SMU-UNHCR

Partnership in Research for Water Sanitation and Hygiene

2011 Final Report

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Executive Summary

Southern Methodist University and the United Nations High Commissioner for Refugees have entered into a research partnership to address issues in the water, sanitation, and hygiene sector. Specifically, the SMU team is to focus on water quality assessment and remediation for chemical contaminants. It has been mutually agreed that UNHCR and its implementing partners have already established reasonable coverage for assessing microbial contamination, water delivery systems, and sanitation. Chemical contamination, however, has often been overlooked due to resources, time, and expertise. Many chemical contaminants have further been thought of as a lesser priority when defining the overall quality of a water source. Water does indeed have the potential for being a disease vector, and microbial abatement should, therefore, be the single greatest concern. However, chemical contamination can become a significant issue once a population is exposed to such a source for an extended period of time. While UNHCR is often regarded as an emergency agency, the average residence time of a refugee has now exceeded fifteen years. It is therefore essential to fully evaluate the chemical status of all water sources and remediate problems where necessary.

The SMU team conducted five sampling missions to UNHCR refugee camps in Uganda, Kenya, Bangladesh, Djibouti, and Liberia. Overall, these missions were considered a success with 17 camps, 7 villages, and a few additional sites visited. The team collected 213 camp samples and 229 total samples for analyses in the laboratory. Camp conditions and source water characteristics varied widely amongst the five countries but also within the camps themselves.

In Uganda, where a combination of ground and surface water sources were used to supply drinking water to the refugees, water was mostly abundant. Surface water was at least minimally treated, and boreholes generally had good yields. The major issues observed by the team were the high iron concentrations and high turbidity at some sites. These issues are themselves not an immediate health concern; however, they do contribute to poor taste which may lead refugees to bypass an otherwise safe drinking water source for one that is microbially contaminated, causing sickness.

In Kenya, water delivery systems were in general very well-designed and efficient. Water was derived from deep boreholes and stored in large elevated tanks. Kakuma had recently experienced significant flash flooding, but the erosion control measures in place to protect the boreholes were successful. In addition, the camp was working to improve its boreholes and overall water delivery system in order to increase capacity for an expected influx of refugees from the Dadaab region and other locations. In the Dadaab area camps, water trucking was temporarily necessary. Borehole sites did include auto-dosing facilities for chlorine additions. Work was also well underway on preparing the water system of camp extensions and the new camp in the region. Solid waste, often in close proximity to boreholes, was an obvious issue in the Dadaab region. Elevated conductivities were also observed throughout the country, and visibly high iron concentrations were noted in several locations.

In Bangladesh, the camps were all characterized by extreme population density, leading to poor sanitation conditions, which threatened the microbial and chemical quality of the drinking water. In Nayapara, water was supplied by an internal reservoir to a water treatment plant and pumped to distribution tanks. However, refugees had only limited access to this water. In Kutapalong, there was excellent tube well coverage, but in some cases, latrines drained toward wells or rice paddies directly abutted the wells, presenting contamination concerns. In addition, pH values varied widely in this camp and were outside the range typically associated with groundwater. Apparently random iron contamination was also observed to be an issue.

In Djibouti, drinking water access was provided by large hand-dug wells, mechanized borehole fed tap stands, and private open wells. One issue that was noted was the lack of an efficient system for distributing water to refugees. The unreliable nature of the refugees and contracted workers who were responsible for constructing and maintaining the wells was also noted. Overall, complaints of poor taste were not observed; however, this was surprising considering the high conductivity levels measured at all sites in Djibouti. An additional concern was the lack of protection for the open wells, especially the nearness to which donkeys were allowed to approach, which created the potential for serious chemical contamination. Finally, solar panels which could have run the borehole pumps in Ali Adde were out of commission due to vandalism by refugees.

In Liberia, water was supplied using boreholes equipped with hand pumps or with submersible pumps that were used to fill permanent or temporary storage tanks for chlorination and distribution. Water yield was generally good, and latrines appeared to be properly situated.

The purpose of the water quality database (WQD) is to collate all of the chemical data measured from drinking water samples collected in refugee camps over a wide spatial and temporal range. While the current output is static and presented as a series of camp-specific At-A-Glance cards, the future goal is to integrate these visuals as an online system of reporting. The following are some of the major findings.

In Uganda, conductivity values increase from southern settlements to northern settlements with conductivities over guideline values at several sites in Nakivale and Kyaka II. High Fe and Mn concentrations, often above established standards, are observed in every camp sampled. Scattered occurrences of elevated Pb, Ni, U, Zn, V, Cu, and/or As have been measured in all camps. Additionally, Kyaka II, Nakivale, and Kyangwali exhibit elevated fluoride concentrations. High nitrite values are also a problem in most of the settlements, especially those in southern Uganda. Scattered high nitrate and chloride concentrations have also been measured.

In Kenya, very high conductivities have been measured in both Kakuma and the Dadaab region. In addition, vanadium values above established guidelines occur in these camps. Scattered sites with elevated Zn, Mo, U, Fe, Cr, and/or possibly Al are present in both locations. Kakuma also has numerous wells with high fluoride concentrations, and nearly all wells in Kakuma and the Dadaab region are elevated in nitrite. Elevated nitrate concentrations are present in a few wells across both camps. Unexpectedly, iodide is not present at elevated levels in the Dadaab camps.

In Bangladesh, both Nayapara and Kutapalong have been sampled. Only one site with elevated Fe has been measured in Nayapara. In Kutapalong, Fe and Mn concentrations above the established standards have been measured at numerous sites. Scattered instances of elevated As, Cr, Co, Ni, Ga, and/or Pb have also been observed. In addition, pH varies widely and is much lower in some sites than is typical of groundwater. Elevated nitrate concentrations are measured in nearly half of the wells sampled in Kutapalong and in a single well in Nayapara. A number of wells in Kutapalong also have high nitrite concentrations. Nitrite and nitrate are inversely related; this redox couple is likely controlling pH which is in turn controlling the sorption of Pb.

In Djibouti, conductivity is high in Ali Sabieh, Ali Adde, and Holhol. Elevated vanadium concentrations have also been measured in these locations. Limited occurrences of elevated Zn and/or Se have also been noted. The high conductivities are tracked well by excessive chloride values. Additionally, elevated fluoride concentrations are present in all samples. Nitrite concentrations are consistently elevated above established standards in all samples. Overall, nitrate is also elevated, some samples excessively so.

In Liberia, elevated concentrations of Mn, Pb and/or Cr have been measured at specific locations. Chloride values are uniformly low, but nitrite and nitrate concentrations elevated above established health standards are present in isolated wells.

Here, it is recommended that the WQD be extended for the 2011 field sites through 2012. At the end of 2012, the sites will be assessed again. It is anticipated that all or most will be removed from the assessment list at that time; however, it is necessary to reproduce the results found in 2011. Having replicated outcomes before moving to full implementation of, for instance, field-scale remediation solutions is fiscally prudent. Additionally, the concentration of a contaminant in a given water source may change over time. Monitoring values over the course of 2012 would give confidence in the reproducibility of the 2011 results and provide insight into the magnitude of variability and overall trending of analyte concentrations. Understanding such trends will be extremely useful in building ultimate solution strategies for identified problems. This is most obviously necessary in the wells in various camps where isolated contamination occurs. In those cases, elevated contaminants of concern (*i.e.*, Ni, Zn, U, Pb, and/or As) are observed and must be confirmed prior to taking steps to remediate or possibly even close wells.

It is also recommended that the WQD add an additional two to four countries, to be determined in concert with UNHCR based on immediate needs. It is important to spread the database geographically to extend the valuable assessment and potential solutions to other regions. There is a limit to the number of total countries that can be addressed each year without a significant increase in resources for further staffing, hence the suggestion of no more than four additional countries. Adding new countries each year and, by next year, removing countries that have been fully addressed would keep the active number of countries consistent and manageable.

New contamination problems have been identified such that immediate action is suggested. Vanadium exists at high levels and with widespread geographic distribution in Ali Adde, Djibouti, and, to a lesser extent, in the Dadaab region of Kenya. Manganese is also a significant problem in Kutapalong, Bangladesh. Targeted projects similar to the current fluoride project are suggested to develop remediation solutions for vanadium and manganese. These would start in the lab while concurrently reproducing field results and fully mapping distribution. Ultimately, field implementation of pilot-scale solutions would follow.

Current targeted remediation projects made good progress in 2011. Of note is the iodide project, which in the final version of the partnership was not funded. The analyses of iodide in the Dadaab region, however, show very clear and actionable results. At this time no significant iodide is measurable in the Dadaab region, and it is therefore suggested that no remediation action is necessary.

Fluoride has been assessed in all sites and determined to be a significant problem in Uganda, Kenya, and Djibouti. However, it is highly recommended that the full spatial extent of fluoride in Southern Uganda be geographically mapped. In addition, laboratory work on a remediation solution is underway with good progress. Modeling and preliminary batch experiments have demonstrated that hydroxyapatite can be successfully used to remove fluoride from solution. Thus, it is recommended that this project be continued in 2012. Additional batch experiments and flow-through column experiments will be used to design and test a potential remediation strategy for affected UNHCR sites. Upon the completion of the prototype, pilot-scale field implementation is suggested. Subsequent field monitoring over time is then necessary to assess fluoride removal efficacy.

Iron concentrations above established standards have been measured in several camps in Uganda, Kenya, and Bangladesh. The iron removal project to develop a remediation strategy for such sites has completed the design phase, and a prototype has been under construction. Lab testing of the prototype is recommended and will begin shortly. Upon completion of the testing phase, field implementation at the pilot scale is recommended. It is essential to then monitor the pilot test regularly to track efficacy. Results will be used to project future efficacy and total lifespan. It is noted that other such pilots have been put in place by other UNHCR partnerships, but these are currently ineffective based on the recently measured removal efficiencies.

It is also recommended that the SMU team continue analyses of suspended sediment from water sources. This work could show a significant level of heavy metals associated with the suspended sediment, which would also be ingested in the drinking water and could affect the health of those who rely on these water sources.

The 2011 SMU UNHCR Partnership in Research for WASH was abbreviated as it only formally began in October with backdating to July. Despite the short timescale, great progress has been made towards a holistic analysis of water quality in the test countries. Additionally, progress had been made in identifying problems not known before the study, clarifying suspected problems, and designing remediation solutions for well documented problems. SMU looks forward to continuing this partnership by furthering the work done in 2011 and expanding the footprint of the effort to more countries served by UNHCR.

Contents

Figures

Chapter 1: SMU Team

1.1 Faculty

Dr. Andrew Quicksall is the principal investigator (PI) for SUPR WASH. He is the J. Lindsay Embrey Assistant Professor of Environmental Science at Southern Methodist University and holds a joint appointment between his home department of Civil and Environmental Engineering and the department of Earth Sciences. Dr. Quicksall's expertise is in water quality with specialty in contaminant metal dynamics between aqueous and soil/sediment phases. While projects in the Quicksall lab group are not solely in water quality research, this continues to be the main focus of the group.

Dr. Lindsay Seders Dietrich is a Visiting Assistant Professor in the Department of Civil and Environmental Engineering at Southern Methodist University. She has a B.S. in Geology from the University of Toledo (Ohio) and a Ph.D. in Environmental Geochemistry from the University of Notre Dame. Dr. Dietrich acts as the Quicksall Lab manager and oversees the use of several instruments, including the ICP-MS. She also does research involving iron oxide and iron sulfide nanoparticles, including the synthesis and characterization of hematite and mackinawite. She is interested in the size-dependent reactivity of iron nanoparticles and their interaction with and incorporation of trace metals.

