Water Quality Analysis of the Piped Water Supply in Tamale, Ghana

by

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B.A., Physics
University of Minnesota Morris, 2013

Submitted to the Department of Civil and Environmental Engineering
in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering in Civil and Environmental Engineering
at the
Massachusetts Institute of Technology

June 2014

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Abstract

The United Nation's Millennium Development Goal Target 7.C is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water". While the UN claimed to have met this goal, studies have shown that the "improved" sources used as a metric to track progress do not always supply safe water. One example of these improved sources is the piped water in Tamale, Ghana, which is an intermittent system. The question raised and goal of this research is to determine whether this water source is indeed safe.

The Ghana Water Company Ltd. in Tamale had handwritten notebooks containing almost ten years of water quality sample data. This data was entered into a computer database so it could be analyzed for seasonal and geographic trends as well as to gain an understanding of overall water quality. From this analysis, it was concluded that seasonal trends do impact the pH and turbidity of source water which influences the water provided to consumers. In addition, 42% of samples did not comply with accepted World Health Organization guidelines for residual free chlorine concentrations. Total coliform was present in 2% of samples. Observations of environmental factors made during field work in Tamale found five "no" answers to a sanitary survey indicating at least a medium contamination risk. Overall, these observations indicate that water from the piped network in Tamale is not always safe. Contamination also happens very readily during storage due to high usage of unsafe storage containers in Tamale combined with the low chlorine residuals.

Thesis Supervisor: Susan Murcott
Title: Senior Lecturer of Civil and Environmental Engineering

Acknowledgements

First of all, I thank God for blessing me with the incredible experience I had during my year at MIT and for health and safety during field work in Ghana.

I would like to thank my adviser, Susan Murcott, for sharing all her knowledge with me this year, for her advice and support for my research, and for encouragement in my future plans.

Thank you to Alison Hynd and the MIT Public Service Center for providing funding and support for my field work in Tamale.

I would like to thank Mr. Edward Agyekum, Mr. Yakubu Adam, and Mr. Henry Quarcoo at the Ghana Water Company Limited, Tamale office for allowing me to collaborate with them and for sharing their water quality data, without which this project would not have been possible.

Thank you to fellow teammate, Reed Miller, for teaching me Microsoft Access, helping me set up a database, reading my draft, providing advice on data analysis, and keeping us smiling while in Tamale.

A huge thank you to the MIT Graduate Christian Fellowship, especially the Sidney Pacific small group (#2), for continually providing support, encouragement, ideas, and even helping with data entry.

My professors from the University of Minnesota Morris taught me how to work hard and think hard. Without the foundation they provided, I would not have had such a successful time at MIT. Thank you.

Finally, thanks to all my Ghana teammates for friendship and support both while in Ghana and throughout the year.

Abbreviations and Acronyms

CDC	Centers for Disease Control
DMA	District Metered Area
GIS	Geographic Information Systems
GWCL	Ghana Water Company Limited
IBNET	International Benchmarking Network for Water and Sanitation Utilities
JMP	Joint Monitoring Program
MCL	Maximum Contaminant Level
MDG	Millennium Development Goal
M.Eng	Master of Engineering
MIT	Massachusetts Institute of Technology
MPN	Most Probable Number
NTU	Nephelometric Turbidity Unit
RADWQ	Rapid Assessment of Drinking-Water Quality
SDWA	Safe Drinking Water Act
SWMM	Storm Water Management Model
TCU	True Color Unit
TDS	Total Dissolved Solids
TTC	Total Thermotolerant Coliforms
UNICEF	United Nations Children's Emergency Fund
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

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1 Introduction

Last year, M.Eng. student Deborah Vacs Renwick began a collaboration with the Ghana Water Company Ltd. (GWCL) in Tamale, Ghana and began researching the quality of water coming from the piped supply. She proposed a few research projects as a continuation of her work to continue exploring the issues surrounding water supply and water quality in a developing country. The goal and objectives of this research are based upon those recommendations.

1.1 Importance of Safe Water

Having access to safe water is something no human being should be without. Current estimates state that there are two billion people in the world who lack access to safe drinking water (Onda, LoBuglio, and Bartram 2012). The implications of drinking unsafe, contaminated water are numerous and still not fully understood. Drinking microbially contaminated water leads to diarrheal diseases, such as cholera. Each year about 760,000 children under the age of five die from diarrheal disease and it is the second leading cause of death in children (WHO 2014). Additionally, diarrheal disease weakens the immune system leading to higher risk of other diseases as well. There are also a number of other diseases, such as guinea worm, which are transmitted through contact with contaminated water when people use contaminated surface waters for drinking and washing. Further, high frequency of diarrheal episodes in children leads to environmental enteropathy which is the decreased ability of the intestine to absorb nutrients. This leads to malnutrition which has even more implications such as stunting and decreased intelligence (Korpe and Petri 2012). Overall, having access to safe drinking water is a major factor in preventing deaths and improving quality of life for low-income households around the world.

1.2 Goal

In 2000, the United Nations issued a set of Millennium Development Goals which were created to eliminate global poverty. One of these goals, Target 7.C, is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" ("United Nations Millennium Development Goals" 2014). Although the UN declared the goal for drinking water has been met, further studies have shown that the improved sources used as a metric (see Section 2.3) for determining safe water are not always safe. This begs the question: is the piped water in Tamale, which would be classified as an improved source, actually safe? Finding the answer to this question was the overall goal of this research project.

1.3 Objectives

In order to achieve the goal, two objectives were pursued.

1. Vacs Renwick identified a set of notebooks at the GWCL Water Quality Laboratory which contained historical water quality data. These records were all handwritten with

very little computerized entry and no analysis done on historical trends. In order to see what the water quality in Tamale has been in the past and to look for trends which can help improve the quality for the future, the handwritten records were entered into a database and spreadsheet.

2. The pipe distribution network in Tamale has not been modelled. Due to the intermittency of the system and lack of pressure contaminants may be entering the pipes. By creating a hydraulic model of the system it might be possible to locate areas at risk of allowing contaminants in due to lack of pressure. A theoretical model could also be compared to measured flow and pressure data. Breaks in pipes and illegal connections could be located by finding areas where measured data differs from theoretical values.

2 Background

2.1 Tamale

Tamale is the capital city of the Northern Region of Ghana and is the third largest city in Ghana. The metropolitan Tamale area has a population of 371,351 people as of the 2010 census. A map showing the location of Tamale is seen in Figure 2-1.

Figure 2-1: Map of Ghana

2.2 The Ghana Water Company Ltd.

2.2.1 History

The Ghana Water Company Ltd. (GWCL) was created in 1999 as an entirely state-owned liability. Prior to its creation, municipal water in Ghana was under the Ghana Water and Sewerage Corporation (GWSC) (GWCL 2012). The GWCL has a district office in Tamale that oversees the distribution system in Tamale as well as Yendi, a nearby city to the East. The water supply for Tamale was first constructed in 1972. In response to a rapidly growing population, an expansion to the system was done in 2008 by a UK-based company, Biwater, in partnership with the GWCL. This upgrade more than doubled the capacity of the treatment plant from 19 to 44 million liters per day. The project also included maintenance to the existing distribution system, such as replacing pumps and pipes, and adding new distribution mains to increase the service area. In addition, in response to problems with non-revenue water, District Meter Areas (DMAs) were created. A DMA is an area of the distribution system with a single inlet and outlet. Pressure and flow data for water through each DMA can be collected to determine how much water is being lost (Biwater 2014).

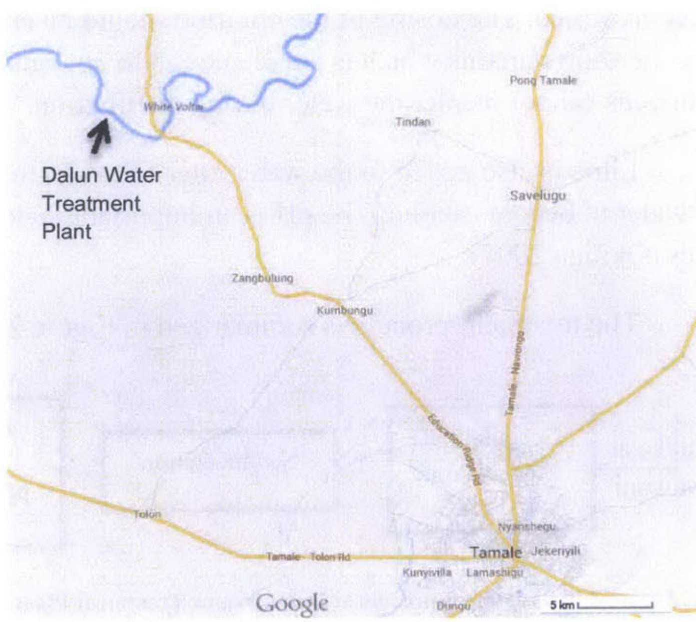


Figure 2-2: Location of water source with respect to Tamale (Google)

2.2.2 Dalun Water Treatment Plant

The water supplied to Tamale comes from the White Volta River (Figure 2-2). Water is pumped to the treatment plant from an intake point located at the village of Nawuni. The Dalun Water Treatment Plant, 35 kilometers north of Tamale, is responsible for treating the raw water. (Note: The author did not have the opportunity to visit the Dalun WTP. The following description of the treatment plant was provided by a previous Master of Engineering student from a visit prior to the 2008 upgrade. Therefore, it is possible that the process may have some differences today.)

The first step in the treatment process is coagulation and flocculation to remove most of the solids from the water. Aluminum sulfate is added to water which is then rapidly mixed. The aluminum sulfate causes the small suspended solids in the water to clump together forming larger flocs which settle out by gravity. The concentration of aluminum sulfate and the mixing speed are determined by jar tests in which the process is simulated on a smaller scale using one to two liters of water and varying doses of the coagulant.

After flocculation, the water goes into sedimentation tanks where solids settle out of the water by gravity. The sludge formed from the particles is mechanically raked from the bottom of the tanks and removed.

Now that the larger particles are removed from the water, the next step in the treatment process is rapid sand filtration to remove the remaining suspended solids from the water and reduce turbidity. In rapid sand filtration, water is passed through a layer of sand via pressure. Filters are regularly cleaned by backwashing when the head becomes too small for the filtration rate.

Chlorine gas is added to the water after filtration as a disinfectant so any pathogens in the water are killed. The dosing of the chlorine should be enough so that a small residual concentration remains which is small enough to not cause taste and odor but large enough so that pathogens cannot reenter the water during distribution.

Lime is also added to the water after filtration to raise the pH, as aluminum sulfate causes the water to become acidic. The pH is an important factor in preventing corrosion of distribution pipes (Okioga 2007).

The treatment process is summarized in Figure 2-3.

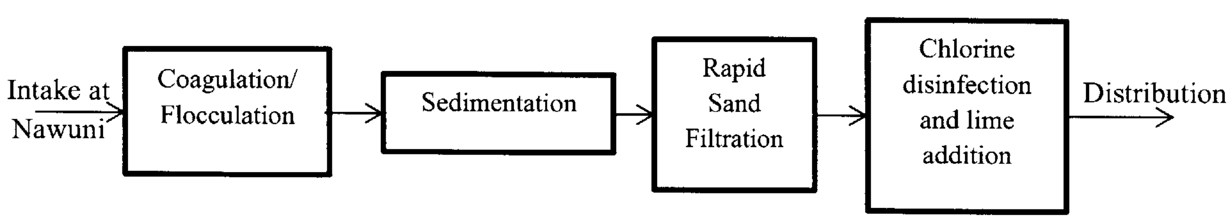


Figure 2-3: Treatment process at Dalun Water Treatment Plant

2.3 Millennium Development Goals

2.3.1 Background

The Millennium Development Goals (MDG) were created by the United Nations in September 2000 to get nations to work together to minimize global poverty. Eight goals were set to: eradicate extreme poverty and hunger; achieve universal primary education; promote gender equality and empower women; reduce child mortality; improve maternal health; combat HIV/AIDS, malaria, and other diseases; ensure environmental sustainability; and develop a global partnership for development with a deadline of 2015 ("United Nations Conferences, Meetings and Events" 2014).

2.3.2 Target 7.C

Target seven of the MDGs in to ensure environmental sustainability. Under that heading, Target 7.C is to "halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation" ("United Nations Millennium Development Goals" 2014)

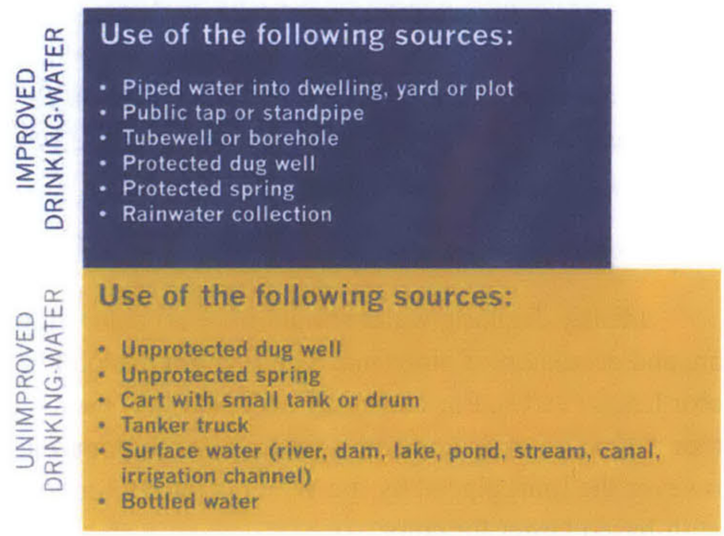


Figure 2-4: JMP Drinking-water ladder (WHO/UNICEF)

In order to monitor the progress towards this goal, the Joint Monitoring Program (JMP) was created between the World Health Organization and UNICEF. The JMP tracks access to safe drinking water by measuring the proportion of the population using an improved drinking-water source. To determine what qualifies as an *improved* drinking-water source the JMP uses a water ladder which ranks water sources from unsafe to safe and defines which are considered improved. The drinking-water ladder is shown in Figure 2-4. Overall, improved sources are ones in which water is protected from outside contamination via an infrastructure improvement (WHO - UNICEF 2013).

2.4 Water Quality Standards

2.4.1 World Health Organization

The World Health Organization (WHO) provides a standard for drinking water quality around the world in *Guidelines for Drinking-water Quality* which is currently in its fourth edition. This publication provides guidelines for a vast array of chemical, microbial, and radiological contaminants commonly found in drinking water. The WHO has health-based targets for many of the contaminants. A health-based target is defined as, "measurable health, water quality or performance objectives that are established based on a judgment of safety and on risk assessments of waterborne hazards." *Guidelines for Drinking-water Quality* also provides a framework for achieving safe drinking water by implementing health-based targets, creating a water safety plan, and maintaining water surveillance.

The guidelines presented for the parameters measured by the GWCL are as follows:

Chlorine:

Chlorine is added to drinking water during the treatment process as a disinfectant to kill pathogens. The WHO suggests a health-based target of less than 5 mg/l. Chlorine does have an effect on the taste of the water and can be detected by consumers at concentrations as low as 0.3 mg/l. In order to ensure drinking water remains free of pathogens and is not re-contaminated during the distribution process, it is important to have a residual level of free chlorine at the point of use. A minimum level of 0.2 mg/l of free residual chlorine is suggested. The WHO also remarks that "for effective distribution, there should be a residual concentration of $\geq$0.5 mg/l after at least 30 min contact time at pH $<$8.0."

Color:

Ideally drinking water should have no color, however organic materials, metals such as iron, and corrosion of pipes may cause slight discoloration of water. Color is measured in True Color Units (TCU). For consumer acceptability, the WHO suggests an upper limit of 15 TCU. Color can be an indicator of the presence of contaminants in the water and should be monitored. However the limit placed by the WHO is purely for aesthetic purposes and they do not provide a health-based target for color.

Conductivity:

Conductivity is a measure of the capacity of water to carry electric charge and is used as an indicator of the amount of total dissolved solids (TDS). Very high conductivity can be an indicator of contamination, but the effect of TDS on taste is why it is usually measured. The WHO does not have a health-based guideline for conductivity, but does recommend water to be less than 1400 µS/cm which is relative to 1000 mg/l TDS, the level at which drinking water becomes "significantly and increasingly unpalatable".

pH:

The WHO does not have a health-based target for drinking water, however the pH is important in the effectiveness of disinfection and impacts corrosion of pipes. A pH of less than 8.0 is most effective for chlorine disinfection, but pH less than 7 has a higher likelihood of being corrosive, although alkalinity and calcium content also influence corrosivity. The best pH for a system varies depending on the specific parameters of a system, however the WHO does suggest a range of 6.5 to 8.5 .

Turbidity:

Turbidity is a measure of light transmission through water which is influenced by the organic and inorganic particles suspended in the water. Turbidity can be an indicator of microbial contamination as microorganisms like to attach to these particles. In the treatment process, lowering turbidity through coagulation, sedimentation, and filtration prior to disinfection makes the disinfection much more efficient as the pathogens attached to particles are removed. Turbidity increase during distribution may be indicative of biofilms inside pipes or of outside contamination entering pipes. Turbidity also affects the physical appearance of the water so visibly turbid water (>4 NTU) is less likely to appeal to the consumer. The unit of turbidity measurement is the Nephelometric Turbidity Unit (NTU). The WHO suggests a maximum of 1 NTU prior to disinfection although <0.5 NTU and an average of 0.2 NTU or less is encouraged for large municipal supplies. The WHO also suggests a maximum of 5 NTU with a goal of 1 NTU for small supplies lacking resources as may be applicable to Tamale.

Temperature:

The WHO does not have any specific guidelines for water temperature but it is noted that higher water temperatures are less pleasing to consumers and warm water encourages microorganism growth.

Total Coliform Bacteria and *E. coli*:

Because there are a plethora of pathogens that can be present in drinking water, it is not feasible or cost-effective to test for all of them. In order to monitor microbial quality of drinking water, certain indicator organisms can be measured to test for fecal pollution. The criteria for these non-pathogen fecal indicators includes universal presence in human and animal feces, does not multiply in water, behaves and responds to treatment similarly to fecal pathogens, and can be easily measured. The most common fecal indicator is *Escherichia coli* (*E. coli*). The guideline value presented by the WHO for *E. coli* is that it "must not be detectable in any 100 ml sample."

Total coliform includes *E. coli* as well as a wide range of other bacteria, traditionally including *Citrobacter, Klebsiella,* and *Enterobacter.* Although it does not meet all the criteria for being a fecal indicator, total coliform can also be measured to monitor the cleanliness of the distribution system, to indicate level of disinfection, and to detect the formation of biofilms (WHO 2011).

2.4.2 U.S. EPA

The United States Environmental Protection Agency (US EPA) regulates the contaminant levels in drinking water under the Safe Drinking Water Act (SDWA). The SDWA also has requirements for monitoring water quality. States may choose to follow the limits set by the US EPA or they may choose to set their own standards, although their standards must be at least as stringent as those set by the US EPA. Although the U.S., being a developed country, has resources to ensure much more stringent regulations on drinking water than Ghana, it is useful to compare the U.S. standards with those accepted by the WHO as well as Ghana.

The EPA created National Primary Drinking Water Regulations which list contaminants along with a maximum contaminant level (MCL) and a public health goal. The health goal is based upon the risk of the contaminant to the most severely impacted groups, such as infants or the elderly. The MCL is then set to a level that can be regulated and must be attainable by treatment plants. The standards set by the SDWA are as follows:

Chlorine:

Chlorine is noted to cause eye/nose irritation and stomach discomfort. As having a chlorine residual is important to ensure disinfection of water at the tap, rather than being designated an MCL and public health goal, chlorine has a maximum residual disinfectant level and a maximum residual disinfection goal of 4.0 mg/l.

Color:

For some drinking water parameters, such as color, the EPA provides secondary MCLs which are non-enforceable guidelines (unless a state chooses to enforce them) and deal mostly with cosmetic effects rather than public health effects. The secondary MCL suggested by the EPA for color is 15 TCU.

pH:

The EPA suggests that the pH for drinking water should be between 6.5 and 8.5.

Turbidity:

Rather than an MCL and health goal, turbidity is regulated by treatment technique. If a system uses conventional or direct filtration the turbidity must never be greater than 1 NTU and 95 percent of samples each month must be less than or equal to 0.3 NTU. If a different filtration method is used, then other state limits are followed, but turbidity must always be lower than 5 NTU. There is not a public health goal for turbidity.

Total Coliform:

The MCL for total coliform is designated as, "no more than 5.0 percent samples total coliform-positive per month." If the total coliform test is positive, the sample must also be tested for fecal coliform or *E. coli*. The system has an acute MCL violation if the fecal coliform or *E. coli* test is positive. The public health goal is that zero total coliform is present in drinking water.

E. Coli:

If a sample tests positive for *E. coli,* repeat sampling and analyses are conducted. If a repeat sample is also positive for *E. coli* the MCL is violated. The public health goal for *E. coli* is zero counts per 100mL sample (US EPA 2009).

2.4.3 Ghana Standards

The Ghana Standard No. 175-1:2008 outlines water quality standards for municipal drinking water. The standards it cites are a minimum free chlorine residual of 0.2 mg/l (the standards actually state this is a "maximum" value, which is believed to be a typographical error) as well as no positive *E. coli* detected in a 100mL sample (Ghana Standards Board 2008).

In addition, making use of the Excel spreadsheet used by the Tamale GWCL (further discussed in Section 4.1), an idea of how they define "compliance" can be gained. The spreadsheet calculates a "percent complying" for the following parameters based upon these criteria:

- pH between 6.5 and 9
- Color less than 15 TCU
- Turbidity less than 5 NTU
- Residual chlorine greater than 0.1 mg/l (assuming free chlorine is meant)
- *E. coli* should have 0 counts in 100mL sample

As seen in the values used for their compliance percentage, the color, turbidity, and *E. coli* values align with WHO guidelines and EPA standards, while the pH range and residual chlorine values are not as stringent as WHO guidelines.

2.4.4 Chlorine Chemistry

Because residual chlorine concentrations are so important in continuing to provide continuing disinfection both during and after treatment it is important to understand how chlorine disinfects and how it can be measured.

When chlorine is added to water it forms hydrochloric acid which kills microorganisms through oxidation. "Available chlorine" is the initial amount of chlorine dosed into the water. It takes some amount of contact time for chlorine to kill these microorganisms. The contact time required for inactivation of a pathogen depends on the pathogen being removed and its resistance to chlorine. After that time some of the chlorine, the "consumed chlorine", has oxidized with organic matter and inactivated pathogens and is no longer available for further disinfection. New chlorine compounds can also be formed through reactions with other organic matter and is called "combined chlorine". Finally, some of the available chlorine is still left in the water which is still available to kill more pathogens. This is "free chlorine" and is the concentration that is of the most interest when looking at water quality at the tap. Having a free chlorine residual means that pathogens that enter the water during distribution or during storage can still be killed (CAWST 2009).

Measuring residual chlorine takes two forms: free chlorine or total chlorine. Free chlorine residual is simply the concentration of chlorine still available for disinfection. Total chlorine measures consumed, combined, and free chlorine and does not specify how much is available versus how much is already used (CAWST 2009). The water quality standards above designate free residual chlorine when recommending values for water safety.

3 Literature Review

3.1 Water Quality of Improved Sources

The drinking water quality ladder used to evaluate progress on MGD 7.C, as discussed in Section 2.2.2, categorizes drinking water sources into improved and unimproved sources. Improved sources are considered to be safe while unimproved are unsafe. Based upon this metric the United Nations declared that the goal for safe drinking water has been met claiming that, "At the end of 2010, some 89 per cent of the world's population, or 6.1 billion people, used improved drinking water sources, according to the report. That figure is one per cent more than the 88 per cent stated in the MDG targets" (United Nations News Service Section 2012). However, further studies have been finding that even improved sources, such as piped water supply like that in Tamale, still have "significant sanitary risks" (Onda, LoBuglio, and Bartram 2012).

In 2012, WHO and UNICEF partnered to look further into the actual water quality of the improved sources measured by the JMP in their "Rapid Assessment of Drinking-Water Quality" (RADWQ). The RADWQ involves an in-depth determination of sample sizes and locations of improved sources to be tested. The selected points are then tested for total thermotolerant coliforms (TTC), turbidity, pH, chlorine residuals, and a sanitary inspection is performed. The sanitary inspection provides information on the environment surrounding a source to determine the potential risk for water to become contaminated, even if water quality analyses deem it safe. It considers ten risk factors which vary depending on the type of source. The sanitary inspection for piped water is broken into the treatment process and the distribution system. The ten parameters for the treatment process are:

1. Are there evident hydraulic surges at the intake? Y/N
2. Are there evident cracks in the pre filters? Y/N
3. Are there leaks in the mixing tank? Y/N
4. Is the mixing tank in an insanitary condition? Y/N
5. Is there evidence of insufficient coagulant dosing (e.g. alum)? Y/N
6. Is any sedimentation tank in an insanitary condition? Y/N
7. Are there mud balls or cracks in any of the filters? Y/N
8. Is the air and water supply distribution in any sand bed uneven? Y/N
9. Are there evident cross connections between backwashed and treated water? Y/N
10. Are free residual chlorine concentrations (minimum 0.2 mg/l) not being achieved? Y/N

and for the distribution system:

1. Do any taps or pipes leak at the sample site? Y/N
2. Does water collect around the sample site? Y/N
3. Is the area around the tap insanitary? Y/N
4. Is there a sewer or latrine within 30 m of any tap? Y/N
5. Has there been discontinuity in the last 10 days? Y/N
6. Is the supply main pipeline exposed in the sampling area? Y/N

7. Do users report any pipe breaks within the last week? Y/N
8. Is the supply tank cracked or leaking? Y/N
9. Are the vents on the tank damaged or open? Y/N
10. Is the inspection cover or concrete around the cover damaged or corroded? Y/N

The source is given a score out of ten. Sources with "no" scores between 9-10 are very high risk, 6-8 are high risk, 3-5 are medium risk, and 0-2 are low risk. The RADWQ has been performed in five pilot countries: Ethiopia, Jordan, Nicaragua, Nigeria, and Tajikistan (WHO and UNICEF 2012).

The WHO took the data from the RADWQ for the five pilot countries and compared it to the data from the JMP for the same countries. They found that there were significant proportions of improved sources did not have water that met the standards for drinking water from the WHO. Table 3-1 shows the results of the improved source testing. As seen in the table, in all of the countries monitored, the improved sources did not have one-hundred percent compliance with WHO guidelines. Even piped water supplies were not always providing safe water. Because of the discrepancy between "improved" and "safe", not as many people have access to safe water as initially estimated by the JMP. In addition, the 1990 baseline which was used to set the goal of "halving" was also overestimated. Overall, the WHO found that the MDG target 7.C had not, in fact, been met in the five countries (Bain et al. 2012).

