ASSESSING THE SANITARY AND MICROBIAL RISK ASSOCIATED WITH HAND-DUG WELLS

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Abstract: The sanitary and microbial risk assessment of the hand-dug wells in Oproama Community was undertaken between February 2010 and January 2011. The sanitary risk assessment of the hand-dug wells reveals very high risk (8-10) based on physical protection of the water point; distance to sources of contamination and open defecation. The quantitative microbial risk assessment (QMRA) of the hand-dug wells for *Escherichia coli* (9.69E03-2.21E03), *Vibrio* sp (1.53E09 - 3.14E09) and *Salmonella* sp. (1.59E09 - 2.83E09) far exceed the risk level of 1.0E-06 (10^{-6}) suggested by the World Health Organisation and indicate a potential health hazard to the consumers in Oproama. The study however, shows how sanitary inspection and QMRA can be used in areas with limited data, and that the outcome can provide valuable information for the management of water supplies.

Keywords: *Escherichia* ***coli,*** **Hand-dug well, Microbial risk, Sanitary,** ***Salmonella, Vibrio***

Introduction

The modern world is aware of the relationship between water and waterborne disease as a vital public issue. Throughout the world, about 2.3 billion people suffer from diseases that are linked to water related problems (WHO, 1997), which, continue to kill millions of people yearly, debilitate billions, thereby undermining developmental efforts (Nash, 1993; Olshansky *et al.*, 1997). In rural settings in the Nigeria's Niger Delta area, major sources of water for drinking and domestic purposes are: rivers/creeks/streams/pond, hand-dug wells and harvested rain water (FGN, 2000). The provision of potable water has been a major problem in Nigeria, a characteristic feature of developing countries (Ashbolt, 2004). For many years the water sector has relied upon compliance with end-product standards to ensure water safety. Recently, the water sector has begun moving towards the use of risk assessment coupled with risk management as a more effective tool for the control of water safety (Deere *et al.*, 2001; Davison *et al.*, 2005). In the 3rd edition of its Guidelines for Drinking-Water Quality (2004) (GDWQ) the World Health Organization (WHO) promotes the use of risk assessment coupled with risk management for the control of water safety in drinking water supplies (Howard *et al.*, 2006). Quantitative microbial risk assessment (QMRA) provides a tool for estimating the disease-burden from pathogenic microorganisms in water using information about the distribution and occurrence of the pathogen or an appropriate surrogate. The major tasks of a QMRA have been defined by Haas and Eisenberg (2001) as exposure assessment, dose-response analysis and risk characterisation. In order to capture and compare the various outcomes from different pathogens, the use of disability adjusted life years (DALYs) has been recommended in risk assessment (Havelaar and Melse, 2003; WHO, 2004). Murray and Lopez (1996) provide data from which to

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calculate DALYs for health effects derived from infection by waterborne pathogens. QMRA is typically confined to individual causative agents and specific disease symptoms rather than undifferentiated health effects (Haas *et al.* 1999). The limited data on pathogens in developing countries requires that a QMRA be based on the occurrence of indicator organisms. Despite the weaknesses of using indicator organisms, Haas *et al.* (1999) believe that many initial QMRAs will have to be performed using data on indicator organisms due to inadequate data for occurrence of pathogens. Although QMRA has been used to estimate disease burden from water supplies in developed countries, the method has not been evaluated in developing countries where relevant data may be scarce (Howard *et al.*, 2006). Therefore, this study aims to assess the sanitary and microbial risk associated with hand-dug wells in Oproama.

Materials and Methods

Oproama Community is in Asari-toru Local Government Area of Rivers State. The Community lies on Latitude 4° 47' and 4 ° 56' North and Longitudes 6° 50' and 6° 41'.

The microbiological (*Escherichia coli*, *Vibrio* sp. and *Salmonella* sp.) quality of water from seven shallow hand-dug wells was evaluated from February 2010 to January 2011 employing membrane filtration. All isolates were characterised and identified according to Harrigan and McCance (1976) and Chesseborough (1984).

