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Analysis of groundwater quality using multivariate and spatial analyses in the Keta basin, Ghana

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ABSTRACT

A holistic assessment of the quality of groundwater from the shallow unconfined aquifers of the Keta strip of the Keta basin has been conducted using multivariate statistical and spatial analyses. A groundwater classification scheme has been developed for groundwater in the area using a robust water quality index (WQI) modified for the case of the Keta basin. On the basis of the WQI so computed, groundwater in the area has been spatially classified into 'good', 'fair', and 'marginal' water types using ordinary kriging developed from a well fitted linear semivariogram function. This study finds that the salinity of groundwater in the basin is largely attributed to mineral weathering and seawater intrusion. Groundwater is stable within kaolinite and Na-smectite field, suggesting the predominance of Na-rich silicate minerals over the high temperature Ca-rich minerals. There are localized influences of domestic waste discharge and agricultural activities on the hydrochemistry of groundwater in the area. Where these effects are high, high nitrate and fluoride concentrations have been noted. Four groundwater clusters have also been distinguished: clusters 1 and 4 are low salinity Ca–HCO_3 waters distinguished by differences in pH, whereas clusters 2 and 3 represent high and intermediate salinity Na–Cl waters respectively. This study further finds that clusters 1 and 4 present the best water types for irrigation purposes in the Keta basin. On account of high salinity, cluster 2 members are not suitable for irrigation of any crop in the basin. Sodium adsorption ratio (SAR) appears to display weak seasonal variations due to the influence of seawater intrusion, whose effects vary with the level of the water table relative to sea level. During dry seasons when the water table is low, saline water intrusion elevates the content of sodium in groundwater. This is reflected in the SAR values in some of the wells sampled.

1. Introduction

In the Keta basin attention on groundwater abstraction from the aquifers has increased during the last decade (Bannerman, 1994; Jorgensen and Banoeng-Yakubo, 2001; Helstrup et al., 2007). This is due to rising water demands from a growing population and an increased electrical conductivity (EC) of especially near coastal shallow groundwater in the Keta basin (Helstrup et al., 2007). A major problem in drinking water quality and management of domestic water supply in the Keta basin is salinization of groundwater in dug wells and in deep boreholes (Gill, 1969; Bannerman, 1994; Helstrup et al., 2007). A lot of prospective sites for wells and boreholes were not completed due to salinity problems in the aquifers, and some existing deep wells and dug wells have been abandoned due to increasing salinity over time. Almost all communities in the basin have relied on groundwater from the perched shallow aquifers to meet both domestic and irrigation needs over the past several years. However, sanitary conditions around the wellhead in most cases are very poor leading to contamination from surface sources.

In addition to the rising demands of potable water in households, the shallow aquifers have been the source of water for most irrigation schemes in Keta and surrounding areas. Whereas irrigation activities are very much encouraged as poverty reduction strategies, the use of water of high salinity has the tendency to reduce soil and crop productivity in an area over time by destroying soil permeability and reducing the osmotic potential of crops. In the light of this, one of the management strategies for groundwater resources especially in the coastal belt is to ensure that groundwater extraction does not lead to the intrusion of saline seawater into the aquifers. However, due to the relatively low elevations in the area and the lack of strict regulation, groundwater salinization continues to be a problem in some of the coastal areas. On the other hand, this resource is the only source of water for agricultural activities in view of the erratic nature of rainfalls in recent times. The high salinities of groundwater from some of the wells in the area and the heavy reliance of the communities on groundwater for irrigation necessitate an overall assessment of the quality of the resource in the area for irrigation purposes.

This study conducts a holistic assessment of the quality of groundwater resources in the Keta basin for various purposes. A robust water quality index (WQI) weighted for the essential

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parameters in domestic water quality assessment has been used to classify groundwater in the area into spatial water quality types. Ordinary kriging is then applied to produce a WQI map for the basin, highlighting areas with significant groundwater quality problems. R-mode factor analysis and Q-mode hierarchical cluster analysis, HCA, are respectively used to assess the causes of variation in groundwater salinity and the spatial salinity classes in the area. The irrigation quality of groundwater from the basin is assessed using conventional graphical methods.

2. The study area

2.1. Climate

The Keta basin (Fig. 1) lies within the dry equatorial climatic region, and is the driest part of the country. Two seasons are clearly defined in this area: the rainy and dry seasons. The rainy season exhibits double maxima: the main rainy season occurs between April and July, whilst the minor one falls between September and October of every year. June is usually the wettest month in the area. Relative humidity is generally high in the mornings and at night but minimum in the afternoon. Instantaneous values as high as 96% and as low as 63% have been recorded in the mornings and afternoons respectively (Banoeng-Yakubo et al., 2005).

Based on data spanning the period from 1913 to 1992, the mean annual precipitation in the area is 800.8 mm. The highest monthly mean value of 187.5 mm occurs in June while the minimum mean value of 10.6 mm occurs in January. Annual evaporation is about 1785 mm. This is quite high compared to the annual average rainfall in the area. On a monthly basis, it is only in June that rainfall exceeds potential evaporation (Banoeng-Yakubo et al., 2005).