Table 3-1: Results of RADWQ (Bain et. al. 2012)

Compliance of drinking-water sources with WHO guidelines on contamination in five countries, Rapid Assessment of Drinking-Water Quality project, 2004–2005

Improved drinking-water source type,[a] by country	Population coverage[b] (%)	Microbial compliance[c]		Overall compliance[d]	
		Compliant sources (%)	Sources sampled (n)	Compliant sources (%)	Sources sampled (n)
Ethiopia					
Piped supply from a public utility	19.8	87.6	838	80.4	832
Borehole	5.1	67.9	290	65.6	270
Protected spring	7.0	43.3	319	43.3	313
Protected dug well	5.0	54.8	155	54.8	155
Total	36.9	–	1602	–	1570
Jordan					
Piped supply from a public utility	93.4	99.9	1639	97.8	1639
Other improved source[e]	4.5	NA	0	NA	0
Total	97.9	–	1639	–	1639
Nicaragua					
Piped supply from a public utility	69.0[f]	89.9	335	89.1[g]	335
Community supply	6.6[f]	39.0	265	38.6[g]	265
Borehole or tube well	4.6[f]	45.7	442	41.6[g]	442
Protected dug well	3.9[f]	19.3	446	18.5[g]	446
Other improved source[e]	0.1[f]	NA	0	NA	0
Total	84.1[f]	–	1488	–	1488
Nigeria					
Piped supply from a public utility	19.6	77.0	630	77.0	630
Borehole or tube well	14.7	94.0	525	86.0	525
Protected dug well	12.9	56.0	424	51.0	424
Total	47.2	–	1579	–	1579
Tajikistan					
Piped supply from a public utility	58.4	88.6	1286	88.2	1286
Protected spring	9.6	82.0	334	82.0	334
Other improved source[e]	1.2	NA	0	NA	0
Total	69.2	–	1620	–	1620

NA, not available; WHO, World Health Organization.

[a] The Rapid Assessment of Drinking-Water Quality (RADWQ) project assessed only water source types classified as improved by the Joint Monitoring Programme for Water Supply and Sanitation.

[b] The percentage of the population receiving drinking-water from each source in 2004 to 2005 was estimated from RADWQ project reports.

[c] Compliance with WHO guidelines on drinking-water contamination with thermotolerant coliform bacteria.

[d] Compliance with WHO guidelines on drinking-water contamination with thermotolerant coliforms, arsenic, fluoride and nitrates.

[e] Apart from in the Nicaraguan study, types of improved water source used by less than 5% of the population were not sampled during the RADWQ project.

[f] Since, unlike reports for other countries, the RADWQ report for Nicaragua did not record the proportion of unimproved sources, Joint Monitoring Programme figures were used to estimate population coverage in the country.

[g] Since overall compliance was not recorded in the RADWQ report for Nicaragua, overall compliance was estimated from separate chemical and microbial compliance figures on the assumption that the two were independent.

Onda, LoBuglio, and Bertram (2012) also analyzed RADWQ data from the pilot countries using a variety of statistical methods looking at the percentage of samples testing positive for TTC as well as those with greater than two sanitary risks. Using this data they extrapolated estimates for countries not included in the RADWQ using covariates such as country GDP, mortality due to diarrheal disease in children under five, the Government Effectiveness score from the World Bank, the Water Quality Index from Yale's Environmental Performance Index, the Human Development Index, annual precipitation, and percentage of population with tertiary education. Using the estimates for the additional countries, Onda et.al. reevaluated the progress on the MDG 7.C accounting for water that is both safe and at low sanitary risk and determined:

> We estimate that 1 billion (confidence interval 0.75 to 1.6 billion) of the 5.8 billion using piped or other-improved sources receive fecally-contaminated water. This lowers the number of people estimated to use safe water from 5.8 billion (the 2010 JMP figure) to 4.8 billion, and increases the number or people with unsafe water from 0.78 billion to 1.8 billion as of 2010. Of these 4.8 billion using safe water, approximately 1.2 billion people (confidence interval 0.75 to 2.1 billion) receive water from sources that are at risk of fecal contamination by virtue of having greater than two of the common sanitary risks for that source type as defined by RADWQ. If a more stringent definition of safety (requiring both no fecal contamination and low sanitary risk) is used, then the estimate of the number of people with unsafe water is 3 billion, (confidence interval 1.5 billion to 3.9 billion).

Based upon the more stringent definition of safe water used in this article, in 2010, when the UN declared the drinking water goal had been met, it was actually ten percentage points behind, and Onda et. al. predict the goal will still be behind by eight points in 2015 (Onda, LoBuglio, and Bartram 2012).

The designation of piped water supply as an improved source means that it is considered to be safe by the JMP. However, according to the results of the RADWQ, not all improved sources actually meet the drinking-water standards set forth by the WHO. This raises the question: Is the piped water supply in Tamale safe to drink? Answering this question is the goal of this thesis and the motivation for the water quality analysis of the historical data obtained by the author from the GWCL.

3.2 Intermittent Water Supply

3.2.1 Issues Surrounding Intermittency

In high-income countries, water supply is continuous. Pipes are always pressurized and full of water. In developing countries this is usually not the case. An intermittent system is a water supply that provides consumers with water for only certain periods of the day. There are a number of factors that cause this intermittency and are summarized in Figure 3-1. Population growth may cause the amount of water produced at a treatment plant to be insufficient for the demands of the population so water must be rationed in some way. Power outages may cause pumps or treatment processes to be shut off which also leads to a gap in water supply. In addition, non-revenue water, the disparity between water produced and water paid for due to water losses through cracks, breaks, or illegal connections, leads to decreased revenue for the water company. This decreased revenue means that there are insufficient funds for good maintenance of pipes so breaks and leaks occur, which adds to the problem of non-revenue water and further contributes to intermittency (Vacs Renwick 2013).

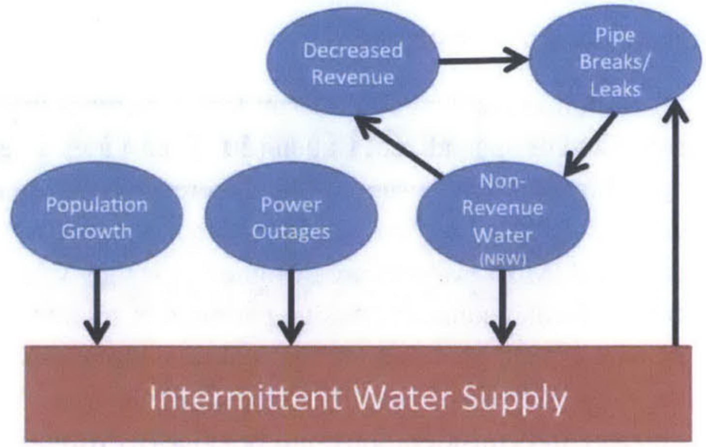


Figure 3-1: Factors influencing intermittency (Vacs Renwick 2013)

Intermittent water distribution systems are very common in developing countries and they operate quite differently than the continuous systems in developed countries. Some of the important issues surrounding intermittent systems are the water quality, the design of such systems, and how to model the water flow and contamination.

Vairavamoorthy, et. al. (2001) focuses on the design of water distribution systems in developing countries. Vairavamoorthy argues that these systems are being designed as if they would be operated as continuous systems despite the fact that it was known prior to design that the system would be operated intermittently. The author calls for the creation of guidelines and tools for the design of intermittent systems. The ultimate goal is to design systems "that can supply sufficient quantities of water to the consumers at adequate pressures at least cost."

Lee and Schwab (2005) give an all-encompassing summary of the problems facing water distribution systems in developing countries. The first problem they discuss is the lack of disinfection residual. Without the residual, organics and pollutants can be reintroduced into the water during distribution and contaminate the supply. Inadequate pressure also creates the risk of disease epidemics because of backflow which can allow contaminants into the system due to a vacuum effect as well as operational problems. The pressure differential may also mean that consumers living further away from the treatment plant receive much less water than those living closer. Lee and Schwab also indicate that intermittent systems cause problems due to stagnant water in pipes and cite numerous studies showing how water quality is drastically reduced in intermittent systems compared to continuous systems. Leakages and non-revenue water is also a large problem in water distribution in developing countries due to poor construction and lack of maintenance. These leaks have the potential to allow contaminants to enter the water distribution. The lack of maintenance and use of low-grade materials also leads to corrosion problems in distribution pipes causing high concentrations of metals in the drinking water as well as creating conditions for more bacterial growth inside pipes.

The water quality in intermittent systems is of concern as there are many possible pathways of contamination. Coelho, et. al. (2003) studied the water quality of intermittent systems in Jordan, Lebanon, and Palestine. They found that the greatest deterioration in water quality is due to storage practices which allow microbial regrowth to occur. The challenges of modeling bacterial growth and flow through the system due to lack of software and difficulties implementing household tanks in the model are also addressed by these authors.

Another challenge in intermittent systems is that the design of such systems is not standardized or specialized. Batish (2003) provides a very good overview of the challenges in the design of intermittent systems. The difference between the continuous system, in which supply is determined by demand, and the intermittent system, in which supply is determined by pressure, is explained. Most systems are designed as if they were continuous but that leads to many problems. Batish considers design parameters such as water supply, residual pressure, charging of the pipes, peak load factors, the problem of overdesigning a system, pressure from air release, leakage, and the use of head loss generating devices. A case study is provided to put these parameters and considerations into practice in designing a better intermittent system.

A resource that is useful for utilities to compare the effectiveness of their system is the International Benchmarking Network for Water and Sanitation Utilities (IBNET). IBNET is a collection of data that is self-reported by a growing number of utilities and organizations around the world. Utilities or organizations can submit data using an Excel spreadsheet and then the data is checked for accuracy. This data is then compiled by IBNET and is available in the IBNET database to anyone, free of charge. This data can be used by utilities to compare their own operations to others to assess their own performance and determine their strengths and weaknesses as well as determine how best to improve their performance.

3.2.2 Modelling Intermittent Systems

One of the biggest challenges facing the modelling and recommendation component of this project is the lack of commercial software available for use in modeling intermittent piped water systems. There is lots of software available for continuous systems as this is the standard in high income countries but this software does not accurately model intermittent systems. However, there is a limited amount of literature available from researchers creating their own software or modifying existing software for use with intermittent systems.

Sashikumar, Mohankumar, and Sridharan (2003) outline some of the problems associated with modeling an intermittent system. They found that the Hazen-Williams C value, which would be a constant in a continuous system, varies over time depending on the flow through the pipes. The value is lower as pipes begin to fill due to air pockets in the pipes and then increases to its true value as pipes fill. These authors also note that peak load factors for intermittent systems are usually much larger than continuous systems. The authors focus on the problems associated with modeling intermittent systems and do not provide considerations for solutions.

Ingeduld et. al. (2006) modeled intermittent systems in India and Bangladesh by modifying EPANET, a free commercial modeling software, to work with the low pressures and limited availability of an intermittent system. EPANET, and other commercial software, is based upon user demand; Ingeduld et. al. have modified it to be based on the pressure at each node.

They also address how to model the household tanks for collecting water that are commonly found in areas with intermittent supplies. Ingeduld et. al.'s paper is rather light on the background and theory of this modelling method and focuses more on case studies in towns in India and Bangladesh.

Cabrera-Bejar and Tzatchkov (2009) use EPANET for modelling intermittent systems but also utilize SWMM (Storm Water Management Model), another free software from the US EPA. SWMM is a rainfall-runoff simulation model which, with the modifications explained in the paper, can be used to model the initial charging of the distribution network. EPANET is then used for modeling the system when the pipes are filled. The authors provide very specific instruction on what modifications to make to the software. They also provide screenshots which are useful in guiding the reader through each step.

3.3 Safe Storage

In 2013, M.Eng student Deborah Vacs Renwick surveyed households in Tamale, Ghana about the availability of water and their water storage practices. She also did water quality tests on water from the tap and from stored water. She found that most contamination occurred when water was stored in an unsafe container that allowed bacteria to enter the water. Her household surveys around the Tamale area found that 53% of households use unsafe storage containers (Vacs Renwick 2013).

According to the CDC and USAID, safe storage containers should have a small opening to prevent contaminated items from coming in contact with clean water, there should be a way to dispense water which does not require contact with hands or bowls, and the size of the container should be appropriate and instructions for usage and cleaning provided (CDC and USAID 2009).

Vacs Renwick also conducted water quality tests of water taken from storage containers in households. She found that 73% of households tested positive for total coliform and 33% for *E. coli*. Over half of the positive coliform tests indicated more than 100MPN (most probable number) per 100mL sample which is considered "very high risk" for microbial contamination by the WHO (Vacs Renwick 2013).

4 Water Quality Data Analysis

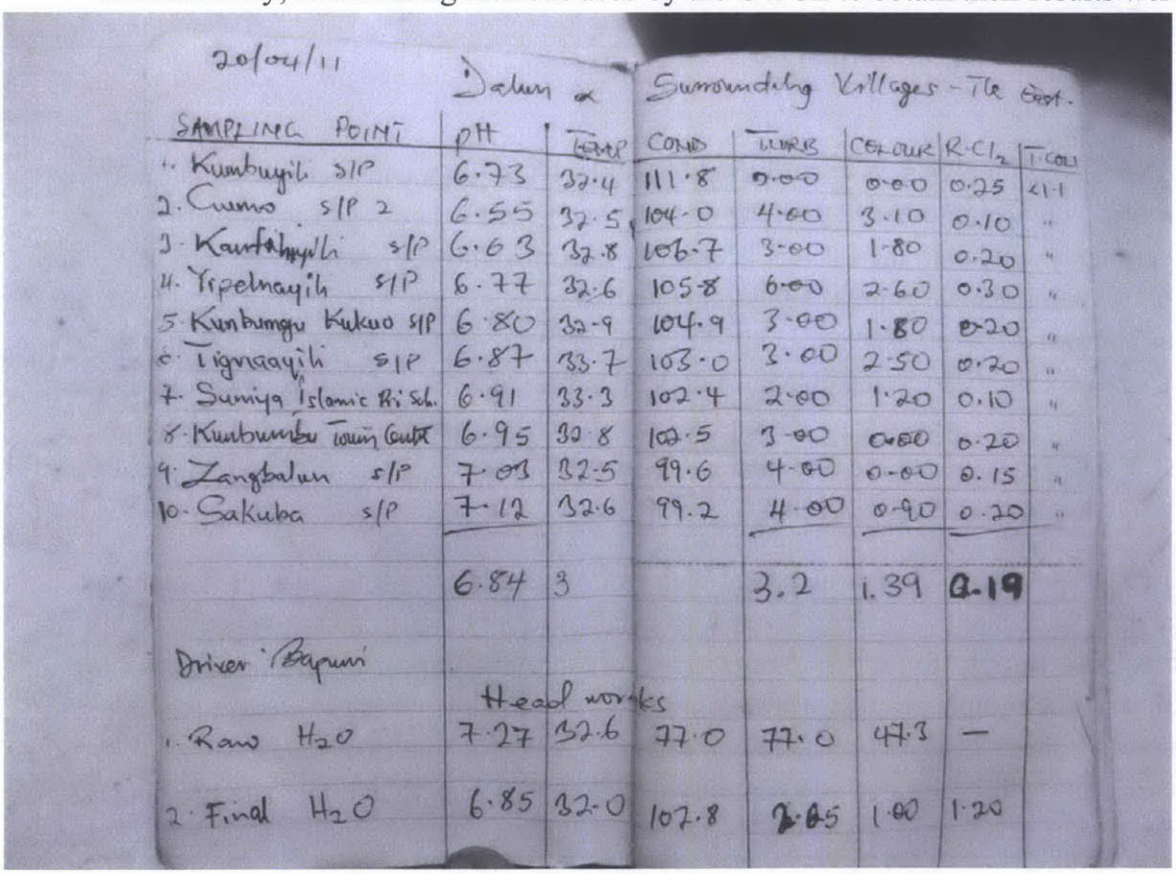
4.1 Methodology

Figure 4-1: GWCL notebooks (Photo: Allison Hansen)

As indicated by Vacs Renwick (2013), the GWCL Water Quality Laboratory in Tamale had notebooks of water quality data dating back to October 2004. The notebooks contain date, pH, temperature, conductivity, turbidity, color, residual chlorine, *E. coli*, and total coliform data for samples taken from various sample locations in the distribution system, see Figures 4-1 & 4-2. Some important things to note about the data organization as seen in Figure 4-2 are that the sample points, listed along the left-hand side, are organized into general areas, as designated at the top of each page, and these areas are within one of three larger districts (Tamale East, Tamale West, and Yendi), written in the upper right corner.

The notebooks also contain raw water and final treated water for the water treatment plants in Dalun and Yendi.

Unfortunately, exact testing methods used by the GWCL to obtain their results were not



20/04/11 Dalun & Surrounding Villages - Tle East.

SAMPLING POINT	pH	TEMP	COND	TURB	COLOUR	R-Cl2	T.COLI
1. Kumbuyili S/P	6.73	32.4	111.8	0.00	0.00	0.25	<1.1
2. Cuma S/P 2	6.55	32.5	104.0	4.00	3.10	0.10	"
3. Kanfahyili S/P	6.63	32.8	106.7	3.00	1.80	0.20	"
4. Yipelnayili S/P	6.77	32.6	105.8	6.00	2.60	0.30	"
5. Kunbungu Kukuo S/P	6.80	32.9	104.9	3.00	1.80	0.20	"
6. Tignaayili S/P	6.87	33.7	103.0	3.00	2.50	0.20	"
7. Suniya Islamic Pri Sch.	6.91	33.3	102.4	2.00	1.20	0.10	"
8. Kunbumbu Town Centre	6.95	32.8	102.5	3.00	0.00	0.20	"
9. Zangbalun S/P	7.03	32.5	99.6	4.00	0.00	0.15	"
10. Sakuba S/P	7.12	32.6	99.2	4.00	0.90	0.20	"
	6.84	3		3.2	1.39	0.19	
Driver: Bapuni							
		Head works					
1. Raw H_2O	7.27	32.6	77.0	77.0	47.3	—	
2. Final H_2O	6.85	32.0	107.8	2.85	1.00	1.20	

Figure 4-2: Sample page of GWCL data (Photo: Allison Hansen)

disclosed to the author. Observations of the water quality laboratory indicated the presence of HACH equipment, and, as counts were recorded for total coliform counts and occasionally for *E. coli* counts, the testing method for coliforms must be either an MPN or membrane filtration method.

4.1.1 GWCL Database

The only data analysis done by the GWCL was to choose thirty sample points from each district per month, enter the values for the sampling parameters into an Excel spreadsheet and look at the mean, min, max, and standard deviation for the data as well as a percentage of samples complying with standards. Table 4-1 shows the GWCL table from their Excel format for Tamale East district in May 2013.

Table 4-1: GWCL analysis example, Tamale East, May 2013

	TAMALE EAST DISTRIBUTION WATER QUALITY ANALYSIS May 2013									
Parameter	No of Samples				Mean	Median	Modal value	Std. Dev.	No of Samples Complying	Percentage Compliance
	Required	Actual	Min	Max						
pH	30	30	6.70	8.0	7.0	6.9	6.9	0.2	30	100%
Colour	30	30	0.00	2.3	1.0	0.9	0.9	0.6	30	100%
Turbidity	30	30	0.70	3.5	1.9	1.9	1.4	0.8	30	100%
R-chlorine	30	30	0.10	0.2	0.2	0.2	0.2	0.0	30	100%
E-coli	30	30	0.00	0.0	0.0	0.0	0.0	0.0	30	100%

The GWCL analysis, as exemplified by Table 4-1, did not consider individual sample points or areas on a smaller scale than the districts and specific dates and locations of sample points were not included in their Excel file. It also considered mean values to be indicative of water quality parameters despite the fact that one bad sample point which is not seen from the mean could mean contaminated water for their consumers receiving their supply from that location. Overall, the GWCL had a lack of understanding of what is really going on in their system because of this lack of analysis and quality control. In addition, as each month was analyzed in a separate file, there was a lack of comparison between months and historical or annual trends were not being evaluated.

In order to create a better means of data entry and analysis for the GWCL the author created a database using Microsoft Access. This database contains all parameters entered in the notebooks: date, sample point, pH, temperature, conductivity, turbidity, color, residual chlorine, and coliform. The sample points were also linked to specific areas and the areas were linked to their respective districts allowing data to be easily analyzed on multiple scales. Microsoft Access also allows reports to be created so a monthly district report showing all the data previously recorded in the Excel files is available. Also, a monthly report breaking the districts into areas was created allowing any locations with poor water quality to be readily spotted and fixed.

A further advantage of Access is the creation of forms so water quality data can be entered easily and efficiently in the future. See Figure 4-3.

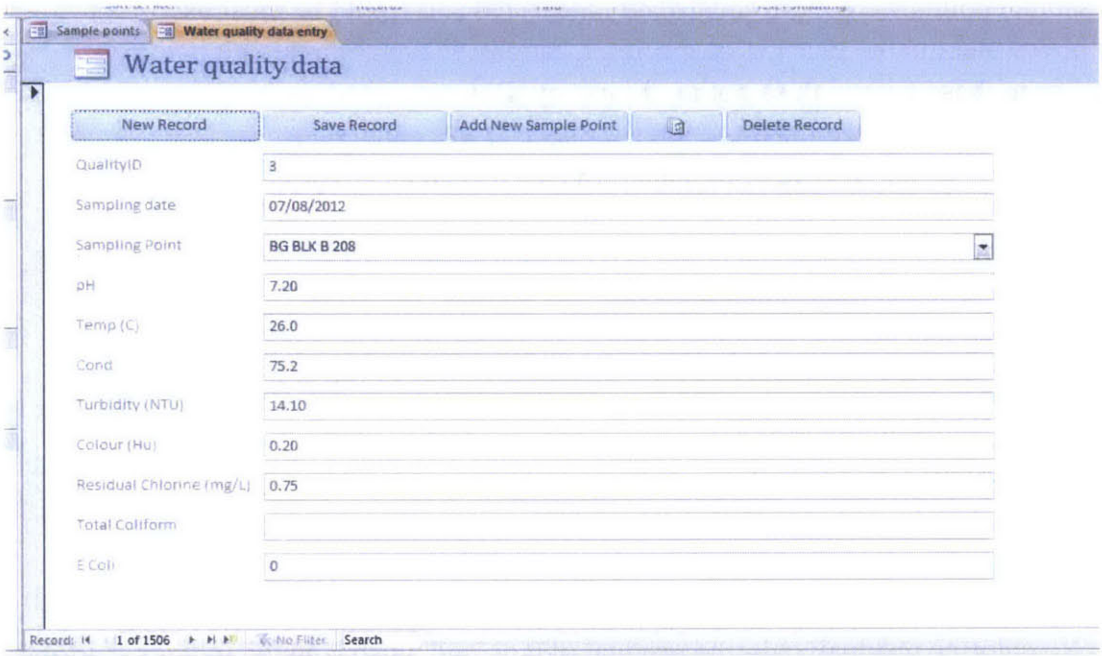


Figure 4-3: Sample data entry form in Microsoft Access

The Access database was left with GWCL employees along with detailed instructions of how to use the database. Hopefully, this database will continue to be utilized by the GWCL so they can better monitor the quality of water they are producing, more readily locate problem areas or points, and be able to identify annual trends to be more effective in treating their water.

4.1.2 Historical Water Quality Analysis

Aside from providing the GWCL with a means to better understand the water quality they are producing and supplying to their consumer, entering the handwritten data into a database also allows the data to be more rigorously analyzed to provide insight that could help the GWCL to be proactive in making improvements for the future based upon past trends. As Ghana has distinct rainy and dry seasons, looking to see if there are annual or seasonal changes in water quality could warn of future high risk times of the year. The data could also be used to interpolate how often the water quality may be harmful to consumers which helps answer the larger question of whether this "improved" source is actually providing safe water.

Due to the large amount of data contained in the notebooks and the limited amount of time available, data entry took three forms:

1) All water quality data for all sample points was entered for the 28 month period from April 2011 through November 2013 just as it appeared in the notebooks.
2) Because the sampling method used by the GWCL is not structured, sample points are not measured in a consistent way. Many points were only measured once in this 28 month period while a few were more frequent. The initial data entry was used to determine which sample points were more consistently measured and would be most useful for seeing how water quality changes at specific locations. Eleven sample points were selected from those with high sampling frequency. Having a good geographic spread was also considered when selecting these points. The data was entered just for those sample points back to October 2004 (earliest data provided by GWCL). The complete data can be found in Appendix A.
3) In order to account for all the data collected, for each sampling date, the total number of points sampled was recorded along with area and district. The numbers of points with water quality not adhering to WHO guidelines as provided in *Guidelines for Drinking-Water Quality, 4th Edition (2011)* were counted and recorded for the parameters of:
    - High pH: pH higher than 8.5
    - Low pH: pH lower than 6.5
    - High turbidity: turbidity higher than 5 NTU (upper bound suggested for less developed treatment systems)
    - Low chlorine residual: chlorine residual less than 0.2 mg/l
    - No chlorine residual: chlorine residual of 0 or "nil" (also counted in "low chlorine residual")
    - Total coliform ("T. coli") and fecal coliform ("F. coli"): any positive counts of total coliform

    This data can be found in Appendix B.

All data for raw and final water at the Dalun Treatment Plant was also entered and can be found in Appendix C. Data for the Yendi Treatment Plant was also available however, as details regarding the intake source and treatment process for the plant were unavailable, this data was not considered in the analysis.

Approximate locations of many of the sample points and areas were found using Google Earth and ArcGIS and are shown in Figure 4-4. This can be used to get a general idea of spatial differences and how water quality is deteriorating as it travels through the system.

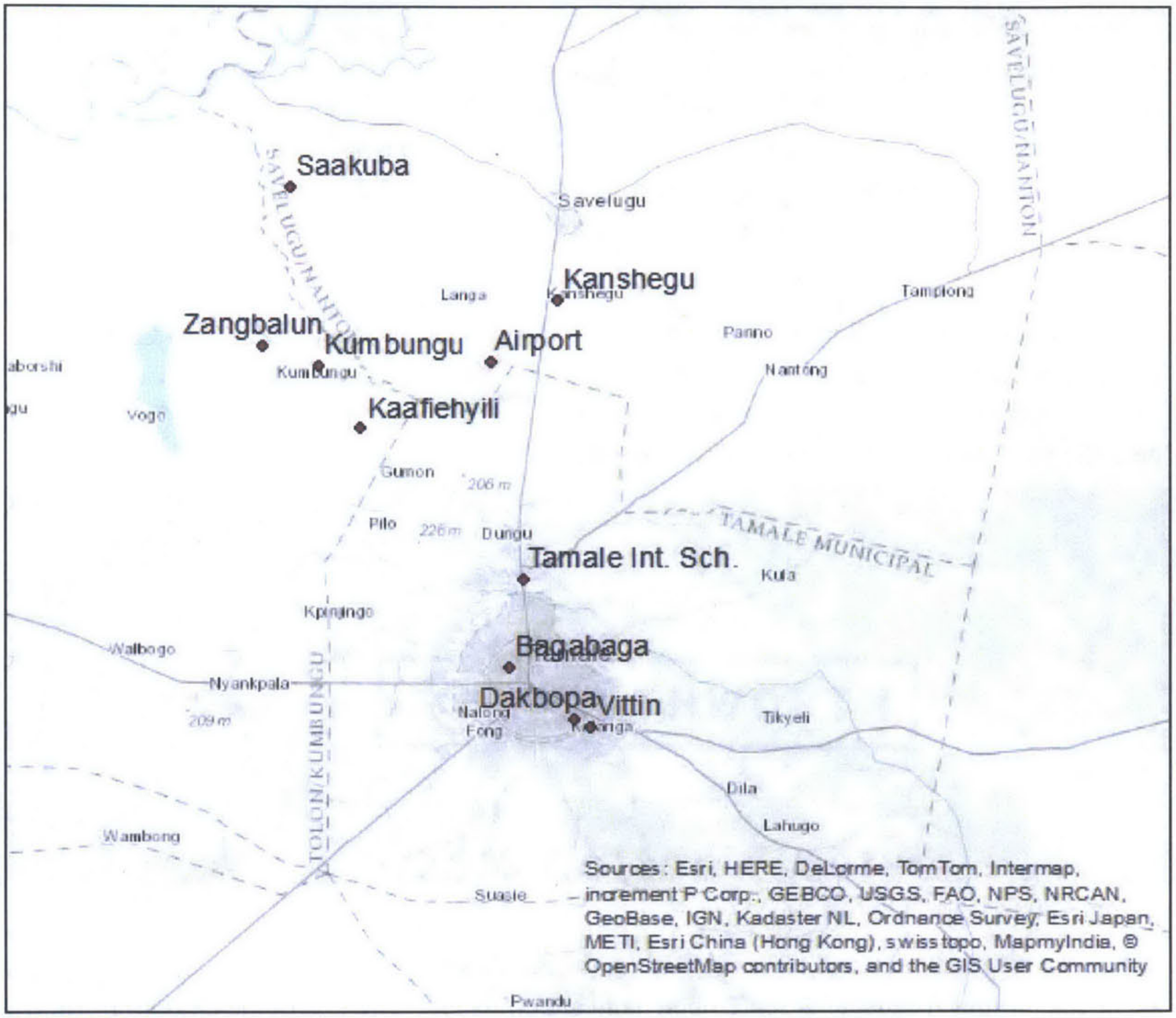


Figure 4-4: Map of sample points

4.2 Results of Water Quality Analysis

4.2.1 Treatment Plant Water Quality

Before being able to understand the water quality reaching consumers, it is important to look at the context of the raw water from the source. The water entering the Dalun Water Treatment Plant comes from the White Volta River. Two important parameters when considering raw water quality are pH and turbidity. pH is important because it affects the effectiveness of chemicals added during the treatment process and the effectiveness of chlorine disinfection. Turbidity is important because it is what is being removed through coagulation and flocculation and filtering. Removing particles also removes some of the pathogens that attach to the sediment. The measure of turbidity can be influential in determining the amount of coagulant to add as well as how often filters need to be backwashed to maintain a good head for filtration. Plots of the pH and turbidity of the raw water entering the Dalun Treatment Plant are seen in Figures 4-6 and 4-7, respectively.

