively higher concentrations of the alkaline earth metals than the alkali metals in these areas.

Figure 8 presents the USSL [15] diagram for the study area. Both salinities and the sodium content are low in the study area as obviously shown in **Figure 8**. About 90% of the samples plot within the C1-S1 category and the remaining 10% plot within the C2-S1 region. This suggests that the use of water from the coastal and southwestern river basins in Ghana for irrigation will not pose sodium or salinity effects. This is however dependent on the conditions of the soils. Although the salinities are generally low, poor drainage can lead to the retention of salts in the soil zone, thus leading to the accumulation of salts in these soils over the long term. The Wilcox [2]
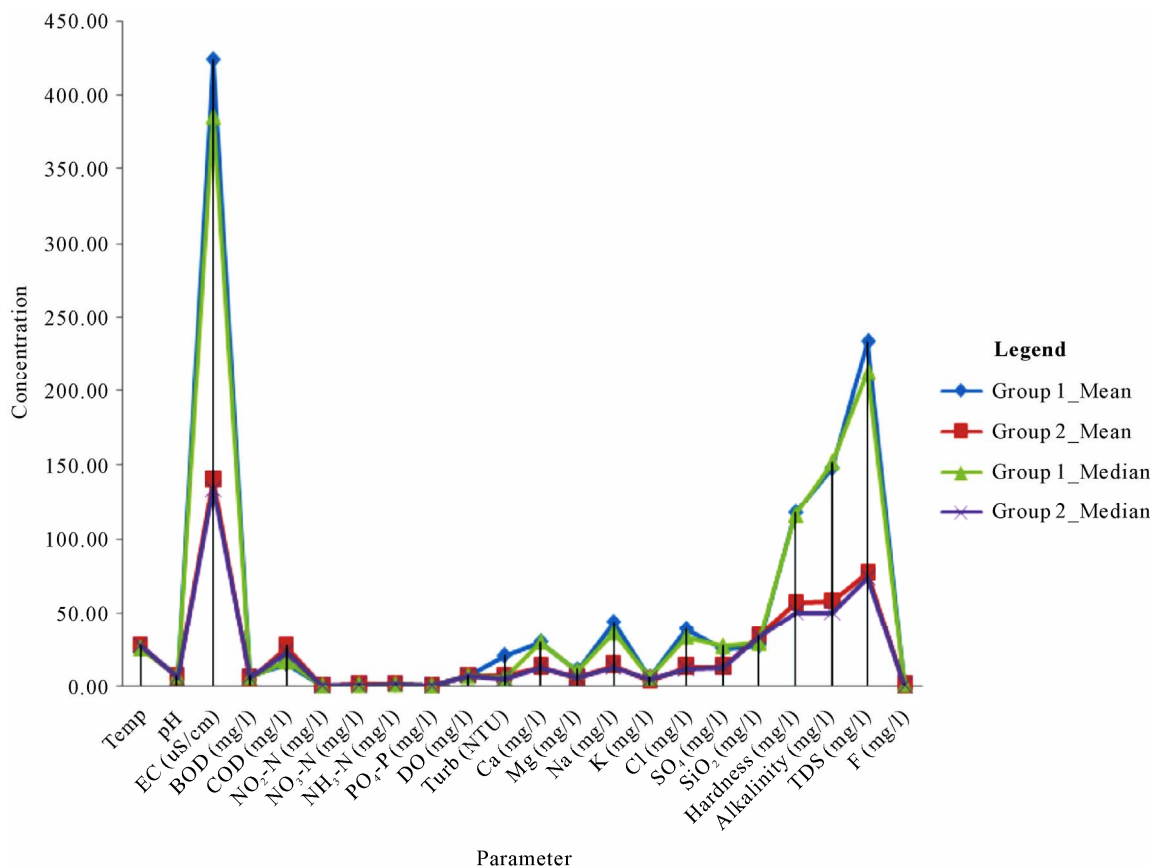
Figure 5. Summaries of the concentrations of the major parameters in clusters 1 and 2 from the Q-mode HCA.
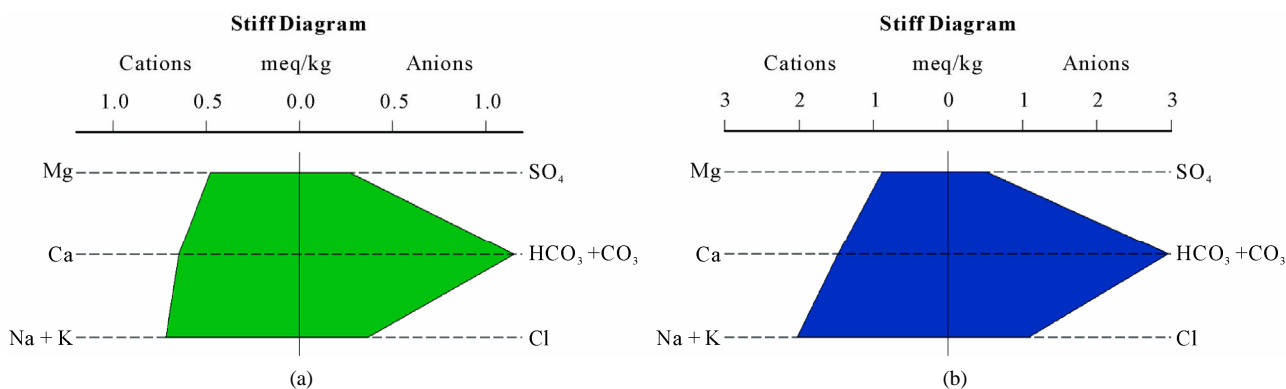

