

Water Quality Monitoring During Emergencies

**A Hands-On Guide for
WASH
Practitioners**



**U.S. CENTERS FOR DISEASE
CONTROL AND PREVENTION**



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Abbreviations & Acronyms

Abbreviation	Definition
CDC	The Centers for Disease Control and Prevention
CFU	Colony Forming Units
DPD	N, N Diethyl-1,4 Phenylenediamine Sulfate
EPA	United States Environmental Protection Agency
FRC	Free Residual Chlorine
FIB	Fecal Indicator Bacteria
HEV	Hepatitis E virus
HCF	Health Care Facility
MoH	Ministry of Health
MPN	Most Probable Number
NGO	Non-Governmental Organization
NTU	Nephelometric Turbidity Units
P-A	Presence Absence
PCR	Polymerase Chain Reaction
pH	Potential Hydrogen
ppm	Parts Per Million
RADWQ	Rapid Assessment of Drinking-Water Quality
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
UNICEF	United Nations Children's Fund
USD	US dollars
UV	Ultraviolet
WASH	Water, Sanitation, and Hygiene
WHO	World Health Organization
WWTP	Waste Water Treatment Plant

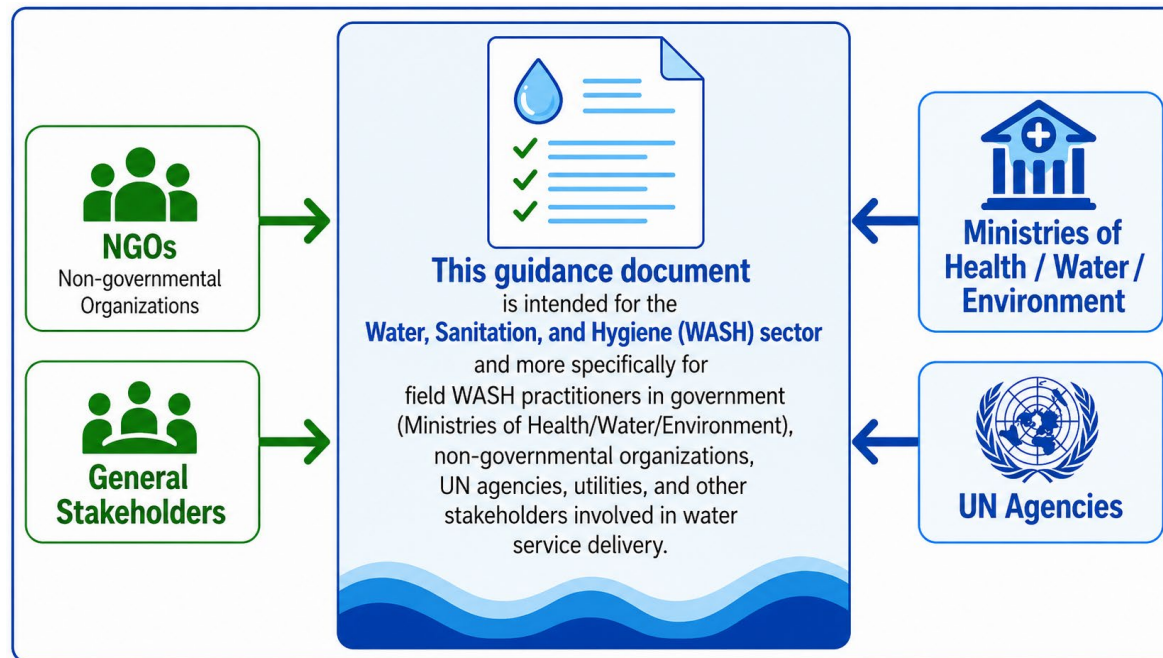
Preface

Access to safe drinking water is critical in humanitarian settings and during waterborne disease outbreaks. Water quality monitoring can identify contaminated water sources and provide water, sanitation, and hygiene (WASH) implementers with vital information to protect people from consuming unsafe water. Ideally, a water quality monitoring program will have already been set up as part of preparedness activities and could be reinstated or simplified during an outbreak response or acute emergency. However, in other cases, an emergency water quality monitoring plan may need to be developed.

This document provides a step-by-step guide on how to monitor water quality in different settings such as an area with a piped network, a rural area where households are targeted with household water treatment interventions, or a community served by boreholes.

The water quality monitoring plan should describe the objectives, in addition to appropriate tests and procedures, for the water quality monitoring program. A well-developed plan will help guide implementers on what data are needed, how to collect that data and by whom, how to analyze and disseminate the results, and how to respond to problems identified through monitoring. If possible, a dual-role approach should be implemented, where monitoring is shared between a service provider or drinking water supplier (e.g., a water vendor or a municipal piped water supply) and an independent authority

responsible for oversight (WHO 2017a). In some settings, these roles may already be defined and governmental agencies such as the Ministry of Health may be responsible for water quality monitoring. However, where this is lacking or has been interrupted, the monitoring plan should clearly define who is going to take on the responsibility of water quality monitoring activities. Testing methods, sampling sites and frequency may vary based on the context of the emergency, water sources included, as well as logistical and financial constraints. In addition, a well-developed monitoring plan will differentiate between the core indicators/parameters, and which should be prioritized during a cholera outbreak or other disease outbreak.



THE BASICS: WATER QUALITY MONITORING

Why it Matters

Developing a water quality monitoring plan is critical during emergencies and disease outbreaks, as monitoring helps to identify contaminated water sources and provides WASH implementers with vital information to protect consumers from contaminated drinking water. Water quality monitoring in emergencies is often a gap in the response and may not be functional during the acute phase of an emergency. **A well-developed water quality monitoring plan can guide water quality monitoring program activities and staff.**

Ideally, a water quality monitoring plan and program will already be set up (developed as part of preparedness activities) which can be modified (often simplified) to meet the specific needs during an outbreak response or acute emergency. In other cases, an emergency water quality plan and program may need to be developed. The Water Quality Monitoring Toolkit aims to provide operational guidance on developing monitoring plans in different contexts, while sharing example tools for data collection, and examples on how data can be presented and shared for corrective action. The aim is to support WASH actors in the field designing and supporting water quality monitoring programs during emergencies and outbreaks.

This toolkit provides a general overview of how to create a monitoring plan during emergencies and waterborne disease outbreaks. It also provides more detailed information on water quality monitoring in different contexts, including water treated at the centralized level (treated piped networks), chlorinated decentralized water sources, untreated decentralized water sources, stored household water, and drinking water sources at healthcare facilities.



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STANDARDS AND THRESHOLDS

When developing the monitoring plan, it is important to consider the **applicable standards for drinking water quality**. In all cases, national standards should be used. In the absence of national standards or in special circumstances, WHO standards may be adopted. In certain situations, operational and logistical realities may not facilitate compliance with the national standards such as during an acute emergency. In these situations, partners should work with the relevant authorities to identify interim standards or targets. Included in this discussion should be the process for sharing these interim standards and the timeframe for which they are applicable.

WHO recommends a risk-benefit approach when developing quantitative thresholds or targets.

The focus should be on defining standards that can be easily measured and enforced and are most important to protect human health in emergency settings (WHO 2017a).

In some instances, the water quality monitoring plan may include certain thresholds for key parameters. If a threshold is surpassed, this would trigger an alert and should result in immediate action. Table 1 summarizes the recommended levels for priority physiochemical parameters and microbial indicators.



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Table 1: Recommended Targets of Physiochemical Parameters During Emergencies and Outbreaks

Parameters		Recommended Targets		
Physiochemical	Free Residual Chlorine (FRC)	 • FRC recommended to be ≥ 0.2 mg/L (ppm) at point of use during emergencies with normal to low risk of disease outbreaks  • FRC recommended to be ≥ 0.5 mg/L (ppm) at point of use during a waterborne disease outbreak  • FRC recommended to be 1.0 mg/L at tapstands  • FRC recommended to be 2.0 mg/L at water trucks at filling  • FRC in drinking water should not exceed 5.0 mg/L (WHO); however, taste and odor may become noticeable at ≥ 2.0 mg/L		
	pH	 6.5 – 7.5	0 ————— 6.5 ————— 7.5 ————— 14	
	Turbidity	 < 5 NTU (Ideally < 1 NTU)	0 ————— 1 ————— 5 ————— 50+	
	Total Dissolved Solids (TDS)	 < 1000 mg/L	0 ————— 1000 ————— 2000+	
	Conductivity	 30 – 1500 $\mu\text{S}/\text{cm}$	0 ————— 30 ————— 1500 ————— 3000+	
Microbial Indicators	<i>E. coli</i>	 < 1 CFU / 100 ml	CFU = Colony Forming Units	
	Fecal (Thermotolerant) Coliforms	 < 1 CFU / 100 ml	CFU = Colony Forming Units	

Point of Collection: Refers to the location where water is collected for household use. Water is then often transported from this location to the home. Examples of points of collection locations include community tapstands and community boreholes. Water is tested at the point of collection to ensure physiochemical parameters and in some cases microbial parameters meet the recommended targets. Chlorine levels can be checked at the point of collection where there is centralized treatment or at point of collection if there is treatment at the point of collection, such as inline chlorinators.

Point of Use: Refers to the location where water is consumed or used by the intended users. An example of point of use water is stored drinking water inside a home. Water is tested at the point of use to ensure physiochemical parameters and in some cases microbial parameters meet the recommended targets for household use. Some chlorination interventions such as household water treatment, specifically treat water at the point of use. Chlorine levels can be checked at the point of use where chlorine products are being used for household water treatment.

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STEPS FOR CREATING A MONITORING PLAN

Monitoring plans should be adapted for the context and type(s) of water sources (EPA 1997). Monitoring plans may include centralized water sources, decentralized water sources, and/or stored household water, depending on the primary sources of drinking water and the purpose and objectives of the program. First, we will go through these key steps relevant to all monitoring plans, and in subsequent sub-sections we will go through the key steps when creating a monitoring plan at different levels: for centralized water sources, decentralized water sources (both chlorinated and untreated), stored household water, and healthcare facilities.

The Key Steps Relevant to All Monitoring Steps Are:

Step	Description
 1	Establish the purpose and objectives of the monitoring plan
 2	Select water source types and appropriate water quality tests
 3	Choose sampling sites reflecting monitoring objectives
 4	Determine the frequency of sampling based on water source type and test requirements
 5	Conduct sanitary inspections to identify contamination sources
 6	Collect and interpret data; disseminate results
 7	Take corrective actions defined in the monitoring plan

Each step for creating a water quality monitoring plan is discussed in depth on the following pages.

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Step 1: Establish the purpose and objectives of the monitoring plan.

Defining the purpose and objectives of a monitoring program will help inform the subsequent steps, including which tests to conduct, who will conduct the testing, where and how often sampling should occur, what risk management approaches can be taken, and decision making based on test results.

The monitoring purpose and objectives should align with the current state of an emergency and may change over time as the emergency transitions from the acute phase to long-term recovery.

While developing the purpose and objectives, it is important to define clearly what information is needed and to assess what information is already available to optimize the use of available resources. In addition, it is critical to consider available financial resources, availability of sampling and testing equipment, laboratory requirements, transport options, and staff capacity to develop a feasible monitoring program (Bartram, 1996).

The monitoring purpose is a broad statement characterizing the expectations of the program. During an acute emergency, the purpose should be to assess water quality of existing sources and conduct continued monitoring to detect emerging problems. In an outbreak scenario, the purpose should be to ensure the potability of water and to reduce the risk to human health. During stable conditions the general purposes may include (1) to assess and rank existing and emerging problems, (2) to describe status and trends (e.g. over time or between rainy and dry seasons), (3) to evaluate the effectiveness of water treatment interventions, (4) to design management and regulatory programs, or (5) any combination therein (EPA 1997).

Monitoring objectives are more detailed statements that help to address the temporal and geographic scale of the plan. The objectives should describe **who, what, when, where, why, and how** of sampling and testing, in addition to defining the specific water quality targets, setting requirements for reporting of results, and establishing corrective actions. When resources are constrained and budgets for monitoring are limited, it is necessary to prioritize the selection of parameters and testing methods (EPA 1997). During an acute emergency or disease outbreak the monitoring objective(s) may prioritize more frequent monitoring of FRC levels, use a higher water quality target, or include a larger number of sampling locations (e.g., points of collection, point-of-use). Objectives may change as the emergency evolves.

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Step 2: Water Source Types and Water Quality Parameters. The objectives of the monitoring program will help guide the decision on which types of water sources to include and which water quality tests are appropriate. When selecting water quality parameters, it is important to avoid selecting more parameters than necessary to meet the plan objectives. Budget, personnel, equipment, space, materials, and time constraints should be considered. Testing for additional parameters may compromise the number of sampling locations, the sampling frequency, or the duration of monitoring and ultimately may affect the effectiveness of the monitoring plan (Dressing 2016). Below are descriptions of which water quality testing parameters to be considered in a water quality monitoring plan, depending on water source type.

These are listed in order of priority.

- Free Chlorine Residual (FRC).** During an acute emergency or waterborne disease outbreak, chlorine treatment and monitoring for FRC is often prioritized. During outbreaks and emergencies, the Free Chlorine Residual (FRC) level of drinking water is recommended to be 0.5 mg/L at the point-of-use, 1.0 mg/l at tapstands, and 2.0 mg/L at water trucks during filling (WHO 1993, MSF 2010, UNHCR 2021). (See table, below.) If

Figure 1: Water Storage Tanks



Image source: CDC, Zambia

Table 2: Recommended Targets of Physiochemical Parameters During Emergencies and Outbreaks

Recommended Targets for Water Quality Parameters			
During Emergencies and Outbreaks			
FREE RESIDUAL CHLORINE (FRC)		PHYSIOCHEMICAL PARAMETERS	
	FRC recommended to be ≥ 0.2 mg/L (ppm) at point of use during emergencies with normal to low risk of disease outbreaks	 pH	6.5–7.5
	FRC recommended to be ≥ 0.5 mg/L (ppm) at point of use during a waterborne disease outbreak	 Turbidity	< 5 NTU (Ideally < 1 NTU)
	FRC recommended to be 1.0 mg/L at tapstands	 Total Dissolved Solids (TDS)	< 1000 mg/L
	FRC recommended to be 2.0 mg/L at water trucks at filling	 Conductivity	30–1500 µS/cm
	FRC in drinking water should not exceed 5.0 mg/L (WHO); however, taste and odor may become noticeable at ≥2.0 mg/L	MICROBIAL INDICATORS	
		 <i>E. coli</i>	< 1 CFU / 100 ml
		 Fecal (Thermotolerant) Coliforms	< 1 CFU / 100 ml

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the FRC is present and meets recommended ranges, microbiological testing may not be necessary unless required by existing regulations. If the water source is potentially chlorinated, testing for FRC at the treatment location should be the first testing parameter and location included in a water quality plan. During emergencies, FRC testing may also be conducted at the household from storage containers if household water treatment is being promoted (Townes, 2018).

- ***E. coli* or fecal coliforms.** Due to the high risk of waterborne diseases, including those of outbreak potential (e.g., cholera, shigellosis, or hepatitis E), assessing the risk from fecal contamination is often an important part of a water quality monitoring program in emergencies (Wisner 2002). However, if FRC is present in a sample of treated water and meets designated thresholds (>0.2 mg/L for water sampled from the point of use), microbial testing is usually not necessary and may not be a strategic use of resources. Testing water directly for all pathogens of potential risk is often unfeasible as it is costly and requires advanced technical expertise, specialized equipment and reagents, and does not provide results within 24 hours; thus, if needed, testing for fecal indicator bacteria (FIB) may be used instead to test for microbiological quality (Townes, 2018). Testing for *E. coli* is recommended, as it is the most precise; however, fecal coliforms (also known as thermotolerant coliforms) can be used as an alternative, if unable to test for *E. coli*. The use of total coliforms as a primary indicator of water quality should be avoided, due to the lack of specificity since coliforms can occur naturally in the environment and may not indicate fecal contamination.

According to WHO guidelines, a sample is “compliant” if there are no detectable *E. coli* or fecal coliforms per 100 mL sample of water. UNHCR guidelines state that 95% of all tests performed should have no detectable fecal coliforms per 100 mL sample of water (UNHCR, 2015). Other regulators stipulate the frequency of testing and minimum percent compliance based upon the system size (e.g., number of connections or population served).