One interesting thing to note is the seasonal periodic variations. Northern Ghana experiences a pronounced rainy season in March through October and then a very dry season in November through February, as shown in Figure 4-5. This rainfall trend can be seen in the periodic variations of pH and turbidity. The pH graph (Figure 4-6) shows local maximums

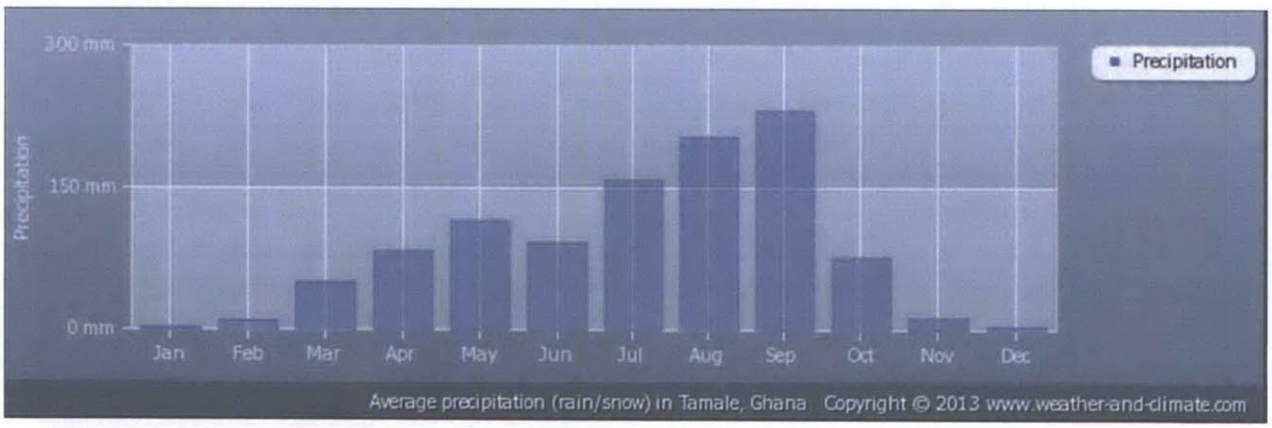


Figure 4-5: Precipitation in Tamale

during the rainy months and lower pH values during the dry months. The turbidity values (Figure 4-7) peak around August and September. This pattern is probably due to the amount of runoff entering the White Volta River at this time of year.

Now that the source quality and trends are understood, the effectiveness of the treatment process can be evaluated. Looking at the parameters of pH and turbidity for the treated water, in Figures 4-8 and 4-9, respectively, a comparison can be made to the source quality. Some of the same seasonal trends can be seen in the treated water however the trends aren't as pronounced and there is some more randomness in values.

The WHO guidelines and US EPA standards both recommend a good pH range of 6.5-8.5 (WHO 2011)(US EPA 2009). These values are shown as horizontal red lines in Figure 4-8. Eighty percent of the data does fall within those boundaries although there are certainly some outliers.

The WHO recommends a turbidity of less than 1 NTU for small, less developed water treatment and an upper limit of 5 NTU, indicated by the red line in Figure 4-9 (WHO 2011). Only 5.8% of the samples actually meet the 1 NTU criteria, and although 78% meet the 5 NTU limit, there is still room for improvement.

During the treatment process, chlorine is added to disinfect the water. The residual free chlorine residual concentrations of the treated water is shown in Figure 4-10. According to WHO guidelines, "for effective distribution, there should be a residual concentration of ≥0.5 mg/l after at least 30 min contact time at pH <8.0" (WHO 2011). Based upon this guideline, the recently treated water should have a residual chlorine concentration of at least 0.5 mg/l which is shown as a red line on the plot. Seventy-seven percent of the samples meet this guideline. In the 104 sample dates, there were three instances in which there was no chlorine residual in the treated water at the treatment plant which puts water at very high risk for being contaminated before it even reaches the pipe network.

In 2008 the treatment plant received an upgrade. This is indicated by a vertical green line in Figures 4-8, 4-9, and 4-10. It seems that this upgrade did lead to an improvement in water treatment. pH values after 2008 appear to have a more narrow range and to be better controlled, however, the source quality also has a smaller range of value for those years, so it is unclear whether this observation can be uniquely attributed to the treatment plant renovation. Turbidity has also improved since 2008 with fewer large values occurring in the samples. A simple linear regression fit to the data shows a downward slope in Figure 4-9 which may indicate an overall improvement in turbidity over time. Similarly, the residual chlorine values show an upward trend in Figure 4-10 although the range of values actually widens with many instances still below guideline values.

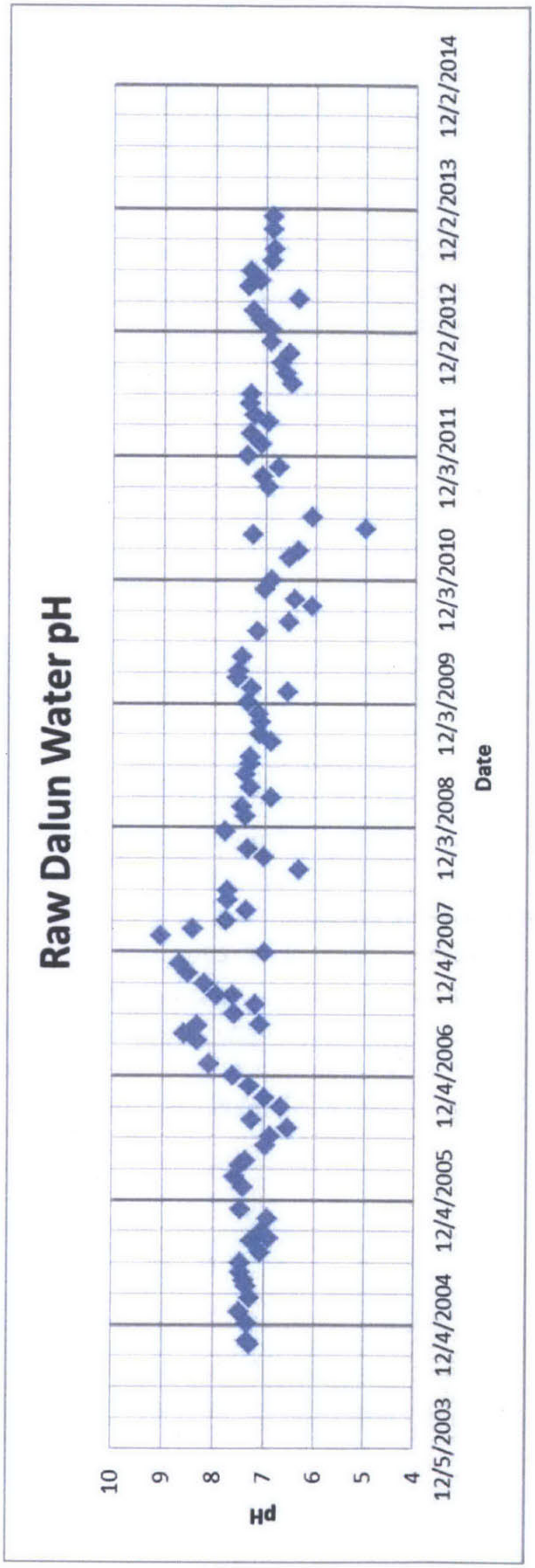


Figure 4-6: Plot of raw pH

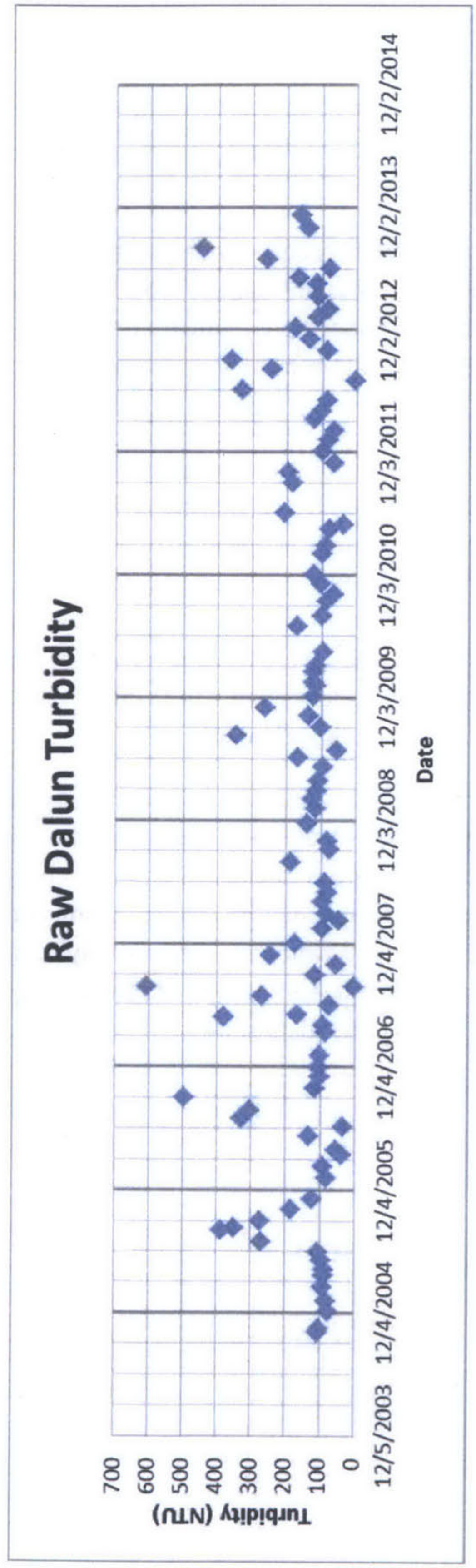


Figure 4-7: Plot of raw turbidity

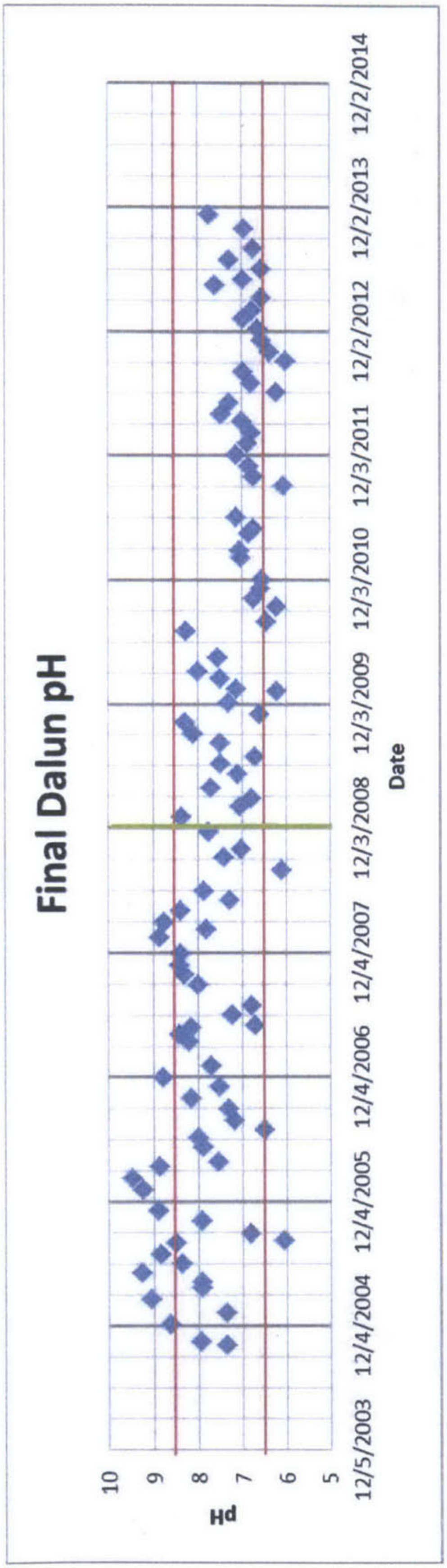


Figure 4-8: Treated water pH

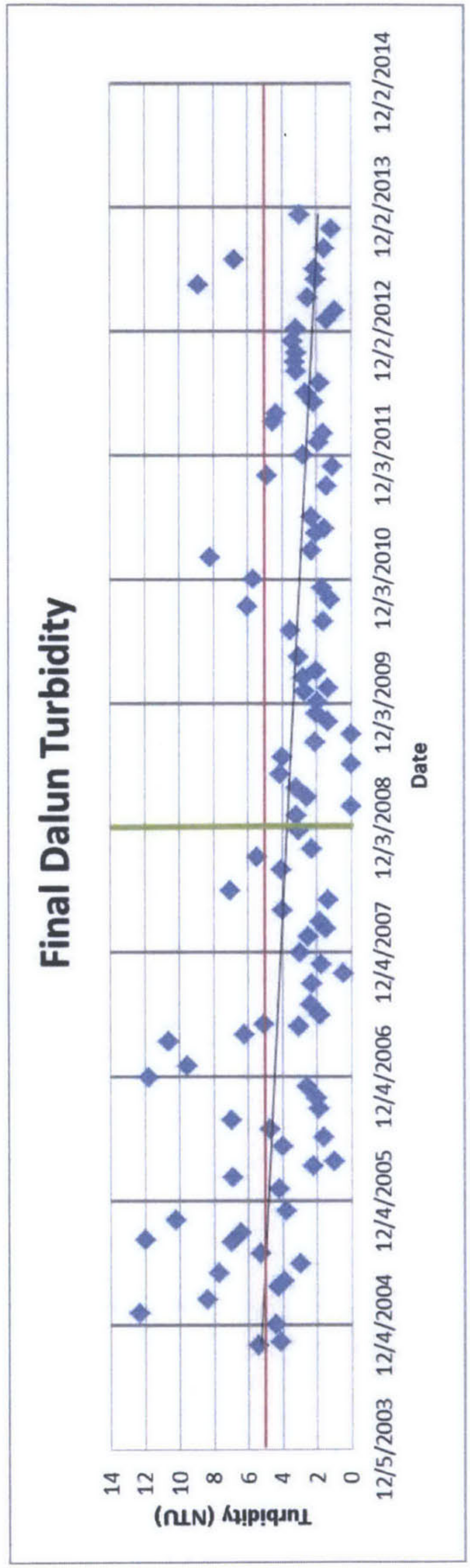


Figure 4-9: Treated water turbidity

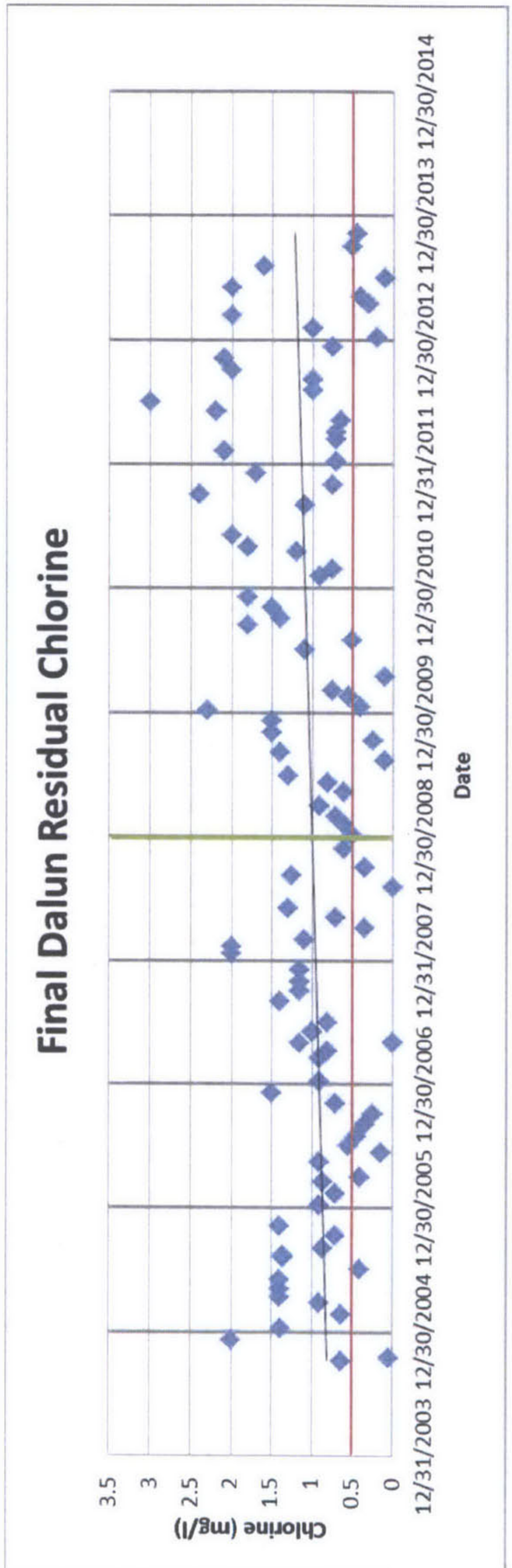


Figure 4-10: Treated water residual chlorine

4.2.2 Sample Point Water Quality and Spatial Trends

Because sample points are not consistently measured by the GWCL on a routine basis and many individual locations occur only a few times in all the notebooks, it made sense to choose some that had a higher frequency of sampling (see n values in table below, compared to n=1 for many of the sample locations), and that could be located on maps, to allow for more accurate comparison between specific locations.

First, a simple average was taken over all dates sampled for eleven of the sample points. The averages for pH, turbidity, and residual free chlorine are shown numerically in Table 4-2.

Table 4-2: Sample point averages

Averages	Airport	Bagabaga	Dakbopa SHS	Kaafieyili	Kanshegu	Kumbungu SHS	Saakuba	Tamale Int. Sch.	Vittin SHS	Yipelnayili	Zangbalun
pH	7.598	7.328	7.307	7.055	7.279	7.005	7.102	7.218	7.423	7.038	7.024
Turb	2.451	3.853	3.079	3.468	2.774	2.966	4.346	3.285	2.691	3.434	3.418
Resid. Ch.	0.065	0.319	0.305	0.568	0.188	0.388	0.494	0.485	0.343	0.271	0.460
n	46	16	11	46	51	38	75	13	7	42	62

To determine if the differences in averages between sample points are statistically significant, two-sample t-tests assuming unequal variance were run using Stata, a statistical analysis software. A t-test is a way of measuring if two sets of data are statistically different from each other, so in this case, it is being used to determine if differences in averages between sample points are actually representative of differences in water quality. The t-test gives a t value which is computed as $t = \frac{\bar{X}_1 - \bar{X}_2}{s_{\bar{X}_1-\bar{X}_2}}$ where $s_{\bar{X}_1-\bar{X}_2} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$. $\bar{X}$ is the standard mean of each data set, s is the standard deviation, and n is the sample size. A p-value is also computed which gives the probability that the difference between samples could be produced by random data. In practice, a p value of 0.05 or less means that there is a statistical difference. T and p-values for various pairs of sample points are shown in Table 4-3. Based upon the p-values calculated, there is a statistically significant difference between the averages of residual chlorine for some of these pairs, especially pairs of points that are further apart. Therefore, it is reasonable to compare average values between sample points to see how residual chlorine concentrations vary geographically. The p-values for pH are all larger than 0.05, with the exception of the Airport-Kanshegu pairing. Some of the p-values for pairings of points further apart may be reasonably small given that the range that pH varies is also small and this test does not take seasonal variation or time trends into account.

Table 4-3: Two-sample t-test results for residual chlorine

	Residual Chlorine		pH	
Pair	**t**	**P(T<t)**	**t**	**P(T> or <t)**
Airport-Kanshegu	-3.0941	0.0013	3.2300	0.0009
Airport-Bagabaga	-3.1988	0.0025	-	-
Dakbopa-Zangbalun	-1.5454	0.0692	1.0213	0.1640
Dakbopa-Kaafiehyili	-2.4149	0.0116	0.9048	0.1919

Zangbalun-Kaafiehyili	-1.2392	0.1092	-0.2915	0.3856
Bagabaga-Zangbalun	-1.5101	0.0704	1.1196	0.1390
Bagabaga-Kaafiehyili	-2.4282	0.0098	1.0002	0.1653
Kumbungu SHS-Kaafiehyili	-1.8169	0.0365	-0.4220	0.3371
Kumbungu SHS- Zangbalun	-0.8005	0.2129	-0.1615	0.4360
Zangbalun-Tamale Int.	-0.1541	0.4398	-1.1228	0.1382
Tamale Int.- Kaafiehyili	-0.4818	0.3181	0.9332	0.1814
Kanshegu-Tamale Int.	-1.8418	0.0442	0.3566	0.3629
Dakbopa-Tamale Int.	-1.0092	0.1631	0.2866	0.3890

In order to more easily visualize the differences in residual chlorine, a map was created using ArcGIS in Figure 4-11. The size of the circles on the map are proportional to the average chlorine residual at that point. Looking at this map, it definitely seems that water quality, as measured by residual chlorine, does deteriorate as it flows through the distribution network, as expected. Points such as Zangbalun, and Kaafiehyili which are located closer to the treatment plant at Tolon have higher residual chlorine concentrations compared to points further out. Concentrations for Kanshegu, Bagabaga, and the airport do tend to be lower than for the other sample points. Bagabaga is located furthest away from the treatment plant so, as it appears that residual chlorine deteriorates as water travel through the pipes, as would be expected. Kanshegu and the airport are not as far away so a different explanation is needed. A possible theory may be that the Kanshegu sample point and the airport sample point are located along the same distribution pipe and this particular pipe has breaks or illegal connections allowing contaminants to enter, but a map of the entire distribution system was not available to verify this. The way in which the intermittency of the water is determined is also unknown so it may be possible that the pipe is fully pressurized less often than others allowing further contamination.

If the reaction coefficients for chlorine were known for the water and pipe composition, the expected natural degradation of the chlorine residual due to first order reactions could be compared with the values from the GWCL. This would indicate whether the decrease in chlorine residual is caused by the expected decay of chlorine or from contamination requiring additional free chlorine for disinfection. This could be a useful exercise for the future.

Figure 4-12 is a map showing variations in average pH over the geographic area. Higher pH is shown as blue and lower pH is shown as green. This map also shows geographic trends in pH. The northeast area has a lower pH than the area around Tamale. There are many factors that can influence pH such as temperature, pipe corrosion, and water composition so the underlying cause of this trend cannot be identified.

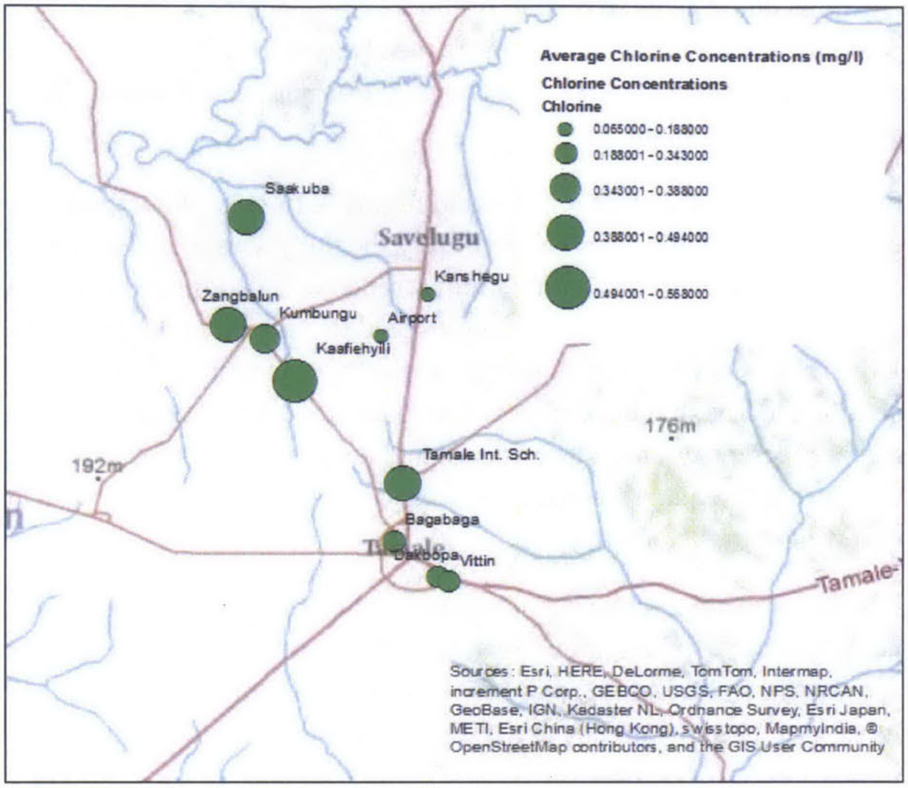


Figure 4-11: Average chlorine residual map

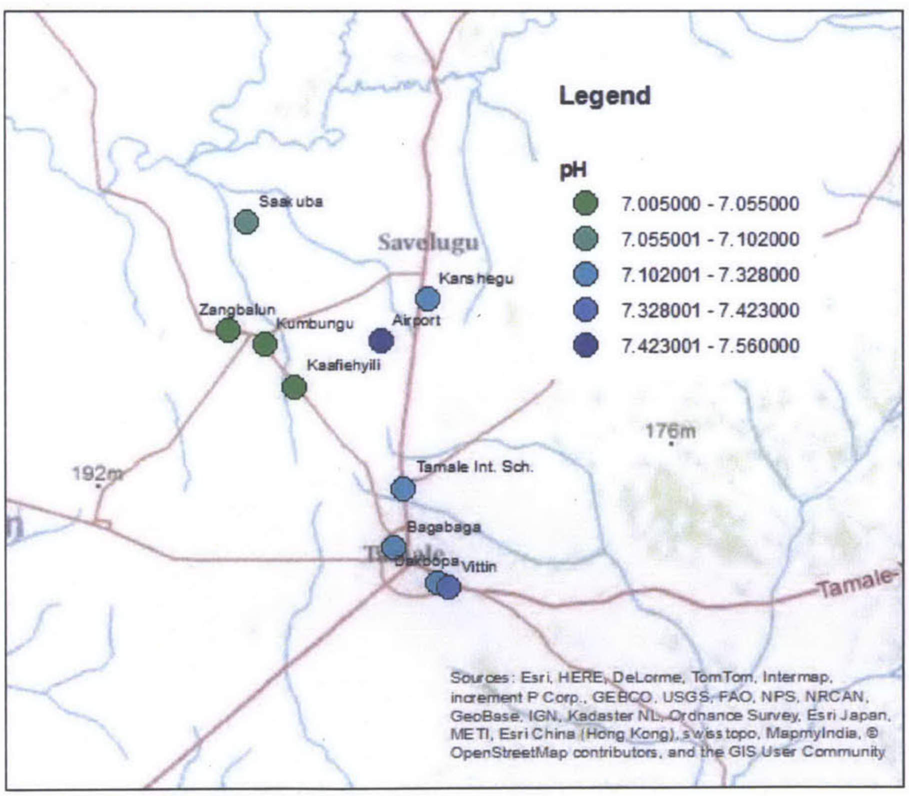


Figure 4-12: Average pH map

pH and residual chlorine were plotted in Figures 4-13 and 4-14, respectively, for several of the sample points with the highest sampling frequency as well as a geographic spread: Kaafiehyili, Zangbalun, Kumbungu SHS, Kanshegu, the airport, and Bagabaga, as well as the final water from the treatment plant.

