
Assessment of well design and sustainability in hard-rock formations in northern Ghana

J. A. Akudago · K. Kankam-Yeboah ·
L. P. Chegbeleh · M. Nishigaki

Abstract Some of the main problems in well construction are associated with installation of casing, especially in the overburden. A total of 1,485 lined and open wells, drilled in the hard rocks of the Precambrian basement complex and Palaeozoic sedimentary (Voltaian) formations in northern Ghana were studied. Of these, 500 were directly monitored. It was observed that the surfaces within the production zones of open wells had weathered, leading to silting and reductions in depth and yield, posing physical water-quality challenges. Also, the average life span of the open wells is about 15 years. The fully lined wells, on the other hand, perform very well with time, lasting for over 40 years on average, with a more sustainable physical water quality over their life span. The comparative cost of constructing an open well was found to be about 26% less than that of a lined well due to less construction material requirements. Although open wells may be relatively cheaper than lined wells to construct in hard rocks, the life span is shorter and should not be encouraged for groundwater exploitation especially in community or rural water supply schemes.

Résumé Quelques-uns des principaux problèmes liés à la construction des puits sont associés au tubage, et

particulièrement dans la couverture. 1,485 puits, chemisés ou à ciel ouvert, forés dans les roches dures du socle complexe Précambrien et les formations sédimentaires du Paléozoïque (Voltaïen), dans le nord du Ghana, ont été étudiés. 500 d'entre eux ont été directement contrôlés. Il a été observé que les surfaces situées au niveau des zones de production des puits à ciel ouvert s'étaient érodées, entraînant un colmatage et une diminution de la profondeur et du rendement posant des problèmes de qualité physique de l'eau. De plus, la durée de vie moyenne des puits à ciel ouvert est d'environ 15 ans. Les puits chemisés, au contraire, ont une bonne tenue dans le temps et fonctionnent au-delà de 40 ans en moyenne, présentant une qualité physique de l'eau viable tout au long de leur durée de vie. L'étude comparative du prix de construction entre les deux types de puits montre qu'un puits à ciel ouvert est environ 26% moins cher car les besoins en matériaux de construction sont moindres. Bien que les puits à ciel ouvert soient relativement moins chers que les puits chemisés lors de forage dans les roches dures, leur durée de vie est plus courte et ils ne devraient pas être conseillés dans le cadre d'exploitation d'eau souterraine, particulièrement pour les plans d'alimentation en eau de communes ou de villages ruraux.

Resumen Algunos de los problemas principales en construcción de pozos están asociados con la instalación del revestimiento, sobre todo en la cubierta sedimentaria sin consolidar. Se estudiaron 1,485 pozos revestidos y abiertos, perforados en rocas duras en formaciones del complejo basamento Precámbrico y del sedimentario Palaeozoico (Voltaiano) en el norte de Ghana. Se monitorearon 500 de éstos directamente. Fue observado que las superficies dentro de las zonas de producción en pozos abiertos tenían meteorización, causando obstrucción con sedimentación y reducciones en la profundidad y productividad, derivando en aparentes problemas físicos de calidad de agua. También, que la vida útil promedio de los pozos abiertos es aproximadamente 15 años. Los pozos totalmente revestidos, por otro lado, trabajan muy bien con el tiempo, durando más de 40 años en promedio, con una calidad física de agua más sostenible a lo largo de su vida útil. Se encontró que el costo comparativo de construir un pozo abierto era aproximadamente 26% menos que un pozo revestido, debido a la menor necesidad de materiales de construcción. Aunque los

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J. A. Akudago (✉) · L. P. Chegbeleh · M. Nishigaki
Geo-Environmental Evaluation Lab,
Faculty of Environmental Science,
Okayama University,
1-1, Naka 3-Chome, Tsushima,
Okayama 700-8530, Japan
e-mail: jaakud@yahoo.com
Tel.: +81-862511041
e-mail: larrypax@yahoo.com
e-mail: makoto@gw.civil.okayama-u.ac.jp

K. Kankam-Yeboah
CSIR-Water Research Institute,
P.O. Box M 32, Accra Ghana
e-mail: kyeb59@yahoo.com

J. A. Akudago · L. P. Chegbeleh
World Vision Ghana Rural Water Project, PMB,
Tamale Ghana
Tel.: +233-71-25442

pozos abiertos pueden ser relativamente más baratos que los pozos revestidos construidos en las rocas duras, su vida media es más corta y no deberían recomendarse para la explotación del agua subterránea, especialmente en proyectos de suministro de agua rurales o comunitarios.

Keywords Water supply · Groundwater development · Well sustainability · Hard-rock formation · Ghana

Introduction

The human population in northern Ghana, which comprises the Northern, Upper East and West regions (Fig. 1), constitutes nearly 20% of the total population of Ghana. It has been estimated that about 80% of the people in northern Ghana live in the rural communities, i.e. communities with population less than 5,000 (Statistical Services of Ghana 2000). For farming and cultural purposes, the communities are usually scattered, remote and far apart. The main sources of water for domestic use in these communities include streams, rivers, lakes, ponds, dugouts, impoundments, reservoirs and groundwater (Ayibotele 1969). The surface waters are easily polluted during the rainy season, which lasts for 4 months beginning from June, and are also the main sources of guinea worm and other water-borne diseases (Dapaah-Siakwan and Gyau-Boakye 2000). Most of the surface water sources dry up during the dry season and water for domestic purposes are inaccessible. The dry season, which

usually starts in October, is characterized by the cold and dry harmattan winds and usually peaks from March to April (Kwei 1997).

