Hydrochemical facies in parts of the Nigerian basement complex

B. A. Raji · S. A. Alagbe

Abstract Water analyses usually involve large amounts of data that require sorting to aid in interpretation. One method that could be used is the hydrochemical facies diagrams. The hydrochemical facies of groundwater from four drainage basins of the Nigerian basement complex, Ife, Asa, Shika, and Kan Gimi, are evaluated using trilinear and Stiff diagrams similar to methods used in lithofacies and geochemical studies. The hydrochemical facies for the basins studied are influenced, aside from the lithology, by the rainfall and their proximity to the sea. In general, no single cation–anion pair exceeds 50%, hence an appreciable percentage of the groundwater in the study areas is of the nondominant type. Within the overburden aquifer of the basement complex, with limited regional flow, a rainfall of about 1150 mm per annum is arbitrarily set as the boundary between alkaline and saline groundwater.

Key words Hydrochemical facies · Basement complex · Saline groundwater · Alkaline groundwater · Nigeria

Introduction

The chemical quality of groundwater depends on the characteristies of the soil and rock media through which it passes enroute to the groundwater zone of saturation. The ionic content of the groundwater tends to increase with the length of the flowpath through the ground. As water infiltrates through the soil layer and comes into contact with soil air, considerable changes occur. The chemistry of the water at the outcrop area (infiltration zone) is modified as it flows through the aquifers. The chemistry that predominates in the outcrop area persists for some distance down-gradient, and the basic change is from a hard calcium bicarbonate water to a soft, alkaline, sodium-rich type, due principally to ion exchange (Ineson and Downing 1963) and precipitation of the least soluble salts first (Chebotarev 1955). The general sequence as outlined by Chebotarev (1955) involves the passage from bicarbonate waters at outcrops to sulfate waters at intermediate depths to chloride waters at greater depths in areas of continous flow. This ideal sequence is, however, modified locally by the occurrence of certain constituents in abnormally higher concentrations in rocks. For example, sulfate waters will dominate the sequence in rocks rich in gypsum or pyrite.

The concept of hydrochemical facies, as discussed by Black (1961), presents a coherent generalization with regard to the diagnostic chemical character of water in aquifers that might otherwise have to be inferred from thousands of diserete facts. The facies reflect the effects of chemical processes in the lithologic environment and the contained groundwater flow patterns (Black 1960; Rodda and others 1976). The main environmental factors affecting the chemical processes are water (rainfall), temperature, and the soil air. In effect, the nature and concentrations of ions in water are determined by the lithologic character, the climate, and the groundwater flow pattern of a particular region (Gorham 1961). The principal characters of the hydrochemical facies can be illustrated by methods similar to those used in lithofacies and geochemical studies – trilinear diagrams (Piper 1944) that show the essential chemical character of a groundwater according to the relative concentration of its constituent and Stiff diagrams (Stiff 1951) that show the chemical character according to the absolute concentrations, thereby giving an overall expression of the cation–anion balance, in an area. These diagrams are useful for screening and sorting large numbers of chemical data, such as appear in water analysis. This method makes interpretation easier. It is also a means of viewing the chemical character of the basin as a single entity, when and where the minor local variations in water quality are not very important, but rather the mean condition is what is required.

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Study area

Four basins were selected from the Nigerian basement. They are Shika and Kan Gimi in the north and Asa and Ife in the west. The Shika Basin lies between latitude 11°7′ and 11°24′N and longitudes 7°31′ and 7°50′E. It is located within Zaria topographical map sheet No. 102 and has an area of about 887 sq km. The Kan Gimi drainage basin is within Igabi Topographical map sheet No. 124 and has an area of about 370 sq km. It is within latitudes 10°30′ and 10°38′N and longitudes 7°30′ and 7°41′N. The Asa Basin lies approximately within Ogbomosho and Ilorin topographical map sheets Nos. 222 and 223, respectively. It is situated between latitudes 8°00′ and 8°30′N and longitudes 4°19′ and 4°38′E and covers an area of about 1080 sq km. The Ife and environs cover an area of about 60 sq km and are situated within latitudes 7°25′ and 7°30′N and longitude 4°30′ and 4°35′E.

