Geochemical Assessment of Springs in the Ho District of Ghana Using Multivariate Statistical Technique

B. K. Kortatsi
Water Research Institute, P. O. Box 58, Achimota, Ghana-CSIR

Abstract

Principal component analysis (PCA) was applied to chemical data of stream water samples from the Ho District of Ghana. The main objective of using this multivariate technique was to determine the processes that influence the chemistry of the stream waters. The results showed that the spread of the data set was largely located in three-dimensional space. The principal direction explained 48.1% of the total variance. The second explained 28.4% and the third 21.1%. Thus, the cumulated variance explained by the three principal (score) components was 97.6%. The varimax rotated loading of the constituent ions on the score matrix indicated that three components accounted for about 72% of the variance in the constituent chemical parameters. The first component explained 31% of the variance while the second and the third component accounted for 26% and 15%, respectively. While carbonate weathering and runoff from agricultural lands were responsible for component 1, component 2 could be attributable to rainwater and some level of concentration due to evaporation. Dissolution of impurities from rocks was apparently responsible for component 3.

Introduction

Potable water supply has been a major problem in the Ho District. Even Ho itself, that doubles as both the Ho District and the Volta Regional capital experiences acute water problem particularly in the prolonged dry season (November-February). This water problem has lead to the incidence of many water-related diseases, particularly guinea worm. Until the recently Danish International Development Agency (DANIDA) funded water project in the Volta Region, Ho District used to be a leading guinea worm endemic area in Ghana.

In order to solve the problem of water borne diseases in the Volta Region, the Government of Ghana sought assistance from DANIDA in 1992 for the provision of potable water. As part of this DANIDA funded water project, an inventory of all hand-dug wells was undertaken as well as the assessment of the shallow groundwater potential. Additionally, all perennial springs and streams were inventorised and measurements were taken of the low and high flows as well as water quality parameters. The results of the inventory revealed that the northern part of the Ho District was endowed with numerous springs, which were most often the only source of drinking water. Thirty-three of them were perennial springs and streams with minimum flows of 0.11 l s^{-1}, and since their sources were at least 30 m above the level of the nearest settlements, they could, therefore, be used for village or community supplies (WRRI, 1993). These springs and streams were recommended for gravity schemes.

In spite of the importance of the springs and streams as potential potable water supply sources, little was known about the phenomena that govern the composition of these springs and streams waters. Geochemical studies on the springs and streams would, therefore, provide an insight into the chemical processes that control the distribution of elements and their fluxes in the springs and streams waters used for drinking in the area. The main objective of this paper therefore was to use principal component analysis, a multivariate statistical technique, to determine the relationships that existed between the stream water chemistry, the host rocks and any other determinants.

Materials and methods

Site description and geomorphology

The Ho District lies approximately between latitudes 60° 20' N and 60° 50' N and longitudes 00° 15' W and 00° 45' N. The location map of the study area is shown in Fig. 1. The area receives adequate rainfall between March and October and its mean annual value is approximately 1300 mm (Mote, 1998). The diurnal temperature is between 20 °C and 30 °C while the potential evapotranspiration is about 1260 mm yr^{-1} although it does not exceed rainfall for most part of the rainy season.

The Ho District is covered with moist semi-deciduous forest although much of the vegetation has been removed for food crop production. Tectonic lines of weakness and orogenic episodes have facilitated extensive and intensive ravine development resulting in the numerous springs and streams that have dissected the area particularly the northern part of the district.

The geology of the Ho District consists of 80% Dahomeyan Formation and 20% Togo Series. The Dahomeyan Formation consists mainly of crystalline gneisses and migmatites with subordinate quartz schists and biotite schists. The rocks of the Togo Series comprise metamorphosed arenaceous and argillaceous sediments. These include indurated sandstones, quartz schist, shale, phyllites, sericite schists, talc, mica schist and some limestones (Kesse, 1985). The geological map of the study area is presented in Fig. 2.

Sampling and analysis

The data set for this study is a subset of the data collected by the Water Resources Research Institute (WRRI) in 1992 during the DANIDA funded inventory and assessment of perennial springs and streams in the Volta Region (WRRI, 1993).

Generally, however, water samples were collected from the perennial springs and streams in July 1992 and 1993 during the rainy season as close as possible to the source or, where the spring emerged, from the ground. Sampling protocols described by Claasen (1982) and Barcelona *et al.* (1985) were strictly observed during sample collection. Samples were collected using 4-1 acid-washed polypropylene containers at the stream banks and in the middle of the streams. Each sample was immediately filtered on site through 0.45μm filters on acetate cellulose. Filtrates for metals analyses were transferred into 100 cm^3 polyethylene bottles and immediately acidified to *p*H < 2 by the addition of Merck™ ultra pure nitric acid. Samples for anions analyses were collected into 250 cm^3 polyethylene bottles without preservation. All the samples were initially stored in an ice chest and later taken to the laboratory, and transferred into a refrigerator where they were stored at a temperature of less than 4 °C. On-site analyses of temperature, *p*H and electrical conductivity were conducted using a WTW-Multiline P4 Universal Meter.

