Case study note: Groundwater residence times for rural groundwater supplies across different climate zones, West Africa

Groundwater Science Programme

Internal Report IR/10/100

BRITISH GEOLOGICAL SURVEY

GROUNDWATER SCIENCE PROGRAMME

INTERNAL REPORT IR/10/100

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Front cover

Photo from groundwater sampling in Zamfara State, Northern Nigeria.

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Foreword

In 2010 the Department for International Development (DFID) commissioned a BGS-led team to undertake a one-year study aimed to improve understanding of the resilience of groundwater in Africa to climate change and links to livelihoods. As part of this project, the research team undertook hydrogeological field studies in West and East Africa, examined the linkages between water use and household economy, and developed an aquifer resilience map for Africa using existing hydrological maps and data. This is one of a series of technical notes which describes the studies carried by the research team under this project.

This report describes the methodology, and results of the West Africa hydrogeological case study, undertaken within the one-year project. Groundwater residence times were assessed in both high and low storage aquifers across 4 different climate zones in a sampling transect from southern Nigeria to central Mali. Groundwater residence times were assessed through the use of multiple tracers: chlorofluorocarbons (CFCs), sulphur hexafluoride (SF_6) and tritium ($^3H/^3He$). The purpose of the case study was to identify how vulnerable rural water supplies may be to climate change.

Acknowledgements

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Nigeria fieldwork

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Dr. M. N. Tijani, Associate Professor University of Ibadan, Nigeria, for field support in Nigeria.

Mali fieldwork

Vinny Casey and Richard Carter, WaterAid London, for facilitating Mali case study work.

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Local Partners for local logistical support within Mali: GAAS (Bandigara), AFRAD (Koro), and ADDA (transport).

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1 Introduction

The hydrogeological case study in West Africa was conducted as part of a one year DFID-funded research programme, aimed at improving understanding of the impacts of climate change on groundwater resources and local livelihoods – see http://www.bgs.ac.uk/GWResilience/.

The main purpose of this case study was to identify how vulnerable rural water supplies may be to climate change. Due to the near absence of any monitoring data in Africa to assess performance of water supplies to past climate variability, a different approach is taken. Groundwater residence times have been assessed through the use of multiple groundwater tracers: Chlorofluorocarbons; Sulphur hexafluoride; Tritium. The residence times (i.e. a measure of the groundwater age or proportion of modern recharge) of groundwater pumped from shallow rural water supplies were assessed for different types of aquifers (both low and high storage) across different climate zones in a sampling transect from southern Nigeria to central Mali (Figure 1).

The rational is as follows: where groundwater residence time is low, the aquifer responds more rapidly to climate and the supplies are highly vulnerable to climate change. Conversely, where groundwater residence times are higher, the aquifer is considered less coupled to modern climate and groundwater resources may be less vulnerable to climate change in the short term. In addition, for any given climate zone the low storage aquifers may be considered more vulnerable to changes in recharge compared to the high storage aquifers.

1.1 MAIN SCIENTIFIC OBJECTIVE

To assess the residence time of groundwater in basement (low storage) and sandstone (high storage) aquifers across different climate zones.

1.2 LINKS TO OTHER PROJECT COMPONENTS

GW resilience map for Africa: the data from this case study will be used to (1) provide targeted data to help validate the groundwater resilience map; (2) provide several examples to help illustrate the groundwater resilience map

Water Security Case study: a slimmed down version of the Water Economy and Livelihoods Survey (WELS) methodology was used to gather socio-economic information from communities on seasonal water availability and use.

Case Study 2: the residence time information for basement aquifers can be used to link with the information from case study 2 on the occurrence and sustainability of high yielding boreholes from crystalline basement aquifers.

1.3 PARTNERS

Nigeria

Dr Tijani: Associate Professor, University of Ibadan, Nigeria – Groundwater sampling

Nigerian Geological Survey – logistic support and field assistants in Nigeria

Mali

WaterAid: help with coordinating logistical support in Mali

GAAS – Mali: local logistical support in Mali

AFRAD – Mali: local logistical support in Mali

ADDA – Mali: provision of transport in Mali

2 Fieldwork activities

2.1 COLLECTION OF RESIDENCE TIME AND CHEMISTRY DATA ACROSS FOUR DIFFERENT CLIMATE ZONES, WEST AFRICA

Groundwater pumped from shallow rural water supplies in high and low storage aquifers were analysed across 4 climate zones, from tropical wet to arid climate, along a sampling transect from southern Nigeria to central Mali. Three field areas within Nigeria and one within central Mali ensured similar high and low storage aquifer types were sampled within each climate zone (tropical wet, seasonal wet, semi-arid and arid).

