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Groundwater classification using multivariate statistical methods: Southern Ghana

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ABSTRACT

This study demonstrates the strength of R-mode factor analysis and Q-mode hierarchical cluster analysis in determining spatial groundwater salinity groups in southeastern Ghana. Three hundred and eighty three (383) groundwater samples were taken from six hydrogeological terrains and surface water bodies and analyzed for the concentrations of the major ions, electrical conductivity and pH. Q-mode hierarchical cluster analysis and R-mode factor analysis were respectively used to spatially classify groundwater samples and determine the probable sources of variation in groundwater salinity. The quality of groundwater for irrigation was then determined using three major indices. The analyses revealed two major sources of variation in groundwater salinity: silicate mineral weathering on one hand, and seawater intrusion and anthropogenic contamination on the other. A plot of the factor scores for the two major sources of variation in the salinity revealed trends which can be used in hydrogeological mapping and assist in drilling potable water boreholes in southeastern Ghana. This study also revealed four major spatial groundwater groups: low salinity, acidic groundwaters which are mainly derived from the Birimian and Togo Series aquifers; low salinity, moderate to neutral pH groundwaters which draw membership mainly from samples of the Voltaian, Buem and Cape Coast granitoids; very high salinity waters which are not suitable for most domestic and irrigation purposes and are mainly from the Keta Basin aquifers; and intermediate salinity groundwaters consisting of groundwater from the Keta basin aquifers with minor contributions from the other major terrains. The major water type identified in this study is the Ca–Mg–HCO_3 type, which degrades into predominantly Na–Cl–SO_4 more saline groundwaters towards the coast.

1. Introduction

In Ghana, groundwater is increasingly gaining prominence as an alternative source of water for various uses. A number of reasons account for this: aquifers underlie almost all communities in Ghana and can be tapped at relatively shallow depths; groundwater is relatively cleaner and does not need extensive treatment before use; most surface water bodies run out during the dry season. There have been increasing demands for groundwater for use in irrigation of various crops in the country. In order to further the exploitation of groundwater for various uses, various studies have been conducted to understand the properties of aquifers in the country. In addition to providing helpful guides to groundwater exploration and exploitation, such studies usually assist in determining the quality of groundwater delivered by the different aquifer units. For instance Dapaah-Siakwan and Gyau-Boakye (2000) compiled a hydrogeological map of Ghana indicating the hydrogeological properties of the different geological terrains in the country. Their work was a compilation of previous hydrogeological works in the country (e.g. Junner and Service, 1936; Junner and Hirst, 1946; Minor et al., 1995; Acheampong, 1996). The quality of groundwater has particularly received immense attention since water of high quality is required for domestic and irrigation needs.

It has been suggested that since groundwater is mostly protected from most surface activities, it is a safer alternative to surface water. In addition to wanton contamination from farming, industrial and household activities, surface water resources are fast depleting due to recent changes in the weather patterns and rampant forest degradation. The foul stench emanating from some of these surface water bodies, and the visual discoloration, testify to pollution from several sources including domestic sewage, agricultural chemicals and industrial wastes. Therefore the capital costs of exploiting groundwater, which is mostly relatively cleaner, is modest compared to treating contaminated surface waters before use. It is for this reason that studies on the hydrogeological and hydrochemical properties of the aquifers underlying the country are currently being pursued to the letter. Recent studies have been focused on the quality of groundwater from specific hydrogeologic terrains in the country. Researchers (e.g. Kortatsi et al., 2008; Yidana et al., 2008a,b,c,d; Yidana, 2008; Banoeng-Yakubo et al., 2009) have applied different methodologies to understand the sources

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of variation in the quality of surface and groundwater basins in Ghana. There is a consensus among all these authors that groundwater hydrochemistry is influenced to a very large extent by the incongruent weathering of silicate minerals in the aquifers. Cation exchange (Kortatsi et al., 2008; Yidana, 2008; Yidana and Yidana, 2009) has been identified as another major factor controlling groundwater chemical quality of some of the hydrogeological sub-terrains in the country, and it comes in the wake of silicate mineral weathering during which clay minerals are formed and act as suitable sites for these reactions. Jorgensen and Banoeng-Yakubo (2001), Helsrup et al. (2007) and Banoeng-Yakubo et al. (2009) identified seawater intrusion as one of the major factors that control groundwater hydrochemistry in the Keta basin. In most cases, if the hydrochemistry is mainly a result of rock–water interactions, the salinity is low and such aquifers lend water of acceptable quality for most uses. Anthropogenic activities and other factors sometimes combine to elevate the salinity and the concentrations of certain parameters, thus reducing the quality of groundwater from some aquifers. Although the causes of variation in the quality of groundwater in most aquifers in Ghana are understood to some extent, there have been no major attempts at studying the spatial variation of these factors. Such a study to identify the spatial variation of groundwater quality control parameters is necessary in order to delineate areas of extremely poor groundwater quality, for treatment before various use.

In this study, multivariate statistical methods have been used jointly with conventional graphical methods, to study the causes of variation in the salinity and spatially classify groundwater from southeastern part of Ghana. Groundwater electrical conductivity (EC) has been used as a measure of salinity since it provides a measure of the total dissolved ions in the groundwater system. Three indices (sodium adsorption ratio (SAR), permeability index (PI), and residual sodium carbonate (RSC)) were then used to determine the suitability of groundwater from these areas for irrigation activities.