Figure 6. (a) Stiff diagram for the average of the concentrations of the major ions in cluster 1 from the Q-mode HCA; (b) Stiff diagram for the average of the concentrations of the major ions in cluster 2 from the Q-mode HCA.

diagram (**Figure 9**) confirms this and ascribes "excellent to good" irrigation quality to all the areas sampled. The generally low concentrations of the physico-chemical parameters in the water is responsible for the low SAR and EC values, which have together influenced the irrigation quality of the surface water from the area. These generally low concentrations of the physico-chemical parameters suggest that the waters are largely pristine and have low residence times over the underlying lithol-

ogy. Just as pertains in regional groundwater flow systems, surface water in the neighborhood of the discharge areas, after a long period of travel, is expected to have high concentrations for the major quality parameters. Low concentrations are characteristic of recharge areas or recently recharged surface waters. In the case of the study area, the concentrations are frequently diluted by rainfall which occurs two times in the year at most places in the locations sampled.
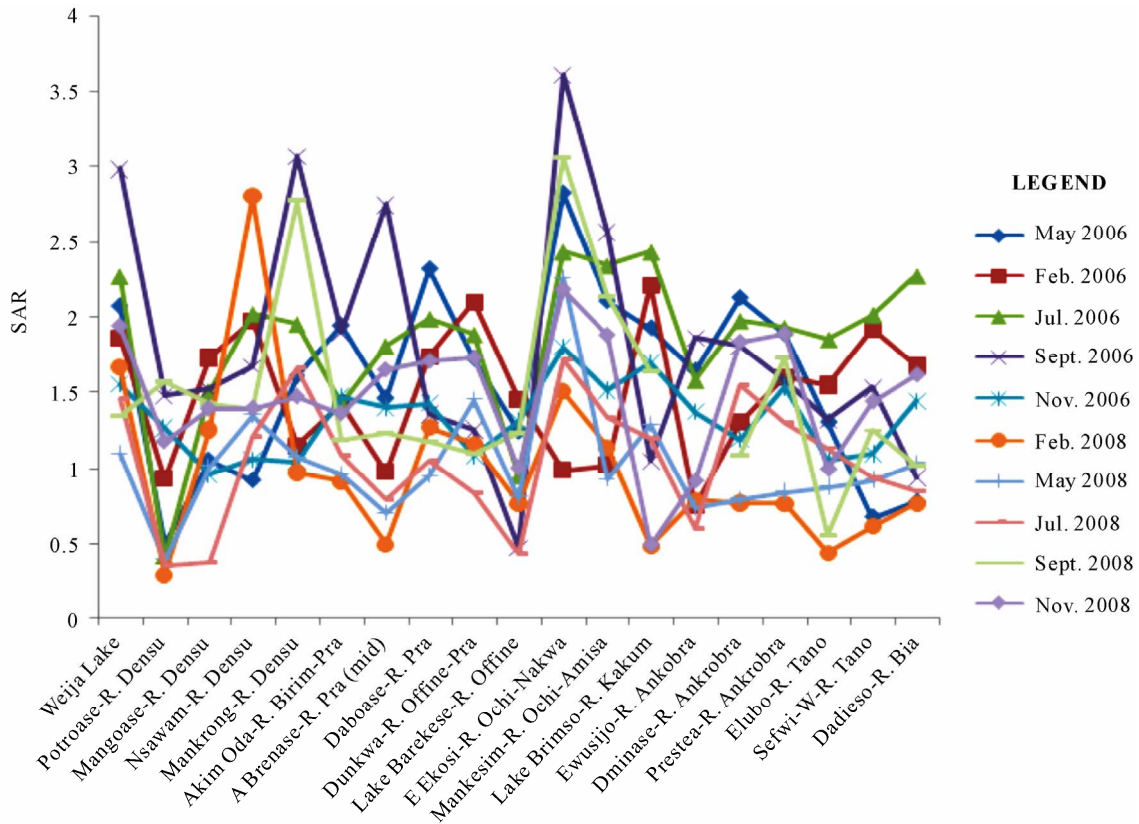
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Figure 7. Spatial and temporal variations of SAR in the area.
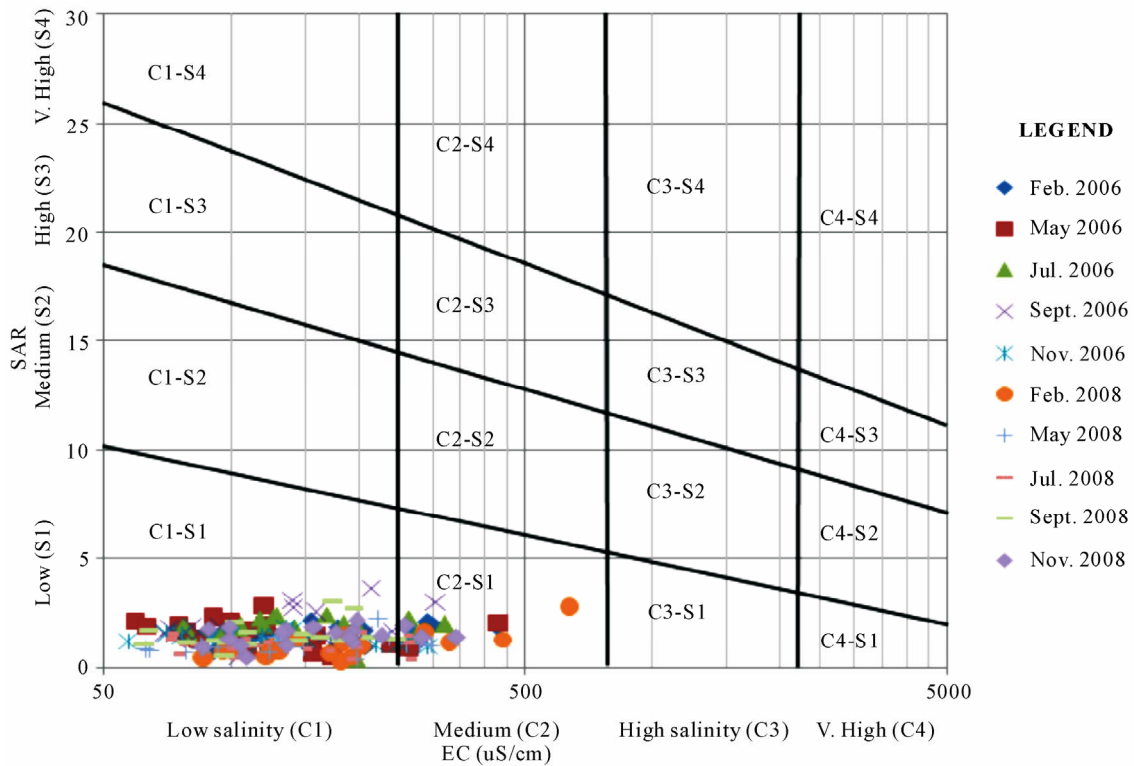

