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TRANSMISSIVITY ANOMALIES AND PROSPECTS FOR GROUNDWATER EXPLORATION IN HARD ROCK AQUIFERS OF GHANA

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Abstract

Regional transmissivity anomaly maps have been used to quantitatively characterise and predict borehole yields in hard rock aquifers in Ghana. Mapping out areas of positive transmissivity anomalies delineates prospective zones for groundwater exploration. In such zones, the minimum expected yields range from 35 to 120 l/min in the various hydrogeological units. These yields are 6 to 15 times higher when compared with probable yields from regions of negative transmissivity anomalies. Detailed investigations in zones of positive transmissivity anomalies could show potential aquifers where large volumes of groundwater could be abstracted for local supplies.

Résumé

Darko, P. K.: *Anomalies de transmissivité et les perspectives d'exploration de la nappe phréatique en roches dures d'aquifères du Ghana:* Les cartes des anomalies de transmissivité régionale ont été utilisées pour caractériser quantitativement et prédire les rendements de trou de sonde dans les roches dures d'aquifères au Ghana. Traçant les zones des anomalies de transmissivité positive délinée les zones de prospection pour l'exploration de la nappe phréatique. Dans ces zones, les rendements minimums espérés varient de 35 à 120 l/min dans les différents unités hydrogeologiques. Ces redements sont 6 - 15 fois plus élevés lorsqu'ils sont comparés avec les rendements probables des régions des anomalies de transmissivité négative. Les études détaillées dans les zones des anomalies de transmissivité positive pourraient révéler les aquifères potentiels oú de grandes volumes de la nappe phréatique pourraient être extrait pour les approvisionnements locaux.

Introduction

In Ghana, many productive freshwater-bearing reservoirs are composed of weathered and fractured hard rocks, and increasing effort has been made to harness groundwater stored in these formations. The disparity in yield and, especially, transmissivity in boreholes drilled even closely in similar hard rock types can be very considerable. This could be due to heterogeneity and anisotropy in related hydraulic characteristics that make predictions in the hard rock aquifers very uncertain. Regional appraisals based on statistical evaluations of the transmissive capacity of aquifers could, however, provide information on the general trend and conditions of groundwater resources and their potential.

The aim of this study was to assess regional hydraulic properties of rocks in various hydrogeologic units through the evaluation and statistical analyses of specific capacity and transmissivity, and to delineate local anomalies that depict prospective zones for groundwater exploration.

Experimental

Hydrogeological background

A variety of Precambrian igneous and metamorphic rocks underlie about 45 per cent of Ghana. Late Proterozoic to early Paleozoic rocks of the Voltaian System cover about 35 per cent of the country; and together, constitute the hard rocks in Ghana. The various rock formations are

