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Impact of Rural Development on Groundwater Quality in Ghana.

by

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SUMMARY

The population of Ghana is predominantly rural and the only feasible and cheap source of potable water for the rural population is groundwater. The increasing use of groundwater for potable water-supplies is being encouraged because it is recognised that traditional untreated surface water sources are often severely polluted and are responsible for the transmission of many of the water-borne diseases.

However the aquifer tapped by many of the water-supply boreholes is shallow, the water-table frequently being within 10 m of the surface, and is vulnerable to pollution as a result of recent changes in human activities. These include the introduction of (a) modern, more intensive techniques of cultivation (b) cattle grazing at high-density near to water-supply boreholes and (c) on-site sanitation systems (pit latrines). These developments can lead to enhanced leaching of nitrogen below the soil and elevated nitrate concentrations and other groundwater quality problems. This report is concerned with the impact that rural development, particularly agriculture, may have on groundwater quality.

The change from a shifting subsistence agriculture to a more settled and increasingly intensive crop production is beginning in Ghana. Concern has been expressed that this change and the introduction of on-site sanitation, could result in increased leaching losses nitrogen, resulting in a build-up of nitrate in the shallow groundwater (Akiti, 1982). Nitrate concentrations in excess of the WHO recommended limit for drinking water (45 mg/l) can be harmful and can cause methemoglobinamia, especially in infants, and possibly carcinogenic nitrosamines.

This report recommends that routine monitoring of groundwater quality be undertaken especially where the aquifer is considered to be most at risk from pollution. Areas vulnerable to pollution include (a) settled agricultural land under intensive crop production, and (b) villages with high density populations, with on-site sanitation systems, using groundwater for water-supply. The purpose of this routine monitoring would be to both gain a greater understanding of the aquifers and how to manage them more effectively and also to establish what impact rural development has, or is likely to have, on groundwater quality. Aquifers are of low transmissivity and groundwater velocities are also low, probably in the range 10-100 m/yr and, as a consequence, a local build-up of a contaminant in the groundwater is possible due to the limited dispersion and dilution within these aquifers.

Groundwater nitrate concentrations in Ghana are generally low and reflect both the generally limited development of intensive agriculture and the considerable separation (100 m) between boreholes and village pit latrines. The present low concentrations of nitrate can be assumed to be an existing baseline and reflects the earlier low level of anthropogenic contamination.

1. Agricultural & Water Development in Ghana.

1.1 Ghana is located on the west coast of Africa just north of the equator between approximately 5^{o} and 11^{o} north, and between 1^{o} east and 3^{o} west and covers an area of about 238,000 km^2. Ghana is bordered by the Ivory Coast to the west, Upper Volta (Bourkina Faso) to the north, Togo to the east and the Gulf of Guinea to the south. The land is low lying although to the east the Togo Hills rise up to about 900 m. Ghana is drained by 3 major rivers, the Black Volta, the White Volta and the Oti. The River Volta has been dammed for hydroelectricity production and the resulting Volta Lake offers considerable potential for irrigation.

1.2 The climate is tropical with marked wet and dry seasons. The south and west of Ghana is warm and humid whilst the north is hot and relatively dry. The mean annual rainfall varies between 1000-1500 mm over most of the country (Fig. 1) although it is as high as 2000 mm in the south-west and as little as 800 mm in the extreme south-east and north-east. The dry season, November-February, is followed by 2 wet seasons; the first (March-July) occurs as the Monsoon front advances northwards across the country bringing rain whilst the second (August-November) marks the retreat southwards of this front. This migration produces two periods of heavy rain in the south of the country (April/May and September/October) however in the higher latitudes these merge as a single period of rain (July/August).

1.3 The main economic activity in Ghana is agriculture, although the area under cultivation is limited, probably less than 10% of the land area and this is mostly carried out on small-holdings of about 1-3 acres using traditional subsistence rainfed cultivation techniques. In recent years and with assistance from Government loans there has been a change to more mechanised and intensive agriculture using increasing quantities of fertilisers and pesticides. The recommended application rate for nitrogen fertilisers is presently 18-20 kgN/ha/crop, generally given as a single application. The main crops grown are maize, millet, rice, yam, groundnut and cassava and 1 or 2 crops each year can be grown depending upon the rainfall.

