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Overseas Geology Series

The hydrogeology of the Oju area, Eastern Nigeria: an initial assessment

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PREFACE

Oju is a remote part of south-eastern Nigeria that experiences severe water shortage during the annual (November to April) dry season. During this period, unprotected ponds, seepages and hollows are the primary source of domestic water. Unfortunately, these sources become less reliable towards the end of the dry season and many become contaminated. As a consequence, much of the population of Oju (300 000 approx.) is badly affected by a variety of water related illnesses, of which guinea worm and malaria are endemic; outbreaks of cholera, typhoid and dysentery are common. In response, DFID have commissioned WaterAid to provide improved village level, year round water sources, primarily utilising the limited groundwater resources of the area.

Due to the complex hydrogeology, WaterAid have asked the British Geological Survey (BGS) to assist with the project. BGS are applying the results of DFID TDR projects undertaken within other parts of the world to study these marginal groundwater resources.

The groundwater investigations by BGS started in September 1996. There are three main aims of the research: (1) to assess the potential of the Oju area for sustainable groundwater supplies; (2) to develop appropriate methods for siting wells or boreholes in the Oju environment; and (3) to recommend appropriate methods and designs for groundwater abstraction.

This report is an initial review of the hydrogeology of the Oju area, prior to detailed investigation. Data have been collected on three separate field visits, 22/8-20/9/96, 11/11-13/12/96 and 3/2-18/3/97. Separate reports are available detailing the literature search, geology, geophysics trials and chemistry surveying.

EXECUTIVE SUMMARY

The aim of this report is to give a broad flavour of the hydrological and hydrogeological conditions within Oju. Existing information has been collated and a literature review undertaken of similar environments. Oju was visited a number of times to collect geological, geophysical and hydrochemical data (reported separately). In addition to a general review of the hydrogeology, a specific study on the potential of the river gravels has been carried out.

Oju suffers from an acute seasonal water shortage. The high annual rainfall (1600 mm) occurs mainly between April and October leaving a five month dry season with virtually no rainfall. The low permeability geology results in very high runoff in the wet season, and negligible river flows in the dry season. Some of the larger rivers have pools of water throughout the dry season - commonly forming a source of guinea worm.

In the wet season water is taken mainly from shallow wells and streams close to the villages. In the dry season most of the shallow wells quickly dry out. This is because many of them tap shallow water bearing zones from the laterite layers. Only wells that penetrate permeable rocks below the laterite layer, or deeper fractures are sustainable through to the dry season. In the south of Oju there are approximately 40 boreholes; most of these are drilled within the Asu River Group. Many of these boreholes have a history of breakdowns. This is often perceived to be solely a pump problem but is more likely a result of poor borehole design and siting, or low permeability geology. The majority of inhabitants take water from small ponds and seepages or travel to ponds in the larger rivers to get water in the dry season.

The hydrogeology of Oju is complex. The greater part of Oju is underlain by Cretaceous sediments. These consist of interbedded shales, siltstones sandstones and limestones. Most common, however is shale. Literature from other studies suggest that only where the shale is significantly fractured will groundwater supplies be feasible, and even then it is a marginal resource. More promising sources of groundwater would be the interbedded siltstones and sandstones. Prior to drilling and testing it is difficult to assess these areas for groundwater potential. South of Oju town, however, the sediments have been affected by regional metamorphism which has made them harder and more fractured. Boreholes located in fracture zones might be the best method of groundwater abstraction in this area. Drilling and testing a series of holes would help to clarify the best method of abstraction.

There is one good aquifer within Oju. The Makurdi Sandstone runs across the middle of the Oju area and comprises fine to medium grained sandstone and arkose. There are few streams on the outcrop area suggesting a more permeable rock unit. Wells dug into the Makurdi Sandstone have tended to collapse due to the swelling of near surface clays and collapse of highly weathered sands. Properly constructed wells which are lined and strengthened through the weathered zone should provide reliable community supplies.

A study has been made of the potential of the river gravels to provide groundwater. A hand auger was used to test the thickness and nature of the gravel at several site:

- River gravel deposits in the base of the major rivers are thin and intermittent - they have very little potential for groundwater storage.
- Thin gravel (~1 m) can be present in smaller rivers on Asu River Group. Although the gravel contains groundwater early in the dry season this resource soon dries out.
- Seepages in the river bed are not generally fed by flow from the gravels, rather it is flow from the sides and the underlying geology that is important.

A monitoring system has been setup within Oju. Rainfall data are being collected at 7 sites throughout Oju. Groundwater-levels are being monitored at 10 sites. This should give valuable data into the natural groundwater fluctuations prior to any development. However, due to the stress on water resources in the dry seasons, the boreholes used for monitoring are also pumped. It would be advisable to drill dedicated piezometers for long term monitoring.

1. BACKGROUND

1.1 Introduction

Oju lies within Benue State in eastern Nigeria (Figure 1). The area is approximately 2000 km^2 and ranges from about 50 to 550 m asl. In 1996, Oju Local Government Area (LGA) was split into two: Obi LGA to the north and Oju LGA to the south. For the purposes of this study the pre-1996 boundaries define the limit of research and the term "Oju area" will refer to the combined area of Oju and Obi LGAs.

Population estimates for the area vary. Census data from 1991 gave the total population as 177 000. However the census was carried at a time when many residents were thought to be absent (Williamson, 1996; Morgan, 1996). An unofficial survey was carried out from September 1990 to January 1991 as part of the RUSAFIYA project (Obe and Daagu, 1991). According to the survey there are more than 420 000 inhabitants in Oju. The survey calculated the population by visiting each village and asking chiefs the number of households for which they were responsible and the average number of people per household.

The Igede people predominate in the Oju area. They are divided into about 30 clan groupings, each headed by a clan chief. These men are greatly respected. Although nominally Christian, the Igede have strong animist roots. Some of these traditions can affect water supply, sanitation and health. For a detailed discussion of the anthropology of the Igede people see Bohannan and Bohannan (1953) and Morgan (1996).

1.2 Physical Geography

The Oju area can be divided into two main topographical areas: (1) the Workum Hills (Plate 1) and (2) low lying plains (Plate 2). The Workum hills occur within the southwest of the Oju area. They trend approximately NE-SW and range up to 550 m asl in height. The plains to the north and east are generally low lying, 50-125 m asl, and gently undulating. Within the plains, however there is a marked scarp at a fairly consistent height of 125 m asl. This scarp appears to be associated with an old ferrecrete peneplain (Plate 3).

Village locations are difficult to obtain for the area. Although 1:50 000 maps exist, they show little other than physical features. Of the few villages that are marked, many are incorrectly named. In an attempt to provided a rough estimate of village locations throughout Oju, Local Government Staff were asked to take the village list provided by the RUSAFIYA project (Obe and Daagu 1991) and locate the position of villages that they knew on a schematic map drawn up at 1:50 000 scale by the WaterAid Engineer. Due to inherent imprecision, the resulting village location map is accurate to about 2 arc minutes (~3 km) and also subject to errors introduced by the confusion and duplication of various village names and the difficulties of reading maps. Nonetheless, it provides a useful starting point for locating villages and can be updated as WaterAid locate villages using a portable Global Positioning System (GPS) (Davies and MacDonald, 1997a). The distribution of villages throughout the Oju area is shown in Figure 2.

Box 1 Summary of Background Information

- Oju is located in Benue State, Eastern Nigeria
- population estimates vary from 180 - 420k
- majority of inhabitants are Igede
- the area is approximately 2000 km^2 and is generally flat with a few hills to the south
- vegetation is mainly savannah woodland with some denser forest.

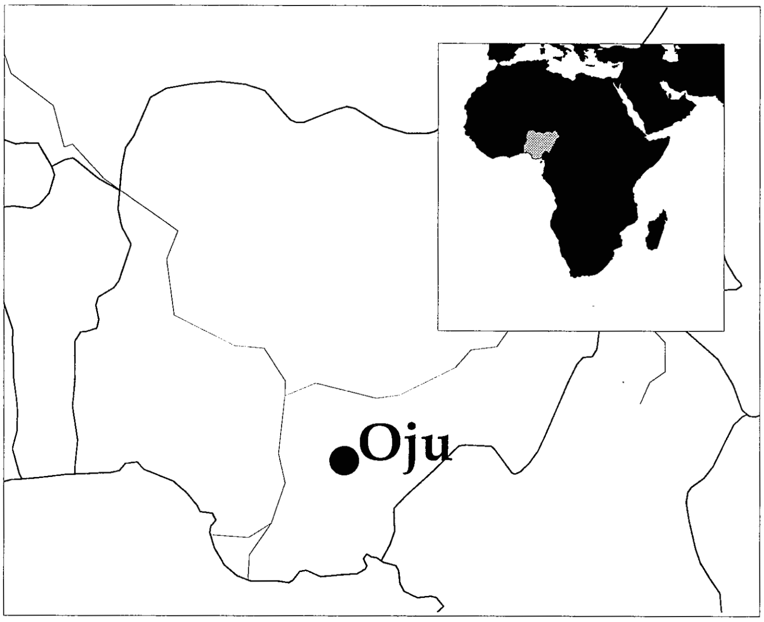

Figure 1. Location of the Oju area, Nigeria.

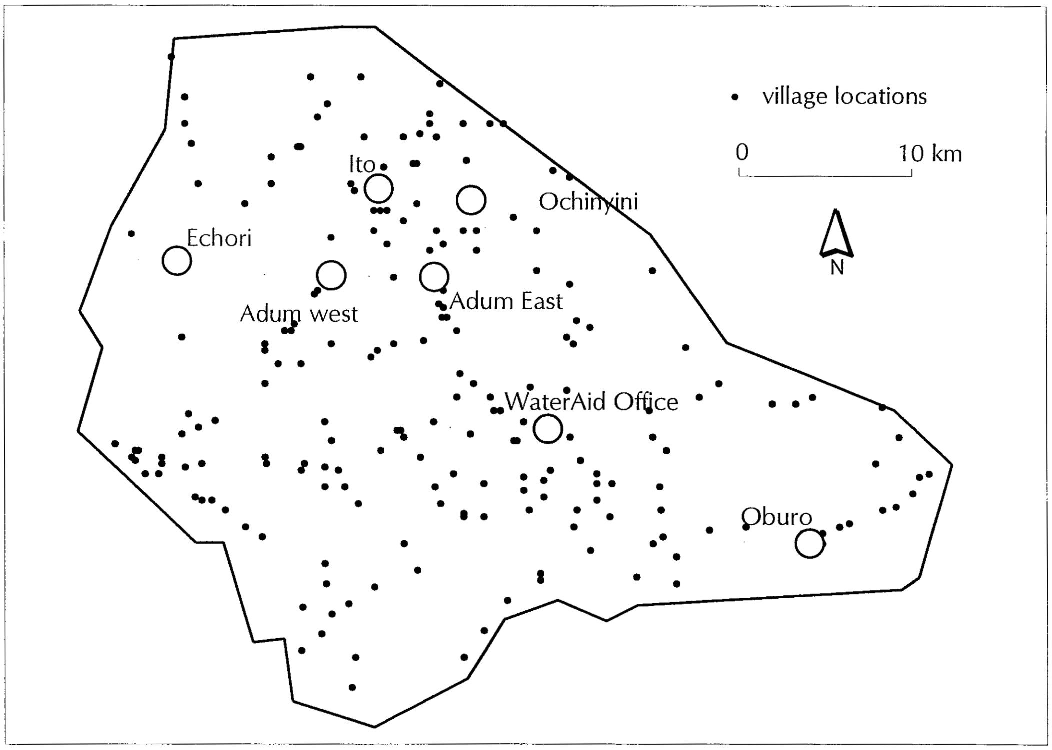

Figure 2. Distriibution of villages within Oju.

The vegetation found in Oju is termed *Savanna Woodland.* It comprises deciduous and semi-deciduous woodland with tall grasses (e.g. Plate 2 and 8). Much of the tree cover has been removed to make way for farmland. Dense vegetation still exists in some places (*Forest Mosaics*); for example along river valleys and at sacred places that have been left as virgin woodland. Within the villages, large trees (usually mango or old fucus trees with buttress roots) have been left to give shade.

The main crops grown in Oju are yams, cassava and rice. Sorghum, millet, maize, benne seed and groundnuts are also grown. The richness of the land for farming has lead to Benue State being called the "food basket of the nation". Annual bush burning is still very much part of the local culture. This is done primarily to try and catch various small animals for bush meat, but is also undertaken to extend farmland and improve access around paths and houses.

1.3 Geology

A detailed discussion of the geology of the Oju area is given in a companion report (Davies and MacDonald, 1997b). A brief résumé is given below.

Box 2 Summary of Geology

- mainly low permeability Cretaceous shales and siltstones
- in the south the sediments have been metamorphosed and are hard and fractured
- A sandstone unit is exposed through the middle of the Oju area
- there are small basic intrusions throughout the area
- laterite and ferrecrete cover much of the area.

The tectonic nature of the Benue Trough area was initially investigated using regional geophysical surveys. These showed the presence of a north east-south west tectonic trough, infilled with folded Cretaceous age marine and fluviatile sediments intruded with thin dolerite sills, bounded to north and south by Precambrian Basement igneous and metamorphic rocks. This major tectonic feature has been interpreted as a failed rift the formed during the initial splitting of the African and South American continents that ultimately formed the Atlantic Ocean. The Oju area is located within the Benue Trough, at the boundary of its Middle and Lower parts, towards the southern edge of the trough. The stratigraphic sequence of Cretaceous sediment present within the Oju area is shown in Table 1 and their geographical range shown on a geological map of the area (Figure 3).

The oldest Cretaceous sediments in the Oju area are those of the Albian Asu River Group. These are bluish black marine, sometimes calcareous shales are interbedded with minor siltstones, limestones and sandstones. The Abakaliki igneous intrusives and pyroclastics of the Workum Hills were deposited contemporaneously, the adjacent sediments being metamorphosed to form well jointed, hard black slatey shales siltstones and limestones. Where weathered and non-metamorphosed these well laminated shales are typically light grey, orange and yellow in colour. Ammonites commonly occur in dark grey mudstones north-east of Oju and in light brown siltstone east of the Workum Hills. The sediments and igneous rocks were folded forming the northern part of the Abakaliki anticlinorium. Interbedded seismite deposits within the sediments indicate the occurrence of contemporaneous intra-depositional seismic activity within this area.

A major unconformity, the Cenomanian hiatus, occurs between the folded and partially metamorphosed Asu River Group sediments and overlying less folded Eze Aku sediments.

The Turonian Eze Aku Formation includes bluish black carbonaceous and dark grey calcareous, well laminated, marine and fluviatile shales with subordinate limestones, interbedded with fluviatile and

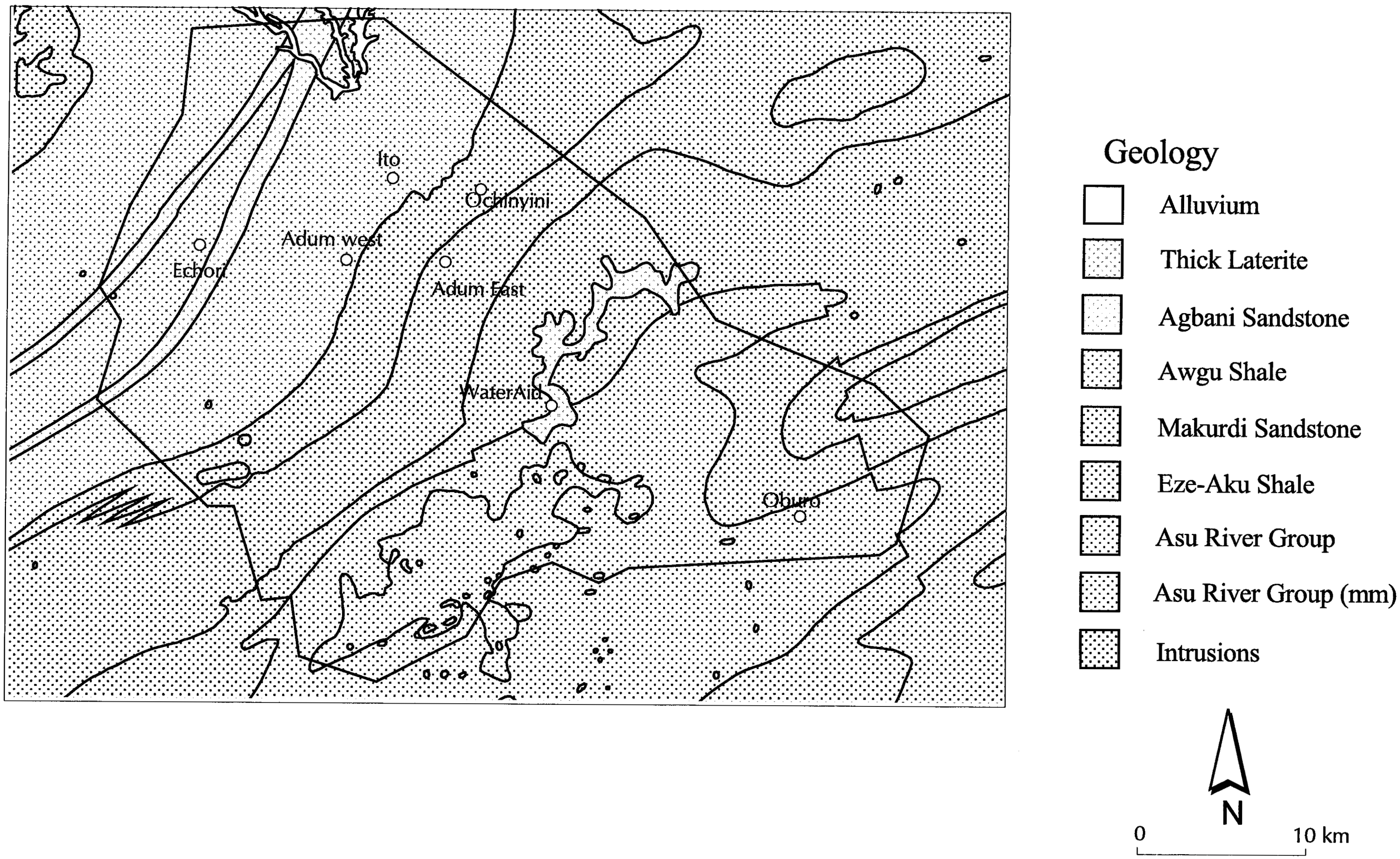

Figure 3. Geology of the Oju area.

sandstones. Sediments of this formation are poorly exposed, being best studied at intermittent exposures along river channels between Ito and Adum east and north of Oju. The lithologies of this formation are generally similar to those of the underlying Asu River Group except that they contain increased sandy facies, notably the Makurdi Sandstone. The Makurdi Sandstone is well jointed, composed of several fining upwards cycles of cross bedded medium to fine grained feldspathic sandstones and interbedded shales and limestones. The formation crops out as a prominant NE-SW trending ridge, as at Adum East and Ochinyinyi.

