Bacteriological Quality of Groundwater Based Drinking Water Sources in South Central Niger

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Abstract

In arid and semi-arid Niger, groundwater is the primary source of water for drinking, household use, livestock watering, and irrigation. The authors were involved with a water-point inventory and sampling program of hundreds of hand-dug open wells and boreholes in five communes in Maradi and Zinder Regions of south-central Niger which serve an estimated rural population of 450,000 people.

Water samples were collected from 278 boreholes and 188 hand-dug wells indicated that total coliform was detected in 64% of the boreholes and in 87% of the hand-dug wells tested, and *E. coli* in 37% of the boreholes and 72% of the hand-dug wells tested. The depths to groundwater in the five communes range from < 10 metres below ground surface (m, bgs) to as deep as 90+ m, bgs.

The hand-dug wells are all unprotected with multiple pathways for bacteriological contamination input. A primary pathway for bacteriological contaminant input to the boreholes is via seepage of contaminated water at the wellhead down unprotected (non-grouted) borehole-casing annuli.

These findings point to the need for: (1) regulatory requirements for borehole construction and grouting standards, and (2) corrective actions for wellhead/ casing annulus cementing repairs.

The findings are likely representative of village water systems in Sub Saharan Africa, as borehole construction standards by the international donor community and national governments are largely absent, particularly in regard to sanitary wellhead protection and borehole casing grouting to a sufficient depth.

Keywords: Boreholes, Hand-Dug Wells, Total Coliform, *E. coli*, Construction Standards, Borehole Protection.

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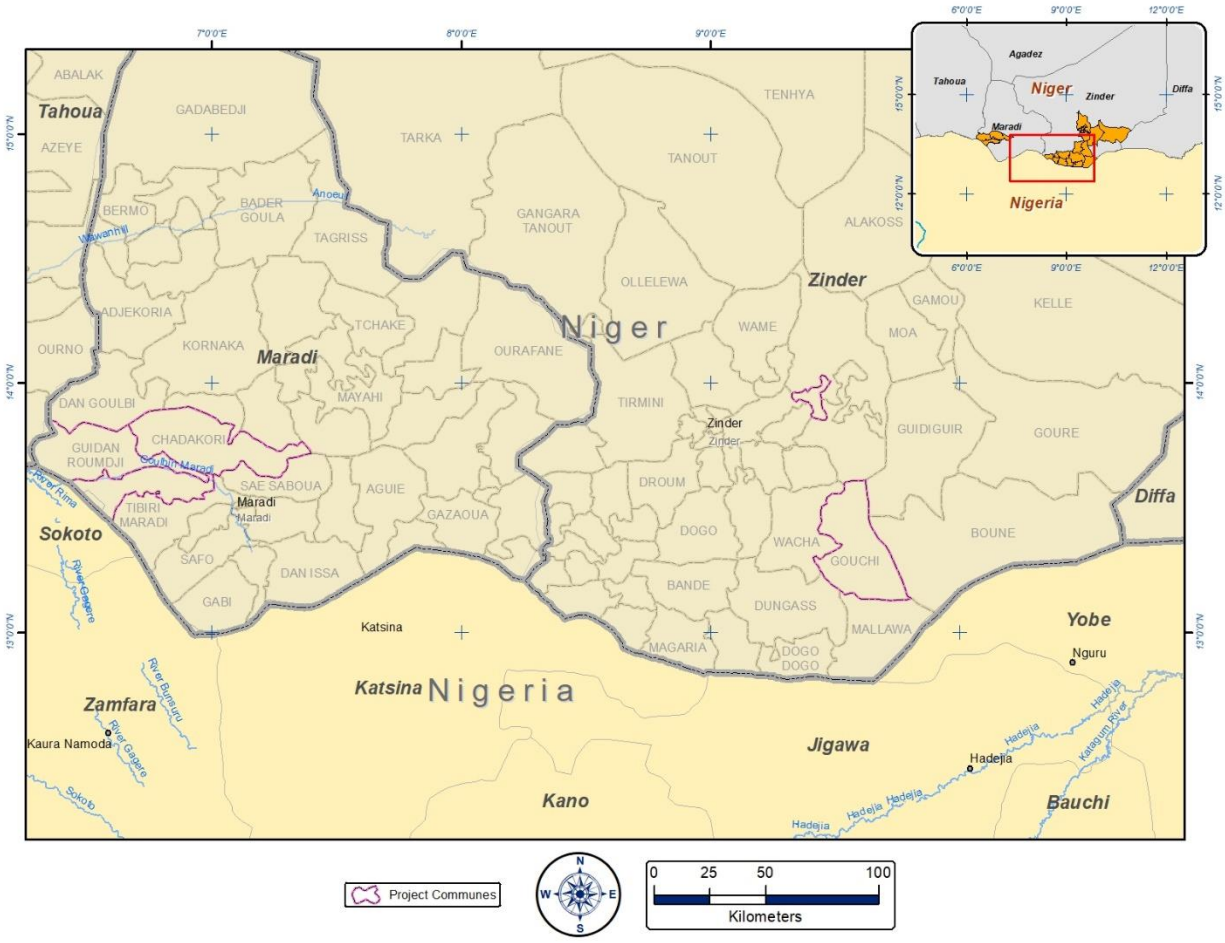