1.2 Graduate Students

Drew Aleto has a B.S. in Civil Engineering and an M.S. in Environmental Engineering from Southern Methodist University. He is currently pursuing a Ph.D. in Environmental Engineering. He has traveled to Uganda, Kenya, and Djibouti as a part of this project and is responsible for anion analysis of all water samples. Drew is also working on the design, experimentation, and implementation of fluoride chemical and physical remediation technologies.

Katherine Grant has a B.S. in Chemistry from the University of Notre Dame. She currently is working towards an M.S. in Environmental Engineering at SMU. She has traveled to Uganda, Kenya, and Bangladesh as a part of this project and is responsible for metals analysis of all water samples.

Haddijatou Bayo is a first-year M.S. student in Environmental Engineering. She received undergraduate degrees in Math and Chemistry from Kentucky State University. She has traveled to Liberia as part of a sampling mission and is currently working on acid digestion and trace metal analysis of the suspended solids in all collected water samples.

Andrea Fernandez has a B.S. in Mechanical Engineering and a B.S. in Mathematics from Southern Methodist University and a Master's in Pastoral Ministry from the University of Dallas.

She is a first-year student pursuing an M.S. in Environmental Engineering at SMU. Andrea is working on creating a cost-effective, easily-maintained water filtration method to remove high concentrations of iron from drinking water in Ugandan refugee camps.

1.3 Undergraduate Students

A variety of undergraduate students majoring in Environmental Engineering at SMU are employed as research support staff in the lab of Dr. Quicksall. They are responsible for assisting graduate students with experimental work and performing other general laboratory tasks.

Chapter 2: Calendar

Activity	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
Uganda Field								
Kenya Field								
Bangladesh Field								
Djibouti Field								
Liberia Field								
Fluoride Modeling								
Fluoride Lab Experiments								
Iron Remediation Design								
Iron Remediation Prototype								
Sediment Acid Digestion								
Ion Chromatography								
Mass Spectroscopy								
Sample Preparation								
Report Writing								
Financial Reporting								

Chapter 3: Background

The Hunter and Stephanie Hunt Institute for Engineering and Humanity at Southern Methodist University (SMU) has the mission of affecting the global poor through innovation, engineering, and science. The Hunt Institute has recently built a partnership with the UNHCR that has included a workshop, focused on innovation, held March 29-31, 2011. It is the intention of the Hunt Institute to support other interactions with the UNHCR beyond this critical workshop and its eventual outputs. Fundamental research with direct implications for humanitarian need lies squarely within the mission of the Hunt Institute. For that reason, this broad research relationship with the UNHCR (SUPR WASH), which is focused on water quality, is an ideal partnership expansion for the Hunt Institute and SMU.

The Quicksall lab at SMU is well suited for such work as it focuses on fundamental research projects relating to the partitioning of contaminants between aqueous and solid phases, especially as it relates to water quality issues. A central theme to the research is the study of aqueous metal enrichment and contamination in the natural environment by probing both solution and solid chemistry of natural materials. The group has active projects in surface functionalizing naturally occurring materials for toxin remediation, fluoride exchange with bone amendment as a remediation technique, using sulfur reducing bacteria for heavy metal sequestration, bio-sand filtration for the removal of pharmaceuticals and hormones in municipal drinking water, disinfection of coliform bacteria from primary sludge particles using electrochemical and UV techniques, the synthesis and reactivity of iron oxide nanoparticles and their reactivity towards heavy metals, and metals speciation analysis in natural and synthetic materials. The lab group has expertise in the analysis of samples using cutting edge, X-ray and electron beam techniques as well as various molecular spectroscopies.

The Quicksall Lab currently is well equipped with environmental, analytical instrumentation. Instruments of interest for water quality research include a total organic carbon (TOC) analyzer, a UV-visible spectrophotometer (UV-Vis), a surface area analyzer, an ion chromatograph (IC), a gas chromatography-mass spectrometer (GC-MS), and an inductively coupled plasma mass spectrometer (ICP-MS). The lab additionally has access to other analytical facilities at SMU including a scanning electron microscope (SEM), an isotope ratio mass spectrometer (IRMS), an elemental analyzer, a thermogravimetric analyzer (TGA), an X-ray diffractometer (XRD), an atomic absorption spectrometer (AA), a Fourier transform infrared spectrometer (FTIR), and a transmission electron microscope (TEM).

The broader SUPR WASH project has several components or projects underway that have had good success in 2011. One immediate project is developing a water quality database that characterizes and tracks the quality of water at UNHCR managed camps. Fully characterizing drinking water supplies in refugee camps over a number of years in a subset of countries of interest is a true need. One must identify, or clearly demonstrate the absence of, contaminants in camp waters if one is to effectively meet basic needs of camp inhabitants. This is a holistic approach, addressed by measuring a large suite of chemical constituents. This type of approach yields valuable data that not only identify contaminants of concern but also provide a full water chemistry picture of each site. This full chemical work-up is necessary in identifying and remediating contaminants. In addition, the chemistry of a water supply evolves through time and may display seasonal variability. Thus, the ultimate goal is to combine the results of this study with additional results from multiple data points over time. This will permit the identification of cyclical changes, as well as offer the potential for forecasting longer range trends. Ideally, this would come from a multi-year dataset.

Another project well underway is assessing fluoride levels and developing remediation solutions to address those that are found to be high. Elevated fluoride concentrations in well waters are a concern in certain regions due to dominant aquifer lithology and sourcing of water. East Africa is a region known to have the potential for groundwater with fluoride at levels of concern for consumption. Recently, Nakivale, Uganda, and Kakuma, Kenya, have been shown to have fluoride concentrations well in excess of the acceptable level. Here, the problems in Nakivale and Kakuma are characterized and possible solutions are examined. Once applied, the efficacy of the remediation strategy will be tracked, and its transferability to other potential sites of fluoride contamination will be assessed.

Finally, iron remediation is of concern for certain UNHCR camps and is another focus of this partnership. High ferrous iron concentrations in drinking water wells pose no threat to human health directly, in that iron is non-toxic. High iron concentration does yield a significant decrease in water quality, however, through its impact on taste. High iron content well waters are often avoided by local populations due to taste in favor of more aesthetically pleasing yet contaminated waters, such as coliform impacted surface waters. Using a known example, Nakivale, Uganda, a design has been developed in the Quicksall lab at SMU to address the high iron concentrations found at this site. The treatment involves the oxidation and subsequent removal of iron from the well water. Work to test this design is ongoing. Implementation will occur at Nakivale, Uganda, and data will be regularly acquired following installation to track efficacy.

Ultimately, all data from the chemical analyses of the sampled drinking waters will be included in an interactive database that will be easily updated with additions. The database will have prescribed outputting features that will condense and display final interpreted data. This will yield the PI and the UNHCR staff a user-friendly, accessible, and flexible tool for accessing, reviewing, and comparing data. Upon building a dataset of possible contaminants that covers a broad spatial area and a significant time series, other systemic problems will likely present themselves through analysis of the database. It is the intention of this broad partnership (SUPR WASH) to address these specific problems with future research proposals as they present themselves. For example, the fluoride problem identified in Kakuma and the iron problem identified in Kakuma and Nakivale became apparent only after measurements of well water chemistry were made. These projects are typical of expected future projects.

Chapter 4: Mission Reports

4.1 Uganda—August 2011

4.1.1 UNHCR Country Office – Kampala

Tuesday, 09 August 2011 to Friday, 12 August 2011

The SMU mission team to Uganda included Dr. Andrew Quicksall, Katherine Grant, and Drew Aleto. They arrived in Nairobi, Kenya, from the United States on the night of Tuesday, 09 August 2011. After spending the night in Nairobi, they boarded a flight to Entebbe, Uganda, the following afternoon where they continued on to Kampala via taxi.

Once present at their hotel accommodations, the teams attempted to make contact with the UNHCR country office in Kampala. It was discovered that the country office was not expecting them until the following day, *i.e.*, the schedule the country office representatives had stated the team's arrival as the following day but with the same final departure date. This was taken as an opportunity, however, to add an extra day of sampling at the camps. Due to the relatively large number of UNHCR refugee settlements in Uganda, this worked out to both the SMU team's and the UNHCR's mutual benefit to obtain more information on more sites.

After making contact with the national office, including Ms. Juliet Mwebesa, the knowledgeable and helpful UNHCR WASH national consultant, the team's initial meeting was able to be moved up a day (that is, the day prior to that scheduled according to the schedule of which the national office was in possession). Therefore, a UNHCR vehicle was arranged for Thursday, 11 August to transport the team to the national office in Kampala.

Upon arrival at the national office on Thursday, the team was able to meet with Mr. Kai Erik Nielson, Uganda country representative, Ms. Francesca Bonelli, Senior Community Services Officer, as well as Ms. Mwebesa. This initial meeting was meant to announce the team's presence, make personal contact with the UNHCR in Uganda, and clarify the team's goals in their visits to the settlements in Uganda such that they were in line with the mission of the partnership with SMU and the UNHCR. It was also meant to detail the benefits the project would provide to the office in Kampala and how it would help their mission to provide for refugees in Uganda.

Following the initial meeting with Mr. Nielson and Ms. Bonelli, the team proceeded to a security briefing with the field safety advisor, Mr. Gard Loken. Here the team was briefed on the few, yet possible, security threats while traveling through Uganda and UNHCR's refugee camps. As this was the team's first foray into the UNHCR's camps, this brief overview of common and safe practice while traveling about was seen as extremely helpful.

The team then felt fully prepared for the mission to the Ugandan camps. The remainder of the time in Kampala was used to fully prepare the field equipment and review field methods. The UNHCR vehicle was arranged for the following morning to depart for the UNHCR sub-office in Mbarara in far southern Uganda. The country office arranged a single driver for the entirety of the mission in Uganda—the experienced and knowledgeable Mr. Peter Edema—who was to meet the team at their hotel accommodation in Kampala the following morning.

The team departed Kampala early in the morning of 12 August. As this was the date the national office had originally scheduled the team to meet with them in Kampala, this afforded a head start into the settlements of Uganda. Arriving in Mbarara that afternoon without incident, the team proceeded to the UNHCR sub-office for a brief, informative meet-and-greet. It was then decided enough time remained in the day to afford a trip to Nakivale a day earlier than planned.

4.1.2 Nakivale

Friday, 12 August 2011

The sampling team met up with the implementing partner's (Deutsche Gesellschaft für Internationale Zusammenarbeit, or GIZ) Nakivale representative, Jean Baptiste, upon arrival on the afternoon of 12 August. The first location toured by the team was the surface water (Figure 4.1) and the adjacent treatment plant (Figure 4.2) used to treat its water. The surface water was directly sampled from the makeshift pier shown in Figure 4.1 (*i.e.*, untreated water). The tap (*i.e.*, post-treated water) was then sampled as well.

Figure 4.1 Nakivale: Surface water used in treatment plant

Figure 4.2 Nakivale: Surface water treatment and storage tanks

The surface water was mechanically pumped from the lake into the tanks shown in Figure 4.2. Chlorine was then added by hand at a dose of 150 g of chlorine per 20 m^3 water (Figure 4.3). The residual chlorine was mentioned by Mr. Baptiste as approximately 0.3 mg/L at the tap. Alum was also added to promote coagulation and flocculation. The water was then gravity-fed to the taps for refugee consumption.

