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Mean-Residence Time of Groundwater in the Basement Complex Terrain of Kano Metropolis (Nigeria) Estimated from Tritium Radioisotope

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Abstract: *Groundwater potential of an area covers not only exploration and quality assessment of the available reserves, but also determination of recharge age of groundwater in order to evaluate the sustainable yield of the resource. Tritium concentrations in groundwater system of the Basement Complex Terrain of Kano metropolis (Nigeria) has been used to determine mean-residence time of groundwater in the Aquifer. This groundwater is exploited for both domestic and industrial use. Using Isotope Techniques in groundwater samples collected from 28 selected motorized boreholes in the year 2010, the results generally, indicated that recharge to groundwater of the area is 'Modern' (water younger than 50 years). However, one borehole showed insignificant tritium of 0.0±0.2 TU. This, in effect, implied that only minimal recharge took place in groundwater around this borehole after the early 1950s, which informs the need for judicious exploitation of this part of the aquifers for sustainability.*

Keywords- *Basement Complex, Isotopes, Paleowater, Recharge Tritium.*

I. Introduction

Groundwater is an important source of water for agricultural, industrial, and domestic uses, and often it may be only source of water supply for the people in arid regions and developing countries. Although groundwater was found to be one of the important components in the hydrological cycle, however, its role is yet to be well understood.

Kano being the most populous state in Nigeria has densely populated metropolis. The exponential growth rate of population of the state during recent decades largely due to rural-urban migration, birth rate and a shift in land use from agricultural to residential has been accompanied by a sharp increase in the demand for water, for both domestic and industrial use [1]. This trend, together with low annual rainfall characteristics of the state, has resulted in high groundwater extraction, especially in certain areas and periods of the year when surface water resources are unable to fulfill the growing water demand. This increased demand for water in the Kano metropolis has brought challenges in the area of assessments of supply and renewal of water resource.

Water dating has been hailed internationally as a breakthrough in managing aquifer systems and in detecting early signs of deteriorating water quality. Age of groundwater recharge, combined with knowledge of the hydrological setting, can provide valuable information for planning for the sustainable management of groundwater resources [2].

Naturally occurring radioactive isotopes that exist in water in the hydrologic cycle have been used to investigate groundwater system since early 1950's. One of such isotopes is tritium (^{3}H), which is used to determine the age of groundwater (the length of time it has been isolated and lost contact with the atmosphere).

Tritium concentration in precipitation is known to show spatial, seasonal, and intra annual variations, complicated mixing often occurs in an aquifer and the mode and extent of mixing of each year's recharge with that of previous years' recharge is difficult to know, mixing with another water bodies are also plausible. Hence, a single groundwater age determination using tritium is a ballpark, but it is highly informative semi quantitative approach. Each water molecule in a groundwater sample has its individual history, and a single groundwater age does not strictly exist. Any given groundwater is a mixture of waters with a distribution of ages. The exponential model (EM) assumes that the age distribution is described by an exponential law so that younger water is present more frequently than older water. This model is mathematically equivalent to the well-known model of good mixing. A mean residence time can be calculated from the EM [3].

Tritium concentration in river water and groundwater increased after the beginning of thermonuclear test and becomes larger than that of precipitation after the end of aerial thermonuclear tests [4]. In groundwater, tritium concentration can be varied from place to place even in a small area. Tritium concentration in ground water at Yola (Nigeria) observed in 2008 ranged from lower than 3.5TU to more than 9TU [5].

Tritium has been employed in this study to improve the knowledge and understanding of groundwater resource of the Basement Complex terrain of Kano metropolis for proper sustainable planning and management of the resource.

II. Materials And Methods

2.1 The Study Area

The study area, which forms part of the greater "Metropolitan Kano", covers an area of approximately 1825 km^2 and is situated within latitudes 11.53°N; 12.08°N and longitudes 8.25°E; 8.75°E, extending from River Rafin Mallam in the North, the village of Tamburawa to the South. The area of study lies on an altitude of approximately 486 meters above sea level, comprising gently undulating Plains, sloping to the Northeast. Challawa River and its main tributary the Kano River drain the Southern part of the area [6]. Within the area, no major stream joins the Challawa in its right bank (fig. 1).