The pH variation at the sample locations in Figure 4-13 does show the same trend as the pH from the treatment plant with lower values during the rainy season and higher values during the dry season. The locations also have very similar trends when compared to each other, as would be expected, although the Bagabaga samples tend to have more outliers. The most likely cause for this is the relative location of Bagabaga to the treatment plant to the other locations. Another explanation could be that Kaafiehyili, Zangbalun, and Kumbungu SHS are all located in the same area and are therefore sampled on the same dates (as seen in Appendix A), however, Kanshegu and the Airport are part of a different area, so their sample dates are different as well, but they still align well with the other points.

The variations of residual chlorine in Figure 4-14 do not show any seasonal trends. The residual chlorine values of the water at the treatment plant are higher than those at sampling locations. One surprising feature of this plot is that residual chlorine values at sampling locations are still very low despite larger residuals at the treatment plant in the years 2011-2013.

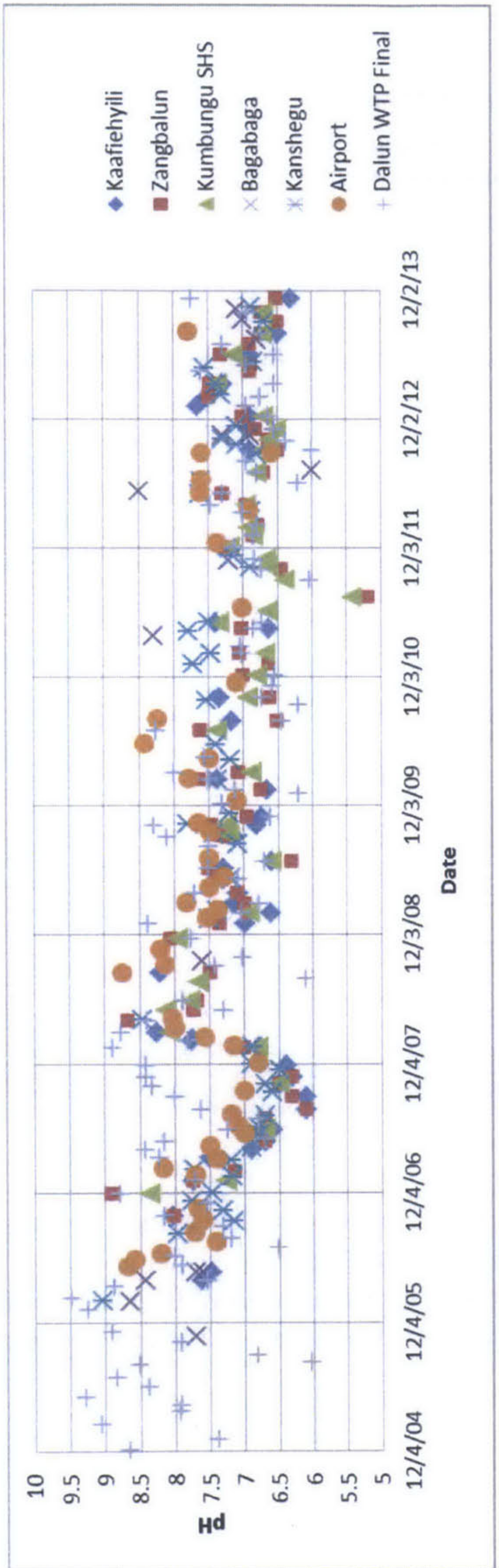


Figure 4-13: Sample point pH

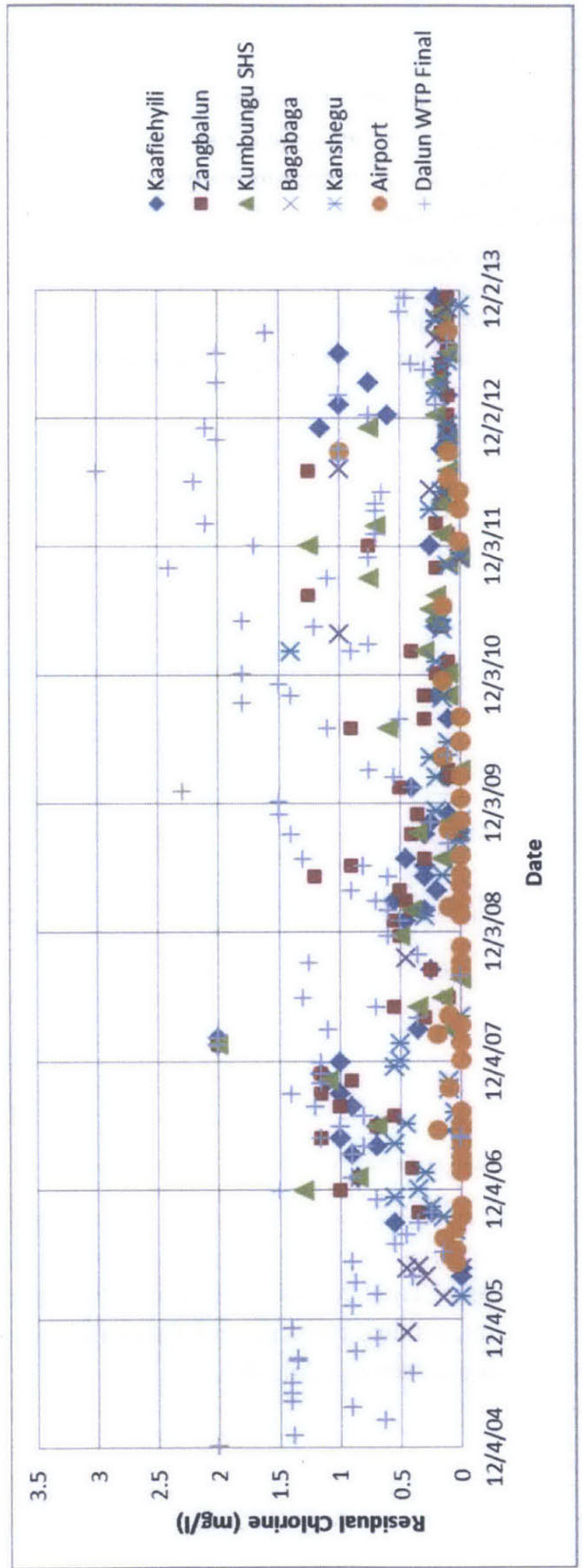


Figure 4-14: Sample point residual chlorine

4.2.3 Water Quality by Area

Using the data of type (3) discussed in Section 4.1.2 and tabulated in Appendix B, a general idea of how often the water quality meets WHO guidelines can be obtained. This methodology is very similar to water quality data collected in the RADWQ in which percentages of samples meeting water quality criteria are used to help determine whether improved sources provide safe water.

In the sample notebooks, sample points were specified to approximately ten areas as specified at the top of each page. Many of these areas can be found on the map in Figure 4-15.

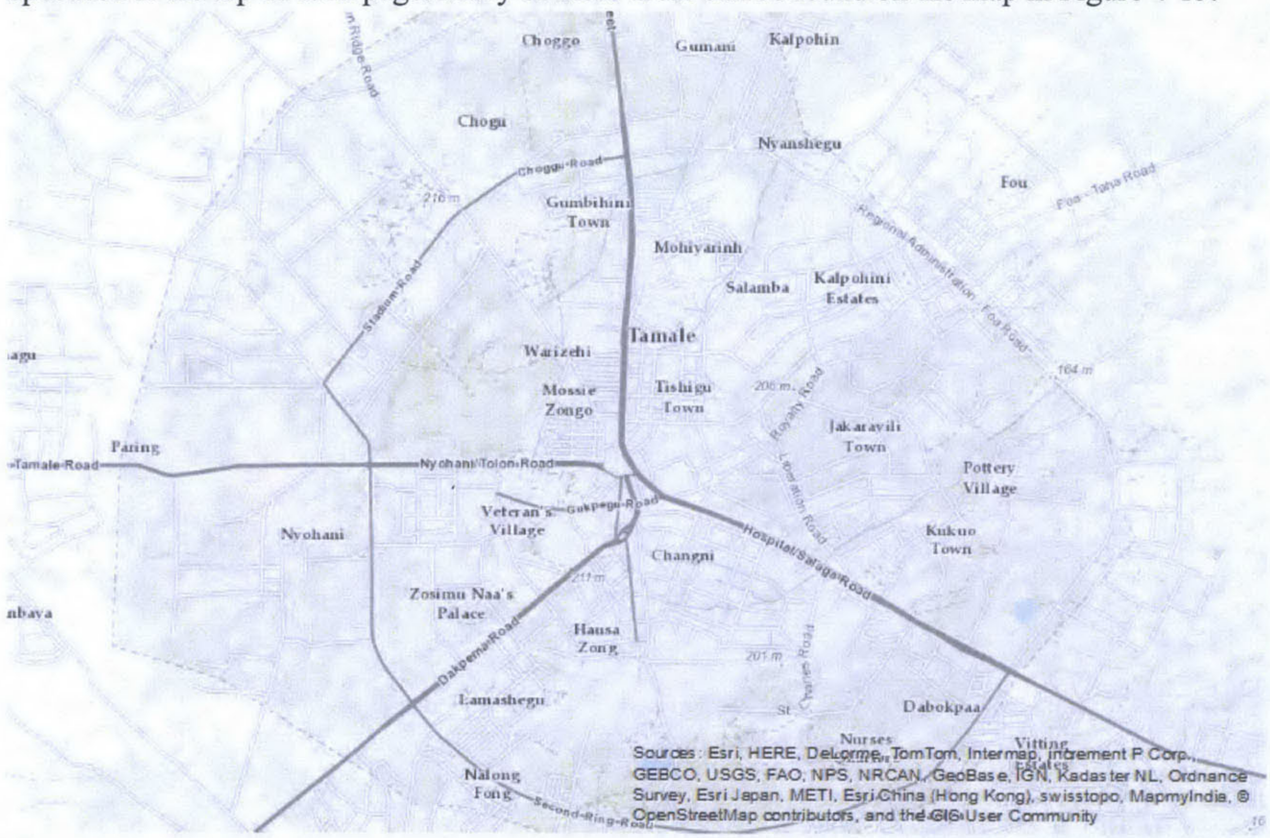


Figure 4-15: Map of Tamale Municipal

There were a few cases in which areas were unable to be read due to poor handwriting or areas that only occurred once, these areas are included in the "all areas" category but not in any individual area. Total counts for the number of samples not complying with WHO guidelines for pH, turbidity, residual chlorine, and total coliform are provided in Table 4-4. The corresponding percentages are seen in Table 4-5.

Table 4-4: Sample point counts not complying with WHO guidelines

	Number of samples outside WHO guidelines										
	All Areas	Choggu/ Jisonayili	Dalun	Gumani	Kukuo	Lameshegu/ Sawaba	Nyohni/ Zogbeli	Savelugu/ Mile 9	Tishegu/ Sakasaka	Vittin	Yendi
No. of Points	6643	508	944	192	461	242	599	934	255	269	1883
High pH (>8.5)	270	18	20	15	7	0	42	13	18	33	84
Low pH (<6.5)	377	87	110	0	30	3	25	21	10	0	75
High Turbidity (>5 NTU)	1579	96	189	23	49	16	130	152	76	63	713
Low Cl (<0.2 mg/l)	2822	100	296	116	148	112	214	549	97	119	927
No Cl	756	34	38	10	25	10	40	187	26	34	315
T. Coli (>0 counts)	105	0	0	0	0	1	6	4	0	2	86

Table 4-5: Sample point percentages not complying with WHO guidelines

	Percentages of samples outside WHO guidelines										
	All	Choggu/ Jisonayili	Dalun	Gumani	Kukuo	Lameshegu/ Sawaba	Nyohni/ Zogbeli	Savelugu/ Mile 9	Tishegu/ Sakasaka	Vittin	Yendi
High pH (>8.5)	4%	4%	2%	8%	2%	0%	7%	1%	7%	12%	4%
Low pH (<6.5)	6%	17%	12%	0%	7%	1%	4%	2%	4%	0%	4%
High Turbidity (>5 NTU)	24%	19%	20%	12%	11%	7%	22%	16%	30%	23%	38%
Low Cl (<0.2 mg/l)	42%	20%	31%	60%	32%	46%	36%	59%	38%	44%	49%
No Cl	11%	7%	4%	5%	5%	4%	7%	20%	10%	13%	17%
T. Coli (>0 counts)	2%	0%	0%	0%	0%	0%	1%	0%	0%	1%	5%

As seen from the data, it is certainly not uncommon for samples to be outside of the criteria suggested for drinking-water quality. The pH is usually within the bounds of 6.5-8.5 although a few areas, Choggu/Jisonayili and Dalun, have higher occurrences of pH greater than 8.5. A high pH makes chlorine disinfection less effective so at times of high pH, there is a higher likelihood of water being contaminated at the tap or becoming contaminated during storage practices. High turbidity, greater than 5 NTU, is also a common occurrence. As turbidity is a measure of suspended sediments on which microbes may attach, high turbidity may also indicate a greater probability of microbial contamination. 42% of all samples had a chlorine residual less than the recommended 0.2 mg/l and 11% had no chlorine residual. The chlorine residual is very important in preventing water from becoming contaminated during storage, and, as the vast majority of people in Tamale store their water, it is very likely that their water becomes contaminated before use or consumption. There were positive counts of total coliform in 2% of all water samples. Yendi, in particular, has a higher occurrence of total coliform. Unfortunately, not much about the Yendi treatment plant and distribution system was provided from the GWCL so insight into the high value cannot be gained. As total coliform is an indicator for microbial contamination, these samples probably had microbial contamination.

4.2.4 Sanitary Survey Risks

In the Rapid Assessment of Drinking-Water Quality, in addition to the numerical data gathered for the sample points, there is also a qualitative aspect to determine the risk of contamination due to the environment surrounding the water source. For a piped water distribution system, the ten survey questions are (WHO and UNICEF 2012):

1. Do any taps or pipes leak at the sample site? Y/N
2. Does water collect around the sample site? Y/N
3. Is the area around the tap insanitary? Y/N
4. Is there a sewer or latrine within 30 m of any tap? Y/N
5. Has there been discontinuity in the last 10 days? Y/N
6. Is the supply main pipeline exposed in the sampling area? Y/N
7. Do users report any pipe breaks within the last week? Y/N
8. Is the supply tank cracked or leaking? Y/N
9. Are the vents on the tank damaged or open? Y/N
10. Is the inspection cover or concrete around the cover damaged or corroded? Y/N

While in Tamale, and briefly surveying a portion of the distribution system, some observations were made in regard to a few of these questions.

While out looking at pressure tapping points, it was observed that some areas near where pipes were accessed there was open defecation. Also, in some areas the open sewers that ran alongside roads were in close proximity to pipes. These observations would mean that the answer to question four of the survey would be "no".

It is well known that the water supply in Tamale is intermittent. The IBNET database for Ghana reports that the average continuity for water supply for the whole country is 11 hours per day (Berg and Danilenko 2011). Based on user surveys conducted by Deborah Vacs Renwick (2013) in Tamale, most respondents reported that water was only available a few days a week. Based upon this evidence, the answer to question five would also be "no".

While surveying different areas, Deborah Vacs Renwick also located a few points where pipes were broken and leaking as seen in Figure 4-16. From her picture, it would also appear that the pipes leading to the taps are exposed. Assuming her observation is not uncommon for other points in the distribution system as well, the answers to questions one and six would be "no" as well.

Figure 4-16: Broken distribution pipe (Photo: Deborah Vacs Renwick)

Finally, while surveying pressure tapping points, it was observed that the covers to many of the access locations were broken or missing. In fact, at one location, a man was using the area underneath the cover as storage for his small sidewalk shop. In another location, the cover to the access point was missing and the area surrounding the exposed pipe was filled with trash. In general, the pipe access locations were not secure and would be easily subject to vandalism. Therefore, the answer to question ten would be "no".

Based on these observations, the distribution system in Tamale has a score of at least five which would be classified as a medium risk in the RADWQ assessment. Further, more targeted, observations in the future may also find additional risks related to the other questions which could not be commented on at this time.

5 EPANET Modelling

The second objective of this project was to create a hydraulic model of a portion of the distribution system to try to understand the effects of intermittency on the water pressure as well as look for areas where low or negative pressure may allow contaminants to enter the water.

Data on the distribution network was provided by the GWCL in the form of an ArcGIS file of a portion of their network. The GIS data included pipe lengths, diameters, and materials as well as the map of the network. This data was used to create a model of the network in EPANET, a free software from the U.S. EPA which models hydraulic parameters and water quality in pipe networks.

Unfortunately, there were many challenges to completing this objective:

1) The portion of the network that the GWCL provided did not contain just a single inflow and outflow
2) Pipes leading outside of the boundaries were cut off and data not provided. This made it impossible to accurately understand what is happening in the whole area provided. A possible solution to this problem is to make use of the District Metered Areas (DMAs). The GIS data did provide which DMA each pipe belonged to and each DMA, by definition, has a single inflow. Using the GIS data, at least one entire DMA was contained within the network section provided, so DMA C4 was selected to be used for the purpose of modelling. Figure 5-1 shows the GIS map provided with DMA C4 highlighted.
3) The GWCL was unable to provide current pressure and flow data for points in the system due to broken equipment at their pressure tapping points.
4) Points where consumers are attached to pipes as well as their demand is not included in the GIS data.
5) Due to the intermittency of water in Tamale, many consumers have their pipes hooked directly to large tanks which fill with water whenever pipes are pressurized. The hydraulic implications of such tanks are a large factor to consider in modeling the system. These tanks also cause the modeling to be very different from developed countries. Data on locations and dimensions of such tanks was unavailable to the GWCL and making reasonable assumptions to factor in the impact of the tanks was unfeasible.
6) As much of the literature points out, commercially available models are designed for continuous supply and are less readily applicable to the discontinuity and pressure losses that occur in developing countries. For example, it is possible for an intermittent system to develop areas of negative pressure; in EPANET negative pressures cause the model to stop running and a warning message is displayed.

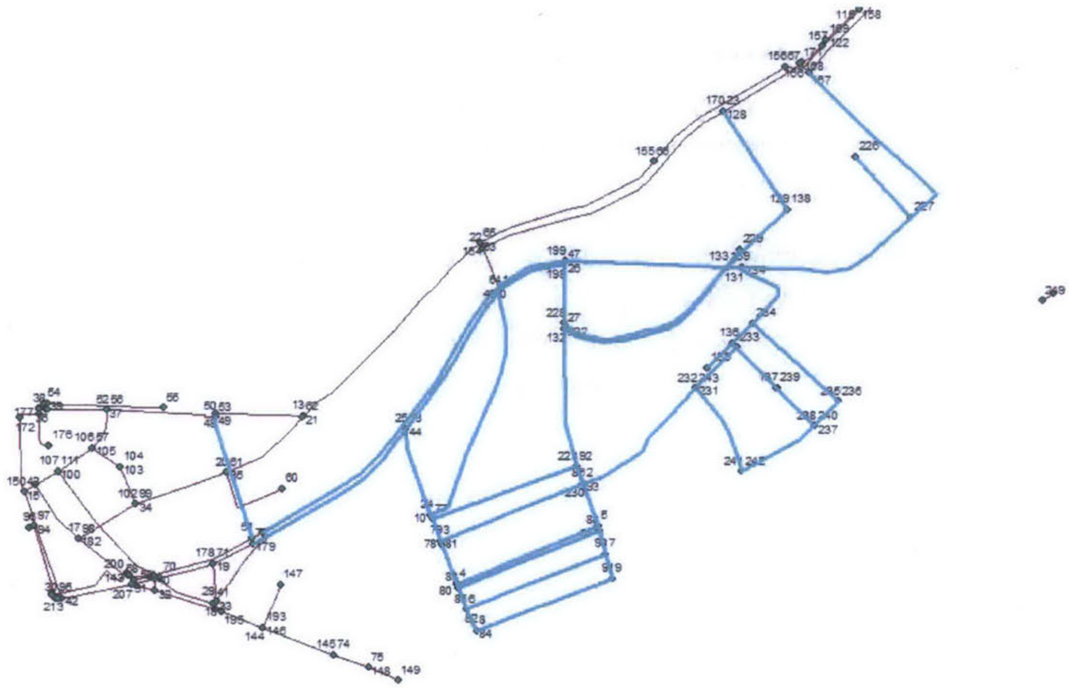


Figure 5-1: GIS map of distribution system portion; DMA C4 highlighted

There are a few possible reasons as to why some of these challenges occurred while collaborating with the GWCL:

- The GWCL may see their data as power and did not want to share this power
- Lack of trust
- Insecurity that their data is accurate
- Fear that data will show shortcomings or failures

Ultimately, the amount of hindrances to creating a model made this part of the project impracticable. In order to create a working model a plethora of assumptions would need to be made. By having so many assumptions, the resulting model, while possibly providing some insight as to how to model intermittent systems in general, would not have been applicable to the real life situation and would not be helpful to the GWCL.

6 Conclusions

6.1 Water Quality in Tamale, Ghana

The analysis of the historical data from the Tamale GWCL revealed a lot about the water quality both at the water source and at the sample points.

The raw water entering the Dalun Water Treatment Plant from the White Volta has some distinct seasonal trends. Both the pH and the turbidity are influenced by the differences between the rainy season and the dry season. These seasonal trends also appear in the treated water although to a lesser extent. pH values after treatment range from about 6 to greater than 9. The pH influences the effectiveness of chlorine disinfection with lower pH values being more desirable for killing pathogens. pH can also have an effect on the corrosion of pipes and the creation of biofilms inside pipes which also add contaminants to the water.

As water leaves the treatment plant and travels through the distribution system, the residual free chlorine concentration does deteriorate. This may be due to water age or due to contaminants entering the pipes. Overall, 42.5% of all samples had a free residual chlorine concentration less than 0.2 mg/l which is the WHO guideline to ensure pathogens are killed. In addition, 11.4% of samples had no free chlorine available. When free chlorine is not available for disinfection, pathogens that may enter water from contact with unwashed hands or unsafe storage containers are then able to infect humans and cause illness.

Further, based upon observations made during field work in Tamale, there are other environmental concerns that may affect water quality. Based upon the RADWQ survey for distribution systems, the distribution system in Tamale likely has a least a medium risk for unsafe water quality. The pipes are, in general, poorly maintained and susceptible to breaks or vandalism which can lead to contamination entering the water.

The GWCL data indicated that 1.6% of all water samples tested positive for total coliform. Comparing this to the 73% of samples collected from households by Vacs Renwick last year, as well as the survey indicating 53% of households use unsafe storage containers, indicates that storage practices are most likely the largest source of contamination of the piped water before consumption. As the residual chlorine levels measured by the GWCL were so low or nonexistent, water is easily re-contaminated during storage. As the testing methods used by the GWCL were not disclosed, it may also be possible that testing methods are outdated or inaccurate or that data is falsified to give the appearance of clean water.

Overall, the goal of this research was: does the "improved" piped water source in Tamale, Ghana actually provide "safe" water? Based upon the results of water quality analysis and prior research by Vacs Renwick, it can be concluded that, having piped water in Tamale does not guarantee that the water is safe for consumption due to the combination of lack of chlorine residual from the treatment plant and unsafe storage practices at households.

6.2 Recommendations to the GWCL

Based upon the observations made during field work in Tamale and the results of the water quality analysis, the author recommends the following improvements:

- First and foremost, the Microsoft Access database created in January should be continuously used and the reports created by the software should be analyzed and any instances of poor water quality or contamination be further investigated and acted upon. The database groups sample points into smaller areas rather than just the large districts formerly used so water quality not meeting standards will be more easily noticed and can be located.
- When taking samples, it is imperative to include time of day in which samples were taken. This would be a simple addition to the sample recording process which would be useful in seeing if water quality varies throughout the course of a day.
- The GWCL should create and implement a better water sampling methodology using either consistent locations and frequency or a stratified random sampling method. Free resources are provided by the WHO such as the *Guidelines for Drinking-water Quality* that can be used by the GWCL to improve their sampling proceduces.
- The water quality standards used by the Tamale GWCL, as indicated by their former Excel spreadsheets, are less stringent than WHO guidelines. In order to ensure safe water and to hold to a higher goal of water quality, the WHO guidelines should be adopted by the GWCL.
- The seasonal trends in pH and turbidity levels of the White Volta River water entering the treatment plant can be used to better predict treatment dosages and to have better control over output levels.
- In general, the pH, turbidity, and residual free chlorine levels immediately after treatment vary widely. Steps to better control these parameters should be taken. For example, better training or education of treatment plant employees may be necessary or more accurate dosing measurements may be required.
- Overall maintenance on the system should be improved to prevent contamination during distribution.
    - During field work it was learned that almost all of the pressure tapping points were broken and so pressure readings could not be taken. The GWCL does have problems with non-revenue water; by taking more regular pressure readings it might be possible to locate areas with low pressure and investigations into pipe breaks or illegal connections could be made in those areas.

    - In addition, many of the covers to the pipe access locations were missing or broken and none of them were locked or sealed in any way to prevent vandalism. By better protecting the access locations it would be harder for further vandalism to take place, trash couldn't build up in the locations, and the pipes would be better protected from outside contamination.
- In particular, it seems that the area around the airport sampling point is a source of contamination as residual chlorine levels are much lower than other points despite being located relatively closer to the treatment plant. This area of the distribution system should be more closely monitored and surveyed to determine the source of the contamination and steps to fix it should be taken.

Unfortunately, the GWCL does not likely have the available revenue to actually act on most of these recommendations.

6.3 Recommendations for Further Research

There are still a lot of potential projects that could continue to build a better understanding of the piped water supply and water quality produced by the GWCL in Tamale.

- Now that data from the notebooks has been entered and is readily available for analysis, further, more detailed analysis could be done in addition to that provided in Section 4.
- Determining if water is "safe" depends on more than just the parameters measured by the GWCL. Aside from microbial contamination detected by coliform presence in samples, water can also be contaminated by metals or other chemicals. These other contaminants do not appear to be routinely measured by the GWCL and were not included in the notebooks provided. Samples from various locations in the distribution system could be taken and analyzed for any number of other contaminants and compared to health guidelines provided by the WHO or US EPA.
- Similarly, a more complete RADWQ could be conducted for Tamale using the methodology outlined in WHO and UNICEF's *Rapid Assessment of Drinking-Water Quality*. This would involve taking samples and testing for the parameters designated in the outline as well as a survey to determine further sanitary risks posed by the environment. Results from this assessment could be compared to results from the five pilot countries.
- Creating a hydraulic model would be an extremely useful tool to better understand the hydraulics and water quality issues of an intermittent system. As more research in this area is conducted, more tools may become available to more easily model such systems. Also, much more data from the GWCL would be required to overcome the challenges faced as outlined in Section 5. This would require more cooperation on behalf of the GWCL.