The study areas experience distinct wet and dry seasons. The wet season usually ocours from March to October with an annual average rainfall of about 1050 mm for Shika, 1250 mm for Asa, 1067 mm for Kan Gimi, and 1290 mm for Ife and environs. Temperatures are fairly high and range from 22 °C to 35 °C (Raji and Alagbe, unpublished data).

The vegetation of the study areas differs. Both the Shika and Kan Gimi basins fall within the Northern Guinea Savanna belt, supporting a tropical bush land and vegetation characterized by grasses and herbs. A few widely scattered deciduous trees were observed. Furthermore, the vegetation of the Asa Basin is a transition one, ranging from the derived Guinea Savanna in the north to the semi-rain-forest in the south. Ife and environs are located in the rain-forest ecosystem.

Although there are slight variations in the geology of the basins in terms of the individual rocks, there is very little difference in the chemistry of the rocks. The geology of the basins is that of the Nigeria Basement, as discussed by Grant (1969) and Oyawoye (1970). The basins are individually underlain by crystalline metamorphic and igneous rocks. A high proportion of the rocks originated from a high-grade metamorphism, mainly gneisses. Undifferentiated schists and quartzites, which are well exposed along river valleys and road cuttings, also occur. The soils observed are clayey in texture for in both the Shika and Kan Gimi basins, sandy in the Asa Basin, and sandy loam in Ife and environs (Raji and Alagbe unpublished data). Mineralogically, all the soils are dominated by kaolinite and sesquioxides (Jones and Wild 1975), typical for most tropical soils.

Methodology

The classification into hydrochemical facies is based on certain chemical constituents of the groundwater. From the study areas, a total of 80 water samples, 20 for each basin were analyzed for the following ions: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Co_3^{2-}, So_4^{2-}, and Cl^{-}. For each of these ions, a percentage value is calculated, as a total of the cation or anion as appropirate, on the basis of concentration in equivalents per million. In the representation of these values on the facies diagram, the triangles are used for clarity of classification, while the third figure – a parallelogram – shows the combined analysis (Fig. 1). In this idealized classification system, waters are classified according to the dominant cation and anion present, or, if a single ion is not dominant in each for both cases, the two principal cations or anions present are used. In nature, however, water from a particular area seldom falls entirely within one hydrochemical facies. The hydrochemical facies in such a case will simply refer to the dominant facies.

Results and discussion

The calculated values in percentages for the anion and cation facies computed on the basis of equivalent per million are shown in Table 1. The positions of these anion and cation facies for all the study areas are shown on the two triangles (Fig. 2).

The hydrochemical facies of waters from the Shika drainage basin are generally $Ca+Mg-HCO_3$ (secondary alkalinity) in composition while waters from the Kan Gimi drainage basin are mainly $Na+K-HCO_3$ (primary alkalinity) in composition. For the Asa drainage basin, the hydrochemical facies of the groundwaters are mainly $Ca+Mg-Cl+SO_4$ (secondary alkalinity) in composition. Unique to all the basins under study, is the fact that an