Sanitary Assessment

Sanitary inspection is a very useful risk assessment tool. Sanitary inspection survey form was used to yield score which enable field workers to deduce the risk that a source may be contamination. Each water source was assigned a risk-factor score (0 to 10 with 10 indicating conditions most prone to contamination) taking into account its physical condition, degree of protection and proximity to potential sources of contamination (Howard *et al.*, 2003) as shown in Table 1. The risk score according to WaterAid (2007) in Nepal (2011); 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low.

Disease Burden Estimation

A key component in undertaking a Quantitative Microbial Risk Assessment (QMRA) of pathogens is to define what level of disease burden could be ascribed to the specific agent, as expressed in DALYs. The following sub-sections provide a description of how a disease burden for each of the identified pathogens can be calculated. The disease burdens that result provide an indication of the burden associated with each pathogen based on the overall range of impacts expected across a population group.

In order to maintain a consistent comparison across the three pathogens, the health burden for each pathogen was related solely to that associated with diarrhoeal disease and death. The estimate of the years of life lost from premature death (the mortality fraction) and years of life impaired (the morbidity fraction) for each pathogen was calculated using the average life expectancy at birth for Nigeria, 52 years (World Bank, 2012), rather than the global life expectancy that has been used in other assessments (Murray and Lopez, 1996; Havelaar and Melse, 2003) and the mortality burden was based on average age of death of 2.5 years.. The use of the local life expectancy was felt to more realistically reflect the impact of diseases in Nigeria and would avoid all diseases having a very large impact. Ideally in a QMRA, the years of life lost should be based on a weighted average of age of death by age group (Havelaar and Melse, 2003); however, for this simplified risk assessment only a single average expected age of death was used.

The use of national life expectancy does introduce a potential problem, as it distorts the size of disease burdens towards morbidity and mortality of the very young.

However, as with many of the assumptions to which QMRA model predictions are sensitive, such imperfections are only significant when the aim is to compare systems in which very different input data and assumptions might be used. When the aim is to provide a consistent internal QMRA estimate the bias is likely to be close to equivalent for the different scenarios under consideration, neutralising the effect of that bias (Howard et al., 2006).

Escherichia coli

E.coli O157:H7 may be transmitted by a number of routes, but drinking-water is a well-proven route of infection, based on available outbreak data (Hunter, 2003). Havelaar and Melse (2003) developed a risk assessment based on data from The Netherlands for E.coli O157:H7, but noted that there was an absence of data from developing countries on which to base an estimate.

The disease burden for pathogenic *Escherichia coli* was based on the strain with most severe outcomes, E. coli O157:H7. Haas *et al.* (1999) have argued that a reasonable estimate of disease burden for E. coli O157:H7 can be made using the widely published dose-response data for Shigella infections. We have used dose-response estimates for Shigella to provide a generic assessment of risk from waterborne bacteria. For watery diarrhoea and bloody diarrhoea, the proportion of symptomatic cases was 53% and 47%, respectively (Havelaar and Melse, 2003). Kotloff *et al.* (1999) have reported a mortality rate for Shigella infection of 0.7% in developing countries. In this analysis we have used the mortality rate quoted by Kotloff *et al.* (1999) since it is more likely to reflect the higher mortality among children in developing countries.

For this assessment the severity weights for the different outcomes were taken from Havelaar and Melse (2003). The duration of watery and bloody diarrhoea was 3.4 and 5.6 days, respectively.

Vibrio sp.

In this QMRA, mild diarrhoea and severe diarrhoea, the proportion of symptomatic cases was 80% and 20% respectively (WHO, 2012). Adagbada *et al.* (2012) reported a mortality rate of 4.1% for cholera outbreak in Rivers State. The severity weights for the different outcomes were from Havelaar and Melse (2003). The duration of mild and severe diarrhoea was 3 days and 5 days respectively.

Salmonella sp.

The outcomes, gastroenteritis (64%), typhoid fever (35.5%). Mortality rate for gastroenteritis (0.76%) and typhoid fever (0.26%) were reported by Akinyemi *et al.* (2012). The severity weights for different outcomes were taken from Havelaar and Melse (2003). The duration of mild and severe diarrhoea was 5 days.