Nigeria sampling: was carried out between 13th – 23rd April 2010. The field team comprised:

- BGS: Dr A MacDonald, D Lapworth
- University of Ibadan: Dr M Tijani
- NGSA: A Alichi ,C Mbacha, Isaac Asana, A Okafor

After a day of training (13th April) the field team split into two groups, each group led by BGS staff. The two teams worked independently for the remainder of the fieldwork.

Mali sampling: was carried out between18th–23rd August 2010. The field team comprised:

- BGS: D Lapworth, H Bonsor
- AFRAD: T Alasseini, F Guindo
- GAAS: Walli
- Bamako Univeristy: Dr. Adama
- ADDA: Guinou

All sampling and WELS surveys were carried out by BGS staff.

Figure 1 shows the location of the three case study areas in Nigeria (Abeokuta, Minna and Gusau) and the case study area within Mali (Bandigara). These areas were chosen because they reflect four distinct climate zones (in terms of annual rainfall), and had suitable sample sites in high storage and low storage aquifers.

In Nigeria the low storage basement was comprised of gneisses and metasediments as well as other minor metamorphic lithologies. Sites situated in granitic terrain were avoided due the reported problem of naturally occurring sources of sulphur hexafluoride in this lithology. The high storage sandstone was of Cretaceous age in all three Nigerian case studies. The three Nigerian case studies had average annual rainfall of between 1800-2000 mm, 1200-1500 mm and 700–850 mm respectively.

Within the Mali field area the low storage aquifer was comprised of fractured Precambrian Sandstone, whilst unconsolidated Tertiary Continental Terminal sand and gravel formations comprised the high storage aquifer studied. The Mali field area was the most arid sampled with an estimated annual rainfall of 350–400 mm.