Figure 4.3 Nakivale: Chemical dosing of surface water for treatment

Due to daylight constraints, the team then had to return to Mbarara after visiting the surface water site and its accompanying treatment plant.

Saturday, 13 August 2011

Saturday, 13 August was a full sampling day at Nakivale. The team arrived in the morning and proceeded directly to another surface water treatment plant. The surface water here was mechanically pumped to concrete tanks (Figure 4.4) where alum and chlorine were added in the single top tank. The water then fed via gravity to the lower tank where it was allowed to settle. The alum dosing is noted to be 25 kg alum per 70 m^3 water (it was previously 30 kg alum). Mr. Baptiste noted that the turbidity of the treated water increased with the decreased alum dosing, as would be expected.

Figure 4.4 Nakivale: Concrete treatment tanks for alum and chlorine addition

Other sources seen in Nakivale utilized boreholes and shallow wells. Most were equipped with manual hand pumps with the exception of one mechanically pumped borehole (Figure 4.5). The pump then fed a tap; both the pump and tap, however, were guarded by a chain-link fence and locked gate.

Figure 4.5 Nakivale: Mechanized borehole tap

The water from this mechanized borehole, however, was extremely turbid (Figure 4.6). This particular borehole, whose pump is powered by a generator, is 70 m in depth yielding 3 to 4 m^3 per hour.

Figure 4.6 Nakivale: Turbid water flowing from tap

A common complaint by the refugees encountered by the team in Nakivale was the taste of the water due to its high iron content. This significant iron content is evident by the deep, dark red staining of the concrete aprons circling the borehole hand pumps (Figure 4.7).

Figure 4.7 Nakivale: High iron content evident by dark red staining of concrete apron

This high iron content was evident on several of the hand pumps encountered by the SMU team. In fact, it was noted that at least two had been completely abandoned due to their extremely high iron content. This problem had been addressed previously. For example, the team encountered a sand and gravel filter in use at one of the hand pumps (Figure 4.8 and Figure 4.9). This filter was attempting to aerate the water as it percolated through the filter in order to remove some of the iron. The efficacy of this filter will be determined by the team by analyzing both pre- and post-filter samples.

Figure 4.8 Nakivale: Filter for iron removal at a hand-pumped well

Figure 4.9 Nakivale: Top view of the iron filter at a hand-pumped well

A total of 16 samples were taken at Nakivale. The team noted that bountiful water was available. A combination of ground- and surface water was used, including certain treatment processes for the surface water. Refugees could also access water from various tap stands (Figure 4.10).

Figure 4.10 Nakivale: Tap stand available to refugees

The overall pH of the water was circumneutral, and the conductivities detected on site were not a concern. As with other camps in Uganda, Nakivale was extremely spread out with a low population density. The water points were also quite spread out; there was usually a drive of several minutes between sampling points. There seemed to be a satisfactory assimilation with the surrounding communities, and the wells seemed to be well cared for by the refugees; cattle guards were common.

4.1.3 Kyaka II

Sunday, 14 August 2011

The team awoke in Mbarara after a full day at Nakivale to continue on to Kyaka II. Sunday was intended as a travel day as the team was transported to Mubende, from which they would visit the Kyaka II settlement. En route, however, the team was able to stop at Kyaka II and make initial contact with the camp personnel. As this was not the intended sampling day and it was relatively late in the afternoon, it was decided the team would return in the morning for a full day of sampling.

The team did observe a feminine sanitary napkin manufacturing process occurring on the outskirts of the settlement. They were able to stop to tour the facility (Figure 4.11).

Figure 4.11 Kyaka II: Sanitary feminine product operation

Here, refugees were given the opportunity to earn an income by working at the facility manufacturing the sanitary pads from shredded paper—a clear benefit provided to the refugees. The team then continued to Mubende.

Monday, 15 August 2011

Sampling at Kyaka II began early in the morning. The team was accompanied in the field by a GIZ consultant. Kyaka II utilizes boreholes, shallow wells, surface water, and natural springs as drinking water sources. The water points were spread out, perhaps even more so than in Nakivale. Several were not accessible by vehicle.

The dammed surface water (Sweswe Dam) available is shown in Figure 4.12. The surface water is utilized in the dry season when groundwater yield greatly diminishes. It is trucked to tanks in the village where the water is treated with alum and chlorine.

Figure 4.12 Kyaka II: Surface water

Like in Nakivale, iron was also a common problem and complaint in Kyaka II. Iron contamination was evident on the concrete apron in Figure 4.13. Iron was similarly evident at several of the wells sampled.

Figure 4.13 Kyaka II: Iron-stained concrete apron

Another problem commonly observed in Kyaka II was high turbidity (Figure 4.14). The turbidity of samples varied spatially. In fact, adjacent wells at times were found to have significantly different turbidities.

Figure 4.14 Kyaka II: High turbidity sample from a borehole

Natural springs were also found and sampled (Figure 4.15). The quality of the springs upon initial observation seems to be quite good: low turbidity, circumneutral pH, and low to average conductivities.

Figure 4.15 Kyaka II: Natural spring well

A total of 13 samples were collected at Kyaka II. Water points tended to be generally far apart and were at times difficult to access. Iron and turbidity were found to be common problems but varied by site in both occurrence and severity. Water seemed to be plentiful, and the wells were well cared for by the refugees. As with Nakivale, cattle guards were a common sight.

Tuesday, 16 August 2011

Upon leaving Kyaka II, the team returned to Mubende for the night. Tuesday was spent driving from Mubende to the UNHCR field office in Hoima. The team's overnight accommodations for the following two nights were also in Hoima from which they would travel to Kyangwali and Kiryandongo.

The group arrived at the Hoima field office in the mid-afternoon for a courtesy visit to the UNHCR local representatives. After a brief meeting similar to others at field and sub-offices, the team retreated to their accommodations to prepare for sampling the following day.

4.1.4 Kyangwali

Wednesday, 17 August 2011

Kyangwali resembled Nakivale and Kyaka II—wells were spread out but water seemed plentiful. Water sources included boreholes and shallow wells, as well as a natural spring (Figure 4.16). The pH ranged from 6.6 to 7.8, a reasonable variation for natural groundwater. Conductivities were well within range of drinking water; none was higher than 1000 µS/cm.

Figure 4.16 Kyangwali: Natural spring

Wells were well maintained by the refugees. Fencing was placed around wells to protect the water points from animals. The areas were also kept free from growth and debris (Figure 4.17). Some discoloration and mud were observed in the cement pours surrounding the wells (Figure 4.18). A few of the wells (*i.e.*, the hand pumps and cement aprons) were noticeably older than others seen both around Kyangwali and around Uganda. The old piping was also causing some discoloration of the water. It was mentioned to the SMU team by those accompanying them through the camp that many of the shallow wells became cloudy after rainfall events. Coliform counts also rose after such events (although this is beyond the scope of this project). A total of 19 samples were collected from Kyangwali.

Figure 4.17 Kyangwali: Protective fencing around a hand-pumped well

Figure 4.18 Kyangwali: Discoloration of cement

4.1.5 Kiryandongo

Thursday, 18 August 2011

The team traveled to Kiryandongo from Hoima for sampling on Thursday, 18 August. The settlement had a similar layout to the previously visited Uganda camps. There was a low population density with long distances between water points. The refugees did not complain of iron contamination; however, there was significant discoloration observed across the camp, which was evidence of iron contamination similar to that seen in Nakivale and Kyaka II (Figure 4.19). Many of the samples were extremely turbid and discolored, as seen in Figure 4.20. Overall pH values were slightly higher in Kiryandongo, averaging between 8.0 and 8.5. These pH values were still within the range of natural groundwater.

Figure 4.19 Kiryandongo: Severe discoloration by iron

Figure 4.20 Kiryandongo: Highly iron contaminated water sample

The use of mechanized boreholes (Figure 4.21) was employed to pump water to larger holding takes for use in the health center of the settlement. This water was then piped to various tap stands throughout the area (Figure 4.22). There were a couple of sites visited that were intended to be sampled but were not operational. Several of the boreholes were also described by others as “old”.

Figure 4.21 Kiryandongo: Mechanized borehole

Figure 4.22 Kiryandongo: Tap stand for mechanized borehole

The sites in Kiryandongo did not seem as well maintained as seen in previous settlements, but many were also older. Some were also seen unprotected from animals (*i.e.*, no cattle guard surrounding the access point).

A total of 19 samples were collected at Kiryandongo. The team was forced to leave Kiryandongo earlier in the afternoon to allow travel time to the Arua sub-office. The team arrived in the evening and was placed in the guest house adjacent to the offices.

4.1.6 Rhino Camp and Imvepi

Friday, 19 August 2011

From Arua, the team was able to visit Rhino Camp and Imvepi for sampling. Due to time constraints and geographic location, both settlements were sampled on the same day. The appearance of the region was quite different from southern Uganda. The elevation was lower, and it was much drier and warmer.

A total of 7 samples were collected at Rhino Camp. All sites visited were boreholes. The depths varied, but the maximum depth at a visited site was much deeper than previously seen (approximately 54 m). Discoloration of the water as well as the concrete aprons was observed (Figure 4.23 and Figure 4.24). Some residents complained of a salty taste, as well. Conductivities in the area were observed to be as low as 596 μS/cm but as high as 805 μS/cm. One point sampled had been abandoned due to *e. coli* contamination.

Figure 4.23 Rhino Camp: Discolored concrete around a hand pump

Figure 4.24 Rhino Camp: Discolored well water

A total of 8 samples were collected at Imvepi. Both hand pumps (Figure 4.25) and tap stands (Figure 4.26) were seen. The protection around the pumps varied. A goat was seen drinking from one hand-pump well, while another was even more poorly protected. Some iron discoloration was seen in Imvepi as well (Figure 4.27).

Figure 4.25 Imvepi: Hand-pump borehole

Figure 4.26 Imvepi: Tap stand

Figure 4.27 Imvepi: Iron-discolored concrete apron

4.1.7 UNHCR Country Office – Kampala

Saturday, 20 August 2011 to Sunday, 21 August 2011

The return trip from Arua to Kampala consumed the entire day Saturday. After awaking in Kampala on Sunday, a meeting was arranged at the UNHCR country office for a debriefing prior to the team's departure from Uganda.

The general experience and immediate observations were conveyed during the debriefing. Water seems to be plentiful in Uganda. Both ground- and surface water were utilized. Most surface water which was used was at least minimally treated (*e.g.*, Nakivale and Kyaka II). Most boreholes were generally good yielding, although this may alter during the dry season.

The major issues immediately observed by the team on this initial visit were the iron and high turbidity at some locations. While not an immediate health concern, iron causes bad taste and may even cause refugees to bypass the safe but poor tasting iron-contaminated source for a microbially-contaminated source which causes sickness. For this and other reasons, the iron contamination was seen as a major issue.

The initial trip to Uganda was mostly considered a success for such a large number of settlements. Most, but not all, were visited, but more time at each camp may be beneficial to both parties.

4.2 Kenya—August 2011

4.2.1 Nairobi

Monday, 22 August 2011 to Thursday, 25 August 2011

The WASH mission in Kenya was solely staffed by Dr. Andrew Quicksall of SMU. The ongoing emergency in the Dadaab region necessitated the leanest of teams due to constraints on logistical support. For this reason, the SMU team decided to staff the Kenya mission with a single team member. The first days in-country were spent in Nairobi. A fraction of this time was spent recuperating from the freshly finished Uganda mission. A courtesy call on the Kenya country office was paid. Dr. Quicksall met with the country WASH officer and discussed WASH issues and logistics for the forthcoming trips. Time in Nairobi was further extended due to a delay in travel to Kakuma. The scheduled flight was delayed one day; the aircraft and flight time were commandeered for a flight to Mogadishu in response to the growing crisis there. The flight was rescheduled for the following morning.