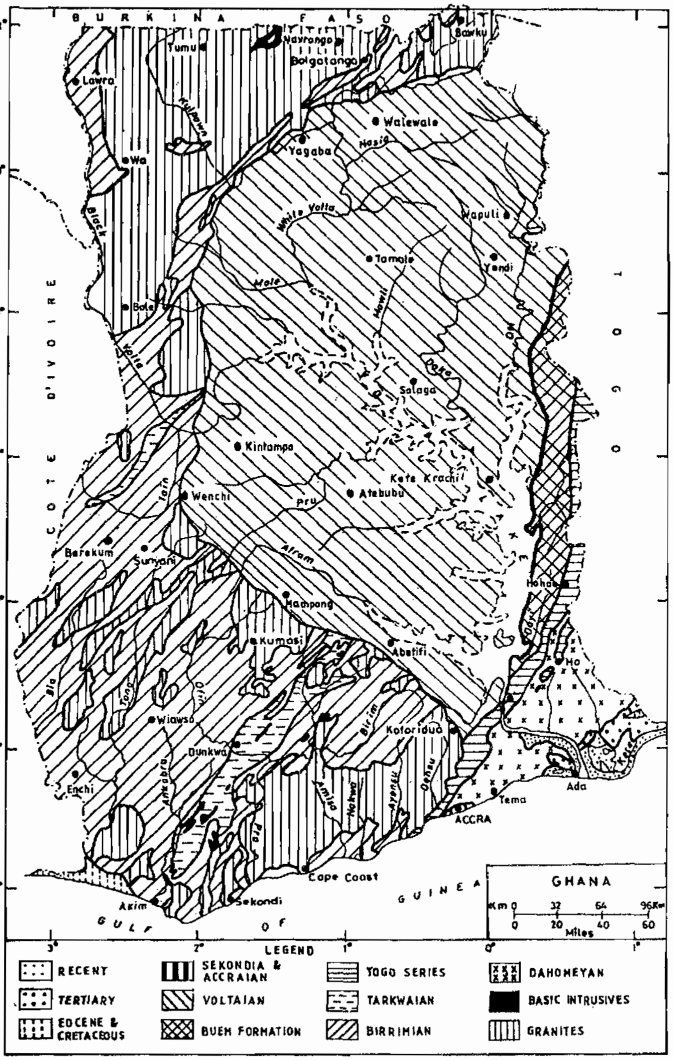

Fig. 1. Geological map of Ghana (by Geol. Survey Dept., Accra).

shown in the geological map of Ghana (Fig.1). The rocks are themselves largely impervious, but contain openings along joints and fractures, bedding and cleavage planes that enhance percolation of water to form limited groundwater reservoirs, which are structurally dependent and discontinuous in occurrence (Gill, 1969).

Boreholes drilled in such hydrogeologic environments have a wide range of yields, with a significant failure rate (Darko, 2001). Table 1 shows borehole yields and depths.

Method of assessment

Readily available specific capacity data are used to assess the water-bearing and yielding potential of aquifers. Defined as the volume of water pumped per unit time (yield) per unit drawdown in the pumping well, specific capacity is an important hydraulic parameter that indicates the transmitting properties of an aquifer. The capacity of an aquifer to transmit water of prevailing viscosity is referred to as its transmissivity. Brown (1963), Razack & Huntley (1991), Huntley, Nommensen & Steffey (1992), and several others have extensively discussed the use of specific capacity to estimate transmissivity. It accounts for the loss in head associated with pumping, and is preferred to yield as a measure of well productivity (Knopman & Hollyday, 1993).

Pumping test data from over 2000 boreholes drilled across the country were used for the study. Except for a few wells intended for supply to small towns where 24-h constant rate pumping tests were conducted, all the boreholes were earmarked for rural, domestic hand-pump supply, and only short-duration pumping tests (6 h) were carried out on them. During pumping, drawdown measurements at regular intervals were recorded in the pumping wells, since observation wells were lacking. When the pump was switched off, a recovery period of 2 h was observed. The specific capacity of each well was computed by dividing the constant discharge rate by the total (steady) drawdown.

TABLE 1

Yields and depths of successful boreholes in Ghana

Geological formation	*No. of boreholes*	*Yield (l/min)*		*Depth (m)*	
		Mean	*Range*	*Mean*	*Range*
Granite	767	67	5 - 607	37	13 -152
Voltaian	779	121	5 -1200	42	22 -355
Togo & Buem	212	94	7 - 525	44	21 -146
Birimian & Tarkwaian	213	126	8 - 600	54	16 -187
Dahomeyan	74	50	9 - 200	39	22 -122

(Data source: WRI, 1999)

From major lithology, age and location, the large data set was grouped into five main hydrogeologic units (Table 1).

Data analysis

The specific capacity was converted into an index of transmissivity Y, introduced by Jetel & Krasny (1968). The transmissivity index Y is given by the relation: $Y = \log(10^6 C)$, where C is specific capacity (l/s/m). The index has the advantage when used as a comparative regional parameter, because most populations of specific capacity values are log-normally distributed (Knopman, 1990). Hence, by converting the specific capacity values into index Y, the data set becomes normally distributed to allow descriptive statistical analysis. From the index Y, the coefficient of transmissivity, T (m^2/day), was estimated by the conversion equation: $T = 86400\,(10^{Y-8.96})$.

To find the prevailing (or background) transmissivity, the mean ($\bar{x}$) and standard deviation (s) of the index Y values in each hydrogeologic unit were determined. The range ($\bar{x} \pm s$) of the index Y values (which accounts for about 68 per cent of the data set) represents the prevailing transmissivity of the different units. The values outside this interval are considered as anomalies, which may be positive or negative. These anomalies have considerable practical importance in geological and hydrogeological investigations, including environmental assessments. The interval between ($\bar{x} + s$) and ($\bar{x} + 2s$) is defined as the area of positive anomalies, and signifies more prospective zones for groundwater exploration when compared with the area of background transmissivity. On the other hand, the values between ($\bar{x} - s$) and ($\bar{x} - 2s$) indicate areas of negative anomalies, and these represent less favourable zones. Extreme anomalies can be found outside the intervals ($\bar{x} \pm 2s$). Areas of extreme negative anomalies are requisite for toxic waste disposal when confronted with such issues.