- In addition, there are still many unanswered questions about how the factors surrounding the intermittency. If the GWCL is willing to share more information about the operation of the distribution system, there is a lot of potential for research on this subject such as determining what the biggest cause of the intermittency in Tamale is, how the periods of service are determined, and whether the intermittency causes any inequality in service between people closer to the treatment plant and those further away. Further user surveys could also be conducted to compare consumer perception to reality.
- The most detailed description of the treatment process at Dalun Water Treatment Plant was from a thesis written prior to the 2008 upgrade. It would be important to better understand what changes were made and provide an updated description. An assessment of the operation of the Dalun Treatment plant could be conducted to learn procedures used. This could be useful in determining why there is so much variability in pH, turbidity, and residual chlorine in the treated water as well as to provide the GWCL with ways they can improve it. In addition, the RADWQ, or similar, survey for treatment plants could be used to determine if there are any sanitary risks at the point of treatment.

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Appendix A: Selected Sample Point Data

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
5/12/06	T. East	Airport	8.68	36.6	145.9	3.1		0.05	0	
5/31/06	T. East	Airport	8.57	34.1	139.8	1.81		0.1		
6/16/06	T. East	Airport	8.2	31.3	130.6	1.26		0.05	0	
7/19/06	T. East	Airport	7.41	34.4		3.68		0.15	0	
8/16/06	T. East	Airport	7.73	29.2	142.5	1.11		0.05	0	
9/19/06	T. East	Airport	7.6	29.6	128.7	0.62		0	0	
10/19/06	T. East	Airport	7.67	32.1	129	1.56		0	0	
1/25/07	T. East	Airport	7.7	29.9	124.3	1.35		0	0	
2/13/07	T. East	Airport	8.16	32.3	123.3	2.52		0	0	
3/12/07	T. East	Airport	7.4	32.4	125.5	2.11		0	0	
4/17/07	T. East	Airport	7.5		775	2.06		0	0	0
5/24/07	T. East	Airport	7	33	135.4	5.39		0.2	0	0
5/24/07	T. East	Airport	7	33	135.4	5.39		0	0	0
6/12/07	T. East	Airport	7.1	32.3	148.9	2.46		0	0	0
7/16/07	T. East	Airport	7.2	29.4	114	1.55		0	0	0
9/18/07	T. East	Airport	7	25.2	116	2.21		0.1	0	0
12/7/07	T. East	Airport	6.8	30.1	104	1.07	0	0	0	
1/25/08	T. East	Airport	7.16	29	97	1.09	0	0	0	
2/19/08	T. East	Airport	7.57	31.2	92	2.45	0	0.2	0	0
3/14/08	T. East	Airport	8	30.9	110	1.59	0	0	0	
4/9/08	T. East	Airport	8.03	32.8	114	3.01	0.2	0.1	0	
8/19/08	T. East	Airport	8.74		120	3.93	2.8	0	0	
9/11/08	T. East	Airport	8.13		113	13	4.9	0	0	0
10/21/08	T. East	Airport	8.2	32.2	111	0.86	2.1	0	0	0
1/21/09	T. East	Airport	7.53	29.1	102	0	0	0	0	0
2/12/09	T. East	Airport	7.39		101	6	1.1	0.1	0	0
3/5/09	T. East	Airport	7.83	29.1		6	2.9	0	0	0
4/15/09	T. East	Airport	7.5		112	0	0	0	0	0
5/15/09	T. East	Airport	7.3		121	6	3.7	0	0	0
7/8/09	T. East	Airport	7.5	31.4	133.3	4	0	0	0	0
9/18/09	T. East	Airport	7.49	30.6	118.6	0	0	0.1	0	
10/16/09	T. East	Airport	7.66	31.3	110.3	1	0	0	0	
12/15/09	T. East	Airport	7.11	29.5	109.5	6	28	0	0	
2/18/10	T. East	Airport	7.79	33.2	111.3	6	1.3	0	0	0
4/15/10	T. East	Airport	7.5	35.1	113.2	3.07	1.1	0.15	0	
5/27/10	T. East	Airport	8.43	35.3	118.5	0.6	0.3	0	0	
8/6/10	T. East	Airport	8.24	31.8	128.9	1.07	2	0	0	

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
11/14/10	T. East	Airport	7.11	31.8	99.7	0	0	0.15	0	
6/14/11	T. East	Airport	7.03	35.2	110.9	1	0.7	0.15	0	0
12/16/11	T. East	Airport	7.39	30	113.3	0.67	0.5	0.01	0	0
3/20/12	T. East	Airport	6.93	33.6	122.1	0.65	3	0.01	0	0
5/7/12	T. East	Airport	7.63	34.5	128.7	1	1	0.01	0	0
6/12/12	T. East	Airport	7.6	34.2	126.7	0.68	0	0.1	0	0
8/28/12	T. East	Airport	7.6	31.8	109.1	1.1	0	0.1		0
8/28/12	T. East	Airport	6.6	29	96.7	2.53	0.8	1		0
8/7/13	T. East	Airport	7.8	30.3	140	0.2	0	0.1		0
10/28/05	T. West	Bagabaga low cost	7.71	33.2	129.3	6.93		0.45	0	0
2/3/06	T. West	Bagabaga low cost	8.65	29.9	114.2	4.71		0.15	0	0
4/3/06	T. West	Bagabaga low cost	8.43	34	122.6			0.3		0
4/27/06	T. West	Bagabaga low cost	7.7	32	114.6	6.82		0.45		0
4/28/06	T. West	Bagabaga low cost	7.61	31.4	113.1	5.82		0		
5/3/06	T. West	Bagabaga low cost	4.44	32.3	112.7	11.4		0.35	0	
9/23/08	T. West	Bagabaga low cost	7.6			5.17	3.1	0.45	0	
3/31/11	T. West	Bagabaga low cost	8.29	32.9	105.1	5	3.1	1	0	
10/31/11	T. West	Bagabaga Low Cost	7.22	30.6	106.2	2	1	0	0	0
5/15/12	T. West	Bagabaga low cost	8.49	32.2	125	1.93	0.2	0.25	0	0
7/13/12	T. West	Bagabaga low cost	6	29.6	141.6	1.84		1	0	0
10/19/12	T. West	Bagabaga low cost	6.9	30.1	92.5	1.06	0	0.1		0
10/19/12	T. West	Bagabaga low cost	7.3	30.9	91.1	1.12	0	0.1		0
7/18/13	T. West	Bagabaga low cost	6.81	32	115.9	1.68	0.8	0.2		0
9/11/13	T. West	Bagabaga low cost	7	28	129.4	1.12	0	0.2		0
10/11/13	T. West	Bagabaga low cost	7.1	26.6	145.4	1.2	3.5	0.1	0	0
9/28/12	T. West	Dakbopa SHS	6.9	27.4	191.3	2.83	1.8	0.1		0
11/14/12	T. West	Dakbopa SHS	6.9	31.6	129.8	5.3	3.3	1		0
2/15/13	T. West	Dakbopa SHS	7.46	28.4	99.6	4.77	4.4	0.6		0
4/25/13	T. West	Dakbopa SHS	7.28	31.2	103.1	1.88	1	0.2		0
6/25/13	T. West	Dakbopa SHS	7.1	28.8	118.7	2.07	1.6	0.1		0
4/4/08	T. West	Dakbopa SHS	8.8	33	115	3.21	0.1	0.1	0	
5/9/08	T. West	Dakbopa SHS	5.2	32.6	116	1.09	0.6	0.35	0	
2/27/09	T. West	Dakbopa SHS	7.81		111	4	2.4	0.25	0	0
3/17/10	T. West	Dakbopa SHS	7.98	32	126.5	2	2.2	0.1	0	0
7/29/10	T. West	Dakbopa SHS	7.61	29.3	130.6	1.72	0	0.4	0	0
10/27/11	T. West	Dakbopa SHS	7.34	31.6	106	5	2.1	0.15	0	0
4/3/06	T. East	Kaafiehyili stand pipe	7.62	33.2	120.1	1.61		0		
4/28/06	T. East	Kaafiehyili stand pipe	7.49	33.5	108.1	10.6		0		
9/5/06	T. East	Kaafiehyili stand pipe	7.66	29	116	2.68		0.55		

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
10/4/06	T. East	Kaafiehyili stand pipe	8.03	31.9	129.5	2.49		0.25	0	
1/9/07	T. East	Kaafichyili stand pipe	7.74	25	111.3	10		0.85	0	
3/19/07	T. East	Kaafiehyili stand pipe	7.5	31.2	109.4	13.1		0.9	0	
4/10/07	T. East	Kaafiehyili stand pipe	6.9	32.9	135.4	6.84		0.7	0	0
5/2/07	T. East	Kaafiehyili stand pipe	6.7	29.5	123.4	4.63		1	0	
5/2/07	T. East	Kaafiehyili stand pipe	6.7	29.5	123.4	4.63		1	0	0
6/5/07	T. East	Kaafiehyili stand pipe	6.6	31.6	119.8	2.2		0.7	0	0
6/5/07	T. East	Kaafiehyili stand pipe	6.6	31.6	119.8	2.2		0.7	0	0
8/1/07	T. East	Kaafiehyili stand pipe	6.1	27.9	101	4.48		0.9	0	0
9/4/07	T. East	Kaafiehyili stand pipe	6.1	28.7	91	3		1	0	0
10/11/07	T. East	Kaafiehyili stand pipe	6.5	31.9	95	1.05		1.1	0	0
11/1/07	T. East	Kaafiehyili stand pipe	6.3	30.7	97	2.34		1.15	0	0
12/5/07	T. East	Kaafiehyili stand pipe	6.4	29.6	93	3.16	0	1	0	
1/21/08	T. East	Kaafiehyili stand pipe	6.8	24.7	97	2.86	0	2	0	
2/12/08	T. East	Kaafiehyili stand pipe	7.75	28.5	114	1.76	0	2	0	
3/5/08	T. East	Kaafiehyili stand pipe	8.25	31.5	103	2.31	0	0.35	0	
8/21/08	T. East	Kaafiehyili stand pipe	8.21	29.3	101	3.68	1.9	0.25	0	
1/8/09	T. East	Kaafichyili stand pipe	6.99	28.5	97	4	0	0.45	0	0
2/5/09	T. East	Kaafiehyili stand pipe	6.62	29.9	95	1	0	0.3	0	0
3/3/09	T. East	Kaafiehyili stand pipe	7.14		107	1	0	0.55	0	0
4/2/09	T. East	Kaafiehyili stand pipe	7.1		104	2	0.7	0.2	0	0
5/12/09	T. East	Kaafiehyili stand pipe	7.3		116	6	4	0.3	0	0
6/11/09	T. East	Kaafiehyili stand pipe	7.3	32	124	1	0	0.3	0	
7/2/09	T. East	Kaafiehyili stand pipe	6.6	30.5	129.1	3	1.8	0.45	0	
9/7/09	T. East	Kaafiehyili stand pipe	7.15	28.5	111.8	1	0.8	0.3	0	
10/13/09	T. East	Kaafiehyili stand pipe	6.82	30.6	125.8	0	0	0.25	0	
11/5/09	T. East	Kaafiehyili stand pipe	6.75	30.5	97.8	1	0.5	0.1	0	0
1/19/10	T. East	Kaafiehyili stand pipe	6.67	26.9	127.3	8	5.1	0.4	0	
2/19/10	T. East	Kaafiehyili stand pipe	7.39	31.5	104.5	6	2.2	0.1	0	
8/3/10	T. East	Kaafiehyili stand pipe	7.17	28.8	106.3	1.01	0.2	0.1	0	
10/8/10	T. East	Kaafiehyili stand pipe	7.35	28.6	15.8	0	0	0.2	0	0
4/20/11	T. East	Kaafiehyili stand pipe	6.63	32.8	106.7	3	1.8	0.2	0	0
5/5/11	T. East	Kaafiehyili stand pipe	7.4	33.4	103.1	3	2.6	0.2	0	0
12/6/11	T. East	Kaafiehyili stand pipe	7.32	28.6	112.5	0.63	0.4	0.25	0	0
9/6/12	T. East	Kaafiehyili stand pipe	6.9	29.6	97	3.07	0.9	0.15		0
11/6/12	T. East	Kaafiehyili stand pipe	6.93	31.1	125.8	8.79	3.3	1.15		0
12/12/12	T. East	Kaafiehyili stand pipe	6.9	32	112	6.43	4.1	0.6		0
1/9/13	T. East	Kaafiehyili stand pipe	7.66	26.2	114.8	3.66	1.4	1		0
2/5/13	T. East	Kaafiehyili stand pipe	7.5	29.1	104.9	1.08	0.1	0.1		0

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
3/13/13	T. East	Kaafiehyili stand pipe	7.3	33.8	104.4	1.84	1.6	0.75		0
6/4/13	T. East	Kaafiehyili stand pipe	6.9	31.3	112	1.17	0.3	1		0
8/5/13	T. East	Kaafiehyili stand pipe	6.5	29.4	120.3	3.92	3.2	0.15		0
11/11/13	T. East	Kaafiehyili stand pipe	6.3	30.4	112.1	2.32	1.9	0.2	0	0
2/6/06	T. East	Kanshegu stand pipe	9.03	31.2	112.9	4.79		0		
8/16/06	T. East	Kanshegu stand pipe	7.97	29.5	131.5	1.32		0.05	0	
9/19/06	T. East	Kanshegu stand pipe	7.16	28	117	3.8		0.15	0	
10/19/06	T. East	Kanshegu stand pipe	7.31	29.7	120.5	2.19		0.25	0	
11/16/06	T. East	Kanshegu stand pipe	7.75	29.6	116.8	2.47		0.55		
12/8/06	T. East	Kanshegu stand pipe	7.46	29.6	110.6	7.75		0.35	0	
1/25/07	T. East	Kanshegu stand pipe	7.18	28.2	110.8	3.96		0.3	0	
2/13/07	T. East	Kanshegu stand pipe	7.72	30.1	112.9	1.86		0	2	
3/12/07	T. East	Kanshegu stand pipe	7.2	33.5	122.8	4.8		0	0	
4/17/07	T. East	Kanshegu stand pipe	6.9		838	1.32		0.55	0	0
5/24/07	T. East	Kanshegu stand pipe	6.8	31.5	110.2	15		0.1	0	0
5/24/07	T. East	Kanshegu stand pipe	6.8	31.5	118	5.03		0	0	0
6/12/07	T. East	Kanshegu stand pipe	6.8	30.7	123.8	8.45		0.45	0	0
7/16/07	T. East	Kanshegu stand pipe	6.7	27.9	105	1.87		0.05	0	0
9/18/07	T. East	Kanshegu stand pipe	6.6	26	109	1.55		0.1	0	0
10/12/07	T. East	Kanshegu stand pipe	6.7	30.8	91	1.15		0.1	0	0
11/19/07	T. East	Kanshegu stand pipe	6.5	31.3	111	1.47	2	0.55	0	
12/7/07	T. East	Kanshegu stand pipe	6.9	29.4	90	2.6	1	0.5	0	
1/25/08	T. East	Kanshegu stand pipe	6.89	29.3	97	2.33	0	0.5	0	
2/19/08	T. East	Kanshegu stand pipe	7.63	31.1	99	1.21	0	0	0	0
4/9/08	T. East	Kanshegu stand pipe	8.46	34.1	115	4.65	0.2	0	0	
1/21/09	T. East	Kanshegu stand pipe	7.5	27.5	96	1	1.1	0.3	0	0
2/12/09	T. East	Kanshegu stand pipe	7.38		106	4	0	0	0	0
5/15/09	T. East	Kanshegu stand pipe	7.2		110	2	0.9	0.15	0	0
8/18/09	T. East	Kanshegu stand pipe	7.1	29.1	117.1	3	1	0	0	
9/18/09	T. East	Kanshegu stand pipe	7.43	28.7	106.6	0	0	0	0	
10/16/09	T. East	Kanshegu stand pipe	7.81	29.4	104.8	4	35	0	0	
11/13/09	T. East	Kanshegu stand pipe	7.22	30.3	110.4	0.43	0	0.2	0	0
2/18/10	T. East	Kanshegu stand pipe	7.38	30.6	111.4	9	3	0.2	0	
4/15/10	T. East	Kanshegu stand pipe	7.2	33.8	106.8	4.5	2	0.25	0	
5/27/10	T. East	Kanshegu stand pipe	7.4	33.3	116.6	0.96	0	0.1	0	
9/29/10	T. East	Kanshegu stand pipe	7.53	28.9	121.3	1	0.6	0.15	0	
1/12/11	T. East	Kanshegu stand pipe	7.73	27.56	98.1	3	0	0.2	0	
2/10/11	T. East	Kanshegu stand pipe	7.47	29.1	100.3	4	2.6	1.4	0	
4/14/11	T. East	Kanshegu stand pipe	7.79	33.7	104.1	1	0	0.15	0	

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
5/11/11	T. East	Kanshegu stand pipe	7.5	32.5	110.3	0	0	0.15	0	0
10/13/11	T. East	Kanshegu stand pipe	6.91	29.5	105	1	0	0.1	0	0
11/14/11	T. East	Kanshegu stand pipe	7.14	30.3	112.8	1.02	0.6	0	0	0
3/20/12	T. East	Kanshegu stand pipe	6.88	33.4	115.5	1.12	4.7	0.25	0	0
5/7/12	T. East	Kanshegu stand pipe	7.63	32.4	125.2	2	0.1	0.15	0	0
6/12/12	T. East	Kanshegu stand pipe	7.6	32.2	123.9	1.13	1	0.1	0	0
8/28/12	T. East	Kanshegu stand pipe	6.8	28.8	102.2	1.27	2	0.1		0
9/24/12	T. East	Kanshegu stand pipe	7.1	29.7	88.8	0.72	0	0.1		0
10/9/12	T. East	Kanshegu stand pipe	7.3	29.8	104.2	1.2	1	0.1		0
11/15/12	T. East	Kanshegu stand pipe	7.1	31.1	130	0.46	0	0.1		0
2/12/13	T. East	Kanshegu stand pipe	7.31	29.1	101.8	4.63	3.6	0.2		0
3/14/13	T. East	Kanshegu stand pipe	7.38	33.9	98.7	1.25	1.7	0.15		0
4/30/13	T. East	Kanshegu stand pipe	7.55	30.6	96.5	1.65	0.3	0.15		0
5/16/13	T. East	Kanshegu stand pipe	6.85	31.2	110.8	3.09	1.3	0.1		0
9/5/13	T. East	Kanshegu stand pipe	6.7	29.4	101.9	2.31	0	0.2		0
10/18/13	T. East	Kanshegu stand pipe	6.88	29.1	112.5	1.17	2.2	0	0	0
12/6/06	T. East	Kumbungu SHS	8.36	29.8	118.3	13.9		1.3	0	
1/9/07	T. East	Kumbungu SHS	7.26	27.7	102.1	9.01		0.85	0	
6/5/07	T. East	Kumbungu SHS	6.7	30.4	117.5	2.09		0.7	0	0
10/11/07	T. East	Kumbungu SHS	6.5	28.7	99	0.97		1.1	0	0
1/21/08	T. East	Kumbungu SHS	6.8	26.9	97	3.27	0.7	2	0	
3/5/08	T. East	Kumbungu SHS	8.07	34.5	105	2.07	0	0.1	0	
5/7/08	T. East	Kumbungu SHS	8.12	32.7	116	1.59	0	0.35	0	
6/3/08	T. East	Kumbungu SHS	7.78	30.2	112	4.16	1.4	0.15	0	
7/25/08	T. East	Kumbungu SHS	7.65	29.6	122.8	18	47.4	0	0	
11/25/08	T. East	Kumbungu SHS	7.94	30.3	115	9	2.4	0.5		
2/5/09	T. East	Kumbungu SHS	6.93	29.6	96	0	0	0.4	0	0
7/2/09	T. East	Kumbungu SHS	6.6	29	126.7	3	3.2	0.15	0	
9/12/09	T. East	Kumbungu SHS	7.22	28.5	111.7	2	9	0.35	0	
10/13/09	T. East	Kumbungu SHS	7.24	29.2	105.9	1	0	0.1	0	
3/10/10	T. East	Kumbungu SHS	6.89	33	101.9	6	3	0	0	
7/6/10	T. East	Kumbungu SHS	7.39	28.6	120	1.73	0.1	0.6	0	
10/8/10	T. East	Kumbungu SHS	6.94	27.6	118.1	5	0.9	0.1	0	0
12/7/10	T. East	Kumbungu SHS	6.8	26.6	98.4	0	0	0.1	0	
2/8/11	T. East	Kumbungu SHS	6.68	32	95.2	0	0	0.3	0	
5/5/11	T. East	Kumbungu SHS	7.35	33.6	102.2	3	0.4	0.2	0	0
6/7/11	T. East	Kumbungu SHS	6.65	31.4	104.6	4	2	0.25	0	0
7/18/11	T. East	Kumbungu SHS	5.42	27.5	112.1	1.32	0	0.2	0	0
9/6/11	T. East	Kumbungu SHS	6.39	28.3	108.3	0.77	2.9	0.75	0	0

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
10/14/11	T. East	Kumbungu SHS	6.63	32	95.7	0	0	0.1	0	0
11/3/11	T. East	Kumbungu SHS	6.67	32.6	107.6	0.88	0.8	0	0	0
12/6/11	T. East	Kumbungu SHS	7.19	29.4	109.9	1.66	0.3	1.25	0	0
1/11/12	T. East	Kumbungu SHS	6.86	25.4	103.3	1.15	3.9	0.15	0	0
2/2/12	T. East	Kumbungu SHS	6.93	28	123.8	2.07	1.6	0.7	0	0
4/4/12	T. East	Kumbungu SHS	6.95	32	112.8	0.76	0.2	0.15	0	0
7/5/12	T. East	Kumbungu SHS	6.8	28.5	143	3.26	0	0.1	0	0
9/6/12	T. East	Kumbungu SHS	6.7	27.8	83.8	2.03	0.8	0.1		0
10/5/12	T. East	Kumbungu SHS	6.61	28.4	110.4	0.79	0.2	0.1		0
11/6/12	T. East	Kumbungu SHS	6.52	30.8	124.4	0.93	0.3	0.75		0
12/12/12	T. East	Kumbungu SHS	6.7	31.5	105	2.94	0.7	0.2		0
3/13/13	T. East	Kumbungu SHS	7.37	33.6	100.6	2.58	3.7	0.2		0
6/4/13	T. East	Kumbungu SHS	7.15	30	115.4	0.42	0.3	0.1		0
8/5/13	T. East	Kumbungu SHS	6.72	27.8	113.4	0.23	0.2	0.15		0
10/2/13	T. East	Kumbungu SHS	6.7	26.5	109.9	1.13	0	0.15	0	0
6/22/05	T. West	Miricha Hotel	7.97	30.8	139.3	5.57		0.25	0	
10/5/05	T. West	Miricha Hotel	7.92	27.6	110.9	2.21		0.15	0	
5/17/06	T. East	Saakuba stand pipe	7.8	30.5	118.8	3.08		0.9	0	0
6/13/06	T. East	Saakuba stand pipe	8.02	31.2	119.3	2		0.15	0	
7/5/06	T. East	Saakuba stand pipe	6.46	32.8	130.1	5.26		0.55	0	
8/1/06	T. East	Saakuba stand pipe	7.16	28.4	117.3	6.45		0.45	0	
9/5/06	T. East	Saakuba stand pipe	7.02	28.9	110.1	1.73		0.35	0	
10/4/06	T. East	Saakuba stand pipe	8.26	31.9	129.8	2.47		0.25	0	
11/7/06	T. East	Saakuba stand pipe	7.54	31.7	118.3	2.64		0.55	0	
12/6/06	T. East	Saakuba stand pipe	8.89	27	115.1	11.2		1.3	0	
1/9/07	T. East	Saakuba stand pipe	7.73	24.5	112.9	14.9		0.85	0	
2/6/07	T. East	Saakuba stand pipe	7.16	29.9	110.7	6.1		0.4	0	
3/19/07	T. East	Saakuba stand pipe	7.7	31.5	110	13.2		1	0	
4/10/07	T. East	Saakuba stand pipe	6.9	27	123.5	10.5		0.1	0	0
5/2/07	T. East	Saakuba stand pipe	6.9		123.7	3.26		1.15	0	
5/2/07	T. East	Saakuba stand pipe	6.9		123.7	3.26		1.15	0	0
6/5/07	T. East	Saakuba stand pipe	6.7	30.8	115.7	1.86		0.7	0	0
6/5/07	T. East	Saakuba stand pipe	6.7	30.8	115.7	1.86		0.7	0	0
7/5/07	T. East	Saakuba stand pipe	6.9	29.7	105	2.36		0.7	0	0
8/1/07	T. East	Saakuba stand pipe	6.3	28.4	99	3.72		1.2	0	0
9/4/07	T. East	Saakuba stand pipe	6.3	25	96	3.08		1.15	0	0
10/11/07	T. East	Saakuba stand pipe	6.4	31.9	94	0.84		1	0	0
11/1/07	T. East	Saakuba stand pipe	6.7	30.9	94	1.63		1.15	0	0
12/5/07	T. East	Saakuba stand pipe	6.4	29.7	91	2.63	0	1.15	0	

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
1/21/08	T. East	Saakuba stand pipe	6.8	25.4	100	2.66	1.1	2	0	
2/12/08	T. East	Saakuba stand pipe	8.06	27.4	113	2.06	1.4	2	0	
3/5/08	T. East	Saakuba stand pipe	8.52	31.8	106	2.43	0	0.45	0	
3/10/08	T. East	Saakuba stand pipe	6.96		112.3	1.93	0.45	0.9	0	
4/7/08	T. East	Saakuba stand pipe	9.03	31.8	115.4	3.48	0.2	0.25	0	
5/7/08	T. East	Saakuba stand pipe	7.66	32.8	109	2.07	0	0.35	0	
6/3/08	T. East	Saakuba stand pipe	7.49	31	112	8.89	4.6	0.9	0	
9/9/08	T. East	Saakuba stand pipe	7.98	30.7	111	62.9	21.7	0.3	0	
11/25/08	T. East	Saakuba stand pipe	8.33	29.3	114	3	1.2	0.5		
1/8/09	T. East	Saakuba stand pipe	7.3	29.4	95	5	1.7	0.5	0	0
2/5/09	T. East	Saakuba stand pipe	6.98	31.4	92	0	0	0.4	0	0
4/2/09	T. East	Saakuba stand pipe	7.3		110	7	2.7	0.7	0	0
5/12/09	T. East	Saakuba stand pipe	7.3		107	7	1.8	0.6	0	0
7/2/09	T. East	Saakuba stand pipe	6.3	30.2	126.3	4	0.9	0.5	0	
8/13/09	T. East	Saakuba stand pipe	7.3	29.8	117.5	7	2.2	0.1	0	
9/7/09	T. East	Saakuba stand pipe	7.47	29.4	102.7	0	0	0.6	0	
11/5/09	T. East	Saakuba stand pipe	6.89	30.3	105.7	4	2.1	0.4	0	0
1/19/10	T. East	Saakuba stand pipe	6.86	25.7	100.4	4	1.6	0.4	0	
2/19/10	T. East	Saakuba stand pipe	7.6	31	105.3	6	2	0.4	0	
3/10/10	T. East	Saakuba stand pipe	7.04	31.9	97.8	7	4.4	0.1	0	
7/6/10	T. East	Saakuba stand pipe	7.2	30.6	118.3	2.04	0.1	0.8	0	
10/8/10	T. East	Saakuba stand pipe	6.66	29.7	115.1	4	0	0.2	0	0
12/7/10	T. East	Saakuba stand pipe	7.28	28.8	105.1	0	0	0.1	0	
1/10/11	T. East	Saakuba stand pipe	6.7	25.2	90.5	0	0	0.5	0	
2/8/11	T. East	Saakuba stand pipe	6.98	28.4	92.7	7	4	0.2	0	
4/20/11	T. East	Saakuba stand pipe	7.12	32.6	99.2	4	0.9	0.2	0	0
6/7/11	T. East	Saakuba stand pipe	6.72	32.2	101.4	3	1	0.15	0	0
10/5/11	T. East	Saakuba stand pipe	6.61	31	94.7	0	0	0.2	0	0
11/3/11	T. East	Saakuba stand pipe	6.88	31.8	106.6	1.13	0	0.6	0	0
12/6/11	T. East	Saakuba stand pipe	7.25	28	107.8	1.82	0.6	0.25	0	0
1/11/12	T. East	Saakuba stand pipe	6.99	25.8	104.4	1.97	3.9	0.1	0	0
2/9/12	T. East	Saakuba stand pipe	6.97	27.2	118.1	0.85	0.3	0.25	0	0
4/4/12	T. East	Saakuba stand pipe	6.97	32	114.9	1.11	0.7	0.35	0	0
5/8/12	T. East	Saakuba stand pipe	7.3	32.2	124.5	4	1.5	0.25	0	0
6/6/12	T. East	Saakuba stand pipe	6.2	30.3	113.6	1.62	1.5	0.15	0	0
7/5/12	T. East	Saakuba stand pipe	6.6	28.2	136.2	7	1.5	0.1	0	0
8/13/12	T. East	Saakuba stand pipe	6.72	28.3	370	3.98	2.1	0.5		0
8/13/12	T. East	Saakuba stand pipe	6.82	28.1	301	2.27	0.9	0.4		0
9/6/12	T. East	Saakuba stand pipe	6.9	28.9	85.4	1.45	0.2	0.1		0