All major ions sodium (Na+), potassium (K+), calcium (Ca++), magnesium (Mg++),

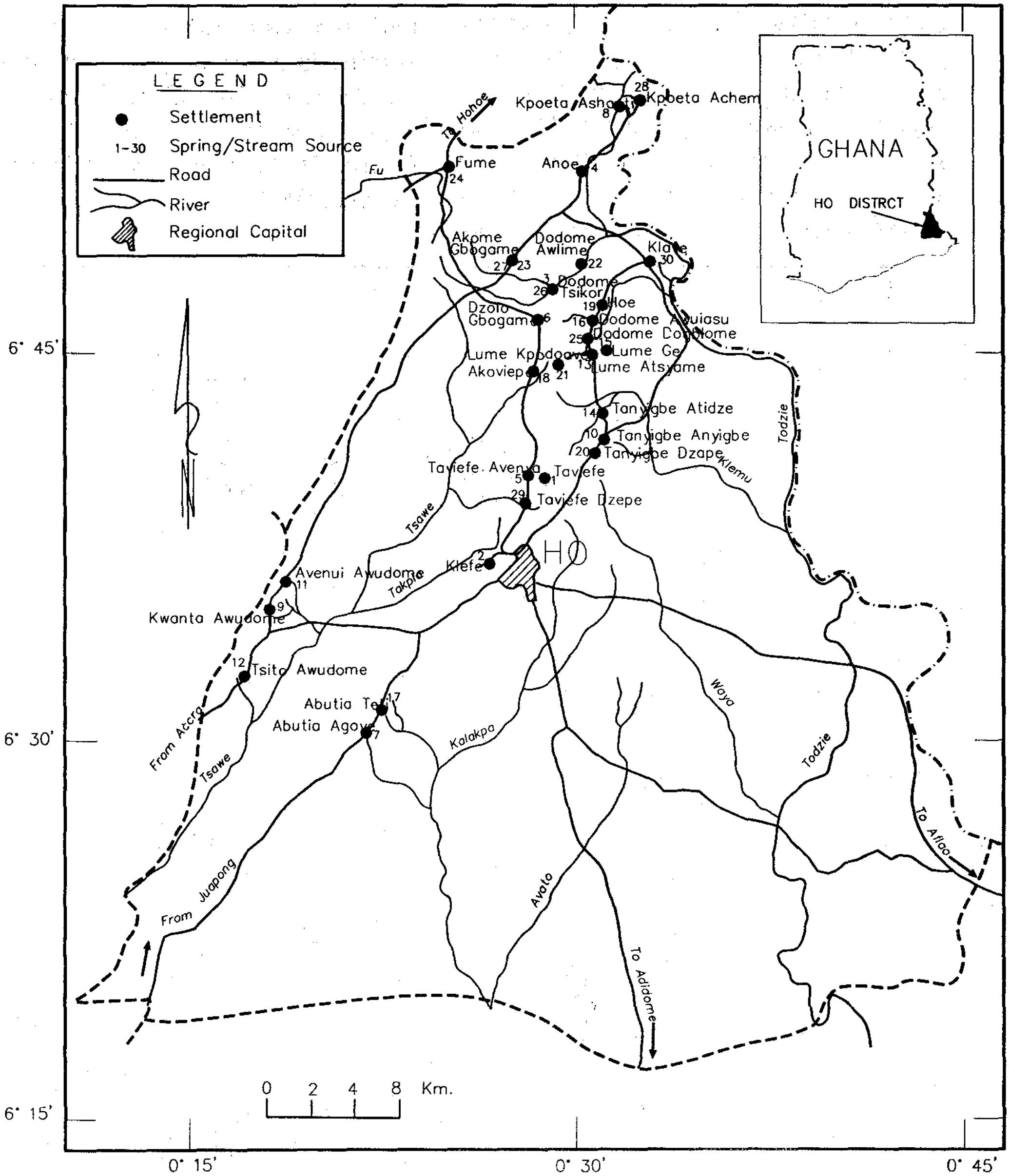


Fig. 1 Map of the Ho District showing spring/stream sampling points (sources)

bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^-) as well as minor elements nitrate (NO_3^-) Fluoride (F^-) and iron (Fe) were initially analysed using Standard Methods for the Examination of Water and Wastewater (Greenberg *et al.*, 1992). An ionic balance was computed for each sample and used as a basis for checking analytical results. In accordance with international standards, results with ionic balance error greater than 5% were rejected (Freeze & Cherry, 1979; Hounslow, 1995; Appelo & Postma, 1999)