1.4 In a few areas, but at present of very limited extent, irrigated agriculture is practiced. The Tono Vea irrigation scheme is currently the largest irrigation project in Ghana (Fig. 1) and covers some 3444 ha. The soils are suitable for irrigation being permeable and freely draining. More than 1500 mm of irrigation water is applied each year and out of this total some 1000 mm is considered 'lost' either as seepage or due to evaporation. Two crops per year are grown and include vegetables, rice, maize and groundnuts, the second crop is grown on a reduced acreage, about 65% of that of the main crop. Similar irrigation schemes are planned in Aveyime and Afife in southern Ghana.

2. Hydrogeological Conditions.

2.1 Ghana is underlain by two principal formations, the Voltaian and the Pre-Cambrian Basement (Fig. 2, Table 1). Weathering of both formations generally produces an extensive shallow aquifer of low permeability, within which definite horizons can be recognised (Table 2).

2.2 The Voltaian consists of hard sandstones, mudstones and occasional conglomerates of Palaeozoic age. These rocks are of very low porosity and water movement is restricted to the weathered and fractured portion. The weathered zone is normally some 6-25 m thick and the water-table is usually within 4-20 m of the surface. Borehole yields vary up to 200 lpm with the yield from the weathered portion probably contributing less than 40 lpm - the higher borehole yields being produced by fractures and joints in the bedrock immediately below the weathered layer.

2.3 The most extensive formation underlying Ghana is the Pre-Cambrian Basement (Table 1) consisting of schists, metamorphosed sedimentary and volcanic rocks, gneisses and granites. As is the case with the Voltaian Sandstones, water occurs in the weathered and fractured rock. This weathered layer is typically 10-15 m thick, although up to 50 m in places, and the water-table is usually within 5-15 m of the surface. Pumping tests performed on the Basement aquifer indicate transmissivities varying from less than 1 m^2/d up to 60 m^2/d (Quist, 1976). Borehole yields up to 800 lpm have been recorded, although they are usually lower but adequate for handpumps.

2.4 Few detailed groundwater investigations have been undertaken and most of the hydrogeological information is limited to that collected during the drilling of village water-supply boreholes. Observation well networks, for routine monitoring of water levels and groundwater quality, have not been widely established.

2.5 Abstraction of groundwater from the aquifer within the shallow weathered and fractured layers is presently limited to rural domestic supplies and probably accounts for less than 1 mm/yr of the available recharge (assuming a rural density of less than 60 per km and a daily consumption of 40 litres per capita). Detailed recharge studies have not been undertaken on these aquifers, however an estimate can be attempted based on the specific yield and the water level fluctuation. The specific yield (storativity) of the aquifer is probably at least 0.05 in the weathered and decomposed rock (but considerably less where the water-level fluctuates within the fractured rock) and the annual water level fluctuations are believed to be in the range 0.3-5.0 m (av. 1.7 m) and thus the recharge is likely to be of the order of 25-100 mm. Infiltration will be considerably reduced where thick clay layers, produced by the decomposition of mafic rocks, occur. Even so, over large areas of Ghana recharge would appear to be significant and, in view of the present limited groundwater abstraction, there would appear to be considerable scope for further groundwater development possibly including small-scale supplementary irrigation as proposed by Quist (1976).

3. <u>Groundwater Quality</u>.

3.1 Groundwater quality in both the Voltaian and the Basement Complex aquifers is good and generally acceptable for both domestic and irrigation purposes. The groundwaters are of a mixed water type with calcium/sodium and chloride/bicarbonate as the dominant cations and anions respectively.

3.2 The waters are acidic (pH 3.5-6.5) and highly corrosive and one consequence of these low pH's is that iron concentrations in excess of 0.3 mg/l, the WHO recommended guideline for drinking water quality, are not uncommon. Excessive groundwater iron concentrations are a serious water quality problem in Ghana and is considered as one reason why some village water-supply boreholes have been abandoned.

3.3 Groundwater nitrate concentrations are generally low, less than 3 mg/l, however rising concentrations, during the late 1970s were reported in the Upper

Region of Ghana (Akiti, 1982) and changes in agricultural practices were considered responsible. Little data on the bacteriological quality of groundwater is available, although the water from most of the village water-supply boreholes is likely to be of a high standard since the boreholes appear to be well constructed and sited at sufficient distances from potential pollution sources. Conversely dugwells particularly those that are not adequately completed are liable to be contaminated and their bacteriological quality may be poor.