The Coniacian Awgu Formation is composed of bluish black thinly laminated, micaceous, pyritic and carbonaceous marine shales with subordinate limestones and occasional gypsiferous layers. The shales are exposed within a series of hand dug well excavations in the north of the area. Calcareous fluviatile Agbani Sandstones, interbedded with the shales of the upper Awgu formation, crop out as a low bifurcating ridge in the north-western part of the area. These sandstones are exposed within a river channel north of Echuri and within hand dug wells within Echuri village.

The occurrence of igneous rocks within the Cretaceous sediments of the Oju area are indicated by positive aeromagnetic survey anomalies. Medium grained dark green dolerites have been located within boreholes and at surface within the Ito and Adum West area. Diorites and associated ashy pyroclastics crop out in the Workum Hills with associated shear zones, within the southern parts of the Oju area. These igneous rocks are associated with large scale tectonics that occurred as folding and faulting episodes during pre- and post-Turonian times.

Table 1. Stratigraphic sequence of the Oju area of the Lower Benue Trough

Age	Formation	Sub-Units	Lithology
Maastrichtian			Post Maastrichtian NW-SE trending folding and faulting
Campanian			
Santonian			Anaerobic black shales NE-SW trending elongate folds and faulting
Coniacian	Awgu Formation	Awgu Shales Agbani Sandstone	Shale, shelly limestone, siltstone with clay pockets Fine to medium sandstones with siltstones
Upper Turonian Lower Turonian	Eze Aku Formation	Makurdi Sandstone Eze Aku Shale	Fine to coarse sandstones with siltstones Shales and siltstone with thin sandstones and limstones
Cenomanian			Hiatus/unconformity
Upper Albian Lower Albian	Asu River Group	Abakaliki Volcanics Abakalili Shales	Pyroclastics and intrusives with mudstone, shale and sandstone Carbonaceous shale, mudstone, limestone, sandstone, siltstone and clay
Precambrian Basement			N-S trending faulting

The geological structure of the area is dominated by the NE-SW trending Benue Trough and associated NE-SW trending elongate folds. Analysis of aerial photography and landsat imagery of the Oju area show this main structural and folding trend of NE-SW, with faulting normal or sub parallel to that trend. The secondary N-S lineament trend is associated with activity along earlier faulting within the underlying Precambrian basement. The pre-Turonian tectonism indicated by the Cenomanian hiatus, and the later Santonian and Maastrichtian tectonic phases caused the intensive fracturing and folding of the Asu River Group, and less intensive fracturing and folding of younger sediments of the Oju area.

The soil cover is a red ferruginous and weathered material regolith some 2-20 m thick generally overlies the Cretaceous age sediments. A thick red lateritic soil developed in the past upon a peneplaned surface at 125 m above sea level. This surface has been much eroded so that only scarped relics remain, around the Workum Hills and the north-south trending water shed. Away from these topographic features soils are generally fairly thin. Above the sandstone layers red sandy earths with low clay content form the regolith layer. In contrast the regolith above the shales and sandy shales is lateritic in character with hard concretionary ferrecrete bodies being compacted by a matrix of reddish clay. The iron oxide content of the latter decreases with depth forming a mottled effect, with a white kaolinitic clay layer occurring at the base of the weathered zone.

To gauge the relative importance of the various geological units for water supply in Oju an estimate was made of the number of people living on each rock type. Estimates of population were taken from for the RUSAFIYA survey (Obe and Daagu, 1991) and combined with a digital version of the 1:250 000 geology map. The data indicate that the Asu River Group supports the largest population with more than 130 000 people living on the formation, 30 000 of which live on the metamorphosed zone (Figure 4). Next is the Awgu Shale which supports 100 000 people. The small exposure of the laterite scarp, igneous intrusions and Agbani Sandstone means they support few people.

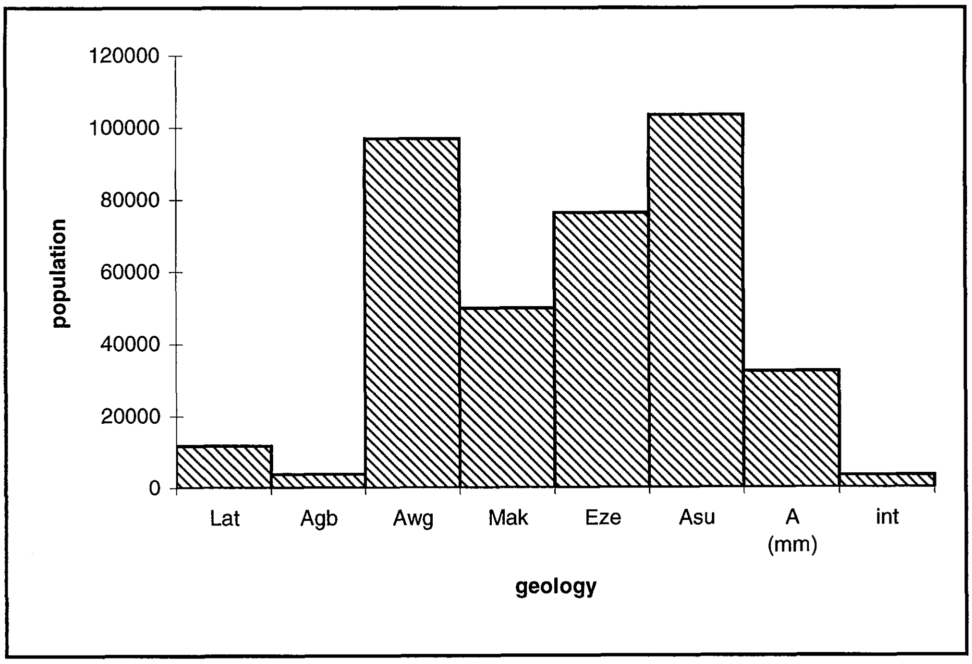

Figure 4. Distribution of population on each rock unit (population data from Obe and Daagu, 1991).

1.4 Health

The lack of sufficient year round water supplies has many health impacts in the Oju area; guinea worm, malaria and diarrhoea are the most common diseases for men, woman and children (Morgan, 1996). There are incidences of other water related diseases such as cholera and typhoid. Guinea worm (*Dracunculiasis*) has been identified by UNICEF and NIGEP/Global 2000 as a priority for eradication. Data for Nigeria as a whole shows that guinea worm cases have fallen from 650 000 in 1988 to 35 000 in 1994 (UNICEF, 1995). Cases in Oju, although reducing are still persisting: currently Oju has the highest incidence of guinea worm within Benue State. Figure 5 shows the distribution of guinea worm throughout Oju. Most of the cases are in the northern area on the outcrop of the Awgu Shales (Figure 6).

Woman and children are mainly responsible for collecting water. In the wet season, water can be collected close to or within the village; towards the end of the dry season woman have to walk many kilometers for water; sometimes as much as 8 km (Obe and Daagu, 1991). Due to the low permeability of the rocks, seepages can be very slow, therefore even at closer sources women might have to queue for several hours before collecting water.

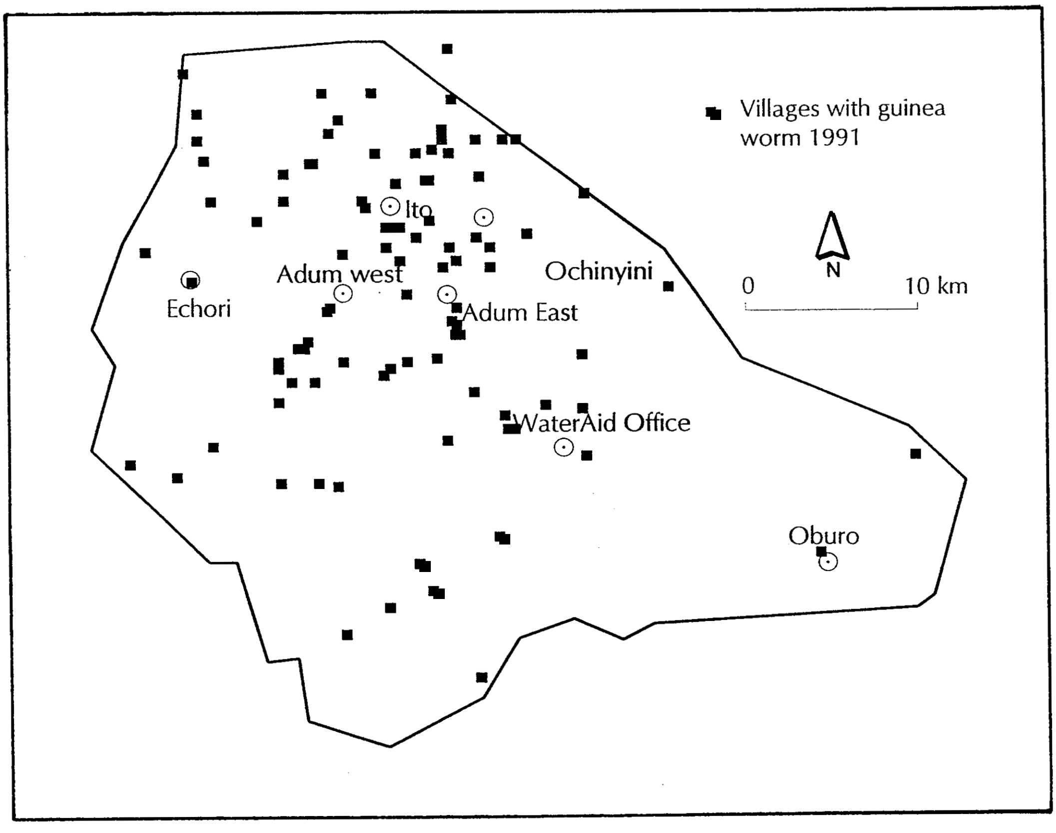

Figure 5. Distribution of villages with cases of guinea worm in 1991. Data adapted from Obe and Daagu (1991).

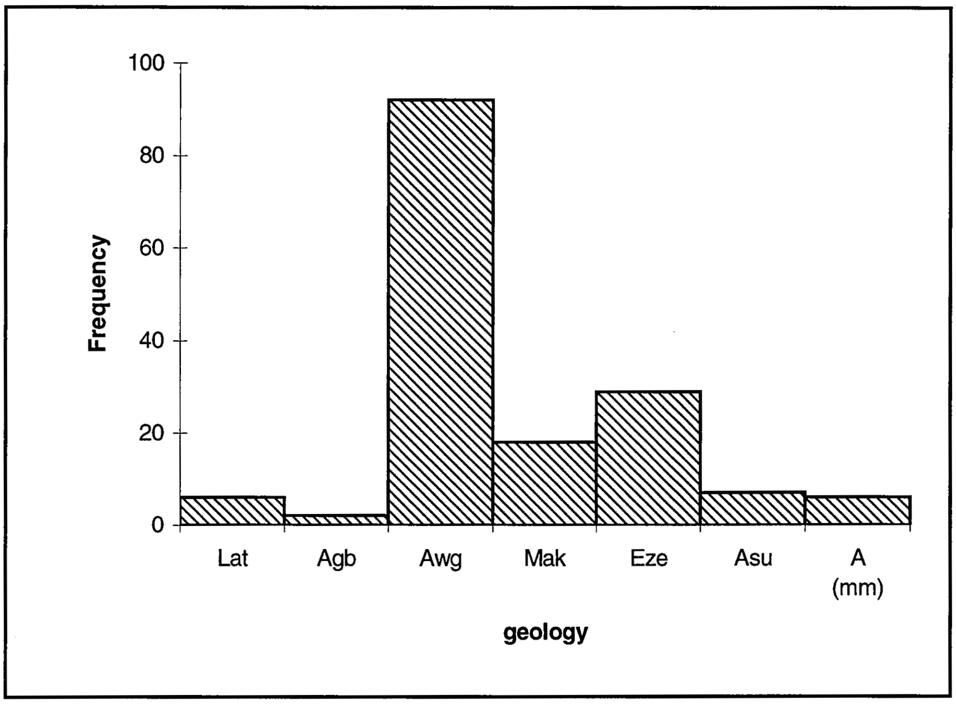

Figure 6. The number of villages on each rock unit with cases of guinea worm in 1991 (data fron Obe and Daagu 1991).

2. PREVIOUS STUDIES IN THE AREA

The Oju area is remote and has not benefited from many of the large development programmes that have taken place in some parts of Nigeria. However, there have been two small rural water supply initiatives over the past 10 years. Unfortunately, these have been poorly documented. Basic data also exist for the area in the form of geological maps, although at a fairly small scale. The University of Nigeria, Nsukka (UNN) has also carried out some investigations in and around the Oju area.

Oju was targeted as one of five local government areas for a UNDP/WB rural water supply and sanitation programme in the early 1990s. This programme (known as RUSAFIYA) used expertise from the state water authority in conjunction with a core team situated in Jos. Working within Oju was found to be difficult, due both to the difficult hydrogeology of the area, and also the lack of counterpart funding. This programme ended ignobly in 1993. During the period of the project several outputs were achieved:

- local government staff were trained
- a rapid survey was conducted of more than 400 communities, although the data were never extensively analysed (Obe and Daagu, 1991)
- several hand dug wells were constructed
- boreholes were drilled for a larger piped scheme which was never completed.

Geophysics was used to site potential groundwater development sites. Resistivity was the preferred method, although this is a slow method which suffers from non-uniqueness problems in clay rich terrains (Habila and Daagu, 1992). The problems encountered in this programme highlighted the need for a more detailed hydrogeological investigation (Davies, 1994).

The Department of Infrastructure, Food and Roads (DIFFRI) drilled a number of boreholes in Oju from 1987 to 1992 there are records of 42 boreholes having been drilled and equipped with India Mk2 handpumps; the majority of boreholes were recorded as being successful. Most of these boreholes were drilled in the south of the area within the Asu River Group formation. On inspecting some of these boreholes in 1997, many of the pumps had stopped working or had a history of frequent breakdowns.

Box 3 Previous Groundwater Studies in Oju

- WorldBank/ UNDP project (RUSAFIYA) ended prematurely in 1993 due to lack of counterpart funding
- DIFFRI drilled 42 boreholes in the south of Oju from 1987-92
- University of Nigeria, Nsukka have carried out several hydrogeological studies in Benue, none are in Oju
- Elim mission commissioned 9 boreholes in 1993 mainly in the south.

A few boreholes were drilled in 1992 by the Elim centre in Oju with funds from the Dutch Embassy. These boreholes are again mostly within the Asu River Group Formation and are largely successful. All were working when inspected in 1997. Unfortumately the driller who carried out this work is now deceased.

Baseline data is available for Oju in the form of maps. A series of topographic maps at 1:50 000 and 1:100 000 scale were produced from areal photographs in the 1950s. These maps provide useful data on topography and hydrology, but little else. The few village names that have been included in the Oju area are fairly unreliable. Geological maps are available from the Geological Survey of Nigeria at a scale of 1:250 000. The field work for these maps was undertaken in the 1950s and 60s. Although data are at a rather small scale, the maps have been very useful, and generally found to be accurate. Aeromagnetic data are available for the Oju area at a scale of 1:100 000. These maps were compiled by Fairey Surveys Ltd in 1975. Background information on water supply within Benue State is available from two different reports (Tahal, 1982 and Wellside Ltd, 1991).

Hydrogeological studies have been carried out by the Department of Geology, University of Nigeria, Nsukka. Unfortunately, none of the studies have been located within Oju area (probably because it is fairly remote), but in surrounding areas. One such study investigated the hydrochemistry and origin of saline water within the Ogoja area (Tijani et al, 1996). Another study investigated the chemistry of groundwater in the Abakiliki and Afikpo area,(just southwest of Oju (Uma et al, 1990). A general paper has also been written on the hydrogeology of the Lower Benue Trough which puts the Oju area into context (Uma and Onuoha, 1990).

3. HYDROLOGY AND CLIMATE

3.1 Climate

Oju falls within a climatic zone known as *tropical wet climate with short dry spells* (Goudie, 1996). Rainfall data has been collected at St Joseph's School in Ito for the last few years. Average monthly data for the period 1988 to 1993 is shown in Figure 7. The wettest months are from May to October with the two months, December and January generally completely dry. The dry season lasts four to five months, but the start of the rains can be quite unreliable. For example in 1988 there was no rain until June, but in 1990 there was significant rainfall within March. The mean annual rainfall for the years 1988-1993 was 1600 mm. The closest meteorological index station to Oju is at Ogoja (6° 39' N, 8° 42' E). Data are published from 1931 to 1960 (Tahal, 1982). Mean annual rainfall is 1800 mm, with 96 rainy days per year; there are an average of 3 rainy days from November to February, with a further 4 in March and 6 in April. Five months can therefore be considered as an approximate average length of the dry season.

The topography of the Oju area, with the Workum hills to the south and the flat plains to the north, may have a significant effect on the rainfall distribution. Knowing accurately the distribution of daily rainfall across Oju can give much information on the hydrology of the area. To try and give a snapshot of the rainfall distribution, seven rainfall stations have been set up across the Oju area (Table 2 and Figure 8). Two of these have standard raingauges and are set up according to standard procedures; these are located at the WaterAid office and at St Joseph's school. The other locations have simpler plastic raingauges. Most rainfall gauges are located at secondary schools, with one at a clinic south of the Workum hills. Records of daily data began in March 1997. In conjunction with the rainfall monitoring, a water-level monitoring system has also been installed (see section 5.2). Water levels are measured at ten sites at least once a month.

Box 4 Summary of Climatic Conditions

- average annual rainfall of 1600 mm
- 5 month dry season from November to March
- hottest month is March (mean daily temp >30°C)
- coolest months are July and August (mean daily temp ~26°C)
- mean annual evaporation is 2200 mm.

The hottest month of the year is March, when mean daily temperatures exceed 30°C. The coolest part of the year is generally July and August where the mean daily temperature is about 26°C (Hayward and Oguntoyinbo, 1987). Mean annual and monthly evaporation has been determined at Makurdi using a raised evaporation tank for the period 1958-1960 (Tahal, 1982). An annual mean of 2200 mm - which is broadly similar to other estimates for the area (Goudie 1996) - was determined.

Northeast trade winds, known as the *Harmattan,* prevail in West Africa. From December until February, and sometimes March, visibility in Oju is limited by large quantities of aeolian dust carried by the Harmattan winds. Concentrations of granular material in this "dust haze" can vary from a few tens to many thousands of $\mu g/m^3$. This dust loading reduces visibility and air quality and probably causes health problems (Lancaster, 1996).

3.2 River Flow

The marked seasonal variation in rainfall and the generally impermeable geology have a marked effect upon the hydrology of Oju. During the wet season, river flows are high with widespread flooding. Many of the rivers are ephemeral and dry up soon after the rains stop. There are no river gauging stations within, or near to, the Oju area, therefore all the discussion of the river system is based on observations made by the project team throughout the 96/97 wet and dry season.