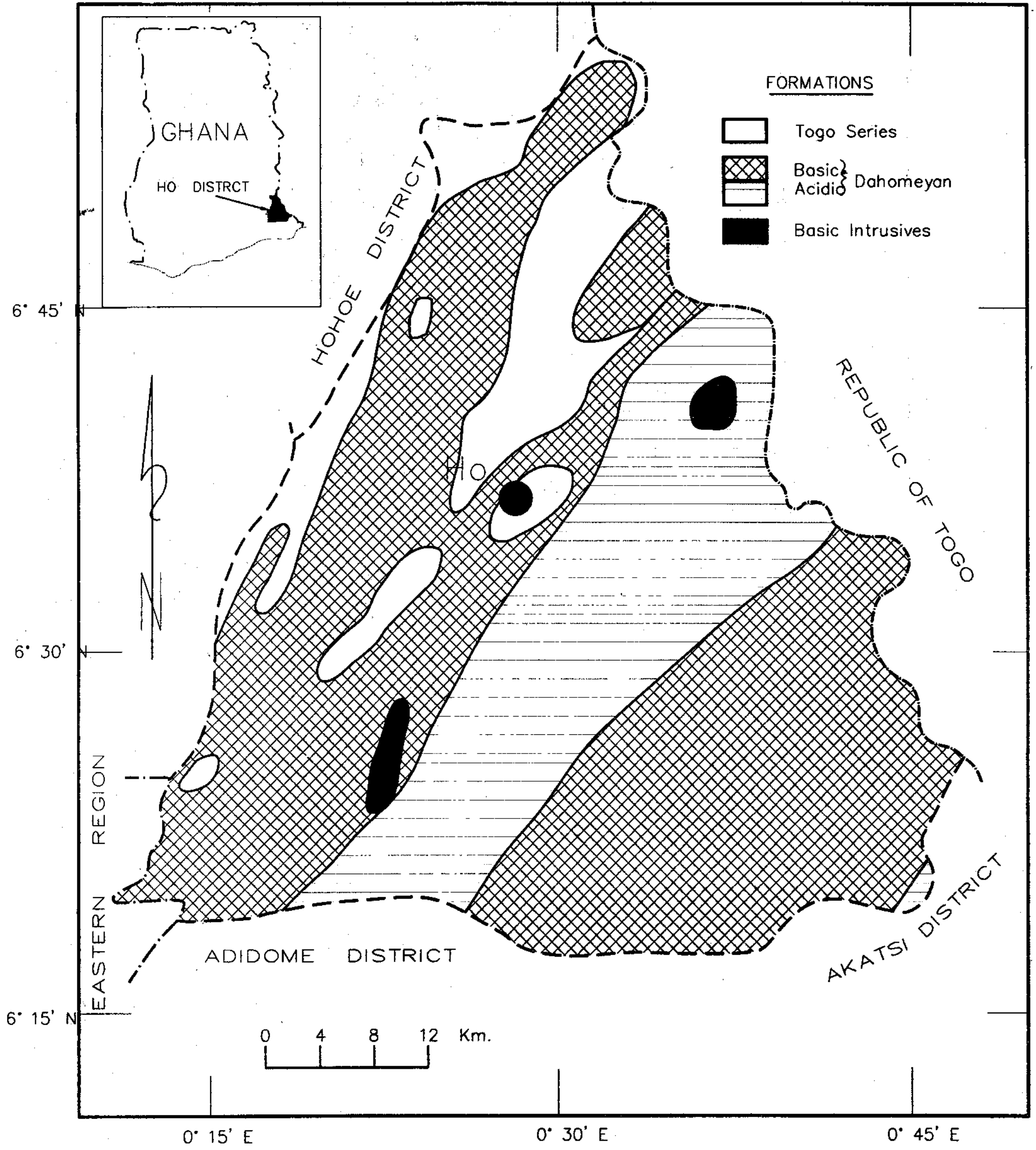


Fig. 2: Geological map of the Ho District

Principle of principal component analysis (PCA)

The Principal Components Analysis (PCA) is a commonly used data reduction technique that does not require the normality of the data distribution as other methods (e.g. Factor Analysis) do. It is often, therefore, used as preliminary steps to other multivariate techniques, which require normality of the data set. Excellent reviews of the principal components analysis technique can be obtained from Morrison (1965), Ehrenberg (1975) and Guertin & Bailey (1970). As a general principle, a component, which describes the maximum variation within a data set, is first extracted by PCA. Subsequent components are then extracted which maximize the remaining variability not captured by the preceding component. Generally, the extracted component is supposed to be independent, uncorrelated and orthogonal to all others (Stevens & Neilson, 1989). The process results in the production of a scores matrix and a loading matrix. In this study, the scores represent the different springs and streams as a function of element concentration whereas the loading represents the contribution of the elements within that component. SPSS for Windows (SPSS Inc, 1996) version 7.5 was used to perform Principal Component Analysis. The PCA option with the Correlation Matrix and Varimax Rotation with Kaiser Normalization was used.

Results and discussion

The concentrations of major some minor ions, and other physico-chemical parameters such as *p*H, temperature, alkalinity and conductivity are presented in Table 1. Initial examination of the chemical data pointed to the fact that the concentrations of the major ions were generally low, and median values were mostly lower than the WHO (1993) recommended limit for potability. The chemical parameters that form the correlation-loading matrix were *p*H, temperature, conductivity, total dissolved solids (TDS), total alkalinity, Ca, Mg, Na, K, HCO_3, SO_4, Cl, Fe, PO_4, SiO_2 and NO_3.