Multivariate analyses have been used copiously in the analysis of hydrochemical data, and have been established as efficient tools in studying hydrochemical patterns of watersheds. Examples of the successful use of multivariate statistical methods in hydrochemical studies are contained in in Güler et al. (2002), Güler and Thyne (2004), Helsrup et al. (2007), Yidana et al. (2008a), and Cloutier et al. (2008). Multivariate statistical methods do not indicate cause-and-effect relationships but they do provide information from which such relationships can be inferred.

2. The study area

The area under study is underlain by aquifers of the Voltaian System, the Togo Series, the Buem formation, the Lower and Upper Birimian System, the Cape Coast and Dixcove granites. Fig. 1 is the location map of the study area.

Annual temperatures range between 21.7 °C in December and 33.9 °C in February (Yidana et al., 2008b). There are two main climatic seasons: the rainy and dry seasons. There are two major rainy reasons. The first one begins in March, peaks in June and drops in July. During this major rainy season, rainfall ranges between 1000 and 1600 mm. The second rainy season begins in August and ends in the second week of December. The dry season begins in November and ends in early March. About 40–60% of the population is engaged in Agriculture and grows crops ranging from rice to corn to vegetables (Yidana et al., 2008b).

2.1. The Voltaian aquifers

The Voltaian System is one of the two major hydrogeological terrains in Ghana. It is subdivided into three major provinces: the Upper, Middle and Lower Voltaian. The study area consists of

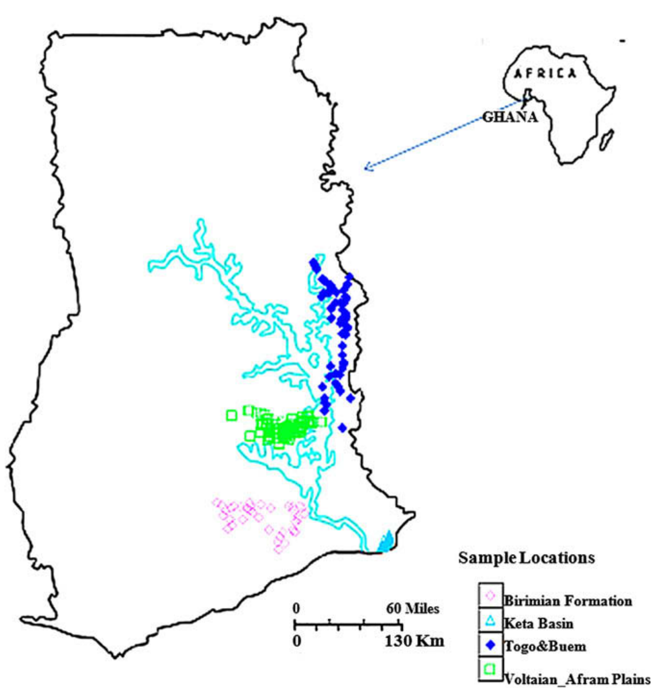

Fig. 1. A map of Ghana showing the locations of the geologic terrains sampled.

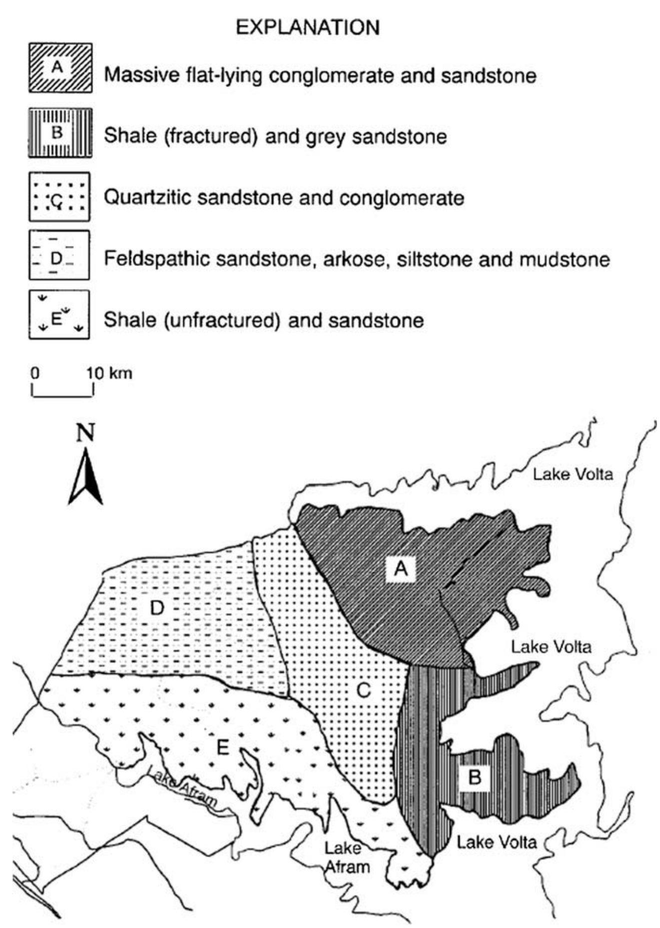

Fig. 2. A geologic map of the hydrogeology of the southern Voltaian.