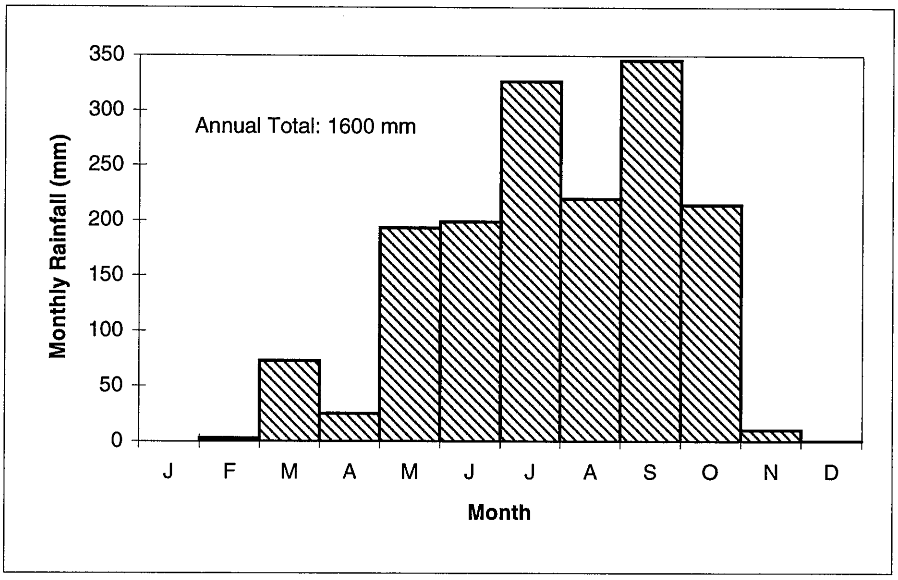

Figure 7. Average monthly rainfall for Ito 1988-1993. Data from St Joseph's School.

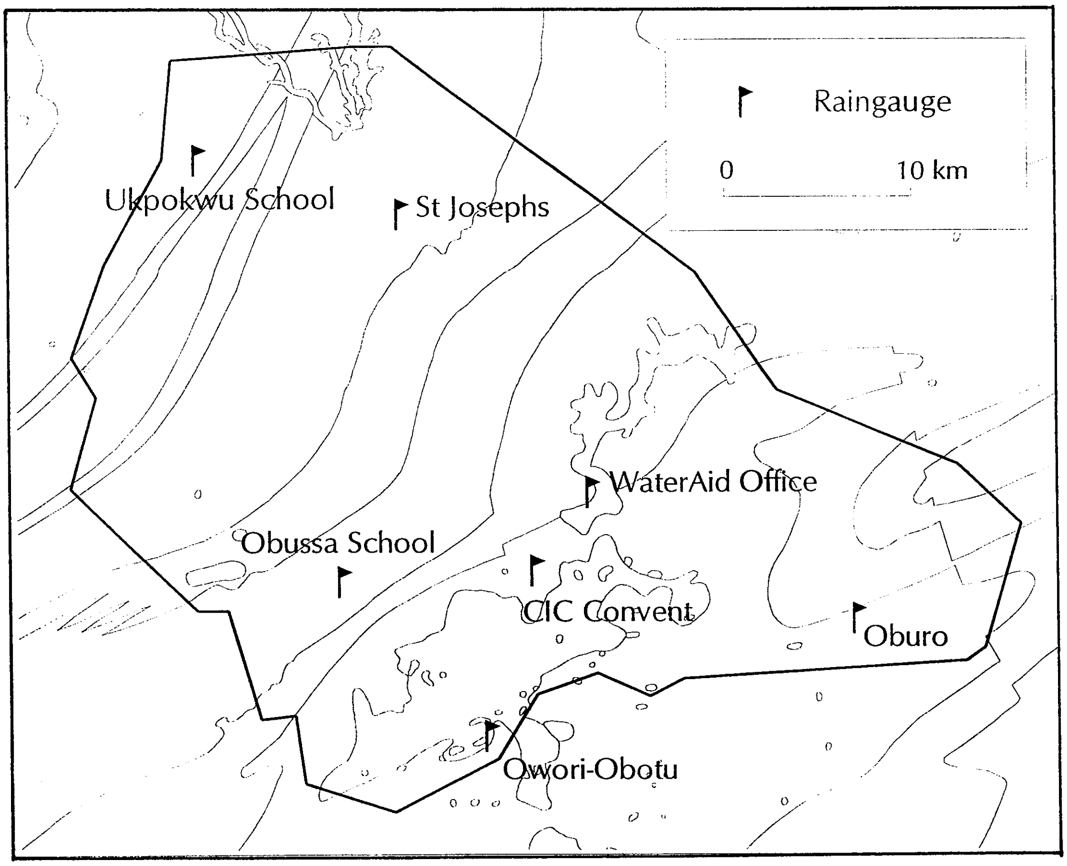

Figure 8. Distribution of rainfall gauges throughout Oju. Consult Figure 3 for the key to the geology.

Oju lies within the northern part of the Cross River Basin, which drains south to the Gulf of Guinea. The main rivers are shown in Figure 9. The two largest rivers are the Obi in the north and west and the Konshisha to the east. These rivers tend to be deeply entrenched and have limited river bed gravel deposits. In the lower reaches of the Obi, flow is perennial. Areal photographs show a change in the drainage pattern across the area. In the areas underlain by the low permeability shales, the drainage density is very high and dendritic; on the outcrop of the higher permeability Makurdi sandstone the drainage density is much lower.

The seasonal distribution is best illustrated by a series of photographs taken throughout the year at the same location. Plates 4-7 show a series of photographs taken of flow in the Obi river (Figure 9 shows the location). Throughout the wet season flow is substantial. Following a few days of intense rainfall, river levels rises rapidly (within a day) and cause widespread flooding. After a few days, the river level subsides to its normal wet season flow. During October/November, as the wet season ends, the river flows rapidly decline, leaving isolated ponds in the upper reaches of the main rivers. The lower reaches of the main rivers sustain perennial flow and are used extensively for water supply. Smaller tributaries dry up completely as the dry season progresses.

Throughout the area - but more commonly on the Makurdi Sandstone - river headwaters tend to form large shallow depressions. These features generally lacking much woodland, are marshy during the wet season but dry out during the dry season (Plate 8). These are similar to features observed in Central Africa, known as *dambos* (Goudie, 1996). Within the Oju area these features are often used for dry season water supply. Their precise role within the hydrological system appears to be unclear. Some authors suggest that they store only direct rainfall, others that they gain water from the surrounding interfluves (Goudie, 1996). There is also doubt as to whether they contribute significantly to dry season stream flows. In Oju some of the dambos contained shallow water towards the end of the dry season.

Table 2. Location of Raingauges in Oju.

ID	Name	Northing (DD)	Easting (DD)
R1	WaterAid Office	8.436	6.872
R2	Okpokwu School	8.213	7.062
R3	St Joseph's	8.329	7.031
R4	CIC Convent	8.404	6.827
R5	Obussa School	8.295	6.821
R6	Owori-Obotu	8.378	6.733
R7	Oburo	8.591	6.799

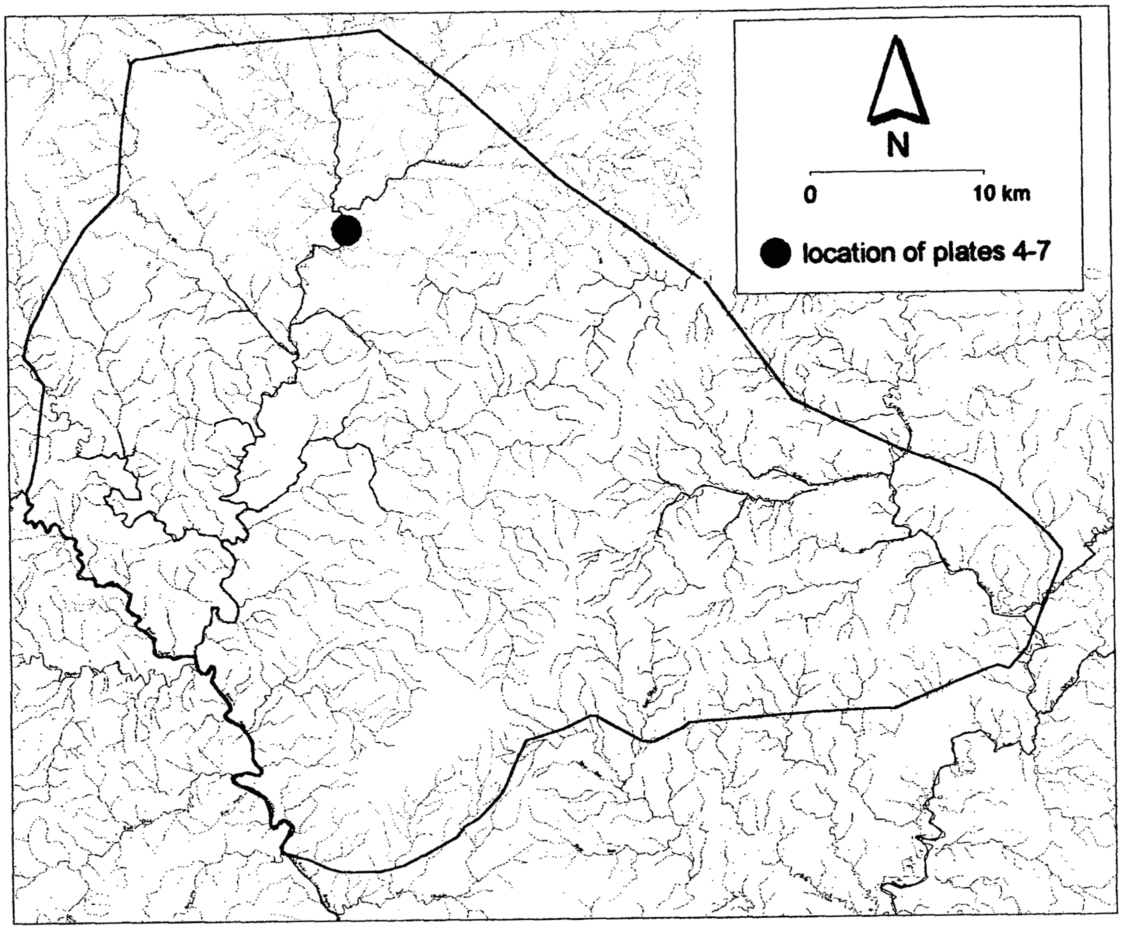

Figure 9. Rivers within the Oju area. The location of Plates 4-7 are shown.

4. WORLD-WIDE EXPERIENCE OF THE HYDROGEOLOGY OF CLAYS, SHALES AND BASEMENT

4.1 Introduction

A literature search has been undertaken to learn from other researchers experience of groundwater occurrence within clays and shales (Davies and MacDonald, 1997). Of all the literature written, the majority discusses shales and clays in the context of waste disposal. Little investigation has been made of shales as a source of water supply. Richer countries of the north can afford to bypass marginal rock units - such as shales - for more productive aquifers or surface water sources. In the southern countries, most work has concentrated on unconsolidated aquifers (UNSAs) and hard rock (basement) aquifers since they underlie large areas of the land surface (Herbert and Adams, 1996, Wright and Burgess, 1992).

This Chapter is split into four: (1) world-wide experience from the study of the hydrogeology of shales and clays, mainly for waste disposal; (2) the hydrogeology of laterite; (3) experience from permeability studies of basement aquifers; and (4) pumping tests in low permeability environments.

4.2 The Permeability of Clays and Shales

It is difficult to accurately measure hydraulic conductivity in low permeability environments. Any small leakage from field or laboratory apparatus can lead to the hydraulic conductivity being over-estimated. There are also the problems of finding a representative sample to test or the smearing of boreholes during drilling. As a result clay permeabilities are among the largest uncertainties when attempting to define subsurface flow.

Neuzil (1994) reviewed published intrinsic permeability measurements in an attempt to identify systematic variations. He found that few laboratories use natural media in an undisturbed state. Taking studies that he thought had been undertaken correctly he deduced that permeability is primarily related to porosity. Microstructural differences were also important and could account for changes up to 3 orders of magnitude; e.g. clays with elongate and fibrous minerals tend to have higher permeability than those that are more platy (Gilliot, 1987). Neuzil (1994) also examined the scale dependence of the measurements by relating laboratory measurements to field measurements by taking examples from inverse modelling of transient flow. He concluded that permeability scale dependence is not common in argillaceous material. This might be a result of the self healing nature of clays that can close up fractures, limiting the secondary permeability (Lomenick and Kasprowicz, 1990). From his studies K (hydraulic conductivity) varied from 10^{-16} to 10^{-8} m/s and ϕ (porosity) from 0 to 0.8.

Other studies have stressed the variation of permeability between field and laboratory measurements. Gilliot (1987) states that field permeability can be greatly enhanced due to fractures and silt content. In a study of the effect of a large fault on the hydrogeology of the Oxford Clay, permeability was found to be enhanced by 1-2 orders of magnitude in the vicinity of the fault (Sen and Abbot, 1991; Hallam et al, 1991). Hydraulic conductivity in the undisturbed samples was found to vary from 10^{-12} to 10^{-8} m/s and specific storage from 10^{-5} to

Box 5 Summary of Research into the Permeability of Clays and Shales.

- laboratory measurements of clays and shales are generally low, <10^{-8} m/s
- field measurement of clays and shales can be 1-3 orders of magnitude greater than laboratory samples due to the presence of fractures (although there is some debate about this at a regional scale)
- interbedded silty layers or limestone layers can significantly enhance permeability and the yield of boreholes
- the orientation of joints is critical in increasing permeability.

10^{-3} m^{-1}. In a review of superficial clays, hydraulic conductivity was found to vary from 10^{-11} to 10^{-5} m/s (Klinck, 1993). Many different studies of glacial till point towards a marked increase, 1-3 orders of magnitude, between fractured and unfractured till (Boumen et al, 1989; Lloyd, 1983; Kazi et al, 1973; Frederica, 1990; Herzog and Morse, 1984; Bosscher et al, 1988; Fortin et al, 1991 and Keller, 1988). Estimates of fractured hydraulic conductivity ranged up to 0.001 m/s (7 m/day).

Bosscher et al (1988) undertook a study into the effect of unconnected joints in soils with a high clay content. They found that joint orientation was critical when the orientation was within 30° of the flow direction and that the hydraulic conductivity of jointed soil was in general two orders of magnitude greater than unjointed soil.

It is difficult to reconcile the above research with Neuzil's (1994) assertion that there is very little difference between properly carried out laboratory and field measurements of intrinsic permeability, k. The implication that the extensive research carried out into clayey glacial till has been undertaken improperly, is unlikely. It is possible that the research has actually been looking at three rather than two different scales: laboratory, field and regional. In a study into the aquifer properties of the Permo-Triassic aquifer in England and Wales, Allen et al (in press) found that hydraulic conductivity measurements derived from regional models were similar to those gained from core analysis. Pumping test results however were considerably higher. It is possible that the fractures that provide the flow into boreholes and wells are not significant for regional flow. Bredehoeft et al (1983) also found a difference between regional permeability (implied from flow modelling), localised permeability from borehole tests and intrinsic permeability from lab tests.

Several studies of clay environments have highlighted the importance of interbedded siltstones and limestones. Barker et al (1988) in studying a landfill sited on shale found that an interbedded cherty dolomite provided an important flow path for contaminants. Capuano and Jan (1996) undertook two aquifer pumping tests (13 and 24 hours) and a tracer injection test in shallow (7.5 m) clay and silt-clay sediments of the fluvial-deltaic Beaumont Formation from the U.S. Gulf Coast. The insitu horizontal hydraulic conductivity determined from these test was found to be approximately 10^{-5} m/s (1 m/d). This value is one to three orders of magnitude larger than that of typical silts and clays, and two to four orders of magnitude larger than the vertical hydraulic conductivity measured on core in laboratory permeameter experiments. No water entered the boreholes until they encountered a silty-clay layer which comprised the aquifer. The more permeable horizons had 42-83% silt and clay and 17-58% fine sand.
Therefore for permeability of less than 10^{-6}m/s borehole and well yields would be low and drawdowns high. Therefore **unfractured shale or clay can never be considered as having potential for groundwater**. Only the fractured shales have permeability values that could be useful for water supply; and even then hydraulic conductivity values of 10^{-6} m/s are above the average recorded.

The Voltaian Basin in Ghana consists of interbedded siltstones, shales and sandstones, much like the sediments of the Benue Trough. There have been many problems in this area with rural water supply. Tod (1981) states that toward the central of the basin only 13-21% of boreholes drilled have been successful (yields >20 l/min). Recently a drilling programme was undertaken using aerial photographs to identify fracture zones, followed by geophysics to site the boreholes. The success rate of this programme was 13% (Iddirisu and Banoeng-Yakubo, 1993). These programmes assumed that fracture zones would be the best targets and were best exploited through boreholes. Although this is often the case in basement areas, in shale/siltstone environment large diameter wells might have been more appropriate (MacDonald and Macdonald, 1997). Currently boreholes are being sighted using Landsat imagery and geophysics and success is thought to have increased (Teeuw, 1995).

Box 6 Ramifications of Low Permeability Research for Water Supply

It is useful to convert measurements of hydraulic conductivity into borehole and well drawdowns. This can be done by using the estimates of permeability from research to build a model of water-levels within an aquifer and borehole/well (see MacDonald and Macdonald, 1997).

Assuming the aquifer to have:

- transmissivity of 1 m^2/d (i.e. 10 m thick with hydraulic conductivity of 10^{-6} m/s)
- storage coefficient of 0.001
- Normal boundary conditions and modelling assumptions (see Barker 1989)

Assume the well:

- pumped at 0.1 l/s for 12 hours a day for 50 days with no recharge
- diameter of 1.5 m
- no recharge

The resulting drawdown in the well at the end of pumping each day and also the recovery level by next morning is shown Figure 10. Drawdown in a less permeable aquifer (transmissivity of 0.1 m^2/d) and a more peremable aquifer (transmissivity of 10 m^2/d) are shown for comparison. It is apparent that the well is under stress by the end of the dry season. If the demand on the well increased slightly, the well would dry up. The aquifer with lower permeability dries up quickly, but the higher permeability aquifer has no problems in meeting year round demand.