The data described above is summarised in Tables 2 below that provides an overview of severity, duration and disease burden for the different outcomes in Disease Adjusted Life Years (DALYs) for *Escherichia coli* O157:H7, *Vibrio* sp. and *Salmonella* sp. Table 3 provides the disease burden per 1000 symptomatic cases and this can be used to provide a disease burden per case by dividing by 1000.

Quantitative Microbial Risk Assessment (QMRA)

The disease burden calculated above is used to undertake assessment of water supply. Within this study, the simplified risk assessment approach contained within the 3rd Guidelines of Drinking Water-Quality (2004) is used. To apply the framework, sources of data came from experimentation; review of existing data or from literature. Key aspect assumptions were made include volume of unheated water that is consumed. World Health Organisation (2003) set this at 1 litre per capita per day. The dose response and risk of infection was drawn from the literature based on outbreaks and medical records. The susceptible fraction reflects that only some of the population may be liable to acquire infection on exposure to the pathogen in water. This was given 100% in the case of Oproama as water from hand-dug wells is the only source of drinking and domestic water.

Results

Microbial Estimation

The mean count for *Escherichia coli* ($3.4 \times 10^1 - 6.16 \times 10^2$), *Vibrio* sp. ($1.5 \times 10^1 - 3.2 \times 10^1$) and *Salmonella* sp ($8.5 \times 10^1 - 3.2 \times 10^1$) is given in Table 5

Sanitary Risk Assessment

The sanitary risk assessment of the hand-dug is shown in Table 6. The sanitary result reveals that the number of 'Yes' observations made (risk) ranged from 8 (station 2) to 10 (station 1). The result also shows that the risk involved is between "high risk" and "very high risk".

Quantitative Microbial Risk Assessment

The simplified risk assessment of the each pathogen is presented in Tables 7, 8 and 9. For *Escherichia coli*, the result shows that the Disease Burden is in the range of 9.69E03 (Station 4) to 2.21E04 (Station 1); *Vibrio* sp. has a range of 1.53E09 (Station 6) to 3.14E09 (Station 3), while *Salmonella* sp. has a range of 1.59E09 (Station 7) to 2.83E09 (Station 1).

Table 1. *Sanitary Risk Assessment*

RISK	ST. 1	ST. 2	ST. 3	ST. 4	ST. 5	ST.6	ST. 7
1. Is there a latrine within 10m of the well? Y/N							
2. Is there any other source of pollution within 10m of well? Y/N (e.g. animal breeding, cultivation, open defecation, footpath, waste dump)							
3. Are the ropes and buckets exposed to contamination? Y/N							
4. Is the height of the headwall (parapet) around the well absent? Y/N							
5. Is the apron (cement floor) around the well less than 1m wide? Y/N							
6. Is there poor drainage, allowing stagnant water within 2m of the well? Y/N							
7. Is the drainage channel absent, cracked or broken? Y/N							
8. Are the walls (well-lining/seal) absent? Y/N							
9. Is the fence around the well absent? Y/N							
10. Is the well-cover damage or open? Y/N							
Total Score of Risks …./10							
(No. Of "YES" in the observations made)							

Y: YES N: NO

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

Table 2. Severity, duration and disease burden for pathogens

Pathogen	Outcomes	Severity	Duration	Disease burden (DALY)
Escherichia coli	Watery diarrhoea	0.067	3.4day s	0.0006
	Bloody diarrhoea	0.39	5.6 days	0.0060
	Death from diarrhoea	1	49.5 years	49.5
Vibrio sp.	Mild diarrhoea	0.067	3 days	0.0005
	Severe diarrhoea	0.23	5 days	0.0029
	Death from diarrhoea	1	49.5	49.5
Salmonella sp.	Gastroenteritis	0.23	5 days	0.0029
	Death from gastroenteritis	1	49.5	49.5
	Typhoid fever	0.23	5 days	0.0029
	Death from typhoid fever	1	49.5	49.5