4.2.2 Kakuma

Friday, 26 August 2011 to Sunday, 28 August 2011

Dr. Quicksall arrived in Kakuma via UN flight one day after the originally scheduled date. This yielded a time pressure to reach all of the camp's water points during the remaining time for the mission. As a result, Dr. Quicksall pressed to begin field work on the day of arrival. Upon arrival, Dr. Quicksall met with the UNHCR WASH consultant. Afterward, a courtesy call was paid to the implementing partner Lutheran World Federation. WASH staff from LWF then accompanied the mission to water points in Kakuma I. The following day sampling work was continued into Kakuma II and III.

The water system in Kakuma was in general very solid, well-designed, and very efficient. All water was derived from deep boreholes accessed by mechanized submersible pumps. Water in Kakuma was then stored in large elevated tanks (Figure 4.28). Large storage enabled even delivery, and the elevation permitted a gravity-flow driven system.

Figure 4.28 Kakuma: Large elevated water storage tanks

Kakuma had recently experienced significant flash flooding. Numerous sites suffered from heavy erosion from both this event and similar recurrent events in the past. Boreholes near the river edge were protected by erosion control measures (Figure 4.29). If borehole sites had been consumed by erosion, physical damage could be irreversible and the borehole could be forced to be decommissioned. Further, flooding of the site without physical damage could increase the likelihood of down hole contamination.

Figure 4.29 Kakuma: Erosion control near borehole

A large revamping of numerous boreholes and the water delivery system was underway. Multiple boreholes were being re-drilled to increase total capacity (Figure 4.30). The current capacity of the system in Kakuma was sufficient, but numerous boreholes were forced to near maximal outputs. This yields a system at risk of failure. If one or more boreholes were to become non-functional due to fuel shortage, generator or other mechanical malfunctions, or the aforementioned physical damage from flash flooding, then the system could become insufficient for the current demand.

Figure 4.30 Kakuma: Drill rig for new borehole construction

Additionally, contingency planning for Dadaab relocations, as well as South Sudan, involve the potential for very large influxes to Kakuma. If such events are to occur, Kakuma will need significantly larger water delivery. It is because of both the potential large increase, as well as the desire to stabilize the current system, that new boreholes are being drilled.

4.2.3 Nairobi

Sunday, 28 August 2011

A short layover in Nairobi was necessary. Kakuma and Dadaab flights do not run daily.

4.2.4 Dadaab Camps

Monday, 29 August 2011 to Thursday, 01 September 2011

Upon arrival in the Dadaab region, Dr. Quicksall met the UNHCR Senior WASH Coordinator. Upon attending to logistical necessities in the UNHCR compound, a courtesy call was then paid to Oxfam. Dr. Quicksall and a team from Oxfam then proceeded to Ifo 2 (or Ifo extension) for water sampling and field measurements. Ifo 2 was one of the locations the Dadaab area was spreading into. Oxfam was preparing the water system as refugees were being located to the area. At the time, the area was filled with short-term temporary tents that sparsely filled the region (Figure 4.31). Elevated water tanks had already been constructed and stood amongst mostly barren land (Figure 4.31). The implementing partners were clearly ahead of the settling of the area in terms of water delivery. This was fortunate as it mostly prevented the necessity of water trucking for this site.

Figure 4.31 Ifo 2: Tents and water tank

Throughout the Dadaab cluster of camps, borehole sites included auto dosing facilities for chlorine additions (Figure 4.32). New construction included these facilities while older sites were retrofitted to include the same.

Figure 4.32 Dadaab Camps: Automated chlorine dosing system

Sodium hypochlorite solutions were stored in protected cabinets (Figure 4.32) and added to the borehole outflow via small dosing pumps also contained within the cabinets (Figure 4.32). Chlorine addition lines were plumbed directly into the system via small bore tubing (Figure 4.33).

Figure 4.33 Dadaab Camps: In-line chlorine addition

Auto-dosing should help to regulate chemical use (and possible waste), and it should improve dosing consistency. There is the risk of residual chlorine loss during storage. This risk exists with batch treatment but may be more frequent in an in-line system if storage times are inconsistent and occasionally long. As long as regular maintenance of these systems occurs and as long as residual chlorine is routinely measured at taps furthest from the borehole, then the addition of such auto-dosing equipment is an excellent improvement.

The following morning Dr. Quicksall proceeded to Hagadera. After a short meeting with CARE Kenya, the team sampled all of the boreholes in Hagadera. Water trucking was necessary during the emergency and was observed in numerous locations including Hagadera (Figure 4.34). Implementing partners were water trucking to the outskirts of camps in the Dadaab region while wells were being rehabbed, new lines were being run, and refugees were moved to more permanent sites.

Figure 4.34 Hagadera: Water truck

In the afternoon Dr. Quicksall sampled in Ifo. This was the original Ifo camp prior to the addition of the newer extension area sampled the day prior. All boreholes were sampled in Ifo 1. Solid waste was an ever obvious issue in the Dadaab region. While in Ifo, it was observed that large heaps of solid waste, both burned and unburned, were in close proximity to boreholes (Figure 4.35).

Figure 4.35 Dadaab Camps: Solid waste

The following morning, sampling was done in Dagahaley. The CARE Kenya team assisted Dr. Quicksall again in sampling all boreholes (Figure 4.36). Dr. Quicksall left the Dadaab region that afternoon and transferred on immediately to a series of return flights to Dallas, TX, USA.

Figure 4.36 Dagahaley: Sampling

4.3 Bangladesh—November 2011

4.3.1 Team Arrival and Introduction

Saturday, 12 November 2011 to Sunday, 13 November 2011

The WASH mission in Bangladesh was an integrated team consisting of a group from Southern Methodist University, Dr. Andrew Quicksall, principle investigator, and Katherine Grant, graduate student, and a team from the Swiss Federal Institute of Aquatic Science and Technology in the Department of Water and Sanitation in Developing Countries (EAWAG-SANDEC), with members Dr. Richard Johnston, Mr. Christoph Luthi, Mr. Mingma Gyalzen, Dr. Haroon Ur Rashid; along with Mr. Dominique Porteaud from the headquarters of UNHCR in Geneva. The individual goals of each team were separate but complementary.

Upon arrival in Dhaka, Bangladesh, the team met with the Country Office to discuss the overall mission plan, take care of introductions, and brief the team on the two different locations to be visited. The team left for Cox’s Bazar that afternoon. After a short flight, the team arrived in Cox’s Bazar and attended a meeting held at the field office to introduce the mission team to the UNHCR field team led by Wilfredo Tiangco (Boyet) and other UNHCR employees who were vital to the success of the mission. There were reportedly 200,000 additional unregistered refugees living in Bangladesh, including in two areas to be visited, Leda and the unregistered camp in Kutapalong. These areas are unassisted by UNHCR due to the political situation.

4.3.2 Nayapara

Monday, 14 November 2011 to Tuesday, 15 November 2011

This camp is located on the far southern tip of Bangladesh on the border with Myanmar and required a two-hour drive from Cox's Bazaar. The team spent two days in Nayapara and stayed overnight in Teknaf, at the Netung Hotel. After arriving at the camp, a meeting was held for introductions and discussion of daily plans and desires. The first order of business was a general camp tour to view all aspects of refugee life and to get an overview of the camp. As was common in Bangladeshi refugee camps, Nayapara was no different in its extreme population densities. There are 17,630 refugees registered and assisted in Nayapara, which has a land area of 3.234 km^2. This leads to extreme density, which can be seen in the tightly compact housing structures in Figure 4.37. Complications arise due to the population size of the camp, especially in the sanitation sector such as overflowing latrines, latrine coverage, and overall maintenance of these facilities (Figure 4.38). The location of latrines is a very sensitive issue to overall water quality, and these sanitation issues were the focus of the EAWAG mission. The handling of sewage was precarious. The latrines are manually emptied and taken to the outskirts of the camp to undergo ‘treatment’; however, the wastes will eventually leach back into the reservoir in a closed loop system possibly elevating levels of nitrate and other chemicals of concern.

Figure 4.37 Nayapara: Housing structures

Figure 4.38 Nayapara: Overflowing latrines

Nayapara had an extensive storm drainage system used in the rainy season for water overflow and control (Figure 4.39). The system was intricate and necessary; however, it seemed, in the dry season, to be used for trash and human waste. There were visible attempts to sanitize these drains through the use of a bleaching product; however, this could become a health hazard as these drains flow back into the water reservoir.

Figure 4.39 Nayapara: Extensive drainage system

Water is supplied through a distribution system consisting of three water treatment plants. The main water source was a surface reservoir, which is replenished, in the rainy season. The water is pumped from the reservoir into the three water treatment facilities consisting of a flocculation (aluminum sulfate addition) and a chlorination treatment (Figure 4.40). After the treatment process the water is pumped to distribution tanks where is it distributed to the different blocks in the camps. The water is only distributed during two periods in the day: a morning and evening shift for approximately thirty minutes. This was not observed to be consistent during the team's visit to the camp. Additionally, taps, normally used to control the flow of water, were removed due to theft. Therefore, the refugees have limited access to water, leading to long lines (Figure 4.41) and ultimately water wastage because there is no control of flow when the water is turned on from the main distribution tanks. Because the tap stands were not metered, the exact amount of water flowing to each tank throughout the camp could not be accurately measured. There are 57 water distribution tap stands throughout the camp. It remains unclear whether the refugees are getting the reported amount of daily water for drinking, and it seemed unlikely that each refugee is getting sufficient water for hygiene and cooking.

Figure 4.40 Nayapara: Water treatment plant

Figure 4.41 Nayapara: Lines formed for water

The SMU team's focus was on the quality of water supplied to the refugees. On-site testing was completed using a YSI field meter and probe to measure pH, temperature, dissolved oxygen (DO), conductivity, and oxidation reduction potential (ORP) (Figure 4.42). These initial tests gave a basic sense of overall quality, but four samples were collected to be taken back and analyzed using laboratory equipment. The initial measurements showed circumneutral pH values and low conductivities. Nine sites were sampled in Nayapara: testing each water treatment plant at various stages in the process, as well as water at individual tap stands to test pipeline contamination. The exact amounts of aluminum sulfate and chlorine added to the raw water were never determined.

Figure 4.42 Nayapara: The SMU team's sampling equipment

During the mission, a group from the company Aquasure held a demonstration of their product (Figure 4.43). This system was an emergency, portable water sanitation and distribution system used to treat extremely turbid surface waters. The demonstration showed it produced clean water; however, this would be a useful solution primarily in an emergency situation, such as a typhoon or flood, but not a sustainable system for everyday water processing.

Figure 4.43 Nayapara: Aquasure demonstration

4.3.3 Leda

Tuesday, 15 November 2011

The team visited the adjacent ‘unregistered’ camp known as Leda. This camp was in utter crisis at the time of the visit. It was estimated that about 13,000 people were living in Leda at this time. Due to the extreme population densities, refugees had abandoned all latrines and were practicing open defecation off the main road, which led to a severe sanitation problem. However, even more dire, was the lack of water in the camp. The previous season the former NGO had left the camp, so a small reservoir was not dammed in the rainy season as was the yearly custom, leaving it dry (Figure 4.44). There was one large open well that had limited water and a small creek (Figure 4.45) to the back of the camp which would be dry in a few weeks, as at the time of the mission it was the beginning of the dry season. If that reservoir had been filled, then there would have been sufficient water as this camp had the necessary water treatment tanks to distribute water through the camp. No water samples were collected in Leda due to the lack of water. These conditions were almost unbearable to witness.