Krasny (1993) classification scheme, which is based on transmissivity magnitude and variation, was used to classify the various hydrogeologic units. This classification scheme provides a practical quantitative method for evaluating the potential for groundwater abstraction in different areas. It also has the additional advantage of making it possible to express various regional hydrogeological conditions and their comparison on hydrogeological maps.

Transmissivity anomaly maps

The Kriging geo-statistical gridding method was used to prepare the regional transmissivity map by contouring the irregularly spaced transmissivity data. Many grid lines were generated and the linear variogram system was used in the exact interpolating format while averaging duplicate values. Fig. 2 shows the regional tendency in transmissivity.

To prepare transmissivity anomaly maps for the respective hydrogeological units, the minimum curvature gridding method was used. This gridding method generates a weighted-average interpolated surface which attempts to follow the data as closely as possible. The maximum residual parameter was set at 0.1 (i.e., 10 % of the data precision) during iterations. By establishing the background transmissivity ($\bar{x} \pm s$), areas with positive and negative anomalies were delineated.

Results

The prevailing transmissivity classes in the Voltaian sedimentary basin are Classes IV and III (Fig. 2). The areas marked by very low transmissivity of Class IV-V are delineated as zones of negative anomaly (Fig. 3). Generally, these areas are considered less favourable for groundwater exploration, since probable yields