The solution to the perennial water problems experienced in the rural communities in northern Ghana is to explore for groundwater sources. This is due to the fact that groundwater is relatively protected from evaporation and surface pollution (Quist et al. 1988). However, the exploitation of this resource requires technology and funds, especially in hard-rock formations where drilling is required to intercept the aquifers.

In many parts of the world, two types of well design exist, namely open and lined wells (Layne 1995). In “open wells”, the hole is lined with steel or polyvinyl chloride (PVC) from the ground surface to the top of the hard rock. The “lined well” has casings (plain and screen) from the ground surface to the bottom of the well. It is desirable to construct open wells in areas with competent rock formations, while in unconsolidated sediments, lined wells are preferable (Driscoll 1986). It would therefore be cheaper to drill open wells than lined wells in hard-rock formations if the life span of wells could be comparatively longer and water quality could be sustained.

The cost of drilling a well varies from country to country and geological formation. In Africa, the cost varies from about US \$2,766 to US \$12,000 per lined well of an average depth of 50 m (Dongen and Woodhouse 1994), as shown in Table 1. In Ghana, the cost of drilling, developing and constructing lined and unlined wells with an average depth of 45 m in 2004

Fig. 1 Location map of the study area (hatched area) in Ghana

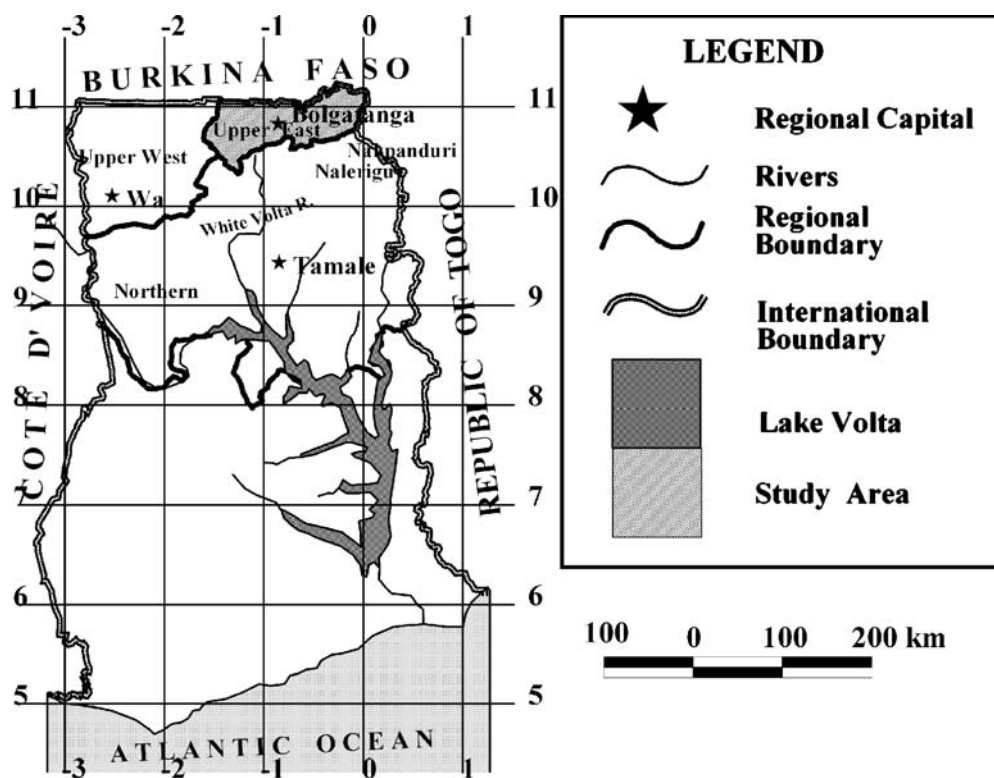


Table 1 Cost of drilling lined wells in Africa

Location	Cost (US\$)/50-m lined well
West Africa	12,000
East Africa	10,000
Southern Africa	2,766

Source: (Dongen and Woodhouse 1994)

was US \$6,000-US \$9,000 and US \$4,000-US \$4,500 respectively (CWSA, unpublished data, 2004; Bukari, Zeypan Geo-Consult Ltd, unpublished data, 2004; Agyekum, Accra Water Research Institute, unpublished data, 2006). The main challenge with many projects and intended private well owners has always been how to minimize cost during well drilling, development and construction. A choice, therefore, has to be made on the type of well design. Assessment of previously constructed wells could help individuals and well drilling project managers to make their choices. In this regard, 1,485 lined and open wells, drilled in the hard rocks of the Precambrian basement complex and Palaeozoic sedimentary (Voltaian) formations in northern Ghana were studied. Five hundred (500) of these were directly monitored.