Figure 4.44 Leda: Empty reservoir

Figure 4.45 Leda: Drying creek

The entire team left Teknaf and traveled back to Cox's Bazar.

4.3.4 Kutapalong

Wednesday, 16 November 2011 to Thursday, 17 November 2011

The Kutapalong camp is located about a one hour drive outside of Cox's Bazar in Ukhiya, Bangladesh. It has 11,679 registered refugees living in 2.70 km^2. It is also surrounded by an estimated 20,000 additional refugees who are unassisted by UNHCR due to political policies dictated by the Bangladeshi government.

The combined team met with camp leaders, but then the SMU team split off to collect water samples, while the team from EAWAG toured the camp. Kutapalong had excellent water coverage, with a total of 107 (97 functioning) tube wells. The SMU team was able to sample 38 wells in a large spatial distribution across the camp area. These tube wells were usually clustered with 2-7 wells in one area (Figure 4.46). This allowed the sampling of more wells in a shorter period of time. The SMU team only had about a day and half for sampling due to scheduling with the other mission. Many times these water clusters were located the required 'walking' distance away from latrines; however, due to elevation changes, the latrines were spatially closer to the water points than reported and many times they were uphill. This is not a likely problem for well contamination since all of the water points are tube wells of sufficient depth; however, drainage toward a water point can possibly be a dangerous sanitary condition. Another observation was that some tube wells were abutting rice fields, the fertilization of which was unclear but suspected. This could lead to potential contamination of nitrate with highly fertilized soils (Figure 4.47).

Figure 4.46 Kutapalong: Cluster of wells

Figure 4.47 Kutapalong: Tube well surrounded by a rice paddy

The pH had extreme variation within the camp. A low value of 3.92 was recorded with the average pH being generally in the 4-5 range, as well as pH values in the 7-9 range. This is not a normal value range for the pH of natural groundwater, particularly in such a small geographic area. Drinking water with a pH of 3 is not harmful; however, an acidic water source can stabilize different metals in solution, which can lead to serious health hazards. For example, water in Kutapalong is collected in aluminum cisterns (Figure 4.48), which at a circumneutral pH would be harmless; however, in more acidic environments aluminum, a toxic metal, can dissolve and leach into the drinking water, becoming a potential health risk. The varying pH values could be an indicator for metal stability in the groundwater.

Figure 4.48 Kutapalong: Aluminum cisterns used to hold water

During sampling and while talking with the refugees, it became clear that there was significant iron contamination across the camp. This contamination was not seen to be clustered, but rather random throughout the tube wells. Depths on the wells were many times unknown, so that could be a reason why one tube well was Fe contaminated, while another one, 2 m away showed no visible Fe contamination. The Fe contamination was so bad that in many cases wells had been completely abandoned for drinking. Iron staining was visible on the outside of the well heads, as seen in Figure 4.49.

Figure 4.49 Kutapalong: Iron contaminated well

4.3.5 Unregistered Camp at Kutapalong

Thursday, 17 November 2011

The SMU team was able to visit the unregistered camp surrounding Kutapalong, for only a very short time. Overall, it was in better condition that Leda because of the access to groundwater. It had the same overcrowding issues that plagued the other Bangladeshi refugee camps (Figure 4.50).

Figure 4.50 Unregistered camp surrounding Kutapalong

The teams presented their initial observations and comments to the Cox's Bazar sub-office.

4.3.6 Final Meeting and Back to Dhaka

Friday, 18 November 2011 to Monday, 21 November 2011

The team traveled back to Dhaka to present their initial report to the Country office. Overall, Bangladesh had excellent water coverage in Kutapalong. The team suggested that Nayapara needed to figure out a more efficient distribution system because refugees were not getting the daily required amounts of water. Initially, Kutapalong showed varying pH values across the camp as well as extensive iron contamination. Chemically, Nayapara did not have any concerns. The two unregistered camps needed to be addressed by the government and water trucking was discussed for Leda. After the debriefing, the team left Dhaka to return to the United States.

4.4 Djibouti—December 2011

4.4.1 Team Arrival

Thursday, 01 December 2011 to Friday, 02 December 2011

The team from Southern Methodist University (SMU) arrived in Nairobi, Kenya. Participating parties in this team traveling onward to Djibouti were Dr. Andrew Quicksall, principal investigator and head of the research group, Dr. Nathan Huntoon, faculty member at the Lyle School of Engineering at SMU, and Drew Aleto, graduate student in the Quicksall research group. The evening of arrival was used to make contact with the appropriate UNHCR personnel and to settle in.

The team from SMU met as previously scheduled with the UNHCR Regional Office in Nairobi on Friday to discuss the planning of the future Field Innovation Centre in partnership with SMU and UNHCR. Principal parties from SMU involved in these discussions were Dr. Andrew Quicksall and Dr. Nathan Huntoon.

The SMU team departed for Djibouti late in the evening of 02 December for a late-night arrival.

4.4.2 Djibouti City/UNHCR Country Office

Saturday, 03 December 2011 to Sunday, 04 December 2011

The SMU mission arrived at Djibouti International Airport at approximately 2:00 AM; visas were acquired on site. Transport via taxi was taken to Hotel Ali Sabieh in the city of Djibouti.

All offices were closed on Saturday; the day was therefore utilized as a work day for the team in the hotel rather than travel to the camps or meetings in the UNHCR country office in the city of Djibouti. During this time, field equipment was checked and the team discussed a plan for the mission.

An arranged UNHCR vehicle transport was scheduled to transport the SMU team from the hotel in the city of Djibouti to the UNHCR country office around 9:00 AM on Sunday. In the vehicle were the UNHCR driver and Edmond Onana, the Water, Sanitation, and Hygiene (WASH) coordinator for the UNHCR Djibouti camps.

At the UNHCR country office in the city of Djibouti, the SMU team and Mr. Onana met with the program officer to express gratitude for the invitation and opportunity to visit the UNHCR camps in Djibouti and discuss the purpose and goals of the team's mission to the Djibouti camps. The goals discussed included obtaining a general idea of the WASH operations in the camps; sampling as many water sites as possible during the time the team was at the camps, including a general spatial distribution of these sampling sites; and obtaining any other information the program officer, WASH representative, government official, or team member deemed important in our drinking water analysis cooperation of UNHCR sites.

Upon completion of the meeting at the UNHCR country office in the city of Djibouti, the drive to Ali Sabieh and then to the Ali Adde camp began. The team arrived in Ali Sabieh to check into their hotel accommodations in the afternoon on Sunday, and then continued to the Djibouti government office for a cordial announcement of the team's presence en route to Ali Adde. Full cooperation was received from the government official with a request that the team also sample a few drinking water points in the town of Ali Sabieh for the benefit of the town's citizens. It was agreed the team would meet with him upon the conclusion of the sampling trip to the camps of Ali Adde and Holhol prior to returning to the city of Djibouti.

4.4.3 Ali Adde

It was then decided that sufficient time remained in the day to make a trip to the Ali Adde camp for a tour and to obtain general camp and layout information; however, no sampling would take place. Upon arrival at Ali Adde, a 4-m well was seen under construction (Figure 4.51) on the far southwest of the camp in the river channel. It had been dug and was in the concrete phase of construction—building the concrete wall which lines the well. The seemingly great distance to the camp was noted. The seemingly lax working hours of the contracted workers was also noted by the accompanying WASH representatives.

Figure 4.51 Ali Adde: Hand-dug well under construction outside of camp

Early in the camp tour, the team noticed solar panels near the 50-m^3 batch chlorination station (Figure 4.52). It was explained the original purpose of these solar panels was to power the motorized pump for the borehole adjacent to the panels (borehole 1 yields 3.5 m^3/hr but was not functioning; borehole 2 yields 3 m^3/hr and was being used to fill the chlorination tank). The panels, however, had been damaged by the refugees themselves despite being surrounded by a chain-link fence with barbed wire—children would throw rocks at the panels—and were damaged to an extent rendering them unusable. The mechanized submersible pump, therefore, was being powered by a generator. In the team's opinion, it seems that if the solar panels can be protected from damage, the pump and chlorination process may be much more efficient. Furthermore, the pumping, chlorinating, and draining of the chlorination tank should be optimized to utilize all resources available (*e.g.*, the solar panels, the storage tank, and the chlorination tank) to their utmost potential. The events should be optimized to provide the most drinking water to the refugees at the most critical times.

Figure 4.52 Ali Adde: Non-functioning solar panels

The team then visited a newly constructed (yet incomplete) 4-m hand-dug well which was still lacking the hand pumps. The mission spent the remainder of the afternoon touring the bulk of the camp and getting a feel for how the refugees accessed water. Water access was provided mainly through these hand-dug 4-m wells along with a batch chlorination tank which was then pumped to a holding tank and gravity fed to tap stands. There were also many privately-owned wells along the river channel which were accessible only by the owners of the well; these were usually kept under lock and key for their sole access. One of many of the privately-owned wells along the river basin is shown in Figure 4.53 with the common locking mechanism and the owning parties who, if sampling were to occur, were needed to be fetched to unlock the well. As aforementioned, no sampling was done on this day due to limited time at the Ali Adde camp.

Figure 4.53 Ali Adde: Privately-owned well

Monday, 05 December 2011

Monday was a full sampling day at Ali Adde. The team departed their hotel accommodations in Ali Sabieh around 8:30 AM to commute to the camp, arriving 45 to 60 minutes later. The first sampling site was a hand pump well near the 50-m^3 batch chlorination tank. It was seen on Sunday although the motorized pump feeding the tank was not on at the time. The pump was, however, turned on shortly thereafter allowing direct sampling from the water filling the tank from the motorized pumping from the borehole (Figure 4.54).

Figure 4.54 Ali Adde: Sampling the batch chlorination tank

Throughout the day, several drinking water points were sampled (in total, 28 samples were collected from Ali Adde). A distribution of sites was chosen based on type (borehole, hand-dug well, private, etc.) and location. Several hand-dug wells under construction were also sampled. Many private wells along the river channel were also able to be unlocked and accessed for sampling. A notable issue with these private wells—and other open wells lacking the appropriate protection—may be defecation by donkeys near the open wells. Donkeys often stand immediately adjacent to the open well while a refugee is obtaining water (Figure 4.55). Furthermore, donkeys are used for transporting items throughout the camp, including among the many open wells along the river basin protected merely with a makeshift cover. This issue and its severity may be reinforced by nitrate and nitrite data found in the samples.

The most glaring issue observed while sampling in Ali Adde was the high conductivity levels. All samples collected had conductivity values above 1000 μS/cm which is widely considered to be the threshold for drinking water without affecting taste.

Figure 4.55 Ali Adde: Donkey with a refugee fetching water from a private well

Near the end of sampling on Monday, the team walked through the refugee camp and was able to speak with a long-time refugee to get an overall impression of the water from the refugees' perspective.

The team also encountered an Ethiopian refugee who was willing to allow sampling of his private in-home ceramic filter (Figure 4.56). Samples were collected both pre- and post-filtration so that filter effectiveness may be observed and reported.