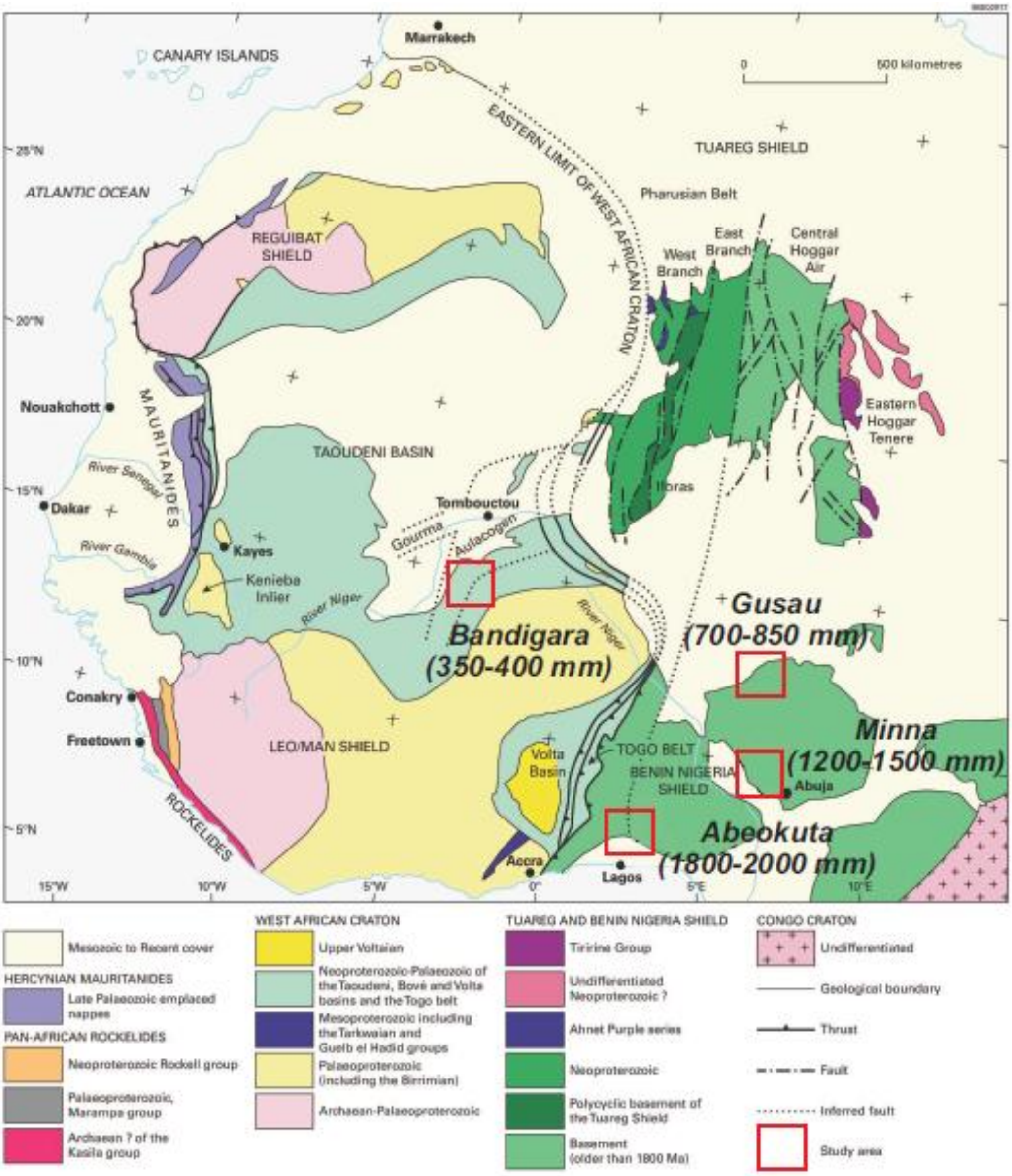

Figure 1 Spatial and geological distribution of sampling areas within West Africa. Average annual rainfall values are shown for each field area.

A total of 57 boreholes were sampled across the transect, 51 equipped with hand pumps and 6 with motorised pumps. The estimated depths of the boreholes were mostly in the range 20–50 m; three boreholes were sampled with an estimated depth of 70–90 m. Considerable care was taken in the selection of sampling sites to ensure that there was no gross contamination around the top of the borehole and the head-works and slab in good repair. All boreholes were in use prior to sampling to ensure that the sample was representative of the groundwater, and an airtight connection was achieved at each site before sampling. Table 1 (Appendix) gives details of the sample sites, location, depth and source type.

In each case study: the following samples were taken:

- Well head chemistry: DO, pH, SEC, temperature, alkalinity
- Comprehensive inorganic chemistry
- Dissolved organic carbon
- Dissolved CFC-11, CFC-12 and SF_6
- Stable isotopes
- Tritium (paid for by IAEA)
- At 6 sites, samples were taken for noble gas analysis to assess recharge temperatures

2.2 COLLECTION OF INFORMATION ON WATER ACCESS AND BASIC SOCIO-ECONOMIC DATA FOR EACH SITE

In conjunction with ODI, a slimmed down WELS approach was developed and applied to each site. This involved wellhead discussions and also discussions with village representatives chosen by the village head. The following information was gathered:

- Basic information about village size, activities, and growth;
- Information on the most productive activities;
- Detailed information on the number of water sources, time taken to collect water at different times of the year, what the water is used for and when each source is operational;
- Information on the borehole construction and functionality.

3 Preliminary results

3.1 SUMMARY RESULTS FROM GROUNDWATER RESIDENCE TIME STUDIES

The completed results from the residence time studies have yet to be issued formally. Preliminary results suggest that the CFC (11 and 12) data show generally consistent results. However, in the case of SF_6 there do seem to be a significant number of samples, particularly from the basement lithologies, which show elevated SF_6 concentrations above modern values. The source of the elevated SF_6 is presumably from natural mineral sources of SF_6, and will preclude the use of data from these samples as part of the residence time study. Groundwater temperatures recorded during sampling were found to be 28°C (+/-3°C), and it is therefore reasonable to use a recharge temperature of 28°C when calculating groundwater ages and the fraction of modern water for these samples.

3.2 SUMMARY RESULTS FROM WELS WATER ACCESS AND SOCIO-ECONOMIC SURVEYS

The tables below summarise the data collated from community and wellhead discussions, following an abbreviated WELS methodology (Coulter 2010). In total, discussions in each village lasted 1 hour (in part due to translation efforts) and the questions assessed the current population, water use, seasonal access to water, and increased demands for water.

Table 1 Summary population and livelihood data from WELS surveys

Climate zone	Country and region	Length of dry season	Average (range) village population	Av increase in village population, last 5 years	Main livelihood activity	Main source of income
Wet (1800-2000mm/yr	NIGERIA, Abeokuta	3-4 months (Oct-Jan)	2300 (200-5000)	34%	Arable farming	Cash crops: Cassava, maize, yams
Seasonal wet (1200-1500mm/yr)	NIGERIA Minna	7-8 months (Sep-May)	1100 (100-2000)	40%	Arable farming	Cash crops: Tomatoes, peppers, maize
Seasonal wet (700-850 mm/yr)	NIGERIA, Gusau	7-8 months (Sep-May)	2300 (500-5000)	36%	Arable farming and livestock	Cash crops: Cotton, maize, tomatoes Livestock: Cows and goats
Semi-arid (350-400mm/yr)	MALI, Bandigara	9 months (Oct-Jun)	2000 (420-7000)	14%	Arable farming and livestock	Cash crops: Onions, tomatoes, peppers Livestock: Cows and goats

.