The objective of this work is to compare the open and lined types of well design and construction with particular reference to their life spans and cost, to serve as a guide for well drilling projects using northern Ghana as a case study.

State of safe water provision to rural communities in northern Ghana

The rural communities in northern Ghana have benefited from various well drilling programmes by governmental and non-governmental organizations (NGOs). Some of these include the Northern Region Rural Integrated Programme (NORRIP), Canadian International Development Agency (CIDA) sponsored Upper East and West and Northern Regions Water Supply Projects, World Bank supported Community Water and Sanitation Programme, Church of Christ Rural Water Development Project, Catholic Diocesan Water Development Programmes, and World Vision International Ghana Rural Water Project.

Since the 1970s, most well drilling projects have been donor supported through the nationally owned, former Ghana Water and Sewerage Corporation (GWSC). However, at present, this is performed by the Community Water and Sanitation Agency (CWSA). All well drilling programmes which took place before the 1990s were carried out with limited participation from the beneficiary communities. This has led to some operational and managerial problems.

The three northern regions have less than 60% reliable and potable water coverage. The main reasons being that, on average, 80% of the people in northern Ghana are poor (Ghana Statistical Service 2000), and cannot afford to drill private wells. Another reason is difficulty in finding

underground water in the complex geological formation in most parts of the region (Darko 2001).

The CWSA, formally known as Community Water and Sanitation Division (CWSD) of GWSC, was established in 1994 to oversee the rural water supply in Ghana, and advocates community ownership and management of wells (CWSD 1996). At its inception, all communities were required to contribute at least 5% of the capital cost of all facilities before being provided with a water point. In this regard, poor communities that might not be able to contribute their portion of the initial cost would end up being deprived of potable water supply. This has been found to be a problem for well development and water supply, even if a sufficient number of yielding wells could be drilled in such communities. Therefore, as from 2006, the Government of Ghana has undertaken to bear this 5% cost on behalf of such poor communities (Ministry of Water Resources, Work and Housing 2005).

Hydrogeological setting of the study area

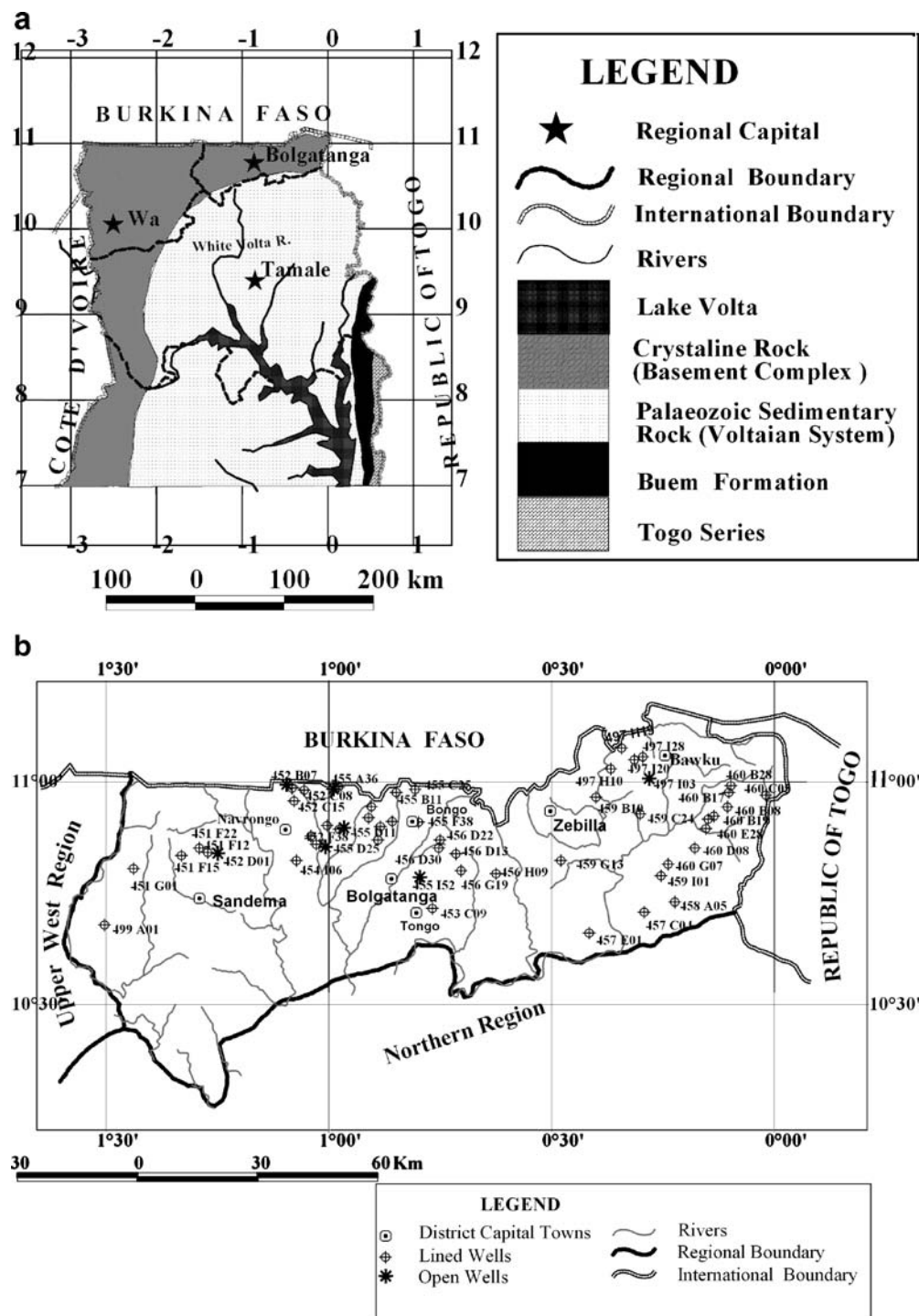
Northern Ghana is characterized by flat to fairly undulating ground with short trees and savannah grassland. The only scarp (Gambaga Scarp), which runs from Nalerigu through Nakpanduri to Togo, is about 350–400 m above mean sea level (Dickson and Benneh 1980). The scarp also separates the Precambrian complex from the sedimentary group, locally referred to as the Voltaian Group.