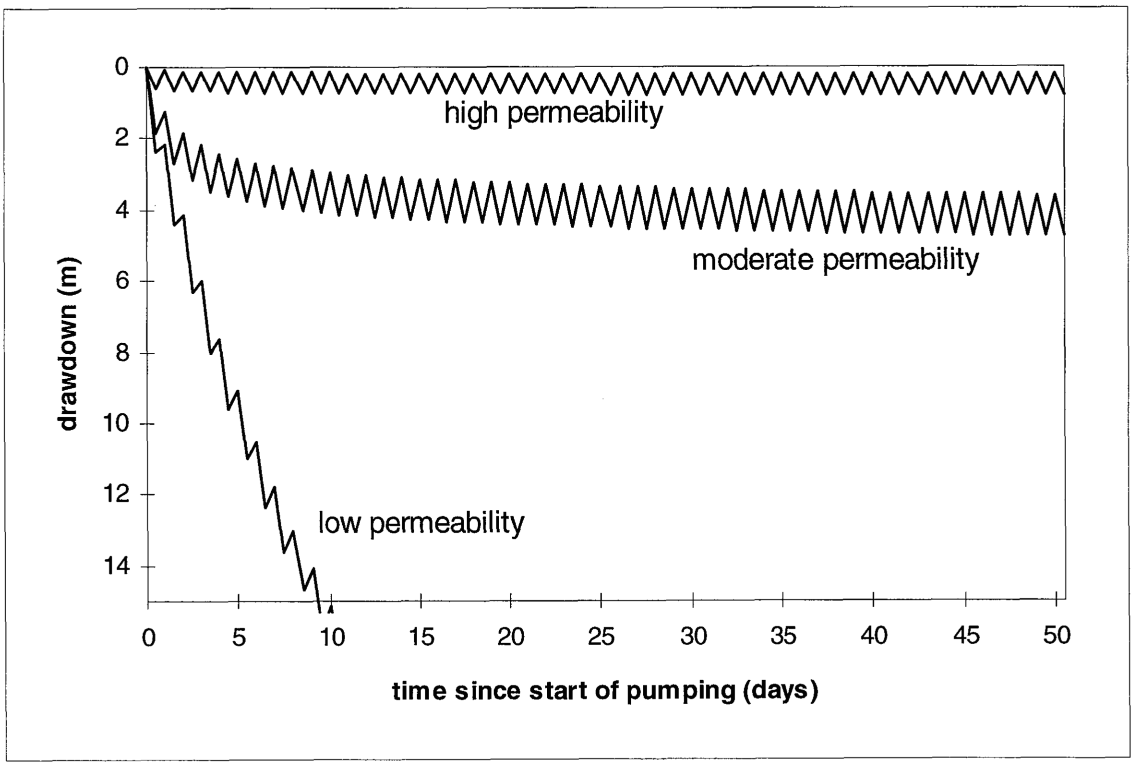

Figure 10. Drawdown in a typical village well in three different aquifers. The well is pumped at 0.1 l/s for 12 hours a day. See Box 6 for further details.

4.3 The Hydrogeology of Laterite

The hydrogeology of laterites is also important in the Oju area. Several studies have been made of the permeability of laterites and their effect on the groundwater resources of an area.

Langsholt (1992) studied the effect of laterite in southwest India. The site was underlain by a well developed 10 m thick lateritic profile overlaying a charnockite bedrock (a coarse granular igneous rock). Rainfall was 2000- 4000 mm/a, distributed over 125 days and the temperature varied from 20 to 32°C. Groundwater response to rainfall was rapid (usually within 10 hours), involving fluctuations of several metres. The recharge mechanisms suggested from the study was water movement via preferred pathways from the ground surface to the capillary fringe where the rapid rise in groundwater level is brought about by a transmitted pressure pulse. A similar study was carried out in Western Australia (Sharma et al, 1987a; Sharma et al, 1987b). They found that the rate of infiltration in lateritic soils was very high but was affected by land use changes, particularly changing from forest to pasture.

4.4 The Hydrogeology of Crystalline Basement Aquifers

Crystalline basement rocks are widely distributed throughout the world. They are most important as a source of groundwater in Africa, Asia, and South America. Like shales and clays, unweathered crystalline rock has very low permeability. Significant aquifers, however develop within the weathered overburden and fractured bedrock. These aquifers provide sufficient groundwater resources to supply domestic requirements of villages and rural communities (Wright and Burgess, 1992). The majority of rural water supply projects carried out in Africa are located on weathered crystalline basement aquifers. Much work has been undertaken to try to understand these aquifer systems. Four factors that contribute to the weathering of basement rocks (Jones, 1985; Acworth, 1987):

- presence and stress components of fractures
- geomorphology of the terrain
- temperature and occurrence of groundwater
- mineral content of the basement rock.

The resulting weathered zone (or *regolith*), can vary in thickness from just a few metres to over 90 m.

The permeability and porosity in the regolith is not constant but varies throughout the profile (Figure 11). Porosity generally decreases with depth, permeability however, has a more complicated relationship, depending on the extent of fissuring and the clay content (Chilton and Foster, 1995). In the soil zone (*collapse zone*), permeability is usually high, but groundwater does not exist throughout the year. Throughout the clay rich saprolite, however, the permeability is low. Towards the base of the saprolite, near the fresh rock interface, the degree of weathering decreases and the clay content decreases dramatically. This horizon consists of fractured and brecciated rock, therefore, has a high permeability, allowing water to move freely (British Geological Survey, 1989). Deeper fractures within the basement rocks are also often an important source of groundwater. These deep fracture zones can sometimes provide supplies of a litre second. There are therefore two main targets for groundwater in basement rocks:

- basal saprolite
- deeper fracture zones.

The effectiveness of both these aquifers depends on how thick they are and the relative depth of the water table; the deeper the weathering, the more sustainable the groundwater. Moreover, due to the complex interactions of the various factors affecting weathering these two different aquifers may not be present at all.

Various techniques have been developed to try and locate groundwater resources within basement rocks. These include remote sensing (Lillesand and Kiefer, 1994) geophysical methods (e.g. Beeson and Jones, 1988; McNeill, 1991 and Carruthers and Smith, 1992) and geomorphological studies (McFarlane et al, 1992). Siting methods are discussed in detail in another report (MacDonald and Davies, 1997).

Box 7 Summary of Research into Basement Aquifers

- groundwater can exist within the weathered zone and deep fracture zones
- permeability is highest at the base of the weathered zone
- groundwater can be located using geophysics, remote sensing and geomorphology
- boreholes are best used to exploit deep fracture zones
- dug wells can be used to exploit the weathered zone, but must be constructed deep enough
- collector wells maximise yield from the permeable basal saprolite.

Various methods have been used to abstract groundwater from basement aquifers (Figure 12). The most common are boreholes and dug wells, collector wells have also been used with much success, although their distribution is at present fairly limited (British Geological Survey, 1989; Ball and Herbert, 1992). Each of these abstraction methods have their own advantages and limitations. Boreholes are quick to drill, can penetrate hard rock fairly easily and can therefore be drilled very deep. However, since they are narrow, they have little storage capacity and require a pump to abstract water. In addition, a drilling rig is usually required to drill boreholes which can limit the participation of communities. They are most useful in basement areas for abstracting water from deep fracture zones. The main advantage of large diameter hand dug wells is that they can have a large storage capacity. Therefore in low permeability aquifers, where the rate of flow from the aquifer to the well is slow, water can be abstracted from *stored* water in the well at a rate much greater than the permeability of the aquifer would allow. Wells also have a large internal surface area, which allows a large amount of seepage from the aquifer. Little specialist equipment is required for their construction (Watt and Wood, 1979) and once completed a pump is not necessary to abstract water. However, it is difficult to construct hand dug wells in hard rock; also, since they are shallow, they can sometimes dry up, although this is often due to large demands put on the wells in the dry season, rather than natural water levels fluctuations (MacDonald and Calow, 1996). Wells are best used to exploit aquifers within thick, near surface, zones of weathering .

Collector wells have been designed to maximise the yield from the basal saprolite aquifers (British Geological Survey, 1989). A collector well consists of a large diameter central shaft with horizontal radials penetrating the surrounding aquifer. These radials are positioned to penetrate the high permeability zone of the basal saprolite. The resulting well has a large storage, but also a high seepage rate and therefore provides a higher sustainable yield (Macdonald et al, 1997). However, collector wells are more expensive to construct than hand dug wells and require a specialist horizontal drilling rig. Other, less expensive methods of constructing radials have been investigated (Morris et al, 1991).

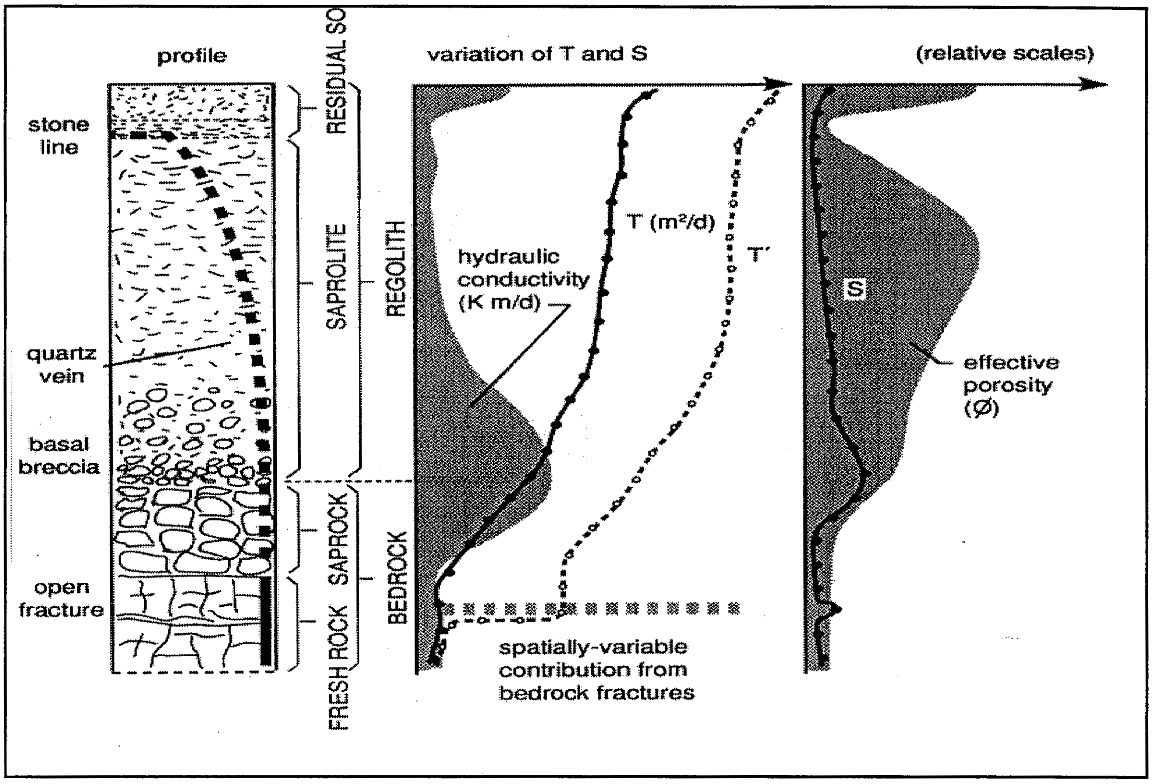

Figure 11. Conceptual model of the hydrogeology of the weatherd crystalline basement in Africa (after Chilton and Foster 1995).

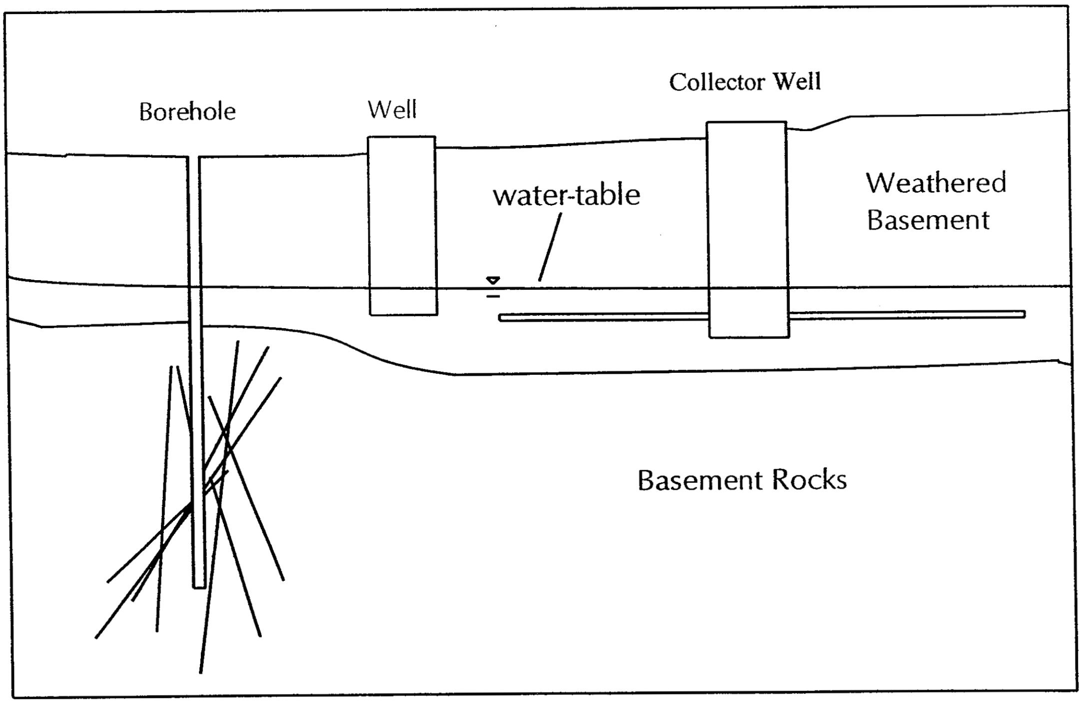

Figure 12. Boreholes, wells and collector wells in crystalline basement.

4.5 Pumping Tests for Measuring the Hydraulic Properties of Clays and Shales

Testing the hydraulic properties of low permeability environments is difficult for a variety of reasons. The above studies highlighted several difficulties encountered during research.

- It is difficult to devise laboratory tests that represent field conditions: fractures, orientation of clays, water content, and over-consolidation,
- It is difficult to extrapolate laboratory results into the field due to inhomogeneities, multiphase flow and representative samples (Gilliot, 1987)
- Weathering can remove any surface expression of faults and fractures down to a depth of 5 m
- The smearing of boreholes (Klinck, 1993)
- The long time required for the compressible clays to respond to changes in the stress regime (Sen and Abbott, 1991)
- Leakage from laboratory apparatus
- Coupled processes, e.g. groundwater flow and osmosis.

Before testing a borehole it is important that it is constructed properly. McKay et al (1993) found that field values of horizontal conductivity measured in the upper 1.5-5.5 m of a weathered and fractured clay-rich till were strongly influenced by smearing around piezometer intakes and the size of the measuring device. K in normal piezometers was 1-2 orders of magnitude lower than those designed to reduce smearing. Smearing should be minimised by flushing with a deflocculant (e.g. sodium hexametaphospahte); an over cored Shelby tube can used to minimise smearing and a sandpack placed around the piezometer tip. The section of the aquifer that is being tested needs to be sealed off from the rest of the borehole by using a bentonite seal and sandpacks throughout the area in question.

Various field methods are used to gain an estimate of hydraulic conductivity in low permeability environments. Straight forward constant rate pumping tests can be undertaken in the higher permeability environments (e.g. Capuano and Jan, 1996). Recovery tests are also popular, where the time taken for a well or borehole to recover its water levels is measured. The most popular method for measuring the hydraulic properties is the **slug test**; these are often used in conjunction with packer tests or in specially constructed piezometers. If the permeability is less than 10^{-9} m/s, however, the tests can take several months to run; e.g. a large brick lined well in glacial till took three months to recover after being emptied. A modification of the slug test (Ngoyen and Pinder, 1984) can overcome some of these problems: Herzog and Morse (1984) found that tests could be completed in a day for clays with hydraulic conductivity from 10^{-10} to 10^{-6} m/s. This test, often referred to as a pressurised slug test - or pulse test - is most useful in very low permeability environment (Klinck, 1993; Klinck and Wealthall, 1996). The borehole is filled with water and then pressurised with additional water. The borehole is then sealed and the decay in the pressure observed - a modification of Cooper et al (1967) is then used to estimate the hydraulic conductivity.

Dennehy and Davis (1981) found standard slug tests to be most useful in hydrogeological environments with transmissivity 10^{-4}-1 m^2/d. Pressurised slug tests were useful when transmissivity was less than 10^{-4} m^2/d. For rural water supply we are most interested in areas with higher transmissivity therefore the pressurised slug test need not be used and the conventional slug test should be most useful.

In summary, for investigating the potential for rural water supply, conventional slug tests, constant rate tests and recovery tests would be most useful. It is imperative that the borehole is constructed carefully with minimum smearing of the borehole sides. The particular section of the aquifer that is being tested should be isolated from the rest of the hole using some sort of impermeable seal.

5. HYDROGEOLOGY

5.1 Hydrogeological Groups

Two hydrogeological groups have been identified in the lower Benue Trough of Nigeria by Uma and Onuoha (1990). The first group occurs to the east of the north-south trending Okaba-Enugu-Okigwi escarpment, while the second underlies the hummocky terrains to the west of this escarpment. The first group comprises thin, shallow and continuous regional aquifers, with localised deep, confined aquifers; this is the group that underlies Oju. Uma and Onuoha (1990) conclude that it may be economically unwise to exploit the thin aquifers of this group by "motorised pumps". Small discontinuous abstractions such as is obtained from hand-pumped boreholes or dug wells should be emphasised for the shallow aquifers.

The Cretaceous rocks of the Oju area are generally overlain by weathered material. Where permeable this comprises a thin shallow unconfined aquifer; groundwater can also occur in fractured shales or sandstone/siltstone beds. Generally depth to the water-table is less than 10 m, but can be less than a metre below ground surface in the wet season. Uma and Onuoha (1990) state (from limited data) that the Asu River Group has the highest yields within this area: well recovery took 5 hours in the Asu River Group while in the others it took 9-13 hours.

At this stage of the research, prior to any drilling and testing, only broad generalisations can be made about the various hydrogeological units in the Oju area. Using the geology map as a guide, the hydrogeology has been split into six different units. As more information is collected, some of these units may be combined, and others divided. The six units are discussed below (Figure 13).

Box 8 Hydrogeological Units in Oju

Asu River Shales: groundwater occurs in sandy/silty layers or, where more consolidated, in fractures.

Metamorphosed Asu River Shales: groundwater can occur in the weathered zone and fractures.

Eze Aku: groundwater occurs in sandstone and siltstone layers.

Makurdi Sandstone: good aquifer, groundwater should occur throughout.

Awgu Shales: poor aquifer, groundwater may exist in the weathered zone or next to intrusions.

Igneous Intrusions: next to intrusions the surrounding rocks are baked - groundwater can occur in fractures.

Asu River Shales. The Asu River Group is located in the south and east of Oju and comprises mainly compact fissile shales. Some pyroclastic rocks and quartzite have also been observed in the field. The boundary between this unit and the second unit (Metamorphosed Asu River Shales) is rather uncertain. Many of the outcrops examined within the Asu River Shales contained very hard rocks, which appeared to be metamorphosed. It is possible that the Asu River Shales unit is actually quite small comprising the area of Asu River Group without any regional magnetic anomalies (see Figure 13). Groundwater may exist within deep weathered pockets and along fracture zones.