- **Turbidity.** It is recommended to keep turbidity below 5 NTUs in drinking water (WHO, 2017; UNHCR, 2021). Where water treatment includes disinfection with chlorine, turbidity is ideally kept below 1 NTU for disinfection to be most effective (WHO, 2017b). High turbidity has a considerable impact on the effectiveness of chlorine disinfection and therefore should be measured in conjunction with chlorine testing. In water sources where there is high turbidity, such as surface water or where there are disruptions in service of municipal water, turbidity testing should be prioritized. Turbidity values can fluctuate by orders of magnitude in the same source (e.g., surface water) and therefore it is important to measure turbidity at regular intervals.
- **Temperature and pH.** Temperature and pH are important but need to be tested less frequently than other parameters. These physical parameters my also impact the effectiveness of chlorine and therefore should be measured in conjunction with

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chlorine testing, especially when starting a monitoring program or when source water is changed (e.g., during a water trucking campaign) (Townes, 2018). Water sources with pH levels greater than 8.5 will require a larger chlorine dose or longer contact time.

- Temperature will impact the disinfection reaction rates. Lower temperatures (e.g., less than 25 degrees Celsius) require longer contact time with disinfectants.

Since many standards are set using testing results at 25 degrees Celsius, treatment times may need to be adjusted in colder climates. Higher temperatures increase the rate of microbial growth and can cause problems related to taste, smell, or color of the water. As temperature and pH do not commonly fluctuate in the same source, testing for these parameters may be less frequent than FRC or FIB, which are typically more dynamic and should be prioritized in an emergency. See Appendix B for specific examples of how pH and temperature impact chlorination.

Key Takeaways – Temperature and pH

- Parameters selected for monitoring should align with monitoring plan objectives.
- Measuring Free Chlorine Residual of treated water is cheap, easy, and fast and should be prioritized.
- Treated water which meets FRC targets is unlikely to contain fecal contamination.
- Turbidity, temperature, pH, and conductivity are often measured as part of water treatment operations.
- *E. coli* and thermotolerant coliforms are commonly used to indicate fecal contamination.
- Direct pathogen testing is not recommended during emergencies.

For emergencies beyond cholera and disease outbreaks it may be worthwhile to consider these additional parameters:

- **Chemical testing.** This may also be done in emergencies but is often of lower priority during acute emergencies unless there are known issues in the area. Some emergencies involving damage to chemical or nuclear facilities or volcanic activity may warrant additional chemical testing (Wisner 2002). In addition, when new water sources such as boreholes are constructed, they should be tested for chemical parameters, such as arsenic, iron, fluoride, manganese, nitrates, nitrites, aluminum, and/or zinc, to ensure the source is safe for the population. In addition, these chemical constituents may impact the chlorine demand of the water. For example, during the emergency response in 2017 in Cox’s Bazar much of the population was relying on shallow groundwater with high iron and manganese levels.

Considerable variability in the levels of these metals make disinfection dosing challenging. National water quality standards should be referred to where appropriate for chemical testing.

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- Other parameters of interest.** Total dissolved solids (TDS) /conductivity may be of interest. TDS is a measurement (in mg/L) of inorganic salts and organic matter dissolved in water. High TDS levels may affect palatability acceptability of drinking water and may contribute to scaling in water pipes, boilers, and other household appliances and most importantly it can contribute to the chlorine demand of water. It is particularly important to consider TDS when developing water supplies in arid environments or in coastal areas. More information on how TDS can impact chlorination can be found in Appendix B.

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	FRC recommended to be 1.0 mg/L at tapstands	 Total Dissolved Solids (TDS)	< 1000 mg/L
	FRC recommended to be 2.0 mg/L at water trucks at filling	 Conductivity	30–1500 µS/cm
	FRC in drinking water should not exceed 5.0 mg/L (WHO); however, taste and odor may become noticeable at ≥2.0 mg/L	MICROBIAL INDICATORS	
		 <i>E. coli</i>	< 1 CFU / 100 ml
		 Fecal (Thermotolerant) Coliforms	< 1 CFU / 100 ml

Step 3: Selection of Sampling Sites. An inventory of all water sources should be completed prior to selection of sampling sites, if feasible (WHO 1997). It may not be possible to monitor all water points thus it is important to decide whether fixed sites (sentinel locations) with routine sampling or a random sample of sites per round will provide more valuable information for your monitoring plan. Selection of sampling sites should reflect the monitoring purpose and objectives. For example, if creating a monitoring plan for a centralized system with fixed treatment locations and user end points, purposively selecting fixed sentinel points would be more useful to observe changes over time and determine corrective actions.



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Selecting random sites may be more useful to detect local issues or sources of contamination (WHO 1997). For example, when we are unable to test all borehole water sources in an area due to the sheer number, selecting a random sample of sources to test monthly would allow you to get a picture of the water quality from that location or from that type of water source each month.

According to WHO, sampling sites for water quality testing should be representative of the different sources in use, uniformly distributed throughout the community taking the population distribution into account, and from potentially unfavorable locations, such as those that are possibly contaminated or located in low-pressure zones (WHO 1997).

If there is an ongoing waterborne disease outbreak, epidemiological data can be used to sample sources where cases are occurring as well as areas that are at high risk of transmission (areas affected in previous outbreaks, areas where unimproved water sources are used, etc.). If case investigations include information on primary source of drinking water, these sources should also be prioritized.

Depending on the emergency context and the goal of the monitoring program, **a rapid assessment** may be applicable. Rapid assessments or surveys are usually ad hoc in nature and finite in duration.

They are intensive programs to measure and observe water quality for a specific purpose and can be performed at the onset of the emergency or as a response to an outbreak of waterborne illness.

During the acute stage of an emergency, a rapid assessment may be conducted to obtain baseline information and a snapshot of water quality. This snapshot can then be used to help develop a more long-term routine water quality monitoring plan.

These assessments are also useful for informing immediate remediation measures such as chlorination and other operational activities and can form the basis for prioritization of scarce resources or when response time is critically important.

Key Takeaway – Selection of Sampling Sites

It may not be possible to monitor all water points thus it is important to decide whether fixed sites (sentinel locations) with routine sampling or a specific number of random sites per round will provide more valuable information for your monitoring plan. If creating a monitoring plan for a centralized system with fixed treatment locations and user end points, selecting fixed sentinel points would be more useful to determine corrective actions and to observe changes over time. Selecting random sites may be more useful when we are unable to test all water sources in an area due to the number, selecting a random sample of sources to test per round would provide a picture of the water quality from that location or from that type of water point. If case investigations include information on primary source of drinking water, these sources should also be prioritized.



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Rapid Water Quality Assessment Example

An outbreak of acute watery diarrhea (AWD) was declared in a region of Ethiopia that had been affected by drought and humanitarian crises for many years. The largest city in the region was served by a piped water system, sourced from deep boreholes, that was meant to be routinely chlorinated. It was estimated that 80% of city residents had access to the piped network primarily through communal tapstands. However, water service was intermittent, and many residents relied on alternative water sources. No water quality monitoring system was in place.

As part of the response, partners identified and mapped priority water points in AWD affected areas by using AWD surveillance data. These water sources included the piped network, water trucks, and donkey carts. Chlorine testing at these priority locations indicated that none of these water sources were being chlorinated regularly. In response, all attendants in charge of releasing water at the city's reservoirs, truck, and donkey cart filling stations were trained on chlorination procedures and supplies were provided. Centralized chlorination methods were used to improve chlorination through the piped network, and trucks and donkey carts were chlorinated at filling stations using decentralized chlorination methods, or bulk chlorination. Approximately one month after chlorination activities started, a rapid assessment of FRC was conducted to provide a snapshot of the chlorination status of different water points in the city's water supply system.

During this rapid assessment, partners found detectable FRC levels at most water points tested and targeted with centralized or decentralized chlorination interventions. It allowed for partners to quickly provide targeted action in the north of city where several water points were not chlorinated. After this assessment, they identified five previously unknown donkey cart filling stations servicing these areas. Staff at these stations were subsequently trained and provided chlorination supplies. This rapid assessment was successful in documenting improvements in water quality and identifying gaps in treatment (Rajasingham, 2020).

Step 4: Frequency of Sampling. Sampling frequency will depend on the type of water source, the test being conducted, the potential for seasonal variability, and the evolution of the emergency. Additionally, the frequency will largely depend on available resources, both financial and human resources (e.g., time of staff available, transport options, laboratory supplies, etc.). During the acute stage of an emergency or when there is a high risk of disease outbreak, drinking water should be sampled more frequently. For example, a piped network should be tested daily for FRC until results have stabilized. When introducing any new water supply, it should be tested for microbiological, physical, and chemical quality (where applicable prior to consumption). In addition, when water is treated through batch chlorination it will be necessary to test

the FRC for each batch. Repeated testing of the same batch (i.e., tank or reservoir) may be needed in cases where the tank is exposed to direct sunlight or when it takes more than 24 hours to empty the tank (Rajasingham, 2019).

Some tests, such as FRC and turbidity, can be easily tested more frequently with on-site test kits where chlorine treatment is being used. The frequency of microbiological testing may vary. Repeat testing is recommended when results come back positive for microbiological contamination (or chemical contamination if applicable). Repeat testing can be done to confirm a contaminated source, to monitor levels over time, or after repairs/disinfection of a source.

Key Takeaway – Frequency of Sampling

Some tests, such as FRC, can be tested more frequently with field test kits in locations where chlorination activities are ongoing. Repeat testing can be done to monitor levels over time, or after repairs or treatment of a source. Repeated testing of the same batch (i.e., tank or reservoir) may be needed when it takes more than 24 hours to empty the tank.

Step 5: Sanitary Inspection. Sanitary inspections may be used in conjunction with water quality monitoring to provide information on causes of contamination and possible necessary corrective actions. Relying solely on water quality monitoring may result in delayed detection, whereas sanitary inspections have the potential to identify problems before they affect the population (WHO 2017a). Sanitary inspections can be used to assess the risk of fecal contamination through potential hazards (e.g., a pit latrine close to a borehole), potential pathways (e.g., crack in borehole casing), or other indirect factors (e.g., lack of fencing around water point) (WHO/UNICEF 2012). Sanitary inspections can be combined with microbial water quality test results to determine a risk score (WHO, 2017). Additionally, the integration of sanitary inspections into a water quality program is a no-cost (or low-cost) method, which provides an important opportunity to engage and empower the community. Where groundwater sources are tested, sanitary inspections are also recommended. The new [Sanitary Inspections created by WHO in 2024](#) are designed by water point type and can be used to identify risks for contamination at water points.

WHO Sanitary Inspections Packages



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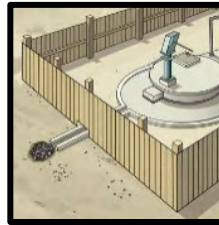


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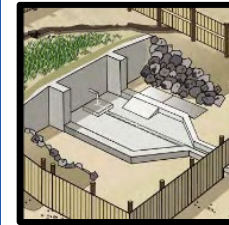
You can access the WHO Sanitary Inspection Packages through the links to pdfs under each image or by going to [WHO Sanitary Inspections Packages](#) for the web version.



1. [Dug well with a hand pump](#)



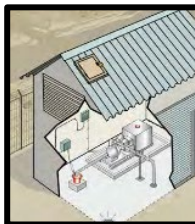
2. [Dug well with a windlass](#)



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4. [Tubewell with a hand pump](#)



5. [Borehole with a motorized pump](#)



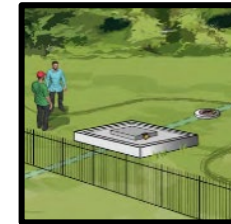
6. [Rainwater collection & storage](#)



7. [Surface water source & intake](#)



8. [Piped distribution – storage tank](#)



9. [Piped distribution – network](#)



10. [Piped distribution – tapstand](#)



11. [Filling station & water cart](#)



12. [Kiosk](#)



13. [Household practices](#)

Images are from the World Health Organization's (WHO) publication *Sanitary inspection packages - a supporting tool for the Guidelines for drinking-water quality: small water supplies*.

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Step 6: Data Collection and Interpretation of Results and Dissemination. The goal of water quality monitoring during emergencies is to generate data for decision making to protect public health and reduce the risk of waterborne disease; thus, data analysis and dissemination of results are critical. When multiple organizations are performing water quality testing, efforts should be made to use consistent testing methods, to measure the same parameters, and to use standardized reporting forms so that data can be compared. It is equally important to define who will be responsible for analyzing data, to set clear timelines for generating reports, define standard indicators, and who will receive the reports. Quantitative service level indicators for water quality may include “the proportion of samples or supplies that comply with guideline values for drinking-water quality and minimum criteria for treatment and source protection” (WHO 1997). During an acute stage of an emergency, it may be necessary to establish interim standards when water supplies fail to meet the ideal criteria. When the situation stabilizes, these standards can be adapted (WHO 1997).

Key Takeaway

During emergencies, routine water quality monitoring is critical to ensure drinking water is safe. Utilizing consistent testing methods and timely sharing of results is essential to ensure data is used by partners for corrective action and for community awareness.

At a minimum, reporting forms should consist of date and time of sample collection, person or agency collecting sample, source type, geolocation information if available, parameters tested on-site (turbidity, pH, FRC, etc.), and unique code to link sample with lab results. It is important that values detected are recorded for all parameters tested. These values can be categorized later during analysis. Forms for data collection are included in Appendix C.

Timely sharing of data between WASH partners and health partners is critical to protecting public health and to guide hygiene promotion and education programs. Results should be shared with water suppliers and those responsible for taking corrective action, whether it is the local or national government or non-governmental organizations (NGOs). In the case of waterborne disease illness, geospatial data on cases may guide those responsible for water quality monitoring on where to target their sampling activities. Dashboards have also been used in several recent outbreaks and emergencies to quickly share data with partners.



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Step 7: Corrective Actions. The goal of a water quality monitoring program is to improve water quality. In an effective program the results would be paired with corrective actions. It is important to respond quickly to all issues that may be detected during water quality monitoring. The monitoring plan should clearly define thresholds which trigger alerts, and corrective actions.

Discussion is necessary between all partners to establish which parties are responsible to make corrective actions. It should also be determined how frequently data is reviewed to identify alerts.

More information may be needed after an alert is triggered to determine the appropriate course of action. For example, if an alert identifies that FRC levels detected are too low more information may be needed to determine whether treatment was not done or whether treatment methods are not adequate. Additional tests such as chlorine demand studies may be necessary to determine this.

Key Takeaway – Corrective Actions

The monitoring plan should define thresholds for priority parameters to trigger alerts and corrective action. The monitoring plan should also define how frequently data is reviewed to identify alerts and necessary corrective actions.

For instance, when the objective of the plan is to monitor operations at a water treatment plant, monitoring data may indicate a need to adjust disinfection dosing targets and/or to carry out additional tests to optimize various treatment processes (e.g. chlorine demand studies, jar tests, etc.).

Review and Adjust Plan

As the emergency evolves it will be necessary to review and adjust the monitoring plan. In general, as the emergency shifts to recovery, it may be possible to decrease the frequency of sampling, the number of parameters tracked, and number of sampling locations included. Partners should work together and come to agreement on how to adjust the plan.

DATA COLLECTION, COMMUNITY PARTICIPATION, COSTING, SUSTAINABILITY, AND CHALLENGES



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Data Collection and Visualization Platforms

Water quality monitoring can be conducted using paper-based forms; however, increasingly emergency partners are opting to use mobile data collection. Multiple data collection applications and platforms are available and include, Kobo Collect, ODK, Ona, mWater, among others. Data collected from these platforms can be utilized to create dashboards for visualization using Power BI, mWater, or other software applications. In creating a dashboard to display results, downloading and analysis of data can be made automatic to reduce workload of monitoring and evaluation staff and to ensure timely data sharing. Different data collection forms are included in Appendix C. One example of a visualization platform is presented in the case study.

Key Takeaway – Data Collection

As the emergency situation evolves it will be necessary to review and adjust the monitoring plan. The following could be adjusted.

- Frequency of Sampling
- Number of Parameters
- Number of Sampling Locations

Community Participation

Community engagement is critical to the success and sustainability of a water quality monitoring effort. Talk with trusted community leaders and members of the community prior to data collection in order to understand the concerns and experiences. Beyond having a vested interest in the quality of the water they consume; community members are uniquely positioned to have knowledge of and familiarity with local water sources and challenges in their area. Invite members of the community to assist with water quality data collection and sanitary inspections, where appropriate. If possible, take time to engage with minority and marginalized groups, as these may not be represented in community leadership but may be disproportionately impacted by poor water quality.

Affected communities have a right to access information on their water’s quality. Accompany water quality results with interpretation and recommendations for action where appropriate (WHO 2024). Coordinate dissemination of results with community leaders and local government, and where possible, leverage existing information channels. Once results are shared, provide opportunities for community members to contribute to decision-making processes about remedial actions taken to address and improve water quality, through community meetings or feedback mechanisms.

