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Research paper

Application of environmental isotope to assess the renewability of groundwater of continental intercalaire aquifer of Sokoto Basin in Northwestern Nigeria

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ABSTRACT

The southeast sector of Iullemmeden Basin is located in Nigeria and referred to as the Sokoto Basin. The aquifer system of Sokoto Basin is multilayered with Continental Intercalaire (CI) aquifer also known as Gundumi-Illo Formation at the bottom, overlain by the Rima Group, Sokoto Group and Continental Terminal (Gwandu Formation). This study is aimed at determining the validity of the statement that the Continental Intercalaire of the basin receives no recharge, through application of environmental isotopes of water molecules (^{3}H, ^{2}H, and ^{18}O) and characteristics deuterium excess (d-excess). The isotope result of oxygen-18 (δ^{18}O) content ranges between −7.72‰ and 3.69‰, and deuterium (δ^2H) content from −51‰ to 9.42‰. These results indicates presence of three categories of water, the waters depleted slightly in isotope signature, the moderately depleted waters and waters highly depleted in δ^{18}O and δ^2H. These results suggests that the waters depleted slightly in isotope signature may be evaporated waters, while moderately depleted values of ^{18}O and ^{2}H of water content from the Continental Intercalaire designates the modern waters and waters highly depleted in isotope signature may be regarded as paleowaters. The tritium (^{3}H) value recorded falls within the range of 0.5–4 TU represents a mixture of pre-1952 and post-1952 water origin. It is thus concluded from the results that Continental Intercalaire aquifer of Sokoto Basin receives modern water as recharge.

1. Introduction

Sokoto Sedimentary Basin is located in the south eastern part of the Iullemmeden aquifer system (Fig. 1). Groundwater is vital in Sokoto Basin where the amount of rainfall is limited to very few months of the year and surface water sources tend to dry up at peak dry season. The groundwater is accessed via dug wells. The total draft of water from dug wells in the Sokoto Sedimentary Basin is estimated to be less than 5 mgd, the individual draft per well is about 1000 gpd, (Anderson and Ogilbee, 1973). The dug wells are subject to seepage from nearby livestock and village wastes, and consequently the water is often contaminated. Sokoto Sedimentary Basin holds 34% of the population of Iullemmeden Basin of over 15million and the population is growing fast (OSS, 2008).

Its groundwater resources are overexploited, considering the serious rainfall deficit from the 1980s to 2000 (GICRESAIT, 2012). Though, several irrigation programmes have been introduced in the Sokoto (Fadama) Basin. Numerous studies have been carried out in this Basin, including studies on geological formations of the basin to water resources integration of the basin (Falconer, 1911; Raeburn and Tattam, 1930; Jones, 1948; Bell, 1961; Du Preeze and Barber, 1965; Anderson and Ogilbee, 1973; Kogbe, 1979; Oteze, 1989; Adelana et al., 2003; Alagbe, 2004; Okuofu, 2006; Sokona et al., 2008; AzTech, 2010; among many others) using mainly hydro-chemical approach. However, in Sokoto Sedimentary Basin, a greater part of Rima and Sokoto Formations are still uncovered using environmental isotope technique despite the limited application in Wurno irrigation scheme in Rima Formation. Environmental isotope hydrology is a relatively new field of investigation based on isotopic variations observed in natural waters. These isotopic characteristics have been established over a broad range and time scale. Isotopes of hydrogen and oxygen are ideal geochemical tracers of water because their concentrations are usually not subject to change by interaction with the aquifer material. They are currently referred to as the ‘DNA’ of water bodies because they can respond

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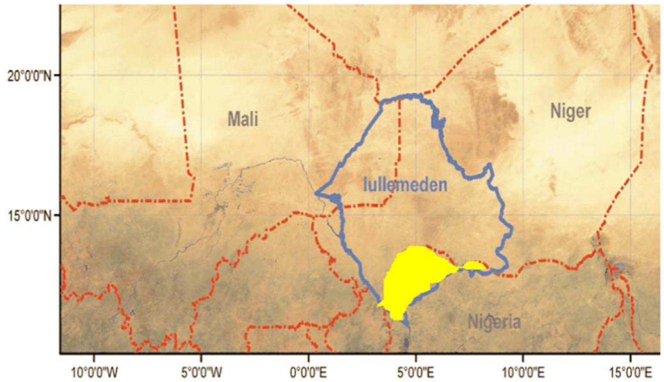

Fig. 1. The Iullemmeden Basin showing the location of the Sokoto Basin (Yellow) (Modified from Source: OSS, 2008).

sensitively to changes in the environment and trace these changes effectively (Hui et al., 2014). They cannot be controlled by man, but can be observed and interpreted to gain valuable regional and local information on the timescale of hydrological events, identify the origin of water, renewal potential of aquifer, turnover and transit time of water in the system which often may not be readily obtained by other techniques. The Continental Intercalaire aquifer is recharged principally on its outcrop area, by infiltration from precipitation and also by effluent seepage from streams in rainy season (Anderson and Ogilbee, 1973) however other previous research work in the area had it that the aquifer system consists of huge stock of non-renewable fossil water. According to Sokona et al. (2008), the Rima River is recharging part of the alluvial aquifer in the Sokoto Basin, while the portion of the paleowater related to the Continental Intercalaire (CI) receives no recharge. Hence, this study is mainly aimed at determining the veracity of the statement (that the groundwater of CI receives no recharge) and establishing whether or not there is a renewal potential of the Continental Intercalaire aquifer system of Sokoto Basin, underlying Sokoto, Kebbi, and part of Zamfara States in Nigeria, using environmental isotope signatures of deuterium (δ^2H), oxygen-18 ($\delta^{18}O$) and tritium (^3H).