Figure 4.56 Ali Adde: Ceramic filter in a refugee's home

At the end of the day en route back to Ali Sabieh, a concrete latrine slab operation was observed where uniform and well-designed concrete slabs are made for the refugees' latrines. While latrines and overall sanitation are not currently within the scope of the project, the activity was noted both for the team's academic purposes, as well as for the overall benefit to the camp and its refugees.

Tuesday, 06 December 2011

Tuesday was the second and final day for sampling in the field. The primary goals at the onset of sampling were to finish a few sites in Ali Adde then travel to Holhol, a camp currently under construction which will accept refugees in the near future. This was convenient as there is a road from Ali Adde to Holhol which eliminates the need to return to Ali Sabieh to get to Holhol.

Firstly, a site was visited to observe a 4-m hand-dug well being constructed in Ali Adde which was in the digging phase of construction. A sample was taken from the groundwater seeping into the well transversely (Figure 4.57). Gravity-fed tap stands near the southeast part of the camp were also sampled prior to departing the camp.

Figure 4.57 Ali Adde: A hand-dug well under construction

As planned, sampling was concluded after a relatively short time in Ali Adde. A total of 28 samples were collected in Ali Adde. The team then traveled to Holhol for sampling although the camp was not yet completed.

4.4.4 Holhol

One 100-m^3 holding tank had been built on a hill adjacent to the river basin (Figure 4.58). The first samples were taken from a tap from a borehole in the river basin near the previously existing UNHCR tank structures (it became known that Holhol had also been a previously occupied camp). There was also a hand-dug well adjacent to the borehole (covered) which was sampled.

Figure 4.58 Holhol: 100 m^3 storage tank

Near the first sampling sites were, like at Ali Adde, solar panels (Figure 4.59). These panels, however, did not look optimized as they were pointed perpendicular to the ground rather than in the appropriate position for the latitude to maximize contact with the sun. Similar to those at Ali Adde, because these are already present at the camp (therefore eliminating the initial capital cost), it seems they should be utilized as a power supply for the adjacent pump to reduce energy use and make the overall operation more efficient.

Figure 4.59 Holhol: Existing solar panels

Several samples were subsequently taken along the river basin. These included samples from the privately-owned wells belonging to current area residents in order to get a spatial representation of the area which will soon be providing drinking water to the refugees in Holhol camp. Recently constructed tap stands which will be fed by the 100-m^3 storage tank were also sampled (Figure 4.60).

Figure 4.60 Holhol: Tap stand nearing completion

A total of seven drinking water samples were collected at Holhol ranging from the borehole to hand-dug and private wells and tap stands, mostly along the river basin. The quality found during on-site measurements at Holhol camp was similar to Ali Adde; the main parameter to note is conductivity. These were higher than what is normally found in drinking water, as also mentioned for the sampled sites at Ali Adde camp. To reiterate, the common threshold for conductivity in drinking water is 1000 μS/cm; all samples in Holhol had conductivity levels significantly above this threshold. Noteworthy as well is the leaking tap at the initial borehole sampled. The attempted—but ineffective—remedy was tape (Figure 4.61).

Figure 4.61 Holhol: Leaking tap

En route to Ali Sabieh for the evening, the SMU team took the opportunity to install a monitoring device on a pump with Massimo Lucania, a consultant working with UNHCR on a temporary basis. Mr. Lucania was available and traveled with the team in the field for discussion and information.

4.4.5 Town of Ali Sabieh

Wednesday, 07 December 2011

All sampling for the UNHCR was completed on the previous days as noted above. Wednesday was used as a travel day from Ali Sabieh to the city of Djibouti for debriefing with the national office. However, en route the team stopped at the local Djibouti government office to fulfill the representative's request from the first meeting to sample drinking water access points in the town of Ali Sabieh.

Upon arrival at the government office, the representative was not present. He was reached via telephone and sent a colleague in his place. Samples were collected from three wells within the town limits—the first in front of a business near the town center while the others were private wells not far from the town center. All were open wells. As these were not within the scope of the SMU-UNHCR cooperation, these samples will be analyzed for spatial and academic purposes only.

The SMU team and UNHCR driver then began their return to the city of Djibouti around midday. Upon return, a meeting with the country office program officer was arranged for the following morning prior to the SMU team's departure from Djibouti.

4.4.6 UNHCR Country Office

Thursday, 08 December 2011

As previously mentioned, a debriefing meeting with the UNHCR country office program officer was prearranged. The team was transported to the UNHCR office where the events of the previous days were discussed in some detail. The overall observations, such as the extremely high conductivities and a lack of cohesive infrastructure, were conveyed, along with the team's overall activities in the field within Djibouti, what was to be done with the data collected and to be obtained through instrumental analyses in the laboratory, and how Djibouti will potentially benefit.

As discussed at the debriefing meeting, drinking water access was provided through multiple options. Several 4-m hand-dug wells were seen in Ali Adde camp. A typical capped well is shown in Figure 4.62, although in this figure the hand pumps have not yet been placed on the concrete cap. Another access type seen was tap stands. A tap stand from Ali Adde is shown in Figure 4.63. The other most common drinking water access included private open wells. A typical private open well is shown in Figure 4.53.

**Figure 4.62 Ali Adde: Typical capped 4-m hand-dug well
Hand pumps yet to be placed**

Figure 4.63 Ali Adde: Tap stand

A few other notable problems and observations were discussed while debriefing in the UNHCR national office. No definitive complaints regarding taste were encountered; this was somewhat surprising considering the high conductivity levels measured at all sites at both Ali Adde and Holhol. One of the issues noticed by the team was the inefficiency in distribution, *i.e.*, a coherent and master-planned system of distributing water to the refugees. Another problem encountered by the team and made clear by the WASH consultants was the lack of a dependable workforce both within the refugee community and the contracted workers. Furthermore, as previously mentioned, the donkeys' proximity to open wells may cause serious chemical contamination. Again, the severity of the contamination likely originating from the donkeys may be reinforced by chemical data from the laboratory, such as the amount of nitrate and nitrite present. The existing solar panels at both Ali Adde and Holhol could also be utilized.

The SMU team then departed Djibouti in the afternoon and returned to Nairobi, Kenya, and eventually to the United States.

4.5 Liberia—December 2011

4.5.1 Team Arrival

Friday, 09 December 2011 to Sunday, 11 December 2011

The Southern Methodist University (SMU) research team arrived at Monrovia Robert's Airport on Friday at 6:30 PM. The research group consisted of the principal investigator, Dr Quicksall, and a graduate student in the Quicksall research team at SMU, Haddijatou Bayo. The bags containing the equipment did not arrive with the flight. As a result, the trip to Sagleipie in Nimba County was postponed to Monday (12 December 2011), instead of Saturday (10 December 2011). A UNHCR driver, Joseph Taylor, picked up the group from the airport and dropped them off at The Cape Hotel. The bags with the equipment arrived Sunday intact, and the SMU team immediately conducted equipment calibrations in preparation for the mission the next day.

4.5.2 Sagleipie/Bahn/Gblah

Monday, 12 December 2011

The group left for Sagleipie at 6:30 AM with Dr. Petros who works for UNHCR as the Head of Public Health in Liberia. Upon arriving in Sagleipie at 12:30 PM, the SMU team was introduced to Liv Almstedt, the UNHCR Water, Sanitation and Hygiene (WASH) Coordinator, who travelled with them to all the refugee camps and host communities for the rest of the mission.

The first stop on the way to Bahn camp was at a village called Gblah. The water in this village comes from boreholes equipped with hand pumps (Figure 4.64). Three wells were tested in total. Water samples were tested for properties like pH, conductivity, temperature, dissolved oxygen (DO), and oxidation reduction potential (ORP). These tests were conducted for all of the wells from each of the sites the SMU team visited in Liberia. Furthermore, water samples were collected from each well at each site, and analyzed in the lab at SMU upon arrival in the U.S. The GPS location for each well was also recorded. Each well to be tested was chosen based on its spatial distribution in relation to other wells to make sure that representative water samples were collected for the whole site.

Figure 4.64 Gblah: Children pumping water from a hand pump

The mission team arrived at Bahn camp at around 3:30 PM. At the time, Bahn was shelter to about 5,000 refugees but had a capacity to hold 15,000 people. Most of the refugees are from Cote d'Ivoire seeking asylum after the unrest that followed the presidential elections in November 2010. Four wells were tested in total. Submersible pumps were used to pull the water out of the well using a generator. The water was then stored in a tank or a large storage bag where it might be chlorinated and then distributed to the taps (Figure 4.65). Water distribution from these taps had to stop during pumping which could take up to 9 hours. All the camps that were visited had outside communal latrines and showers, which were each shared by 12-20 refugees. The latrines were located at least 30 m away from the wells to prevent contamination of the water. The driver had to report back to the UNHCR office by 6 PM, so the SMU team headed back to Sagleipie at 5:30 PM.

Figure 4.65 Bahn: Large water storage bags (front right) connected to taps (back center)

4.5.3 Zwerdu/Dougee/Solo/PTP

Tuesday, 13 December 2011

A UNHCR driver picked up the SMU team at 7:00 AM at the UNHCR guesthouse and headed to Dougee located in Grand Gedeh County. This camp has a capacity of about 10,000 persons and was at only half capacity at the time. The UN staff at Dougee camp explained that it was difficult to distinguish Liberian natives from the refugees and that there might be hundreds of Liberian natives already living in the camp. Some of the refugees who lived in temporary shelters (Figure 4.66) tried to make it more convenient by adding extensions made of pine branches. The yield from the wells that were tested was good. The water at a creek adjacent to the camp was tested because there were plans to construct a new well close by. A new well, walking distance from the camp, was under construction (Figure 4.67).

Figure 4.66 Dougee: Temporary refugee shelters

Figure 4.67 Dougee: Well under construction

The SMU team then visited the host community in Tian Town. After explaining what kind of tests they would be doing, the town people were very helpful, and the team did not have any issues collecting and testing water samples. Three wells were tested in total. There were complaints that some of the wells had low yield during the dry season.

Solo camp, also located in Grand Gedeh County, was next on the SMU mission. Six wells were tested here. The camp had one borehole with a submersible pump that could fill a 95-m^3 tank in 9 hours. This tank was the largest encountered in the camps visited Liberia. One of the wells would become turbid after pumping for a long time. The water yield was good for most of the wells tested.

The SMU team spent the night at Zwerdu UNHCR guesthouse.

4.5.4 PTP/Harper/Little Wlebo/Fish Town

Wednesday, 14 December 2011

Although the visit to PTP camp had been cancelled due to the delay in starting the mission, the team decided to conduct an early-morning visit to the camp on Wednesday. Three wells were tested in total. The refugees constructed a hand-dug well at this camp (Figure 4.68). They explained that they prefer the water from this well because the water was cooler and tasted better than the water from the other wells. After numerous failed attempts to try to stop the refugees from using water from this well, the WASH team leader required that all the water collected from the hand-dug well must be chlorinated with aquatabs on site to lower risk of disease.

Figure 4.68 PTP: Hand-dug well

One of the hand-pump wells was close to a newly-constructed school in the camp. The children were taught in English. This was interesting since most of the parents and the older children spoke only French and their native language. Some of the refugees earned some income by selling different produce like palm oil seeds and habañero peppers. Others with carpentry skills made wooden furniture from the trees around the camp with very few tools (Figure 4.69).