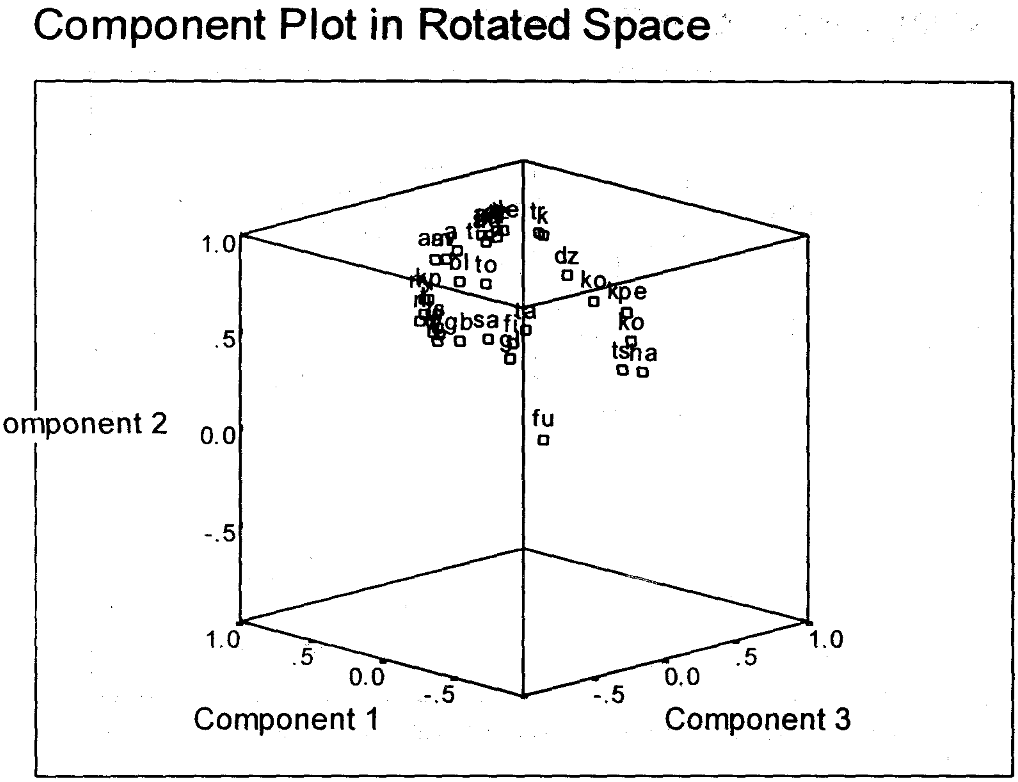
The results of the PCA showed that the spread of the data set was largely located in three-dimensional space (Fig. 3). The principal direction (cluster) explained 48.1% of the total variance. The second explains 28.4% and the third 21.1%. Thus, the cumulated variance explained by the three principal components (clusters) is 97.6%. The varimax rotated loading of the constituent ions on the score matrix is presented in Fig. 4. Three components accounted for about 72% of the variance in the constituent parameters. This means that the abstraction of the first three components extracts the majority of the information that can be obtained from the data set. The first component explained 31% of the variance while the second and the third components accounted for 26% and 15%, respectively (Table 2).

The constituents that loaded positively high (> 0.75) on component 1 include Ca, Mg, HCO_3, total alkalinity (TA) and TDS. Some constituents such as NO_3 (≈ 0.6), PO_4 (≈ 0.7), Fe (≈ 0.5) as the loading in the bracket has indicated, had medium positive loading while the rest had only low loading. Sources of calcium (Ca^{2+}) comprise calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), aragonite ($CaCO_3$), gypsum ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$), fluorite (CaF_2), plagioclase (anorthite, $CaAl_2Si_2O_8$), pyroxene (diopside, $CaMgSi_2O_6$) and

TABLE 1

Chemical parameters of the springs and streams in the Volta Region (All concentrations in m.e.q. l^{-1}. Silica in mmol l^{-1}; EC in µS cm^{-1}; pH in pH unit)