Figure 1: Study Area Communes

Highlights

1. Four hundred and sixty-six (466) samples from 278 boreholes and 188 hand-dug wells were collected and analyzed for bacteriological quality from five (5) communes in Maradi and Zinder Regions in south-central Niger **(Figure 1)**.

2. This study's finding indicated that 64% of the sampled boreholes and 87% of the sampled hand-dug wells are contaminated with total coliform bacteria, and 37% of the sampled boreholes and 72% of the sampled hand-dug wells with *E. coli bacteria*.

3. Boreholes, if properly constructed with 10 to 15m of grouted casing, are generally microbial-free. However, these field study results reveal technical construction defects as well as wellhead management deficiencies that need to be addressed.

4. The presence of elevated levels of total coliform and *E. coli* bacteria in the borehole samples can be attributed to a number of factors including the absence of cement grout in the annular space between the drilled borehole and casing during borehole construction. Such gaps provide a pathway for contaminated water migration into the borehole via the casing annulus pathway.

5. This is a very common occurrence in the industry and can only be mitigated by developing and disseminating "construction standards", construction supervision, and enforcement.

6. The bacteriological quality of drinking water sources in the surveyed villages is a serious public health concern as well as an enormous challenge in regard to total coliform and *E. coli* bacteria contamination.

Introduction

Groundwater constitutes the major source of water for drinking, household use, livestock watering, and agricultural irrigation in arid and semi-arid Niger and for much of Sub-Saharan Africa (SSA). Groundwater is accessed via boreholes and hand-dug wells that tap shallow, medium depth, and deep aquifers. Boreholes are relatively deeper than the hand-dug wells, mostly fitted with hand pumps, and in a few cases submersible pumps. A majority of the hand-dug wells are open and generally without any form of protection.

Maradi and Zinder Regions are adjoining regions located in south-central Niger, West Africa. The climate is the North Sahelian type and characterized by a rainy season from June to September and a dry season from October to May. Of the several communes with each region, five communes (three in Maradi and two in Zinder) were assessed for groundwater supply status and bacteriological and chemical quality in this study (**Figure 1)**.

The authors were involved with a water-point inventory and sampling program of hundreds of hand-dug wells and boreholes in these communes in late 2019 and early 2020. The inventory documented the physical location of village drinking and livestock water sources, water sampling, and testing for bacteriological (Total Coliform and *E. coli*) and chemical content (TDS, pH, Arsenic, Fluoride and Nitrates).

A total of 854 water points, consisting of 506 boreholes (BHs) and 348 hand-dug wells (HDWs) were inventoried. These water points serve an estimated rural population of 450,000 people. 83% (420) of the boreholes and 95% (329) of the hand-dug wells were functional and in use. A subset of the functional water points were sampled for bacteriological and chemical analysis. **Table 1** provides a summary of the distribution of water points inventoried.