Figure 4.69 PTP: Food items for sale

The SMU team immediately headed to Zwerdu just in time to get on a small UN-chartered plane to Harper. The 45-minute flight departed from the Pakistani Battalion camp in Zwerdu. At the airport, the team was introduced to Sara, a trainee, who worked for the UNHCR under Liv Almstedt. She was in charge of constructing a desludging site at Little Wlebo camp in Harper. Harper, a city on the coast of Liberia, is mostly covered with savannah grassland with pockets of dense forests. The views of the beaches were very breathtaking. The buildings looked old and tattered, but they provided a glimpse of what Harper used to look like before the war six years ago.

Thursday, 15 December 2011

The research team headed to Little Wlebo in Maryland County. Some tests were conducted at an estuary close to the sea and at a stream close to Little Wlebo camp. As expected, the conductivity was extremely high at the estuary. The water from a well close to the estuary was also tested, and the conductivity was normal. The spring-fed stream was tested because the water was sometimes used as a back-up for some people when the other wells were out of service. The water from this stream was quite turbid.

Nine wells in total were sampled at Little Wlebo. One could immediately see that the flood trenches (which were dug to prevent the homes from being flooded during the rainy season) at this camp were more advanced compared to the other camps (Figure 4.70).

Figure 4.70 Little Wlebo: Flood trenches

These flood trenches were thankfully covered and will hopefully prevent numerous diseases. Each well had its own number for easy identification, and the yield from these wells was good. The engineer also included concrete slabs (Figure 4.71) to help with hand washing.

Figure 4.71 Little Wlebo: Concrete slabs for hand washing

The team then collected water samples at the host community near Little Wlebo camp.

On the way back to the UNHCR office, water samples were collected at Fish Town. The town people explained that they have been experiencing water shortage due to low yield and mechanical issues with the hand pumps.

The SMU team spent the night at the Christian Missionary Guesthouse in Harper.

4.5.5 Departure

Friday, 16 December 2011 to Sunday, 18 December 2011

The SMU team went to the local market in Harper to buy souvenirs. They were disappointed to see that almost all the goods being sold were imported from other countries. They asked a restaurant owner, Bob, if he knew of artists around the area, but he said that he did not know of anyone (Figure 4.72). He explained that he used to paint before the war.

Figure 4.72 Harper: Bob (left) and his assistant (right)

The SMU team was scheduled to fly to Monrovia at noon from Harper, but due to some complications, they had to travel by road. The trip back to Monrovia took two days, and the team had another opportunity to see the beautiful countryside from the car. The team spent the night at Zwerdu UNHCR guesthouse, and Prince, the cook, provided them with a delicious meal.

On Saturday, the SMU team arrived at The Cape Hotel in Monrovia at around 5:00 PM and left for the United States the next day.

Chapter 5: Water Quality Database

5.1 Rationale

Typical water quality measurements under emergency situations center on turbidity, coliform, and post-treatment residual chlorine. Measurements beyond these few tests are unlikely and for good reason. Under emergency conditions the goal is to produce potable water that will not be a vector for disease. Low turbidity, or clear, water that is devoid of coliform bacteria fits this need. Effective levels of residual chlorine provide a lasting outcome as well. Providing water to populations on short timescales is well served by such efforts. Once a community gains minimal stability and is to utilize a water source for intermediate- to long-term periods, there are numerous other water quality issues that must be addressed.

To identify and quantify these issues, a full chemical screening of a drinking water well must be obtained. This must include direct measurement of specific trace toxic species, such as a variety of different heavy metals. Additionally, chemical analyses for more abundant, non-toxic species are required as these compounds can play a large role in indirectly controlling water quality.

Metals of interest include many that are typically non-toxic under normal conditions (*e.g.*, Fe, Mn, Ca, Na, K, Mg, Al, Ba, Rb, Sr). Knowing the concentrations of such metals is useful in characterizing the bulk water chemistry at each water source and helps to provide a better understanding of the chemistry of more toxic species. In addition, these typically non-toxic metals can themselves pose health problems if they are present outside of normal ranges. A suite of toxic trace metals will also be measured (*e.g.*, Cu, Ni, V, U, Pb, Cd, Co, Ag, Hg, As). These metals may pose serious health risks at very low concentrations.

Anions of interest include non-toxic, abundant species with importance for water quality (*e.g.*, nitrate, phosphate, chloride, sulfide, and sulfate). Anionic species that are less abundant but that have the potential for toxicity (*e.g.*, fluoride and iodide) will also be measured.

While the current output is static and presented as a series of camp-specific At-A-Glance cards, the future goal is to integrate these visuals as an online system of reporting. The current At-A-Glance cards can be found in Chapter 10 of this document. Comprehensive analytical results for each site are provided in Appendix B.

5.2 Methods

5.2.1 Field Sampling

At each site, water is collected from the source (tap stand, shallow well, borehole, or natural spring) into a 500 mL polypropylene Nalgene bottle rinsed three times with source water. Sample water is immediately transferred into a 10 mL polypropylene syringe fitted with a 0.45 µm PTFE filter, and a 'raw' unfiltered sample is collected in a 15 mL polypropylene centrifuge tube. Six aliquots are filtered into 1.5 mL polypropylene microcentrifuge tubes. Two aliquots are immediately acidified with 33% HNO_3 to pH around 2 to keep metals in solution for ICP analysis. The other four aliquots are unamended for IC analysis. Simultaneously, the 500 mL of sample water is analyzed for temperature, pH, dissolved oxygen (DO), conductivity, and oxidation reduction potential (ORP) using a YSI 556 MPS Meter and Probe (YSI Incorporated, Yellow Springs, OH).

5.2.2 Metals Analysis

Inductively coupled plasma-mass spectrometry (ICP-MS) is used to determine the concentrations of dissolved metals in samples collected from a range of drinking water sources. Analyses are conducted on a Thermo XSeries 2 ICP-MS (Thermo Fisher Scientific, Waltham, MA) in collision cell mode with kinetic energy dispersion. Prior to analysis, an aliquot of one of the original samples is diluted both 50:1 ("light" dilution) and 1000:1 ("heavy" dilution) to bring major and trace analytes into the working range of the instrument. In general, major analytes typically include Ca, Mg, K, Na, and occasionally Fe. All others are typically in the trace analyte range, which include Li, Be, Al, V, Cr, Mn, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Mo, Ag, Cd, Cs, Ba, Hg, Tl, Pb, Th, and U.

Calibration standards in the range of 0.05 ppb to 500 ppb are prepared from a multi-element standard that includes all previously listed elements except for Hg, Mo, and Th. Mo and Th are added to the multi-element standard from single-analyte standards. Mercury is analyzed as a separate calibration curve at the end of each analysis to prevent element carryover. A 5% HNO_3 blank is also analyzed every 10 samples. Ultrapure 18 MΩ water (Barnstead Nanopure, Fisher Scientific, Pittsburgh, PA) and concentrated, trace metal grade HNO_3 (Fisher Scientific, Pittsburgh, PA) are used to prepare a 5% HNO_3 solution for making dilutions, calibration standards, blanks, and quality control samples.

5.2.3 Anion Analysis

Anions are detected in the field samples using ion chromatography (IC) with an ICS-1100 (Dionex, Bannockburn, IL). Two separate analytical chromatography separation columns are used for analysis: the Dionex® IonPac® anion selective (AS) AS18 is used for nitrite and nitrate analysis, while the Dionex® IonPac® AS20 column is used for fluoride, iodide, and chloride analysis. Both columns are 4 x 250 mm. The use of two separate columns requires two separate analytical instrument runs for each sample. These cannot be performed simultaneously.

Therefore, two instrumental samples are prepared for each sample collected in the field for IC analysis.

For each of the two IC runs, one filtered and unacidified field sample is filtered once more into a 5 mL IC vial using a syringe and 0.45 µm PTFE filter. The sample is massed and diluted to a volume of 5 mL. This is done twice for each sample—once for the AS18 column IC run and one for the AS20 column IC run.

Combined standards of the analytes for the column in use are prepared and also placed in the 5 mL IC vials. The eluent (mobile phase) for the AS18 column is 23 mM NaOH; the eluent for the AS20 column is 35 mM NaOH. These are prepared for each sample run in 2-L batches. Each column is run with automatic eluent recycling with conductivity suppression. The suppression is performed at 60 mA for the AS18 column and 90 mA for the AS20 column prior to conductivity detection. The flow rate is 1 mL/min with a total sample injection of 750 µL for each injection. Sample blanks are run periodically to ensure instrument performance.

Each sample is analyzed for 18 min on the AS18 column and 14 min on the AS20 column. The specific retention times are determined using the prepared standards. The area of each analyte peak is related to its concentration to create the calibration curve which is, in turn, used to calculate the unknown concentrations of the respective analyte in the samples.

5.3 Results and Discussion

5.3.1 Uganda

The fluoride results indicate a spatial trend in Uganda: the settlements in the southern part of the country contain elevated levels of fluoride across many of the sampled wells, while those in the northern part of Uganda do not. On the other hand, nitrite analysis shows elevated levels in the northern Ugandan camps but not in the southern camps.

Of the 16 wells sampled in Nakivale, nine are above the aesthetic standard for Fe set by the World Health Organization (WHO) of 300 µg/L (Figure 5.1). Multiple values are in the 10 to 20 mg/L range, with a maximum value of 25 mg/L. This can lead to extreme discoloration of the water, staining of the cement platform around the well, staining of clothing, formation of iron oxides during the cooking process, and a foul taste and odor. Conductivities are above 1000 µS/cm in 7 of the measured wells (Figure 5.2). The U.S. EPA aesthetic guideline for total dissolved solids (TDS) is 500 mg/L, while WHO suggests water with TDS above 1000 mg/L is unpalatable. TDS can be related to conductivity by an empirical factor (http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/interp/interp-01.htm), which sets the suggested range for conductivity between 700 and 1400 µS/cm. The midpoint of this range (1000 µS/cm) is shown in Figure 5.2 and throughout the report for comparative purposes. At these values, water contains high amounts of base cations, such as Na^{+}, Mg^{2+}, K^{+}, Ca^{2+}, causing the water to taste salty. Drinking highly saline water over time leads to dehydration of the body. Manganese is elevated over the WHO aesthetic value of 100 µg/L in 15 of the well samples, while 6 wells exceed the WHO health guideline of 400 µg/L (Figure 5.3). In four wells (NV7, NV10, NV11, and NV12), elevated levels of strontium are observed. While strontium does not have any established guidelines and is not a health concern, these elevated levels are interesting. One well, NV6, has an elevated lead level at 3.02 µg/L. While not high enough to be a health concern, it should be measured again and monitored over time. Elevated uranium is seen in one well, NV7; at 33.83 µg/L, this is above the WHO guideline of 30 µg/L. However, there is uncertainty about the toxicity of uranium. One sample, NV1, has elevated Ni of 45.6 µg/L but is not above the WHO guideline of 70 µg/L. One of the sites in Nakivale, NV7, had fluoride levels above the WHO standard of 1.5 mg/L (Figure 5.4). The detected concentration of fluoride was 2.52 mg/L, much above the WHO limit. Both NV15 and NV16 have fluoride levels approaching the WHO standard. It should also be noted that the U.S. EPA and the United States Department of Health and Human Services (HHS) in cooperation with the Centers for Disease Control (CDC) recently released a recommendation to decrease its enforceable fluoride standard from 4 mg/L to 0.7 mg/L (http://www.hhs.gov/news/press/2011pres/01/20110107a.html). This action clearly expresses concern by the U.S. EPA, HHS, and the CDC regarding the prolonged exposure to fluoride in drinking water at levels even less than 1 mg/L. Nakivale has nitrite levels in excess of the U.S. EPA enforceable standard of 3.3 mg/L in two sites; one of these sites, NV7, has three times this amount, 11.1 mg/L (Figure 5.5). There is also one site, NV12, which has nearly twice the nitrate concentration as the U.S. EPA enforceable standard of 44.3 mg/L (Figure 5.6).