Key Takeaway – Community Participation

- Discuss water quality concerns, experiences, and needs with the community
- Seek assistance from the community in data collection
- Engage community members in discussions regarding water quality results
- Involve the community in decision-making processes regarding remedial actions if water quality standards are not met

After remedial actions are taken or planned, close the feedback loop by returning to communities to communicate how these actions have been carried out.

Community Participation Example

In some areas, such as North Kivu, DRC, community health workers and other community members are directly involved with water quality testing, particularly FRC testing. In 2022, hygiene and water management committees were set up and trained in two health areas in the Goma area following population displacement due to the eruption of Mt. Nyiragongo.

The training included community health workers, water vendors, health area staff, and village leaders in Turunga and Kiziba health areas. Trained committee members were equipped with chlorine test kits and reagent to monitor FRC at treated water sources. Additionally, they were trained in Kobo Collect for data collection. Internal alert mechanisms were put into place to take immediate corrective actions with private water resellers. When a private reseller had a dissatisfactory FRC level, the committee members revisited to take a follow-up measurement following corrective actions to ensure provision of treated water. The committee shares a monthly report with health zone officials.

Since 2022, this system has been expanded to additional health areas within the city of Goma, and efforts are underway to include the health zone and water utilities more in data reporting and sharing. By involving community members in all stages of water quality testing, this allows for timely corrective actions and dissemination of results to the affected population. Additionally, households receive the information from trusted members of their communities.

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Costing

The cost of water quality monitoring programs should be considered when establishing an emergency program and when considering how or if the system will continue after the emergency. Potential costs include transport to sampling locations, water quality testing equipment and consumables, phones or tablets for data collection, mobile data for data collection devices, and human resources included in the water quality monitoring program. The exact costs will depend on the location, length of time of the program, and quantity of each cost included in the program. Although costs will be context specific, some example budgets from our experience include: (1) \$5,700 per month in an urban outbreak setting with chlorinated piped network and water tanks focusing on the chlorine testing, (2) \$30,000 for three months during an acute emergency in an urban setting monitoring the piped network and treatment tanks focusing on chlorine and microbiological testing and (3) \$60,000 a year for preventative monitoring of a chlorinated centralized system in an urban setting focusing on chlorine testing and physical parameters.

The below template includes costs that should be considered when planning water quality monitoring program activities. It is important to consider capital expenditure, operating expenditure, and any direct support. Other costs may also be applicable.

Key Takeaway – Costing

- Consider costs associated with transport, human resources, internet, and devices.
- Cost will be dependent on time period of program.
- Consider sustainability of emergency monitoring programs when determining cost



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Table 3: Costing Template Example

Description	Unit	Unit Cost (USD)	Number	Sub-Total
A. Capital Expenditure				
Training of staff	Per training			
Mapping and identification of sentinel sites				
Tablets or phones for data collection	Per device			
FRC Colorimeters/ pool testers	Per device			
			Sub-Total	
B. Operating Expenditure				
Field reagents	Per month			
Allowance	Per month			
Lab consumable costs (if lab testing included)				
			Sub-Total	
C. Direct Support Expenditure				
Management of Water Quality Program (staff time ~10%)	Per month			
Transport for site visits	Per month			
Mobile data/ internet	Per month			
Internet in Office	Per month			
Lab analysis costs (if lab testing included)				
Airtime	Per month			
			Sub-Total	
			One-off costs (A)	
			Monthly costs (B+C)	

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Sustainability

When creating an emergency water quality monitoring program, it is important to determine what the objectives will be once the emergency moves from the acute phase to the recovery phase. If the aim is for the same program or a scaled down version of the water quality monitoring program to continue after the acute emergency ends, considerations should be made to ensure this is possible. First, to ensure sustainability, those staff who are responsible for routine water quality monitoring during and after emergencies should be trained and included in the emergency program. This will allow for strengthening of the existing workforce and enable continuity of work. Second, partners will have to determine if the same water quality parameters should be tested for (step 2), whether the number of sampling sites needs to remain the same, or decrease (step 3), and whether the frequency of sampling should remain the same or decrease (step 4). Third, it will also be important to consider how the program will be supported financially after the emergency transitions to the recovery phase.

Key Takeaway – Sustainability

Determine factors that may change within the water quality monitoring program when the emergency transitions to the recovery phase. Plan for these in advance so that a scaled down version of the program can continue in the recovery phase. Consider who will conduct the monitoring both in the short term and the long term. Determine if the frequency of testing or number of sampling locations will decrease over time.

Water Quality Monitoring as a Prevention or Preparedness Activity

Unique considerations are required when implementing a water quality monitoring program as part of preparedness or prevention activity. When creating a prevention or preparedness monitoring program there is less urgency than during an outbreak or other type of emergency. As a result, there may be delays in planning, identifying resources and staff, monitoring, and determining processes for data visualization and corrective action. Ensuring sustainability is paramount when creating a water quality monitoring program for preparedness purposes.



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Preventative Water Quality Monitoring Example from Zanzibar

Zanzibar experienced 17 major cholera outbreaks between 1978 and 2008. A recent outbreak ended in 2017.

There are several water, sanitation, and hygiene (WASH) challenges facing Zanzibar that increase the risk of cholera transmission. In 2019, the Government of Zanzibar launched the multi-sectoral Zanzibar Comprehensive Cholera Elimination Plan (ZACCEP) with the aim of making Zanzibar cholera free by 2028. In 2021, to support the ZACCEP prevention pillar, CDC, UNICEF, and the Zanzibar Water Authorities (ZAWA) started collaborating on a water quality monitoring project. At the start of the project, ZAWA estimated that the piped network coverage in Zanzibar was at 62% and the remaining population in Zanzibar depended on informal water vendors, boreholes, and other water sources. ZAWA, CDC, and UNICEF worked to establish a regular water quality monitoring system. The team mapped all ZAWA distribution tanks in which water is chlorinated and identified sampling locations close to treatment points and further down the system. Sampling points were first identified in the five districts with cholera hotspots and later in all districts of Zanzibar.

Since the start of the program, areas of the piped water network that are chlorinated have been monitored weekly to ensure adequate water treatment and ensure remedial action is taken to ensure water provided is treated to the appropriate levels. All data is now collected in mWater and ZAWA has been trained on how to collect, collate, and analyze results. CDC created a monitoring and reporting dashboard so that government partners are able to quickly track results and complete corrective actions. Example remedial actions include, identifying when HTH is running low, adjusting the manual chlorination dose at a treatment tank, or increasing dosing so that sampling points further down the line are receiving water treated to the appropriate levels. Data is reviewed weekly, and partners meet every two weeks to review data and identify corrective actions. After the program started, it took approximately 6 weeks for reliable monitoring to start, and about 12 weeks for residual chlorine to be at least 0.2 mg/L at all sampling locations.

Common Challenges

There are common challenges that have been faced when establishing a water quality monitoring system. The first challenge is the perceived sensitivity of water quality monitoring data and sharing of data. It is important to determine at the onset of the monitoring plan who will be able to view data in order to plan for corrective actions and whether it will be shared with end users. Second, corrective actions needed to fix water points and improve water treatment require funding. When patterns are noted in water quality monitoring results, the patterns can be used to advocate for improvements. Third, as mentioned earlier, planning for what happens to the monitoring plan after the emergency ends is important to ensure sustainability. Often water quality monitoring is prioritized as an emergency activity, but planning should be done to ensure it can continue as the emergency transitions. Fourth, coordination between partners and stakeholders involved in the water quality monitoring program can be a

challenge. Efforts should be made to ensure those conducting the monitoring and those making corrective actions are coordinated.

WATER QUALITY MONITORING IN DIFFERENT CONTEXTS



Chlorinated Centralized Level (Piped Network)

Piped water networks, which allow for the provision of water to many end users, may vary by the water source and of the size of the population served, which can range from a few households to a large city. Chlorine is a common method of disinfection and may be used at the water treatment facility and/or at booster stations along the distribution system. In other systems, each reservoir is chlorinated separately. In

chlorinated systems, routine testing of FRC levels is essential to ensure the continued provision of safe water during emergencies and to prevent waterborne disease outbreaks throughout the piped network.

Key Takeaway –

In centralized piped water systems, FRC can be difficult to maintain, especially at the collection points furthest from treatment. This may be due to chlorine consumption from organic matter in the pipeline (e.g., biofilm) or contamination entering the distribution system due to low pressure or leaks (Elala, 2021).

During outbreaks and emergencies, the recommended FRC level is 1.0 mg/L for drinking water at taps (e.g. community tapstands) connected to piped networks (WHO 1993). Outside of outbreaks or emergencies, the recommended FRC range is 0.5-1.0 mg/L at a community tapstand connected to a piped network. Higher FRC levels, where drinking water is consumed soon after collection, may lead to rejection due to smell or taste, so monitoring plans should include recommendations for corrective actions both when FRC is too low or too high.

Centralized piped water networks are crucial for providing safe water to numerous end users. Chlorine is commonly used for disinfection in these systems, necessitating routine testing of FRC levels to ensure water safety, particularly during emergencies and disease outbreaks. Maintaining adequate FRC levels can be challenging in centralized systems, especially at points distant from treatment facilities, due to factors such as chlorine consumption from organic matter or contamination from low pressure or leaks. To address this, a comprehensive monitoring plan is essential, consisting of several key steps:

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Step 1: Establish the purpose and objectives of the monitoring plan. The objective of an emergency water quality monitoring program of a piped network should include ensuring continued provision of safe water by monitoring water quality at various points in the network, from the point of treatment to the furthest point in the piped network.

Step 2: Water Sources and Water Quality Tests. If the piped network is chlorinated, testing for FRC on site should be prioritized. When there is damage to the network or other potential sources of contamination or undetectable FRC, microbiological testing may be warranted on an ad hoc basis according to need, resources, and time. If *E. coli* or fecal coliforms are detected in a piped water network post-treatment, contamination may be entering the piped water network and may not be indicative of contamination at the piped water source. When introducing a new source to the piped network, comprehensive water quality testing is recommended, including testing for microbiological, physical and chemical parameters, such as arsenic, fluoride, manganese, nitrates, nitrites, aluminum, and/or zinc, to ensure the source is safe for the population. During an acute emergency some chemical tests may be conducted subsequently to ensure the continued provision of safe water.

When the piped network is not chlorinated, Microbiological testing should be conducted, along with turbidity and other physiochemical tests; however, all efforts should be made to begin chlorination of the piped network as quickly as possible. In addition, it may be necessary to monitor turbidity levels. In a piped network, if the turbidity levels exceed 1 NTU, microbiological testing may be warranted.

Step 3: Selection of Sampling Sites. Multiple points should be included in a piped network monitoring system. The number of points depends on the length of the distribution system, the number of supplemental tanks and sites of additional treatment after the water treatment plant, overall number of connections, and the geographic area the piped network covers. At minimum, FRC should be tested at the point of treatment immediately following chlorination, at tapstands nearest to the point of chlorine treatment where levels are likely to be the highest, and at tapstands the furthest point from treatment where levels are likely to be the lowest (WHO 1997). Additional sampling sites should include before and after chlorine boosting sites, locations of low pressure in the network, and at the end of the distribution network. Finally, if there is an outbreak and a spatial clustering of cases, additional sampling sites should be included in this area to determine if there is a potential source of contamination within the piped network and to ensure safe water is available to the affected population.

Step 4: Frequency of Sampling. When first starting a piped network water quality monitoring plan and during the acute stage of an emergency or outbreak, it is important to test FRC daily to ensure water treatment levels are appropriate and that no corrective action is needed. Once FRC levels stabilize it would be appropriate to reduce the frequency. Microbiological testing can supplement if turbidity is high or if no FRC is detected or when new water sources come online.

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Step 5: Sanitary Inspection. A sanitary inspection may be done at the water source(s) (e.g., borehole, spring box, or surface water intake) providing water to the network as well as at points throughout the network. This is particularly important where there is an acute threat to the water supply/systems or after a natural disaster when there is damage, or if other concerns of source contamination arise.

Step 6: Data Collection and Interpretation of Results and Dissemination. It is important to determine who will oversee data collection and how this information will be shared with those managing the treatment plant and distribution system for regular review and corrective action.

Data collected should be presented at defined time intervals, for example daily or weekly. It is also important that values detected are recorded for all parameters tested. These raw values can be categorized later during analysis. Indicators that are important to include are as follows.

- Total number of sentinel sampling points that will be routinely visited
- GPS Coordinates of sampling points, if feasible
- Number of points visited during the time interval of interest
- Type of point visited (water treatment tank, community tapstand, household tap, etc.)
- Number (%) of points visited that had water available for sampling
- FRC levels detected
 - Number (%) of points with water available with FRC in the recommended range, for example following the data break points below:
 - < 0.1 mg/L (no detectable FRC)
 - 0.1 - < 0.2 mg/L
 - 0.2 - < 0.5 mg/L
 - 0.5 – 1.0 mg/L
 - > 1.0 mg/L *
- Other parameters of interest collected at the same time

*It is also possible that you want to track high FRC reading > 2.0 mg/L for taste or other treatment concerns

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Where applicable, results may be further broken down by locations in the piped network, including water treatment plant, booster stations, community tapstands, or household taps. The traffic stoplight colors can be used to indicate whether results are in the recommended range. Sample data collection forms are included in Appendix C.

Spatial reporting may be useful to identify potential sources of contamination but may be limited to showing results from one testing period per map. Dashboards can be created to show spatiotemporal water quality results. During an emergency, FRC testing should be conducted and reported daily until levels are stabilized and then may be done less frequently.

Below are example table shells for both daily and weekly reporting, in addition to spatial reporting.

Daily and Weekly Reporting Examples

Table 5: Example Table Shells for Daily FRC Reporting (Sampling from a piped network)

Daily Reporting							
Location	Total Visits	Water Available for Sampling	Number of Samples (%) < 0.1 mg/L	Number of Sample (%) 0.1 - < 0.2 mg/L	Number of Samples (%) 0.2 - < 0.5 mg/L	Number of Samples (%) 0.5 - 1.0 mg/L	Number of Samples (%) >1.0 mg/L
Treatment Tank	5	4 (80%)	0 (0%)	0 (0%)	1 (25%)	3 (75%)	0 (0%)
Community Tapstands	76	70 (92%)	5 (7%)	1 (1%)	53 (76%)	11 (16%)	0 (0%)
Total	81	74 (91%)	41 (36%)	0 (0%)	31 (27%)	28 (25%)	0 (0%)

Key Takeaways

Daily and Weekly Reporting:

- Determine a target number of sites that need to be visited per day or per week.
- Conduct frequent monitoring (daily if possible) at the onset
- Reduce monitoring frequency once consistent levels of chlorine are observed.

Spatial Reporting:

- Ensure sampling points are at key points geographically so that spatial trends can be detected over time and interventions can be targeted to areas of concern.
- If monitoring a centralized system, include points close to and further away from points of treatment.

Table 6: Example Table for Piped Network Results

Piped Network Results: Oct 19, 2024 to Oct 19, 2024															
	# sites visited	Water available		% water available	Free Residual Chlorine (mg/L)						% <0.1 mg/L	% 0.1 - <0.2 mg/L	% 0.2 - <0.5 mg/L	% 0.5 - 1.0 mg/L	% > 1.0 mg/L
		Yes	No		<0.1 mg/L	0.1 - <0.2 mg/L	0.2 - <0.5 mg/L	0.5 - 1.0 mg/L	>1.0 mg/L	None					
Piped network sampling point	36	33	3	92%	0	0	22	11	0	0	0%	0%	67%	33%	0%
Treatment tank	4	4	0	100%	0	0	1	2	1	0	0%	0%	25%	50%	25%
Summary	40	37	3	93%	0	0	23	13	1	0	0%	0%	62%	35%	3%

Table 7: Example Table Shells for Daily and Weekly FRC Reporting (Sampling from a piped network)

Daily Reporting							
Location	Total Visits	Water Available for Sampling	Number of Samples (%) < 0.1 mg/L	Number of Sample (%) 0.1 - < 0.2 mg/L	Number of Samples (%) 0.2 - < 0.5 mg/L	Number of Samples (%) 0.5 - 1.0 mg/L	Number of Samples (%) >1.0 mg/L
Week 1: Treatment Tank	32	32 (100%)	4 (13%)	0 (0%)	7 (22%)	21(66%)	0 (0%)
Week 1: Community Tapstands	456	441 (97%)	44 (10%)	11 (2%)	276 (63%)	110 (25%)	0 (0%)
Week 1 Total	488	473 (97%)	48 (10%)	11 (2%)	283 (60%)	131 (28%)	0 (0%)
Week 2: Treatment Tank	33	33 (100%)	1 (0.1%)	0 (0%)	4 (12%)	24 (73%)	0 (0%)
Week 2: Community Tapstands	459	443 (97%)	7 (2%)	1 (0.1%)	290 (65%)	145 (33%)	0 (0%)
Week 2 Total	493	473 (96%)	8 (2%)	1 (0%)	294 (62%)	169 (36%)	0 (0%)

*FRC ranges used for reporting may vary depending on types of chlorine testers. With pool testers where there is a minimum detectable level, it is important to distinguish results where there is no detectable FRC and those where the results show some color change less than the minimum detectable level.