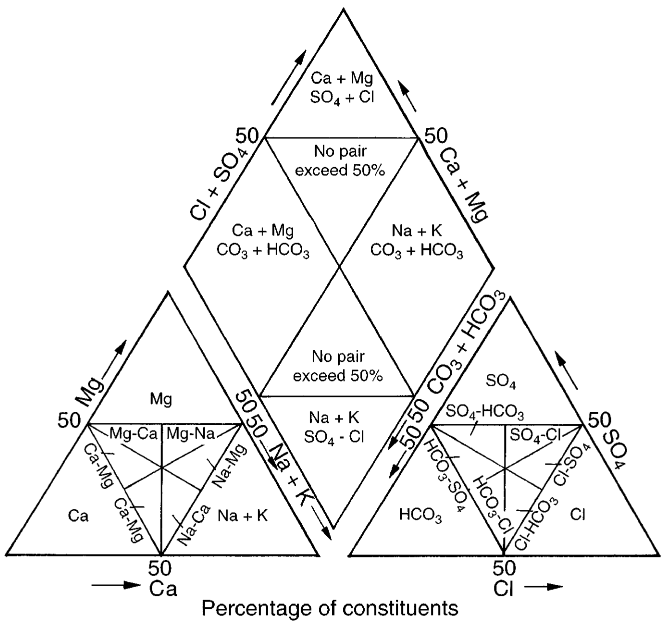

Fig. 1
An idealized classification of hydrochemical facies

Table 1
Hydrochemical facies of study areas[a]

	Shika	Kan Gimi	Asa	Ife
Ca + Mg	73	37	97	51
Na + K	27	63	3	49
$Cl^- + SO_4^{2-}$	48	41	57	64
HCO_3^-	52	59	43	36
TDS (mg l^{-1})	84.66	46.76	546.00	156.39
Rainfall (mm)	1050	1067	1275	1290
Water class	Secondary alkalinity	Primary alkalinity	Secondary salinity	Primary salinity

[a] Values are in percentages, computed on the basis of milligrams per liter

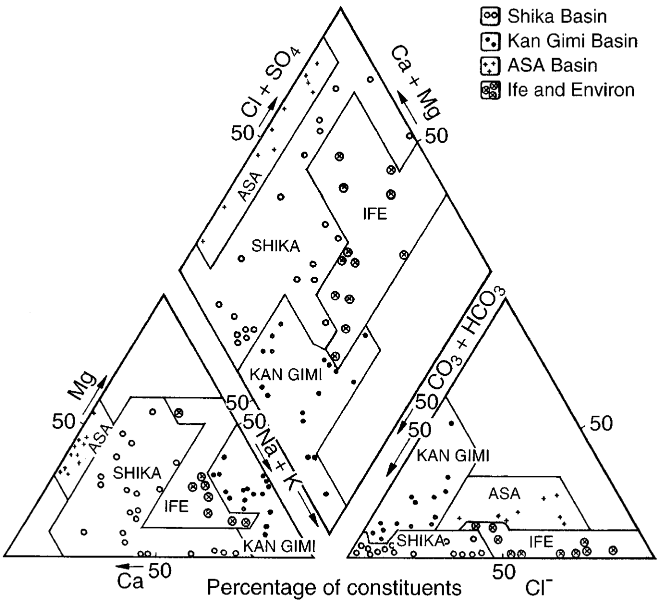

Fig. 2
Hydrochemical facies classification for Shika, Kan-Gimi, Ife, and Asa drainage basins

appreciable percentage of the water has facies in which no single cation–anion pair exceeds 50% in composition. Similar findings have also being reported by Amadi (1987) and Tijani (1994) for parts of the Nigerian Basement complex. These range from 10% for Asa, 25% for Shika, 50% for Kan Gimi, and 60% for Ife and environs (Table 2).

The hydrochemical facies of groundwaters are affected by the lithology, climate, and flow pattern, but in the study areas the influence of climate is high. This is evident in the fact that in the Nigerian basement areas aquifers are unconsolidated to semiconsolidated weathered overburden units that seldom exceed 50 m in thickness. The unconfined nature of the groundwater system in the study areas suggests an open system, which receives direct recharge by rainfall and from which water is discharged without coming in contact with any other aquifer or other water. In most cases, the regional flow of the groundwater is punctuated by massive unweathered outcrops of the underlying basement rocks. The hydrochemical nature of the groundwater in the basement is therefore likely to be affected in a limited way by horizontal flow. In the four drainage basins under study, there is no horizontal connection of groundwater flow. The differences in the hydrochemical facies observed between them must therefore be attributed to an interplay of precipitation (climatic factor) and weathering (dissolution) processes. Since there is little or no difference in the geology of the areas, the depth of groundwater flow and the climatic factors (temperature and rainfall) are the only two natural factors left. Artificial factors such as pollution are unlikely because of the low level of industrialization and low fertilizer usage in all the study areas.