- **Days were converted to years before calculation**

Table 3. Disease burden for Pathogens

Pathogen	Outcomes	Disease burden per 1000 Symptomatic cases		Disease burden (DALY)
Escherichia coli	Watery diarrhoea	1000 x 53% (watery diarrhoea) x 0.067 x 0.009	=	0.3
	Blood diarrhoea	1000 x 47% (bloody diarrhoea) x 0.39 x 0.015	=	2.8
	Death from diarrhoea	1000 x 0.7% (death) x 49.5	=	346.5
	Total diarrhoea only		=	349.6
Vibrio sp.	Mild diarrhoea	1000 x 80%(mild diarrhoea) x 0.067 x 0.008	=	0.43
	Severe diarrhoea	1000 x 20% (severe diarrhoea) x 0.23 x 0.013	=	0.59
	Death from diarrhoea	1000 x 4.1% x 49.5	=	2029.5
	Death from diarrhoea		=	2030.52
***Salmonella* sp.**	Gastroenteritis	1000 x 64% x 0.23 x 0.013	=	1.93
	Death from gastroenteritis	1000 x 0.76% x 51	=	376.2
	Total from gastroenteritis		=	378.13
	Typhoid fever	1000 x 35.5% x 0.23 x 0.013	=	1.06
	Death from typhoid fever	1000 x 0.26% x 51	=	128.7
	Total from typhoid fever		=	129.76
	Total (gastroenteritis and typhoid fever)		=	507.89

Table 4: Simplified Risk Assessment Procedure (Adapted from WHO, 2004)

	Escherichia coli	*Vibrio* sp.	*Salmonella* sp.
Raw water quality, organism per lite (C_R)	Calculated from organisms in samples		
Treatment Effect (PT)	estimated or calculated removal of pathogen		
Drinking water quality (C_D)	C_R x (1-PT)		

Table 4: Simplified Risk Assessment Procedure (Adapted from WHO, 2004)

	Escherichia coli	*Vibrio* sp.	*Salmonella* sp.
Raw water quality, organism per litre (C_R)		Calculated from organisms in samples	
Treatment Effect (PT)		estimated or calculated removal of pathogen	
Drinking water quality (C_D)		C_R x (1-PT)	
Consumption of unheated drinking Water (V)		WHO (2003)	
Exposure by drinking water, organism Per litre (E)		C_D x V	
Dose-response (r)	Rose and Gerba (1991) Haas *et al.* (1999)	FAO/WHO (2005)	Regli ***et al.*(1991)**
Risk of infection per day ($P_{inf,d}$)		E x r	
Risk of infection per year ($P_{inf,y}$)		$P_{inf,y}$ x 365	
Risk of diarrhoea disease given ($P_{ill/inf}$)	**Haas *et al.* (1995)**	Adagbada *et al.* **(2012)**	Akinyemi *et al.* (2012)
Risk of diarrhoea disease (P_{ill})		($P_{inf,y}$) x ($P_{ill/inf}$)	
Disease burden (db)	Section 2.14.1	Section 2.14.2	Section 2.14.3
Susceptible fraction (fs)		From Study Area	
Disease Burden (DB)		P_{ill} x db x fs	

Table 7. Simplified Risk Assessment for *Escherichia coli*

	STN 1	STN 2	STN 3	STN 4	STN 5	STN 6	STN 7
Raw water quality, organism per litre (C_R)	716667	483333	491667	341667	533333	616672	316667
Treatment effect (P_T)	0	0	0	0	0	0	0
Drinking water quality (C_D)	7.16E05	4.83E05	4.91E05	3.14E05	5.33E05	6.16E05	3.16E05
Consumption of unheated drinking	1	1	1	1	1	1	1

Table 5. Mean Count of *Escherichia coli*, *Vibrio* sp. and *Salmonella* sp. (cfu/ml)