4. Review of Groundwater Pollution.

4.1 Groundwater nitrate concentrations are generally low and reflect both the lack of intensive agriculture and the considerable separation (100 m) between water-supply boreholes and village pit latrines.

4.2 Only a small percentage of the rural area of Ghana, perhaps as little as 10%, is under cultivation and this is mostly a shifting subsistence type cultivation using small inputs of nitrogen fertilisers. Consequently there is no immediate and widespread threat to groundwater supplies from the leaching of nitrogen fertilisers. However rising nitrate concentrations have been reported in some boreholes in the Upper Region of Ghana (Akiti, 1982) and the change to more intensive agriculture was considered responsible.

4.3 Even in areas where more intensive rainfed cropping has been introduced supported by inorganic fertilisers, the quantities of nitrogen applied are still small (18-20 kgN/ha/crop) and generally only one, or at the most two crops are grown each year. Leaching of nitrogen from these soils to groundwater is likely to be variable and dependent upon both rainfall amounts and intensities. However losses of nitrogen up to an amount equivalent to 30% of the applied rate are possible (in UK the comparable rate is 20-40%) and where 2 crops per annum are grown this could produce, on mixing with infiltration (25-100 mm), concentrations up to 200 mg/l in the recharging groundwaters (Fig. 3). Since groundwater movement and storage within the aquifer is limited, there will be little dilution or dispersion of the nitrate and a local 'build-up' of groundwater nitrate concentrations is likely. However the nitrate concentrations in water supply boreholes are unlikely to exceed the WHO recommended limit (45 mg/l) except under extreme conditions, although this situation may change if the area under cultivation is increased and improved crop yields sustained by higher fertiliser applications are encouraged.

4.4 Leaching losses beneath irrigated agriculture are likely to be as high, or higher, than beneath rainfed agriculture (i.e. equivalent to up to 30% of the applied rate) and less variable. However the greater infiltration to groundwater beneath irrigated soils, due to seepage losses, will mean that the nitrate concentration of recharging groundwater is unlikely to exceed 50 mg/l. Further, since most water-supply boreholes are located outside the irrigated areas, the threat to these boreholes is at present neither considerable nor immediate. Despite this, leaching losses do represent a considerable waste of valuable crop nutrients and a leaching loss of 12 kgN/ha/a (equivalent to 30% of the applied fertiliser for 2 crops) has a value of approximately 800 cedis/ha (or >£6/ha).

4.5 Improvements in sanitation is widely accepted as necessary if standards of health are to be raised in many developing countries. On-site sanitation systems, such as the ventilated pit latrine, are suitable for rural populations and are being introduced in Ghana. The leaching of nitrate to groundwater can, however, be enhanced by the construction of such pit latrines. An indication of the magnitude of the potential nitrate pollution problem from on-site sanitation systems can be demonstrated by the following observations. A typical village of 500 people covering an area of 25 ha will discharge some 100 kgN/ha/a and the nitrogen, if completely oxidised and leached by 50 mm of infiltration, would produce nitrate concentrations approaching 900 mg/l at the water table. Even if only 10% of the nitrogen in the excreta is leached to groundwater, concentrations at the water table would still exceed the WHO recommended limit of 45 mg/l. The build up of high nitrate groundwater beneath the village area and the slow movement of this groundwater towards the water supply boreholes will eventually lead to elevated nitrate concentrations in the pumped water.

4.6 The more immediate threat to borehole water supplies is through contamination by pathogenic micro-organisms, but this is not thought to be likely since most village boreholes appear to be well constructed, with an adequate sanitary seal to prevent rapid percolation down the outside of the casing and because the boreholes are sited at least 100 m from pit latrines or other likely sources of pollution.

4.7 It must be stressed that there will be little regional mixing of groundwater (due to the limited aquifer permeability) and so the quality, and in particular the nitrate concentration, of an individual borehole will be largely dependent upon local factors - land-use, quantities of fertiliser used, proximity to village areas, animal grazing, thickness and permeability of soils, depth to water-table. A schematic section through the aquifer is shown (Fig. 4).

5. Discussion.

5.1 Groundwater is available at shallow depths and in quantities suitable for hand-pumped boreholes over most of Ghana. Shallow boreholes account for some 40% of the present village water supplies (Mr G Osibo, pers. comm.) and further development of groundwater resources is planned to meet both the domestic requirements of the rural population and possibly small-scale irrigation.