The two major hydrogeological provinces in the study area, namely the Precambrian (Basement Complex) and Palaeozoic sedimentary (Voltaian) provinces (Dapaah-Siakwan and Gyau-Boakye 2000), are shown in Fig. 2a.

The Precambrian Province is composed of granitic complexes, mafic volcanic and sedimentary rocks metamorphosed to greenschist facies (Kesse 1985). The granite and gneisses associated with the Precambrian complex, locally referred to as the Birimian formation, are inherently impermeable, but have developed secondary permeability and porosity as a result of fracturing and weathering. In most cases, the weathered intrusives (granites and gneiss) and the fractures form very good aquifers and are, therefore, the targets in groundwater exploration, as can be observed by the locations of the wells in Fig. 2b. The Birimian phyllites, schist, slate, greywacke, tuff and lava are very foliated and fractured. These fracture zones act as groundwater flow paths and are also favourable locations for groundwater exploitation. About 95% of wells in the Upper East and Upper West regions are completed within the overburden (Apambire et al 1997). The overburden thickness extends to 30m in some places and well yields in many areas are generally low, between 9 and 22.5 l/min, but sufficient for hand pumps (Wardrop and Associates, unpublished data, 1980).

The Voltaian hydrogeologic province is of the late Proterozoic to early Palaeozoic Era (Anani 1999) and is underlain by consolidated sedimentary rocks, which include mudstone, sandstone, conglomerate, shale and some limestone. Aquifers are mostly located in fractures

Fig. 2 **a** Simplified hydro-geological map of northern Ghana (modified from GSG 1969). **b** Map showing the location of open wells (see Table 4) and lined wells (see Table 5) in the Upper East Region



and are confined or semi-confined (Comwasan Consult, unpublished data, 1999).

In both provinces, groundwater is exploited through wells fitted with hand or electric pumps. These wells are either lined or are just used as open wells. Groundwater quality generally conforms to the World Health Organisation (WHO) standards. However, higher concentrations of fluoride have been reported in some parts of the Upper East Region (Apambire 1996).

Well casing, design and construction

Well casing is a lining for the drilled hole and is intended primarily to prevent the unconsolidated overburden from caving in, and thus maintains an open hole from the land surface to the water-bearing formation (AWWA 1973). Casings also seal out surface water from direct contamination of the aquifer wherein the well is developed. In drilling, when a well is successful (produces at least the