Metamorphosed Asu River Shales. The Asu River Group has undergone regional metamorphism in the vicinity of the Workum Hills in the south of Oju. The area outlined in Figure 13 is taken from the geological map but may actually be much larger (see above). The unit comprises hard, slaty and flinty shale with weathered pockets. There are also pyroclastic rocks and various basic intrusions. Where the

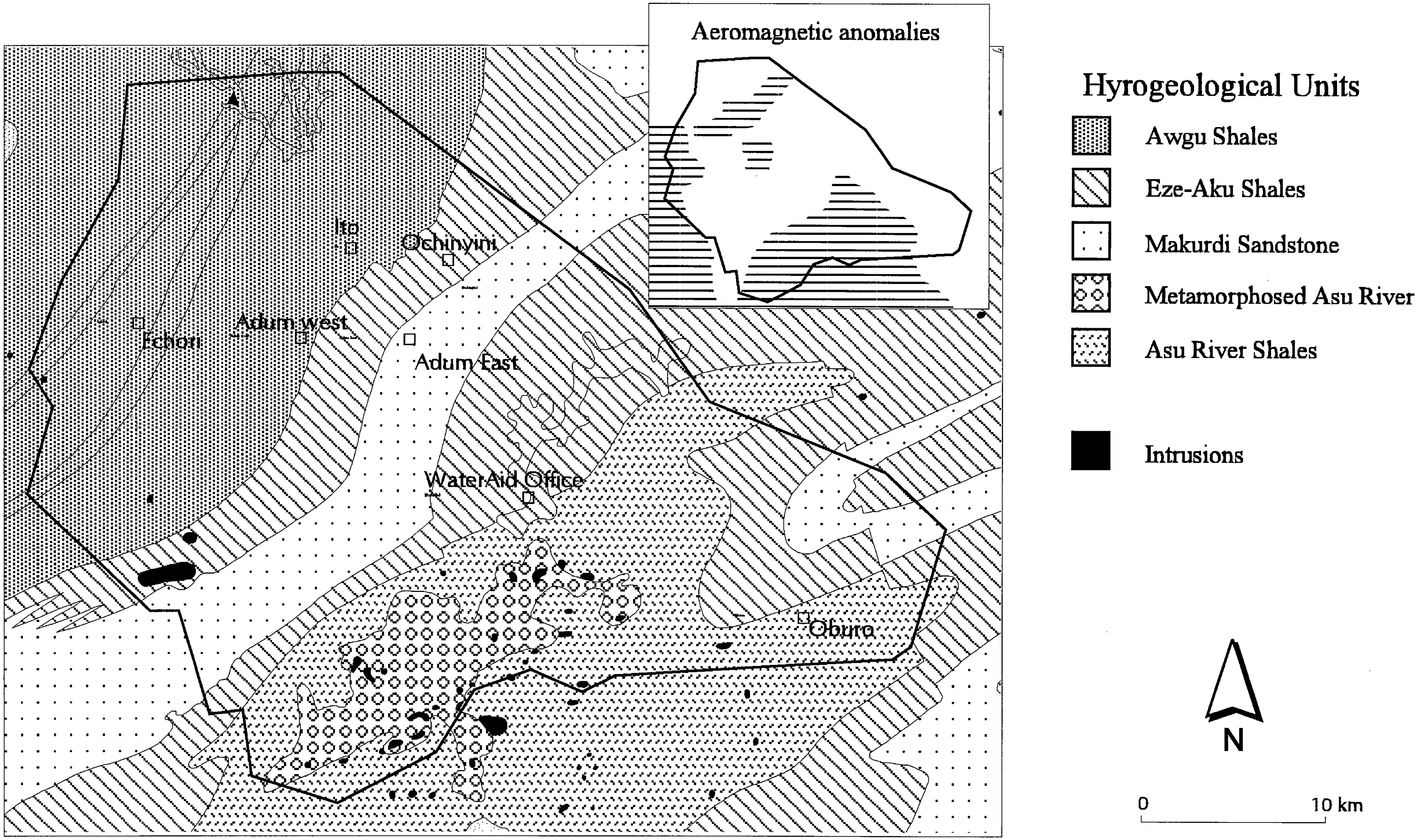

Figure 13. Preliminary hydrogeological map of Oju.

unit is weathered, the shales become softer. Groundwater primarily occurs within fracture zones, but may also exist within the deeper weathered zone. It will be important to determine whether open fractures exist at the base of the weathered zone as occurs in basement aquifers. Boreholes drilled within this zone have been largely successful.

Eze Aku Shales. The third hydrogeological unit is found mainly across the centre of Oju, but also occurs in the far east. It comprises interbedded shales, siltstones, limestones and sandstones, and also the laterite scarp. Groundwater primarily occurs within the siltstone and sandstone layers, but may also be available from within fractures. There is little information available at present to indicate how frequent the sandstone and siltstone layers are.

Makurdi Sandstone. The Makurdi Sandstone is the most productive aquifer within the Oju area. Its distribution is shown in Figure 13. The aquifer comprises mainly fine-medium grained sandstones with siltstone and shale beds (Plate 9). Groundwater potential is high within the sandstone layers, however, the extent and thickness of the shales within this unit is at present unclear. The sandstone has a high feldspar content, which weathers to swelling clays (see Davies and MacDonald, 1997). As a result, many of the wells dug into the sandstone have collapsed as the clay expands during the wet season. Properly constructed hand dug wells, that are reinforced through the clay zone should not collapse.

Awgu Shales. The Awgu Shales occur in the north of the Oju Area. They consist primarily of soft shales but also have sandstone and siltstone layers. Most noticeable of the sandstones is the Agbani Sandstone which strikes NE-SW through Echori. The Awgu Shale appear to have little potential for groundwater in their unaltered state. However, large open fractures have been observed, where the shale is weathered (Plate 10). At present it is uncertain as to how widespread this weathering is, and how sustainable flow through the fractures might be. The sandstone layers, where present appear to have adequate groundwater to support village supplies.

Igneous Intrusions. Throughout Oju, there are igneous intrusions - mainly basic dykes and sills. Where present, these intrusions bake the surrounding rocks making them hard, and generally fractured (Plate 11). These can be good targets for groundwater supply; for example, the high yields found by the RUSAFIYA project at Ito are due to the presence of a dolerite sill. Locating these intrusions is not easy. However, most igneous rocks have a slightly different magnetic susceptibility that sedimentary rocks, therefore aeromagnetic anomalies might suggest an increased probability of finding an intrusion. Figure 13 shows areas of magnetic anomalies from the 1:100 000 aeromagnetic map (Faireys, 1975). Intrusions are probably most important for water supplies in the north of the area where the unaltered Awgu Shale has generally low groundwater potential.

In all of the hydrogeological units, fracture zones are important for groundwater supplies. Large fracture zones are linked to the tectonic stresses, past and present in the Benue Valley. The main fracture sets trend NE-SW and NW-SE with a subordinate fracture set trending N-S (Davies and MacDonald, 1997). Fracture zones can show up on areal photographs and satellite data as straight lines or *lineaments.* Near to villages however fracture zones can be confused with anthropogenic features. In a recent study in Ghana, Teeuw (1995) found that fracture zones identified from satellites were more accurate than those identified from areal photographs. After identifying fracture zones from remote sensing, the location can be determined more accurately on the ground using geophysics.

Laterite also has an important impact on the hydrogeology of the Oju area. Horizons of ferrecrete nodules and also the hard vermiform ferrecrete can be very permeable. These layers are generally shallow, so are above the water table during the dry season; during the wet season, however groundwater can move quickly though the layers forming small ephemeral springs and contributing to the fast response of rivers to rain (see Plate 12). These shallow permeable layers might also contribute to the "flashy" nature of wells. Wells in Oju have very shallow water levels in the wet season. In response to rainfall, water can move horizontally though the laterite and discharge to springs and also through wells (Figure 14). Individual intense rainfall events might cause peaks in groundwater level as the excess water is dissipated through the permeable laterite (see section 5.2 on water levels). As the wet season ends, the laterite dewaters. Wells that are totally dependent on flow within the laterite will quickly dry up.

5.2 Water Levels

There are few data on the natural fluctuations of groundwater levels within Oju. Daily measurements have been taken in the WaterAid compound since the beginning of the project (September 1996). Although, a complete years data has yet to be collected, already it has proved useful in understanding something of the hydrogeological environment. The water-levels in both the new (pumped) well, and the traditional well are shown in Figure 15. Three distinct sections are apparent in the hydrographs of both wells.

September-October: water-levels vary rapidly up to 2 m in a few days. The water levels return to a base-level every few days. This section is attributable to heavy rainfall (see above) - rapid infiltration occurs through the laterite and quickly fills up the well. After a few days with no recharge, the upper highly permeable layers of the laterite dewater and the water levels return to a base level, probably attributable to water within the weathered zone of the Asu River Group.

November-January: water-levels fairly static at the same depth as the base-level observed during September and October. There was no rainfall during this period, but water was abstracted every few days for use in the house and office. The permeability of the aquifer must be sufficiently high to allow quick recovery of the well.

February to March: water levels quickly decline in the pumped well and slowly decline in the observation well. The dry season was advanced and abstraction in the well had increased substantially from the beginning of February. It appears that the abstraction was much greater than the well could cope with, the recovery of the well was much slower than earlier in the season. The gradual decline of the traditional well is due to a combination of natural recession, interference from the pumped well and also unauthorised abstraction.

Similar responses were observed in traditional hand dug wells throughout Oju. In the wet season, water-levels are very shallow and can respond quickly to rainfall. As the dry season progresses the water-levels fall and the wells dry up. Wells that rapidly dry up probably gain all their water from the shallow permeable zones. More sustainable wells have deeper sources of water.

Water levels will continue to be monitored daily in the two wells throughout the length of the project. Monthly water level measurements are also being taken at a variety of locations throughout the Oju area. a total of 10 sites have been monitored since March 1997 (see Table 3 and Figure 16). However, acquisition of accurate long term water-level fluctuation data in Oju requires installation of a network of dedicated piezometers. Within low permeability shale formations monitoring of pumped wells and boreholes cannot provide the data required (due to the extremely slow rate of recovery of wells).

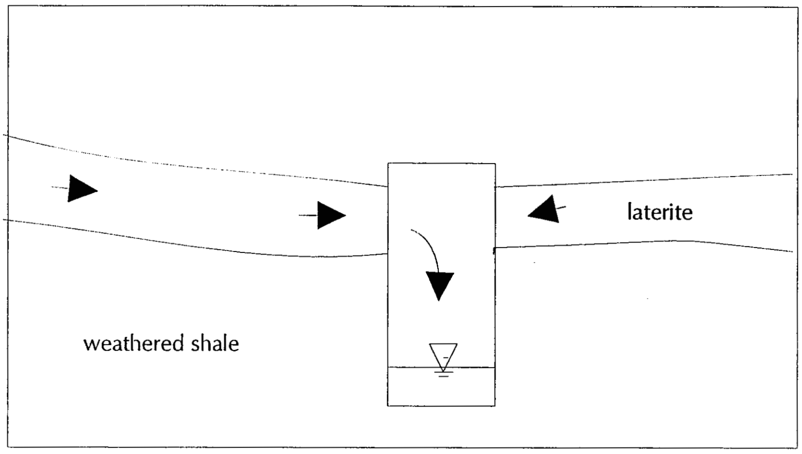

Figure 14. In the wet season water can flow rapidly through the laterite and quickly recharge the wells.

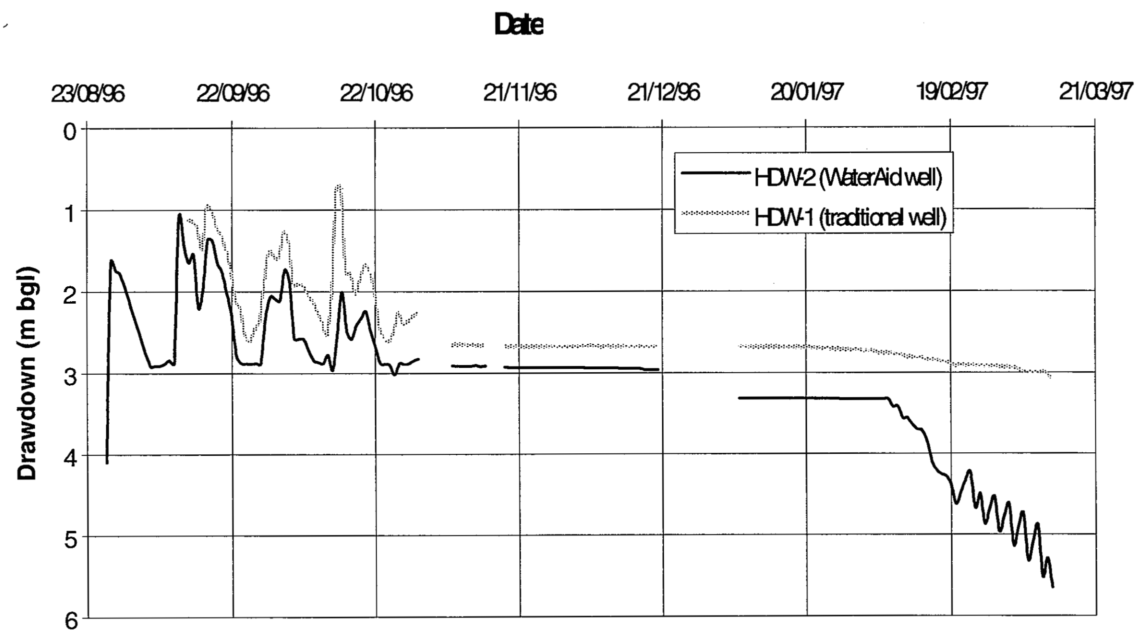

Figure 15. Water level fluctuations in the traditional (not pumped) and improved (pumped) well in the WaterAid Compound.

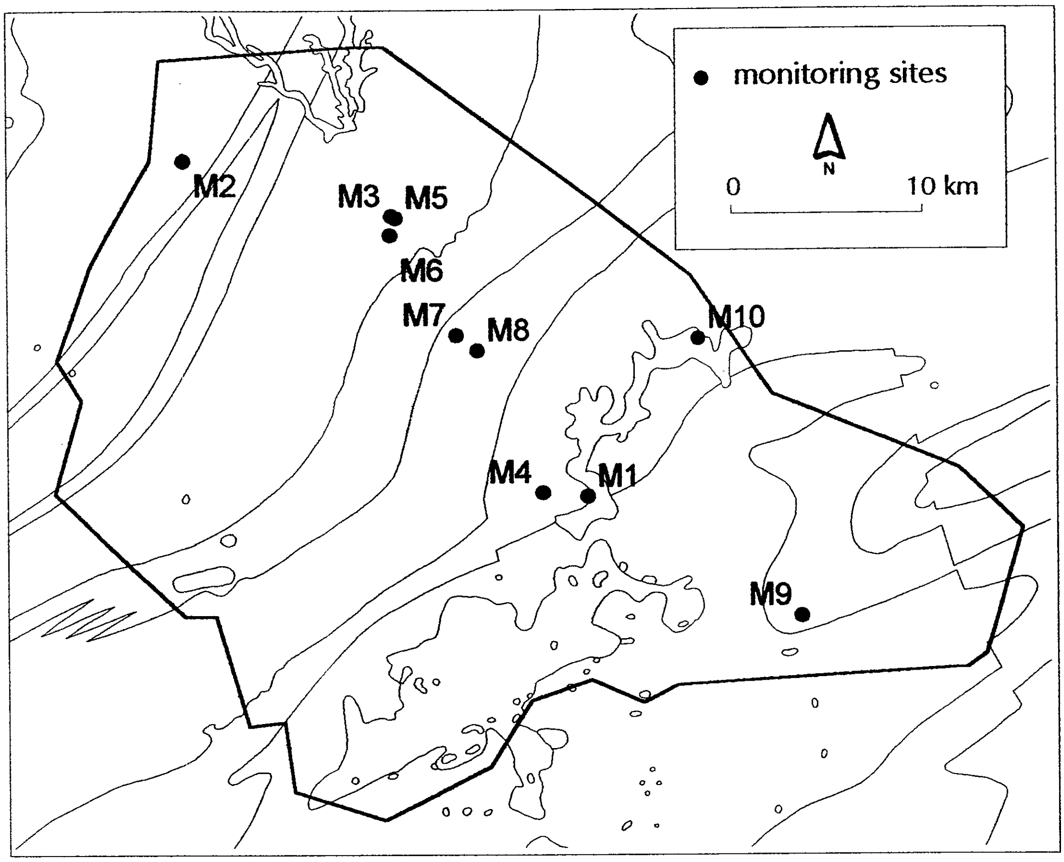

Figure 16. Distribution of water-level monitoring boreholes throughout Oju. Consult Figure 3 for the key to the geology and Table 2 for details of the boreholes.

Table 3. Groundwater-level Monitoring Sites within Oju.

ID	Name	Northing [DD]	Easting[DD]
M1	WaterAid Office	8.436	6.872
M2	Okpokwu School	8.210	7.062
M3	St Joseph's	8.327	7.031
M4	Elim	8.411	6.874
M5	Ito Church	8.329	7.029
M6	Ito petrol	8.326	7.020
M7	Adum East Well	8.363	6.963
M8	Adonal Well	8.374	6.954
M9	Okpinya Village	8.560	6.804
M10	Ohuma Ukpa	8.501	9.961

5.3. Investigation of the River Bed Deposits

In many parts of the world, and especially southern Africa, river bed deposits are a useful source of groundwater. Some ephemeral rivers contain so much sediment they are called *sand rivers* and water continues to flow through the sediment even in the dry season. In Oju, abstractions from dugouts and ponds in river beds is an important source of water in the dry season.

To try and estimate the size and nature of the water resources within the river bed deposits a study was undertaken during March 1997. Five different rivers were visited (Figure 17). At some locations, augering was carried out to gauge the nature and depth of the deposits.

Several sites were visited in the two major rivers in Oju, the Obi and the Konshisha. Water was still flowing in the lower reaches of the Obi (Plate 13) therefore, no information could be gained on the nature of the bed. Two sites were visited further upstream. At the first site, Adum West, the river is about 15 m wide and deeply entrenched (5-8 m). There was a few tens of centimetres of water in the bottom, but it didn't appear to be flowing (Plate 14). Bedrock was exposed in the river bed, therefore augering was not necessary to illustrate that what gravel was there was thin and intermittent. However, there may be some accretion of sediment at this point: the right hand bank is sandy, possibly a point bar deposit. Since point bar deposits are found on the inside of meanders they are usually small and isolated and therefore of little use for containing groundwater.

The River Obi was also examined further upstream at the Ito bridge. Here the river is not so deeply entrenched and has a marked floodplain on either side of the river (Plate 7). Water is found in isolated ponds on the river bed. The river bed is strewn with large boulders and there are little gravels. The auger couldn't penetrate the deposits since there were so many cobbles and boulders. Bedrock is again exposed in the river bed. The floodplain on either side of the river contained virtually no sediment. Rather it appeared that the flooding river had eroded the weathered zone of the shales leaving exposures of coherent shales.

Perhaps the most convincing evidence that there are negligible groundwater resource within the river bed is that there are no dugouts for water supply. The River Obi is a major source of water in both the wet and dry season for the many people who live in villages strewn along its banks. However, water is taken only from the ponds in the river - no one digs into the river bed to take clean water as they do elsewhere in Oju.

Two sites were also visited in the Konshisha River in the east of Oju. Again this river is deeply entrenched: about 15 m wide and 7-10 m deep. Like the Obi, there were a few centimetres of water in the bottom, and it is a major source of water for the villages within a 10 km radius. Plate 15 illustrates that there are no deposits in the river at the first (downstream site). The bedrock is again exposed within the river bed. Like the Obi, however, there were substantial sandy deposits on the inside of the meander. These have limited storage and have little potential for groundwater supply. Weathered shale and siltstones were exposed low down in the river banks of the second (upstream site) of the Konshisha River There

Box 9 Summary of the Investigation into the River Beds within Oju

- River gravel deposits in the base of the major rivers are thin and intermittent - they have very little potential for groundwater.
- Thin gravel (~1 m) can be present in smaller rivers on Asu River Group. The gravel contains groundwater early in the dry season but is thin and quickly dries out.
- Seepages in the river bed are not generally fed by flow from the gravels, rather it is flow from the sides and the underlying geology that is important.