Some prior studies focused on bacteriologic quality of drinking water sources in rural settings include: *Kimpel et. al, 2016, Ray et al, 1993, and Water Development Project, Betul, Madhya Pradesh, India 1976.*

The objectives of this paper are to:

- Share the findings of the state of bacteriological groundwater quality in five communes in two regions of Niger.
- Opine on the causation of bacteriologic contamination.
- Recommend solutions for improving drinking water quality in the affected villages.
- Discuss the wider implications over SSA where borehole construction standards by the international donor community and national governments are largely not implemented particularly in regard to sanitary wellhead protection and borehole casing grouting to a sufficient depth (i.e. 15 metres (m) minimum).

Table 1: Water Source Inventory in Maradi and Zinder Regions

Region	Commune	Estimated Population	Number of Villages	Water Point Type				Total Water points
				Boreholes		Dug Wells		
				F	NF	F	NF	
Maradi	Chadakori	108,711	73	52	7	64	3	126
	Guidan Sori	93,771	119	70	12	90	0	172
	Guidan Roumdji	117,138	188	57	20	85	6	168
Zinder	Mazamni	40,404	44	27	24	25	5	81
	Gouchi	97,775	176	214	23	65	5	307
TOTAL		**457,799**	**600**	**420**	**86**	**329**	**19**	**854**

F ---Functional; NF---Nonfunctional

Principal Aquifer Systems

Maradi Region: Chadakori, Guidan Sori, and Guidan Roumdji Communes **(Figure 1)** in Maradi Region are underlain the Continental Intercalaire (CI)/Hamadien (CH) Aquifer and a shallow alluvial aquifer along the Goulbi Maradi drainage channel. The Goulbi Maradi Alluvium Aquifer is about 20 - 40m thick. The CI/CH Aquifer system is in the range of 40 to 100m thick (average 60m) in the eastern part of Maradi Region and thickens to ~ 60 to 200m in the west. Static water levels in the Goulbi Maradi Alluvium are reported to range from <10 to 30m, below ground surface (m, bgs), and range between 10 to >90 m, bgs, in CI/CH Aquifer System depending on local topography.

Borehole yields range from less than 10 cubic metres per hour (m^3/h) to more than 30 m^3/h (*Water Resources of the Department of Maradi, 1991*).

Figure 2 depicts the principal aquifers in the three communes in Maradi Region and **Figure 3** is a west - east oriented hydrogeologic cross section depicting the underlying aquifer units and depths to groundwater. Groundwater recharge is limited and thought to be principally "focused recharge" from the infiltration of surface water runoff in the ephemeral Goulbi Maradi drainage channel.