Organism	Stations						
	1	2	3	4	5	6	7
Escherichia coli,	$7.1x10^1$	$4.8 x10^1$	$4.91 x10^2$	$3.4 x10^1$	$5.3 x10^1$	$6.16 x10^2$	$3.16 x10^2$
Vibrio sp.	$2.2 x10^1$	$2.8 x10^1$	$3.2 x10^1$	$2.3 x10^1$	$2.2 x10^1$	$1.5 x10^1$	$1.6 x10^1$
Salmonella sp.	$1.47 x10^2$	$1.06 x10^2$	$9.3 x10^1$	$9.6 x10^1$	$1.25 x10^2$	$8.9 x10^1$	$8.2 x10^1$

Table 6. Sanitary Risk Assessment

RISK	ST. 1	ST. 2	ST. 3	ST. 4	ST. 5	ST.6	ST. 7	
1. Is there a latrine within 10m of the well? Y/N		Y	N	N	N	N	N	N
2. Is there any other source of pollution within 10m of well? Y/N (e.g. animal breeding, cultivation, open defecation, footpath, waste dump)	Y	Y	Y	Y	Y	Y	Y	
3. Are the ropes and buckets exposed to contamination? Y/N		Y	Y	Y	Y	Y	Y	Y
4. Is the height of the headwall (parapet) around the well absent? Y/N	Y	N	Y	Y	Y	N	Y	
5. Is the apron (cement floor) around the well less than 1m wide? Y/N	Y	Y	Y	Y	Y	Y	Y	
6. Is there poor drainage, allowing stagnant water within 2m of the well? Y/N	Y	Y	Y	Y	Y	Y	Y	
7. Is the drainage channel absent, cracked or broken? Y/N	Y	Y	Y	Y	Y	Y	Y	
8. Are the walls (well-lining/seal) absent? Y/N		Y	Y	Y	Y	Y	Y	Y
9. Is the fence around the well absent? Y/N	Y	Y	Y	Y	Y	Y	Y	
10. Is the well-cover damage or open? Y/N	Y	Y	Y	Y	Y	Y	Y	
Total Score of Risks ..../10 (No. Of "YES" in the observations made)	**10**	8	9	9	9	9	9	

Y: YES N: NO

Risk score: 9-10 = Very high; 6-8 = High; 3-5 = Medium; 0-3 = Low

Table 7. Simplified Risk Assessment for *Escherichia coli*

	STN 1	STN 2	STN 3	STN 4	STN 5	STN 6	STN 7
Raw water quality, organism per litre (C_R)	716667	483333	491667	341667	533333	616672	316667
Treatment [illegible] ([illegible])	0	0	0	0	0	0	0
Drinking water quality (C_D)	7.16E05	4.83E05	4.91E05	3.14E05	5.33E05	6.16E05	3.16E05
Consumption of unheated drinking [illegible]	1	1	1	1	1	1	1
Exposure by drinking water, organism Per litre (E)	7.16E05	4.83E05	4.91E05	3.14E05	5.33E05	6.16E05	3.16E05
Dose-response (r)	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Risk of infection per day ($P_{inf,d}$)	7.16E02	4.83E02	4.91E02	3.14E02	5.33E02	6.16E02	3.16E02
Risk of infection per year ($P_{inf,y}$)	2.16E05	1.77E05	1.79E05	1.14E05	1.95E05	2.24E05	1.15E05
Risk of diarrhoea disease given infection ($P_{ill/inf}$)	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Risk of diarrhoea disease (P_{ill})	6.52E04	4.42E04	4.47E04	2.85E04	4.87E04	5.60E04	2.87E04
Dis[illegible]	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Suscep[illegible]	1	1	1	1	1	1	1
Disease Burden (DB)	2.21E04	1.50E04	1.51E04	9.69E03	1.65E04	1.90E04	9.75E03

Table 8. Simplified Risk Assessment for *Vibrio* sp.

