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ASPECTS OF ISOTOPE HYDROLOGY IN NIGERIA

1. INTRODUCTION

Environmental isotopes have proved an important tool in hydrological research and practical applications (UNESCO, 1972). Stable isotopes of hydrogen (H-2 = deuterium) and oxygen (O-18) as well as radioactive isotopes of hydrogen (H-3 = tritium) and carbon (C-14) occuring in natural waters are used to assess the inter-relationships of water from various sources within the hydrological cycle. Field work, including sampling and chemical analyses, was carried out by the author during 1978-79. Isotope determinations were carried out in the Institute of Environmental Physics, University of Heidelberg, West Germany, under the supervision of Dr C SONNTAG.

2. PHYSICAL SETTING

Nigeria is a land of widely varying landscapes and climates covering an area of 924.000 km^2. The land rises steadily from the Atlantic coast (Bights of Benin and Biafra respectively) reaching an altitude of 300 - 900m a.s.l. in the north. The highest ground is the Jos Plateau (1800m a.s.l.) almost in the centre. The country is drained by the River Niger and its major tributary, the River Benue. The two river valleys are geologically old features, associated with Cretaceous troughs dissecting the Pre-Cambrian Basement Complex in a Y-shaped pattern. Toward the northwest the Niger valley lies in the Sokoto basin while to the northeast the Benue River traverses the Chad basin. The coastal sedimentary basin is of course located in the south. These basins constitute potential groundwater resources which are not fully developed.

Recharge to the aquifers is reduced in the northern regions due to lower rainfall. Rainfall decreases from 2000mm or more each year in the southern rain forest belt to less than 500mm in the northern savanna areas. Climatic conditions are governed by the movement of the Intertropical Front. Southwesterly winds carry rain bearing equatorial maritime air masses inland to cause a distinct wet season from March/May to October. The dry season ("Harmattan") on the other hand is dominated by tropical continental air masses blown by northeasterly winds from the Sahara (BUCHANAN & PUGH, 1976).

3. PRECIPITATION

The isotopic composition of rain is of major importance because it can indicate the main source of surface and groundwater replenishment, particularly in the southern region. There is only one station in Nigeria belonging to the IAEA/WMO network, at Kano. Early data were interpreted by DANSGAARD (1964) while latest information is published in IAEA Technical Reports. Kano, which has a continental climate, cannot be regarded as representative of the entire country. An "amount effect" can, however, be reckoned throughout Nigeria. It was quantified for Kano with 2.2‰ ^{18}O per 100 mm (DANSGAARD). In the $\delta D/\delta^{18}O$ relationship diagram the isotope for rain at the beginning and the end of the wet season plot along a low slope line (<8) whereas wet season samples follow the slope ≃8 according to the Meteoric Water Line (MWL): $D‰ = 8\delta^{18}O‰ + 10$ (fig.2). The same tendency was observed at Ife (southwestern Nigeria) with individual samples collected since August 1978. δ-values range between -6.8/+1.8‰ for oxygen-18 and -42/+24‰ for deuterium. This wide fluctuation is narrowed down to $\delta^{18}O = -2.9 \pm 0.2‰$ and $\delta D = -11.7 \pm 1.1$ ‰ and $D = -11.7 \pm 1.1‰$ in infiltrated water as repeatedly sampled in a shallow well in which the tritium content was found to be 16.8±4 T.U.

4. SURFACE WATERS

Streams were sampled only arbitrarily except in southwestern Nigeria where several perennial rivers were regularly surveyed in order to estimate baseflow contribution to dry season discharges (fig.1). The stable isotopes composition of these waters does not differ very much from the springs sampled (fig.2): $\delta D = -9/-15‰$, $\delta^{18}O = -2.6/-3.5‰$. More positive values occur downstream toward the end of the dry season as a result of evaporation. Some streams, sampled in their upper reaches, show tritium concentrations < 10 T.U. which reveal contribution by "deep storage" as explained later in this paper. A quantitative approach would have to take into account interflow to be separated from genuine groundwater flow.