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
10/5/12	T. East	Saakuba stand pipe	6.65	29.8	105.7	2.59	1.1	0.4		0
11/6/12	T. East	Saakuba stand pipe	6.8	31	118.9	1.49	0.6	0.1		0
12/12/12	T. East	Saakuba stand pipe	6.55	29.7	101.9	8.99	3.8	0.3		0
1/9/13	T. East	Saakuba stand pipe	7.25	27.7	107.7	2.26	4	0.1		0
2/5/13	T. East	Saakuba stand pipe	6.83	26.4	93.7	1.38	0	0.1		0
3/13/13	T. East	Saakuba stand pipe	7.05	32.8	92.2	2.35	3.1	0.15		0
4/19/13	T. East	Saakuba stand pipe	7.17	33.3	94.9	1.01	0.99	0.1		0
5/7/13	T. East	Saakuba stand pipe	6.9	32	101.4	2.95	1.7	0.2		0
6/4/13	T. East	Saakuba stand pipe	7.14	31.4	101	1.02	0.5	0.15		0
7/3/13	T. East	Saakuba stand pipe	6.6	30.1	83.9	4.2	2.5	0.1		0
8/5/13	T. East	Saakuba stand pipe	6.9	29	116	1.23	0.9	0.15		0
9/4/13	T. East	Saakuba stand pipe	6.7	28.2	112.5	1.35	0.5	0.2		0
10/2/13	T. East	Saakuba stand pipe	6.56	28.2	104.9	2.12	0	0.2	0	0
11/11/13	T. East	Saakuba stand pipe	6.7	29.3	118.2	1.31	3	0.15	0	0
4/13/06	T. East	Tamale Int. Sch.	7.84	33.9	120.8	6.91		0		0
8/9/06	T. East	Tamale Int. Sch.	7.34	27.5	135.3	2.62		0.35		
5/14/07	T. East	Tamale Int. Sch.	7	29.2	126.4	6.79		0.1	0	0
5/14/07	T. East	Tamale Int. Sch.	7	29.2	126.4	6.79		0	0	0
6/25/07	T. East	Tamale Int. Sch.	6.3	30.1	100.9	2.78		0.8	0	0
7/24/08	T. East	Tamale Int. Sch.	7.22	28.9	113.6	4.02	0	0.45	0	
2/13/09	T. East	Tamale Int. Sch.	7.29		105	1	0	0.4	0	0
7/7/10	T. East	Tamale Int. Sch.	8.32	30.1	127.3	2.01	0	0.5	0	
4/7/11	T. East	Tamale Int. Sch.	7.81	32.3	98.4	2	2	0.3	0	
1/27/12	T. East	Tamale Int. Sch.	7.01	30.5	112.5	1.18	1.1	0.01	0	0
11/15/12	T. East	Tamale Int. Sch.	6.5	30.5	121.8	1.26	0	1.2		0
2/25/13	T. East	Tamale Int. Sch.	7.51	30.6	105.2	3.03	2.4	2		0
5/6/13	T. East	Tamale Int. Sch.	6.7	31.8	99.2	2.32	2.8	0.2		0
5/9/08	T. West	Vittin SHS	8.2	33.1	116	1.29	0.6	0.25	0	
7/29/10	T. West	Vittin SHS	7.76	29.9	131.8	1.55	0.1	0.55	0	0
10/27/11	T. West	Vittin SHS	7.02	30.6	106.4	4	2.1	0.1	0	0
1/23/12	T. West	Vittin SHS	7.02	28	111.6	3.75	3.6	0.7	0	0
2/15/13	T. West	Vittin SHS	7.51	30.9	99.5	4.39	2.9	0.6		0
4/25/13	T. West	Vittin SHS	7.25	33	100.3	1.64	1.4	0.1		0
6/25/13	T. West	Vittin SHS	7.2	30.9	124.5	2.22	1.99	0.1		0
5/3/06	T. East	Yipelnayili stand pipe	7.06	32.9	109.7	9.48		0.3	0	
5/17/06	T. East	Yipelnayili stand pipe	7.36	29.5	116.9	3.31		0.15	0	0
6/13/06	T. East	Yipelnayili stand pipe	8.43	32	120.9	1.98		0.25	0	
11/7/06	T. East	Yipelnayili stand pipe	7.64	32	121.2	3.16		0.25	0	
3/5/08	T. East	Yipelnayili stand pipe	8.21	32.8	104	2.37	0	0.15	0	

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
8/21/08	T. East	Yipelnayili stand pipe	8.16	29.1	98	3.45	1.9	0.3	0	
1/8/09	T. East	Yipelnayili stand pipe	7.06	28.4	97	4	0	0.4	0	0
2/5/09	T. East	Yipelnayili stand pipe	6.66	29.5	94	1	0	0.4	0	0
4/2/09	T. East	Yipelnayili stand pipe	7.1		99	6	2.7	0.3	0	0
5/12/09	T. East	Yipelnayili stand pipe	7.3		113	6	3.8	0.25	0	0
6/11/09	T. East	Yipelnayili stand pipe	7.3	31.9	121.5	2	0.3	0.2	0	
7/2/09	T. East	Yipelnayili stand pipe	6.5	30	123.8	8	4.1	0.4	0	
8/13/09	T. East	Yipelnayili stand pipe	7	29	121.9	3	0.4	0.4	0	
9/12/09	T. East	Yipelnayili stand pipe	7.2	27.7	117.6	5	19	0.35	0	
10/13/09	T. East	Yipelnayili stand pipe	7.05	29.9	113.7	1	0	0.3	0	
1/19/10	T. East	Yipelnayili stand pipe	6.76	26.7	114.7	2	1.3	0.45	0	
3/10/10	T. East	Yipelnayili stand pipe	7.14	32.3	111.7	1	0.1	0	0	
7/6/10	T. East	Yipelnayili stand pipe	7.36	30.1	114.8	1.95	0.3	0.25	0	
10/8/10	T. East	Yipelnayili stand pipe	7.02	28.6	20	6	3.1	0.15	0	0
12/7/10	T. East	Yipelnayili stand pipe	6.85	29.1	95.3	4	2.1	0.1	0	
4/20/11	T. East	Yipelnayili stand pipe	6.77	32.6	105.8	6	2.6	0.3	0	0
5/5/11	T. East	Yipelnayili stand pipe	7.37	32.8	102.2	2	0	0.2	0	0
6/7/11	T. East	Yipelnayili stand pipe	6.6	32	103.5	1	0.1	0.25	0	0
7/18/11	T. East	Yipelnayili stand pipe	5.35	29.8	107.5	0.76	0	0.15	0	0
11/3/11	T. East	Yipelnayili stand pipe	6.64	30.2	106.3	1.31	2.1	0.2	0	0
2/9/12	T. East	Yipelnayili stand pipe	6.98	28.9	126.9	1.66	0.7	0.8	0	0
4/4/12	T. East	Yipelnayili stand pipe	6.93	32.7	116.6	1.79	1.2	0.2	0	0
7/5/12	T. East	Yipelnayili stand pipe	6.5	28.2	140.6	4.1	3.1	0.1	0	0
8/13/12	T. East	Yipelnayili stand pipe	6.6	27.7	659	12.8	7	0.25		0
9/6/12	T. East	Yipelnayili stand pipe	6.7	28.6	91	2.77	0.6	0.1		0
10/5/12	T. East	Yipelnayili stand pipe	6.6	29.5	110.3	2.21	1.3	0.5		0
11/6/12	T. East	Yipelnayili stand pipe	7.14	30.7	113.8	2.41	1.7	0.15		0
12/12/12	T. East	Yipelnayili stand pipe	7.1	30.4	118.1	7.34	4.3	0.7		0
1/9/13	T. East	Yipelnayili stand pipe	7.62	25.8	117.5	7.04	4.2	1		0
2/5/13	T. East	Yipelnayili stand pipe	7.52	29.3	103.7	1.65	0.6	0.1		0
3/13/13	T. East	Yipelnayili stand pipe	7.16	32.4	98.9	2.21	3.4	0.2		0
4/19/13	T. East	Yipelnayili stand pipe	7.52	32.8	100	1.25	0.7	0.1		0
7/3/13	T. East	Yipelnayili stand pipe	6.9	30.3	113.5	1.74	1.7	0.1		0
8/5/13	T. East	Yipelnayili stand pipe	6.5	28.9	101.8	2.16	1.1	0.15		0
9/4/13	T. East	Yipelnayili stand pipe	6.7	27.6	98.6	2.2	0	0.2		0
10/2/13	T. East	Yipelnayili stand pipe	6.71	27.3	106.2	1.22	0	0.15	0	0
11/11/13	T. East	Yipelnayili stand pipe	6.51	29.2	114.3	3.92	2.7	0.15	0	0
10/4/06	T. East	Zangbalun S/P	8.02	29.6	126.3	2.32		0.35	0	
12/6/06	T. East	Zangbalun S/P	8.9	26.4	113.5	11.4		1	0	

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
1/9/07	T. East	Zangbalun S/P	7.74	24.9	116.9	14.1		0.85	0	
2/6/07	T. East	Zangbalun S/P	7.14	29	111	5.75		0.4	0	
5/2/07	T. East	Zangbalun S/P	6.7	30.3	122.5	3.77		1.15	0	
5/2/07	T. East	Zangbalun S/P	6.7	30.3	122.5	3.77		1.15	0	0
6/5/07	T. East	Zangbalun S/P	6.7	30.5	116.4	1.84		0.7	0	0
6/5/07	T. East	Zangbalun S/P	6.7	30.5	116.4	1.84		0.7	0	0
7/5/07	T. East	Zangbalun S/P	6.7	30	105	3.05		0.55	0	0
8/1/07	T. East	Zangbalun S/P	6.1	27.6	100	3.64		1	0	0
9/4/07	T. East	Zangbalun S/P	6.3	28	91	2.88		1.15	0	0
10/11/07	T. East	Zangbalun S/P	6.5	31.7	94	0.8		0.9	0	0
11/1/07	T. East	Zangbalun S/P	6.3	29.5	96	1.52		1.15	0	0
1/21/08	T. East	Zangbalun S/P	7	25.8	101	2.66	0	2	0	
4/7/08	T. East	Zangbalun S/P	8.67	34.8	114.1	3.75	0	0.3	0	
5/7/08	T. East	Zangbalun S/P	7.72	33.3	115	1.64	0	0.55	0	
6/3/08	T. East	Zangbalun S/P	7.67	31	112	13.9	8	0.1	0	
8/21/08	T. East	Zangbalun S/P	7.48	29.3	91	3.19	1.8	0.25	0	
11/25/08	T. East	Zangbalun S/P	8.05	29.7	113	3	1.1	0.5		
1/8/09	T. East	Zangbalun S/P	7.35	28.9	94	7	3.3	0.55	0	0
2/5/09	T. East	Zangbalun S/P	6.92	31.3	93	0	0	0.4	0	0
3/3/09	T. East	Zangbalun S/P	6.99		105	1	0	0.45	0	0
4/2/09	T. East	Zangbalun S/P	7.1		106	4	0.9	0.5	0	0
5/12/09	T. East	Zangbalun S/P	7.4		109	6	0.7	1.2	0	0
6/11/09	T. East	Zangbalun S/P	7.5	31.8	124.5	4	0.8	0.9	0	
7/2/09	T. East	Zangbalun S/P	6.3	29.6	122.7	5	3.3	0.3	0	
9/7/09	T. East	Zangbalun S/P	7.24	28.8	100.5	0	0	0.4	0	
9/12/09	T. East	Zangbalun S/P	7.34	26.8	110.5	10	66	0	0	
10/13/09	T. East	Zangbalun S/P	7.47	30.4	98.9	2	0	0	0	
11/5/09	T. East	Zangbalun S/P	6.96	30.2	105	3	2.1	0.35	0	0
1/19/10	T. East	Zangbalun S/P	6.75	27	103.3	5	1.8	0.5	0	
2/19/10	T. East	Zangbalun S/P	7.64	30.8	100.3	9	3.4	0.1	0	
3/10/10	T. East	Zangbalun S/P	7.08	31.5	99.8	5	2.1	0.1	0	
7/6/10	T. East	Zangbalun S/P	7.62	30.5	119.7	1.47	0.1	0.9	0	
8/3/10	T. East	Zangbalun S/P	6.51	29.2	100	1.47	0	0.3	0	
10/8/10	T. East	Zangbalun S/P	6.62	28.8	115.4	0	0	0.3	0	0
12/7/10	T. East	Zangbalun S/P	7.01	28.4	104.1	0	0	0.2	0	
1/10/11	T. East	Zangbalun S/P	6.64	25.6	91.5	8	0.2	0.1	0	
2/8/11	T. East	Zangbalun S/P	7.06	28.6	96.2	5	0	0.4	0	
4/20/11	T. East	Zangbalun S/P	7.03	32.5	99.6	4	0	0.15	0	0
7/18/11	T. East	Zangbalun S/P	5.18	30	113.5	2.08	0	1.25	0	0

Date	District	Point	pH	Temp (C)	Cond	Turb. (NTU)	Color (TCU)	Resid Chlor (mg/L)	T. Coli	E. Coli
10/5/11	T. East	Zangbalun S/P	6.45	30.6	94.1	5	2.5	0.2	0	0
12/6/11	T. East	Zangbalun S/P	7.24	27.7	106.4	2.06	0.2	0.75	0	0
1/11/12	T. East	Zangbalun S/P	6.85	25.7	108.1	1.64	5.1	0.1	0	0
2/9/12	T. East	Zangbalun S/P	6.78	29.4	119.7	3.67	2	0.2	0	0
4/4/12	T. East	Zangbalun S/P	6.96	32.7	118.5	0.74	0.9	0.15	0	0
5/8/12	T. East	Zangbalun S/P	7.29	33	123.2	3	0	0.1	0	0
7/5/12	T. East	Zangbalun S/P	6.7	28	140.6	4	4	1.25	0	0
9/6/12	T. East	Zangbalun S/P	6.5	28.7	91	3.53	1.7	0.1		0
10/5/12	T. East	Zangbalun S/P	6.64	29.5	101.4	0.85	0.4	0.1		0
11/6/12	T. East	Zangbalun S/P	6.82	30.3	116.9	1.96	0	0.1		0
12/12/12	T. East	Zangbalun S/P	7	30.6	106	4.7	0.1	0.1		0
2/5/13	T. East	Zangbalun S/P	7.49	27.3	99.3	1.26	0.2	0.1		0
3/13/13	T. East	Zangbalun S/P	7.46	33	99.4	1.76	4.2	0.15		0
4/19/13	T. East	Zangbalun S/P	6.9	32.7	100.4	1.56	1.2	0.15		0
5/7/13	T. East	Zangbalun S/P	6.89	33.9	103.7	1.05	0.6	0.15		0
6/4/13	T. East	Zangbalun S/P	7.32	30.6	108.7	0.82	0.4	0.1		0
7/3/13	T. East	Zangbalun S/P	6.9	29.8	87.9	3.03	1.6	0.1		0
8/5/13	T. East	Zangbalun S/P	6.73	29	99.1	0.92	0.6	0.15		0
9/4/13	T. East	Zangbalun S/P	6.5	28.7	104.3	0.92	0	0.1		0
10/2/13	T. East	Zangbalun S/P	6.73	27.7	104.4	0.37	0	0.15	0	0
11/11/13	T. East	Zangbalun S/P	6.52	29.1	113.6	1.22	1.9	0.1	0	0

Appendix B: Area Counts Data

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
3/20/2006	Yendi	15	0	0	0	15	0	0	
9/19/2006	Savelugu/Mile 9	16	0	0	1	13	0	0	
9/25/2006	T. Poly	16	0	0	0	7	0	0	
10/3/2006	Choggu/Jisonayili	16	0	0	0	15	7	0	
10/11/2006	Dalun	12	0	0	0	1	0	0	
10/13/2006	Yendi	16	0	0	13	0	0	0	
10/18/2006	Nyohni/Zogbeli	16	0	0	15	3	2	2	0
10/19/2006	Savelugu/Mile 9	16	0	0	0	8	3	0	
10/20/2006	Nyohni/Zogbeli	16	0	0	1	16	0	0	
10/21/2006	Choggu/Jisonayili	14	0	5	0	1	0	0	
10/24/2006	Yendi	15	0	0	15	1	0	0	
11/2/2006	Kukuo	12	0	0	0	0	0	0	
11/3/2006	T. Poly	6	0	0	0	0	0	0	
11/6/2006	Gumani	16	0	0	0	2	0	0	
11/7/2006	Dalun	14	0	0	0	1	1	0	
11/9/2006	Yendi	16	0	0	0	1	0	0	
11/13/2006	Tishegu/Sakasaka	12	0	0	5	0	0	0	
11/16/2006	Savelugu/Mile 9	14	0	0	1	4	2	0	
11/22/2006	Yendi	14	0	0	13	11	9	0	
11/28/2006	T. Poly	11	0	0	0	0	0	0	
12/5/2006	Yendi	16	0	4	0	0	0	0	
12/6/2006	Dalun	16	10	0	14	0	0	0	
12/8/2006	Savelugu/Mile 9	16	0	0	15	6	0	0	
12/12/2006	Gurugu?	16	0	0	16	1	1	0	
12/19/2006	Yendi	14	0	0	0	9	0	0	
12/21/2006	Vittin	11	0	0	10	2	1	0	
12/28/2006	Choggu/Jisonayili	14	0	0	10	1	0	0	
1/5/2007	Gurugu?	16	0	0	16	0	0	0	
1/8/2007	Tishegu/Sakasaka	16	0	4	16	8	2	0	
1/9/2007	Dalun	15	0	0	14	0	0	0	
1/11/2007	Yendi	16	0	0	0	16	1	0	
1/19/2007	Nyohni/Zogbeli	16	0	0	16	1	0	0	
1/25/2007	Savelugu/Mile 9	16	0	0	5	5	2	0	
1/26/2007	Yendi	16	0	0	0	4	0	0	
1/29/2007	T. Poly	12	0	0	5	0	0	0	
2/1/2007	Kukuo	5	0	0	0	0	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
2/5/2007	Tishegu/Sakasaka	16	0	1	15	15	15	0	
2/6/2007	Dalun	16	0	0	14	1	0	0	
2/7/2007	Yendi	16	0	0	0	12	5	0	
2/13/2007	Savelugu/Mile 9	16	0	0	3	15	12	1	
2/15/2007	Kukuo	5	0	0	1	0	0	0	
2/16/2007	Nyohni/Zogbeli	12	0	0	8	1	0	0	
2/22/2007	Choggu/Jisonayili	11	0	0	10	1	0	0	
2/27/2007	Yendi	16	0	14	0	2	0	0	
3/5/2007	Tishegu/Sakasaka	16	0	0	15	1	1	0	
3/12/2007	Savelugu/Mile 9	16	0	0	0	16	16	1	
3/17/2007	Nyohni/Zogbeli	16	0	0	0	0	0	1	?
3/19/2007	Dalun	14	0	0	14	1	1	0	
3/28/2007	Vittin	16	0	0	8	1	1	1	
3/30/2007	Yendi	16	0	0	0	4	0	0	
4/10/2007	Dalun	10	0	0	9	4	1	0	
4/11/2007	Yendi	14	0	14	11	0	0	0	
4/16/2007	Choggu/Jisonayili	10	0	0	0	0	0	0	
4/17/2007	Savelugu/Mile 9	14	0	0	0	2	1	0	0
4/26/2007	Yendi	15	0	0	12	15	13	0	
5/2/2007	Dalun	16	0	0	0	0	0	0	0
5/2/2007	Dalun	16	0	0	0	0	0	0	0
5/7/2007	Kalpohin	10	0	0	0	9	4	0	0
5/7/2007	Kalpohin	10	0	0	0	10	10	0	
5/8/2007	Tishegu/Sakasaka	11	0	0	3	0	0	0	0
5/8/2007	Yendi	16	0	3	16	15	7	0	0
5/8/2007	Yendi	16	0	3	15	16	16	16	
5/14/2007	Choggu/Jisonayili	10	0	0	10	7	0	0	0
5/14/2007	Choggu/Jisonayili	10	0	0	10	10	10	0	
5/22/2007	Yendi	16	0	0	0	14	5	0	0
5/22/2007	Yendi	16	0	0	0	16	14	16	
5/24/2007	Savelugu/Mile 9	16	0	0	15	8	0	0	0
5/24/2007	Savelugu/Mile 9	16	0	0	16	13	12	0	
5/28/2007	Tishegu/Sakasaka	11	0	0	3	1	0	0	
6/4/2007	Choggu/Jisonayili	14	0	0	7	2	2	0	0
6/4/2007	Choggu/Jisonayili	14	0	0	7	2	2	0	
6/5/2007	Dalun	10	0	0	0	0	0	0	0
6/5/2007	Dalun	10	0	0	0	0	0	0	
6/8/2007	Yendi	16	0	0	0	15	10	0	0
6/11/2007	???	10	0	0	0	1	0	0	0
6/12/2007	Savelugu/Mile 9	12	0	1	2	5	2	0	0

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
6/14/2007	Kukuo	12	0	0	0	0	0	0	0
6/20/2007	Nyohni/Zogbeli	10	0	4	10	0	0	0	0
6/25/2007	Choggu/Jisonayili	14	0	13	0	0	0	0	0
6/26/2007	Yendi	16	0	0	0	16	15	15	0
7/5/2007	Dalun	12	0	1	0	0	0	0	0
7/9/2007	Tishegu/Sakasaka	5	0	0	0	0	0	0	0
7/10/2007	Yendi	15	0	0	0	15	14	4	0
7/12/2007	Vittin	5	0	0	0	0	0	0	0
7/16/2007	Savelugu/Mile 9	16	0	0	0	16	12	0	0
7/17/2007	Choggu/Jisonayili	16	0	9	0	0	0	0	0
7/18/2007	Kukuo	12	0	1	2	1	1	0	0
7/26/2007	Choggu/Jisonayili	17	0	16	0	0	0	0	0
7/27/2007	Nyohni/Zogbeli	12	0	3	0	0	0	0	0
7/30/2007	Yendi	12	0	0	0	11	0	0	0
8/1/2007	Dalun	14	0	14	3	0	0	0	0
8/3/2007	Savelugu/Mile 9	11	0	10	0	8	0	0	0
8/6/2007	Yendi	16	0	0	0	15	10	15	
8/7/2007	Choggu/Jisonayili	16	0	2	0	1	0	0	0
8/8/2007	Yendi	16	0	0	12	5	0	0	0
8/15/2007	Kukuo	12	0	10	0	0	0	0	0
8/22/2007	Yendi	16	0	0	1	12	0	0	0
8/27/2007	Choggu/Jisonayili	12	0	1	0	0	0	0	0
8/30/2007	Town Centre	12	0	4	0	12	12	2	0
8/31/2007	Nyohni/Zogbeli	12	0	0	1	12	2	0	0
9/4/2007	Dalun	16	0	16	3	0	0	0	0
9/12/2007	Yendi	16	0	3	15	0	0	0	0
9/14/2007	Choggu/Jisonayili	8	0	8	0	0	0	0	0
9/18/2007	Savelugu/Mile 9	16	0	4	0	10	0	0	0
9/20/2007	Vittin	10	0	0	7	6	0	0	0
9/25/2007	Choggu/Jisonayili	14	0	0	0	0	0	0	0
9/29/2007	Yendi	18	0	0	3	4	0	0	0
10/3/2007	Choggu/Jisonayili	14	0	0	0	0	0	0	
10/10/2007	Yendi	15	0	0	15	1	0	0	0
10/11/2007	Dalun	16	0	4	0	0	0	0	0
10/12/2007	Savelugu/Mile 9	12	0	0	0	10	3	0	0
10/19/2007	Nyohni/Zogbeli	16	0	0	0	0	0	0	0
10/20/2007	Lameshegu/Sawaba	9	0	0	0	1	0	0	
10/22/2007	Choggu/Jisonayili	14	0	12	0	0	0	0	
10/24/2007	Kukuo	5	0	5	2	0	0	0	
10/25/2007	Yendi	16	0	0	16	0	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
11/1/2007	Dalun	10	0	9	0	0	0	0	
11/6/2007	Yendi	13	0	0	13	0	0	0	
11/14/2007	Changli (west)	13	0	0	0	0	0	0	
11/19/2007	Savelugu/Mile 9	14	0	1	0	1	1	0	
11/29/2007	Yendi	16	0	0	0	1	0	0	
12/5/2007	Dalun	10	0	9	1	0	0	0	
12/11/2007	Yendi	16	0	0	0	0	0	0	
12/17/2007	Savelugu/Mile 9	16	0	0	3	2	1	0	
1/15/2008	Tamale Stadium	3	2	0	3	2	2	2	
1/21/2008	Dalun	12	0	0	0	0	0	0	
1/23/2008	Tamale Hotels	8	0	0	1	5	5	0	
1/25/2008	Savelugu/Mile 9	15	0	0	2	3	1	0	
1/29/2008	Choggu/Jisonayili	18	1	0	7	16	10	0	
1/31/2008	Yendi	16	0	0	14	16	0	0	
2/12/2008	Dalun	12	0	0	0	0	0	0	
2/13/2008	Yendi	16	0	0	0	4	0	0	
2/19/2008	Savelugu/Mile 9	15	0	0	0	8	4	0	0
2/21/2008	Kukuo	15	0	0	0	0	0	0	
2/27/2008	Town Centre	16	16	0	0	1	0	0	
2/28/2008	Yendi	10	0	0	3	0	0	0	
2/29/2008	Choggu/Jisonayili	17	17	0	0	0	0	0	
3/5/2008	Dalun	16	0	0	0	5	0	0	
3/12/2008	Yendi	11	0	0	3	0	0	0	
3/14/2008	Savelugu/Mile 9	10	0	0	0	4	2	0	
3/15/2008	Tishegu/Sakasaka	14	2	0	0	3	0	0	
3/31/2008	Yendi	14	0	0	0	13	0	0	
4/4/2008	Vittin	12	10	0	1	11	0	0	
4/7/2008	Dalun	10	10	0	0	1	0	0	
4/9/2008	Savelugu/Mile 9	14	0	0	5	14	4	0	
4/14/2008	Gumani	10	0	0	0	10	0	0	
4/16/2008	Nyohni/Zogbeli	10	10	0	0	10	0	0	
5/7/2008	Dalun	14	0	0	1	1	0	0	
5/9/2008	Vittin	10	0	0	0	1	0	0	
5/15/2008	Kalpohin	12	0	0	1	12	0	0	
5/20/2008	Lameshegu/Sawaba	8	0	0	1	8	0	0	
6/3/2008	Dalun	16	0	0	4	12	0	0	
6/5/2008	Yendi	14	0	0	0	0	0	0	
6/23/2008	Savelugu/Mile 9	14	0	0	1	11	4	0	
6/24/2008	Yendi	11	0	0	3	2	1	0	
7/10/2008	Yendi	15	0	0	2	9	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
7/24/2008	Choggu/Jisonayili	14	0	0	0	0	0	0	
7/25/2008	Dalun	10	0	0	10	10	8	0	
7/30/2008	Yendi	10	0	7	7	2	1	0	
8/13/2008	Yendi	14	0	0	13	1	1	0	
8/19/2008	Savelugu/Mile 9	16	10	0	0	14	10	0	
8/20/2008	Kukuo	16	0	0	1	16	1	0	
8/21/2008	Dalun	16	0	0	8	8	1	0	
8/25/2008	Tishegu/Sakasaka	5	0	0	0	3	3	0	
8/26/2008	Yendi	11	0	0	5	10	7	0	
8/28/2008	Kukuo	13	0	0	0	0	0	0	
9/4/2008	Yendi	15	0	0	2	15	7	0	
9/9/2008	Dalun	10	0	0	8	0	0	0	
9/11/2008	Savelugu/Mile 9/Mile 9	14	0	0	14	14	6	0	
10/2/2008	Choggu/Jisonayili	10	0	0	1	0	0	0	
10/3/2008	Dalun	10	0	0	0	0	0	0	
10/15/2008	Yendi	14	12	0	6	1	0	0	0
10/21/2008	Savelugu/Mile 9	10	0	0	0	10	10	0	0
10/23/2008	Kukuo	11	0	0	0	11	11	0	0
10/28/2008	Yendi	11	11	0	8	11	11	0	0
11/24/2008	Yendi	12	0	0	0	1	0	0	0
11/25/2008	Dalun	16	0	0	1	0	0	0	0
12/2/2008	Gumani	16	14	0	0	16	1	0	0
1/7/2009	Yendi	15	0	0	0	11	7	0	0
1/8/2009	Dalun	16	0	0	6	0	0	0	0
1/21/2009	Savelugu/Mile 9	16	0	0	5	6	1	0	0
1/29/2009	Nyohni/Zogbeli	16	0	0	0	4	0	0	0
1/30/2009	Yendi	10	0	0	0	7	0	0	0
2/5/2009	Dalun	14	0	1	0	0	0	0	0
2/6/2009	Yendi	15	0	0	0	15	7	0	0
2/12/2009	Savelugu/Mile 9	16	0	0	4	8	2	0	0
2/13/2009	Choggu/Jisonayili	10	0	0	0	0	0	0	0
2/25/2009	Yendi	15	1	0	0	14	5	0	0
2/26/2009	Nyohni/Zogbeli	16	0	0	5	1	0	0	0
2/27/2009	Vittin	14	0	0	8	5	0	0	0
3/3/2009	Dalun	10	0	0	0	0	0	0	0
3/5/2009	Savelugu/Mile 9	12	0	0	3	7	2	0	0
3/12/2009	Yendi	16	0	0	6	14	0	0	0
3/13/2009	Tolon/Nyakpala/Kumbungu	9	0	0	9	8	0	0	0
3/19/2009	Town Centre	11	0	0	1	2	0	0	0
3/20/2009	Nyohni/Zogbeli	10	0	0	0	1	0	0	0