	STN 1	STN 2	STN 3	STN 4	STN 5	STN 6	STN 7
Raw water quality, organism per litre (CR)	22442	28417	32700	23958	22035	15867	16889
Treatment Effect (PT)	0	0	0	0	0	0	0
Drinking water quality (CD)	2.24E04	2.84E04	3.27E04	2.39E04	2.20E04	1.58E04	1.68E05
Consumption of unheated drinking Water (V)	1	1	1	1	1	1	1
Exposure by drinking water, organism Per litre (E)	2.24E04	2.84E04	3.27E04	2.39E04	2.20E04	1.58E04	1.68E05
Dose-response (r)	1.00E06	1.00E06	1.00E06	1.00E06	1.00E06	1.00E06	1.00E06
Risk of infection per day (Pinf,d)	2.24E11	2.84E11	3.27E11	2.39E11	2.20E11	1.58E11	1.68E11
Risk of infection per year (Pinf.y)	8.17E13	1.03E14	1.19E14	8.72E13	8.03E13	5.67E13	6.13E13
Risk of diarrhoea disease given Infection (Pill/inf)	1.31E-05	1.31E-05	1.31E-05	1.31E-05	1.31E-05	1.31E-05	1.31E-05
Risk of diarrhoea disease (Pill)	1.07E09	1.34E09	1.55E09	1.14E09	1.05E09	7.54E08	8.03E08
Disease burden (db)	2.03	2.03	2.03	2.03	2.03	2.03	2.03
Susceptible fraction (fs)	1	1	1	1	1	1	1
Disease Burden (DB)	2.17E09	2.72E09	3.14E09	2.31E09	2.13E09	1.53E09	1.63E09

Table 9. Simplified Risk Assessment for *Salmonella* sp.

	STN 1	STN 2	STN 3	STN 4	STN 5	STN 6	STN 7
Raw water quality, organism per litre (C_R)	147000	106250	93804	96667	125000	89583	82917
Treatment Effect (PT)	0	0	0	0	0	0	0
Drinking water quality (C_D)	1.47E05	1.06E05	9.38E04	9.66E04	1.25E05	8.95E04	8.29E04
Consumption of unheated drinking Water (V)	1	1	1	1	1	1	1

	STN 1	STN 2	STN 3	STN 4	STN 5	STN 6	STN 7
Raw water quality, organism per litre (C_R)	147000	106250	93804	96667	125000	89583	82917
Treatment Effect (PT)	0	0	0	0	0	0	0
Drinking water quality (C_D)	1.47E05	1.06E05	9.38E04	9.66E04	1.25E05	8.95E04	8.29E04
Consumption of unheated drinking Water (V)	1	1	1	1	1	1	1
Exposure by drinking water, organism Per litre (E)	1.47E05	1.06E05	9.38E04	9.66E04	1.25E05	8.95E04	8.29E04
Dose-response (r)	2.36E05	2.36E05	2.36E05	2.36E05	2.36E05	2.36E05	2.36E05
Risk of infection per day ($P_{inf,d}$)	3.46E10	2.50E10	2.21E10	2.27E10	2.95E10	2.11E10	1.95E10
Risk of infection per year ($P_{inf,y}$)	1.26E13	8.75E12	8.06E12	8.28E12	1.07E13	7.70E12	7.11E12
Risk of Salmonella associated disease given infection ($P_{ill/inf}$)	4.5E-04	4.5E-04	4.5E-04	4.5E-04	4.5E-04	4.5E-04	4.5E-04
Risk of Salmonella associated disease (P_{ill})	5.67E09	3.93E09	3.62E09	3.72E09	4.81E09	3.46E09	3.19E09
Disease burden (db)	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Susceptible fraction (fs)	1	1	1	1	1	1	1
Disease Burden (DB)	2.83E09	1.96E09	1.81E09	1.86E09	2.40E09	1.73E09	1.59E09

shown that scaling up such water sources remains risky to people's health and counterproductive to achieving the Millennium Development Goals (MDGs) on widening access to safe and clean water.

Sanitary surveillance should be carried out periodically to ensure that the sanitary condition around these water-points (hand-dug wells) is conducive to the preservation of safe drinking water. Secondly, proper drainage channels should be constructed around these water-points to keep away stagnant water that may contribute to the pollution of the wells. Thirdly, water chlorination of all water-points should be embarked upon including the advocacy of point-of-use (households use) treatment and safe storage practices of water. Finally, the Niger Delta Development Commission (NDDC) should complete the abandon water scheme project in the Community.

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