Kano state lies within the tropical Savannah zone of Nigeria. Temperatures are high throughout the year. The mean annual maximum temperature is between 27–35°C and the mean minimum temperature is between 16–21°C [7]. The state has two broad seasons: the rainy season and the dry season. Rainy season starts from May to October with decreasing rainfall from southern to the northern part of the state [8]. Precipitation remains averagely 104 days a year, divided unequally. Annual rainfall is closely related to latitudinal position with over 1000mm/a recorded in extreme south and about 780mm/a or less in the north [7]. Evaporation is generally high and is in excess of rainfall, except in the months of July–August.

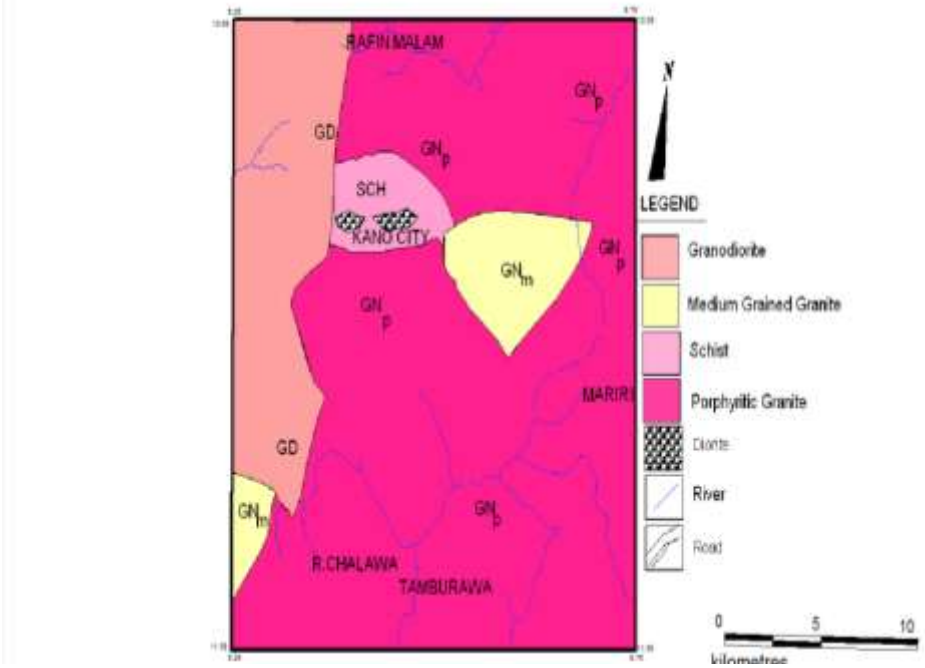

Figure 1: map showing geology of the state

2.2 Geology and Hydrogeology of the Area

This area of study falls within the Basement Complex rocks of Central Nigeria. The main lithologic units mapped in the area include schists, diorites, granodiorites, and granites. The Basement Complex (in which the younger granites intrude) consists of hard crystalline rocks, which may be jointed, fractured and or weathered, and are overlain by superficial deposits (fig.1).

Groundwater in the Basement Complex occurs mainly under unconfined water table conditions. The water table is very shallow, and in most cases, it is at a depth of about 20 metres below the ground surface [8]. The average values of transmissivity and coefficient of permeability for the Basement Complex, as observed from many boreholes log, are 0.5134 m^2/hr (12.32 m^2/day) and 0.0138 m/hr (0.33 m/day) respectively [9].