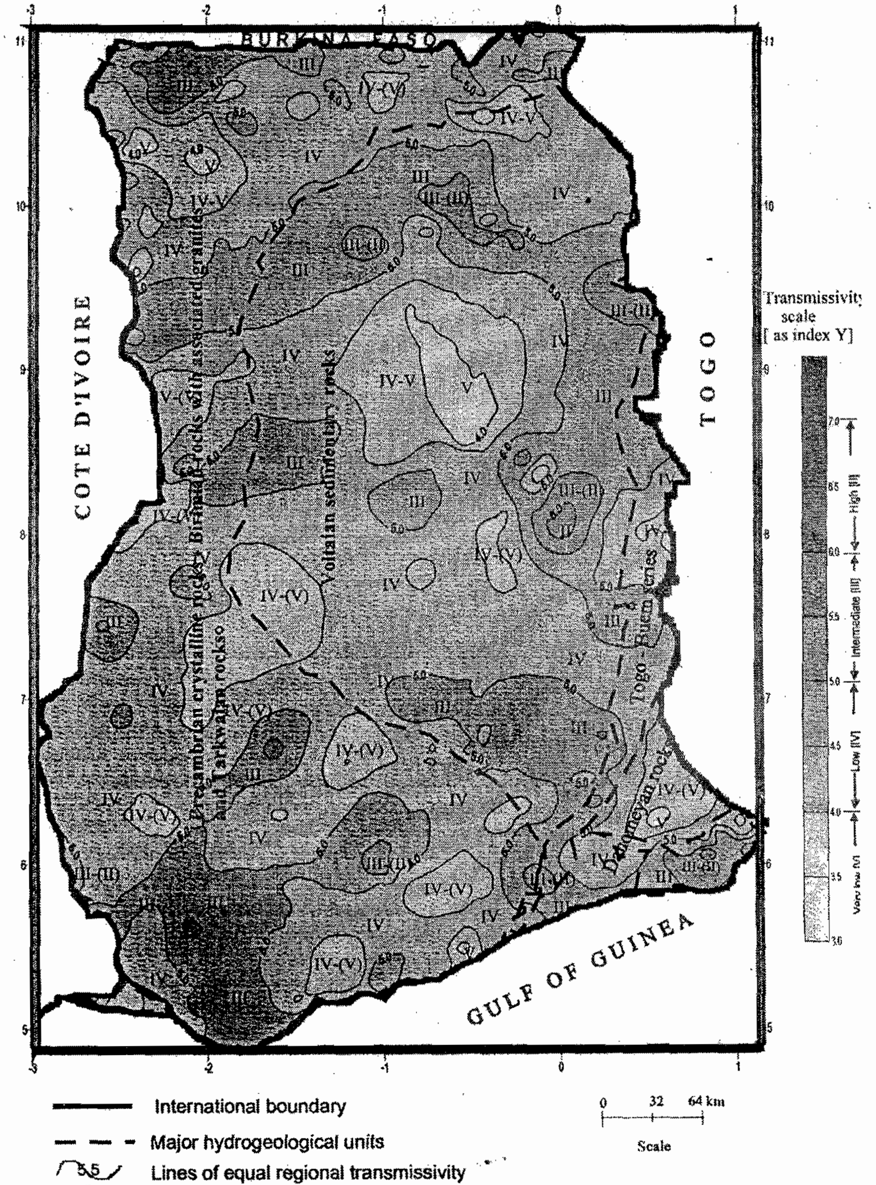

Fig. 2. Regional transmissivity trends in hard rocks of Ghana. V-IV = Classes of transmissivity magnitude (based on Krasny [1993] classification scheme).