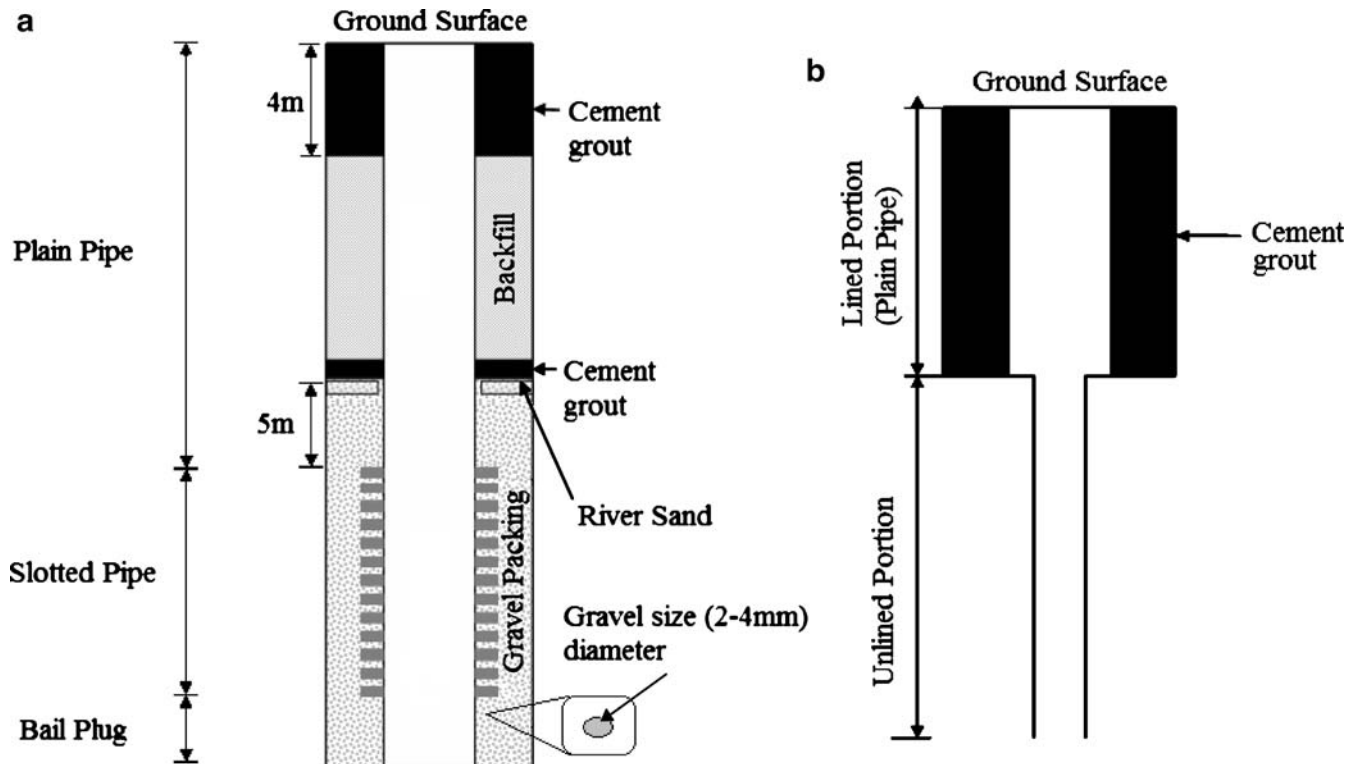


Fig. 3 Illustrative section of wells: **a** lined well; **b** open well

minimum quantity of water required per minute), it is either completed with lining or retained as an open well. A lined well is one in which a screen (slotted/perforated steel or PVC pipe) is placed through the productive zones of the aquifer, with plain pipe of similar material and diameter at the non-productive zones. A filter medium (gravel of 2–4 mm grain size) is placed in the annular space between the walls of the well and the pipes up to about 5 m above the top of the screen. Cement grout is poured on a thin layer of river sand above the gravel, in order to prevent infiltration of surface waters. The remaining portion is backfilled and the last 4 m is also grouted (Fig. 3a).

On the other hand, an open well is one in which only a plain pipe of specified diameter is placed from the ground surface through the weathered overburden to the hard-rock surface to prevent the loose wall from collapsing. The hard-rock portion and water-bearing zones of the aquifer are left bare, i.e. uncased. In this case, gravel packing cannot be provided. Cement grout is placed in the annular space between the plain pipe and the upper walls of the well, i.e. in the overburden material. The well normally has a larger diameter at the lined part and a smaller diameter in the hard-rock section (Fig. 3b).

In weathered aquifers, the filter medium can be clogged, as well as the well surface. This eventually prevents inflow into the well as the effective porosity of the gravel will be reduced. Filter media filter the water and allow only particles finer than the connected pore spaces within the filter media to enter the well, leaving behind the bigger particles. The trapped particles tend to cause

clogging as groundwater flowing towards the well surface keeps pushing them into the pore spaces within the filter media. The amount of silt accumulated in the well is thus reduced. However, in the case of open wells, the water is not filtered, hence allowing more solid particles to enter the well which could cause rapid siltation as compared to the lined wells. The continuous clogging and/or siltation close to or in fracture zones could block or reduce screen and fracture opening sizes. Ishida et al. (2003) reported that deposition of infiltrated clay in fractures of limestone of Miyakojima Island of Japan reduced the hydraulic conductivities of the rock. The conductivities fluctuated between 1/10th and 1/100th of the original conductivities. In order to free the well from siltation and/or particle clogging, the well must be rehabilitated from time to time. It is usually better to redevelop the well after a certain period of time, at most 10 years to maintain or even increase the yields. The life span of a well, therefore, depends on the type of construction and the frequency of rehabilitation. However, many wells are not usually rehabilitated for lack of funds, equipment or technology. A concise and very cost effective way of redeveloping

Table 2 The distribution of wells drilled in the various decades in the Upper East Region

Year of construction	Lined well	Open/unlined well	Total
1950–1959	39	36	75
1960–1969	18	13	31
1970–1979	1,338	41	1,379
Total	1,395	90	1,485

Source: (Wardrop and Associates, unpublished data, 1979)

Table 3 Summary of lithology and depth range of open wells in Upper East Region

Geology/lithology	Number of wells drilled in weathered to fresh rock	Depth range of open wells (m)	Lined portion, depth range (m)	Lined portion, mean depth (m)	Unlined portion, depth range (m)	Unlined portion, mean depth (m)
Granite	70	11.6–121.9	0–60.4	14.6	3–121.9	30.5
Granitic gneiss	8	29.0–36.6	0–18.9	15.2	9.8–36.6	32.1
Schist/phyllite	10	10.7–52.1	0–33.5	13.7	6.1–52.1	26.4
Green stones	2	30.8–36.0	0–16.2	12.6	9.1–36.0	31.4

Source: CWSA/COWAP redevelopment exercise (CWSA/COWAP, unpublished data, 1993–1997) and Wardrop and Associates (Wardrop and Associates, unpublished data, 1979)

wells is elaborated on in the Community Water Project (COWAP) of Ghana, Field Paper 28 (Nampusuor 2001).