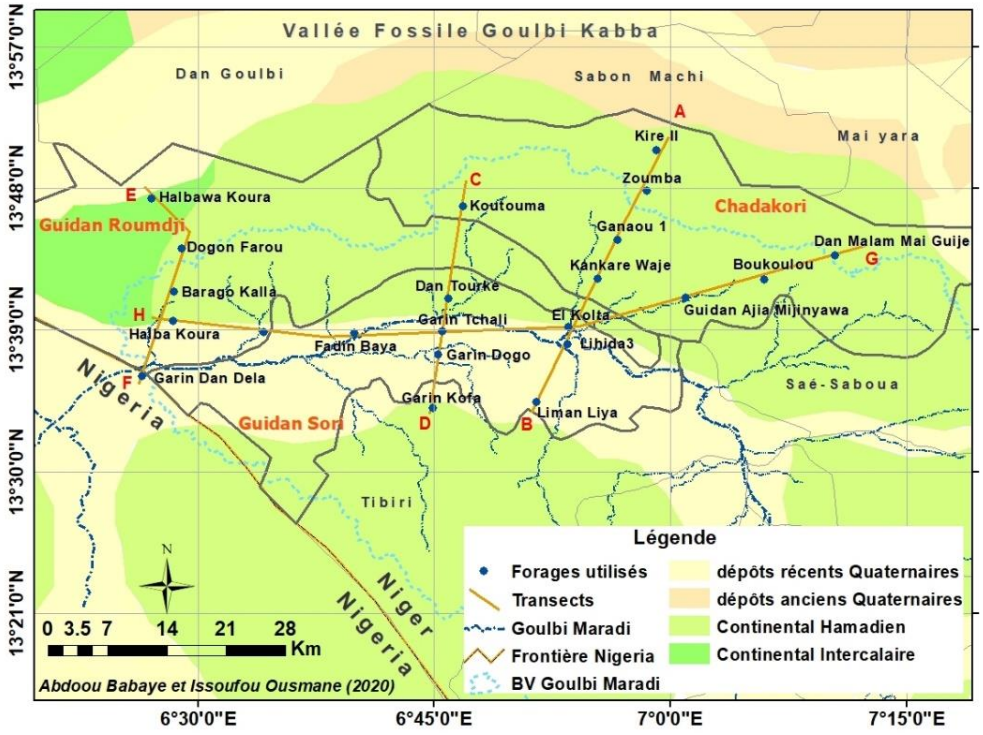

Figure 2: Principal Aquifers in Three Maradi Communes (modified from Babaye and Ousmane, 2020)

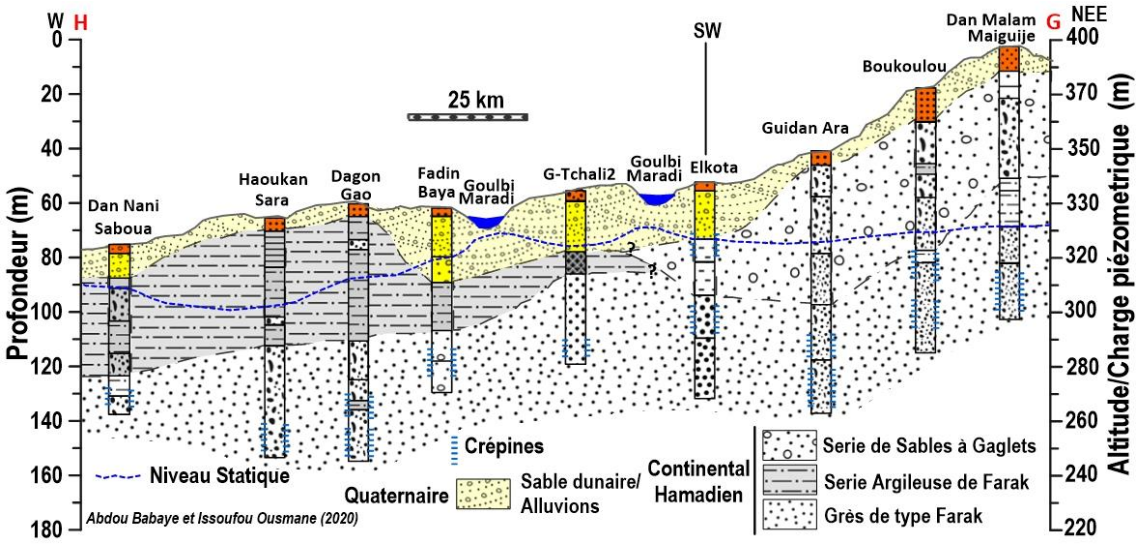

Figure 3: West – East Oriented Hydrogeologic Cross Section H-G, refer to Figure 2 for Section Line (modified from Babaye and Ousmane, 2020)

Zinder Region: Mazamni Commune is underlain by a Basement Rock aquifer system comprised of weathered overburden or saprolite (clay, granite saprolite, silts, and sands) that overlie competent granitic bedrock. Borehole yields in the Basement Rocks are generally low ranging from less than 1 to 2 m^3/h. Borehole drilling failure rates are reportedly greater than 50%.

Gouchi Commune is underlain by three geologic formations that outcrop at different locations: (1) Basement Rocks (Damagaram Massif) of Precambrian Age in the northeast and central northwest; (2) unconsolidated sediments (Korama Sands) of recent Quaternary Age in the north and central areas; and (3) the Malawa Sandstone unit in the southern central commune areas (*Sandao, I., 2015*).