5.2 Over much of Ghana the groundwater is of high quality and suitable for potable supplies. However the shallow aquifer is vulnerable to pollution both because the water table is within a few metres of ground level and because the limited storage and groundwater movement prevents dispersion and dilution of contaminants. There is the possibility of future conflicts of interest between rural development and potable groundwater supplies as has been discussed earlier in this report.

5.3 However, the threat to groundwater quality is neither widespread nor immediate. In view of the importance of groundwater as the only available source of untreated potable water over most of the country and the considerable investment in terms of rural water-supply boreholes, it is clear that these aquifers need to be carefully managed. In this respect it is important to undertake routine monitoring (every 3-4 months) of the aquifers and to establish an existing baseline against which changes in groundwater quality with time can be measured. The importance of routine monitoring of shallow groundwater in Ghana has been reviewed in some detail (Bannerman and Ayibotele, 1984).

5.4 The Water Resources Research Institute have already established a monitoring network in the Accra Plains and Ghana Water Supply and Drainage, who are responsible for maintenance of village water supplies, accept that routine monitoring is desirable and are interested to undertake such work in other regions. Routine monitoring of water levels and groundwater quality would allow the following questions, of crucial importance to the effective management and protection of these aquifers, to be answered:

(a) Is the aquifer either over-pumped, resulting in declining water levels or under utilised?

(b) What is the available and effective storage in the aquifer?

(c) What is the natural and unpolluted groundwater chemistry and is the quality likely to deteriorate as a result of human activities on the surface?

(d) Why are some village water-supply boreholes abandoned - is this due to a declining water-table or unacceptable water quality? Excessive iron is a major problem in many tropical aquifers and a reason why villages often abandon 'safe' water-supplies and return to their traditional, and often polluted, sources.

5.5 In addition to the above monitoring, which would allow a regional understanding of the aquifer to be gained, more detailed monitoring should be carried out where the aquifer is considered to be most at risk due to pollution resulting from rural development. Particular areas of concern would include:

(a) The more densely populated villages served by on-site sanitation and using shallow boreholes for water supply. The pollution risk will be increased where the soil is thin and relatively permeable.

(b) Areas under cultivation, supported by inorganic fertilisers, particularly where underlain by permeable and freely draining soils. Boreholes selected for monitoring should be located such that they are recharged, largely, by infiltration from cultivated soils.

(c) Areas downgradient of industries, including mining, which discharge effluent likely to pollute shallow groundwater.

6. Conclusions and Recommendations.

6.1 Groundwater quality is generally good throughout Ghana and reflects the very low levels of contamination by human activity. It is recommended that monitoring of the shallow aquifers be undertaken as detailed in the previous section such that changes in groundwater quality as a result of rural development can be observed.

6.2 Regular monitoring of groundwater would also enable a greater understanding of the aquifer to be gained. In particular whether the resources are over or under-utilised and whether the natural groundwater chemistry is a limiting factor for its use and is a reason why some borehole supplies have been abandoned. The following ions at least should be measured in any monitoring programme; sodium, fluoride, magnesium, iron, manganese, sulphate, chloride and nitrate. Measurements of pH, bicarbonate and nitrate should be undertaken at well-head, whilst filtered, and in some cases (iron and manganese) acidified, samples should be collected for the analysis of the other ions.

6.3 BGS are presently undertaking research on the pollution of groundwater in developing countries, particularly the leaching of nitrogen from tropical soils, and would be interested in the results of any monitoring carried out in Ghana by WRRI. If the WRRI were to identify areas where the aquifers are considered vulnerable to pollution and were also to initiate regular monitoring (every 3-4 months) BGS could recommend that minor items of equipment (specific ion meter, nitrate electrodes, etc.) be purchased by ODA to help in this research. BGS would be keen to liaise with WRRI during this monitoring programme and if the results demonstrated that high nitrates do occur, BGS could further assist WRRI.

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Table 1. Simplified summary of the geology of the principal formations of Ghana (summarised from various reports of the Geological Survey of Ghana).