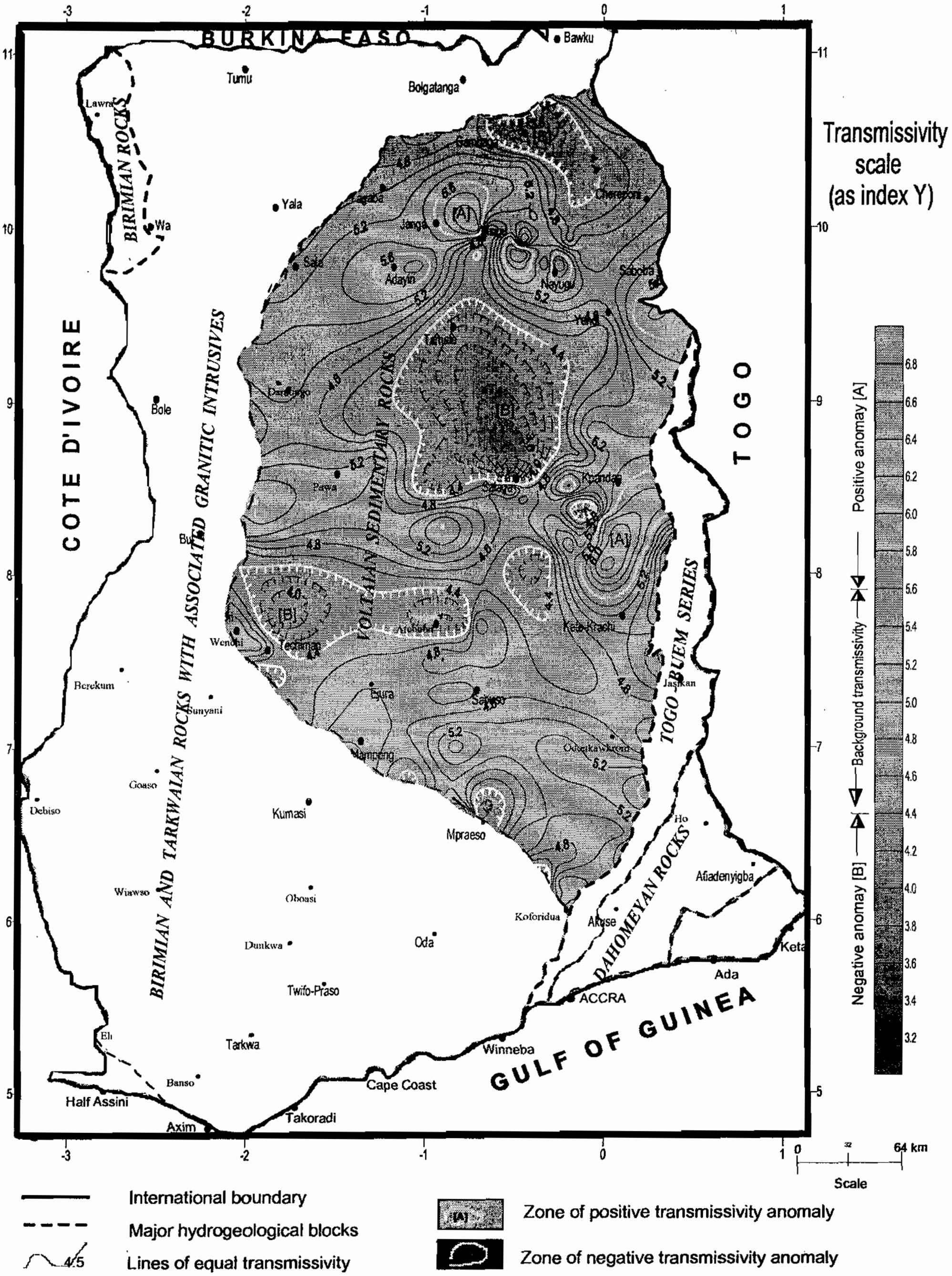

Fig. 3. Map of Ghana showing positive and negative transmissivity anomalies in Voltaian consolidated sedimentary rocks.

would be less than 8 l/min (Table 2). The regions that belong to transmissivity Class III-II represent areas of positive anomaly. These regions offer better prospects for groundwater abstraction with borehole yield expected to be more than 120 l/min.

TABLE 2

Minimum expected yields in zones of transmissivity anomalies in hard rocks of Ghana

Hydrogeologic unit	*Expected minimum yield (l min)*	
	Negative anomalies	*Positive anomalies*
Voltaian	8	120
Granite	6	60
Birimian & Tarkwaian	7	85
Togo & Buem	10	65
Dahomeyan	6	35

The areas underlain by granites are associated mainly with low transmissivity and belong to transmissivity Class IV. The areas noted with very low transmissivity are marked as zones of negative anomalies with expected yield of about 6 l/min (Fig. 4). The yield at locations of positive anomalies is expected to exceed 60 l/min (Table 2).

The Birimian and Tarkwaian are characterised in many places by low to intermediate transmissivity of Classes IV and III. The expected yield in zones of negative anomalies (Fig. 5) would be only 7 l/min or less. However, in those areas of positive anomalies, the probable yields of wells would be more than 85 l/min.

The Togo and Buem rocks also give intermediate to low transmissivity Classes III-IV in most places (Fig. 2). The probable yields in areas of negative transmissivity anomalies would be less than 10 l/min, whereas in zones of positive transmissivity anomalies, the expected yield will be at least 65 l/min. The groundwater potential of zones of negative anomaly in the Dahomeyan gneiss could be very low. The yield of wells would be less than 6 l/min, with little prospects for groundwater abstraction. At those areas marked as positive transmissivity anomalies, yields are expected to be more than 35 l/min.

The Togo and Buem rocks also give intermediate to low transmissivity Classes III-IV in most places (Fig. 2). The probable yields in areas of negative transmissivity anomalies would be less that 10 l/min, whereas in zones of positive transmissivity anomalies, the expected yield will be at least 65 l/min. The groundwater potential of zones of negative anomaly in the Dahomeyan gneiss could be very low. The yield of wells would be less than 6 l/min, with little prospects for groundwater abstraction. At those areas marked as positive transmissivity anomalies, yields are expected to be more than 35 l/min.

Discussion

The assessments were carried out on the premise of stochastic distribution of data within each hydrogeologic unit. Geologic, structural, weathering characteristics, and other related variables such as local effects in the immediate vicinity and the need to locate wells close to intended users could, however, make the data distribution non-random and, thus, introduce a source of variation and bias into the data set.

The large database and widespread distribution, nevertheless, provide enough bases for statistical deductions within the individual hydrogeologic units for regional comparative studies. Furthermore, the classification scheme used for the comparison was based on standard deviation around the sample mean (i.e., on a concept of prevailing or background transmissivity values).

The results drawn from these specific capacity modifications were based mainly on statistical averaging on regional scales, without accounting for the several other factors that could contribute to groundwater movement and storage in fractured and weathered rocks. The results are, however, the sum total of the interplay of all these contributing factors on the accumulation and water-yielding properties of the fractured rocks on regional scale. The results correspond largely with those obtained from borehole yield maps as