A redevelopment scheme involving 1,485 wells in the Upper East Region, operated by the CWSA and COWAP between 1993 and 1997, aimed to change all the existing hand pumps to the Village Level Operation and Maintenance (VLOM) pumps. It was revealed that:

1. 1,366 wells were good for VLOM installation
2. 25 wells were defective
3. 87 wells were dry or condemned, and therefore not redeveloped
4. 7 wells were low yielding

The defective wells had problems mainly with their screens (broken screens), hence causing silting and infiltration of dirty water into the well. 500 wells were directly monitored. Out of the 119 defective, low yielding and dry or condemned wells, 90 were open wells and many of these broke down in the first 15 years of development. However, all the 1,366 wells found to be good for VLOM pump installations were lined wells. Some of the wells were constructed in the 1950s and 1960s, but most were constructed in the 1970s as shown in Table 2.

Methodology

Well data from the CWSA programme from the Upper East Region (CWSA; unpublished data, 1993–1997) were

acquired and supplemented by interviews with well users in the various communities, to assess the state of the wells since construction. Figure 2b shows the location map of some of the wells visited. The interviews were conducted during the hydrogeological investigations to select sites for the replacement wells. Some of the questions related to:

1. The year of well construction
2. How long have the wells been in use
3. How many times were the wells redeveloped
4. Whether the colour of the water remained the same throughout the year(s)

Well logs were studied, and the depths of some wells were also measured using a plumb line. For wells which had collapsed and whose depths could not be measured, efforts were made to solicit information from knowledgeable local people, giving a rough idea of the number of pump rods that were inside the well before the collapse. The depths were compared with the original pump installation depths in the well records.

Results and discussion

The data revealed that wells in the area had never been rehabilitated since they were constructed (except a few). The first rehabilitation was carried out by COWAP and CWSA between 1993 and 1997. The data also indicated that most of the wells had maintained or slightly improved upon their initial yields after the rehabilitation. The water

Table 4 Measured depths of some open wells, in Upper East Region between February 1996–April 1997)

BH No	Longitude (X°) west	Latitude (Y°) north	Date of construction	Drilled depth (m)	Depth at time of study (m)	Date of measured depths	Siltation (m)
452 D-01	1.08673	10.9927	27/10/56	25.91	22.34	11/02/97	3.57
455 A-36	1.24060	10.8392	20/03/57	31.70	28.48	5/12/96	3.22
455 D-05	0.98265	10.9831	11/04/57	21.95	19.40	10/04/97	2.55
452 B-07	0.95933	10.8966	29/03/57	20.73	18.25	14/02/96	2.48
455 D-25	1.00002	10.8536	12/08/78	24.69	22.65	12/02/97	2.04
497 I-03	0.78961	10.7861	20/03/57	30.78	29.00	21/08/96	1.78
455 I-52	0.2782	11.006	06/12/78	15.54	14.50	07/11/96	1.04

Source: CWSA/COWAP redevelopment exercise (CWSA/COWAP, unpublished data, 1993–1997). The numbering system used to identify wells is based on the 1:50,000 topographic map sheets covering the area. Each of the map sheets has been assigned a number by the Ghana Survey Department. In the Upper East Region, the map sheets numbers range from 358 to 501. For precise well location, each map sheet is divided into nine blocks lettered A to I. Wells completed in a block are numbered consecutively as they are completed. For example, a well assigned 455 A-36 is located on map sheet 455, block A and is the 36th well drilled in the block. Well 455 I-52 means it is located in map sheet 455, block I and is the 52nd well drilled in the block