Time Division	Formation	Description
Palaeozoic (Cambrian-Silurian)	Voltaian	sandstones, shales, mudstones and occasional conglomerates
Pre-Cambrian		
Upper	Buam	metamorphosed shales, sandstones and volcanic rocks
Middle	Togo	metamorphosed shales, sandstones, quartzites and volcanic rocks
	Tarkwaian	metamrophosed schists, sandstones, quartzites and phyllites
Lower	Birrimian	phyllites and schists, granites
	Dahomeyan	massive crystalline gneisses, migmatite and schists

Table 2. Layering developed within shallow-weathered aquifer.

	Layer	Description
Layer 1:	totally decomposed rock	This layer is characterised by totally decomposed rock. The weathered material has no consistency and crumbles when touched. Most minerals have been chemically transformed. The feldspars have been kaolinised, the micas transformed into clay and only resistant minerals like quartz have not been chemically altered.
Layer 2:	partly decomposed rock	This layer is characterised by spheroidal weathering where corestones of fresh rock, surrounded by successively more weathered mantle, are buried in rotten rock. Jointing is well developed in this layer allowing water circulation.
Layer 3:	slightly weathered rock	In this layer weathering has resulted in widening of joints; these joints and fractures are frequently coated by ferruginous deposits and filled with clayey material.

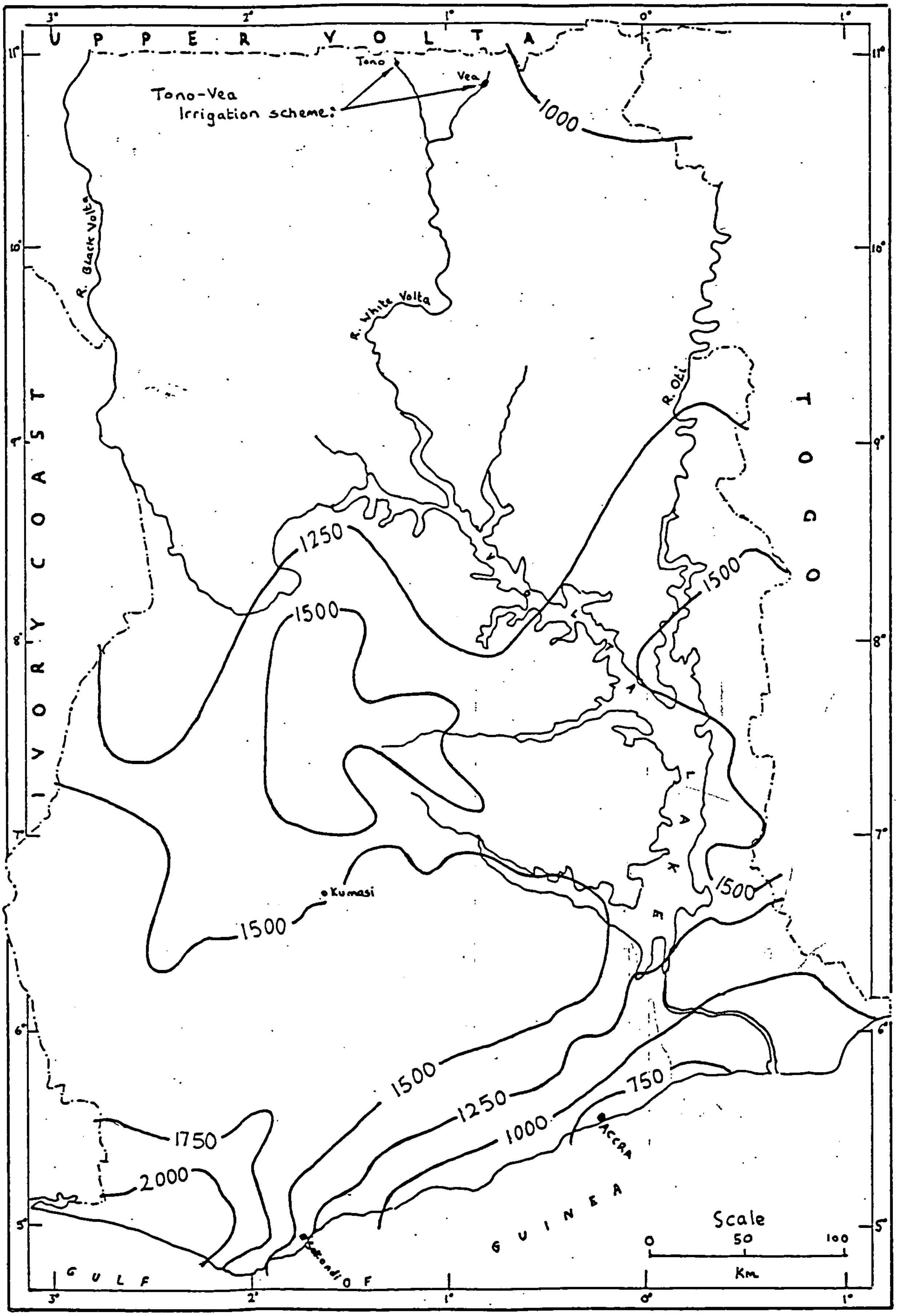


FIG. 1 AVERAGE ANNUAL RAINFALL (MM)