2.3 Tritium Fundamentals

The radioactive isotope of hydrogen, ^3H, naturally originates from a nuclear reaction between atmospheric nitrogen and thermal neutrons in the upper atmosphere [10]:

$$^{14}N\left(\boldsymbol{n}, ^{12}C\right)^{3}H \qquad (\mathbf{1})$$

$$^{2}H\ (\boldsymbol{n}, \boldsymbol{gamma ray})\ ^{3}H \qquad (\mathbf{2})$$

The ^{3}H thus formed enters the hydrologic cycle after oxidation to $^{1}H^{3}HO$, it reaches the surface of the earth as part of rain water, in which it is essentially a conservative tracer. Production rate of natural tritium in the atmosphere is estimated to be 2500atoms/m^2/s (troposphere: 840, stratosphere: 1660) [11]. Tritium finally decays according to the equation (3):

$$^{3}H \rightarrow\ ^{3}He + \boldsymbol{\beta}^{-} \qquad (\mathbf{3})$$

with $E_{\beta_{max}} = 18KeV$ and half-life of 12.32 years [12].

The tritium content is expressed in tritium units (TU). One tritium unit is defined as one atom of ^{3}H per 10^{18} atoms of ^{1}H, which is equivalent to a specific activity of 0.118 Bq/L or 3.19 pCi/L of water.

Tritium is produced naturally in the Earth's atmosphere, though its main use in hydrology stems from its production in large quantities by atmospheric testing of thermonuclear bombs. During this period, artificial tritium of 236x10^{18}Bq was released into the earth [11], which amounts to about 181 times higher than that of natural tritium in the earth. Since 1952, tritium contents of precipitation and groundwater increased and reached a peak in 1963. Tritium activities in continental precipitation prior to the advent of nuclear weapons testing in 1952 were in the range of 1 to 20 TU's [13]: tritium concentration in surface water on land is found to be 2-8TU (0.2 - 0.9Bq/L) whereas 1TU (0.1Bq/L) in the surface ocean. In late 1963, a moratorium on atmospheric testing was declared, and tritium activities in precipitation have decreased since then to pre-1953 levels. Tritium is thus used as an indicator of pre-1953 or post-1953 recharge of groundwater.

In 1990's, tritium concentrations at many stations, seems to be flattened out. Ottawa: 10 - 30TU, Ryori: 3 - 8TU, Jakarta: 2 - 3TU, Kaitoke: 2 – 3TU and Hally Bay (Antarctica): 6 - 20TU (IAEA, 2001). The formation rate of tritium depends on cosmic rays produced by neutron flux. The neutron flux is four times greater in the polar region than in the equatorial region. Therefore, tritium concentration is higher in higher latitudes even after the artificial tritium is disappeared [11].

Groundwater dating based on tritium uses the fact that the initial concentration A_o (expressed in TU) in recharging groundwater decreases with time according to the decay equation (4):

$$\boldsymbol{A(t) = A_o}\mathrm{e}^{-\boldsymbol{\lambda t}} \qquad (\mathbf{4})$$

where A(t) is the tritium concentration measured in a sample after decay over time t and λ is the decay constant.

Trend in variation of tritium in precipitation for N'djamena (Chad) station (Lat. 12.13^{o}N; Long. 15.03^{o}E; At. 294 msl) has been observed to follow the usual pattern in one hand, and to give fruitful information on tritium level at the atmosphere around the study area on the other [14]. This is depicted in fig. 2.