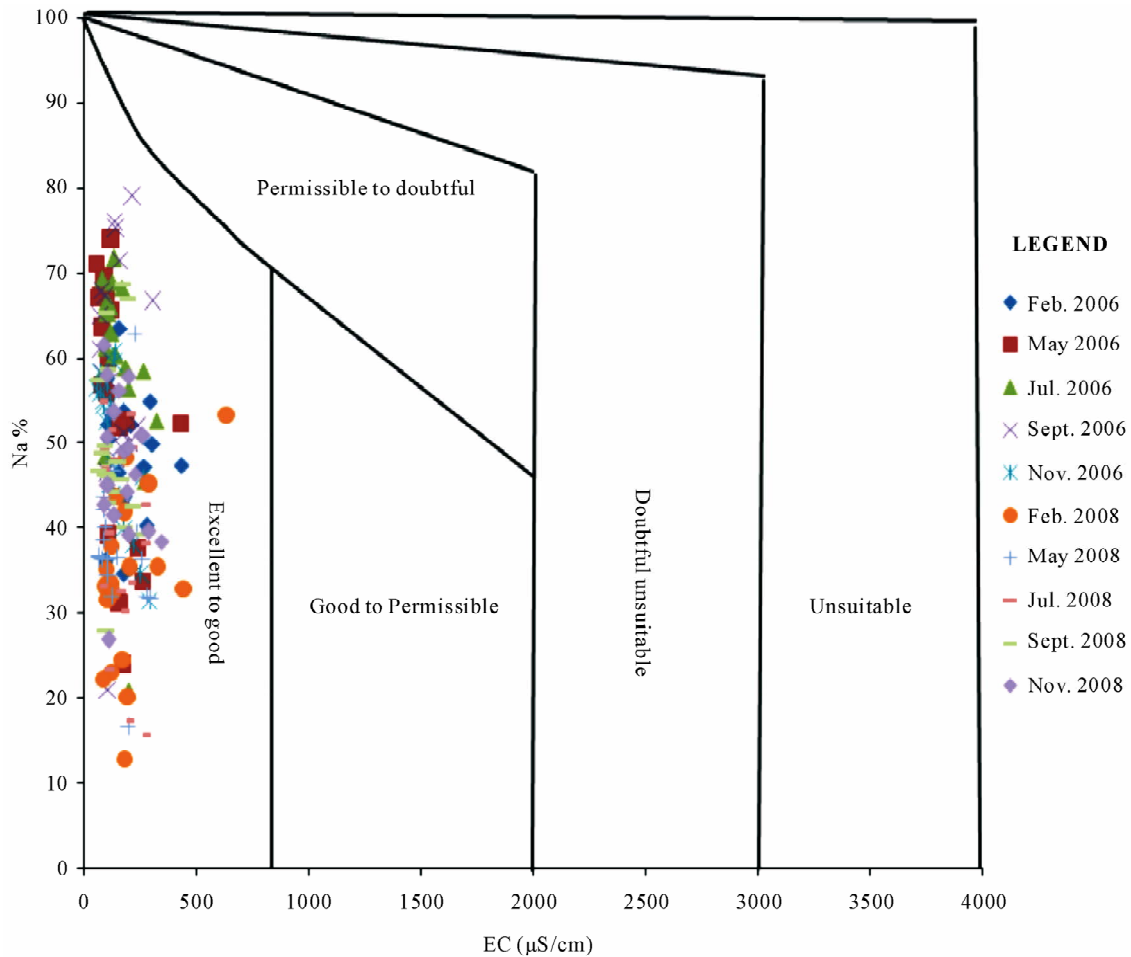**Figure 8. Assessment the irrigation quality of water from the study area using the USSL (1954) methodology.**

Figure 9. Wilcox (1955) diagram for assessing the irrigation quality of surface water from the Coastal and Southwestern River Basins.

5. Conclusions

Surface water from the southwestern and coastal river basins was sampled to assess the major causes of variation in the hydrochemistry, and the suitability of water from these basins for irrigation purposes. Irrigation has been envisaged as a viable alternative or compliment to the current rain fed agriculture. Irrigation is one of the many intervention measures that have been introduced to circumvent the ramifications of global climate change which have led to drastic changes in the rainfall distribution in the country. This study has shown that the concentrations of the major parameters are low and below the regulated limits for domestic uses. The hydrochemistry is principally controlled by contamination from solid waste, rainfall chemistry, silicate mineral weathering and agricultural chemicals in that order of importance. Leachate from solid wastes from domestic and mining activities in the area is the principal mechanism controlling the major ion content of surface water from both the

southwestern river basins and the coastal river systems in Ghana. Silicate mineral weathering has no significant role. This is partly attributed to the fact that unlike groundwater, the residence times of the waters in the surface water basins is rather too short to encourage significant rock-water interactions. Due to the low salinities and SAR values, the water from both river systems is suitable for irrigation without the prospect of causing sodium effects and high salinity effects in irrigation waters.

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