Spring name	*Location*	pH	*Temp.*	*EC*	*TDS*	*Alk*	*T hard*	*Na*	*K*	*Ca*	*Mg*	*Fe*	*Cl*	SO_4	HCO_3	NO_3	PO_4	*Silica*
Agbator	Lune Atsyame	7.0	26	70	1.508	0.480	0.428	0.114	0.028	0.287	0.107	0.011	0.387	0.002	0.394	0.027	0.00020	0.15
Agbi	Tanyegbe Atidze	7.6	26	48	1.244	0.480	0.332	0.091	0.044	0.085	0.174	0.007	0.209	0.006	0.394	0.024	0.00030	0.21
Ahawoe	Lune-Ge	6.0	26	45	1.121	0.239	0.269	0.085	0.010	0.231	0.030	0.009	0.196	0.010	0.392	0.027	0.00020	0.13
Amaku	Dodome Awuiasu	6.6	25	67	1.502	0.400	0.160	0.082	0.051	0.029	0.365	0.009	0.328	0.002	0.488	0.026	0.00020	0.12
Avatia	Abutia Teti	7.5	26	105	1.909	0.560	0.560	0.239	0.018	0.114	0.374	0.006	0.508	0.004	0.460	0.032	0.00020	0.15
Bluvu	Akcviepe	7.4	26	59	1.459	0.360	0.580	0.161	0.038	0.146	0.173	0.001	0.426	0.085	0.295	0.023	0.00020	0.11
Dega	Hoe	7.3	26	32	1.000	0.161	0.152	0.187	0.046	0.029	0.008	0.010	0.339	0.025	0.132	0.032	0.00020	0.19
Droga	Tanyigbe Dzape	6.0	25	45	1.087	0.400	0.288	0.085	0.015	0.226	0.049	0.001	0.220	0.015	0.328	0.021	0.00020	0.13
Dzadze	Lune Kpodoave	7.0	25	37	0.880	0.239	0.168	0.165	0.069	0.057	0.008	0.011	0.198	0.023	0.196	0.027	0.00150	0.12
Dzifa	Dodome Awline	7.1	27	16	0.961	0.100	0.284	0.126	0.031	0.062	0.115	0.001	0.169	0.083	0.082	0.031	0.00020	0.26
Fiate	Akome Gbogame	7.0	26	72	2.909	0.759	1.838	0.153	0.028	0.168	1.366	0.002	0.279	0.054	0.623	0.031	0.00220	0.20
Fu	Fume	7.3	26	68	11.530	5.635	7.254	0.451	0.158	0.990	4.475	0.017	0.466	0.117	4.622	0.042	0.00630	0.19
Gadze	Dodome Dogblome	7.2	25	40	1.001	0.239	0.168	0.213	0.018	0.057	0.001	0.009	0.322	0.002	0.196	0.029	0.00020	0.15
Gbalime	Dodome Tsikor	7.2	26	124	3.995	1.279	2.038	0.727	0.060	0.268	1.286	0.014	0.409	0.050	1.049	0.019	0.00170	0.11
Gleme	Akome Gbogame	7.2	25	99	4.090	1.319	2.778	0.132	0.043	0.275	2.005	0.006	0.262	0.054	1.082	0.034	0.00440	0.19
Hatoe	Kpoeta Achem	6.9	24	17	2.187	0.160	1.719	0.083	0.013	0.088	1.471	0.006	0.198	0.054	0.131	0.018	0.00080	0.13
Koklonoe	Taviefe Dzepe	6.6	26	18	1.230	0.080	0.524	0.365	0.015	0.119	0.189	0.001	0.248	0.073	0.066	0.027	0.00010	0.12
Koklonoe	Taviepe-dzepe	6.9	26	22	2.076	0.080	1.319	0.161	0.015	0.076	1.107	0.004	0.260	0.092	0.066	0.031	0.00540	0.26
Kpegbe	Klave	7.2	25	159	4.018	0.880	1.171	0.640	0.056	0.023	1.102	0.007	1.013	0.229	0.722	0.023	0.00030	0.20
Kporekorlu	Taviefe	6.6	26	30	0.692	0.080	0.160	0.135	0.003	0.029	0.082	0.005	0.203	0.029	0.066	0.031	0.00020	0.11
Nyohonu	Klefe	7.0	26	220	5.097	2.399	2.018	0.692	0.307	0.457	0.740	0.010	0.367	0.339	1.968	0.024	0.00030	0.19
Nyronui	Dodome Tsikor	7.2	25	132	3.035	1.199	0.999	0.403	0.074	0.212	0.705	0.001	0.434	0.071	0.984	0.024	0.00050	0.13
Saciatoe	Kpedze Anoe	7.5	28	100	3.151	1.119	2.118	0.165	0.028	0.290	1.306	0.007	0.231	0.058	0.918	0.021	0.00250	0.12
Tahalahal	Taviepe Avenya	7.0	26	71	3.138	0.480	1.818	0.368	0.043	0.146	1.410	0.005	0.418	0.071	0.393	0.024	0.00130	0.26
Tortor	Dzolo Gbogame	7.5	25	174	4.222	1.199	1.463	0.861	0.077	0.215	0.856	0.001	0.908	0.094	0.984	0.023	0.00040	0.20
Tortor	Dzolo Gbogame	6.9	26	130	4.973	1.119	2.098	1.141	0.063	0.238	1.430	0.006	0.821	0.050	0.918	0.018	0.00190	0.29
Trah	Abutia Agove	7.4	26	25	0.875	0.161	0.152	0.174	0.003	0.029	0.074	0.004	0.243	0.006	0.132	0.024	0.00020	0.19
Tsii	Kpoeta Ashanti	6.8	25	24	2.403	0.240	1.679	0.124	0.015	0.074	1.471	0.009	0.237	0.067	0.197	0.026	0.00140	0.18
Tsika	Nkwanta Awudome	7.4	26	225	6.092	2.799	2.922	0.566	0.033	0.514	1.481	0.009	0.869	0.067	2.296	0.024	0.00020	0.23
Unze	Tanyigbe Anyigbe	7.2	25	47	1.324	0.239	0.240	0.265	0.008	0.057	0.082	0.009	0.415	0.010	0.196	0.026	0.00020	0.25
Wutor	Avenui Awudome	7.6	26	315	7.673	3.834	4.256	0.561	0.018	0.827	1.933	0.008	0.869	0.063	3.145	0.015	0.00030	0.23
Wuve	Tsito Awudome	7.4	25	362	8.529	4.159	4.916	0.583	0.059	0.856	2.525	0.006	0.773	0.021	3.411	0.061	0.00020	0.23