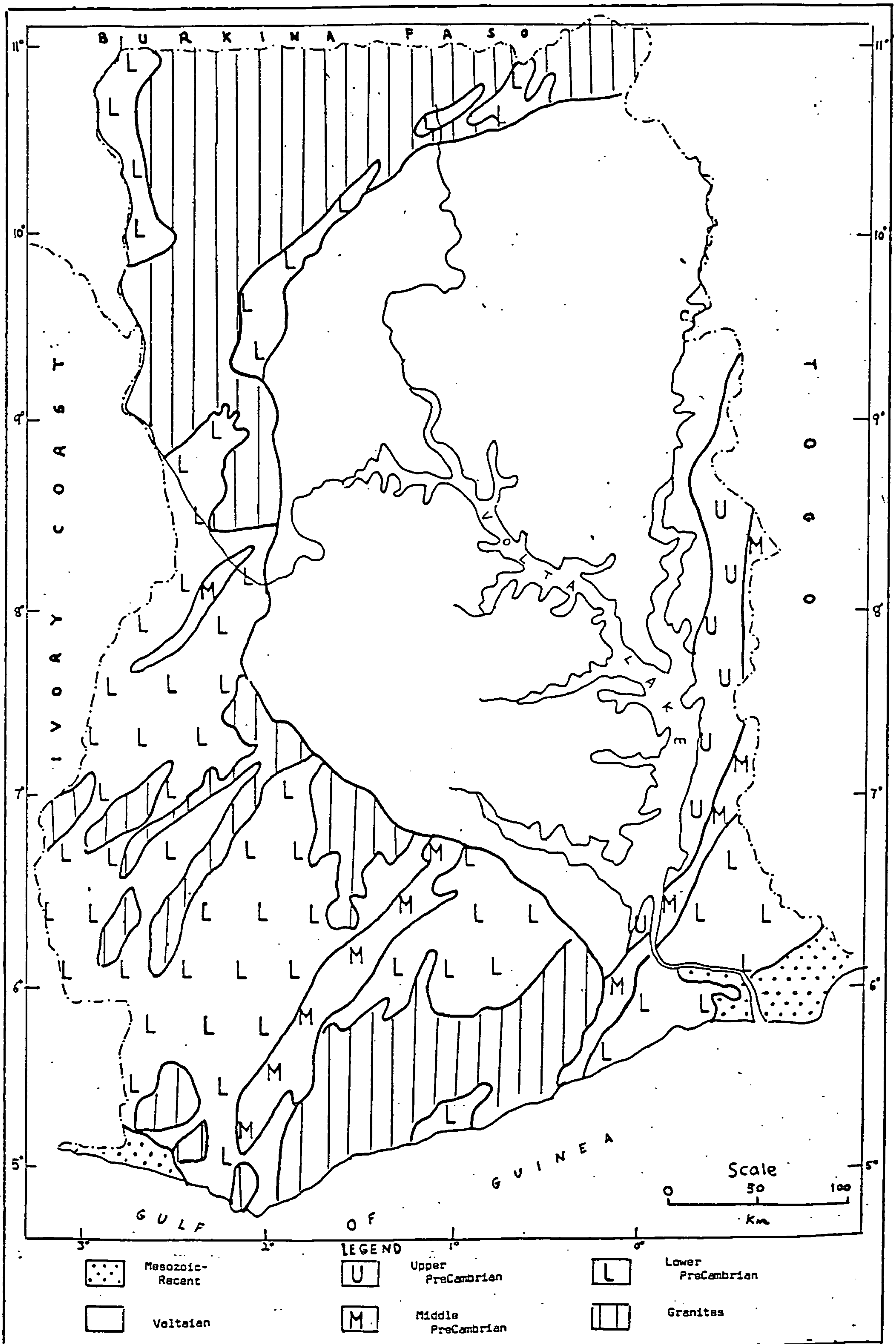