2. Study area

2.1. Location, geography and morphology

The Iullemeden Aquifer System (IAS) is located in the arid and sem-arid zone of three contiguous countries in Africa: Mali, Niger and Nigeria, (Fig. 1). This IAS is locally referred to as Sokoto Sedimentary Basin in Nigeria. The study area, Sokoto Sedimentary Basin covers three fourth of the States in the north western section of the Northern Region within Nigeria which make up Sokoto Basin. The States covered includes Sokoto, Kebbi and Zamfara States. The study area falls within latitude 8°35′0″N to 4°0′0″N and longitude 3°5′00″E to 8°30′00″E and covers a geographical areal extent of 60,000 km^2 (Fig. 2).

2.2. Geology, hydrogeology, and climatic features

The Precambrian basement occupied mainly the south-eastern segment of Sokoto River Basin; it was composed of crystalline rock (granite and related stones) and metamorphic rock (gneiss, schist, quartzite) that made up its Basement Complex (Fig. 3), which was part of the craton of the West African shield. Three major fault trends are prominent in the Sokoto basin (AzTech, 2010). The Sokoto Basin also consist of up to 2000 m of classic sequences that rests upon the Basement (Zboril, 1984). Moreover, in the Sokoto basin sequences of semi-consolidated gravels, sands, clay, some limestone and ironstone are found. According to Kogbe (1989), Adelana et al. (2003) and GICRESAIT (2012) the sedimentary sequences are sub-divided from bottom to top into the late Jurassic to early Cretaceous Illo and Gundumi Formations (composed of sandstone and clay, belong to the Continental Intercalaire"),

the Maestrichtian Rima Group (sub-divided into Taloka clayite, Dukamaje schist and Wurno soft sandstone Formations), the late Paleocene Sokoto Group (sub-divided into Dange pelite, Gamba and Kalambaina marine limestone which caps the Intercalary Continental of Sokoto Group) and the Eocene-Miocene Gwandu Formation (composed of sandstone and clayite formation, belong to Terminal Continental) (Fig. 4). Overlying all the formations is Dune and laterite hardpan formation of Quaternary period, yielding water to most dug wells in the area.

The Sokoto Basin water resources can be divided into precipitation, surface water and groundwater. The precipitation in the area is concentrated within 3–5 months resulting in a periodic, short-lived but strong surface runoff (Adelana et al., 2003). The dry season lasts for about 7–8 months, the rainy season is short, with violent rain spells. The potential evapo-transpiration is very high, systematically higher than rainfall, except in August (AzTech, 2010).

Rainfall is directly responsible for stream discharge in these areas; the groundwater contribution to stream flow is usually small.

Due to the sporadic nature of rainfall and fast surface run-offs, infiltration into the groundwater system is drastically reduced. However, between Sabon Birni (about 70 km North East of Rabah village) and Sokoto town; the Rima River loses about 5.07×10^7 m^3 of water to the ground every year (Oteze 1989; Adelana et al., 2003). This region displays a gentle relief ranging between 250 and 400 m above sea level where rainfall is irregular in the area with major interannual variability. The average rainfall is between 350 mm in the north in Kalmalo and 670 mm at the Sokoto airport. Prominent drainage systems are the Rivers Rima and Sokoto, joining close to Sokoto town, draining into River Niger and ultimately into the Atlantic Ocean. The headwaters of the Rivers Sokoto and Rima and their tributaries take off from the pre-Cretaceous crystalline basement terrain east of the basin and flows west and south. The River Niger gets about 46 million m^3/year from the CI and 79 million m^3/year from the TC, for an annual total of 125 million m^3. Its tributary Rima River provides about 20 million m^3/year to the CI and receives about 12 million m^3/year from the TC before joining the river Niger (OSS, 2008).

Ground water in the Sokoto Basin is both confined as artesian water or unconfined beneath the water table, in most of the permeable members of the Cretaceous-Tertiary Sedimentary sequence. While confined water occurs downdip·and at depth in semi-consolidated sand or gravel of at least three important aquifers, in the Gundumi Formation, the Rima Group, and the Gwandu Formation. And unconfined ground water also occurs in the Quaternary alluvial. The climate is semi-arid or Sahelian.

3. Materials and methods

Eighty seven water samples were collected from hand dugwells, tubewells, boreholes, and surface waters such as Rivers Rima, Sokoto, Zamfara, and reservoir like Goronyo Dam in two major sampling exercises. Garmin 72H model Global Positioning System (GPS) was used to take coordinates and altitude of each location. Water samples were collected in airtight High Density Polyethylene (HDPE) containers for further laboratory analyses. One 500 ml and one 60 ml HDPE containers were used for collection of water sample from each well for isotopic analyses. While the 500 ml HDPE container was utilized for stable isotope measurement and 60 ml HDPE container was used for collection of water sample for Tritium determination. The oxygen-18, deuterium, tritium analyses were carried out at the Center National des Sciences et Technologies Nuclear (CNESTEN), Rabat, Morocco. Tritium concentrations were measured with liquid scintillation counter and expressed in Tritium Units (TU) with a precision of ±0.5. Deuterium and Oxygen-18 were measured by infrared Laser spectro-