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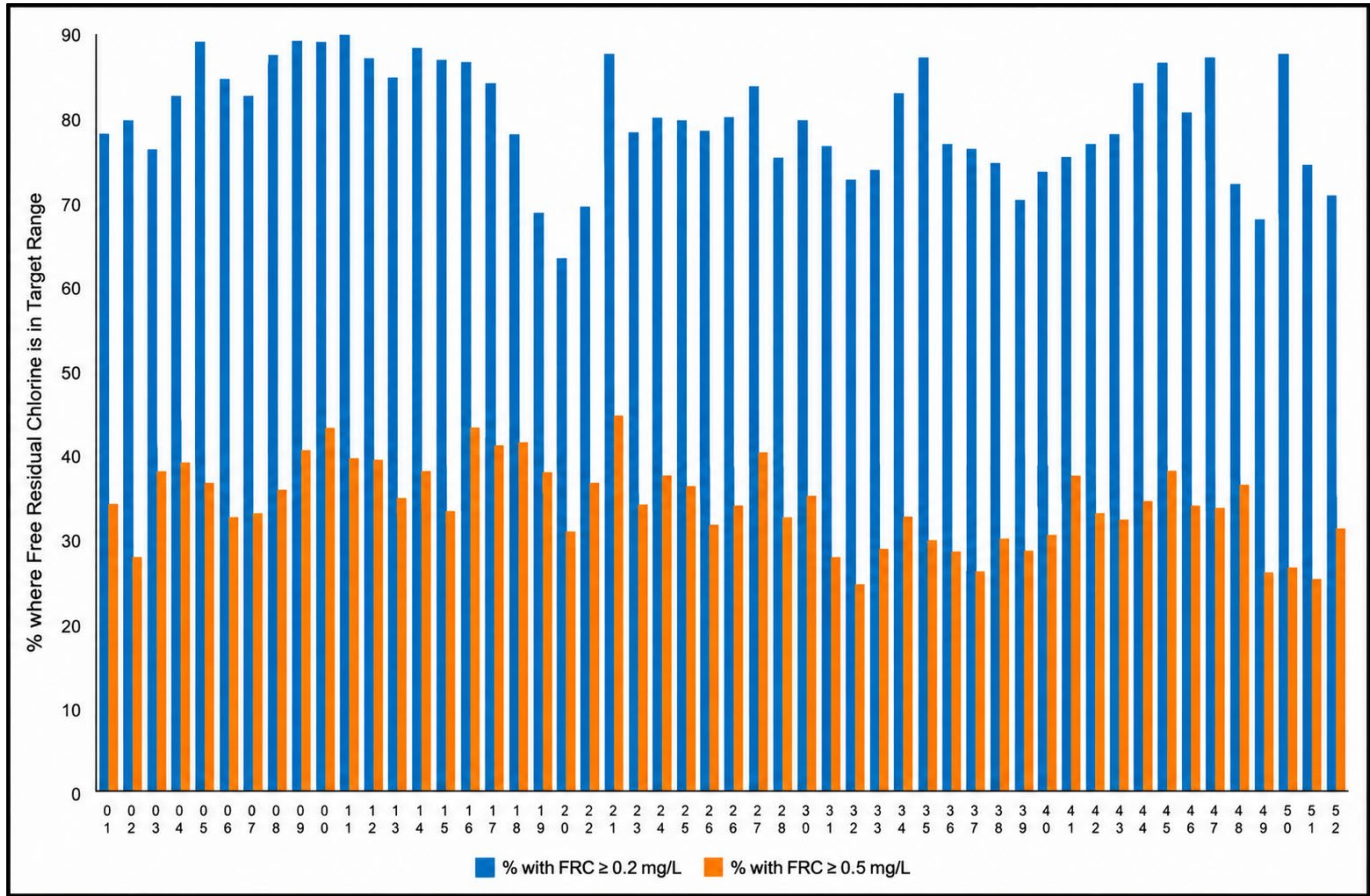


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Table 8: Example of Piped Network Results from May 27 to June 2, 2024

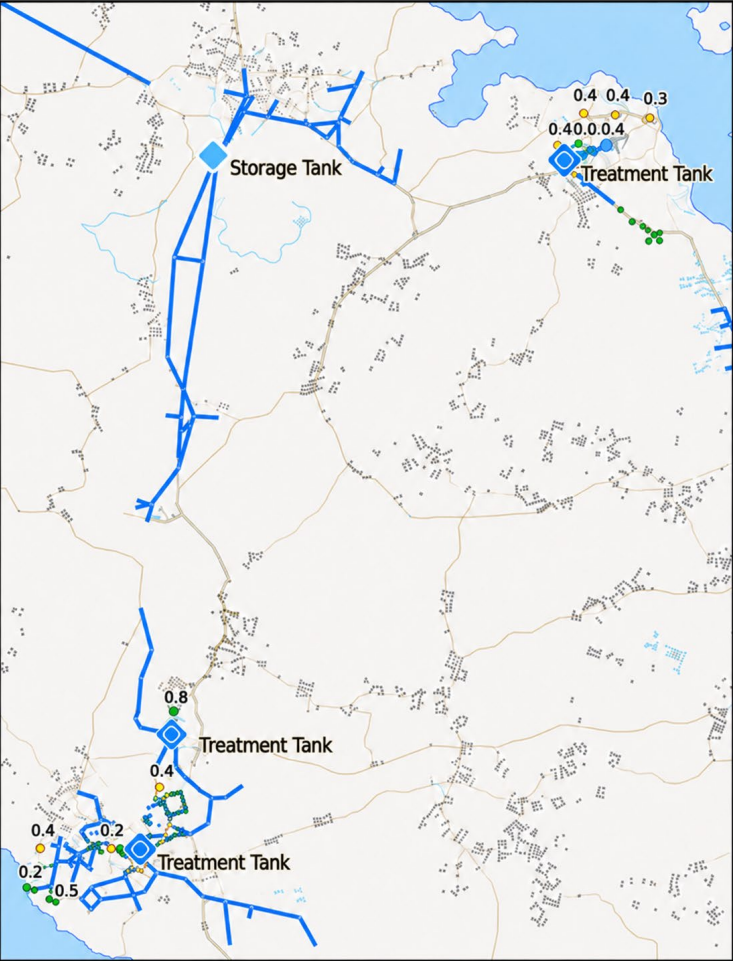
Piped Network Results: May 27, 2024 to Jun 2, 2024															
	# sites visited	Water available		% water available	Free Residual Chlorine (mg/L)						% <0.1 mg/L	% 0.1 - <0.2 mg/L	% 0.2 - <0.5 mg/L	% 0.5 - 1.0 mg/L	% > 1.0 mg/L
		Yes	No		<0.1 mg/L	0.1 - <0.2 mg/L	0.2 - <0.5 mg/L	0.5 - 1.0 mg/L	>1.0 mg/L	None					
Piped network sampling point	76	73	3	96%	0	0	36	37	0	0	0%	0%	49%	51%	0%
Truck filling station	0	0	0	-	0	0	0	0	0	0	-	-	-	-	-
Treatment tank	8	8	0	100%	0	0	0	7	1	0	0%	0%	0%	88%	13%
Storage tank	0	0	0	-	0	0	0	0	0	0	-	-	-	-	-
Summary	84	81	3	96%	0	0	36	44	1	0	0%	0%	44%	54%	1%

Figure 1: Example of Weekly Monitoring Trends Over the Course of One Year



Step 7: Corrective Actions. Based on data collected, stakeholders in charge of both water quality testing and managing water treatment should review data regularly and meet periodically to decide if corrective action is required. During an acute emergency, these meetings may take place daily or multiple times per week. Adjustments to chlorine dose should be made if FRC levels are detected below or above the recommended level. If FRC levels are below recommended levels at specific points in the distribution system, additional investigation and action may be needed. For example, if there are breaks in the network, these will need to be repaired; if no breaks have been identified, additional interventions may be necessary such as booster chlorination stations to increase levels. Once the FRC levels are stabilized, the frequency of data review and meetings may be adjusted.

Figure 2: Piped Water Network and Sampling





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Piped Network Water Quality Monitoring Example:

After Cyclone Idai and subsequent cholera outbreak in Mozambique, government and humanitarian partners collaborated to create a mobile phone-based water quality monitoring and reporting program to monitor daily free chlorine residual (FRC) levels in the piped network in the city of Beira, Sofala Province. Water quality monitoring data were collected and analyzed daily and summarized three times per week both quantitatively and spatially. This information was sent to all emergency collaborators on this project who met regularly to discuss results and plan remediation strategies based on results.

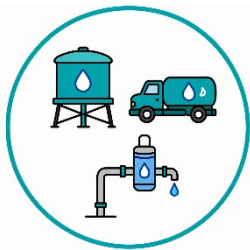
Overall, 87% of the 1,080 samples from the piped network had detectable FRC, and 46% of the samples were in the recommended range for FRC: 0.5-1.0 mg/L. Daily FRC levels in the piped network remained relatively consistent during the week, with lower FRC detected over weekends; 78% of weekend samples had detectable FRC versus 87% of weekday samples. Analyzing data from this water quality monitoring program descriptively and spatially allowed for the identification of several trends that helped increase the effectiveness of the emergency response, including identifying areas where booster chlorination stations could be installed, locations with potential network line breaks, issues with the consistency of daily chlorine treatment, and locations where water availability was limited and needed to be increased.

If immediate treatment of the piped network is not feasible or if adequate levels of FRC cannot be obtained throughout the distribution system, emergency tanks and/or household chlorination campaigns may be considered as immediate corrective actions (WHO, 2017b).

Table 9: Summary of Steps for Centralized Level Piped Network

Step	Description
 1	Establish purpose and objectives of the monitoring plan.
 2	Prioritize FRC testing in chlorinated systems. Conduct microbiological testing when necessary (ex when FRC < 0.1 mg/L).
 3	Include comprehensive testing when introducing new water sources. Monitor turbidity levels and conduct microbiological testing if exceeding thresholds.
 4	Select multiple sampling sites, considering system length and coverage area. Daily and Weekly Reporting: • Determine a target number of sites that need to be visited per day or per week. • Conduct frequent monitoring (day if possible) at the onset • Reduce monitoring frequency once consistent levels of chlorine are observed. Spatial Reporting: • Ensure sampling points are at key points geographically so that spatial trends can be detected over time and specific geographic locations that need interventions can be located. • For a centralized system, include points close to and further away from points of treatment.
 5	Conduct sanitary inspections around water sources providing water to network, especially after disasters.
 6	Test FRC daily during emergencies; adjust frequency as chlorine levels stabilize. Conduct microbiological testing when necessary (ex when FRC < 0.1 mg/L). • Total number of sampling points • GPS Coordinates of sampling points, if feasible • Number of points visited during the time interval of interest • Type of point visited (water treatment tank, community tapstand, household tap, etc.) • Number (%) of points visited that had water available for sampling ○ Number (%) of points with water available with FRC in the recommended range, for example following the data break points below: ▪ < 0.1 mg/L (no detectable FRC) ▪ 0.1 - < 0.2 mg/L ▪ 0.2 - < 0.5 mg/L ▪ 0.5 – 1.0 mg/L ▪ > 1.0 mg/L Other parameters of interest collected at the same time
 7	Collect and interpret data, sharing with relevant stakeholders. Review data regularly to identify corrective actions. Adjust chlorine dosage and implement additional measures as necessary.

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Chlorinated Decentralized Water Sources and Access Points (e.g., water storage tanks, water trucks, bucket chlorination, and inline chlorinators)

During emergencies, provisional point-of-collection water points, such as storage tanks, bladders, kiosks, and water trucks, are commonly set up to increase availability of water. Wherever possible, these points of collection should be disinfected and FRC should be monitored to prevent and control outbreaks of waterborne disease. Additionally, some boreholes and wells may be chlorinated, either with bucket chlorination or inline chlorinators, and should also be monitored. Point-of-collection locations such as storage tanks, bladders, kiosks, and water trucks are common water sources during emergencies. One-off disinfection of wells with chlorine is not recommended, as it is temporary measure and provides a false sense of security. Wherever possible, efforts should be made to disinfect water at the point of collection and to monitor FRC to prevent and control outbreaks of waterborne disease. In this section we provide recommendations for creating a water quality monitoring plan for chlorinated decentralized water sources in the community where FRC monitoring is emphasized. The Untreated Decentralized Water Sources section provides additional information on developing a monitoring plan for untreated water sources.

Step 1: Establish the purpose and objectives of the monitoring plan. The main objectives of an emergency water quality monitoring program targeting chlorinated decentralized water sources should be to ensure that all water sources are treated and have adequate and consistent FRC levels. The recommendations in this section are provided by water source type. It is also important to determine who will collect data and how this information will be shared with those managing the community level water sources as well as any relevant regulatory body or local authority.

Step 2: Water Sources and Water Quality Tests. Where possible, chlorination of water sources should be prioritized during emergencies and routine FRC testing should be implemented at all chlorinated water sources. Supplemental microbiological testing may be recommended where there is concern of potential contamination, where outbreaks are occurring, and where FRC levels are undetectable.

Step 3: Selection of Sampling Sites. Sampling sites at point-of-collection water sources will depend on the source type included in the monitoring program.



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Water storage tanks. All chlorinated tanks should be included in the FRC monitoring system, if feasible and if resources are available. If resources are not available to test all tanks, a representative random sample of storage tanks could be selected. If there are outbreaks occurring or clustering of waterborne disease, all storage tanks in these affected areas should be selected. Purposively sampling could also be used to select tanks in high-risk areas or tanks serving large populations and that are frequently refilled.

Water trucks. When water trucks are used during an emergency, FRC should be monitored. If the source water at the truck filling station is chlorinated, FRC testing may be conducted at the station source water prior to filling to ensure proper treatment. If water is treated in the truck tank, FRC testing should be done at least 30 minutes after treatment. Sampling sites may include trucks at filling stations or end points where trucks deliver water, such as emergency storage tanks or bladders.

Boreholes. All boreholes with on-site chlorination should be included in the FRC monitoring system, whether through inline chlorinators, bucket chlorination or other point-of-collection chlorination programs. As with storage tanks, if resources are not available to test all boreholes, a representative sample of boreholes should be selected.

Figure 3: Water Storage Tanks



Image source: CDC, Tanzania

Step 4: Frequency of Sampling. The frequency of sampling will depend on the emergency type and water source included.

- **Water storage tanks.** When first starting a water quality monitoring program for treated water storage tanks, it is important to test FRC levels daily to ensure water treatment levels are appropriate and that no corrective action is needed (MSF, 2010). Where tanks are filled and batch chlorinated more than once a day, testing FRC with each batch is recommended. Once FRC results stabilize it would be appropriate to reduce the frequency of monitoring.

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- **Water trucks.** During the acute emergency phase or when disease outbreak risk is high (or there is an on-going outbreak), testing water from all trucks is recommended, whether before or after filling. Before filling is preferred when chlorination is done at the source at a boosted dose. After filling is required when each truck is being treated manually, to ensure the correct dose is being applied to different volumes. Once the situation stabilizes, it may be possible to reduce testing and test a random selection of truck tanks if individual trucks and end points. However, particular care should be taken in situations where water is trucked from various sources as each water source may have different characteristics (e.g., temperature, turbidity, pH) that would affect the necessary chlorine dosage to achieve the target FRC. If unsure whether trucks are filling from approved sites, you may want to test trucks while they are delivering water to tanks or bladders to ensure the water has been treated to adequate levels or test water in tanks soon after delivery. Of note, testing should be done soon after delivery, as chlorine may diminish over time and not provide adequate information to correct chlorine dosing at filling stations or in truck tanks. If truck water is tested hours later or the next day the chlorine level may be low to provide enough information to adjust chlorine dosing.