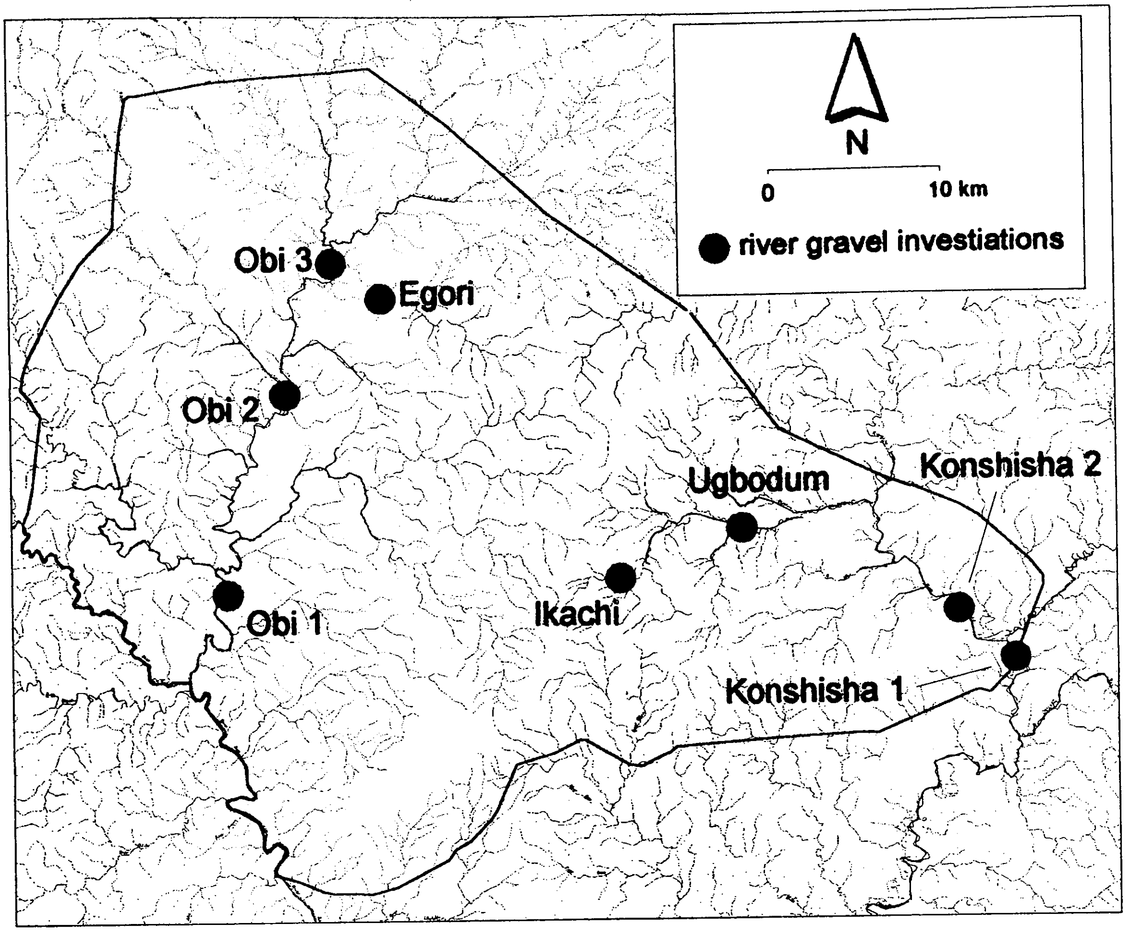

Figure 17. Location of river gravel investigations.

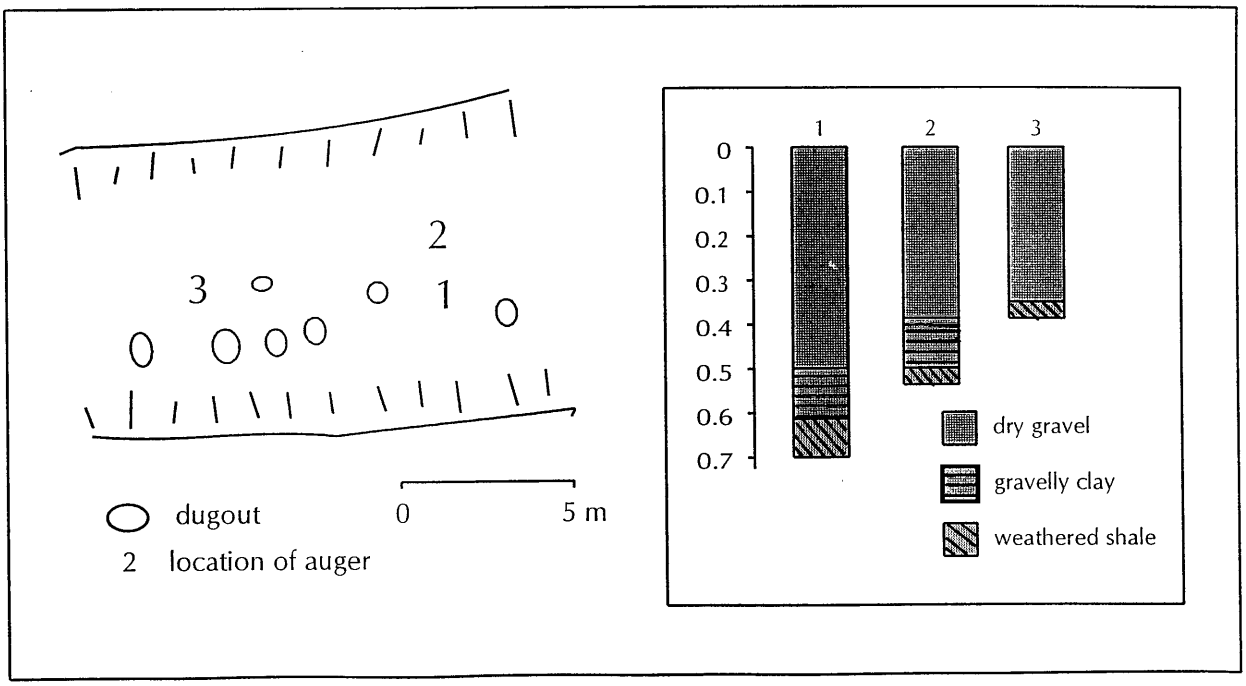

Figure 18. Location and logs of auger holes at Ugbodum River.

was some water in the bottom of the river, so no augering could be carried out in the centre of the river channel. The exposures of shales fairly low down in the banks did not appear promising however.

More detailed studies were undertaken in the bed of the Ugbudu River. A series of six auger holes were drilled into the River Bed. The first three auger holes were located within a long straight section of the river; at this point the river is 9 m wide and 4-5 m deep, with steep sides (Plate 16). There are ten shallow dugouts averaging 0.4 m deep and, at the time of investigaton (11/3/97), abandoned. Figure 18 shows the location and logs of the auger holes. The augers showed 0.6 to 0.3 m thick gravel deposits with sub-rounded cobbles up to 50 mm in size. Below the gravel was black weathered shale. At the base of the gravel was a brownish yellow clay layer. There was no groundwater within the gravels. However, the presence of so many dugouts illustrates that water must have been available earlier in the dry season. Storage is limited and the gravels soon dry out.

Further downstream, there was a small pond that was used by the local village as a water supply (Plate 17). The pond itself was used for washing clothes and a small dugout about a metre from the pond was used for drinking water. The pond is located at a bend in the river which is about 5-7 m deep and 10-15 m wide (Figure 19). Hard Asu River Group Shales are exposed a few metres away in the river bed. The rock is slightly deformed and contains some strained ammonites. An Auger hole was drilled into a gravel bank a few metres from the dugout. This proved about 0.6 m of dry gravel. The rest of the gravel bank was investigated with a firkling stick. This indicated that the maximum depth of the gravel was 0.7 m; the gravel was dry. In the bottom of the seepage there was only 0.05 m of gravel. It is therefore very unlikely that the gravel contributes to the seepage late on in the dry season.

Two more auger holes were drilled into the side of the river bank. The first was vertical and proved about 0.5 m of yellowish-brown silty clay with blue-black friable shale to 0.9 m. Water was struck at about 0.3-0.4 m within the silty clay. Another auger was drilled at a 40° angle into the river bank. This proved 0.8 m of yellowish brown silty clay with blue black friable shale to 1.6 m; water was struck at 1.2 m within the shale. When left for a few minutes, the auger holes filled with water, which implies that the weathered shales are moderately permeable. Baseflow to the seepage therefore comes from the river banks, not the gravels.

A smaller stream was investigated at Ikachi [6° 51.26', 8° 27.83'] on 10/3/97. There was one dugout being used for water supply, but would soon dry out; another was being dug which reputedly would last through the dry season (see Plate 18). The stream is located on hard, metamorphosed Asu River Group; steeply dipping bedrock is frequently exposed in the stream bed. Augering at the site proved very difficult, there were many large (>100 mm), platy cobbles that the auger couldn't penetrate. The first dugout was 1.2 m deep and located at the confluence of two streams; the second dug out was 2 m deep and located about 10 m up one of the streams (Figure 20). The first dugout taps the thick gravel deposit created by the confluence; the second dugout is located behind a bedrock "dam" and taps a thick gravel pocket. The gravel was very similar to that found at Ugbudum with the addition of the large platy cobbles.

The pockets of gravel are much thicker than in the larger rivers, but appear to be discontinuous due to the outcrop of basement. Some groundwater is stored within the gravels: e.g. if a gravel pocket, 10 m by 2 m, has a porosity of 20% and is 1 m thick, then there is 4 m^3 of groundwater available. This is hardly sufficient to keep even one family through the dry season. Yield may be increased by seepage from the sides, or seepage down the river bed, through fractures in the "dams". It was difficult to assess how many people would be using the dugouts, but there were no queues or evidence of people having waited. Nearby, within a kilometre are working boreholes.

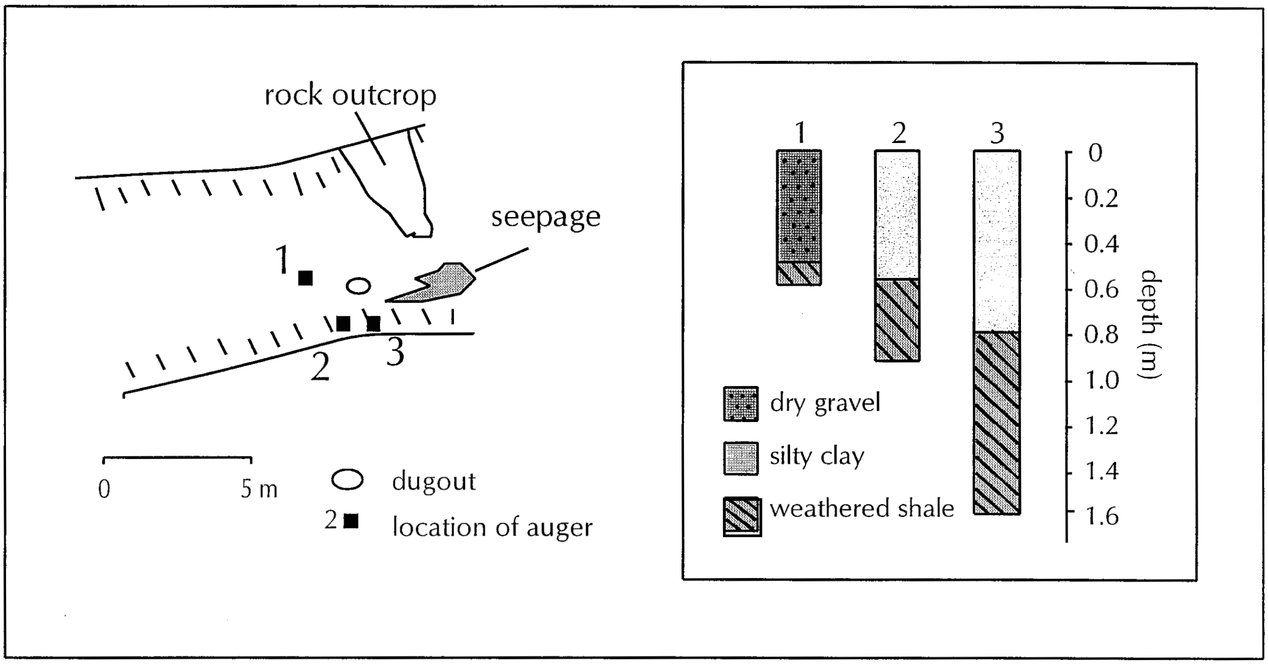

Figure 19. Location and logs of auger holes at Ugbodum seepage. Auger 3 is orientated at a 45 degree angle into the river bank. Water was struck in Augers 2 and 3 at 0.4 and 1.2 m respectively.

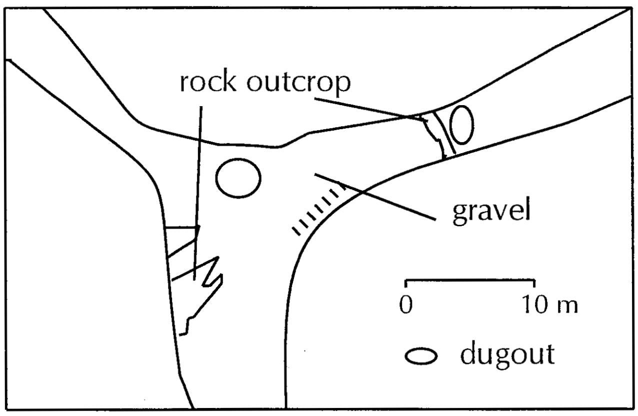

Figure 20. Schematic map of the river bed at Ikachi. The dugouts showed up to 2 m of gravel.

Another small river bed was examined in the north of the area near Egori [7° 00.53', 8° 10.85']. This is a small meandering stream about 5 m wide and 3 m deep. The stream is located on the Awgu Shale. There are many (>15) dug outs in the bank of the stream, most of them finish at 0.6 m in weathered shale. An auger at the site (Figure 21) proved 0.9 m of clayey sand with gravel overlying grey shale. The water level was 1.1 m below the river bed. The clayey gravel in the auger was similar to that observed in weathered shale profiles (see Davies and MacDonald, 1997), therefore it is likely not to be a sediment deposit, but weathering of the underlying shales. The dugouts in the stream are a major source of water for Egori village (Plate 19). As the dry season proceeds, the dugouts are deepened into the shale; women from the village said that they would last through to the end of the dry season. There are virtually no river deposits, the water table is within the weathered shale. Therefore groundwater storage cannot be within the river deposits, rather groundwater flows laterally, or along the length of the river, through the weathered shale. Although this is disappointing in that it illustrates the lack of a resource within the river, it is encouraging that in this instance the weathered shale appears to be quite permeable.

5.4 Pumping Tests

A series of eight cycles of pumping and recovery were monitored in the WaterAid well at Oju during March 1997. The well is approximately 1.4 m in diameter in the top section, with 1 m diameter caissons for the bottom 2 m. The well is equipped with a submersible pump which can pump at a rate of approximately 4.3 l/s. The water was pumped to an overhead tank, water levels were measured in the well using a dipper. Recovery within the well was very slow (Figure 22). After pumping a full tank (approximately 3 m^3) the well had not fully recovered even after 3 days. The well recovers quickest when the water-level is within the narrower diameter caissons; recovery slows, but is still approximately linear, as the water-level rises to within the wider diameter lining.

The pump test data were analysed using software developed by BGS for large diameter wells (Barker, 1989). Quite a good fit is given by using a transmissivity of 1 m^2/d and storage coefficient of 0.0001. However the model predicts slightly faster initial recovery and slower final recovery. This is partly due to the model not taking into account the changes of saturated thickness as the water-levels fall. To get the model to fit the data, a diameter of over 2 m was required for the well throughout its entire depth. This physically could be accounted for by the increased fracturing around the well due to the digging and also the porous concrete and gravel around the caissons would increase the effective diameter of the bottom of the well.

The bulk aquifer parameters determined from the recovery tests can be used to estimate when the well would be likely to fail in the future under various pumping regimes. Therefore the behaviour of the well under village conditions or a particularly long dry season could be assessed. Although recovery tests on large diameter wells can give information on the bulk aquifer properties, they give little data on the hydraulic structure of the aquifer. The behaviour could be explained equally well by the water flowing through a thin shallow zone, or seepage throughout the well. If the former is the case, deepening the well would be of little value, while with the latter a larger, deeper well would improve performance. There are two problems with using large diameter wells to assess the nature of an aquifer: (1) the geometry of the well is complex, therefore changes in recovery gradient may be due more to changes in the well diameter than changes in permeability; and (2) the diameter of the well is so large that recovery is very slow. a smaller diameter well would recover much quicker[1]. Therefore a small diameter well with constant diameter should give more information on the aquifer. To properly assess the changes in permeability through the weathered zone however, some sort of packer testing would be required.

[1]As the diameter of a well *increases*, the volume of the well increases in proportion with r^2 while the seepage face increases only as r. Therefore the larger the well the slower the recovery.

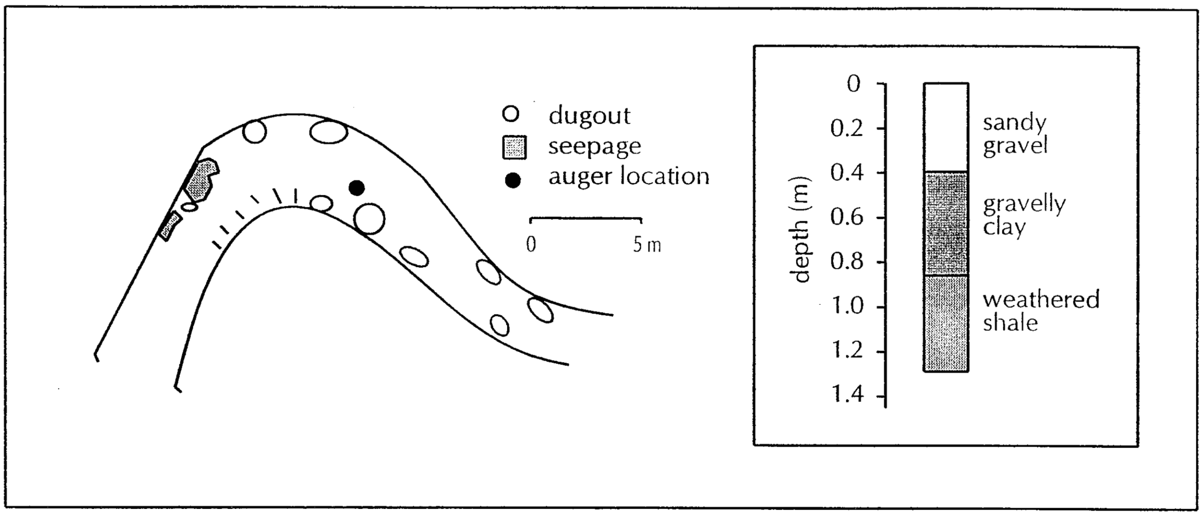

Figure 21. Location and log of auger hole at Egori. Water level in the auger was 1.15 m.