The effect of the depth of flow is greater within a given basin (Raji and others 1990) than between the basins. This is so, since sampling of the groundwater analyzed was done between 1 and 10 m of the ground surface in all the basins.

Differences in rainfall (Table 2) and the nature of its ionic concentration seem the most probable factors ac-

Table 2
Hydrochemical facies and rainfall in study areas

Basin	Latitude	Differences in latitude	Amount (mm)		Percentage					Hydrochemical facies	Water class
			Rainfall	Differences in Rainfall	non-dominant type	Ca + Mg HCO_3	Na + K HCO_3	Ca + Mg Cl + SO_4	Na + K Cl + SO_4		
Shika	11°00′	30′	1050	10	25	55		15	5	Ca + Mg HCO_3	Secondary Alkalinity
KanGimi	10°30′	2°30′	1060	215	50	20	30			Na + K HCO_3	Primary Alkalinity
Asa	8°00′	30′	1275	15	10	30		60		Ca + Mg Cl + SO_4	Secondary Salinity
Ife	7°30′		1290		60				40	Na + k Cl + SO_4	Primary Salinity

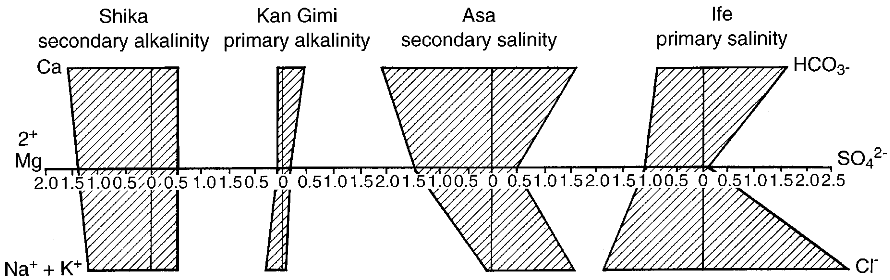

Fig. 3
Stiff diagram for Shika, Kan-Gimi, Ife, and Asa drainage basins

counting for the observed differences in hydrochemical facies. The ionic concentration of the rainfall was not determined. From the literature (Rodda and others 1976; Stevenson 1968; Gorham 1958), however, the sea and industrial contaminations are the principal sources of chloride, sulfate, and sodium, while calcium, magnesium, potassium, and carbonate are assumed to come from the soil. In Nigeria, the proximity to the sea fosters a high rainfall, which, coupled with the high temperatures of the tropics, results in rapid chemical weathering and leaching (Acworth 1987). As a consequence, sodium and potassium get concentrated after calcium and magnesium are leached out of the system.

In the study areas, it is evident that the differences in hydrochemical facies (Table 2) can be attributed to location relative to the sea and the resulting rainfall. The Stiff diagram (Fig. 3) shows the chemical character of the groundwaters according to absolute concentrations. Its importance lies in the fact that the absolute concentrations commonly are decisive with many problems of interpretation (Walton 1970). For the areas under study, the contrast in the chemical character of the waters is more apparent from the Stiff diagrams. Water from Shika and Kan Gimi are somewhat similar in chemical content (both alkaline) but much different in chemical content from waters from Ife and Asa, which are similar and saline.

Conclusion

The hydrochemical facies identified for the study areas (part of the Nigerian basement areas) are influenced, aside from the lithology, by the rainfall and their proximity to the sea. An appreciable percentage of the waters have facies in which no single cation–anion pair exceeds 50% in any study area. Preliminarily, a rainfall value of about 1150 mm yr^{-1} could be arbitrarily set as the boundary between saline and alkaline groundwater within the Nigerian basement complex. More detailed work, however, needs to be done to verify this assumption.

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