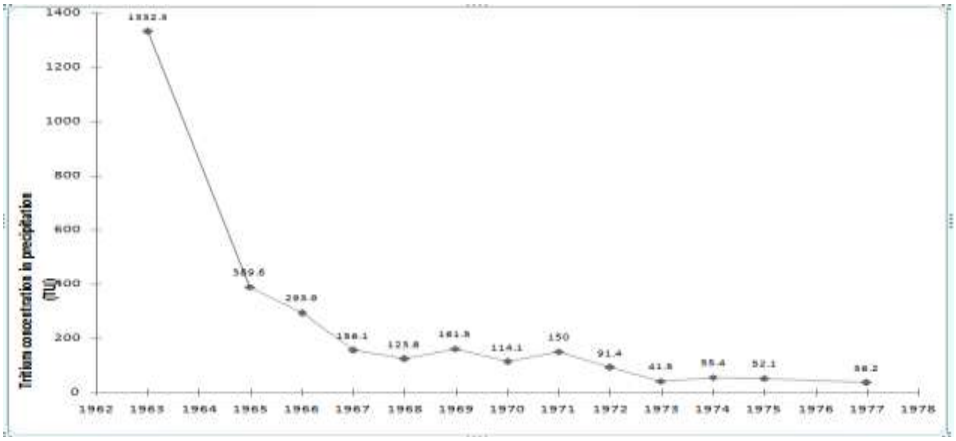

Figure 2: variation of tritium with time in precipitation at N'djamena (Chad)

2.4 Sampling and Analysis

Samples of unfiltered, unacidified groundwater were collected from random selected hand-pump motorized boreholes that are in continuous abstraction and whose hydraulic information, depth, locations are known. Samples were always collected after pumping for at least 10 minutes if water was not already being pumped prior to arrival at the pump site. This was to purge the boreholes of stagnant water around the pump parts, so that the water samples are isotopic representative of the aquifer. They were kept in high-density polyethylene bottles and sealed with a plastic cone-seal cap. Overall, 28 groundwater samples were selected for tritium measurement between 6th December 2010 and 25th April 2011 as illustrated in fig. 3.

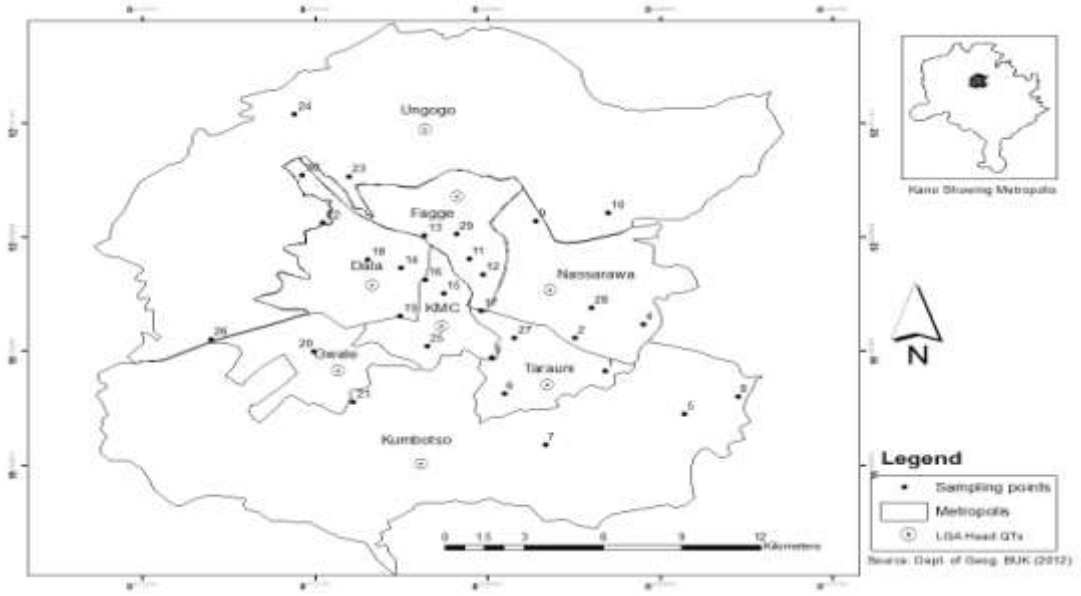

Figure 3: map showing sampling points

Tritium analysis of groundwater samples was performed by Liquid Scintillometry at the Environmental Isotope Group (EIG) of iThemba Laboratories, Gauteng, Johannesburg, South Africa.

Electrolytic enrichment of tritium more than 10 times is recommended prior to the measurement by a liquid scintillation counter. When water is electrolyzed to hydrogen and oxygen, tritium, the heaviest isotope of hydrogen, strongly enriches in water phase rather than in hydrogen gas, therefore, tritium separation factor between water and hydrogen is highly important [15].