5. GROUNDWATERS

At a first glance the groundwaters display a

Figure 1. South Western Nigeria. Frequency Distribution of Deuterium and Tritium in perennially flowing river waters

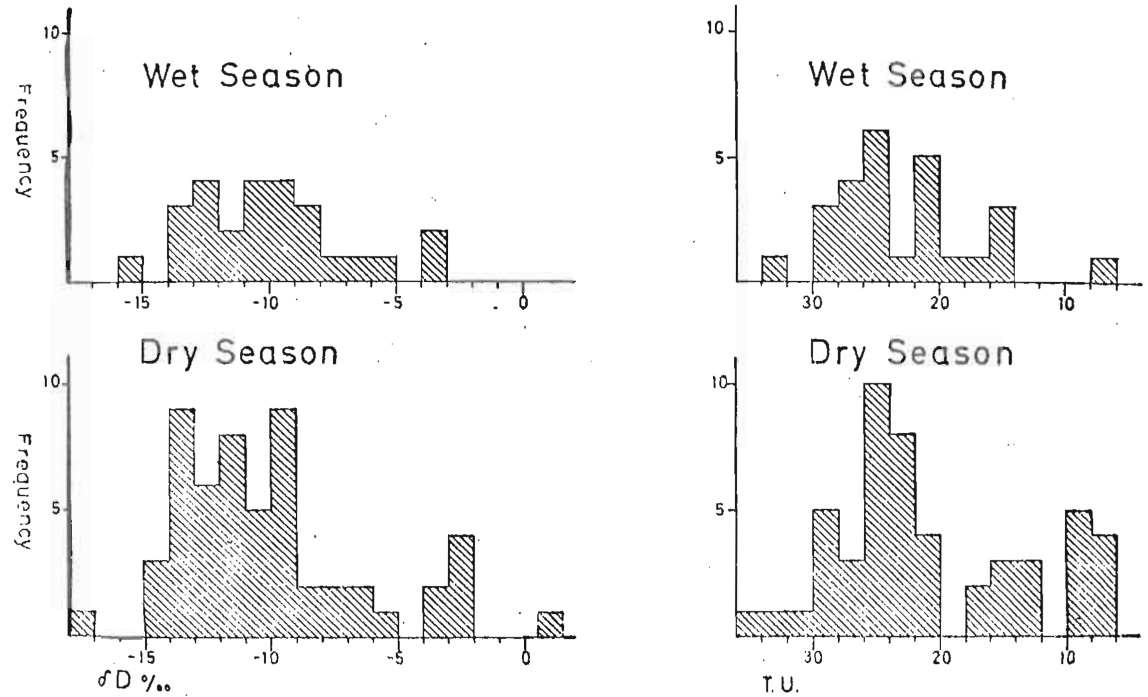
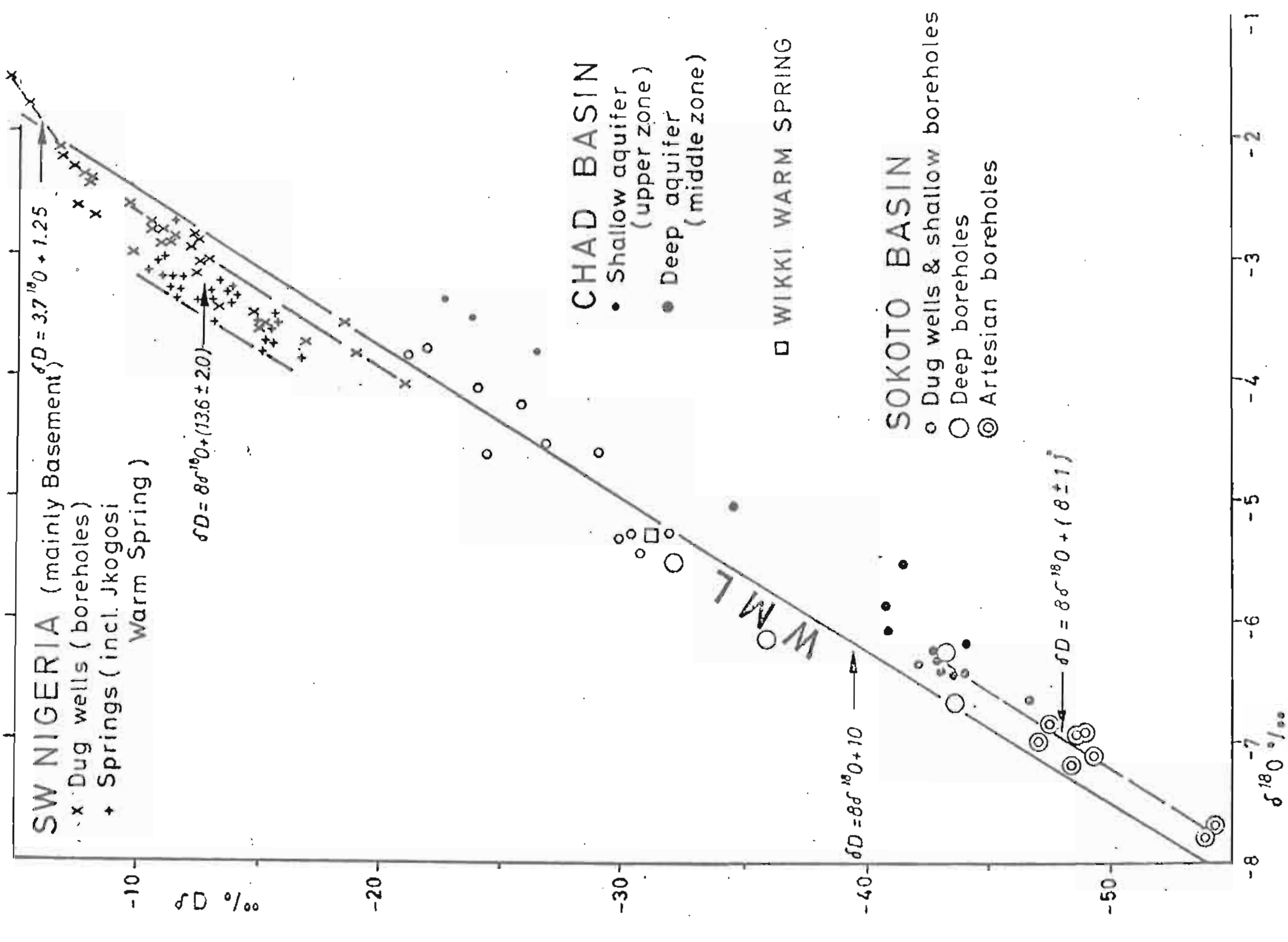