Table 2 Summary water access data from WELS surveys

Climate zone	Country and region	Water sources accessible (% villages with access)	Important water sources		Use of BH sources (Av. L/d)		Av. dry season BH collection times (min)	Av. depth of BH (mbgl)	Reliance on traditional wells for drinking water in dry season	Estimated BH access per person L/d
			Wet season	Dry season	Wet season	Dry season	Av. (range)	Av. (range)	% villages	Av. (range)
Wet (1800-2000mm/yr	NIGERIA, Abeokuta	BH(100), RH (57), W (35), R (30)	BH>RH>>W =R	BH>>W	5500	5900	32 (5-90)	37 (20-70)	20	2.2 (0.6-5)
Seasonal wet (1200-1500mm/yr)	NIGERIA Minna	BH (100), R (85),RH (70),W (30)	BH>R=RH>> W	BH>R>W	4500	4600	44 (10-120)	30 (20-40)	20	4.3 (0.7-9)
Seasonal wet (700-850 mm/yr)	NIGERIA, Gusau	BH (100), W(60), RH (60),R (45)	BH>W>RH> R	BH>W	8000	8100	56 (5-180)	35 (20-90)	60	3.5 (0.8-5)
Semi-arid (350-400mm/yr)	MALI, Bandigara	BH (100), W (100), P (86), R (20), RH (13)	BH>W>P	BH>W	5400	7600	57 (20-120)	23 (15-30)	70	6 (1-13)

Sources: BH = borehole, W = traditional well, RH = rainfall harvesting, R = river, P = seasonal ponds, Av. = average

Table 3 Summary water use data for different water sources in wet and dry seasons from WELS surveys

Climate zone	Country and region	Boreholes: Uses and average collection times (min)		Traditional wells: Uses and average collection times (min)		Rivers: Uses and average collection times (min)		Rainfall harvesting: Uses	Seasonal Ponds: Uses
		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Wet
Wet (1800-2000mm/yr	NIGERIA, Abeokuta	D,C,W (25)	D,C,W (32)	D*,C,W (11)	D*,C,W, A (13)	D*,C*,W *,A (34)	W*,A (34)	D,C	N/A
Seasonal wet (1200-1500mm/yr)	NIGERIA Minna	D,C (15)	D,C,A (44)	D,C,W (8)	D,C,W,A (18)	D*,W,A (31)	W,A (30)	D,C	A,W,C,B
Seasonal wet (700-850 mm/yr)	NIGERIA, Gusau	D,C,W (33)	D,C,A (56)	D,C,W,A (16)	D,C,W,A,I* (29)	D*,W,A (35)	N/A	D,C	D*,A, W,B
Semi-arid (350-400mm/yr)	MALI, Bandigara	D,C,W (30)	D,C,W, A* (57)	D,C,W,A (29)	D,C,W,A,I* (48)	N/A	N/A	D*,C*	D*,A, W,B

Uses: D = drinking, C = cooking, W = washing, A = animals, I = irrigation, B= building * = few instances

4 Case study outputs

The main output from the research will be a scientific paper on the residence times of groundwater in basement and sandstone aquifers across different climate zones. The results from the case study will require careful analysis and interpretation, particularly with multiple residence time indicators. The results will feed into the development of the Africa map on groundwater resilience to climate change, helping to transform the hydrogeological map into a resilience map. The socio-economic and water security information will be written up jointly with ODI to feed into the case study on the links between water security and livelihoods.

References

COULTER, L. (2010) Assessing seasonal water access and implications for livelihoods, RiPPLE WELS Toolkit report, RiPPLE-ODI Ethiopia.