- **Boreholes.** At boreholes with on-site chlorination FRC should be tested at the start of the emergency to ensure chlorination interventions are working and no corrective action is needed. Once FRC results stabilize it would be appropriate to reduce the frequency of monitoring.

When introducing any new borehole, it should be tested before use for microbiological and physiochemical water quality, where applicable. Microbiological testing can also be done ad hoc if there is concern of potential contamination. During the acute stage of the emergency, more frequent testing may be done, but this may be reduced as results stabilize.

Step 5: Sanitary Inspection. A sanitary inspection could be done around the boreholes and other point sources, including protected dug wells and springs included in a water quality monitoring program. Links to the sanitary inspection forms are on page 17. Sanitary inspections can be carried out regardless of whether the source is treated (e.g., through disinfection with chlorine).

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Step 6: Data Collection and Interpretation of Results and Dissemination. Data collected should be presented by water source type and include a defined time interval for reporting, for example daily or weekly. Indicators that are important to include are:

- Total number of points sampled by water source type
- Number of points visited during the time interval of interest by water source type
- Number (%) of points visited that had water available for sampling by water source type
- Number (%) of points with water available with FRC in the recommended range by water source type
 - The following data break points may be used: < 0.1 mg/L, 0.1 - < 0.2 mg/L, 0.2 - < 0.5 mg/L, 0.5 - 1.0 mg/L, and > 1.0 mg/L
- Number (%) of points with water available with *E. coli* at the following levels by water source type (where applicable)
- The following data break points may be used: <1 CFU/100ml meets standard, 1-10 CFU/100ml, 11-100 CFU/100ml, and > 100 CFU/100ml. Break points should follow local/national guidelines.

An example table shell is found in the *Chlorinated Centralized Level (Piped Network)* section for piped water networks for both daily and weekly reporting if daily FRC levels are collected. In addition, results can be shown spatially. However, spatial results may be limited to showing results or one testing period per map. Similar to piped water networks, dashboards can be created to show spatiotemporal water quality results.

Step 7: Corrective Actions. Stakeholders responsible for monitoring and managing water points should review data regularly and meet periodically to see if corrective action is required. For decentralized water points, committees may oversee corrective actions. If FRC levels are below the recommended level, the managing body may need to adjust chlorine dose and carry out chlorine demand testing. If FRC levels are below recommended levels in a storage tank, this may be due to chlorine decay due to long storage time or sunlight. Corrective actions could include boosting chlorine or increasing frequency of water tank filing.



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Example of Monitoring at Decentralized Locations

In the fall of 2017, over 750,000 Rohingya refugees fled Myanmar to Cox's Bazaar where they moved into makeshift settlements. In early 2018, there was the need to improve chlorination to prevent cholera during the monsoon season. At this stage of the response water sources included tube wells and water storage tanks which were filled by water trucks that collected water directly from boreholes. Chlorine was added to the water trucks as they were filled to facilitate mixing. Bucket chlorination was started at the tube wells where a paid attendant dosed individual containers with a 1% chlorine solution prepared daily. A FRC monitoring system was put into place. FRC was regularly tested from the following locations.

- From water storage containers treated via bucket chlorination, after waiting 30 mins (required minimum contact time) to ensure FRC ≥ 0.5 mg/L
- From water collected from the decentralized storage tank receiving trucked water to ensure FRC ≥ 0.5 mg/L (point of collection recommended minimum after at least 30 minutes contact time)
- From a selection of household stored water containers collected from any of the chlorinated water sources to ensure that FRC was ≥ 0.2 mg/L (point of use recommended minimum after at least 30 minutes contact time)

The results were used to help fine tune chlorine dosing and ensure presence of bucket chlorination attendants.

If *E. coli* or fecal coliform testing is conducted and levels are low, between 1 to 10 CFU or MPN/100mL, repeat testing should be conducted to further assess contamination. If levels are higher than 10 CFU or MPN/100mL, treatment should be considered or alternative sources may be used (Wisner 2002, WHO 2017b). Also consider repeat testing for low levels and consider treatment and/or find alternative sources. Based upon the results, it may be necessary to conduct repairs to the infrastructure (i.e. rebuild apron) and/or treat the source, or it may be necessary to discontinue access to this source and alternative sources may be used (Wisner 2002, WHO 2017b). Further, after water point repairs or shock chlorination are implemented repeat sampling to monitor for recontamination.

Table 10: Summary of Steps for Chlorinated Decentralized Water Sources

Step	Description
 1	Establish purpose and objectives of the monitoring plan.
 2	Prioritize FRC testing at points of chlorination such as at bucket chlorination points, chlorinated tanks, or water trucks that are chlorinated. Conduct microbiological testing when necessary (ex when FRC < 0.1 mg/L).
 3	When introducing any new borehole, it should be tested before use for microbiological and physiochemical water quality, where applicable. Microbiological testing can also be done ad hoc if there is concern of potential contamination.
 4	Select multiple sampling sites, considering system length and coverage area. Daily and Weekly Reporting: • Determine a target number of sites that need to be visited per day or per week. • Conduct frequent monitoring (day if possible) at the onset • Reduce monitoring frequency once consistent levels of chlorine are observed. Spatial Reporting: • Ensure sampling points are at key points geographically so that spatial trends can be detected over time and specific geographic locations that need interventions can be located. For a centralized system, include points close to and further away from points of treatment.
 5	A sanitary inspection could be done around the boreholes and other point sources, including protected dug wells and springs included.
 6	Data collected should be presented by water source type and include a defined time interval, for example by day or by week. Indicators that are important to include are: • Total number of points sampled by water source type • Number of points visited during the time interval of interest by water source type • Number (%) of points visited that had water available for sampling by water source type • Number (%) of points with water available with FRC in the recommended range by water source type ○ The following data break points may be used: < 0.1 mg/L, 0.1 - < 0.2 mg/L, 0.2 - < 0.5 mg/L, 0.5 - 1.0 mg/L, and > 1.0 mg/L • Number (%) of points with water available with <i>E. coli</i> at the following levels by water source type (where applicable) • The following data break points may be used: <1 meets standard, 1-10 CFU/100ml, 11-100 CFU/100ml, and > 100 CFU/100ml.
 7	Collect and interpret data, sharing with relevant stakeholders. Review data regularly to identify corrective actions. Adjust chlorine dosage and implement additional measures as necessary.

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Untreated Decentralized Water Sources (e.g., boreholes, wells, etc.)

At some decentralized sources, such as boreholes and wells, it may not be feasible to treat at the point of collection and household water treatment may be recommended. In this section we provide recommendations for creating a water quality monitoring plan for untreated decentralized water sources in the community.

Step 1: Establish the purpose and objectives of the monitoring plan. Objectives of an emergency water quality monitoring program targeting untreated boreholes and wells should ensure the continued provision of safe water. It is also important to determine who will oversee collecting the monitoring data and how this information will be shared and used with those managing the community level water sources as well as any relevant regulatory body or local authority.

Step 2: Water Sources and Water Quality Tests. If water is not treated, routine *E. coli* or fecal coliforms testing may be conducted. Routine microbiological testing at all boreholes or shallow wells is resource intensive, and the number of sampling sites will largely depend on available resources, both financial resources and time of staff available. Shallow wells are more prone to more contamination. Where shallow wells are being used as a source of drinking water during an outbreak, it is recommended to implement household water treatment programs or consider alternative water sources over microbiological testing, as this would require extensive resources. Please see the next section on monitoring at the household level.

Step 3: Selection of Sampling Sites. Strategic sampling of boreholes in areas where there is a potential source of contamination or where epidemiological data shows cases of cholera or other waterborne diseases should be prioritized, followed by those in surrounding areas. As microbiological laboratory testing is resource intensive it is important to have a plan on how data will be collected and how results will be used. For example, in an emergency, if boreholes are determined to be contaminated it may be more resource effective to distribute household water treatment products to households in the affected area and set up a household water quality monitoring plan for FRC. Other options include setting up point-of-collection chlorination, such as bucket chlorination points or installing inline chlorinators, and conducting FRC monitoring at the water point (as described in previous section on Chlorinated Decentralized Water Points).



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Step 4: Frequency of Sampling. When introducing any new borehole or shallow well, it should be tested before use for microbiological and physiochemical water quality, where applicable. During the acute stage of the emergency, more frequent testing may be done, but this may be reduced as results stabilize during a prolonged emergency. At a minimum, *E. coli* or fecal coliforms should also be tested seasonally, namely at the start of rainy and dry seasons to assess any seasonal variation associated with rainfall. Source water microbiological testing could continue but much less frequently.

Step 5: Sanitary Inspection. A sanitary inspection could be done around the boreholes and other point sources, including protected dug wells and springs included in a water quality monitoring program. The Sanitary Inspections created by WHO in 2024 can be used to identify risks for contamination at specific water points.

Step 6: Data Collection and Interpretation of Results and Dissemination. Data collected should be presented by water source type and include a defined time interval for example by week. Indicators that are important to include are:

- Total number of points sampled by water source type
- Number of points visited during the time interval of interest by water source type
- Number (%) of points visited that had water available for sampling by water source type
- Number (%) of points with water available with *E. coli* at the following levels by water source type
- The following data break points may be used: <1 meets standard, 1-10 CFU/100ml, 11-100 CFU/100ml, and > 100 CFU/100ml

Step 7: Corrective Actions. Stakeholders monitoring and managing water points should review data regularly and meet periodically to see if corrective action is required. For decentralized water points, committees may oversee corrective actions. If *E. coli* or fecal coliform testing is conducted and levels are low, between 1 to 10 CFU or MPN/100mL, repeat testing should be conducted to further assess contamination. If levels are higher than 10 CFU or MPN/100mL, treatment should be considered or alternative sources may be used (Wisner 2002, WHO 2017b). If there is a large outbreak, continuous chlorination of water after collection or via in-line chlorination may be recommended. The results from the sanitary inspection can inform whether specific improvements or rehabilitation is needed (e.g. fixing a cracked borehole casing).

Table 11: Summary of Steps for Untreated Decentralized Water Sources

Step	Description
 1	Establish purpose and objectives of the monitoring plan targeting untreated boreholes and wells.
 2	If water is not treated, routine E. coli or fecal coliforms testing may be conducted. Routine microbiological testing at all boreholes or shallow wells is resource intensive, and the number of sampling sites will largely depend on available resources.
 3	Strategic sampling of boreholes in areas where there is a potential source of contamination or where epidemiological data shows cases of cholera or other waterborne diseases should be prioritized, followed by those in surrounding areas.
 4	When introducing any new borehole, it should be tested before use for microbiological and physiochemical water quality, where applicable. During the acute stage of the emergency, more frequent testing may be done, but this may be reduced as results stabilize during a prolonged emergency. At a minimum, E. coli or fecal coliforms should also be tested seasonally
 5	A sanitary inspection could be done around the boreholes and other point sources, including protected dug wells and springs.
 6	Data collected should be presented by water source type and include a defined time interval, for example by day or by week. Indicators that are important to include are: • Total number of points sampled by water source type • Number of points visited during the time interval of interest by water source type • Number (%) of points visited that had water available for sampling by water source type • Number (%) of points with water available with FRC in the recommended range by water source type ○ The following data break points may be used: < 0.1 mg/L, 0.1 - < 0.2 mg/L, 0.2 - < 0.5 mg/L, 0.5 - 1.0 mg/L, and > 1.0 mg/L • Number (%) of points with water available with E. coli at the following levels by water source type (where applicable) • The following data break points may be used: <1 meets standard, 1-10 CFU/100ml, 11-100 CFU/100ml, and > 100 CFU/100ml.
 7	Collect and interpret data, sharing with relevant stakeholders. Review data regularly to identify corrective actions. Adjust and implement additional measures, as necessary.

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Household Level

Household-level water quality monitoring can be conducted to assess contamination in stored household drinking water, either due to contamination from a water source or secondary contamination after water collection. It can also be used to evaluate whether a water treatment program is working – either at the point of collection, such as bucket chlorination or household water treatment programs. Monitoring can be used to evaluate whether household water treatment programs are improving household water quality and whether stored water is within the recommended FRC range. In this section we will go over the steps to consider when designing a water quality monitoring program at the household level.

Step 1: Establish the purpose and objectives of the monitoring plan. The objectives of an emergency water quality monitoring program targeting households will define the frequency of testing and the parameters included in the program. When there are distributions of household water treatment products, including chlorine products, coagulant/flocculants, or filters in emergency settings, post-distribution monitoring of usage and acceptability is required. Additional objectives could be determining the level of drinking water contamination at the household level and monitoring FRC levels in stored water after distributing household water treatment products. Where there is chlorination in piped water networks or at point-of-collection, it may be necessary to assess whether FRC levels are sufficient at the community level after water collection and household storage.

Step 2: Water Sources and Water Quality Tests. The water quality parameters to prioritize and include in the monitoring plan will depend on the objectives of the household water quality monitoring program. Some suggestions are listed below by potential objectives in Table 8. For evaluation of emergency household water treatment programs, the parameter of interest will depend on type of water treatment product. If chlorine products are distributed, FRC should be monitored. If filters are distributed, microbiological testing may be conducted, in addition to turbidity.

Step 3: Selection of Sampling Sites. At the household level, stored household drinking water can be tested. For post distribution monitoring of chlorine products, a representative sample of households should be selected from different areas to conduct FRC testing. We include one example in the pop out box on the next page. Include enough households to sample to provide an estimate of water treatment product use. If water treatment filters are distributed during an emergency, a sample of households may be selected to collect stored household water for microbiological testing for *E. coli*. This can be done pre and post filtration for programs using filters. As FIB testing is more resource intensive, the number of households to be sampled may be fewer than selected for FRC testing. Timing of monitoring is also important. Monitoring just after receiving products is useful to ensure proper use of products. To assess sustained use of water treatment products during an emergency, the team may conduct repeated visits, for example soon after distribution of products to determine if households are using them correctly and after one month or another defined period of time to determine if the product is still being used.

Table 12: Recommendations for Household Water Quality Monitoring Program during Emergencies / Outbreaks

	 Objective	 Water Sources	 Key Parameter	 Optional Parameters
1	 To assess emergency household water treatment programs using chlorine products	 Sample of households in geographic area of interest	 FRC (for household water treatment programs including chlorine products)	 E. coli, if no FRC detected or for household water treatment programs including filters or other non-chlorine products. - If there is concern about levels of iron, manganese, or arsenic in the area's drinking water, these parameters could be tested at a smaller scale on an ad hoc basis.
2	 To assess emergency household water treatment programs using filters	 Sample of households in geographic area of interest	 E. coli or fecal coliforms FRC, if also treated with chlorine Post-treatment turbidity, for filter distributions program	
3	 To understand whether a community-level water treatment program is dosing at the appropriate levels	 Sample of households in geographic area of interest	 FRC	
4	 To assess contamination in stored drinking water and to assess safe storage at the household level	 Sample of households in geographic area of interest	 E. coli or fecal coliforms - If the drinking water source is chlorinated or household water treatment products are used, FRC should also be tested	



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How many households should you sample from? *Here is one example.*

A. Background and Objective

Tropical Cyclone made landfall producing torrential rains and strong winds and severely affecting several provinces. Cholera is endemic to the cyclone-impacted region. A few weeks later a cholera outbreak was declared. As part of the cholera response efforts, several local non-government-organizations (NGO), provided households in cholera affected areas with chlorine products for household water treatment. The Post-Distribution Monitoring (PDM) Survey's objectives were to collect data on whether households received chlorine products in areas targeted, on household's knowledge of product use, and reported and confirmed use of the chlorine product to improve response efforts.

B. Timing of PDM

Ideally, PDM would start 1-2 weeks after receiving chlorine products to be able to understand use and document whether behaviors have changed. However, if you want to know if the product is lasting the full time period monitoring towards the end of targeted time period is also suggested.

C. Free Chlorine Residual Testing

Free Chlorine Residual (FRC) testing should be conducted at all households included in the PDM survey to confirm presence of residual chlorine. FRC testing will be used to better understand chlorine product use. Documentation of FRC test kit used should be included with data from the PDM surveys.

D. Household Selection

When collecting data at the household level we need to ensure that 1) households are not purposively selected and 2) an appropriate number of households are included in the selection. In order to capture a representative random sample of people that received chlorine products, it is recommended that partner organizations implement a systematic random sampling scheme for the PDM. With this approach, all households that received chlorine products have an equal likelihood of being selected for the PDM. This equal likelihood of inclusion in the survey, along with a high survey response rate, will help ensure that the final PDM data are representative of all households in the chlorine product distribution area.