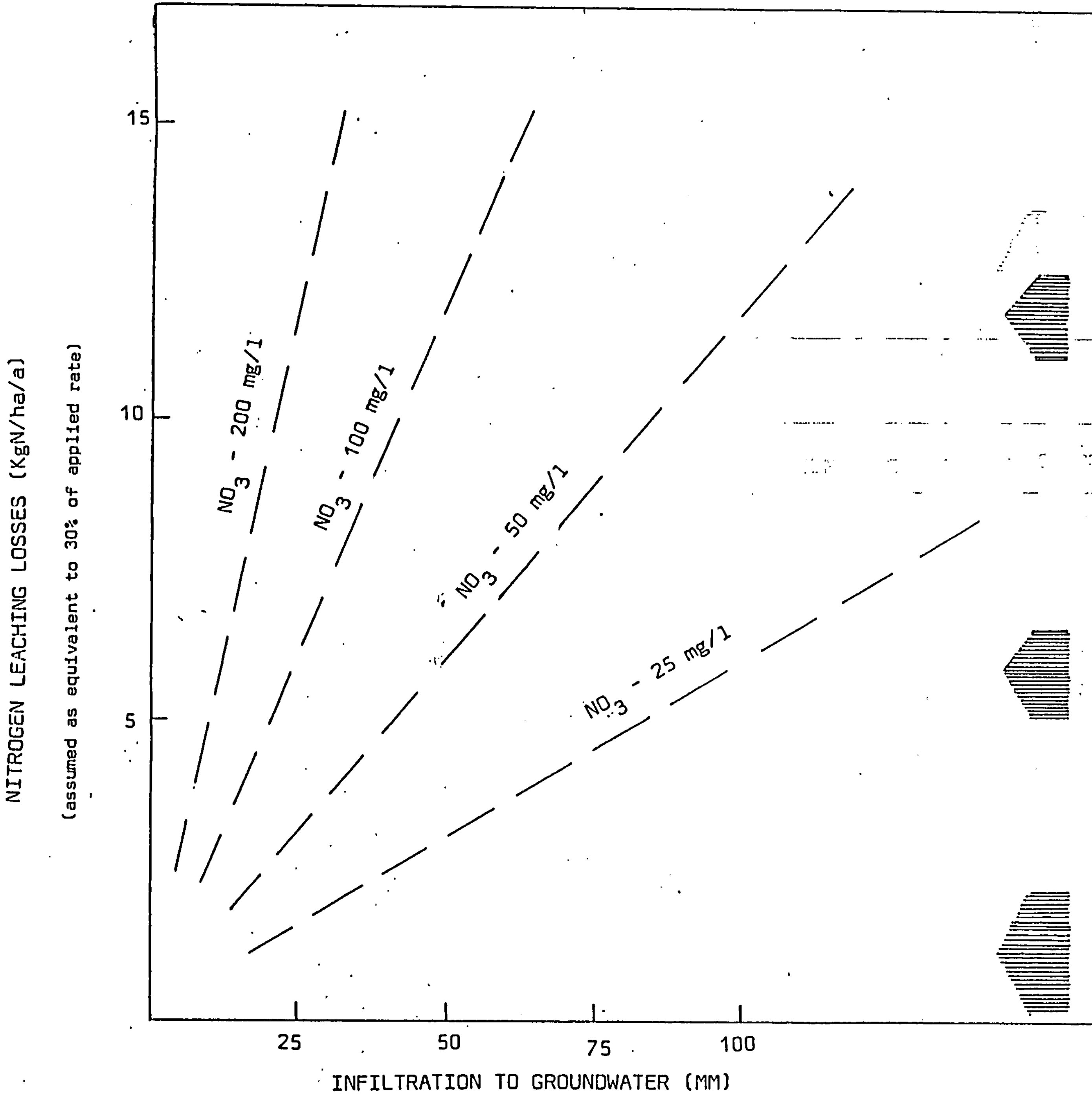