Appendices

A1 SITE LOCATION DETAILS FROM GROUNDWATER RESIDENCE TIME STUDIES

Field ID	Date	Location	State	Country	Case Study	Depth (mbgl)	Pump	Completion	Aquifer Yield
A17	22/04/2010	Ishaga	Ogun	Nigeria	Abeokuta	40 m	Motorised	2005	High
A18	22/04/2010	Iboro	Ogun	Nigeria	Abeokuta	40 m	Motorised	2005	High
A19	23/04/2010	Ibara-Orile	Ogun	Nigeria	Abeokuta	30 m	Motorised	2006	High
A20	23/04/2010	Aiyetoro	Ogun	Nigeria	Abeokuta	40 m	Motorised	2006	High
A21	23/04/2010	Igan-Okoto	Ogun	Nigeria	Abeokuta	20 m	IndMk2	2007	High
A22	24/04/2010	Folafem	Ogun	Nigeria	Abeokuta	50 m	Motorised	2009	High
A23	24/04/2010	Owode	Ogun	Nigeria	Abeokuta	70 m	Motorised	2005	High
B13	22/04/2010	Sekere	Oyo	Nigeria	Abeokuta	>45m	IndMk3	1994	Low
B14	22/04/2010	Akeroro	Oyo	Nigeria	Abeokuta	30 m	IndMk2	2008	Low
B15	22/04/2010	Idi-Ope	Oyo	Nigeria	Abeokuta	30 m	IndMk2	2005	Low
B16	23/04/2010	Ojo-Oluno	Ogun	Nigeria	Abeokuta	30 m	IndMk2	2005	Low
B17	23/04/2010	Akintobi	Ogun	Nigeria	Abeokuta	30 m	IndMk2	2005	Low
B18	23/04/2010	Abule-Ode	Ogun	Nigeria	Abeokuta	30 m	IndMk2	2007	Low
B19	24/04/2010	Adulu	Ogun	Nigeria	Abeokuta	30 m	IndMk2	2007	Low
A6	15/04/2010	Essa	Niger	Nigeria	Minna	30 m	IndMk4	1982	High
A7	15/04/2010	Ndabisan	Niger	Nigeria	Minna	40 m	IndMk2	2007	High
A8	15/04/2010	Gbakogi Kasara - 1	Niger	Nigeria	Minna	40 m	IndMk4	2001	High
B3	15/04/2010	Kalachi	Niger	Nigeria	Minna	30 m	IndMk2	2005	High
B4	15/04/2010	Aliyu	Niger	Nigeria	Minna	30 m	IndMk2	2007	High
B5	15/04/2010	Kudugi- Tswachi	Niger	Nigeria	Minna	> 25 m	IndMk2	2008	High
A1	13/04/2010	Gbalipa	Niger	Nigeria	Minna	30 m	IndMk2	N/A	Low
A2	13/04/2010	Kitikpa	Niger	Nigeria	Minna	30 m	IndMk2	2006	Low
A3	14/04/2010	Gurusu	Niger	Nigeria	Minna	30 m	IndMk2	2003	Low
A4	14/04/2010	Sabon Gida	Niger	Nigeria	Minna	20 m	IndMk2	1995	Low
A5	14/04/2010	Godna	Niger	Nigeria	Minna	30 m	IndMk4	2000	Low

Field ID	Date	Location	State	Country	Case Study	Depth (mbgl)	Pump	Completion	Aquifer Yield
B1	14/04/2010	Kadna	Niger	Nigeria	Minna	25 m	IndMk2	2009	Low
B2	14/04/2010	Vemu	Niger	Nigeria	Minna	> 30 m	IndMk2	1992	Low
A13	18/04/2010	Gidan Kano	Zamfara	Nigeria	Minna	30 m	IndMk2	2008	High
A14	19/04/2010	Dolenmoriki	Zamfara	Nigeria	Minna	30 m	IndMk2	2008	High
A15	19/04/2010	Badarawa	Zamfara	Nigeria	Gusau	30 m	IndMk2	2009	High
A16	19/04/2010	Tungan Gurguri	Zamfara	Nigeria	Gusau	25 m	IndMk2	2009	High
B10	18/04/2010	Rufai Farm	Zamfara	Nigeria	Gusau	90 m	Motorised	2007	High
B11	19/04/2010	Damri	Zamfara	Nigeria	Gusau	N/A	IndMk2	2010	High
B12	19/04/2010	Badamma Dangara	Sokoto	Nigeria	Gusau	25 m	IndMk2	2007	High
A9	17/04/2010	Kadaddaba	Zamfara	Nigeria	Gusau	20 m	IndMk2	2008	Low
A10	17/04/2010	Dangamji	Zamfara	Nigeria	Gusau	30 m	IndMk2	2009	Low
A11	17/04/2010	Kadauri	Zamfara	Nigeria	Gusau	30 m	IndMk2	2009	Low
A12	18/04/2010	Kuzawa Kwara	Zamfara	Nigeria	Gusau	50 m	IndMk4	1982	Low
B6	17/04/2010	Matankari	Zamfara	Nigeria	Gusau	40 m	IndMk2	2009	Low
B7	17/04/2010	Fakai	Zamfara	Nigeria	Gusau	42 m	IndMk2	1995	Low
B8	18/04/2010	Danmanau	Zamfara	Nigeria	Gusau	> 35 m	IndMk2	2004	Low
B9	18/04/2010	ADC Batura	Zamfara	Nigeria	Gusau	N/A	IndMk2	2007	Low
M1	18/08/2010	Ene	Mopti	Mali	Bandigara	40 m	IndMk2	2009	High
M2	19/08/2010	Togotina	Mopti	Mali	Bandigara	48 m	IndMk2	2007	High
M3	19/08/2010	Karakmba	Mopti	Mali	Bandigara	76 m	IndMk2	2004	High
M4	19/08/2010	Bene Bana	Mopti	Mali	Bandigara	30 m	IndMk2	2008	High
M5	19/08/2010	Tere	Mopti	Mali	Bandigara	25 m	IndMk2	2008	High
M6	20/08/2010	Yanda Tougo	Mopti	Mali	Bandigara	36 m	IndMk2	1984	High
M7	20/08/2010	Damasongo	Mopti	Mali	Bandigara	25 m	IndMk2	1984	High
M8	20/08/2010	Guinedia	Mopti	Mali	Bandigara	54 m	IndMk2	2000	High
M9	21/08/2010	Bodia	Mopti	Mali	Bandigara	62 m	IndMk2	1995	Low
M10	21/08/2010	Sinkarmma	Mopti	Mali	Bandigara	N/A	IndMk2	1994	Low
M11	22/08/2010	Kema	Mopti	Mali	Bandigara	40 m	IndMk2	1991	Low
M12	22/08/2010	Sokolo	Mopti	Mali	Bandigara	60 m	IndMk2	1995	Low