This section describes recommendations for using systematic random sampling in the chlorine product PDM survey. Minimum samples sizes for the PDM based on the total number of households included in the Chlorine product distribution, are included in the next section.



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Systematic random sampling requires three steps:

1. The first step of systematic random sampling is to generate a random starting point in the total list of households.

Have a bag with numbers 1-20 written on pieces of paper. Randomly select a piece of paper to use as your random starting point. If 14 was selected, start with the 14th house from one edge of your catchment sampling area. If you go to another area to conduct PDM, randomly select a new number when you start in a new area to make sure there is no pattern in your selection of your starting point. Ex: It is unlikely that household 14 would be selected twice.

2. Next, determine the appropriate sampling interval. The sampling interval will depend on the desired sample size for the PDM (see Sections F for specific recommendation per sampling area) and is calculated by taking the total number of households and dividing it by the number of households that will be included in the sample.

For example, if 500 households received NFIs, and it is desired to survey 100 households (20% of households), the sampling interval is 5. This means every 5th household is visited and interviewed.

For example, if 1200 households received NFIs, and it is desired to survey 120 households (10% of households), the sampling interval is 10. This means every 10th household is visited and interviewed.

If the sampling interval is not a whole number, it should be rounded up to the nearest whole number.

3. The final step of systematic random sampling is to determine which households to include in the PDM. The list of eligible households starts with the first household identified at the random starting point (in our case the 14th household). Count every n th household to be surveyed, where n is the sampling interval. Households are counted until the total desired sample size is reached. Example if you are going to every 10th household make a check list for 10th, 20th, 30th, 40th household, etc.

If a selected household is unavailable at the first household visit, it is recommended that the field teams make at least three follow-up visits to the unavailable house. These visits should be conducted at three different times. Only after the three visits should the household not be included in the sample. Replacement sampling is not recommended. If a selected household is unavailable for the PDM visit, it is recommended that the field teams continue with the list of selected households (based on the sampling interval).



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E. Sample Size Recommendations

In large chlorine product distribution areas, where more than 1000 households received products, you should aim to include 10 percent of the households in the PDM survey. This could be done for instance after a whole geographic area has received chlorine product. Try to sample and collect data from different areas of the geographic area.

Medium NFI distribution areas, where between 100 and 500 households in an area received products, teams should aim to include 20 percent of households in the PDM survey. This sample size may be appropriate if doing PDM after a few areas have received products. If distributing in many small to medium catchment areas, the data from these smaller units should be aggregated to make a larger dataset.

F. Data Collection

Persons that distributed the chlorine products should not be responsible for collecting PDM data. Include and train other staff for this activity. However, those staff can lead data collectors to the areas where the product was distributed. Interviews should only be conducted with adults that consent to participate. Every effort should be made to interview the individual that collects and treats water as they will have the most knowledge on chlorine product use.

G. Data Reporting

In all areas where data was collected, organizations should list the sample size used and the justification for this size (ex: targeted unit A where all 1400 households in this unit were targeted with Chlorine product, thus we sampled 140 households at an interval of every 10th household).

Step 4: Frequency of Sampling. Monitoring at the household level does not need to be conducted as frequently as monitoring at the centralized level given the time and resources required to visit households. It could be done when first starting a program and on an ad hoc basis for post distribution monitoring purposes.

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Step 5: Sanitary inspection. If useful, a sanitary inspection could be done if households have a household water source on their compound, such as a borehole or shallow well, but this information may be more helpful to collect at the community level. Sanitary inspection forms can also be used to understand household practices of collection, handling, and storage of drinking water before and after any treatment which is performed by the household. These inspections can be an opportunity to directly observe the household treatment processes to identify any incorrect processes or risky behaviors (e.g. adding an insufficient concentration of chlorine, not allowing sufficient chlorine contact time, not bringing the water to a rolling boil; adding an insufficient concentration of chemical coagulants; using expired treatment chemicals, etc.) (WHO, 2024).

Step 6: Data Collection and Interpretation of Results and Dissemination. Data collected should be presented by a defined by how long it has been since the distribution of products and by geographic area. Indicators that are important to include are:

- Number (%) of households reporting household water treatment.
- Total number of households visited
- Number (%) of households with stored drinking water available for sampling
- Number (%) of household stored drinking water samples with FRC in the recommended range
 - The following data break points may be used: < 0.1 mg/L, 0.1 - < 0.2 mg/L, 0.2 - < 0.5 mg/L, 0.5 - 1.0 mg/L, and > 1.0 mg/L
- Number (%) of samples from stored household drinking water with E. coli at the following levels
 - The following data break points may be used: <1 meets standard, 1-10 CFU/100ml, 11-100 CFU/100ml, and > 100 CFU/100ml

Step 7: Corrective Actions. Based on data collected, stakeholders should meet periodically to see if corrective action is required.

- If FRC levels below the recommended level are detected, corrective actions could include increasing hygiene promotion efforts to educate household members on safe water storage, household water treatment, and proper dosing or use of distributed products. Where FRC levels are above recommended levels, it may be necessary to verify whether there is chlorination at the point of distribution or point of collection or to increase education on proper dosing. It is important to note also that if FRC is low it could be due to length of storage. Households might be dosing correctly but FRC levels are low due to time since treatment. To better understand this during monitoring include a question on when water was treated, also type of storage vessel (closed or open) used. Where FRC levels are above recommended levels, it may be necessary to verify whether there is chlorination at the point of distribution or point of collection or to increase education on proper dosing

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Where *E. coli* or fecal coliforms are tested and detected, corrective actions may include increased hygiene promotion on safe water storage and household water treatment. Additional efforts may be necessary to improve water quality at the source or to change the source.

Table 13: Summary of Steps for Household Level Monitoring

Step	Description
 1	Establish purpose and objectives of the monitoring plan. Define frequency of testing and parameters to be included.
 2	Prioritize water quality parameters based on monitoring objectives. Conduct FRC testing for household water treatment products with chlorine, microbiological testing if program uses filters, and turbidity assessment.
 3	Select representative sampling sites, including households with stored drinking water. Ensure geographic coverage and consider repeated visits for post-distribution monitoring to monitor use over time.
 4	Determine sampling frequency, considering resource constraints and monitoring objectives. Conduct initial monitoring and ad hoc sampling for post-distribution evaluation.
 5	Conduct sanitary inspections <i>if necessary</i> , focusing on household water sources.
 6	Collect and interpret data, presenting results by defined time intervals and geographic areas. Include indicators such as the number of households visited, percentage with stored water available, percentage with detectable FRC in stored water, and <i>E. coli</i> levels (If applicable).
 7	Review data periodically to identify corrective actions. Increase hygiene promotion efforts for low FRC levels or detected <i>E. coli</i> . Verify chlorination or increase education for high FRC levels. Implement additional measures to improve source water quality if necessary.

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Healthcare Facilities

Water quality is of utmost importance in healthcare facilities (HCFs) in emergency situations due to the increased vulnerability of the population and heightened risk due to the emergency. A water quality monitoring plan should be developed for each healthcare facility. This may be done in conjunction with assessment of the HCF, including services offered at the facility, population served, access to water, sanitation, hygiene, environmental cleaning, and medical waste management, and any special considerations. In this section, we go over the seven steps for setting up a water quality monitoring plan in HCFs. The information below is synthesized from WHO's *Essential Environmental Health Standards in Health Care* (2008).

Step 1: Establish the purpose and objectives of the monitoring plan. The objective of an emergency water quality monitoring program at the HCF is to protect the health of all patients, staff, and visitors and to ensure provision of safe water for drinking, as well as adequate quality for all services, medical procedures, environmental cleaning, and laundry. It is important to determine who will oversee collecting the monitoring data, if it will be available environmental health staff or others, and how this information will be shared with those managing the HCF for regular review and corrective action.

Step 2: Selection of water source types and water quality tests. HCFs may be served by a variety of water sources, including improved sources such as a piped network, on-site boreholes, rainwater, etc. The type of water quality tests to conduct will depend on which sources are found at the facility. All water sources used for drinking, medical services, procedures, and infant and child feeding programs should be included in monitoring plan.

Drinking water at HCFs should meet the national standards for drinking water and where applicable WHO guidelines for drinking water. If healthcare facility water is chlorinated FRC should be tested first. FRC protects recontamination of drinking water and thus the health of patients and healthcare workers. Control of microbial contamination is the most important objective for drinking water in healthcare facilities. Supplementary disinfection may be required if water is from a piped source, storage tank, or water tanker/truck or other source which has been previously treated with chlorine. Drinking water should contain a FRC between 0.5 mg/L and 1.0 mg/L in accordance with WHO Drinking Water Quality Guidelines.

Table 2: Recommended Targets of Physiochemical Parameters During Emergencies and Outbreaks

Recommended Targets for Water Quality Parameters			
During Emergencies and Outbreaks			
FREE RESIDUAL CHLORINE (FRC)		PHYSIOCHEMICAL PARAMETERS	
	FRC recommended to be ≥ 0.2 mg/L (ppm) at point of use during emergencies with normal to low risk of disease outbreaks	 pH6.5–7.5	
	FRC recommended to be ≥ 0.5 mg/L (ppm) at point of use during a waterborne disease outbreak	 Turbidity< 5 NTU (Ideally < 1 NTU)	
	FRC recommended to be 1.0 mg/L at tapstands	 Total Dissolved Solids (TDS)< 1000 mg/L	
	FRC recommended to be 2.0 mg/L at water trucks at filling	 Conductivity30–1500 $\mu\text{S}/\text{cm}$	
	FRC in drinking water should not exceed 5.0 mg/L (WHO); however, taste and odor may become noticeable at ≥ 2.0 mg/L	MICROBIAL INDICATORS	
		 <i>E. coli</i> < 1 CFU / 100 ml	
		 Fecal (Thermotolerant) Coliforms< 1 CFU / 100 ml	

Additional steps may be necessary to ensure adequate water quality for special purposes at healthcare facilities, such as renal dialysis or hemodialysis (Adams 2008). The range of possible water treatment options may be further limited since common disinfectants (e.g., chlorine and iodine) or coagulants (e.g., alum) may result in byproducts or residuals that exceed the standards. Testing for *E. coli* or thermotolerant bacteria is required if the drinking water is not chlorinated or if there is no detectable FRC. No drinking water sample should contain a detectable amount of *E. coli* or thermotolerant bacteria in a 100 mL sample. Additionally, all drinking water should be treated with a disinfectant to prevent recontamination.

Physical parameters should meet national and/or WHO guidelines. Turbidity is a major parameter of concern as it will interfere with disinfection. Simple techniques such as filtering can reduce turbidity below 5 NTUs. A simple turbidity tube may be used in low resource environments. Other physical parameters should attempt to meet national or WHO guidelines and not dissuade users because of odor, taste, or smell. If users find the water unpalatable, they may look to other unsafe sources of water.

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Water used for cleaning, laundry, and handwashing may be lower in quality than drinking water if water is used with a detergent or disinfectant. However, if water is used for multiple purposes including drinking, the water should meet drinking water standards.

Steps 3-7: The remaining steps in developing a water quality monitoring plan at healthcare facilities will vary depending on water source type at the facility. See sections titled, Chlorinated Centralized Level, Chlorinated Decentralized Water Sources and Access Points, and Untreated Decentralized Water Sources and Access Points for recommendations on piped water networks, chlorinated decentralized water points, and untreated water points.

Table 14: Summary of Steps for Healthcare Facilities

Summary of Steps for Healthcare Facilities	
Step	Description
 1	- Establish purpose and objectives of the monitoring plan. - Define the objective of protecting the health of patients, staff, and visitors by ensuring provision of safe water for drinking and all medical services. - Determine who will oversee data collection and how information will be shared for regular review and corrective action.
 2	- Identify water source types and conduct water quality tests accordingly. - Include all water sources used for drinking, medical services, procedures, and infant/child feeding programs. Test for FRC in drinking water between 0.5 mg/L and 1.0 mg/L. - Test for <i>E. coli</i> if FRC is not detectable. - Ensure water quality meets WHO or national guidelines for chemical, and physical parameters.
 3-7	Follow steps 3-7 from the water quality monitoring in the different contexts section based on the type of water source at the healthcare facility used for drinking water. These steps include selection of sampling sites, frequency of sampling, conducting sanitary inspections, data collection and interpretation, and implementation of corrective actions.

CASE STUDIES

WATER QUALITY MONITORING DURING A CHOLERA OUTBREAK—HARARE, ZIMBABWE

We would like to acknowledge Varaidzo Mavetera, John Manyara, and Chipso Muwombi from the City of Harare Health Department for their contributions to the case study.

In this section, we will go over one water quality monitoring case study. The case study will go through the seven steps of creating a water quality plan and will show data that was collected and how it was analyzed and visualized. There will also be a brief description of the corrective actions as a result of the monitoring program. Table 11 briefly reviews the seven steps on creating a water quality monitoring program.



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Table 15: Water Quality Monitoring Template for Case Studies

Step		Checklist Items	Status
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	 2	• Prioritize water quality parameters based on objectives and available resources. • Prioritize Free Chlorine Residual (FRC) testing during emergencies and outbreaks, where applicable. • Consider testing for <i>E. coli</i> or fecal coliforms to assess fecal contamination risk. • Measure turbidity, temperature, and pH to evaluate water quality and chlorine effectiveness. • Perform chemical testing as necessary, considering specific emergencies and local conditions.	
	 3	• Complete an inventory of all water sources. • Select representative sampling sites based on objectives. • Decide between fixed and random sites based on monitoring purpose. • Prioritize sites in areas of waterborne disease outbreaks or clusters.	
	 4	• Determine sampling frequency based on water source type, test requirements, and available resources • Sample drinking water more frequently during emergencies and outbreaks. • Test new water supplies before consumption and regularly where batch chlorination is utilized. • Repeat testing for microbiological and chemical contamination as needed.	
	 5	• Conduct sanitary inspections to identify contamination sources and assess risk factors. • Combine survey findings with water quality test results to determine risk scores. • Integrate surveys into monitoring programs to engage and empower the community.	
	 6	• Analyze data to make informed decisions and protect public health. • Ensure consistency in testing methods and reporting forms among organizations. • Define responsibilities for data analysis and report generation. - Share results with stakeholders promptly. • Use geospatial data to target sampling activities during outbreaks. • Disseminate results to the community and stakeholders with interpretation and recommendations.	
	 7	• Respond promptly to issues identified during monitoring. • Establish clear thresholds for triggering corrective actions. • Define responsible parties for implementing corrective measures.	

Background: Water Quality Monitoring During a Cholera Outbreak in Harare, Zimbabwe

Chlorination of drinking water supplies during a cholera outbreak is a high priority. During a cholera outbreak, the World Health Organization (WHO) recommends Free Chlorine Residual (FRC) levels of at least 0.5 mg/l at the point-of-use and 1.0 mg/l at tapstands (WHO, 1993). In addition, routine monitoring of FRC levels is recommended to ensure continued water safety (WHO, 2017).

Harare Water provides municipal piped water to the city of Harare. The raw water used in the piped network comes from two sources, Lake Chivero and Seke dam (Prince Edward). There are two water treatment plants in Harare – Morton Jeffrey and Prince Edward. Treatment processes at the plants include flocculation/sedimentation, pH adjustment, and chlorine disinfection (ESAG, 2018). Upon treatment, water is pumped to elevated reservoirs around the city. The water then gravitates to consumers throughout the piped network. Harare Water reports to boost chlorination at select reservoirs and pump stations around the city.

The city of Harare faces challenges with their municipal water system. First, the City of Harare's water demand is currently greater than what the two treatment plants are designed to produce. It has been estimated that even if the treatment plants were able to operate at design capacity, there is insufficient supply to meet current population demand. Therefore, households that have municipal water also use other water sources such as boreholes and shallow wells. Second, due to aging infrastructure and frequent pipe bursts, water losses from the piped network are projected to be 60.7%. Third, water availability is low. A rapid assessment conducted by ESAG in 2018 in the suburbs of Harare most affected by cholera, found that households in low lying areas of Glen View and Budiro had 2-3 hours of municipal water availability during the day and that households in higher areas had 2 hours of water availability at night (ESAG, 2018). Fourth, due to lack of rain the water table in Harare is low. Lastly, there are many treatment challenges and FRC levels detected from municipal taps around Harare have been low.

Households in Harare are not collecting water from the municipal piped system or that use multiple types of water sources, often collect drinking water from boreholes (both those with bush pumps and submersible pumps), water kiosks, unprotected and protected shallow wells. In the past, particularly during the rainy season, many shallow wells and some boreholes have been found to be contaminated.