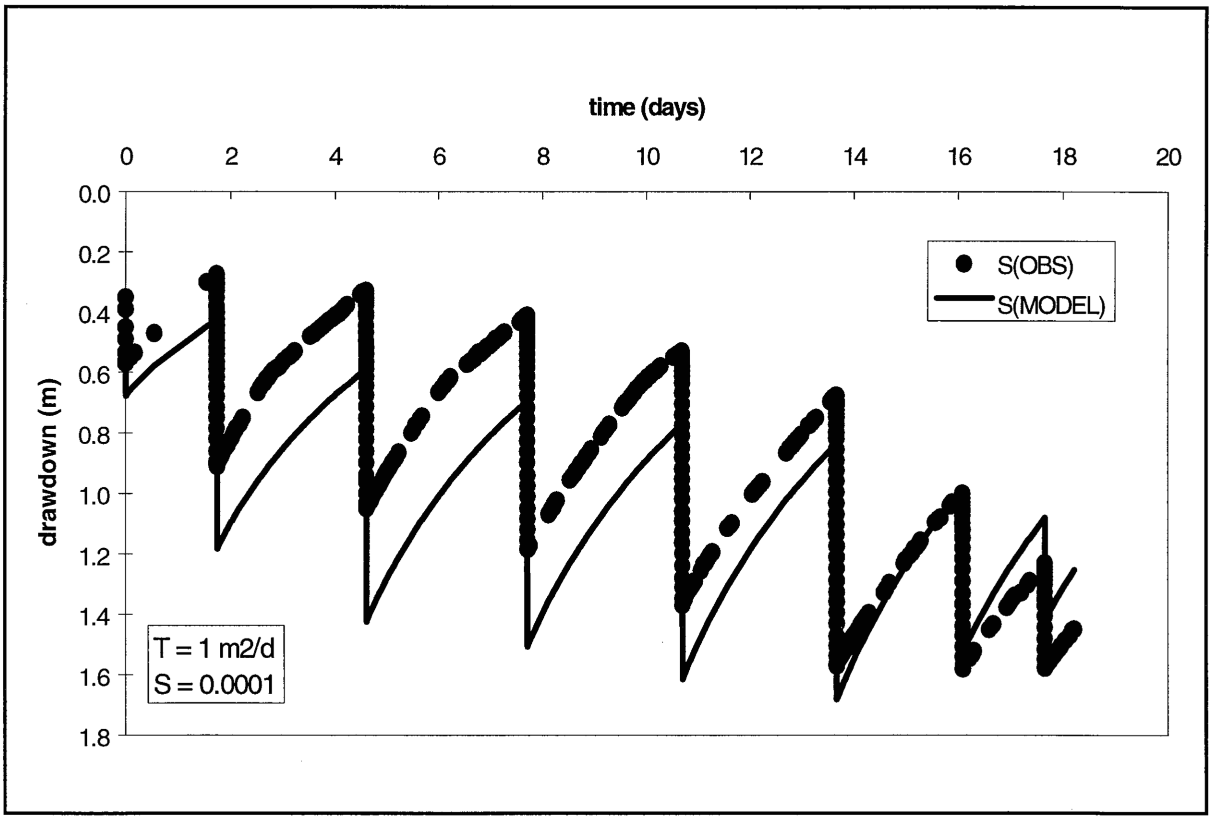

Figure 22. Drawdown and modelled data for the WaterAid well pumping tests.

6. WATER SOURCES IN OJU

Water is abstracted in many and various ways in Oju. The distance travelled and the type of source changes dramatically from the wet to the dry season. No comprehensive survey of sources has been carried out within this study, but data exist from the survey carried out by RUSAFIYA (Obe and Daagu, 1991). These data have not been analysed before. In addition, the various sources of water have been examined during the wet and dry seasons of 96/97.

6.1 RUSAFIYA Survey

As part of the RUSAFIYA rapid survey, information about village water supply was collected. The actual questions asked of each community are not known but data were recorded on the wet and dry season sources and the distance travelled to water. There were seven different categories of water sources the exact definition of which is again unknown: pond, stream, well, borehole, spring, piped supply and rainfall. For the purposes of this study it is assumed that a stream is running water and a pond is either stagnant water or dug-outs; the piped supply is a small scheme from a borehole.

From the composition of the data it appears that what has been recorded is the sources that a village uses in the wet and dry season. This means that a single source could be recorded several times if it is used by more than one village. In addition *all* the sources used by a village have been recorded without distinguishing which is the most important. The result of these two factors is that there are many more sources recorded than actual sources or villages. Nevertheless, despite these shortcomings, the data do give a general idea of the most important sources of water in Oju.

Figure 23 shows the wet season sources for Oju. The geology of each village has been included in the analysis. The most widespread sources of water identified by the villages were rainwater (37%) and streams (37%). The third most common source were wells (13%); wells were most common in the north of the area on the Awgu Shale and Eze-Aku - few wells were used in the Asu River Group. Ponds were identified as a source by 11% of the villages and boreholes by 2%. The majority of villages using boreholes are located on the Asu River Group. Only 2 villages made use of piped water.

The dry season sources of water are very different to the wet season (Figure 24). By far the majority of villages (80%) take their water from ponds; this is spread throughout the various geology types of Oju. The second most important source are streams (13%). These villages are mainly located in the north of the area within the Awgu Shales where the River Obi is a major source. Five percent of villages take their water from boreholes, again mainly from the Asu River Group. It is interesting that the actual number of villages relying on boreholes rises from 15 in the dry season to 20 in the wet season. This increase could be due to people travelling to another village in the dry season, or the repair of broken boreholes in the dry season. Just over 1% of the villages used wells as a dry season source; one village used a spring and one a piped supply.

Women have to walk long distances to collect water in the dry season (Figure 25). According to the RUSAFIYA survey data the average distance travelled in the dry season is around 3 km, with more than 50 villages having to travel in excess of 6 km. In the wet season the majority of villages have water within a kilometres of the village.

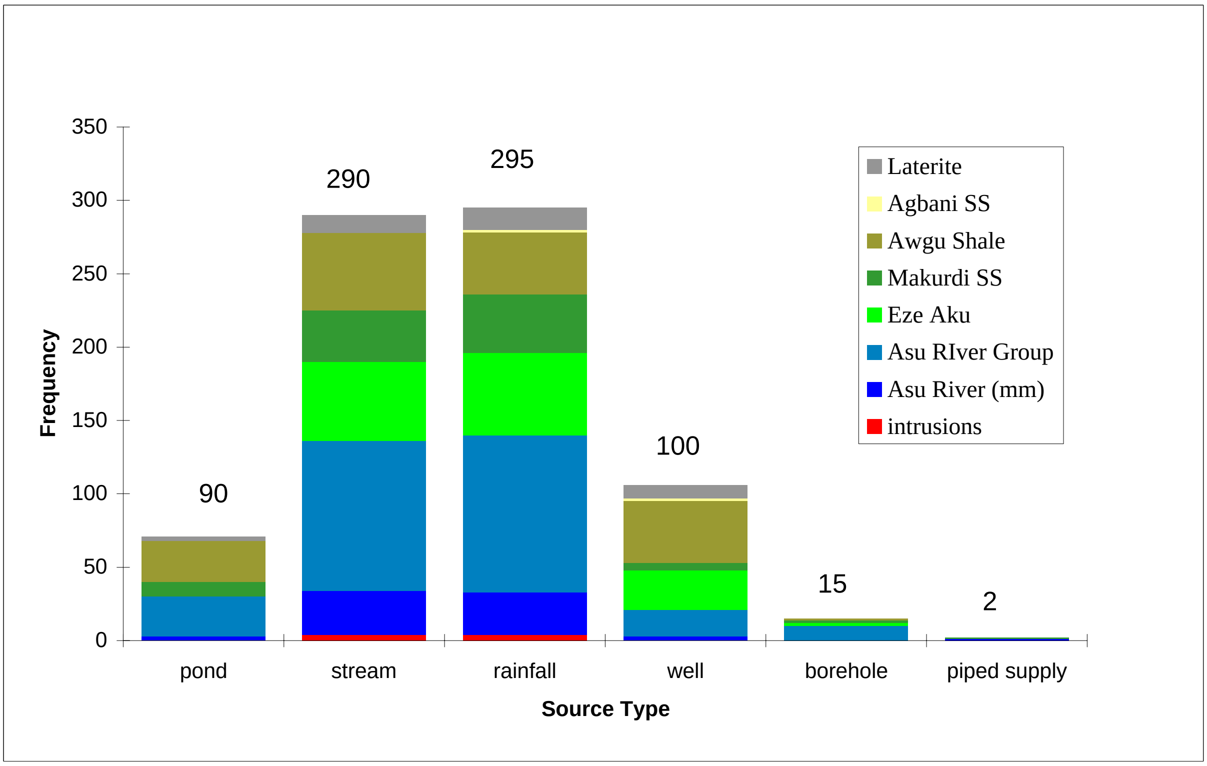

Figure 23 Wet season sources of water used by villages in Oju (original data from RUSAFIYA survey 1991

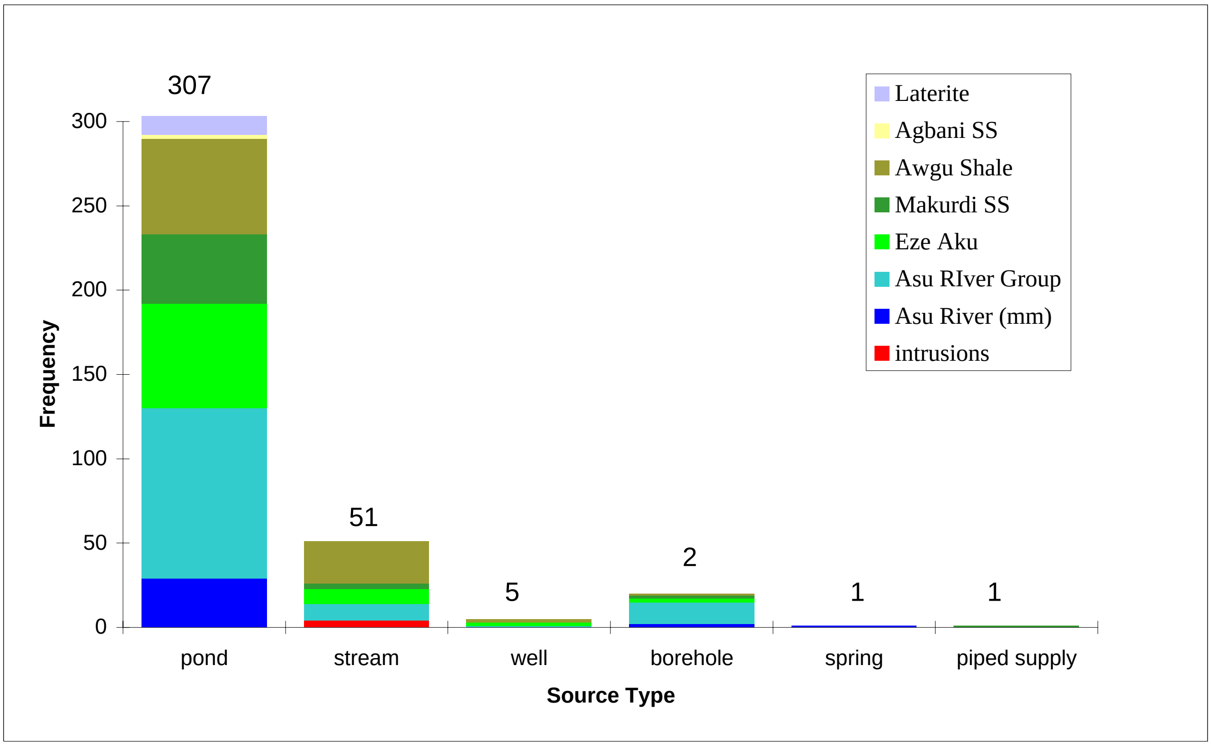

Figure 24 Dry season sources of water used by villages in Oju (original data from RUSAFIYA survey, 1991)

6.2 Sources of Water

During the wet season of 1996 and the dry season of 1996/97, examples of the various sources of water within Oju were examined by the BGS team. The most important sources of water in the wet season are rivers, rainfall, wells and boreholes, while in the dry season water is collected from rivers, stream seepages and dug-outs, pond seepages, boreholes, with some water collected from shallow wells.

6.2.1 *Wet season sources*

Rainfall: Oju has a high annual rainfall (1600 mm) which falls between April and October. Rainwater is generally collected in a haphazard manner with no serious development. Runoff from metal roofs is channelled to pots or small tanks and used as required. Rainfall events can be sufficiently intense that significant water can be collected in basins left out in the rain (Plate 20). Pots are also placed to catch the runoff from thatched roofs. There is no significant[2] rainwater stored into the dry season

Rivers: As shown in Section 3.2, river and stream flow in Oju is intense during the wet season. There is a network of numerous small ephemeral streams that are used for water supply by the villages. Often the larger rivers are too fast flowing to abstract water. Plate 21 shows a typical ephemeral river during the wet season.

Boreholes: Some boreholes are used during the wet season. However, many of them are locked to conserve the resource for the dry season; some are broken and are only fixed when the demand becomes high enough during the dry season. In general people do not like the taste of borehole water - there is a high iron content which gives it a bitter taste. However, most people are aware of the health benefits and therefore would use borehole water if it is close at hand. Boreholes are discussed in more detail in the section on dry season sources.

Shallow Wells: In the wet season shallow wells are an important source of water. Many villages have small wells dug in the middle of the village or in family compounds. These tend to be quite shallow (only dug down to the dry season water-table) and unlined. The diameter of the wells are fairly rough with some parts of the well sides collapsed. Some of them are cleaned out every year. The completion of the wellhead varies from place to place. Some are only covered by branches, others are strengthened with logs, occasionally with a lockable trap door (Plate 22, 24). A certain amount of wells have a concrete well head. The shallow wells tent to be owned by a family group and are not often for village use, probably because the yield in the dry season is so low. There are few wells in the south of the area where the rocks are hard.

In the wet season, the wells have very shallow water levels, often within a metre of the ground surface. Recovery in the wells is generally fast due to the intense rainfall and high permeability of the shallow layers. The wells give a plentiful supply. Water is abstracted in a variety of ways. When the water table is shallow, water can be scooped out by hand using a calabash. Otherwise a piece of rope tied to a plastic container or inner tube is used (Plate 23).

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[2]The Elim mission keep a small (3 m^3) tank for drinking water, since they find the borehole water bitter.

6.2.3 *Dry season sources*

Rivers: As the dry season progresses smaller rivers quickly dry out. The lower reaches of the larger rivers are generally perennial and are very important sources of water. Water is collected from both the Obi and the Konshisha rivers by people living in villages many kilometres away. Further upstream in the larger rivers and in some of the smaller rivers large pools develop as the river dries up; these are major sources of water. People living along the upper reaches of the Obi are especially dependent on these pools since there are few alternatives. Since the water is stagnant and people use it for washing, swimming and drinking these sources are especially vulnerable to guinea worm etc... (Plate 25). It is possible that the Obi river is the main reason that incidences of guinea worm are so high in the north of Oju.

Stream Seepages and Dug-outs: As rivers and streams dry out small seepages within the stream bed become important sources of water. Seepages occur where the stream passes over fractured bedrock, or where there is significant water stored within the gravels. These seepages can form open ponds, commonly a source of guinea worm. Seepages are used mainly for washing clothes. Drinking water is taken from small dugouts dug beside the seepages (Plate 26). The seepages diminish during the dry season and generally dry up completely.

Dug-outs commonly occur as numerous shallow pits dug along valley courses into the thin river gravels (Plate 27). As the dry season continues, the gravel is dewatered and the dug-outs generally abandoned. Where the underlying bedrock is soft, the dug-outs can be deepened into the bedrock. These capture water from within the weathered zone of the shales and siltstones, probably mainly from the river banks, but possibly also from fractured bedrock. The surface area of the dugouts is generally fairly small so they are much less at risk from guinea worm. Water is generally abstracted by hand using a calabash. As the dry season continues, the dugouts are deepened and in some cases can dry out completely.

Pond Seepages: Pond seepages are taken here to describe seepages that are not in distinct river beds. They fall into two categories: dambo dug-outs and ponds. Dambos, which occur mainly within the sandstone/siltstone areas of Oju, are used for water supply in the dry season. Wide diameter dugouts are dug up to a depth of 3 m into the dambo (Plate 28). Dugouts further up the dambo run dry early in the dry season, and those further down are used. The dugouts are cleaned out and deepened as the dry season progresses. In one dugout a small adit was created to increase the flow. The same dugouts are used each year. Due to their limited size these do not form guinea worm sources.

Ponds are important sources of water and occur along local depressions. They are probably sustained by groundwater. In some places the pond water is used directly for drinking, in others, small dugouts are created along side the pond and used for drinking. As the ponds dry out, they are cleaned out and dugouts made in the bed and banks (Plate 29). Large ponds commonly form sources of guinea worm infestation and mosquito breeding areas.

Shallow Wells: During the dry season, the majority of wells fail. This is because many of them are recharged only by the shallow permeable layers, which dewater as the dry season progresses. As other sources of water fail, the wells are heavily exploited until they demand far exceeds the yield that the well can sustain and the well fails (MacDonald and Calow, 1996).They are often over used, have little potential for recharge, so many, if not all, fail. The time of failure depends on the use, depth and permeability of the rock in the lower sections of the well.

The Native Authority put in several wells in the Oju area during the 1960s. These wells are deep and concrete lined and most last well into the dry season (Plate 31).

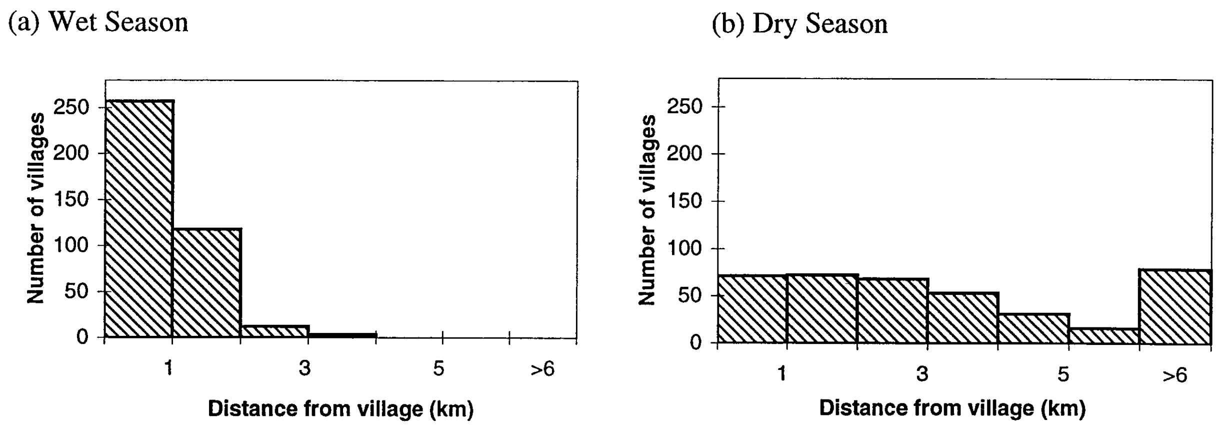

Figure 25 Average daily distance travelled in each village to collect water (original data from RUSAFIYA survey 1991).