Field ID	Date	Location	State	Country	Case Study	Depth (mbgl)	Pump	Completion	Aquifer Yield
M13	22/08/2010	Sibi-Sibi	Mopti	Mali	Bandigara	16 m	IndMk2	1995	Low
M14	23/08/2010	Bendiely	Mopti	Mali	Bandigara	N/A	IndMk2	1996	Low
M15	23/08/2010	Ogolda	Mopti	Mali	Bandigara	5-20 m	Wavin	1994	Low

A2 NOTES FROM WELS SURVEY

Nigeria

Abeokuta case study (rainfall of 1800–2000 mm/y)

The settlements in this area were usually quite large (average population of 2000 for sampling sites) and many boreholes were located in larger towns (>20,000) that were not suitable for sampling, due to possible contamination, or for the community discussion as they were largely privately owned. Across the sedimentary aquifer there is a high proportion of large diameter hand dug wells that have been fitted with submersible pumps suggesting that water accessibility and electricity supply is less of a problem in this area than other parts of Nigeria. Several of the boreholes sampled also had dedicated generators that were funded locally. There has been a significant increase (20-50%) in the population of most settlements in the last 5-10 years. This has put pressure on the local infrastructure, including water resources, and has also been a valuable source of labour.

Groundwater is a very important source of water for processing farm products, e.g. maize, cassava. This is the main source of income for the rural community and adds significant value to the farm products. The settlement sizes were on the whole larger across the sedimentary aquifer (>5000) in this area compared to the basement aquifer (<1000). The time taken to collect water was less than 30 minutes at >90% of sites irrespective of aquifer or settlement size. Groundwater was generally not used for livestock in this area due to the plentiful supply of alternative sources. Water quality problems (fine silts/ cloudy water) were only encountered at a small proportion of the sites visited (10%) and this was usually after heavy rain. Pump use was rationed in only a small proportion of sites (<10%) to manage demand and minimise waiting times. In one case the water committee charged up to 5 NGN for 3 basins and used this money to maintain and service the pump and borehole. River water is a very important source throughout the year, especially for less wealthy villages. Most villages have zinc roofs in this area and rainfall harvesting is very common. Overall the standard of living seems to be quite high compared to the other case study areas, the availability of electricity is higher and there was a much higher proportion of mechanised boreholes. While boreholes are the dominant source of groundwater in the basement aquifer, large diameter hand dug wells are very common in the sedimentary aquifer.

Minna case study (rainfall of 1200–1500 mm/y)

Of the three case studies in Nigeria this area had on average the lowest settlement population (c.1000). The main source of income in this area was from selling cash crops (e.g. tomatoes, pepper, maize, yam, potatoes in some places). The settlements had smaller livestock holdings compared to the Gusau case study, mainly goats rather than cows, and the borehole water was not usually used as a water supply for livestock.

As with the other Nigerian case studies the population had reportedly increased in the last 5-10 years (20-50%) putting added pressure on the water resources. Collection times for water from hand pumps were greater than 30 minutes for more than half of locations in the dry season (November-April). All boreholes are used for drinking, washing and cooking all year, with a third of them also being used as sources of water for livestock in the dry season. A decline in yield was found to be an issue at 20% of sites during the dry season, there is a much larger demand on hand pumps in the dry season compared to the wet season. Survey results indicate that boreholes met demand in the dry season for only half the settlements that were visited, this was the case for both the basement and sedimentary aquifers. At around half of the site visited rationing was required during the dry season to manage demand. The boreholes are usually managed by a water committee, they organise the rationing as well as the collection of donations if repair work needs to be carried out on the borehole, however, users of the hand pumps were not charged for collecting water. The boreholes and hand pumps in this area were for the most part donated by NGO's (between 3-10 years old), some were also funded by local government.