Partners collaborated with the City of Harare- Department of Environmental Health to strengthen water quality monitoring of the municipal piped water network by modernizing the data collection and visualization platforms used for collecting and collating data from the piped network sentinel points around Harare. The Environmental Health Sampling Unit visits and samples water from the municipal piped network regularly. The data is collected in mWater and shared regularly with City Health and Harare Water to inform corrective actions.



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The City of Harare Environmental Health Department also conducts routine water quality testing at community boreholes, shallow wells, and at water sources associated with cholera case investigations. Partners also collaborated to strengthen the monitoring of borehole and shallow well water by modernizing the data collection and visualization platforms used for collecting and collating water quality information using mWater. The monitoring of decentralized sources is described separately.

Water Quality Monitoring of the Piped Network

Step 1: Development of the purpose and objectives. The purpose of the piped network monitoring system is to regularly sample municipal taps and reservoirs around Harare to document water availability, FRC, pH, and turbidity, and when FRC levels are 0.1 mg/L or below test for total coliforms and *E. coli*. The purpose of this monitoring system is to determine if FRC levels and other parameters at sentinel sites throughout the piped water network meet the determined criteria and inform City Health, Harare Water, and WASH stakeholders to make corrective actions where needed.

Step 2: Selection of water source types and water quality tests. The piped network sampling would focus on the piped network that serves Harare. Testing for FRC was prioritized as all municipal water should be chlorinated during an outbreak. As turbidity and pH can affect chlorination, these were tested in conjunction with FRC (WHO, 2017). Total Chlorine was tested for where appropriate, for example when FRC levels was not detected but Harare Water had reported treatment. When FRC levels are 0.1 mg/L or below, a sample was taken to test for total coliforms and *E. coli*. FRC was tested using HACH CN-66 kits, using the DPD colorimetric method. Turbidity was tested using the Bioevopeak, and pH using the Hanna portable pH reader. Total coliforms and *E. coli* were tested in the Sampling Unit lab using the AquaSafe WSL50 Premium kit.

Step 3: Selection of sampling sites. The City of Harare Environmental Health Department has municipal tap and reservoir locations that serve as sentinel points in the Harare piped network. These locations are at various points in the municipal system and in a number of suburbs. Sampling locations include locations near reservoirs and pump stations where piped network booster chlorination is conducted, and locations further down the distribution system. A larger number of sampling locations are located in the suburbs most affected by cholera.

Step 4: Frequency of sampling. The aim was to go to all municipal sentinel points monthly with the additional aim that those points in the suburbs affected by cholera are visited weekly.

Step 5: Sanitary inspection. A sanitary inspection was not included for the piped network sampling but was included for the borehole and other water source sampling that will be discussed in the next section.

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Step 6: Data collection and reporting of the results. To inform corrective action and improve monitoring, mobile data collection forms were created in mWater and an associated dashboard to view results collected at piped networking sampling points was also created in mWater. The forms and dashboard were created in collaboration with the Sampling Unit team members and City Health leadership. GPS coordinates were taken at all locations where water was tested or sampled using mWater. An “alerts” section was created for when residual chlorine was 0.1 or 0 mg/L at reservoir and sampling point locations in order to inform the water utility for action.

Table 2: Recommended Targets of Physiochemical Parameters During Emergencies and Outbreaks

Recommended Targets for Water Quality Parameters				
During Emergencies and Outbreaks				
FREE RESIDUAL CHLORINE (FRC)		PHYSIOCHEMICAL PARAMETERS		
	FRC recommended to be ≥ 0.2 mg/L (ppm) at point of use during emergencies with normal to low risk of disease outbreaks	 pH	6.5–7.5	
	FRC recommended to be ≥ 0.5 mg/L (ppm) at point of use during a waterborne disease outbreak		Turbidity	< 5 NTU (Ideally < 1 NTU)
	FRC recommended to be 1.0 mg/L at tapstands		Total Dissolved Solids (TDS)	< 1000 mg/L
	FRC recommended to be 2.0 mg/L at water trucks at filling		Conductivity	30–1500 µS/cm
	FRC in drinking water should not exceed 5.0 mg/L (WHO); however, taste and odor may become noticeable at ≥2.0 mg/L	MICROBIAL INDICATORS		
			<i>E. coli</i>	< 1 CFU / 100 ml
			Fecal (Thermotolerant) Coliforms	< 1 CFU / 100 ml

Results can be exported from the dashboard for the time interval of interest, daily, weekly, bi-weekly, or monthly. The tables below show example exports from the piped network from August 5-9, the water quality sampling unit visited 32 piped network sentinel point locations around Harare. Of the 32 locations visited, 8 were reservoir locations and 24 were municipal taps at consumer endpoints. Of the 8 reservoirs visited, 7 (88%) had water available for testing, zero samples were <0.1 mg/L, zero samples were 0.1 mg/L, and two sample were between 0.2-0.4 mg/L, and one was between 0.5-1.0 mg/L. Of the 24 municipal taps visited, 21 (88%) had water available for sampling at the time of the visit. Of these 21, FRC was detected at 19 (90%) points. Three points (23%) had a FRC level of < 0.1 mg/L, zero (0%) had FRC of 0.1 mg/L, and 10 (77%) had FRC between 0.2-0.4 mg/L. The FRC levels detected in the system during this time are summarized in Table 13.

The spatial distribution of the municipal tap locations sampled and the distribution of FRC observed are shown below.

Table 16: Dashboard Results and Alerts from Piped Network Sampling – August 5-9, 2024

Harare Piped Network Results Aug 5, 2024 to Aug 9, 2024														
	# sites visited	Water available at the time of sampling		% water available	Free Chlorine Residual (mg/L)					% <0.1 mg/L	% 0.1 - <0.2 mg/L	% 0.2 - <0.5 mg/L	% 0.5 - 1.0 mg/L	% > 1.0 mg/L
		Yes	No		<0.1 mg/L	0.1 - <0.2 mg/L	0.2 - <0.5 mg/L	0.5 - 1.0 mg/L	>1.0 mg/L					
Reservoir tank point	8	7	1	88%	2	1	4			29%	14%	57%	0%	0%
Piped network sampling point	24	21	3	88%	2	2	15	2		10%	10%	71%	10%	0%
Summary	32	28	4	88%	4	3	19	2		14%	11%	68%	7%	0%

Figure 4: Harare Spatial Results – August 5-9, 2024

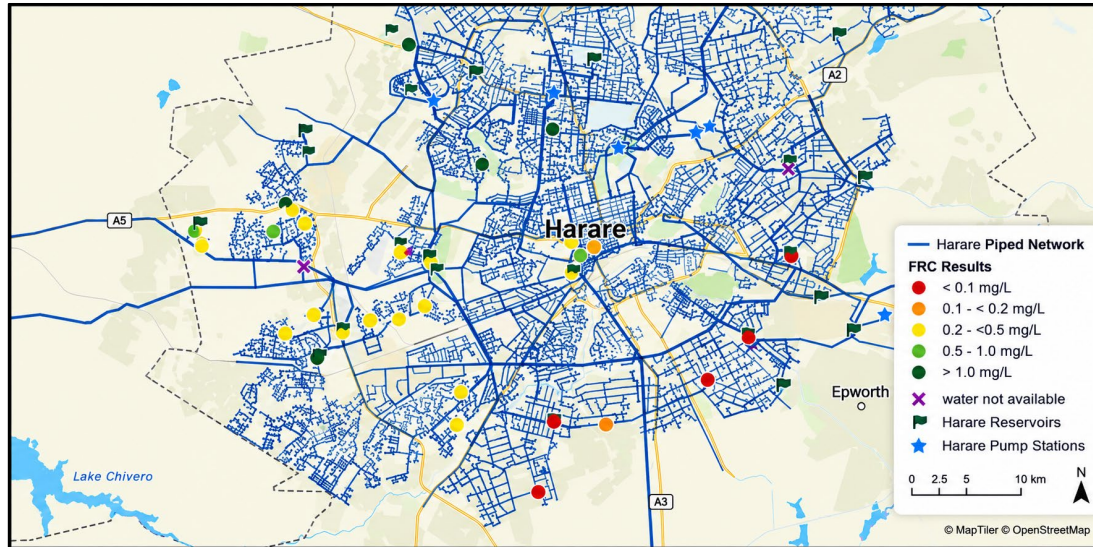


Table 17: Reservoir Monitoring Point Alerts – June 18-21, 2024

Reservoir Monitoring Point Alerts									
Date visited	What type of sentinel sampling point is this?	Name of sampling point (piped network)	Other point	Water available at time of visit?	Free Residual Chlorine (mg/L)	Turbidity (NTUs)	pH	Lab used for microbiological testing	E. Coli

Table 18: Sentinel Piped Network Point Alerts – August 5-9, 2024

Sentinel Piped Network Point Alerts									
Date visited	suburb	Name of sampling point (piped network)	Other point	Free Residual Chlorine (mg/L)	Total Chlorine	Turbidity (NTUs)	Lab used for microbiological testing	E. Coli	GPS Point
Aug 9, 2024				0.1	0.1	2.1	Water Quality Sampling Lab	0	
Aug 9, 2024				0	0.1	0.78	Water Quality Sampling Lab	0	
Aug 9, 2024				0	0	1.48	Water Quality Sampling Lab	0	
Aug 5, 2024				0.1	0.3	0.89	Water Quality Sampling Lab	0	

Step 7: Corrective actions based on results. The dashboard water quality monitoring results at reservoir points and sampling points can be viewed by the water utility for corrective action directly through the mWater system. The utility is able to use both reservoir alerts and alerts from the sampling points to fine-tune dosing. Using preliminary results from the system additional chlorination interventions were identified including the installation of booster chlorinators at select reservoirs in the system that regularly had low FRC results.

Borehole, Shallow Well, and Other Water Source Monitoring

Step 1: Development of the Purpose and Objectives. The City of Harare Environmental Health Department also conducts routine water quality testing at community boreholes and water sources at institutions such as schools and healthcare facilities to ensure water quality is safe. During an outbreak the team also conducts sampling of water sources such as boreholes, shallow wells, and other water sources associated with cholera case investigations.

Step 2: Selection of Water Source Types and Water Quality Tests. The water sources targeted for this system included boreholes, shallow wells, and water kiosks and tanks. At all water points, turbidity, pH, total coliforms, and *E. coli* were tested. In Harare, some boreholes had inline chlorinators attached to them that provide chlorination as water is pumped. At any boreholes with inline chlorinators or at chlorinated water kiosks, FRC was also tested. If FRC was <0.1 mg/L then a sample was also taken for microbiological testing for both total coliforms and *E. coli*. FRC was tested using HACH CN-66 kits, using the DPD colorimetric method. Turbidity was tested using the Bioevokepeak, and pH using the Hanna portable pH reader. Total coliforms and *E. coli* were tested in the Sampling Unit lab using the AquaSafe WSL50 Premium kit.

Step 3: Selection of Sampling Sites. Boreholes at healthcare facilities, schools, and in areas affected by cholera are routinely sampled as sentinel sites. Water sources associated with suspect cholera cases were also sampled when implicated. These included boreholes with handpumps, boreholes with submersible pumps, shallow wells, water kiosks, and water tanks.

Step 4: Frequency of Sampling. During this initial period all sources visited were tested once. If *E. coli* was detected a repeat sample was taken within a week.

Step 5: Sanitary inspection. A sanitary inspection was conducted at all water sources from which samples were taken. Sanitary inspection questions were taken from the Zimbabwean Ministry of Health Sanitary inspection Tool. Questions were also adapted from the WHO Sanitary Inspection forms (WHO, 2024).

Step 6: Data Collection and Reporting of the Results. To inform corrective action and improve monitoring, data collection forms were created in mWater for water source sampling at boreholes, shallow wells, water tanks, and other water points. Type of location was also included in the form so that results at healthcare facilities and schools could be tracked. In addition, the form included a sanitary inspection. A dashboard was created to view results. The forms and dashboard were created in collaboration with the Sampling Unit team members and City Health leadership. “Alerts” sections were included for boreholes tested, shallow



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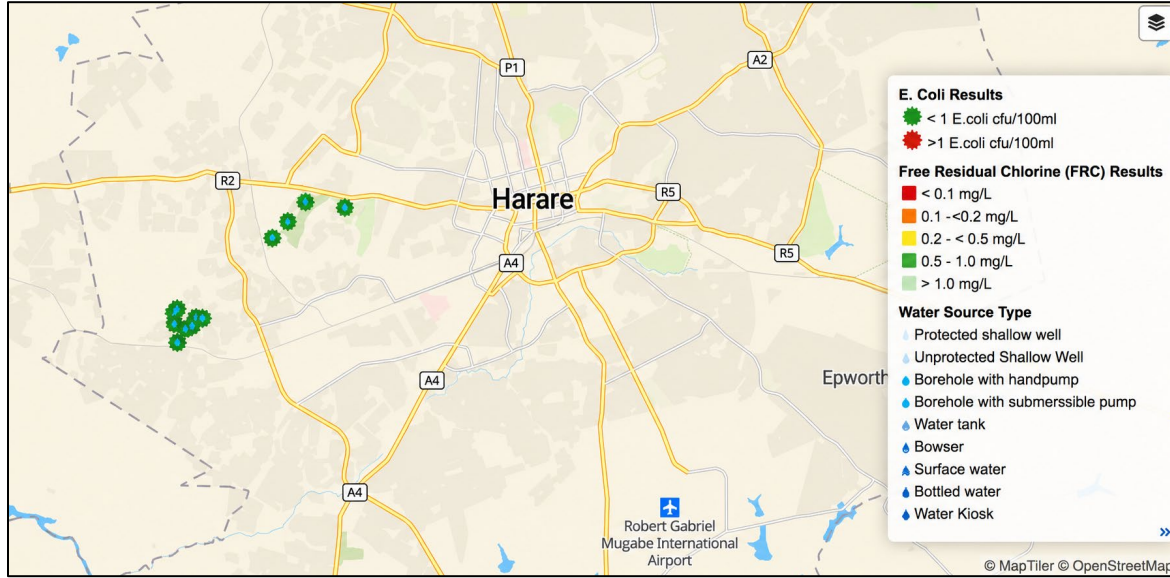
wells tested, healthcare facility water sources sampled, and school water sources sampled. Borehole alerts were created when *E. coli* was detected in a sample, or when a borehole that had an inline chlorinator that had a residual chlorine reading of 0.1 or 0 mg/L, shallow well alerts were created when *E. coli* was detected in a sample, health facility alerts were created if *E. coli* was detected in a water source sample or if a water source with an inline chlorinator had a residual chlorine reading of <0.1 mg/L, and school alerts were created if *E. coli* was detected in a water source sample or if a water source with an inline chlorinator had a residual chlorine reading of <0.1 mg/L. Data was collected on mobile devices using the mWater software data collection tool.

Results can be exported from the dashboard for the time interval of interest, daily, weekly, bi-weekly, or monthly. The tables below show example exports from the borehole, shallow well, and other water sources dashboard from July 15-17th. The water quality sampling unit visited 21 boreholes. Six of the 14 boreholes with submersible pumps had an inline chlorinator, one borehole with a hand pump had an inline chlorinator, 19 microbiological samples were taken for testing, and no samples were associated with cholera case investigations. The borehole alert section is shown in Table 14 and is meant to identify exactly where corrective action is needed. In the data presented in this example, none of the boreholes monitored had contamination however seven inline chlorinators were not functional with FRC readings of <0.1 mg/L indicating corrective action was needed. In table 17 sanitary inspection results are shown for those boreholes with alerts to provide additional information.