Groundwater recharge to the aquifers is generally from the direct infiltration of precipitation and by the focused infiltration of surface water in seasonal surface drainage networks. As such, the aquifer systems are dependent on annual rainfall and susceptible to climatic variation. Many hand-dug wells dry up in the dry season months, causing some of the population to revert to surface-water ponds for their drinking and household supply.

Methods

Four hundred and sixty-six (466) samples from 278 boreholes and 188 hand dug wells were collected and analyzed for bacteriological quality. Two Wagtech International field-based Potalab kits were used for Total Coliform (TC) and *Escherichia. coli* (*E. coli*) incubation and to determine TC and *E*. *coli* counts. Water samples were filtered

through a 0.45µm paper filter and incubated at 37ºC and 44ºC for TC and *E. coli,* respectively.

The kits were set up at field camps where prescribed bacteriological sample preparation procedures were conducted (Clesceri et al., 1998). The membrane filtration method was used to determine colony counts. Prior to sample collection at each water point, field-level physiochemical parameters (pH, conductivity, and total dissolved solids) were measured. For quality control and assurance purposes, duplicates of every 10^{th} sample were collected and analyzed. The results were reported as colony-forming units per 100 milliliter (CFU/100ml). Positive and negative results are defined in terms of the presence or absence of bacteria tested for in a 100ml water sample.

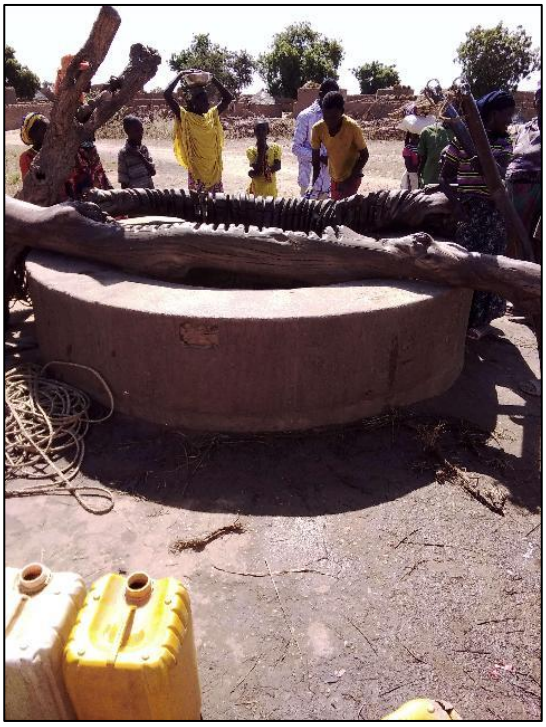

Photo 1: Kouloumbouteye Village (Maradi Region) – Hand-Dug Well with a Measured 51m Depth to Static Water Level

Results and Discussion

Total coliform were detected in 64% of the boreholes and in 87% of the hand-dug wells tested, and *E. coli* bacteria in 37% of the boreholes and 72% of the hand-dug open wells tested in the five communes. The depths to groundwater in these communes ranged from <10 m, bgs to as deep as 90+ m, bgs.

The hand-dug wells are all open and unprotected with multiple pathways for bacteriological contamination input. A primary pathway for bacteriological contamination input of boreholes is via seepage of contaminated water at the wellhead down unprotected (not grouted) borehole-casing annuli.

Photo 2: Handpump with Poor Drainage – Makera Village in Gouchi Commune, Zinder Region

Table 2: Summary of Bacteriological Analyses Results for Boreholes in Maradi and Zinder Regions, Niger

Commune	Number Sampled	Total Coliform (cfu/100ml)		Percent Positive	*E. coli* (cfu/100ml)		Percent Positive
		Positive	Negative		Positive	Negative	
Chadakori	38	14	24	37	5	33	13
Guidan Sori	59	34	25	58	25	34	42
Guidan Roumdji	50	29	21	58	21	29	42
Mazamni	18	11	7	61	5	13	28
Gouchi	113	89	24	79	45	68	40
Totals	**278**	**177**	**101**	**64**	**101**	**177**	**37**

In Maradi Region communes, the *E. coli* results indicate a percent positive range from 13% to 42% of the boreholes tested. In the Zinder Region communes, 28% to 40% of the boreholes tested show *E. coli* occurrence.