Table 5 Measured depths of some lined wells in Upper East Region

BH No	Longitude (X°) west	Latitude (Y°) north	Date of construction	Drilled depth (m)	Depth at time of study (m)	Siltation (m)
456 D-22	1.49272	10.6825	09/08/1976	36.27	17.43	18.84
498 E-10	1.26048	10.8444	01/02/1977	29.26	11.40	17.86
456 D-30	1.3201	10.8364	14/12/1978	35.36	17.98	17.38
498 H-16	1.27935	10.8526	19/03/1976	14.94	0.00	14.94
498 G-28	1.42608	10.8089	Not known	24.69	9.97	14.72
452 C-15	1.07341	10.9849	08/10/1976	29.26	16.40	12.86
460 D-08	1.04488	10.9794	08/02/1975	28.04	15.36	12.68
459 C-24	1.07194	10.9566	26/02/1977	17.07	6.57	10.50
451 G-01	1.01978	10.8584	02/04/1979	33.22	27.87	5.35
449 A-01	1.03053	10.8799	23/02/1976	23.16	18.51	4.65
498 G-29	1.06543	10.8241	20/04/1957	18.29	13.80	4.49
452 I-06	0.76045	10.7387	07/06/1979	22.25	17.86	4.39
459 G-13	0.97488	10.9917	18/05/1976	17.68	13.56	4.12
455 B-06	0.89593	10.9441	04/06/1976	23.77	19.68	4.09
459 B-10	0.84319	10.9743	19/07/1976	24.08	20.38	3.70
455 A-50	0.88617	10.9174	04/01/1979	21.03	17.56	3.47
451 F-15	0.8011	10.9823	26/04/1979	12.19	8.73	3.46
455 F-38	0.99648	10.9042	15/11/1978	23.16	19.89	3.27
452 F-38	0.96599	10.8973	28/07/1978	24.08	20.85	3.23
460 B-17	0.87707	10.8997	03/04/1975	31.70	28.54	3.16
460 B-28	0.87209	10.8632	28/11/1976	13.41	10.55	2.86
498 I-10	0.88212	10.8695	21/03/1976	14.02	11.42	2.60
457 E-01	0.7591	10.9031	27/06/1976	25.91	23.50	2.41
460 B-02	0.70615	10.831	10/01/1975	21.18	18.89	2.29
460 G-07	0.74559	10.8522	13/03/1975	19.81	17.55	2.26
497 H-19	0.73918	10.8502	08/02/1977	21.34	19.20	2.14
452 C-04	0.69745	10.8025	20/10/1975	15.24	13.37	1.87
458 A-05	0.61813	10.7941	01/05/1975	20.51	18.65	1.86
498 H-12	0.28858	10.7114	16/05/1975	24.38	22.58	1.80
459 I-01	0.40994	10.6647	15/03/1975	29.57	27.84	1.73
455 E-33	0.22164	10.7337	09/11/1978	18.90	17.22	1.68
452 C-08	0.39884	10.9663	31/03/1976	29.26	27.63	1.63
497 I-20	0.30587	10.9731	10/05/1976	14.33	13.00	1.33
451 F-22	0.47302	10.8283	16/07/1979	12.19	11.20	0.99
456 G-19	0.25093	10.7936	01/10/1976	17.68	16.79	0.89
455 B-11	0.13491	10.9224	09/06/1976	15.85	14.99	0.86
498 D-20	0.10459	10.9448	11/11/1976	24.99	24.30	0.69
498 H-06	0.10122	10.978	10/05/1975	17.68	17.03	0.65
453 C-29	0.14424	10.9173	05/08/1978	10.36	9.74	0.62
455 B-26	0.09578	10.9926	23/11/1978	16.15	15.56	0.59
460 B-08	0.01905	10.9692	20/01/1975	17.19	16.63	0.56
455 D-11	0.17504	10.8515	18/08/1971	18.59	18.05	0.54
460 C-05	0.1502	10.9004	26/01/1975	24.17	23.69	0.48
455 E-34	0.23803	10.8162	10/11/1978	14.33	13.85	0.48
456 D-13	0.3642	11.0308	02/11/1956	18.29	17.89	0.40
456 H-09	0.33936	11.0769	08/07/1976	18.59	18.20	0.39
452 F-36	0.31105	11.049	14/11/1976	28.35	28.00	0.35
455 C-25	0.29098	11.0552	11/08/1976	17.07	16.78	0.29
498 I-07	0.22297	11.1488	22/05/1975	13.72	13.49	0.23
498 F-04	0.20784	11.1107	21/01/1977	24.08	23.85	0.23
460 E-28	0.16109	11.1348	04/03/1977	28.35	28.17	0.18
497 H-10	0.00583	11.0897	26/04/1976	23.16	22.98	0.18
455 D-01	0.20337	11.0609	25/09/1975	17.68	17.57	0.11
497 I-28	0.17385	11.0749	06/02/1977	23.47	23.37	0.10
498 D-12	0.14326	11.0774	21/04/1976	18.9	18.81	0.09
455 E-17	0.15272	11.0643	01/06/1976	17.98	17.90	0.08
457 C-04	0.11655	11.0638	25/03/1975	29.96	29.89	0.07
460 B-19	0.02425	11.0794	25/03/1976	25.30	25.27	0.03
451 F-12	0.06343	11.0512	05/03/1976	24.69	24.67	0.02

Source: CWSA/COWAP redevelopment exercise, (CWSA/COWAP, unpublished data, 1993–1997) and Wardrop and Associates (Wardrop and Associates, unpublished data, 1979)

was also cleaner than before. As shown in Table 3, the mean well depths vary between 12 and 45 m, but six open wells were deeper than the general depth range. Table 3 also shows a summary of the geological formation, number of wells drilled and the depths ranges of the open portions of wells, above which are lined portions, and the general open wells. Table 4 shows the depth of seven open wells which were measured at the time of redevelopment. A summary of the depths of some lined wells at the time of the redevelopment exercise, together with their respective drilled depths is also shown in Table 5.