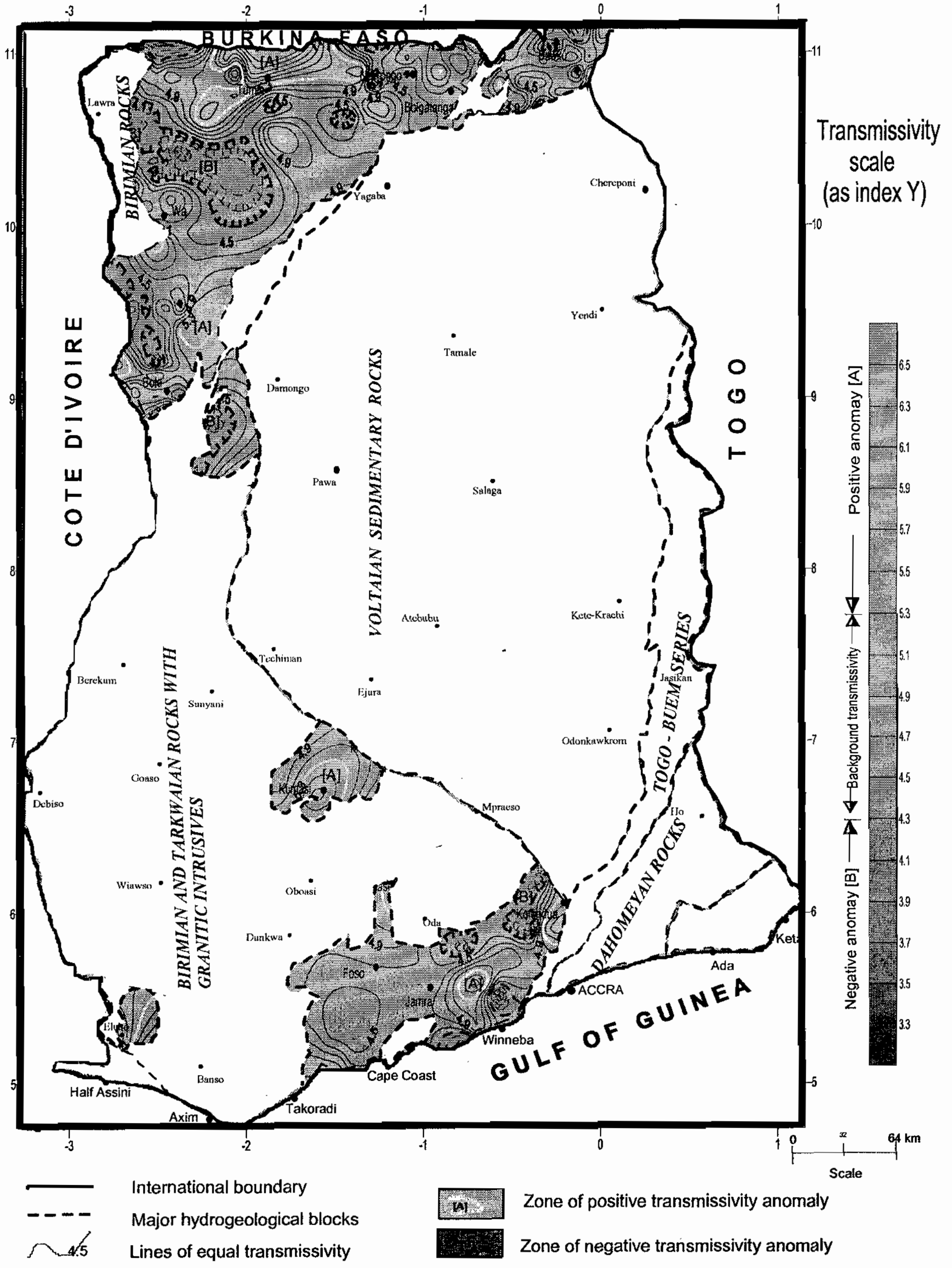

Fig. 4. Map of Ghana showing positive and negative transmissivity anomalies in areas underlain mainly by granite.