The hand-dug well results **(Table 3)** also indicate a very high percentage of the wells tested showed *E. coli* contamination (as high as 91 percent in Guidan Sori Commune sources).

Table 3: Summary of Bacteriological Analyses Results for Hand Dug Wells in Maradi and Zinder Regions, Niger

Commune	Number Sampled	Total Coliform (cfu/100ml)		Percent Positive	*E. coli* (cfu/100ml)		Percent Positive
		Positive	Negative		Positive	Negative	
Chadakori	16	11	5	69	7	9	44
Guidan Sori	33	29	4	88	30	3	91
Guidan Roumdji	84	74	10	88	67	17	80
Mazamni	17	15	2	88	9	8	53
Gouchi	38	35	3	92	23	15	61
Totals	**188**	**164**	**24**	**87**	**136**	**52**	**72**

Conclusions

Causation of Bacteriological Contamination: This study's finding indicated that 64% of the sampled boreholes and 87% of the sampled hand-dug wells are contaminated with Total Coliform and 37% of the sampled boreholes and 72% of the sampled hand-dug wells with *E. coli* bacteria. This contamination was found across all the project communes.

Boreholes, if properly constructed with 10 to 15m of grouted casing, are generally microbial-free. However, these results reveal technical construction defects as well as wellhead management deficiencies that need to be addressed.

Photo 3: Hand Pump with Poor Drainage –
Galmeri Village in Mazamni Commune, Zinder Region

Photo 4: Poor Drainage Around a Hand-Dug Well – Magelwa Kaba Village in Gouchi Commune, Zinder Region

Photo 5: Poor well head construction Drainage around Hand Pump

The presence of elevated levels of total coliform and *E. coli* bacteria in the borehole samples can be attributed to a number of factors including:

- Improper grouting of the annular space between the drilled borehole and casing during borehole construction. Such gaps provide a pathway for contaminated water migration into the borehole via the casing annulus pathway. This is a very common occurrence in the industry and can only be mitigated by developing and disseminating “construction standards”, construction supervision, and enforcement.

- Deterioration of wellhead cement pads allowing contaminated water to infiltrate along the borehole casing - annulus pathway into the borehole.

- Poor wellhead management in terms of drainage of water away from the borehole, and animal grazing at the borehole area.

- Leaky pump heads and missing pump parts allowing entranceways for water into the pump column.

- Inappropriate handling and non-disinfection of boreholes after repairs of broken-down pumps.

The poor bacteriological water quality of hand-dug wells is due to:

- Open and unprotected well designs with exposure to the environment and the use of inappropriate water-collection receptacles.

- Poor drainage away from the wellheads which allows stagnation and infiltration of bacteriologically contaminated water down the well/borehole casings **(Photos 2, 3, & 4).**

- Failure to appropriately protect and manage the water facilities. Village water management structures exist in some villages but are inactive in many.

Recommended Corrective Actions

Regulatory – Governmental and Donor Community

- Develop construction standards for borehole casing grouting practices that require inspections by public health officials/donor representatives during casing grouting of new boreholes.

- Driller training.

Wellhead Improvements:

- Repair of wellhead drainage systems to prevent contaminated water infiltration into the boreholes.

- Enhancement of the capacity of the village management teams and the reorganization of management systems that incorporate a WASH behavioral change communication approach.

Corrective Action Approaches:

- Boreholes that show the presence of *E. coli* bacteria should be re-visited and a program initiated that focuses on:
    - Wellhead and casing annulus cementing repairs.
    - Drainage system improvement
    - Comprehensive borehole rehabilitation
    - Regular inspection by the relevant authority/NGO

- The implementation of semi-annual testing programs for hand-dug wells and boreholes that are used for drinking water for total coliform and *E. coli* analysis.

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