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
3/30/2009	Tishegu/Sakasaka	12	0	0	3	4	0	0	0
3/31/2009	Yendi	14	0	0	0	14	4	0	0
4/2/2009	Dalun	12	0	0	3	3	1	0	0
4/7/2009	Hospital? Bulpela	12	0	0	0	3	1	0	0
4/8/2009	Yendi	16	0	0	0	16	0	0	0
4/15/2009	Savelugu/Mile 9	16	0	0	0	9	2	0	0
4/16/2009	Choggu/Jisonayili	12	0	0	0	4	3	0	0
4/17/2009	Yendi	14	0	0	14	14	14	0	0
4/23/2009	Vittin	10	0	0	1	4	1	0	0
4/30/2009	Nyohni/Zogbeli	8	0	0	3	2	1	0	0
5/12/2009	Dalun	14	0	0	9	2	2	0	0
5/15/2009	Savelugu/Mile 9	14	0	0	2	6	2	0	0
5/22/2009	Nyohni/Zogbeli	19	0	0	6	0	0	0	0
5/25/2009	Yendi	18	0	4	17	18	18	0	1
5/27/2009	Gumani	12	0	0	4	12	8	0	0
6/2/2009	Lameshegu/Sawaba	11	0	0	3	1	1	0	0
6/4/2009	Yendi	12	0	7	11	12	12	0	0
6/10/2009	Yendi	20	0	0	5	20	20	0	
6/11/2009	Dalun	15	0	0	4	2	0	0	
6/16/2009	Savelugu/Mile 9	15	0	0	3	14	11	0	
6/17/2009	Vittin	16	0	0	10	16	10	0	
6/18/2009	Kukuo	14	0	0	14	14	0	0	
6/24/2009	Tishegu/Sakasaka	10	0	0	3	6	0	0	
6/25/2009	Yendi	10	0	0	5	8	5	0	
7/2/2009	Dalun	16	0	9	6	5	0	0	
7/6/2009	Yendi	15	0	0	11	1	1	1	0
7/8/2009	Savelugu/Mile 9	14	0	0	3	14	3	0	0
7/9/2009	Town Centre	10	0	0	3	9	2	1	1
7/17/2009	Nyohni/Zogbeli	14	0	0	6	0	0	0	
7/24/2009	Choggu/Jisonayili	10	0	0	2	5	0	0	
7/24/2009	Lameshegu/Sawaba	6	0	0	2	3	0	0	
7/27/2009	Yendi	15	0	0	5	6	2	0	
8/11/2009	Yendi	18	0	0	8	4	0	0	
8/13/2009	Dalun	16	0	0	4	7	0	0	
8/18/2009	Savelugu/Mile 9	14	0	0	3	14	13	0	
8/24/2009	Kukuo	15	0	0	3	15	2	0	
8/26/2009	Yendi	15	6	0	14	1	1	0	
8/28/2009	Vittin	15	12	0	1	15	9	0	
8/31/2009	Tishegu/Sakasaka	10	8	0	2	10	3	0	
9/7/2009	Dalun	14	0	0	0	2	1	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
9/8/2009	Yendi	16	0	0	14	2	0	0	
9/18/2009	Savelugu/Mile 9	16	0	0	1	16	9	0	
9/19/2009	Lameshegu/Sawaba	16	0	0	1	16	0	1	
9/24/2009	Kukuo	14	0	0	4	14	4	0	
9/25/2009	Yendi	15	0	0	4	15	11	0	
9/29/2009	Gumani	10	0	0	0	8	0	0	
10/13/2009	Dalun	10	0	0	1	7	3	0	
10/14/2009	Yendi	14	0	0	11	10	5	0	
10/16/2009	Savelugu/Mile 9	10	2	0	1	10	7	0	
10/27/2009	Nyohni/Zogbeli	14	9	0	11	14	8	0	
10/28/2009	Tishegu/Sakasaka	10	0	0	2	10	2	0	
10/29/2009	Yendi	16	0	0	12	2	0	0	
10/31/2009	Nyohni/Zogbeli	16	9	0	9	7	1	0	
11/3/2009	Yendi	16	1	0	16	11	0	0	0
11/5/2009	Dalun	14	0	0	4	6	1	0	0
11/13/2009	Savelugu/Mile 9	14	0	0	0	5	0	0	0
11/17/2009	Kukuo	15	2	0	0	4	1	0	
11/18/2009	Nyohni/Zogbeli	14	0	0	0	4	0	0	
11/25/2009	Yendi	14	9	0	1	0	0	0	
12/9/2009	Dalun	15	0	0	6	6	2	0	
12/10/2009	Yendi	16	13	0	16	1	1	0	
12/15/2009	Savelugu/Mile 9	15	0	0	3	9	8	0	
12/16/2009	Nyohni/Zogbeli	15	0	0	1	1	1	0	
12/18/2009	?	15	2	0	10	0	0	0	
12/21/2009	Yendi	14	0	0	0	2	0	0	
1/13/2010	Yendi	16	16	0	0	1	0	0	
1/19/2010	Dalun	16	0	0	4	2	1	0	
1/26/2010	Gumani	14	0	0	5	3	0	0	
1/27/2010	Kukuo	15	0	0	2	15	5	0	
1/28/2010	Lameshegu/Sawaba	15	0	0	1	9	2	0	
1/29/2010	Yendi	14	0	0	0	13	10	0	
2/18/2010	Savelugu/Mile 9	20	1	0	18	7	2	0	
2/19/2010	Dalun	10	0	0	8	7	0	0	
3/3/2010	Gumani	12	1	0	10	6	1	0	
3/5/2010	Yendi	18	0	0	13	18	15	0	
3/10/2010	Dalun	16	0	0	4	16	12	0	0
3/17/2010	Vittin	15	11	0	3	15	11	0	0
3/19/2010	Nyohni/Zogbeli	15	14	0	10	7	2	0	
3/23/2010	Yendi	10	0	0	0	10	10	0	
4/13/2010	Kalpohin	10	0	0	0	7	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
4/15/2010	Savelugu/Mile 9	15	0	0	1	1	0	0	
4/20/2010	Lameshegu/Sawaba	15	0	0	0	15	6	0	
4/21/2010	Yendi	18	0	0	18	18	3	0	
4/26/2010	Yendi	12	0	0	0	8	0	0	0
4/28/2010	Kukuo	15	0	0	0	5	0	0	
5/14/2010	Yendi	16	0	0	1	16	2	0	
5/18/2010	Gumani	16	0	0	0	13	0	0	
5/22/2010	Yendi	14	0	0	0	8	0	0	
5/25/2010	Vittin	16	0	0	0	0	0	0	
5/27/2010	Savelugu/Mile 9	14	0	0	0	14	6	0	
5/31/2010	Nyohni/Zogbeli	14	0	0	0	14	10	0	
6/3/2010	Tishegu/Sakasaka	12	0	0	0	3	0	0	
6/9/2010	Yendi	15	0	0	0	11	1	0	
6/25/2010	Tishegu/Sakasaka	18	8	0	0	0	0	0	
6/28/2010	Yendi	15	0	0	2	14	0	0	
6/29/2010	Kukuo	15	5	0	0	0	0	0	
6/30/2010	Lameshegu/Sawaba	15	0	0	0	0	0	0	
7/6/2010	Dalun	16	0	0	0	4	1	0	
7/7/2010	Savelugu/Mile 9	14	0	0	0	1	0	0	
7/15/2010	Yendi	12	0	0	0	6	0	0	0
7/27/2010	Lameshegu/Sawaba	18	0	0	0	18	0	0	
7/28/2010	Yendi	18	0	0	18	5	1	0	0
7/29/2010	Vittin	12	0	0	0	0	0	0	0
8/3/2010	Dalun	10	0	1	0	5	2	0	
8/6/2010	Savelugu/Mile 9	4	0	0	0	4	4	0	
8/10/2010	Yendi	16	0	0	12	10	3	0	
8/18/2010	Kukuo	16	0	0	0	0	0	0	
8/20/2010	Nyohni/Zogbeli	14	0	0	4	0	0	0	
8/25/2010	Yendi	14	0	0	13	9	2	0	
8/27/2010	Choggu/Jisonayili	16	0	0	4	0	0	0	
9/1/2010	Yendi	16	0	0	16	16	6	2	
9/16/2010	Tishegu/Sakasaka	14	0	0	9	4	0	0	
9/22/2010	Lameshegu/Sawaba	16	0	0	0	1	0	0	
9/23/2010	Nyohni/Zogbeli	14	0	0	3	4	0	0	
9/29/2010	Tishegu/Sakasaka	16	0	0	0	11	0	0	
9/30/2010	Yendi	13	0	0	0	11	0	0	
10/5/2010	Gumani	12	0	0	4	10	0	0	
10/8/2010	Dalun	10	0	0	1	6	0	0	0
10/12/2010	Yendi	14	0	0	9	12	0	0	
10/18/2010	Savelugu/Mile 9	8	0	0	4	7	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
10/26/2010	Vittin	16	0	0	1	5	0	0	
10/29/2010	Yendi	16	0	0	13	2	0	0	
10/30/2010	Nyohni/Zogbeli	14	0	0	0	2	0	0	
11/5/2010	Kukuo	10	0	0	1	0	0	0	
11/10/2010	Yendi	16	0	0	16	16	0	0	
11/12/2010	Chanle	10	0	0	0	0	0	0	
11/15/2010	Choggu/Jisonayili	16	0	0	0	0	0	0	
11/19/2010	Nyohni/Zogbeli	10	0	0	1	1	1	0	
11/24/2010	Savelugu/Mile 9	14	0	0	1	3	0	0	
11/25/2010	Yendi	14	0	0	13	7	0	0	
12/7/2010	Dalun	14	0	0	0	8	0	0	
12/9/2010	Savelugu/Mile 9	16	0	1	1	8	0	0	
12/10/2010	Yendi	14	0	0	2	14	0	0	
12/21/2010	Yendi	16	0	0	0	14	0	0	
12/22/2010	Nyohni/Zogbeli	16	0	0	1	0	0	0	
12/23/2010	Vittin	14	0	0	2	0	0	0	
1/6/2011	Kukuo	14	0	0	2	1	0	0	
1/10/2011	Dalun	10	0	0	2	2	0	0	
1/12/2011	Savelugu/Mile 9	12	0	0	2	1	0	0	
1/14/2011	Yendi	14	0	0	0	0	0	0	
1/20/2011	Lameshegu/Sawaba	16	0	0	3	2	0	0	
1/24/2011	Choggu/Jisonayili	8	0	0	2	1	0	0	
1/25/2011	Yendi	16	0	0	0	16	0	0	
2/3/2011	Yendi	14	0	0	0	10	0	0	
2/8/2011	Dalun	8	0	0	1	0	0	0	
2/10/2011	Savelugu/Mile 9	12	0	0	3	1	0	0	
2/15/2011	Choggu/Jisonayili	10	0	0	0	0	0	0	
2/17/2011	Vittin	16	0	0	4	0	0	0	
2/21/2011	Lameshegu/Sawaba	14	0	0	2	0	0	0	
2/22/2011	Yendi	16	0	0	0	14	2	0	
3/4/2011	Savelugu/Mile 9	7	0	0	1	2	0	0	
3/9/2011	Kalpohin	13	0	0	1	0	0	0	
3/10/2011	Yendi	14	0	0	4	8	0	0	
3/17/2011	Kukuo	14	0	0	0	0	0	0	
3/23/2011	Yendi	16	0	0	0	1	0	0	
4/6/2011	Chile	14	0	0	1	0	0	0	
4/7/2011	Choggu/Jisonayili	10	0	0	0	0	0	0	
4/8/2011	Yendi	14	0	0	1	13	0	0	
4/14/2011	Savelugu/Mile 9	10	0	0	0	10	0	0	
4/20/2011	Dalun	10	0	0	1	3	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
4/27/2011	Lameshegu/Sawaba	16	0	0	0	0	0	0	
4/28/2011	Yendi	16	0	0	0	1	0	0	
5/5/2011	Dalun	10	0	0	0	3	0	0	0
5/16/2011	Kukuo	16	0	0	5	1	0	0	0
5/20/2011	Nyohni/Zogbeli	14	0	0	0	1	0	0	0
5/24/2011	Gumani	10	0	0	0	3	0	0	0
5/26/2011	Yendi	16	0	0	15	1	0	0	0
6/1/2011	Nyohni/Zogbeli	12	0	0	0	1	0	0	0
6/7/2011	Dalun	12	0	0	0	5	0	0	0
6/9/2011	Yendi	14	0	0	14	14	0	13	9
6/14/2011	Savelugu/Mile 9	10	0	0	0	9	0	0	0
6/20/2011	Vittin	18	0	0	2	10	0	0	0
6/28/2011	Tishegu/Sakasaka	8	0	5	0	0	0	0	0
7/5/2011	Yendi	16	0	5	2	1	0	0	0
7/12/2011	Choggu/Jisonayili	8	0	8	2	0	0	0	0
7/18/2011	Dalun	12	0	12	0	5	0	0	0
7/20/2011	Kukuo	16	0	13	0	0	0	0	0
7/25/2011	Savelugu/Mile 9	10	0	0	0	6	0	0	0
7/27/2011	Nyohni/Zogbeli	14	0	0	0	0	0	0	0
7/28/2011	Yendi	14	0	0	1	0	0	0	0
8/3/2011	Chile	5	0	0	0	4	0	0	0
8/22/2011	Choggu/Jisonayili	14	0	13	6	1	0	0	0
8/23/2011	Yendi	14	0	11	14	0	0	0	0
8/24/2011	Dalun	10	0	10	0	8	0	0	0
8/30/2011	Nyohni/Zogbeli	20	0	14	0	2	0	0	0
9/2/2011	Lameshegu/Sawaba	14	0	3	0	10	0	0	0
9/6/2011	Dalun	10	0	9	0	1	0	0	0
9/8/2011	Yendi	11	0	0	2	2	0	0	0
9/13/2011	Savelugu/Mile 9	10	0	4	0	10	0	0	0
9/20/2011	Nishie	10	0	8	0	10	0	0	0
9/27/2011	Town Centre	16	0	4	2	16	0	0	0
9/29/2011	Yendi	18	3	0	18	0	0	0	0
10/5/2011	Dalun	10	0	4	0	7	0	0	0
10/7/2011	Yendi	14	0	0	14	3	0	0	0
10/13/2011	Savelugu/Mile 9	10	0	0	1	10	0	2	2
10/14/2011	Tolon/Nyakpala/Kumbungu	10	0	0	0	10	0	0	0
10/19/2011	Yendi	16	0	0	16	0	0	2	2
10/27/2011	Vittin	14	0	0	2	14	1	1	1
10/31/2011	Nyohni/Zogbeli	16	0	4	1	16	10	3	3
11/3/2011	Dalun	12	0	0	0	7	0	0	0

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
11/5/2011	Savelugu/Mile 9	10	0	0	0	4	0	0	0
11/9/2011	Yendi	14	12	0	14	0	0	0	0
11/14/2011	Savelugu/Mile 9	12	0	0	0	11	0	0	0
11/15/2011	Tolon/Nyakpala/Kumbungu	6	0	0	0	5	0	1	1
11/24/2011	Nyohni/Zogbeli	14	0	0	0	0	0	0	0
11/25/2011	Kukuo	16	0	0	1	0	0	0	0
11/29/2011	Yendi	16	0	0	1	0	0	0	0
12/6/2011	Dalun	12	0	0	0	3	0	0	0
12/7/2011	Nyohni/Zogbeli	14	0	0	1	1	0	0	0
12/8/2011	Yendi	14	0	0	0	0	0	0	0
12/16/2011	Savelugu/Mile 9	18	0	0	0	2	0	0	0
12/20/2011	Kukuo	16	0	0	1	2	0	0	0
12/21/2011	Yendi	16	0	0	0	0	0	0	0
1/11/2012	Dalun	14	0	0	0	6	0	0	0
1/12/2012	Yendi	14	0	0	0	0	0	0	0
1/23/2012	Vittin	16	0	0	3	1	0	0	0
1/24/2012	Savelugu/Mile 9	16	0	0	1	2	0	0	0
1/25/2012	Yendi	16	0	0	1	0	0	0	0
1/27/2012	Choggu/Jisonayili	14	0	0	0	1	0	0	0
2/9/2012	Dalun	15	0	0	1	0	0	0	0
2/13/2012	Choggu/Jisonayili	10	0	0	0	0	0	0	0
2/17/2012	Yendi	16	0	0	0	0	0	0	0
2/24/2012	Gumani	12	0	0	0	4	0	0	0
2/28/2012	Yendi	14	0	0	14	2	0	1	1
2/29/2012	Nyohni/Zogbeli	8	0	0	0	5	0	0	0
3/21/2012	Savelugu/Mile 9	20	0	0	0	4	0	0	0
3/23/2012	Kukuo	19	0	0	0	1	0	0	0
3/26/2012	Yendi	19	0	0	0	6	0	0	0
3/28/2012	Nyohni/Zogbeli	10	0	0	0	7	0	0	0
3/29/2012	Yendi	10	0	0	0	8	0	0	0
3/30/2012	Tishegu/Sakasaka	10	0	0	0	2	0	0	0
4/4/2012	Dalun	16	0	0	0	8	0	0	0
4/5/2012	Yendi	16	0	0	0	0	0	0	0
4/16/2012	Savelugu/Mile 9	14	0	0	0	14	0	0	0
4/17/2012	Lameshegu/Sawaba	18	0	0	0	12	0	0	0
4/24/2012	Gumani	12	0	0	0	12	0	0	0
4/25/2012	Yendi	14	0	0	12	1	0	0	0
5/7/2012	Savelugu/Mile 9	15	0	0	2	15	0	0	0
5/8/2012	Dalun	14	0	0	1	11	0	0	0
5/29/2012	Yendi	18	0	0	4	13	0	1	1

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
5/31/2012	Nyohni/Zogbeli	17	0	0	9	16	0	0	0
6/6/2012	Dalun	9	0	9	3	3	0	0	0
6/11/2012	Gumani	11	0	0	0	11	0	0	0
6/12/2012	Savelugu/Mile 9	10	0	0	1	10	0	0	0
6/19/2012	Choggu/Jisonayili	12	0	0	6	8	0	0	0
6/20/2012	Nyohni/Zogbeli	18	0	0	0	17	0	0	0
6/25/2012	Yendi	16	0	0	0	14	0	0	0
6/29/2012	Yendi	14	0	0	1	5	0	0	0
7/5/2012	Dalun	12	0	0	6	10	0	0	0
7/10/2012	Yendi	18	0	0	11	0	0	0	0
7/17/2012	Savelugu/Mile 9	18	0	0	2	3	0	0	0
7/20/2012	Nyohni/Zogbeli	16	0	0	2	3	0	0	0
7/27/2012	Kukuo	14	0	0	2	1	0	0	0
8/13/2012	Dalun	8	0	0	1	3	0	0	
8/14/2012	Gumani	7	0	0	0	3	0	0	
8/28/2012	Savelugu/Mile 9	9	0	0	1	4	0	0	
8/29/2012	Kukuo	13	0	1	2	2	0	0	
8/31/2012	Lameshegu/Sawaba	2	0	0	0	2	1	0	
9/6/2012	Dalun	8	0	0	0	7	0	0	
9/24/2012	Savelugu/Mile 9	8	0	0	0	8	0	0	
10/5/2012	Dalun	9	0	0	0	8	0	0	
10/8/2012	Kukuo	13	0	0	0	13	0	0	
10/9/2012	Yendi	9	0	0	2	6	0	0	
11/6/2012	Savelugu/Mile 9	12	0	0	2	4	0	0	
11/14/2012	Kukuo	8	0	0	5	0	0	0	
11/15/2012	Choggu/Jisonayili	12	0	0	7	2	0	0	
11/30/2012	T. Poly	15	0	0	3	0	0	0	
12/6/2012	Gumani	16	0	0	0	0	0	0	
12/12/2012	Dalun	10	0	0	3	1	0	0	
12/18/2012	Kukuo	3	0	0	0	1	0	0	
1/9/2013	Dalun	8	0	0	4	2	0	0	
1/16/2013	Savelugu/Mile 9	9	0	0	0	2	1	0	
1/17/2013	Kukuo	10	0	0	0	2	0	0	
1/25/2013	Lameshegu/Sawaba	11	0	0	0	1	0	0	
1/30/2013	Choggu/Jisonayili	10	0	0	0	3	0	0	
2/5/2013	Dalun	8	0	0	0	8	0	0	
2/12/2013	Tishegu/Sakasaka	5	0	0	0	1	0	0	
2/13/2013	Savelugu/Mile 9	7	0	0	0	0	0	0	
2/15/2013	Kukuo	4	0	0	1	0	0	0	
2/21/2013	Kukuo	10	0	0	0	1	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
2/25/2013	Choggu/Jisonayili	8	0	0	3	1	0	0	
2/28/2013	Lameshegu/Sawaba	9	0	0	3	0	0	0	
3/13/2013	Dalun	6	0	0	0	2	0	0	
3/14/2013	Choggu/Jisonayili	5	0	0	0	2	0	0	
3/25/2013	Tishegu/Sakasaka	7	0	0	0	2	0	0	
3/28/2013	Nyohni/Zogbeli	7	0	0	0	3	0	0	
4/19/2013	Dalun	11	0	0	2	9	0	0	
4/25/2013	Vittin	5	0	0	0	5	0	0	
4/29/2013	Nyohni/Zogbeli	10	0	0	3	10	1	0	
4/30/2013	Savelgu/Mile 9	7	0	0	0	6	0	0	
5/6/2013	Choggu/Jisonayili	9	0	0	0	7	0	0	
5/7/2013	Dalun	8	0	0	0	6	0	0	
5/16/2013	Savelugu/Mile 9	7	0	0	0	5	0	0	
5/20/2013	Nyohni/Zogbeli	6	0	0	0	6	1	0	
5/30/2013	Kukuo	9	0	0	0	9	0	0	
6/4/2013	Dalun	8	0	0	0	4	0	0	
6/11/2013	Savelugu/Mile 9	4	0	0	0	4	0	0	
6/12/2013	T. Poly	10	0	0	0	1	0	0	
6/25/2013	Vittin	3	0	0	0	3	0	0	
6/28/2013	Kukuo	10	0	0	0	10	0	0	
7/3/2013	Dalun	8	0	0	0	8	0	0	
7/9/2013	Choggu/Jisonayili	3	0	0	2	1	0	0	
7/12/2013	Lameshegu/Sawaba	10	0	0	0	10	0	0	
7/17/2013	Savelugu/Mile 9	4	0	0	0	4	0	0	
7/18/2013	Nyohni/Zogeli	9	0	0	0	6	0	0	
7/23/2013	Tishegu/Sakasaka	8	0	0	0	4	0	0	
8/5/2013	Dalun	6	0	0	0	3	0	0	
8/7/2013	Choggu/Jisonayili	4	0	0	0	4	0	0	
8/14/2013	Savelugu/Mile 9	6	0	0	0	6	1	0	
8/22/2013	Tishegu/Sakasaka	4	0	0	0	4	0	0	
8/27/2013	Vittin	5	0	0	0	5	0	0	
9/4/2013	Dalun	8	0	0	0	7	0	0	
9/5/2013	Gumani	6	0	0	0	3	0	0	
9/11/2013	Choggu/Jisonayili	10	0	0	0	4	0	0	
9/16/2013	Lameshegu/Sawaba	3	0	0	0	3	0	0	
10/2/2013	Dalun	8	0	0	0	7	0	0	
10/11/2013	Nyohni/Zogbeli	8	0	0	3	8	0	0	
10/17/2013	Tishegu/Sakasaka	5	0	0	0	5	0	0	
10/18/2013	Savelugu/Mile 9	9	0	0	0	9	5	0	
10/19/2013	Nyohni/Zogbeli	11	0	0	0	7	0	0	