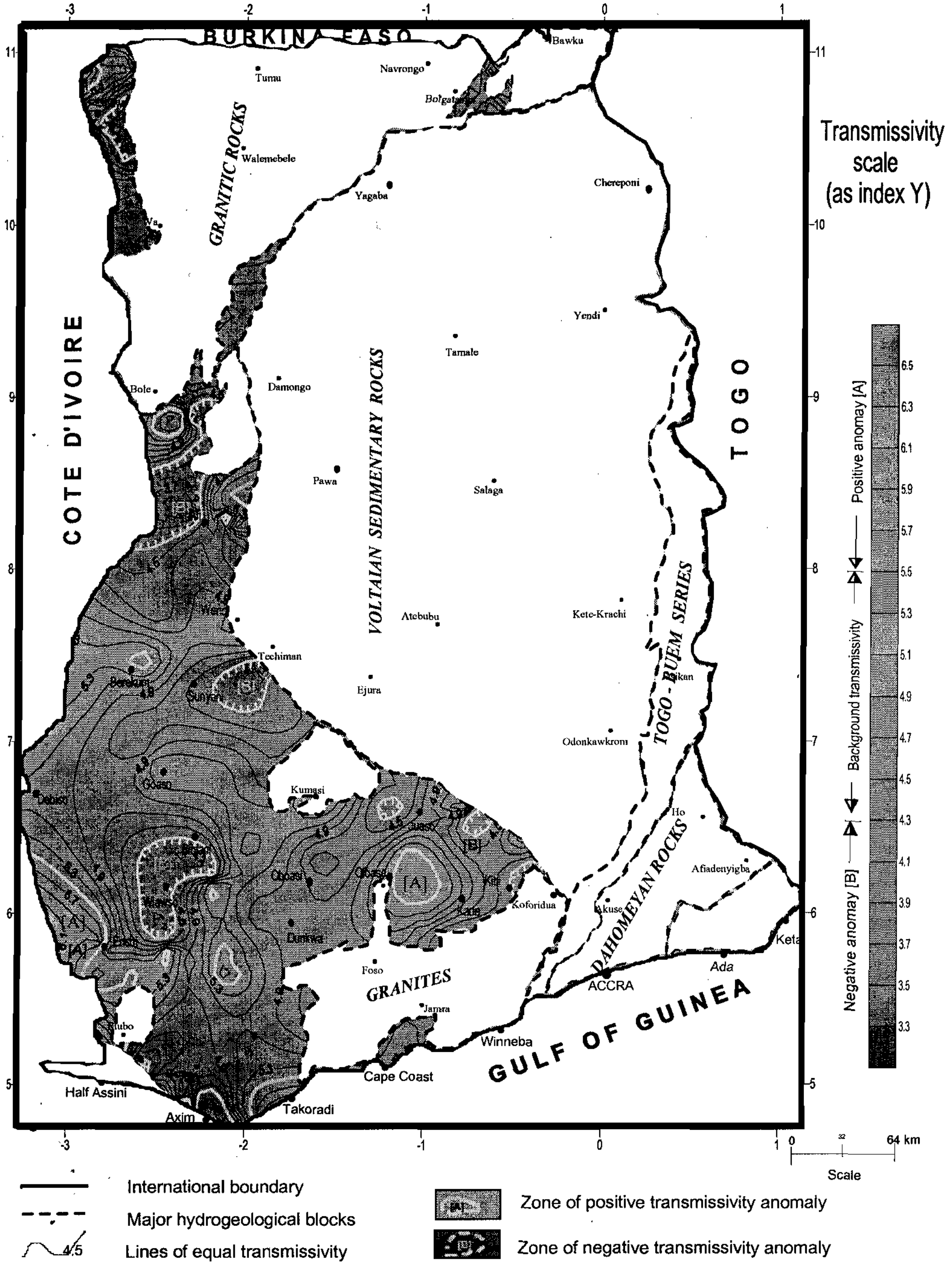

Fig. 5. Map of Ghana showing positive and negative transmissivity anomalies in areas underlain by Birimian and Tarkwaian rocks (with some granitic intrusives).

reported by Dapaah & Gyau-Boakye (2000).

The effect of the transmissivity differences on the yields of wells has been expressed based on a general available drawdown of 5 m. This drawdown has been considered as a practical value for rural, domestic hand pump-operated water supply systems (Darko & Krasny, 2000).

Conclusion

The quantitative assessment of specific capacity and its modifications has enabled the delineation of local transmissivity anomalies to depict prospective zones for groundwater exploration and estimate the probable yield of wells in the various hydrogeological units in Ghana.

In zones of negative transmissivity anomalies, the probable yields range from 6 l/min in the Dahomeyan to 10 l/min in the Togo and Buem formation. The expected yields in zones of positive anomalies range from 35 to 120 l/min in the Dahomeyan and Voltaian rocks. The yields expected from areas of positive anomalies are about 6 to 15 times higher when compared with yields expected from areas of negative anomalies.

Related variables such as topographic setting, structural factors, well construction and discharge, primary use of water and quality will all have to be considered and investigated in detail before any conclusions on local groundwater abstractions could be made.

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