Some 500 ml of the water sample, having first been distilled and containing sodium oxide was introduced into the cell for enrichment. using stainless steel - mild steel electrode, tritium concentration enriched about 20 times when water volume was reduced to some 25 times. Samples of standard known tritium concentration (spikes) were run in one cell of each batch to check on the enrichment attained. During electrolysis, hydrogen and oxygen mixture is released from an electrolysis cell. As this gas mixture is very dangerous, ventilation was provided.

To measure low levels of tritium, it is recommended to use a low-background type liquid scintillation counter, which is equipped with an anti-coincident counter, and lead shield that largely reduces background of cosmic ray origin. After the preparation of samples by mixing water sample with 11 ml Ultima Gold liquid scintillator, each sample and back ground was counted in tritium channel for 500-1000 hours. After T-channel counting, external standard channel ratio (ESCR) was measured to obtain counting efficiency. Quenching standards with known amount of tritium werre also measured for T-channel counting and ESCR.

III. Results

The obtained results are presented in TABLE 1. The tritium concentration in TU at the day of measurement has been corrected for decay to the day of sample collection.

The measured tritium concentrations in groundwater samples ranged from less than the lower detection limit of 0.0 TU to 6.7 TU (mean 2.7±0.3 TU). The two-sigma precision estimate for all samples was 0.2 TU (TABLE 1). Thus, tritium concentrations for all but one of the boreholes (Number 22) were higher than the counting error.

Table 1: Tritium concentration values of rain and groundwater samples corrected for the day of sample collection.

Sample Location	Latittude(°)	Longitute(°)	Altitude (m)	Tritium (T.U.)
1	N11.96154	E8.57076	485	2.8 ± 0.3
2	N11.97623	E8.56065	486	2.9 ± 0.3
3	N11.96740	E8.53228	474	1.8 ± 0.3
4	N11.98209	E8.58397	487	3.6 ± 0.3
5	N11.95153	E8.53646	468	3.7 ± 0.4
6	N11.92877	E8.55042	467	2.5 ± 0.3

7	N11.95004	E8.61612	498	3.4 ± 0.3
8	N12.03148	E8.57186	467	2.0 ± 0.3
9	N12.01129	E8.52439	485	2.4 ± 0.3
10	N12.00432	E8.52906	474	2.0 ± 0.3
11	N12.02152	E8.50932	473	1.9 ± 0.3
12	N12.00727	E8.50126	484	1.9 ± 0.3
13	N11.99575	E8.51581	481	6.7 ± 0.4
14	N12.00193	E8.50945	473	2.5 ± 0.3
15	N11.98827	E8.52844	486	3.4 ± 0.3
16	N12.01086	E8.48999	483	2.5 ± 0.3
17	N11.98581	E8.50094	493	5.1 ± 0.3
18	N11.97012	E8.47146	479	2.5 ± 0.3
19	N11.94792	E8.48498	482	3.7 ± 0.3
20	N12.02718	E8.47458	492	2.4 ± 0.3
21	N12.04749	E8.48338	494	3.7 ± 0.3
22	N12.07532	E8.46491	500	0.0 ± 0.2
23	N11.97243	E8.51023	481	1.4 ± 0.3
24	N11.97559	E8.43654	459	2.8 ± 0.3
25	N11.98943	E8.56613	482	2.5 ± 0.3
26	N11.97633	E8.54003	485	3.0 ± 0.3
27	N11.94253	E8.59785	484	1.6 ± 0.3
28	N12.02780	E8.54734	464	1.7 ± 0.3
Rain Water 29	N11.97623	E8.56065	486	3.1 ± 0.3
Rain Water 30	N11.97623	E8.56065	486	4.2 ± 0.4
Rain Water 31	N11.97623	E8.56065	486	3.5 ± 0.3

IV. Discussion

Tritium is a relatively short-lived isotope of hydrogen, having a half-life of 12.32 years. Knowledge of tritium concentrations in precipitation is a prerequisite for estimating tritium input function in a given area for interpreting tritium concentration in groundwater. Tritium has therefore become a standard for definition of Modern groundwater, as its decay from natural pre-bomb levels cannot be detected in groundwaters recharged prior to 1953. Modern groundwaters are then younger than about 60 years relative to the year 2010 [16].