Comparing the two types of well design, a variety of costly materials (pipes, filter media, etc) were used to construct lined wells. For open wells, only plain pipes were used in the upper portions, but the pumps frequently broke down and suction depths had to be reduced to avoid blocking the nozzles. In order to appreciate the holistic view of open and lined wells, a comparative construction cost in Ghana was sought through field monitoring and personal communication, as mentioned earlier (Bukari, Zeypam Geo-Consult Ltd, unpublished data, 2004; Agyekum, Accra Water Research Institute, unpublished data, 2006). Although open wells are not a general practice in Ghana of late, it was clear that the cost of installing an open well was less than that of a lined well, the cost difference being about US \$1,500. In rural water supply projects, where a large number of wells are required, a lot of savings could be made at US \$1,500 per open well drilled. It would have, therefore, been relatively cheaper to install open wells than lined ones. However, the data gathered revealed that, the average life span of the open holes was just about 15 years, and none of them was functional after 40 years of construction and use. Even during their operational period, community members mentioned dirty, cloudy or milky water infiltration during the rainy season. Due to the unavailability of physico-chemical monitoring data on water quality, their claim could not be substantiated. However, according to Wardrop and Associates (Wardrop and Associates, unpublished data, 1980) final hydrogeological report for drilling program 1974–1979, prepared for the Ghana Water and Sewerage Corporation and the Canadian International Development Agency, the quality of groundwater from both lined and open wells was appropriate for domestic use.

The problems of the open wells may have resulted from the weathering of the well face, which could have caused the cloudiness in the water and reduction in well

depth and yield. Another possibility could have been that in the lined portion, the lining had failed. From Table 3, it is also clear that the average depth of the open wells falls within the general depth of weathering in the rocks as mentioned earlier and a lot of debris could, therefore, be transported into the well during recharge. Again, when the well face weathers, the resistant mineral grains will drop and cause siltation of the well, while some of the secondary minerals will remain in suspension and cause cloudiness in the water. Also, in regards to weathering, some of the mafic minerals (such as hornblende and biotite) produce clay, which tend to block existing fractures and prevent them from transmitting groundwater (Ishida et al. 2003; Love 2004). The absence of a filter medium (gravel pack) in the open well design is a contributing factor to the silting. These problems may have led to the total collapse of the wells and the affected communities seeking alternative sources of water. Most of the open holes had collapsed at the time of study; seven open wells showed a range of siltation depth from 1 to 5 m. The lined wells also experienced some siltation, usually a few centimetres thick. However, there were a few cases of wells with defective screens where siltation was up to about 18 m as shown in Table 5. There were no lined wells that had totally collapsed, suggesting that if even the well silts up, it can still be redeveloped, provided the screens are not damaged.

In order to prolong the well's life, sustain the good appearance of the groundwater, and maintain well yield, it is better to regularly redevelop or de-silt the holes, especially for open wells. Unlike the lined wells, where the filter media and screen separate the silting material from the well face, the silting material in the open wells are heavier and rapidly fill the fractures. In such cases, the well must be de-silted early otherwise there is the possibility of having a dead-end (sealed) fracture at the well face. However, de-siltation and well redevelopment have been difficult to achieve because beneficiary communities take over ownership and management of the facilities after the well drilling programme has ended, and the equipment and funds for well rehabilitation might not be available for communities to use.

As indicated in Table 6, the open holes in the various communities had to be replaced with new wells during the well replacement exercise between 1997 and 1999. The cost of replacing these wells could have been used to provide communities with new or additional potable water

Table 6 Comparison of lined and open wells

Well	Relative initial construction cost	Average life span	Formation suitability	Remarks
Lined	Expensive	Up to 40 years or more	Suitable for all geological formations	Can be used for a very long time. Suitable for community water supply. Cost effective in the long term
Open	Cheaper	About 15 years (rarely last up to 40 years)	Only suitable in very competent and unweathered geological formations	May have to be replaced after short life span. More expensive in the long term.

sources. However, no adverse effects were found with the lined wells, except those with defective screens as mentioned above. Some of the condemned wells were the result of objects of nearly equal diameter being dropped into the well after a broken pump was removed. A few of the lined wells that were constructed in the 1950s are still functional, yielding water with very good physical appearance.

Conclusion

The study involved 1,485 wells in the Upper East Region of northern Ghana, of which over 500 lined and open holes were directly accessed and monitored. The following observations were made:

1. All the wells that were considered good for the Village Level Operation and Maintenance (VLOM) pump installation system during the redevelopment programme were lined at the time of construction.
2. About 75% of wells rejected for the VLOM, and therefore needing replacement, were open wells.
3. The lined wells have average life span of more than 40 years, whereas the open wells have average life spans of about 15 years (and rarely last up to 40 years).
4. Rehabilitation of wells was not carried out often and, during the study period, was the first of its kind since the wells were drilled (except a few). Lack of frequent rehabilitation could lead to siltation and decrease in well yield.
5. In terms of cost and long-term sustainability, open wells cannot adequately serve the beneficiary community since they may have to be replaced after collapse, hence doubling the initial cost of drilling. The end result makes community water supply very expensive if open wells are constructed.

It is therefore noted from the study that, although hard rocks may be stable enough to support open wells for a number of years, open wells, although relatively cheap to install, should not be encouraged, especially in community or rural water supply schemes. It is recommended that the well-drilling projects should include well rehabilitation costs in their estimates, based at least once every 10 years to ensure long term functioning and sustainability of the facility.

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