Agbator	ag	Hatoe	ha
Agbi	agb	Koklonoe	ko
Ahawoe	ah	Kpegbe	kpe
Amaku	am	Kporekorlu	kpo
Avatia	av	Nyohonu	nyo
Bluvu	bl	Nyronui	ny
Dega	de	Savitoe	sa
Droga	dr	Tahalahal	ta
Dzadze	dz	Tortor	to
Dzifa	Dzi	Trah	tr
Fiate	Fi	Tsii	tsi
Fu	Fu	Tsika	ts
Gadze	Ga	Unze	un
Gbalime	gb	Wutor	w u
Gleme	Gl	Wuve	w v

Fig. 3. Three-dimensional scatter plot of varimax principal component scores (springs and streams)

amphibole ($NaCa_2$-(Mg,Fe,Al) $Si_8O_{22}(OH)_2$). Similarly the sources Mg in natural waters include dolomite ($CaMg(CO_3)_2$), olivine($(Mg,Fe)_2SiO_4$), pyroxene(diopside, $CaMgSi_2O_6$), amphibole ($NaCa_2$-$(Mg,Fe,Al)Si_8O_{22}(OH)_2$) (Hounslow. 1995). The fact that the high positive loadings were contemporaneous for these constituents and bicarbonate (HCO_3) while silica had low loading suggests that carbonate weathering was responsible for component 1.

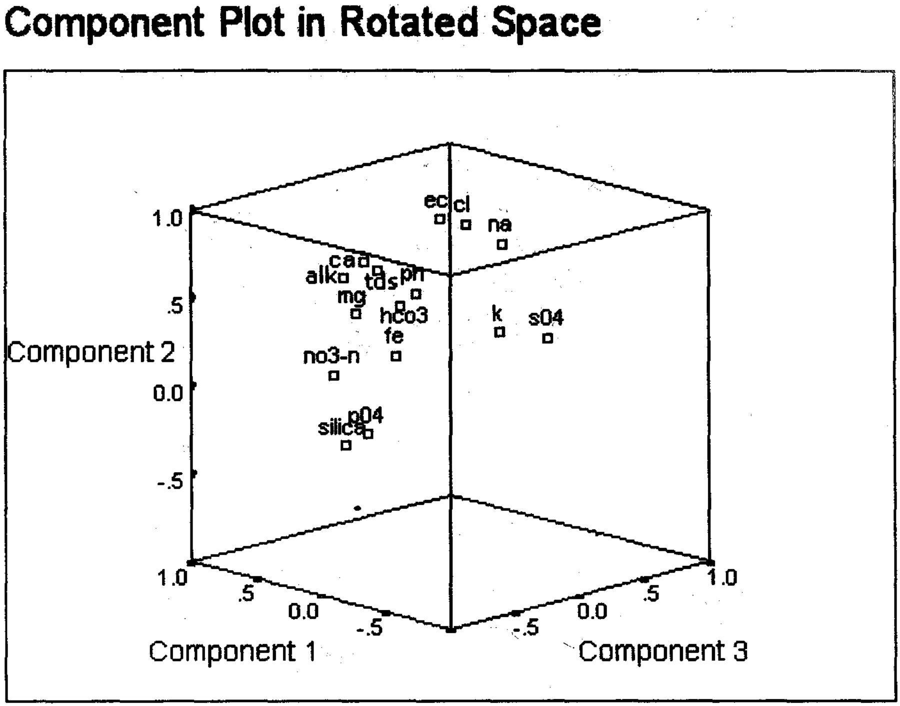


Fig. 4. Three-dimensional scatter plot of normalized varimax principal loadings of constituent chemical parameters

The constituents (Ca, Mg, HCO_3) that had high positive component 1 loadings characteristically were present in a significant number of streams. This is consistent with assertion by WRRI (1993) that approximately 40% of the streams in the Ho District are calcium or magnesium bicarbonate waters. The expanded Durov diagram of the chemical constituents of the springs and streams samples is presented in Fig. 5. As can be seen from this diagram, significant proportion of the of the samples fall into the Ca-Mg-HCO_3 field confirming the earlier statement that considerable number of the springs and streams are calcium-magnesium-bicarbonate in character. The streams that had high positive scores for component 1 include Agbator Tapo, Agbi, Ahawoe, Amaku, Bluvũ, Droga, Gbalime, Kpegbe, Nyohonu, Nyronui, Tortor, Tsika, Wutor and Wuve (Table 3).