Thus, due to its relatively short half-life, the useful range for groundwater dating with tritium is less than 60 -70 years when the enriched method (detection limit = 0.2 TU) are used for the analyses. Tritium is often used in a semi quantitative manner to date groundwater: water with zero tritium (in practice < 0.2 TU) is dated prior to 1953, water with little, but measurable tritium (0.2 - 2 TU) seems to be a mixture of pre-1953 (palaeo-groundwater) and post-1953 water, water with a concentration greater than some 2 TU is of a post-1953 age and a significantly high concentration (> ~ 30 TU) indicates recharge during the 1960s [13].

In the same vein with the above classification, as indicated in fig. 2, the tritium concentration in precipitation as of 1963 at N'djamena station was recorded to be 1332.3 TU. If groundwater of this location has resulted from precipitation of 1963, then decay series could be established to project on the possible tritium concentration after 60 years and a tritium value of greater than or equal to 30 TU would have been obtained.

Tritium concentrations of the precipitation collected at Location 2, in the months of May, June and July 2010, varied from 2.1±0.3 to 4.2±0.4 TU with mean value of 3.6±0.3 TU (n=3, Table 1). Low levels observed in these samples indicated the fact that tritium concentrations of precipitation in the study area have returned to the presumed natural background level.

Groundwater with tritium concentrations 2.0 TU, 2.0 TU and 1.4 TU for Locations 8, 10 and 23 respectively showed great deal of mixing with paleowater in a manner that younger water is present more frequently than older water as suggested by exponential Model [17] as well as their more depleted relative stable isotopic contents. Moreover, all the concentrations of tritium in groundwater samples with exception of samples at Locations 8, 10, 22 and 23, have similar tritium concentrations as precipitation in the area. This strongly suggested that the water is part of an active hydrological cycle that resulted from heavy rainstorms; therefore, Modern recharge within the past few decades was expected.

Tritium concentration of groundwater at location 22 was found to be less than the detection limit of 0.2 TU. This value of 0.0±0.2 TU, typically recent to fossil, supported that the water is not young but rather paleowater [18]. This may mean groundwater that infiltrated as rain probably before 1953 (pre-bomb rain) and no recent recharge from rainfall has taken place in this part of the aquifer.

The relatively higher values of tritium concentration showed that the residence times of groundwaters in the twenty-four (24) boreholes are very short. This implied rapid circulation and recent recharge by

precipitation. When the aquifers are exploited, mining of groundwater will not occur. Conversely, the groundwater samples at locations 8, 10 and 23 showed relatively lower tritium values that indicated commingled old plus young water in these parts of the Aquifer. This implied that, in general, the aquifers are being recharged with water Modern in age (water younger than 50 years). As noted by [19], these relatively high concentrations are much below the maximum permissible concentration of tritium in water.

V. Conclusion

Environmental radioisotope tritium has been used to study age distribution of groundwater in the Basement Complex Terrain of Kano Metropolis with a view to contribute to better understanding of their mean residence time in the aquifers. By tracking the isotopes of water, valuable information can be obtained quickly, which otherwise may require decades of hydrological data collection.

The distribution of tritium content in groundwater indicates recharge on a time scale of approximately 60 years. Tritium concentrations in groundwater and rainwater samples collected in the study area ranged from 1.4 ± 0.3 to 6.7 ± 0.4 TU.

A direct examination of the results obtained suggests that the groundwater of Kano Metropolis is Modern in age, however, one borehole showed insignificant tritium of 0.0±0.2 TU. This in effect implies that only minimal recharge took place, which informs the need for judicious exploitation of this part of the aquifers for sustainability. For reliability, the data should only be used in conjunction with additional hydrological and hydrogeological information.

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