River water is an important source of water during the wet season (April/May – October) and it is not uncommon for villages to still use river water for drinking during this period. Hand dug wells are also an important source of water during the wet season, but are not fitted with mechanised pumps as was the case in the Abeokuta area. Rainwater harvesting is used during the wet season across this area and is stored in large containers for later use to supplement the groundwater sources for drinking, cooking and washing. The early rains have an impact on the shallow groundwater quality (fine silts/muddy water) a half of the sampled sites in this study area.

Gusau case study (700–850 mm/y)

The settlements in this area were arable and livestock farmers, in contrast to the other two areas in Nigeria which were dominantly arable farmers. The populations of the settlements sampled were of a comparable size to those in the Abeokuta case study with an average population of 2000. As with the other two areas in Nigeria there had been a reported marked increase in population during the last 5-10 years with villages almost doubling in size during this period. This is the driest of the three areas in Nigeria and there was a heavy reliance on groundwater sources, especially during the dry season (approx. October – June). Within the sedimentary aquifer hand dug wells were a very important source of water, in several places this was the main source, and the yield was usually sufficient. The main sources of income for this region was from selling livestock and cash crops e.g. cotton, corn, tomatoes and potatoes. In a few cases seasonal work was obtained in nearby towns during the dry season. There is a seasonal migration back to the rural areas during the farming season (June-September).

Hand pumps have been used as an important source of water in this area for some time, particularly in the basement aquifer. Many of the boreholes sampled had been recently installed by NGO’s (e.g UNICEF) and training had also been provided during the installation on borehole maintenance. A large proportion of the boreholes were managed by a water committee (>60%), and no contribution was required to use the hand pump. In most cases the hand pumps were used for livestock as well as drinking, cooking and washing. The time taken to collect water from the hand pumps was usually more than 30 minutes and in on extreme case was up to 4 hours in the dry season. Borehole yields were usually stable throughout the year and met demand for around 70% of sites in this survey. Rationing was not common, it only happened at one site in this survey, and there were no water quality problems in boreholes sampled due to infiltrating fines during the early rains resulting in muddy water.

Groundwater is increasingly becoming important source of water for irrigation in Zamfara and Sokoto, on both a large scale (government/private run paddy rice and maize farms) as well as on a smaller scale for farming beans and vegetables. There is a large dam which is also used for irrigation in this area. A schemes to irrigate using sprinklers from >20 high yielding boreholes (for maize crops) is in the planning stage with thee working boreholes and sprinklers. This is a government contract with technical support from USA, there are other similar local schemes in this area.

Mali

Bandigara case study (rainfall 350–400 mm/y)

Koro region (high-yielding aquifer)

Of the two field areas this area had, on average, the smaller settlement populations (1400) and fewest villages. The area is relatively sparsely populated, with significant distances (several to tens of kilometres) between villages. The settlements are arable farming villages, with most having a subsistence existence. Food shortages occur throughout August, in between the two harvest seasons. For most villages the main source of income remains the sale of cash crops (e.g. onions, peanuts, beans, sesame seeds), within the wet season, when there is surplus.

Income is therefore reliant on rainfall, and most villages have seen a decrease in income over the last five years, as a result of declining rainfall and a shortened wet season. Yet within the same period village populations have grown by approximately 12%, which has placed a higher demand on food, and water resources.

The semi-arid climate, and absence of surface water resources, means the Koro area is heavily reliant on groundwater for all water. Large diameter hand dug wells are the main groundwater sources across the sedimentary aquifer in the region, and for most villages these are the only water source; very few villages have a borehole/hand pump. The deepest (40-60m) large diameter wells within villages were generally of sufficient yield to meet demand year-round. Hand dug wells which were less than 20 m deep, generally failed by the middle of the dry season. None of the large diameter wells seen within the region were fitted with a mechanised pump.

Boreholes are a relatively new within the area, and half of the boreholes sampled had only been installed within the last 2-3 years by NGO's (e.g. UNICEF). Training had been provided on maintenance and good hygiene practice during installation of the boreholes, and most villages are able to carry out routine maintenance and minor repair work. The villages still relied on external assistance for major mechanical repairs. The mechanical functionality of the hand pumps sampled was generally very good, with most only failing once a year, or once every two years. All boreholes sampled were managed by a water committee.

Borehole yields were usually stable throughout the year, and met demand. Rationing did not occur at any of the sites, but the hand pumps could only be used at morning and night and some (38%) villages charged for use of the borehole (50 CFA/20 L bucket). A decline in yield was found to be an issue at 30 % of the sites during the dry season, and survey results indicate that within half the villages, the drinking water demand in the dry season was only met by people increasing the use of hand dug wells as a secondary drinking water source/people using less water. No villages had storage containers to increase the storage capacity of the groundwater sources, - perhaps in part reflecting the lack of development work so far conducted within the area, rather than hydrogeology.