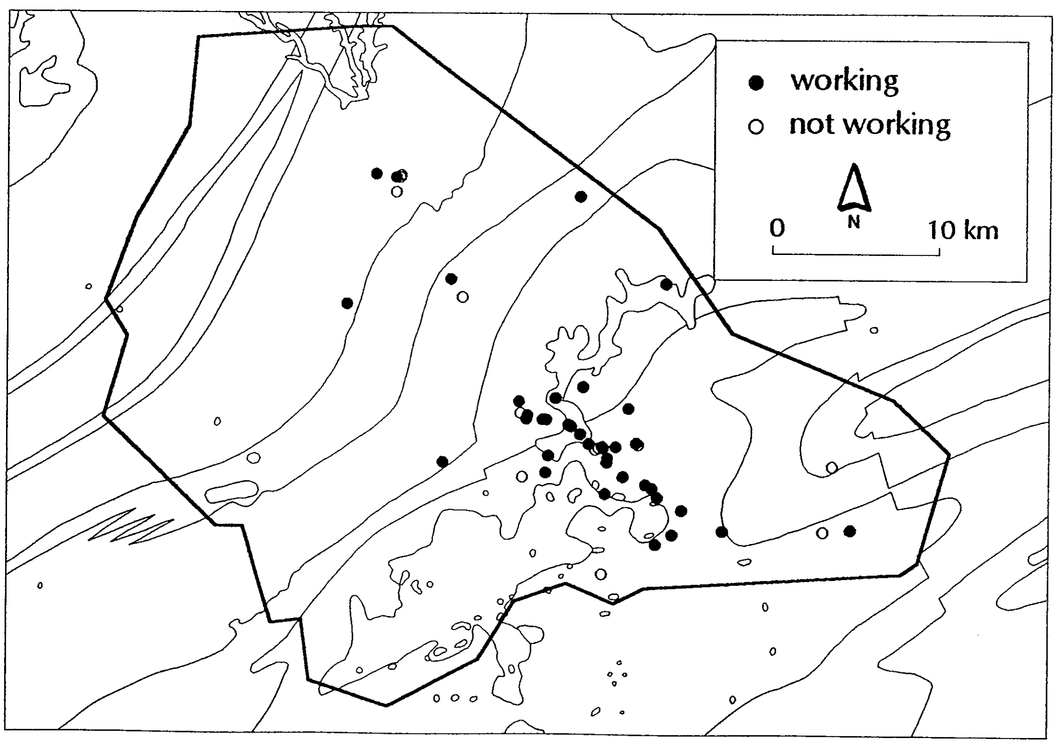

Figure 26. Distribution and status (1997) of boreholes throughout Oju. Consult Figure 3 for geology key.

Springs: Only one spring has been observed in the Oju area. This is located in the Workum Hills at Ameka. The springs is an important source for the large village of Ameka. Several years ago a local main dug out the spring source and created a small dam (Plate 32). The dammed water is contaminated by people walking through it to reach the "clean" water at the eye of the spring.

Boreholes: There are approximately 40 boreholes in the Oju area, most of which are located in the south (Figure 26). The rocks in the south have generally been metamorphosed so are harder and more fractured then the rocks elsewhere. Most supply very large population groups especially during the dry season (Plate 32). However, the borehole pumps have a very high failure rate. Pump failure occurs for several reasons: (1) erosion of pump leathers due to pumping of fine sediments; (2) lack of appreciation of well hydraulics during the height of the dry season; e.g. water levels commonly decline to below pump level (popular misconception is that the pump is faulty); (3) large drawdowns due to low permeability requires water to be pumped from depths beyond normal recommended levels - this and heavy usage cause failure of pump parts especially drive rod joints (Plate 33). Often the local village are unaware of the reasons for failure and perceive the situation as a pump problem rather than a borehole problem.

Borehole pumps tend to be locked up during the day to avoid them being misused and to allow the water levels to recover; water is abstracted in the morning and evening. Several of the working boreholes visited could only sustain a yield of a few basins per day. Borehole water has quite a bitter taste due to the high iron content; many people preferred to take water from the wells if available.

Piped Schemes: There are a few piped schemes in the Oju area. Two small schemes were put in about 8 years ago: one in Ito and another at Ihiokwu in Ukwukw district (Plate 34). Only the Ihiokwu scheme was operational in March 1997. The system pumps water from a borehole to an overhead tank which is then accessed by one stand pipe. This is controlled by a caretaker who charges for water by the bucket. A much larger piped scheme, taking water from the River Obi, has not been operational for about 5 years.

Water Tanker: Communities living beside the main road into Oju are supplied with drinking water from Oturkpo. A water tanker fills from a supply within Oturkpo town and stops at any village on the road that requests water. The tanker, however, is not reliable and does not keep to any schedule. People living within Oju town also get water from the tanker. It can take several days for the tanker to visit, by which time a long queue has formed (Plate 35).

7. CONCLUSIONS

Conclusions cannot be made at this stage of a water supply project. However, the preliminary studies have highlighted several aspects of the hydrogeology of Oju that are important for water supply.

- Most of the 1600 mm annual rainfall falls from April to October. There is very little rainfall from November to March.

- Ephemeral river flows are very "flashy". During the wet season, surface runoff is high leading to high river levels which respond rapidly to rainfall. In the dry season , rivers quickly dry up, leaving isolated ponds in the larger rivers. Downstream in the Obi and the Konshisha, flows are perennial.

- There is little potential for groundwater in the river gravels. Dugouts are dug in the smaller rivers to access the gravel water for a month or so after the river stops flowing. Seepages in the river bed are not generally fed by flow from the gravels, rather it is flow from the sides and the underlying geology that is important.

- The geology of Oju comprises low permeability Cretaceous sediments. Figure 27 shows a preliminary groundwater potential map. The unhatched areas show areas that are primarily underlain by shale - it is virtually impossible to say anything about the potential of these areas without drilling and testing.

- In the south of Oju, the sediments have been hardened by regional metamorphism. Groundwater is most likely to occur within fracture zones. If this is the case, properly sited and constructed boreholes would be the best option.

- A good aquifer runs across the centre of Oju (Figure 27). The Makurdi Sandstone comprises feld spathic sands, which should provide sustainable groundwater supplies. A near surface swelling clay layer (0.5-2 m thick) is often developed in the weathered sandstone, which causes traditional wells to collapse. Therefore wells should be reinforced through this clay layer. Although sandstone is the major component of the Makurdi Sandstone, interbedded shales and siltstones are also present which would not be appropriate for wells. Prior to the construction of a well it would be advisable to prove the existence of sandstone (either using geophysics or augering).

- There are small igneous intrusions throughout the area. Adjacent to these, the shales have been baked and are often hard and fractured. Wells or boreholes sited next to intrusions may have a high potential for groundwater. This is the reason why the wells in Ito have high yields.

Drilling and testing a number of boreholes in each hydrogeological unit should help to characterise the groundwater potential throughout Oju. However it is important to appreciate that the geology of Oju is heterogeneous. Data would be required from a number of test sites before the results could be extrapolated to the whole of that unit.

Prolonged monitoring of the rainfall, groundwater chemistry and water-levels is required to assess the sustainability of the groundwater resources of the area. It must be emphasised that only with good quality data can the hydrogeology of Oju be understood and sustainable water supplies developed.

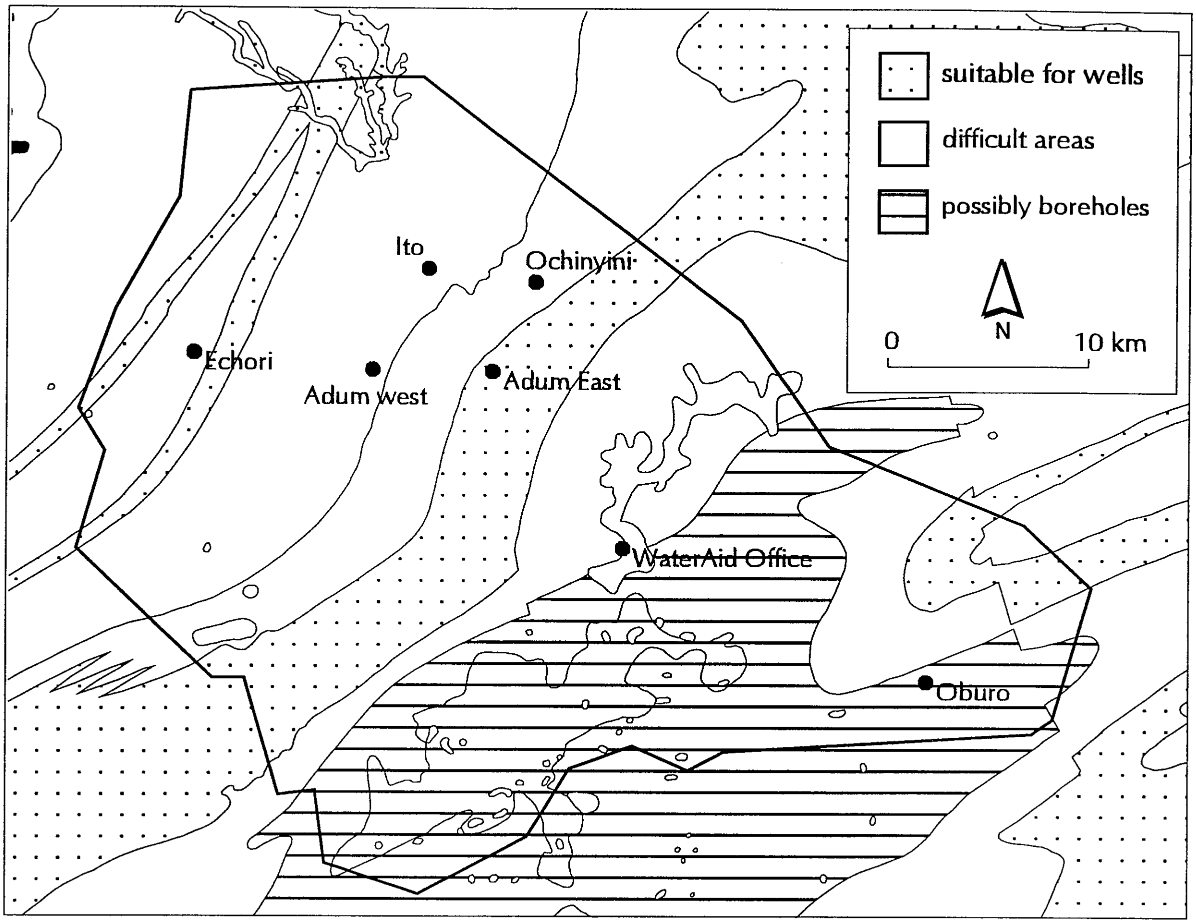

Figure 27. Preliminary groundwater potential map of Oju. The dotted areas should be suitable for hand-dug wells.

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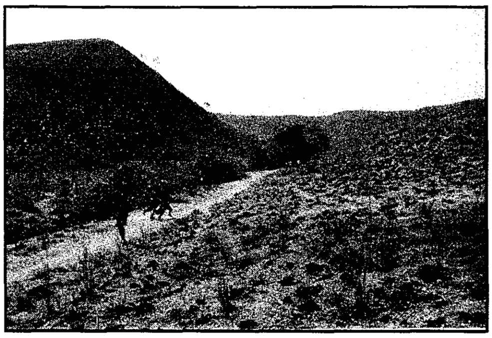

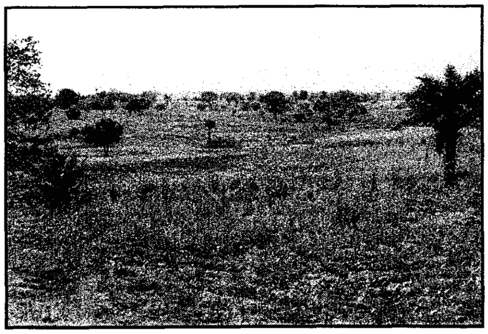

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Plate 1 A view of the Workum hills at Amaka in the south of Oju.
Plate 2 The plains visible throughout most of northern Oju.
Plate 3 The laterite escarpment viewed from Ebonda.
Plate 4 A typical wet season flow in the Obi.
Plate 5 The River Obi after heavy rainfall.
Plate 6 Flow in the Obi after the rains have stopped (December 1996).
Plate 7 Flow in the Obi towards the end of the dry season (8 March 1997).
Plate 8 Flat depression (dambo) near to Adum East.

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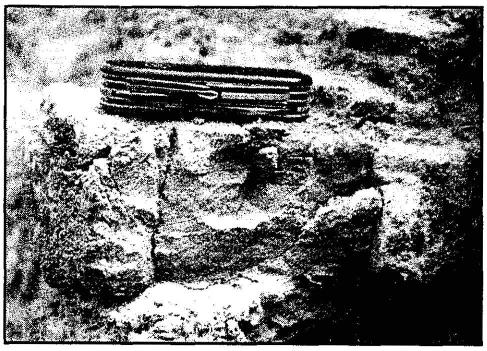

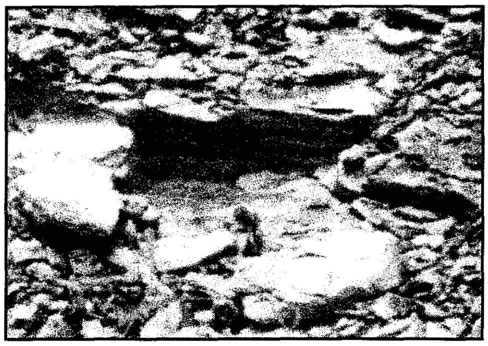

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Plate 9	Outcrop of the Makurdi Sandstone at Adum East.
Plate 10	Water flowing out of an open fracture in the Awgu Shale at Ito.
Plate 11	Dolerite sill at Adum West. Note the hard fractured Awgu Shale below the sill.
Plate 12	Water pouring out of ferrecrete following heavy rainfall.
Plate 13	The River Obi at the river intake during the dry season (March 1997).
Plate 14	The River Obi at Adum West (March 1997); there are few river bed gravels.
Plate 15	The River Konshisha (March 1997); note the rock cropping out in the river bed.
Plate 16	The River Ugbodum (March 1997); the river gravels are less than 1 m thick.

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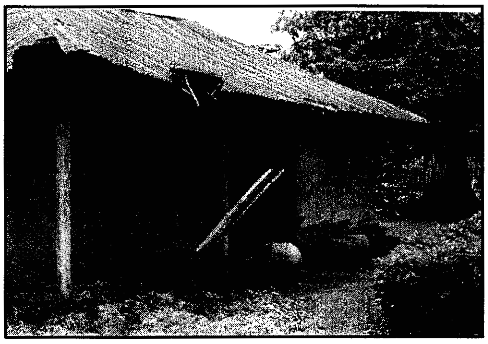

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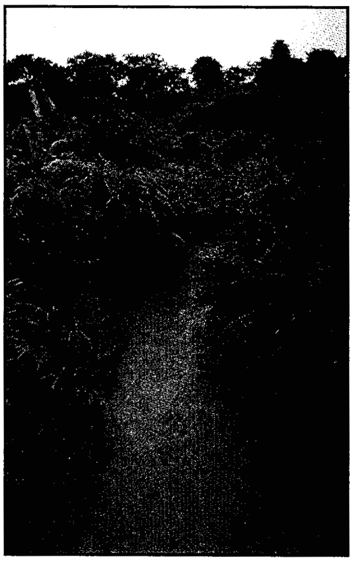

Plate 17	Seepage downstream in Ugbodum River (site of Figure 19).
Plate 18	Dugout being dug at Ikachi (site of Figure 20).
Plate 19	Auger hole and dugouts in riverbed at Egori (site of Figure 20).
Plate 20	Rainwater harvesting tanks in Oju.
Plate 21	Ephemeral streams are a widespread source of water in the wet season in Oju.
Plate 22	A shallow traditional well covered by sticks and branches.
Plate 23	Plastic containers or inner tubes are used to extract water from the shallow wells.

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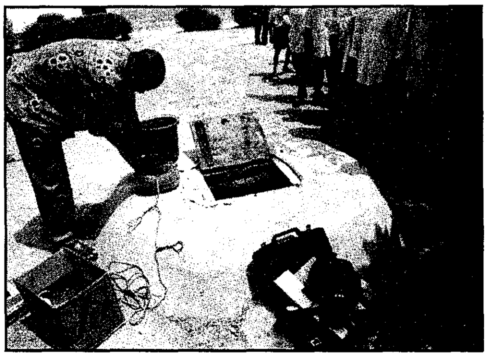

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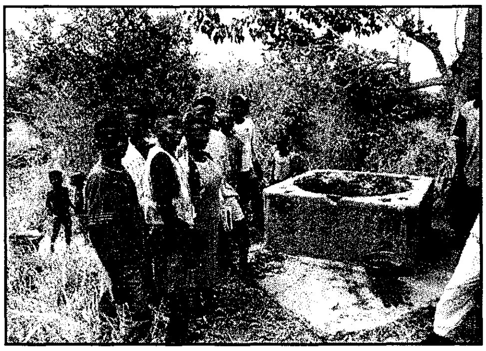

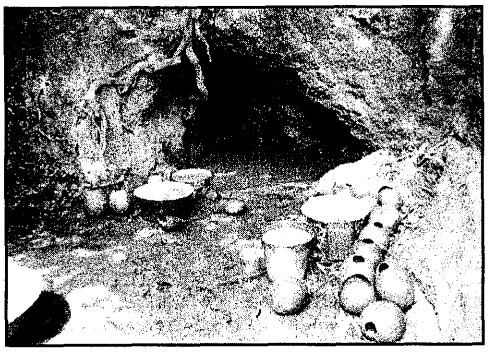

Plate 24	A traditional well with concrete well head and a lockable trap door.
Plate 25	A stagnant pool in Adum West used for drinking water in the dry season.
Plate 26	Ugbodum river bed: drinking water is taken from the dugout, while the seepage is used for washing clothes.
Plate 27	Water is collected from dugouts in river banks with a calabash.
Plate 28	Large shallow dugout into the Adum East dambo.
Plate 29	Dugouts dug into the bed of a dried up pond at Ebonda.
Plate 30	A Native Authority well constructed at Obussa in the 1960s. The well is still used.
Plate 31	A spring at Amaka. Water is taken from the eye of the spring at the back of the pond.

(32, 33)

(34, 35)

Plate 32 Borehole at Otunche Anchin fitted with India Mk2 pump. Only a trickle of water is available, the pump is locked throughout most of the day to help the borehole recover.

Plate 33 Borehole at Anyawogbu. The pump has to be worked vigorously to get any water - this leads to frequent pump failure.

Plate 34 The piped scheme at Ihiokwu. Water is pumped once a week to the storage tank and is accessed through one controlled tap. Towards the end of the dry season it is pumped every day.

Plate 35 A queue of buckets waiting for the water tanker in Oju town.