Table 19: Dashboard Results and Alerts from Borehole, Shallow Well, and Other Water Source Sampling

Summary Results by Water Source Type Jul 15, 2024 to Jul 17, 2024											
	Number of Sources Visited	Is the Water Source Functional (Providing Water)	Inline Chlorinator Present	Microbiological Sample	Case Investigation	FRC <0.1 mg/L	FRC 0.1 - < 0.2 mg/L	FRC 0.2 - <0.5 mg/L	FRC 0.5 -1.0 mg/L	E.Coli <1 cfu/100ml	Total Unsatisfactory E.coli (1->100 cfu/100ml)
		yes									
Borehole with handpump	7	5	1	5		1	0	0	0	5	0
Borehole with submerssible pump	14	14	6	14		6	0	0	0	14	0
Summary	21	19	7	19		7	0	0	0	19	0

Figure 5: Spatial Results of Water Quality Data -- July 15-17, 2024



*not all water quality data points have GPS locations due to device availability

Table 20: Borehole Water Quality Results July 15-17, 2024

Borehole Water Quality Results Jul 15, 2024 to Jul 17, 2024											
	Total Sources Visited	Currently providing water	Inline Chlorinator Present	FRC < 0.1 mg/L	FRC 0.1 - < 0.2 mg/L	0.2 - < 0.5 mg/L	0.5 - 1.0 mg/L	> 1.0 mg/L	Microbiological sample taken	E.Coli < 1 cfu/100ml	Total Unsatisfactory E.coli (1->100 cfu/100ml)
Borehole with handpump	7	5	yes	1	0	0	0	0	5	5	0
Borehole with submersible pump	14	14	6	6	0	0	0	0	14	14	0
Summary	21	19	7	7	0	0	0	0	19	19	0

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Table 21: Borehole Water Quality Alerts – July 15-17, 2024

Borehole Water Quality Alerts (E.Coli > 1 cfu/100ml or FRC < 0.2 mg/L)												
Date of Visit	Name of location	Type of location	suburb	What type of water source is this?	If borehole, is there an inline chlorinator?	Is the inline chlorinator functional?		Free Residual Chlorine (mg/L)	Lab	E. coli cfu/100ml	Total Coliforms cfu/100ml	GPS point
Jul 17, 2024		Open space		Borehole with submerssible pump	yes	yes- working	yes	0	Water Quality Sampling Lab	0	0	
Jul 15, 2024		Shopping center		Borehole with submerssible pump	yes	yes- working	no	0	Water Quality Sampling Lab	0	0	
Jul 15, 2024		Open space		Borehole with submerssible pump	yes	yes- working	no	0	Water Quality Sampling Lab	0	0	
Jul 15, 2024		Open space		Borehole with submerssible pump	yes	yes- working	no	0	Water Quality Sampling Lab	0	0	
Jul 15, 2024		Shopping center		Borehole with submerssible pump	yes	yes- working	no	0	Water Quality Sampling Lab	0	0	
Jul 15, 2024		Open space		Borehole with handpump	yes	yes- working	no	0	Water Quality Sampling Lab	0	0	
Jul 15, 2024		Open space		Borehole with submerssible pump	yes	yes- working	no	0	Water Quality Sampling Lab	0	0	

Table 22: Sanitary inspection Results for Borehole Alerts – July 15-17, 2024

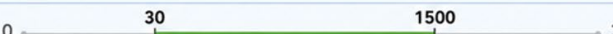
Sanitary Survey Results for Borehole Alerts (E.Coli > 1 cfu/100ml or FRC < 0.2 mg/L)												
Date of Visit	suburb	Name of location	Type of location	If borehole, is there an inline chlorinator?	Is there a latrine or sewer line 10 meters from the water source?	If yes, is the latrine on higher ground than the water source?	Is there any pollution within 30 meters of the water source (animal excreta, rubbish, stagnant water)?	Is there an unprotected well within 20 meters of the borehole	Is the apron area and seal intact (not cracked or damaged)?	Is the borehole casing intact?	Is there drainage around the water source? (stagnant water near source)	Is there fencing around the water source?
Jul 15, 2024			Open space	yes	no	no	no	no	yes	yes	no	yes
Jul 15, 2024			Shopping center	yes	no	no	yes	no	yes	yes	no	yes
Jul 15, 2024			Open space	yes	no	no	no	no	yes	yes	no	yes
Jul 15, 2024			Open space	yes	no	no	no	no	yes	yes	no	yes
Jul 15, 2024			Shopping center	yes	no	no	no	no	yes	yes	no	yes
Jul 15, 2024			Open space	yes	no	no	no	no	yes	yes		yes
Jul 17, 2024			Open space	yes	yes	yes	no	no	yes	yes	no	yes

Step 7: Corrective actions based on results. The water quality results from the dashboard inform which water sources visited are contaminated, which sources need inline chlorinator improvements, or maintenance. These results can be shared with the relevant government and partner organizations for appropriate intervention.

The data collection tools that were used for this case study are linked here.
[Zimbabwe Water Source Sampling and Sanitary Inspection Form](#)
[Zimbabwe Piped Network Monitoring](#)

APPENDICES

Appendix A: Recommended Targets of Physiochemical Parameters During Emergencies and Outbreaks

Parameters		Recommended Targets		
Physiochemical	Free Residual Chlorine (FRC)	    	- Emergencies with normal to low risk of disease outbreaks, FRC should be ≥ 0.2 mg/L (ppm) at point of use. - During a waterborne disease outbreak, FRC should be ≥ 0.5 mg/L (ppm) at point of use. - FRC recommended to be 1.0 mg/L at tapstands. - FRC recommended to be 2.0 mg/L at water trucks during filling. - FRC in drinking water should not exceed internationally recommended guidelines (WHO 0.5 mg/L); however, taste and odor may be an issue at ≥ 2.0 mg/L.	
	pH		6.5 – 7.5	
	Turbidity		<5 NTU (Ideally <1 NTU)	
	Total Dissolved Solids (TDS)		<1000 mg/L	
	Conductivity		30 – 1500 μ S/cm	
Microbial Indicators	<i>E. coli</i>		< 1 CFU / 100 ml	CFU = Colony Forming Units
	Fecal (Thermotolerant) Coliforms		< 1 CFU / 100 ml	CFU = Colony Forming Units

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Appendix B: Turbidity, pH, Temperature, and Total Dissolved Solids (TDS)

Additional information on how turbidity, pH, temperature, and TDS impact chlorination.

The effectiveness of chlorine as a disinfectant will depend on other water parameters detailed below including turbidity, pH, temperature, total dissolved solids (TDS), and metals. Organic matter as well as reduced compounds (e.g., nitrogen, ammonia, hydrogen sulfide, and metals) contribute to the chlorine demand of the water and decrease the amount of chlorine available for disinfection (CDC 2014). Therefore, depending on the context, it may be advisable to monitor these additional parameters in conjunction with FRC testing (Ariel Branz 2017). Some metals, including iron, which can be directly tested for, may be challenging to measure in emergency scenarios, both in terms of necessary equipment and waste disposal. Conductivity or total dissolved solids (TDS) can also be measured, as detailed below. Some parameters, such as temperature, pH, and conductivity are relatively stable, while others, such as turbidity, can change with increased rainfall or runoff. Parameters that are less stable, including FRC and turbidity, should be tested more frequently.

Turbidity

Turbidity describes the cloudiness of water created by suspended particles and is most often measured using Nephelometric Turbidity Units (NTUs) (WHO 2017). Measuring turbidity is an assessment of aesthetics of the water and possible contamination from runoff, spills, or inflow from broken pipes (WHO 2017). Turbidity is an important parameter to measure, as it may affect chlorine disinfection and other treatment methods, stimulate bacteria growth, or clog filtering devices (WHO 1997).

For disinfection with chlorine, WHO recommends that turbidity be kept below 1 NTU for disinfection to be most effective (WHO, 2017b). However, this may be difficult during emergency response, as turbidity of raw waters can exceed 100 NTUs in some settings, particularly where flooding occurs (Ariel Branz 2017). UNHCR recommends that drinking water should not exceed 5 NTU (UNHCR, 2020). In the case of high turbidity waters, it may be necessary to find an alternative non-turbid water source or to implement pre-treatment (e.g., settling, filtration, or coagulation). If finding an alternative source or pre-treatment is not feasible, increasing the chlorine dose may be necessary (Ariel Branz 2017, WHO 2017). Higher chlorine doses may lead to users rejecting treated water due to strong taste and odor issues, however. Chlorine disinfection can also lead to the formation of disinfection byproducts, which may have an impact on human health when there is extended exposure; however, disinfection should not be compromised to reduce the risk of waterborne diseases in attempting to control disinfection by products (WHO, 2017).



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pH (Acidity/Alkalinity)

The potential hydrogen (pH) ion concentration is the negative logarithm of hydrogen activity in a solution (WHO 2017). pH is measured on a scale from 0 to 14, with 7 considered neutral, below 7 acidic, above 7 basic, and a typical range for drinking water of between 6.5 and 8.5. As the scale is logarithmic, a one-unit change means a ten-fold increase or decrease. While the pH of drinking water does not necessarily pose a health threat, highly acidic water can corrode metal pipes or dissolve minerals in rocks and soil contaminating the water. pH values outside the typical range can also be an indication of chemical contamination which may pose a threat to human health. In addition, the pH is critically important for the operation of water treatment. If the pH is above 8.0, it is necessary to reduce the pH or increase chlorine dose and/or contact time to obtain the necessary FRC (Branz, 2017). The pH of water may also affect coagulation treatment with alum if outside the optimum range of 6.5-7.5 (Oxfam-Oxford 2001).

Temperature

Extreme temperatures, both high and low, must be taken into consideration when carrying out disinfection, particularly with chlorine-based disinfection. Temperature impacts the speed of chemical reactions and therefore will impact the required contact time (i.e., reaction time) for disinfection. In cold environments, increasing the contact time may be required to achieve the desired pathogen deactivation (Ariel Branz 2017). WHO recommends chlorination at 25°C (77°F) or above. However, high temperatures will result in faster decay or loss of chlorine, and FRC may dissipate quickly in water stored in bladders, tanks, or household water storage containers in high temperatures or in direct sunlight. This is an important consideration for the storage of stock solutions and chlorine-based chemicals which should be maintained in closed containers in cool environments out of direct sunlight. Always refer to manufacture instructions for proper storage. Additionally, if batch chlorination is planned and water tanks are in direct sunlight, it may be necessary to monitor FRC values in the water at various time periods as the tanks are emptied.

Total Dissolved Solids (TDS) and Conductivity

Total dissolved solids (TDS) are inorganic salts and organic matter dissolved in water from natural sources, sewage, urban and agricultural runoff, and industrial wastewater (WHO, 2017a). WHO does not have any specific health targets; however, high levels of TDS in water can be objectionable to consumers. WHO recommends a taste threshold of 1000 mg/L (WHO 2011). **Salinity** is the measure of salts in water and can vary greatly depending on type of source and (hydro)geology. Since most dissolved solids consist of inorganic ions, which are the components of salts, salinity and TDS are conceptually similar.

Conductivity is the quickest and easiest way to approximate the levels of TDS (or salinity) in water. It is a measure of a solution's ability to pass an electrical current and can be used to calculate TDS indirectly.



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Appendix C: Example Forms for Data Collection



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1) Chlorinated Centralized Level (Piped Network)

This data collection form was used after a natural disaster and subsequent cholera outbreak to monitor the FRC levels in a piped network. The Kobo questionnaire and programmed .xlsx sheet are below.

Basic Forms:

- [Chlorinated Centralized Level Piped Network Questionnaire](#) (PDF)
- [Chlorinated Centralized Piped Network Monitoring](#) (Excel)

Advanced Forms:

- [Centralized Piped Network Monitoring - Advanced Questionnaire](#) (PDF)
- [Centralized Piped Network Monitoring - Advanced](#) (Excel)
- [Advanced Questionnaire Coding Notes](#) (PDF)

2) Chlorinated Decentralized Water Sources and Access Points (e.g., water storage tanks, water trucks, bucket chlorination, and inline chlorinators)

This data collection form was used to monitor chlorinated water storage tanks managed by water vendors and institutions that provide water to community members.

- [Water Tank Monitoring Kobo](#) (PDF)
- [Water Tank Monitoring](#) (Excel)

3) Untreated Decentralized Water Sources and Access Points (e.g., boreholes, wells, etc.)

This data collection form was used to monitor boreholes in an area with cholera hotspots. It includes sanitary inspection questions for boreholes with handpumps and motorized boreholes.

- [Decentralized Borehole Monitoring Questionnaire](#) (PDF)
- [Decentralized Borehole Monitoring](#) (Excel)

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4) Household Level – Post Distribution Monitoring

This data collection form was used to better understand use of WASH items distributed as part of a recent cholera response. It includes questions on cholera knowledge, receipt and use of WASH items, and household WASH characteristics. The Kobo questionnaire and programmed .xlsx sheet are below.

- [Household PDM Questionnaire](#) (PDF)
- [Household PDM Cholera Outbreak](#) (Excel)

5) Healthcare Facilities – Water Quality Monitoring

This data collection form can be used to monitor water quality at health care facilities. It focuses on water quality and is meant to help guide those in charge of water services within health care facilities on tasks and corrective actions (WHO, 2024b).

- [Healthcare Facilities Water Quality Monitoring – Annex 1 & 2](#) (PDF)
- [Healthcare Facilities Water Quality Monitoring – Annex 1 & 2](#) (resource page)

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REFERENCES

- Adams J, Bartram J, Chartier Y. (Eds.). (2008). Essential environmental health standards in health care. Geneva: World Health Organization.
- Bartram J, Balance R (Eds.). (1996). Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programs. Geneva: World Health Organization (WHO) and United National Environment Programme (UNEP). Retrieved from <http://www.who.int/iris/handle/10665/41851>.
- Emergency Strategic Advisory Group (2018). Harare, Zimbabwe WASH Rapid Technical Assessment Report.
- MSF, Public Health Engineering in precarious situations, 2010
- <https://www.humanitarianlibrary.org/resource/public-health-engineering-precarious-situations>
- Rajasingham A, Harvey B, Taye Y, Kamwaga S, Martinsen A, Sirad M, Aden M, Gallagher K, Handzel T; Improved chlorination and rapid water quality assessment in response to an outbreak of acute watery diarrhea in Somali Region, Ethiopia. Journal of Water, Sanitation and Hygiene for Development 1 September 2020; 10 (3): 596–602. doi: <https://doi.org/10.2166/washdev.2020.146>
- Rajasingham A, Hardy C, Kamwaga S, Sebunya K, Massa K, Mulungu J, Martinsen A, Nyasani E, Hulland E, Russell, S, Blanton C, Nygren B, Eidex R, Handzel T. (2019). Evaluation of an Emergency Bulk Chlorination Project Targeting Drinking water Vendors in Cholera-Affected Wards of Dar es Salaam and Morogoro, Tanzania. *Am J Trop med Hyg*, 100(6):1335-1341. doi: 10.4269/ajtmh.18-0734.
- Townes D. (Ed.) (2018). Health in Humanitarian Emergencies: Principles and Practice for Public Health and Healthcare Practitioners. Cambridge University Press
- UNHCR. (2015). UNHCR Emergency Handbook. (4th Ed.). Retrieved from <https://emergency.unhcr.org>.
- HCR (2020). UNHCR WASH Manual: Practical Guidance for Refugee Settings (7th Ed.). Retrieved from [UNHCR WASH - Practical Guidance for Refugee Settings | UNHCR](#)
- United States Environmental Protection Agency (EPA). (1997). Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls. Retrieved from <https://www.epa.gov/nps/monitoring-guidance-determining-effectiveness-nonpoint-source-controls>.

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- Wisner B, Adams J (Eds.). (2002). Environmental health in emergencies and disasters: A Practical Guide. Geneva: World Health Organization. Retrieved from [WHO. Environmental health in emergencies and disasters: A Practical Guide](#)
- World Health Organization (WHO). (1993). Guidelines for Cholera Control. Retrieved from: [WHO. Guidelines for Cholera Control](#)
- World Health Organization (WHO). (1997). Guidelines for Drinking-Water Quality. Vol. 3. Surveillance and control of community supplies. (2nd Ed.) Geneva: World Health Organization. Retrieved from: [Guidelines for drinking-water quality. Vol. 3, Surveillance and control of community supplies. Vol. 3, Vigilancia y control de los abastecimientos de agua a la comunidad \(who.int\)](#)
- World Health Organization (WHO), UNICEF. (2012). Rapid assessment of drinking-water quality: A handbook for implementation. Geneva: WHO/UNICEF. Retrieved from https://www.who.int/water_sanitation_health/publications/rapid_assessment/en/
- World Health Organization (WHO). (2017a). Guidelines for Drinking-water Quality (4th Ed.). Geneva: World Health Organization. License: CC BY-NC-SA 3.0 IGO. Retrieved from: [WHO. Guidelines for Drinking-water Quality](#).
- World Health Organization (WHO). (2017c). Water quality and health – Review of turbidity. Information for regulators and water suppliers. Geneva: World Health Organization. Retrieved from https://www.who.int/water_sanitation_health/publications/turbidity-technical-brief/en/
- World Health Organization (WHO). (2024). Guidelines for drinking-water quality: small water supplies. Geneva: WHO. Retrieved from [Water Sanitation and Health](#)
- World Health Organization (WHO). (2024b). Health care facility Water supply and management checklist: Supporting material for WASH FIT improvements. Retrieved from [Water-Quality-Monitoring-Checklist.pdf](#)