2.2. Geology and hydrogeology

The Keta basin is a fault-controlled Mesozoic/Tertiary sedimentary basin along the coast of the Gulf of Guinea (Akpati, 1978; Jorgensen and Banoeng-Yakubo, 2001). The basement complex consists of early Precambrian Dahomeyan gneisses, migmatites, and schists. These rocks were affected by the Pan-African orogeny and crop out along the fringes of the basin to the north (Jorgensen and Banoeng-Yakubo, 2001). The basal sedimentary sequence in the basin comprises Lower to Middle Devonian marine shale, sandstone, and siltstone, which are overlain by Jurassic dolerites and sills (Akpati, 1978; Jorgensen and Banoeng-Yakubo, 2001). A series of Cretaceous–Eocene marine sediments composed of limestone, shale, and glauconitic sandstone outcrops in the eastern edge of the basin close to the Togo–Ghana boundary (Jorgensen and Banoeng-Yakubo, 2001). The sandstones and limestones in this area are highly consolidated and thicken towards the coast in the southwest of the basin. Scattered deposits of Neogene continental sediments unconformably overlying the Cretaceous–Eocene limestone and sandstones occur in the northeastern sections of the basin. These materials are mainly made of unconsolidated to semi-consolidated limonitic argillaceous sands with gravelly beds at the base. The central part of the basin is dominated by quaternary unconsolidated coastal sediments, marine sands, and gravels, which are averagely 30 m thick around Keta, though they thicken toward the Volta River estuary. Nerquaye-Tetteh (1993) identified four major aquifers in the Keta basin according to the geography and geological setting. These are:

- Weathered Dahomeyan gneiss along the northeastern rim of the basin.
- Surficial Neogene continental deposits of unconsolidated to semi-consolidated limonitic argillaceous sands in the northeastern and central parts of the basin.
- Quaternary coastal marine sands and gravels in the Volta River estuary and Keta Lagoon area. These unconsolidated sands and gravels are generally associated with high groundwater recharge.
- Cretaceous–Eocene marine limestones and sandstone beds that are exploited for drinking water in the central and southeastern parts of the basin; these units constitute the major and most important deeper aquifer in the Keta basin (Jorgensen and Banoeng-Yakubo, 2001).

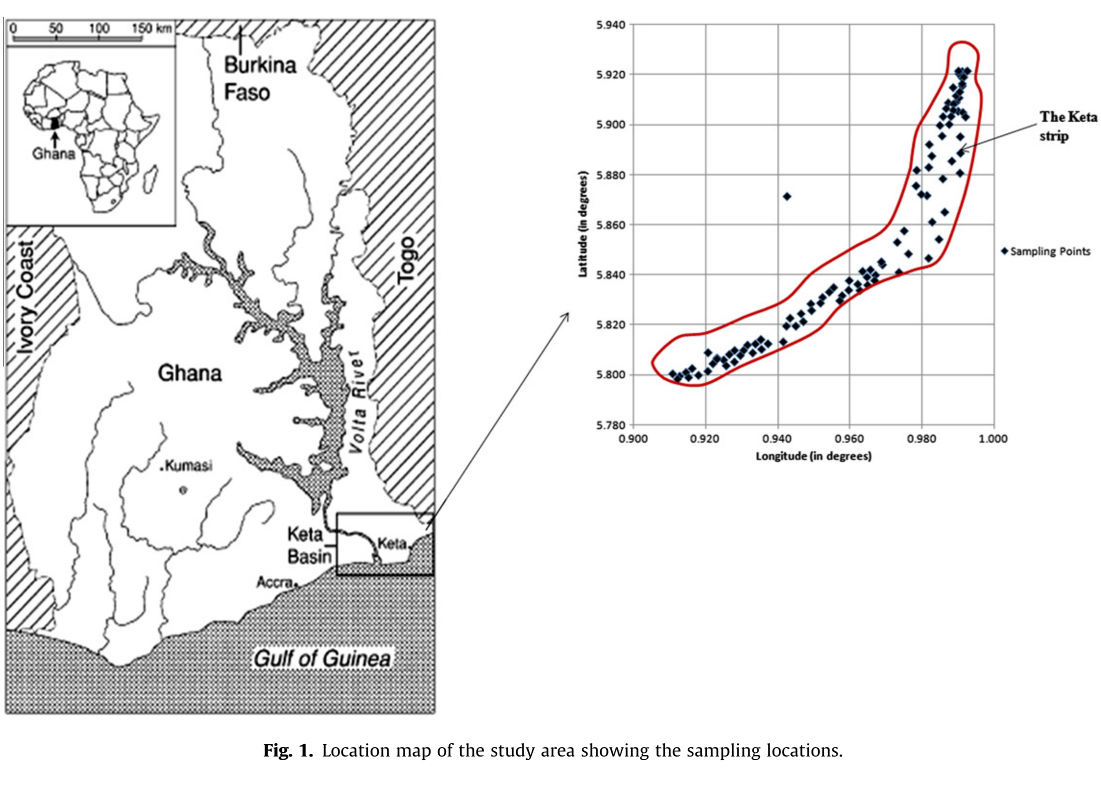

Fig. 1. Location map of the study area showing the sampling locations.