Almost all the springs and streams in the Ho District take their sources from the Togo ranges or the contact zone between the Togo Series and the Dahomeyan Formation. As has been stated earlier, the rocks of the Togo Series contain carbonates either in the form of impure limestone or as cement in the matrices of the sandstone. These carbonates are the most soluble mineral type within the Togo Series and, thus, constitute the source of the Ca, Mg, HCO_3^- in the spring and stream waters. The concentrations of Fe, NO_3, PO_4 in the springs and streams were low. Median values were 0.18 mg l^{-1}, 1.6 mg l^{-1} and 0.08 mg l^{-1}, respectively. Fe is associated with certain

TABLE 2

Total variance explained

	Initial Eigenvalues		*Extraction sums of squared loadings*			*Rotation sums of squared loadings*		
Component total	*Percent of variance*	*Cumulative %*	*Total*	*Percent of variance*	*Cumulative %*	*Total*	*Percent of variance*	*Cumulative %*
1	6.8745.79	45.79	6.87	45.79	45.79	4.58	30.51	30.51
2	2.3215.50	61.28	2.32	15.50	61.28	3.78	25.21	55.72
3	1.5910.63	71.91	1.59	10.63	71.91	2.43	16.19	71.91
4	0.97 6.48	78.39						
5	0.86 5.70	84.10						
6	0.80 5.33	89.43						
7	0.59 3.92	93.35						
8	0.43 2.87	96.22						
9	0.27 1.80	98.02						
10	0.15 0.97	98.99						
11	0.10 0.63	99.62						
12	0.04 0.30	99.92						
13	0.01 0.08	100.00						
14	0.00 0.00	100.00						
15	0.00 0.00	100.00						

Extraction method: Principal component analysis.

rock types within the Togo Series (Kesse, 1985).

On the other hand, NO_3^-, which might have been generated through agricultural activities or ammonification and nitrification, is very mobile in groundwater. It may move with the water with no transformation and little or no retardation over large distances from input areas (Freeze & Cherry, 1979). A common phosphate-containing mineral is apatite that has very low solubility in water. Thus, the main source of phosphate is anthropogenic mainly agricultural and sewerage. It also follows that the medium positive loading that these constituents (Fe, NO_3, PO_4) showed with Ca, Mg, HCO_3, total alkalinity (TA) and TDS in component 1 suggests that Fe, NO_3 and PO_4 could be impurities associated with the carbonate rocks or could have been derived from run off from the several agricultural lands within the catchment areas of the streams (Table 4).

Electrical conductivity (EC), chloride (Cl) and sodium (Na) had high positive loading (> 0.7) on component 2 while HCO_3^- and TDS had medium positive loading (≈ 0.6). Metamorphic rocks that dominate the geology of the Togo Series contribute little chloride. However, Cl is known to be mobile and relatively conservative and, thus, can travel long distances with the water. Nonetheless, the concurrently high positive loading of Cl and Na coupled with the generally low TDS values (< 100 mg l^{-1}) and its medium positive loading suggest component 2 is attributable to atmospheric precipitation that might have been concentrated to some degree by evaporation. The constituents (Cl and Na) that had high positive component 2 loadings typically occurred in a sizeable number of

TABLE 3

Normalized rotated component score matrix (springs and streams)

	Component		
Spring/Stream	*1*	*2*	*3*
Agbator Tapo	0.84	0.24	0.48
Agbi	0.79	0.27	0.53
Ahawoe	0.75	0.23	0.61
Amaku	0.85	0.1	0.51
Avatia	0.88	0.2	0.42
Bluvu	0.78	0.37	0.5
Dega	0.64	0.18	0.74
Droga	0.78	0.25	0.56
Dzadze	0.72	0.18	0.67
Dzifa	0.28	0.45	0.84
Fiate	0.62	0.74	0.26
Fu	0.28	0.87	-0.16
Gadze	0.74	0.17	0.65
Gbalime	0.79	0.56	0.26
Gleme	0.62	0.76	0.17
Hatoe	0.06	0.97	0.19
Koklonoe	0.27	0.67	0.69
Kpegbe	0.89	0.28	0.35
Kpete	0.2	0.95	0.24
Kporekorlu	0.6	0.19	0.78
Nyohonu	0.91	0.34	0.24
Nyronui	0.9	0.29	0.32
Saciatoe	0.71	0.66	0.25
Tahalahal	0.59	0.74	0.3
Tortor	0.89	0.31	0.31
Trah	0.56	0.22	0.79
Tsii	0.17	0.96	0.22
Tsika	0.86	0.46	0.2
Unze	0.68	-0.02	0.26
Tortor	0.79	0.55	0.27
Koklonoe	0.16	0.92	0.34
Wutor	0.86	0.47	0.18
Wuve	0.86	0.47	0.17

* Extraction method: Principal component analysis.
** Rotation method: Varimax with Kaiser normalization.

TABLE 4

Normalized rotated principal component loadings matrix for chemical parameters

	Component		
	1	*2*	*3*
Alk	0.7859	0.5541	0.1784
Ca	0.7860	0.5350	0.1256
Cl	0.0490	0.8786	0.1697
EC	0.2744	0.8645	0.1907
Fe	0.4805	0.0689	0.0691
$HC0_3$	0.7859	0.5541	0.1784
K	0.3714	0.0894	0.7652
Mg	0.8746	0.2160	0.1399
Na	0.0300	0.7192	0.4406
$P0_4$	0.7023	-0.4237	0.0711
*p*H	0.2120	0.4970	-0.0582
$S0_4$	0.1431	0.0740	0.9089
SiO_2	0.1157	-0.2350	-0.6906
NO_3-N	0.5705	0.0145	-0.3257
TDS	0.7837	0.5461	0.2496

* Extraction method: Principal component analysis.
** Rotation method: Varimax with Kaiser normalization.
*** Rotation converged in five iterations.

streams. This is also coherent with the plot in the expanded Durov diagram Fig. 5 and the WRRI (1993) statement that approximately 33% of the springs and streams in the Ho District were probably Na-Cl waters. The streams that probably contributed to the component 2 were Fiate, Fu, Gleme, Hatoe Kpete, Tahalahal, Tsii and Koklonoe.