Figure 2. Oxygen - 18 vs Deuterium in Nigerian Groundwaters



wide range of stable isotope compositions (fig. 2). In combination with tritium and carbon-14 some clues are given as to the origin of waters in the three hydrogeological provinces.

5.1. Sokoto Basin

Waters from artesian and deep boreholes mainly tapping the Tertiary Gwandu aquifer are depleted in O-18 and D. The most depleted water in the basin is slightly saline and comes from Kaloye borehole (Cretaceous Rima aquifer). The Artesian waters are free of tritium and their C-14 activities range from 2 - 7.4 p.m.c. (percentage modern carbon) indicating an age of 20.800 - 31.300 years B.P. These are fossil waters infiltrated under humid conditions prior to the ice-age maximum. Their deuterium excess is markedly lower with respect to the WML: $\delta D = 8\delta^{18}O + (8 \pm 1)$ (fig. 2). Wastes from the shallower boreholes and dug wells with more positive stable isotope values either represent mixtures of fossil and recent recharge or just recent recharge, the latter scattered around the WML and with tritium up to 85 T.U. in perched aquifers.

5.2. Chad Basin

Waters from the "deep" aquifer of late Tertiary to Quaternary age (middle zone of the Chad Formation after BARBER & JONES, 1960) are closely related to the artesian and deep borehole water of the Sokoto basin in respect of their excessive deuterium content. The recharge period for both basins thus assumed to be the great pluvial. In fossil Saharan groundwaters, differences in the δ-values are believed to be due to an ancient "continental effect" caused by westerlies (SONNTAG et al., 1978). The Nigerian data do not seem to support this hypothesis of western drift but paleoclimatic information from south of the Sahara is still sparse and inconclusive. Groundwaters pumped from the "shallow" aquifer of the Chad Basin (upper zone) do contain tritium proving local, present-day recharge. Wikki spring yielding warm water from the Eocene Kerri-Kerri Formation is, however, tritium free, with C-14 of 70.4 p.m.c. The water temperature (31°C) corresponds to an aquifer depth of 36m within the Chad Basin (fig. 7 in MILLER et al., 1968).

5.3 Southwestern Nigeria

All the groundwaters in this basin are relatively enriched in stable isotopes (fig. 2), whether from springs, dug wells or boreholes, the latter being located in the sedimentary area south of the Basement. The majority of these waters show deuterium excesses between 11.6 - 15.6 i.e. above the WML. Short residence times underground are hinted at by tritium contents in the range of that of current precipitation. "Deeper storage" is associated either with fault systems, which are responsible for elevated spring-water temperature (37°C at Ikogosi Warm Spring) or karst features (exceptionally high dissolved $CaHCO_3$. Two C-14 analyses of water which contains less than 4 T.U. yielded 78.2 - 83.2 p.m.c. This means the water is approximately 50 - 100 years and is thus the oldest water so far traced in the Basement Complex.

Some dug well waters follow an evaporation line: $\delta D + 3.7\delta^{18}O + 1.25$.

Recharge is currently occurring in some of the deeper Quaternary and Cretaceous strata since boreholes tapping these aquifers yield waters with tritium. On the other hand, other deep aquifers have waters which are tritium-free. These aquifers are therefore not being recharged.

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