FIG. 2 GEOLOGY MAP, GHANA



CULTIVATION PRACTICES

type of agriculture	No. of crops per year	Application rate of nitrogen fertilisers (KgN/ha/a)
intensive crop production	2	36 - 40
intensive crop production	1	18 - 20
subsistence crop production	1 - 2	4

FIG. 3 INFLUENCE OF AGRICULTURE AND INFILTRATION ON GROUNDWATER NITRATE CONCENTRATIONS.

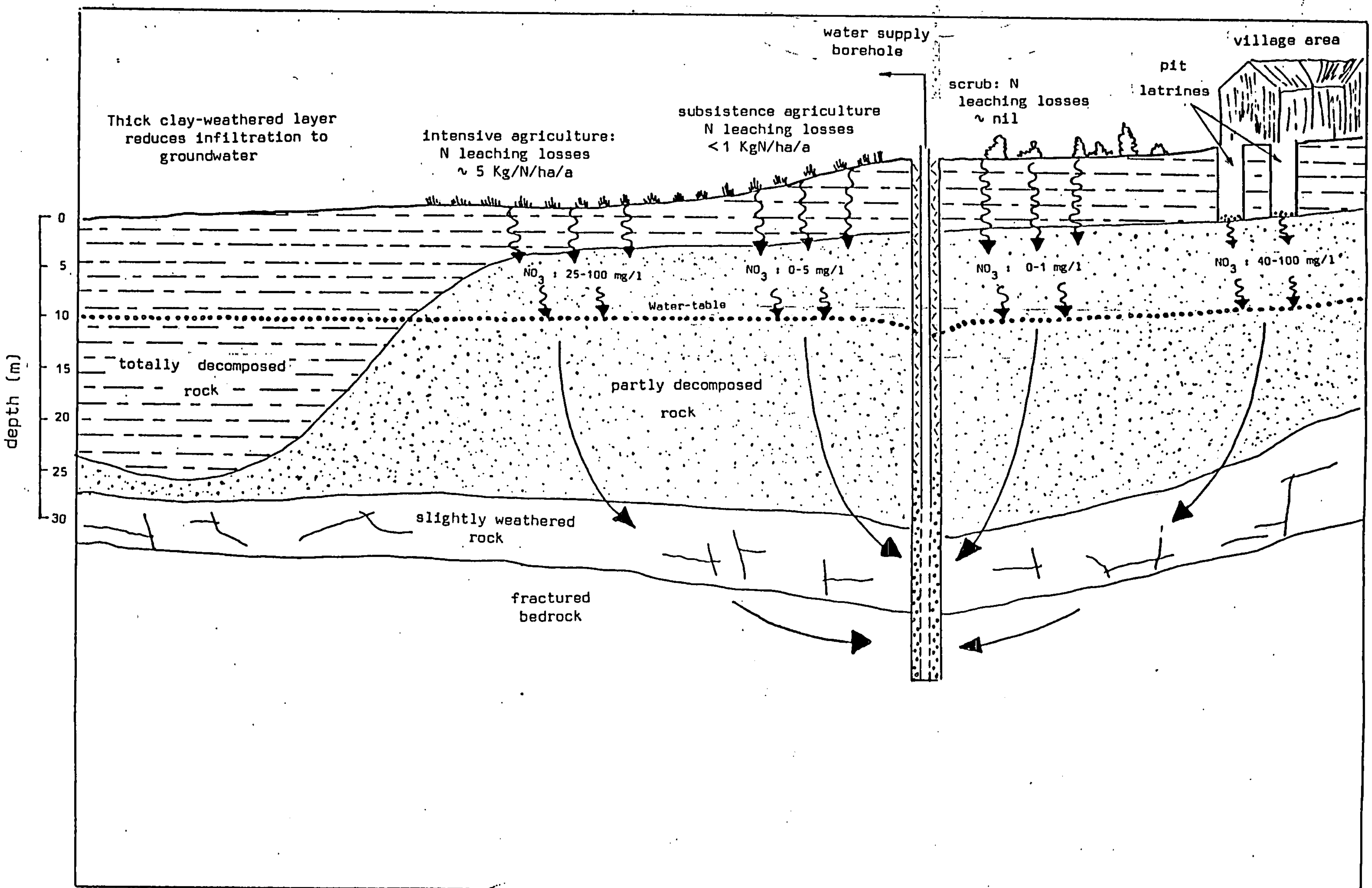


FIG. 4 SKETCH SECTION THROUGH SHALLOW AQUIFER SHOWING INFLUENCE OF LAND USE ON GROUNDWATER NITRATE CONCENTRATIONS