Date	Area	# Points	High pH	Low pH	High Turbidity	Low Chlorine	No Cl	T. Coli	F. Coli
10/25/2013	Kalpohin	9	0	0	0	9	0	0	
10/28/2013	Kukuo	9	0	0	0	9	0	0	
11/11/2013	Dalun	7	0	2	0	6	0	0	

Appendix C: Treatment Plant Data

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
10/9/2004	Dalun WTP	Raw Dalun	7.29	31	86.6	107				
10/9/2004	Dalun WTP	Settled Dalun	6.77	30.8	88.4	14.8				
10/9/2004	Dalun WTP	Final Dalun	7.37	30.6	108.1	5.38		0.63		
10/19/2004	Dalun WTP	Raw Dalun	7.34	31.9	78.5	102				
10/19/2004	Dalun WTP	Settled Dalun	7.02	31.7	87.1	10.5				
10/19/2004	Dalun WTP	Final Dalun	7.94	31.4	110.8	4.1		0.05		
12/10/2004	Dalun WTP	Raw Dalun	7.32	29.1	86	76				
12/10/2004	Dalun WTP	Settled Dalun	7.15	28.9	99.1	11.5				
12/10/2004	Dalun WTP	Final Dalun	8.64	29.7	130.6	4.36		2		
1/11/2005	Dalun WTP	Raw Dalun	7.49	23.7	95.1	80.9				
1/11/2005	Dalun WTP	Settled Dalun	6.86	22.9	97.5	12.1				
1/11/2005	Dalun WTP	Final Dalun	7.38	22.6	116.2	12.3		1.38		
2/22/2005	Dalun WTP	Raw Dalun	7.28	20.9	94.3	90.5				
2/22/2005	Dalun WTP	Settled Dalun	6.34	30.2	118.7	7.76				
2/22/2005	Dalun WTP	Final Dalun	9.06	29.8	152	8.39		0.63		
3/29/2005	Dalun WTP	Raw Dalun	7.35	33.6	81.6	87.7				
3/29/2005	Dalun WTP	Settled Dalun	6.78	32.8	95.2	7.54				
3/29/2005	Dalun WTP	Final Dalun	7.93	35.4	120.3	4.24		0.9		
4/14/2005	Dalun WTP	Raw Dalun	7.41	32.9	83.4	87.2				
4/14/2005	Dalun WTP	Settled Dalun	6.72	32.2	98.5	4.95				
4/14/2005	Dalun WTP	Final Dalun	7.92	32	121	3.89		1.4		

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
5/10/2005	Dalun WTP	Raw Dalun	7.48	30.9	100.8	95.5				
5/10/2005	Dalun WTP	Settled Dalun	7.29	31.1	114.3	11.1				
5/10/2005	Dalun WTP	Final Dalun	9.27	31.4	156.2	7.69		1.4		
6/6/2005	Dalun WTP	Raw Dalun	7.47	31.2	87.5	107				
6/6/2005	Dalun WTP	Settled Dalun	6.7	31.1	98.6	3.89				
6/6/2005	Dalun WTP	Final Dalun	8.38	31.2	120.3	2.98		1.4		
7/5/2005	Dalun WTP	Raw Dalun	7.07	29.8	71.8	270				
7/5/2005	Dalun WTP	Settled Dalun	5.97	30.2	91.6	7.53				
7/5/2005	Dalun WTP	Final Dalun	8.84	30.3	118.5	5.27		0.4		
8/9/2005	Dalun WTP	Raw Dalun	7.25	28.9	80.1	387				
8/9/2005	Dalun WTP	Settled Dalun	6.42	29	91.4	14.1				
8/9/2005	Dalun WTP	Final Dalun	8.51	29	122.8	6.99		1.35		
8/16/2005	Dalun WTP	Raw Dalun	6.91	26.1	62	351				
8/16/2005	Dalun WTP	Settled Dalun	4.53	27.2	131.9	13.8				
8/16/2005	Dalun WTP	Final Dalun	6.04	27	126.8	12		1.35		
9/5/2005	Dalun WTP	Raw Dalun	7.05	29.4	69.5	274				
9/5/2005	Dalun WTP	Settled Dalun	4.62	28.5	116.3	10.6				
9/5/2005	Dalun WTP	Final Dalun	6.82	28.7	116.1	6.41		0.87		
10/12/2005	Dalun WTP	Raw Dalun	6.94	29.8	68.6	185			5000	5000
10/12/2005	Dalun WTP	Settled Dalun	6.58	28.4	81.9	19.1			2	0
10/12/2005	Dalun WTP	Final Dalun	7.92	29.3	110.7	10.2		0.7	0	0
11/9/2005	Dalun WTP	Raw Dalun	7.46	31.9	91.9	124				

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
11/9/2005	Dalun WTP	Settled Dalun	7.02	30.5	101.5	7.14				
11/9/2005	Dalun WTP	Final Dalun	8.9	31.4	122.9	3.78		1.4		
1/12/2006	Dalun WTP	Raw Dalun	7.43	28.5	81.5	83			5000	
1/12/2006	Dalun WTP	Settled Dalun	6.89	26.5	87.9	8.82				
1/12/2006	Dalun WTP	Final Dalun	9.25	27.1	114.1	4.2		0.9	0	
2/14/2006	Dalun WTP	Raw Dalun	7.58	30.5		92.9				
2/14/2006	Dalun WTP	Settled Dalun	6.89	30.4		9.03				
2/14/2006	Dalun WTP	Final Dalun	9.49	30.2		6.9		0.7		
3/20/2006	Dalun WTP	Raw Dalun	7.5	32.8	101.7	35.9				
3/20/2006	Dalun WTP	Settled Dalun	7.15	32	103.4	4.93				
3/20/2006	Dalun WTP	Final Dalun	8.86	32.4	126.9	2.21		0.87		
4/3/2006	Dalun WTP	Raw Dalun	7.37	31.9	90.9	53.3				
4/3/2006	Dalun WTP	Settled Dalun	6.79	31.6	107.3	4.46				
4/3/2006	Dalun WTP	Final Dalun	7.54	31.7	114.8	0.98		0.4		
5/17/2006	Dalun WTP	Raw Dalun	6.99	28.3	84.1	134			5000	2300
5/17/2006	Dalun WTP	Settled Dalun	6.43	27.3	92.5	9.97			160	270
5/17/2006	Dalun WTP	Final Dalun	7.89	27.8	115.9	3.97		0.9	0	0
6/13/2006	Dalun WTP	Raw Dalun	6.9	30.7	97.9	34.6			5000	350
6/13/2006	Dalun WTP	Settled Dalun	6.38	29.1	96.2	5.91			440	160
6/13/2006	Dalun WTP	Final Dalun	7.99	29.7	116.3	1.62		0.15	0	0
7/5/2006	Dalun WTP	Raw Dalun	6.55	30.7	820	329			5000	
7/5/2006	Dalun WTP	Settled Dalun	5.47	30.7	111.3	23.4			680	

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
7/5/2006	Dalun WTP	Final Dalun	6.51	30.9	126.6	4.72		0.55	0	
8/1/2006	Dalun WTP	Raw Dalun	7.26	27.5	63.2	305				
8/1/2006	Dalun WTP	Settled Dalun	5.78	27.3	101.3	6.6				
8/1/2006	Dalun WTP	Final Dalun	7.19	28.1	117.9	6.99		0.45		
9/5/2006	Dalun WTP	Raw Dalun	6.68	27.3	44.7	496				
9/5/2006	Dalun WTP	Settled Dalun	4.55	27.5	92	7.78				
9/5/2006	Dalun WTP	Final Dalun	7.32	27.9	106.3	1.87		0.35		
10/4/2006	Dalun WTP	Raw Dalun	7	31.3	69.1	117			5000	
10/4/2006	Dalun WTP	Settled Dalun	6.24	30	90.4	7.68			5000	
10/4/2006	Dalun WTP	Final Dalun	8.15	31	129.3	2.02		0.25	0	
11/7/2006	Dalun WTP	Raw Dalun	7.31	30.8	74.8	103				26
11/7/2006	Dalun WTP	Settled Dalun	6.24	30	94.2	8.48				5
11/7/2006	Dalun WTP	Final Dalun	7.53	30.4	117.6	2.57		0.7		0
12/6/2006	Dalun WTP	Raw Dalun	7.63	24.6	75	107				
12/6/2006	Dalun WTP	Settled Dalun	7.5	24.8	83.6	12.9				
12/6/2006	Dalun WTP	Final Dalun	8.78	25.8	108.4	11.8		1.5		
1/9/2007	Dalun WTP	Raw Dalun	8.09	23.5	78.5	103				176
1/9/2007	Dalun WTP	Settled Dalun	7.7	23.6	94.7	13.2				9
1/9/2007	Dalun WTP	Final Dalun	7.71	23.4	106.7	9.53		0.9		0
3/19/2007	Dalun WTP	Raw Dalun	8.34	32.1	96.2	84.6			1800	300
3/19/2007	Dalun WTP	Settled Dalun	8.13	30.3	99.4	20.2			150	100
3/19/2007	Dalun WTP	Final Dalun	8.22	31.5	110.6	10.6		0.9	0	0

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
4/10/2007	Dalun WTP	Raw Dalun	8.58	31.9	91.4	91.7				
4/10/2007	Dalun WTP	Settled Dalun	8.09	30.9	105.7	5.74				
4/10/2007	Dalun WTP	Final Dalun	8.43	30.3	120.8	6.23		0.8		
5/2/2007	Dalun WTP	Raw Dalun	8.32	27.5	74.6	381		422	192	
5/2/2007	Dalun WTP	Raw Dalun	8.32	27.5	74.6	381			422	192
5/2/2007	Dalun WTP	Settled Dalun	7.63	28	97.1	6.95		211	46	
5/2/2007	Dalun WTP	Settled Dalun	7.63	28	97.1	6.95			211	46
5/2/2007	Dalun WTP	Final Dalun	8.15	27.6	117.3	3	1.15	0	0	
5/2/2007	Dalun WTP	Final Dalun	8.15	27.6	117.3	3		1.15	0	0
5/8/2007	Dalun WTP	Raw Dalun	7.1	29.1	228	169			5000	5000
5/8/2007	Dalun WTP	Settled Dalun	6.62	29.6	262	12.9			3	2
5/8/2007	Dalun WTP	Final Dalun	6.7	29.5	279	5.05		0	7	7
6/5/2007	Dalun WTP	Raw Dalun	7.62	30.3	92.5	74.7			116	72
6/5/2007	Dalun WTP	Settled Dalun	7.08	30.3	105.9	4.09			13	3
6/5/2007	Dalun WTP	Settled Dalun	7.01	30.3	105.9	4.09			13	3
6/5/2007	Dalun WTP	Final Dalun	7.24	28.8	112.8	1.83		1	0	0
7/5/2007	Dalun WTP	Raw Dalun	7.2	27.7	72	270			5000	5000
7/5/2007	Dalun WTP	Settled Dalun	6.2	27	91	5.68			44	11
7/5/2007	Dalun WTP	Final Dalun	6.8	28.5	105	2.37		0.8	0	0
8/1/2007	Dalun WTP	Raw Dalun	7.97	24.7	52	609			5000	5000
8/1/2007	Dalun WTP	Settled Dalun	6.82	23.1	93	5.38			5000	5000
8/1/2007	Dalun WTP	Final Dalun	7.63	25.7	97	2.39		1.2	0	0

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
9/4/2007	Dalun WTP	Raw Dalun	8.19	24.8	60	117			420	240
9/4/2007	Dalun WTP	Settled Dalun	7.9	28	80	5.26			5000	66
9/4/2007	Dalun WTP	Final Dalun	8	28	91	2.26		1.4	0	0
10/4/2007	Dalun WTP	Raw Dalun	8.52	34.4	70	55.2				
10/4/2007	Dalun WTP	Settled Dalun	8.05	29.4	91	1.93				
10/4/2007	Dalun WTP	Final Dalun	8.32	31.8	99	0.49		1.15		
11/1/2007	Dalun WTP	Raw Dalun	8.68	26.3	75	246			5000	5000
11/1/2007	Dalun WTP	Settled Dalun	8.27	26	85	5.39			40	19
11/1/2007	Dalun WTP	Final Dalun	8.41	26.2	95	1.76		1.15	0	0
12/5/2007	Dalun WTP	Raw Dalun	7	27.3	68	175			5000	5000
12/5/2007	Dalun WTP	Settled Dalun	6.2	24	95	6.13			5000	10
12/5/2007	Dalun WTP	Final Dalun	8.4	25.8	95	2.98		1.15	0	0
1/21/2008	Dalun WTP	Raw Dalun	9.06	22.7	78	96.4			5000	5000
1/21/2008	Dalun WTP	Settled Dalun	8.86	21.4	90.1	7.77			182	9
1/21/2008	Dalun WTP	Final Dalun	8.88	23.2	99	2.52		2	0	0
2/12/2008	Dalun WTP	Raw Dalun	8.42	26.8	97	48.5			5000	5000
2/12/2008	Dalun WTP	Settled Dalun	7.89	25.7	99	5.55			5000	13
2/12/2008	Dalun WTP	Final Dalun	7.81	26.2	118	1.5		2	0	0
3/5/2008	Dalun WTP	Raw Dalun	7.78	31.9	76	83.1	47.5		5000	5000
3/5/2008	Dalun WTP	Settled Dalun	6.71	31.2	88	7.21	1.5		82	41
3/5/2008	Dalun WTP	Final Dalun	8.77	30.8	106	1.81	0	1.1	0	0
4/7/2008	Dalun WTP	Raw Dalun	7.38	31.9	82.4	93.4			5000	62

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
4/7/2008	Dalun WTP	Settled Dalun	7.25	30.1	98	14			142	34
4/7/2008	Dalun WTP	Final Dalun	8.39	31.1	117.2	3.99		0.35	0	0
5/7/2008	Dalun WTP	Raw Dalun	7.74	31.9	87	81.9			5000	5000
5/7/2008	Dalun WTP	Settled Dalun	7.11	31.7	98	5.89			167	18
5/7/2008	Dalun WTP	Final Dalun	7.29	32.5	109	1.34		0.7	0	0
6/3/2008	Dalun WTP	Raw Dalun	7.76	30.7	83	87.6			550	250
6/3/2008	Dalun WTP	Settled Dalun	6.94	30.5	94	5			64	29
6/3/2008	Dalun WTP	Final Dalun	7.87	30.8	116	7.06		1.3	0	0
8/4/2008	Dalun WTP	Raw Dalun	6.32		56.3	189				
8/4/2008	Dalun WTP	Settled Dalun	4.87		77.4	3.15				
8/4/2008	Dalun WTP	Final Dalun	6.1		186.2	4.06		0		
9/9/2008	Dalun WTP	Raw Dalun	7.03	29.7	73	74.2			5000	5000
9/9/2008	Dalun WTP	Settled Dalun	6.71	29.5	78	5.71			48	78
9/9/2008	Dalun WTP	Final Dalun	7.41	30.2	112	5.45		1.25	0	0
10/3/2008	Dalun WTP	Raw Dalun	7.35	30.1	82	79.9			5000	5000
10/3/2008	Dalun WTP	Settled Dalun	6.78	29.9	80	5.32			157	62
10/3/2008	Dalun WTP	Final Dalun	7.02	30.5	85	2.28		0.35	0	0
11/25/2008	Dalun WTP	Raw Dalun	7.8	29.3	80	139				
11/25/2008	Dalun WTP	Settled Dalun	7.25	29.8	90	9				
11/25/2008	Dalun WTP	Final Dalun	7.76	29	111	3		0.6		
1/8/2009	Dalun WTP	Raw Dalun	7.39	27.4	70	114			252	165
1/8/2009	Dalun WTP	Final Dalun	8.37	26.9	100	3.18		0.5	0	0

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
2/5/2009	Dalun WTP	Raw Dalun	7.48	25.9	78	127	68.5		98	
2/5/2009	Dalun WTP	Final Dalun	7.04	26	92	0	0	0.6	0	
3/3/2009	Dalun WTP	Raw Dalun	6.89	29.1	82	112	85.5			
3/3/2009	Dalun WTP	Final Dalun	6.78	28.5	100	2.55	2.55	0.7		
4/2/2009	Dalun WTP	Raw Dalun	7.3		77	109	65.5		680	440
4/2/2009	Dalun WTP	Final Dalun	7.7		112	3.18	0	0.9	0	0
5/12/2009	Dalun WTP	Raw Dalun	7.4		84	94.2				
5/12/2009	Dalun WTP	Final Dalun	7.1		105	4.13		0.6		
6/11/2009	Dalun WTP	Raw Dalun	7.3	30.6	80.2	168	95.5		1440	
6/11/2009	Dalun WTP	Final Dalun	7.5	30.8	119.9	0	0	0.8		
7/2/2009	Dalun WTP	Raw Dalun	7.3	30.1	60.4	53.5	330		5120	980
7/2/2009	Dalun WTP	Final Dalun	6.7	30.3	129.5	4	0.8	1.3	0	0
8/13/2009	Dalun WTP	Raw Dalun	6.9	29.9	59.5	346	209		2880	108
8/13/2009	Dalun WTP	Final Dalun	7.5	28.7	115	2.1	0	0.1	0	0
9/7/2009	Dalun WTP	Raw Dalun	7.13	28.6	69.1	102	54.4		2880	510
9/7/2009	Dalun WTP	Final Dalun	8.1	28.9	96.7	0	0	1.4	0	0
10/13/2009	Dalun WTP	Raw Dalun	7.09	30.3	67.8	137	74		2280	159
10/13/2009	Dalun WTP	Final Dalun	8.28	30.7	101.7	1.33	0	0.25	0	0
11/5/2009	Dalun WTP	Raw Dalun	7.15	30.6	74.8	263	1620		4500	1350
11/5/2009	Dalun WTP	Final Dalun	6.61	30.1	104.1	2.05	6	1.5	0	0
12/10/2009	Dalun WTP	Raw Dalun	7.35	26.7	84.6	121	1060		800	340
12/10/2009	Dalun WTP	Final Dalun	7.31	26.4	109	1.93	2	1.5	0	0

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
1/10/2010	Dalun WTP	Raw Dalun	6.57	24.3	78	117	88.5		700	
1/10/2010	Dalun WTP	Final Dalun	6.2	24.4	94.5	2.72	1.2	2.3	0	
1/19/2010	Dalun WTP	Raw Dalun	7.29	27.2	81.2	124	84.5			
1/19/2010	Dalun WTP	Final Dalun	7.12	25.7	101.1	1.34	0.4	0.4		
2/19/2010	Dalun WTP	Raw Dalun	7.56	30.9	76.2	121	101.5			
2/19/2010	Dalun WTP	Final Dalun	7.51	30.8	99.5	2.79	0.9	0.55		
3/10/2010	Dalun WTP	Raw Dalun	7.53	31.6	76.8	116	99.5		1820	250
3/10/2010	Dalun WTP	Final Dalun	7.99	31.6	111.6	2	1.4	0.75	0	0
4/20/2010	Dalun WTP	Raw Dalun	7.46	31.1	78.3	94	49.2		1080	520
4/20/2010	Dalun WTP	Final Dalun	7.55	30.9	103.3	3	1	0.1	0	0
7/6/2010	Dalun WTP	Raw Dalun	7.17	30.4	83.1	172	55		540	390
7/6/2010	Dalun WTP	Final Dalun	8.26	30.4	125	3.49	0.5	1.1	0	0
8/3/2010	Dalun WTP	Raw Dalun	6.53	29.3	56.5	99.5				
8/3/2010	Dalun WTP	Final Dalun	6.45	29.6	104.6	1.63		0.5		
9/17/2010	Dalun WTP	Raw Dalun	6.07	27.6	77.7	83.6				
9/17/2010	Dalun WTP	Final Dalun	6.2	27.8	113.3	6.04		1.8		
10/8/2010	Dalun WTP	Raw Dalun	6.42	29.6	85.5	64.2	41.5		4700	4500
10/8/2010	Dalun WTP	Final Dalun	6.73	29.6	118.5	1.223	0.2	1.4	0	0
11/8/2010	Dalun WTP	Raw Dalun	7.03	30.2	64.8	103	60		1020	
11/8/2010	Dalun WTP	Final Dalun	6.58	30.2	86.9	1.69	0	1.5	0	
12/7/2010	Dalun WTP	Raw Dalun	6.9	28	76.8	122	89			
12/7/2010	Dalun WTP	Final Dalun	6.54	28.1	101.3	5.67	3.1	1.8		

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
2/8/2011	Dalun WTP	Raw Dalun	6.55	27.4	77.3	97.2	75.5		2400	
2/8/2011	Dalun WTP	Final Dalun	7.03	26.4	104.8	8.16	0	0.9	0	
3/2/2011	Dalun WTP	Raw Dalun	6.36	31.8	73.2	88.4				
3/2/2011	Dalun WTP	Final Dalun	7.04	31	94.1	2.28		0.75		
4/20/2011	Dalun WTP	Raw Dalun	7.27	32.6	77	77	47.3	0	0	0
4/20/2011	Dalun WTP	Final Dalun	6.85	32	102.8	2.05	1	1.2	0	0
5/5/2011	Dalun WTP	Raw Dalun	5	32.9	114.8	35.9	0	0	2.28	1.1
5/5/2011	Dalun WTP	Final Dalun	6.73	32.1	103.2	1.57	0	1.8	0	0
9/6/2011	Dalun WTP	Raw Dalun	6.97	30.3	58	184	172.5		3120	1650
9/6/2011	Dalun WTP	Final Dalun	6.04	30	102.2	1.43	0.2	1.1	0	0
10/5/2011	Dalun WTP	Raw Dalun	7.08	31.2	75.1	199	125		1680	930
10/5/2011	Dalun WTP	Final Dalun	6.73	31.1	101.2	4.86	1.8	2.4	0	0
11/3/2011	Dalun WTP	Raw Dalun	6.74	32	84.6	65.5				
11/3/2011	Dalun WTP	Final Dalun	6.83	31.8	53.2	1.06		0.75		
12/6/2011	Dalun WTP	Raw Dalun	7.38	27.5	80.4	98.3	112.5		480	2400
12/6/2011	Dalun WTP	Final Dalun	7.13	26.7	114.1	2.77	3.72	1.7	0	0
1/11/2012	Dalun WTP	Raw Dalun	7.09	26.4	85.7	80.8	85.5			
1/11/2012	Dalun WTP	Final Dalun	6.86	25	104.8	1.85	0.2	0.7		
2/9/2012	Dalun WTP	Raw Dalun	7.3	24.9	96.7	64			400	120
2/9/2012	Dalun WTP	Final Dalun	6.8	25.2	112.5	1.59		2.1	0	0
3/14/2012	Dalun WTP	Raw Dalun	6.95	30	86.8	122	87			
3/14/2012	Dalun WTP	Final Dalun	7.01	29.4	110.3	4.55	1.2	0.7		

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
4/5/2012	Dalun WTP	Raw Dalun	7.24	31.8	91.9	101	64.5			
4/5/2012	Dalun WTP	Final Dalun	7.46	30.9	119.3	4.33	2	0.7		
5/8/2012	Dalun WTP	Raw Dalun	7.32	32.3	89.9	85.3	45.1		430	190
5/8/2012	Dalun WTP	Final Dalun	7.3	31.9	118.3	2.12	1.2	0.65	0	0
6/6/2012	Dalun WTP	Raw Dalun	7.3	31.6	67.5	334	248.5		9.16	8.2
6/6/2012	Dalun WTP	Final Dalun	6.2	30.4	122.9	2.66	1.6	2.2	0	0
7/5/2012	Dalun WTP	Raw Dalun	6.5	28.8	67.1	1.9	13.05			
7/5/2012	Dalun WTP	Final Dalun	6.8	28.3	143.5	1.8	1.1	3		
8/7/2012	Dalun WTP	Raw Dalun	6.6	28	59.6	248	285	0		0
8/7/2012	Dalun WTP	Final Dalun	6.96	27.9	121.7	3.17	0.7	1		0
9/6/2012	Dalun WTP	Raw Dalun	6.7	29.5	54.1	364	0	0		0
9/6/2012	Dalun WTP	Final Dalun	6	29.2	93.7	3.21	0	1		0
10/3/2012	Dalun WTP	Raw Dalun	6.54	30.9	70.2	85.5	48.1	0	790	540
10/3/2012	Dalun WTP	Final Dalun	6.37	30.7	102.1	3.16	1.1	2	0	0
11/6/2012	Dalun WTP	Raw Dalun	6.92	31.8	79.2	136	81	0	7650	4.59
11/6/2012	Dalun WTP	Final Dalun	6.54	31.1	119.7	3.39	0.1	2.1	0	0
12/12/2012	Dalun WTP	Raw Dalun	6.92	29.2	67.9	178	113	0	850	0
12/12/2012	Dalun WTP	Final Dalun	6.64	28.8	94.2	3.18	2.4	0.75	390	0
1/9/2013	Dalun WTP	Raw Dalun	7.12	26.5	82.1	111	0	0	0	0
1/9/2013	Dalun WTP	Final Dalun	6.96	26	96	1.39	0	0.2	0	0
2/5/2013	Dalun WTP	Raw Dalun	7.27	27.7	72.5	82.4	0	0	0	0
2/5/2013	Dalun WTP	Final Dalun	6.75	25.6	90.1	0.91	0	1	0	0

Date	TP	Final/Raw	pH	Temp (C)	Cond	Turb (NTU)	Color (TCU)	Resid Chlor (mg/l)	T. Coli (count /100mL)	E. Coli (count /100mL)
3/13/2013	Dalun WTP	Raw Dalun	6.36	32.1	83	111	0	0	0	0
3/13/2013	Dalun WTP	Final Dalun	6.55	31.3	96.3	2.5	0	2	0	0
4/19/2013	Dalun WTP	Raw Dalun	7.35	32.2	75.1	116	56.5	0	0	0
4/19/2013	Dalun WTP	Final Dalun	7.6	31.7	99.5	8.85	5.8	0.3	0	0
5/7/2013	Dalun WTP	Raw Dalun	7.12	31.9	68.6	166	0	0	0	0
5/7/2013	Dalun WTP	Final Dalun	6.96	31.9	102.3	2.04	0	0.4	0	0
6/4/2013	Dalun WTP	Raw Dalun	7.3	31.8	81.6	76.8	0	0	0	0
6/4/2013	Dalun WTP	Final Dalun	6.55	30.8	103.4	2.09	0	2	0	0
7/3/2013	Dalun WTP	Raw Dalun	6.9	30.4	65.5	260	0	0	0	0
7/3/2013	Dalun WTP	Final Dalun	7.3	30.2	86.1	6.77	0	0.1	0	0
8/5/2013	Dalun WTP	Raw Dalun	6.84	28.9	76.6	446	0	0	0	0
8/5/2013	Dalun WTP	Final Dalun	6.74	28.5	115.4	1.54	0	1.6	0	0
10/2/2013	Dalun WTP	Raw Dalun	6.86	28.4	99.9	139	0	0	0	0
10/2/2013	Dalun WTP	Final Dalun	6.94	28.5	108.2	1.13	0	0.5	0	0
11/11/2013	Dalun WTP	Raw Dalun	6.87	28.5	106	161	0	0	0	0
11/11/2013	Dalun WTP	Final Dalun	7.74	28.6	120.3	2.94	0	0.45	0	0