The individual loadings for component 3 were generally much lower than those of components 1 and 2. Only potassium (K^+) and sulphate (SO_4^{2-}) had high positive loading (>0.75). Silica had medium negative loading of (–0.70). The concentration of K^+ and SO_4^{2-} were generally very low and close to background levels suggesting that component 3 can be attributable to trace impurities contained in the rocks that were dissolved.

Conclusion

The study provides data on the geochemistry of streams in the Ho District. Using principal component analysis to appraise the

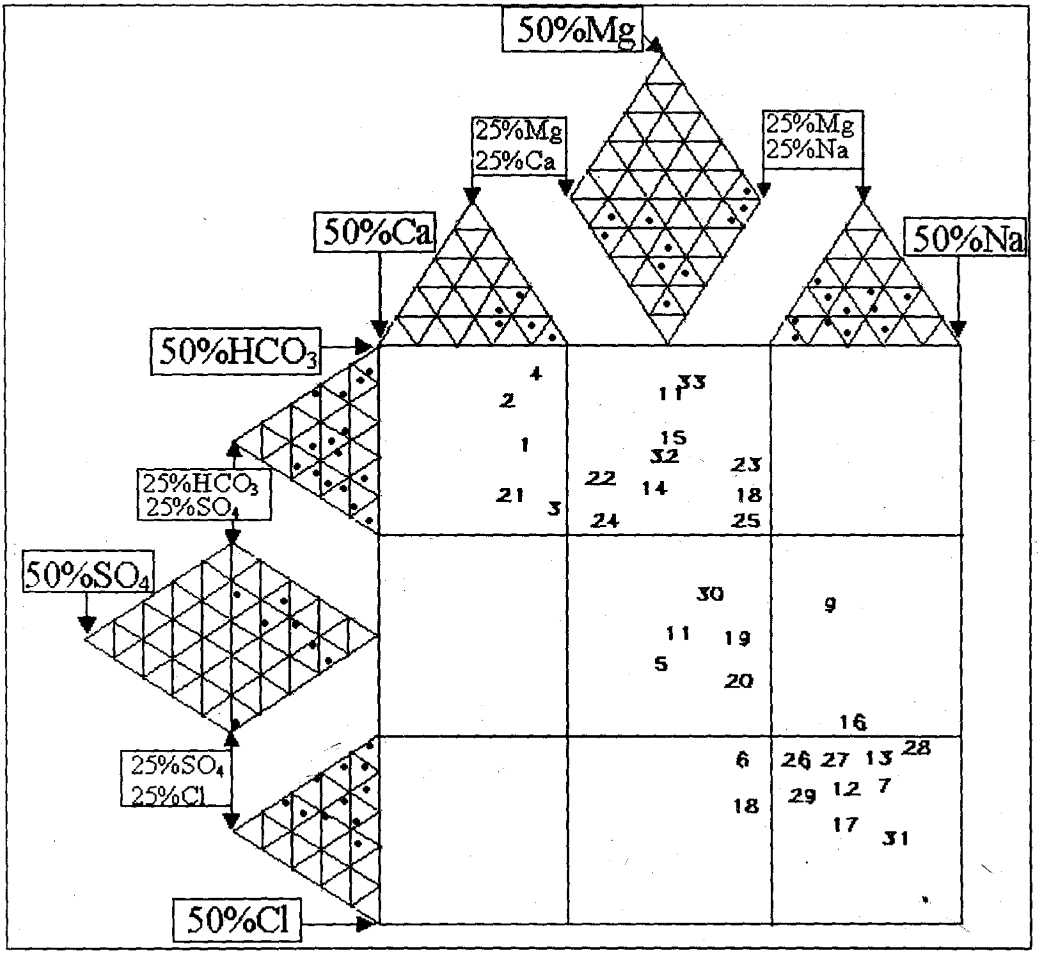


Fig. 5. Durov diagram for the spring and sream samples from the Ho District

relationships among the dissolved constituents in the stream waters, it is apparent that lithology played major role in the evolution of the chemistry of stream in the Ho District. The most important process was carbonate weathering. Approximately 40% of the streams showed characteristic evocative of carbonate rock-water interaction, suggesting that carbonate weathering was a major source of chemical constituents in the water. Another important process that exerted some control on the geochemistry of the streams was the composition of rainwater. Approximately 33% of the streams were sodium chloride in character and contributed to 26% of the variability in the loading of the constituent chemical parameters. Since the rocks are not known to contain halite and TDS values were low, rainwater composition seems to be the most plausible for the observed variability in chemical composition of the stream waters. A small, though significant, proportion (15%) of the variability in the chemical constituents of the streams can be attributable to impurities in the rocks that were leached into the streams.

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