The time taken to collect water from the hand pumps was generally reported to be 30 minutes to 1 hour within the dry season, but in extreme cases people queue overnight. Most of the boreholes sampled are only used by the immediate village, and therefore distances travelled to the collect the water are rarely over 500 m in the region. Some villages reported deterioration (discolouration) of groundwater quality from the hand pumps towards the end of the dry season when the water-level dropped.

Hand pumps were the most important source of drinking water in the villages visited – however, there was still a heavy reliance on traditional hand dug wells as a secondary water source. There are very few rivers within the Koro plain region on the sedimentary aquifer, and seasonal ponds are the only surface water resource accessible by many villages. Within the wet season, the ponds form an important source of water for washing, livestock and brick construction. Rainfall harvesting was very rare within the region, due to the lack of metal roofs. None of the villages had electricity and the overall standard of living was quite low.

Bandigara region (low-yielding aquifer)

The populations of the settlements sampled within this region were generally larger than in the Koro region, with an average population of 2600. The Bandigara area is still, however, relatively sparsely populated, with significant distances (several kilometres) between villages on the sandstone plateau. The settlements in this zone were again mainly subsistence arable farming villages. Food shortages occur for a longer period than in Koro, with villages reporting hunger throughout August and September, as a result of the shorter wet season in this region. The main source of income in the area are cash crop sales (e.g. onions, tomatoes, peppers), when surplus exists during the wet season, and the sale of livestock. Most villages have seen an increase in income over the last five years in this region, due to higher market prices and demand for produce. Tourism within the area does not seem to have brought significant increased income to the farming villages. Population growth in the region has increased significantly in the last 5 years with most villages having seen a 16% increase in size (470 people/ village).

Despite the presence of some seasonal rivers and streams upon the sandstone plateau, the region is still heavily reliant on groundwater sources, particularly during the dry season. As in the Koro region, large diameter hand dug wells form the main groundwater sources for most villages, and are the only water source for some villages. Hand-dug wells in the basement aquifer are generally much shallower (<20 m) than in the sedimentary aquifer, and have much larger seasonal water table fluctuations (5-15m), than the wells within the Tertiary sedimentary aquifer at Koro. However, the hand dug wells usually were of sufficient yield to meet demand year-round in villages. The success of the hand dug wells was very localised –adjacent wells within metres of each other, could have very different yields. Water quality from the wells was variable with many villages reporting a deterioration of water quality in the dry season as a result of dust blowing into the uncovered large diameter wells, and incidences of guinea worm when the water-level dropped. As a result several villages filter water from shallow hand dug wells in the dry season.

In contrast to the Koro region, boreholes have been used as an important source of water within the basement aquifer for some time (>10 years). Most of the boreholes sampled had been donated and installed 14-15 years ago by the Japanese International Cooperation Agency (JICA). All boreholes sampled were managed by a water committee, who organised the collection of donations if repair work was required. Rationing or charging did not occur at any of the villages visited, and hand pumps were used on a first come, first served, basis. Most villages required external assistance with all but very minor repair work to the hand pumps.

In most of the villages visited borehole yields showed a slight decline towards the end of the dry season, but most (60%) met demand. Very high demands at the end of the dry season were only met in 30% of the villages visited by the increased use of hand dug wells as a secondary source of drinking water/using less watee.

Across the basement aquifer, hand pumps were generally reserved for drinking water, and all other water requirements (cooking, washing and livestock) were met by secondary water sources (hand dug wells and seasonal surface water). The time taken to collect water from hand pumps was longer than within the Tertiary sedimentary aquifer region, with queuing times generally reported to be 1-3 hours in the dry season, and in extreme cases hand pumps were used continuously over night. The mechanical functionality of the hand pumps sampled was much poorer than that observed in the Koro region, with most failing 2-5 times a year, and some failing up to 10 times a year.

Boreholes sampled were only used by the immediate village, and distances travelled were usually short (less than 1km) in the region. Seasonal use of the boreholes by Fulani people in some villages was not reported to affect the yield or sustainability of the sources. Groundwater quality was generally reported to be good, however, in some cases guinea worm was a problem within the dry season.

There are a few seasonal rivers within the basement aquifer region, which exist for 4-5 months during the wet season, and are important sources of water for washing, animals and irrigation. In many of the villages, micro-dams have been constructed along small seasonal rivers in the last 5 years by local NGOs (e.g. GAAS), to facilitate small-scale rice cultivation, and to provide irrigation water for other crops. These schemes have lengthened the growing season, and led to increased crop yields through small-scale irrigation, however, long-term effect of the micro-dams on the groundwater resource is unknown. Rainfall harvesting is not conducted within the region, due to the lack of metal roofs. Only one of the villages visited in the region had electricity and the overall standard of living was quite low, despite growing tourism within the Bandigara region in the past 10-15 years.