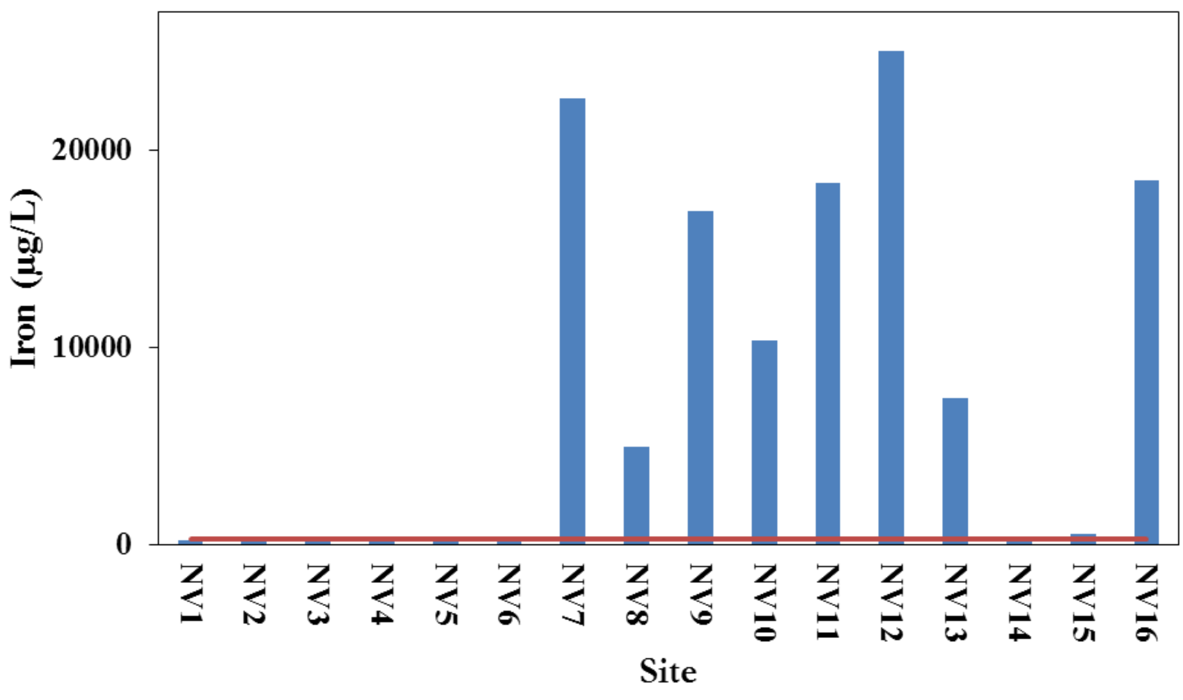


Figure 5.1 Nakivale: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

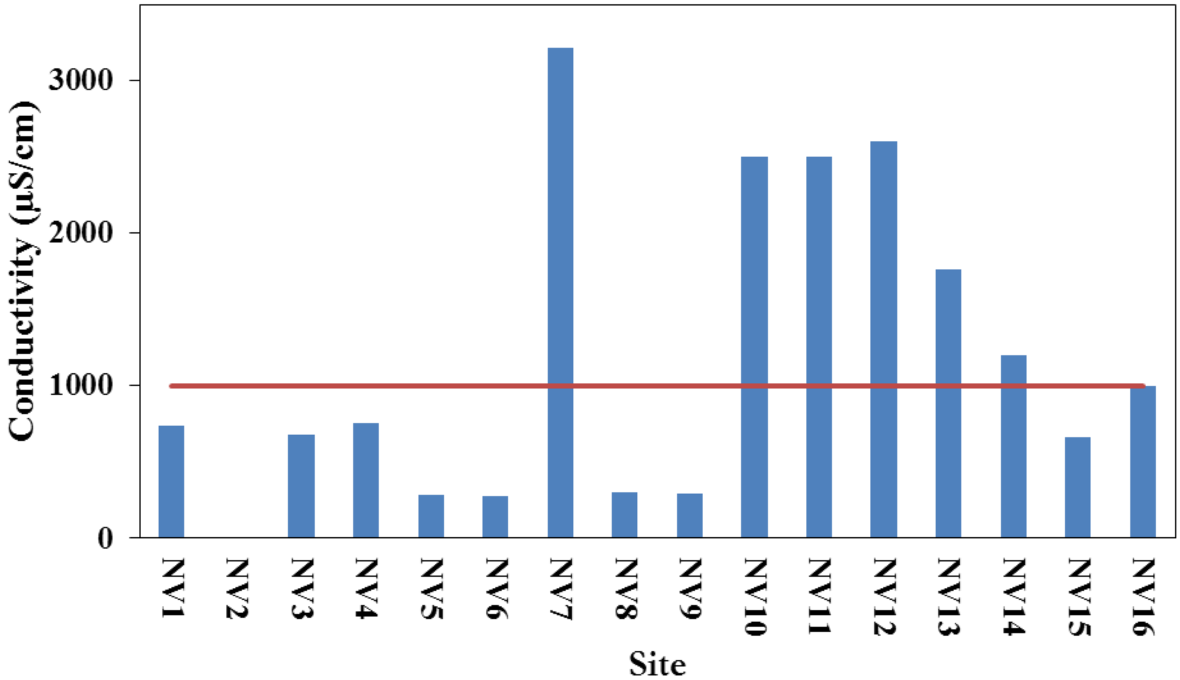


Figure 5.2 Nakivale: Measured conductivity values
Aesthetic guideline is 1000 µS/cm (red line)

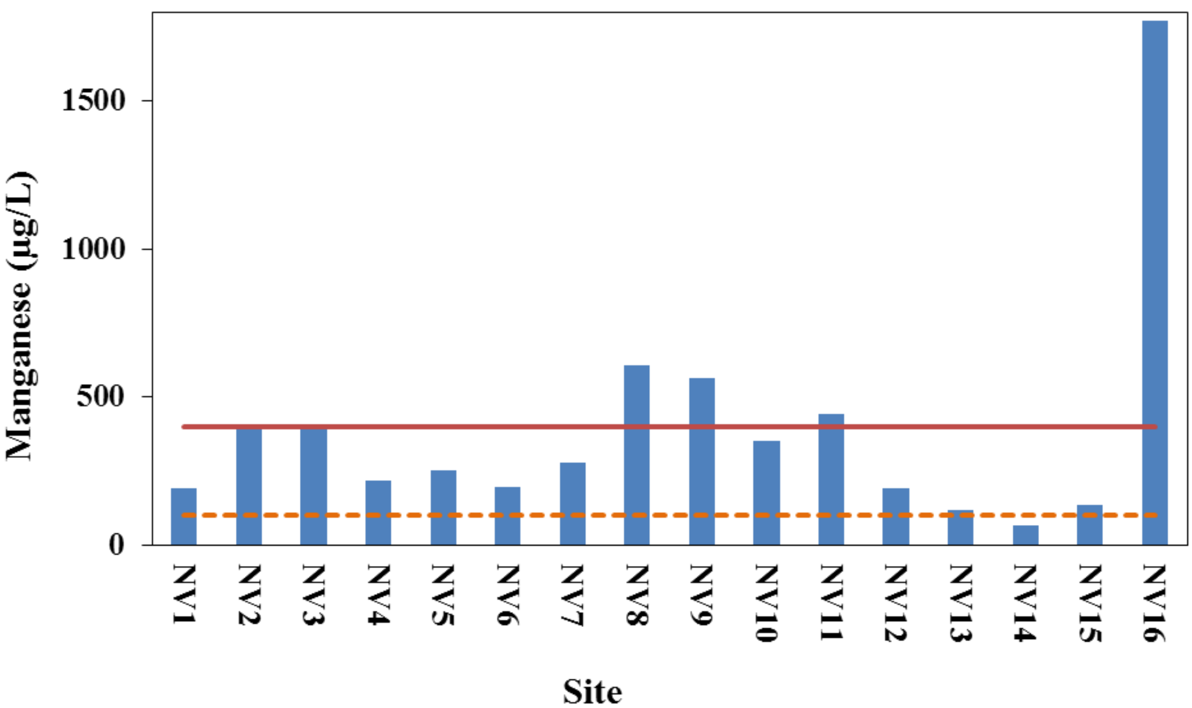


Figure 5.3 Nakivale: Measured manganese concentrations
WHO aesthetic guideline is 0.1 mg/L (orange dashed line); WHO health guideline is 0.4 mg/L (red line)

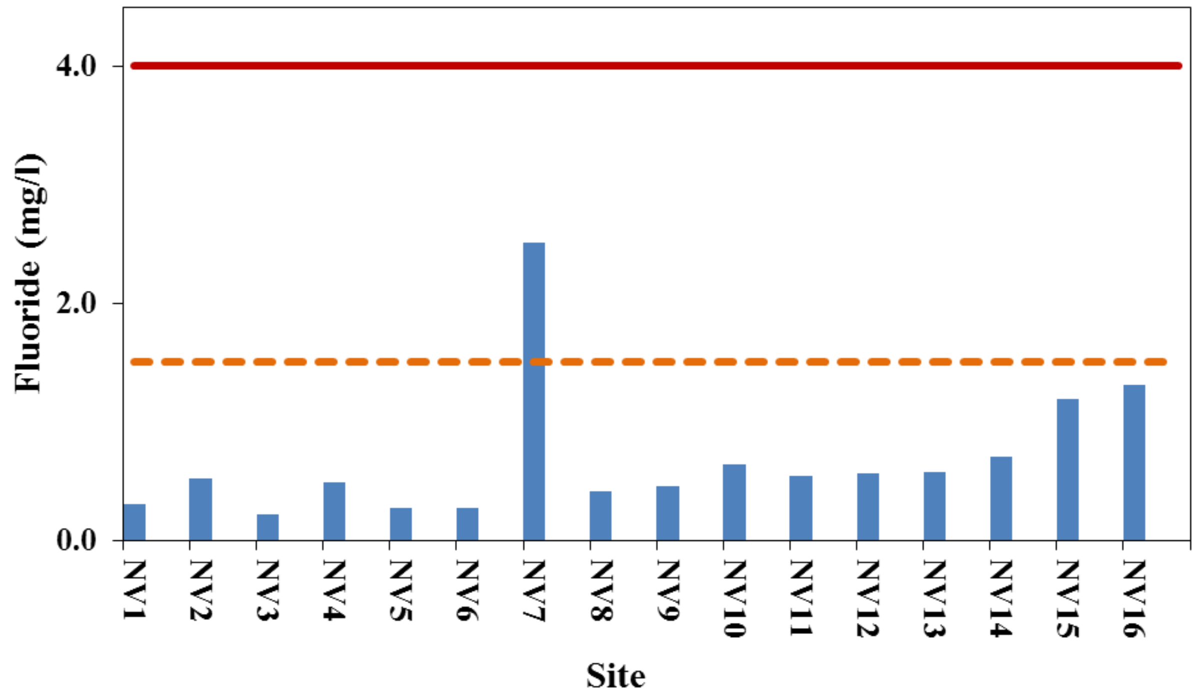


Figure 5.4 Nakivale: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)

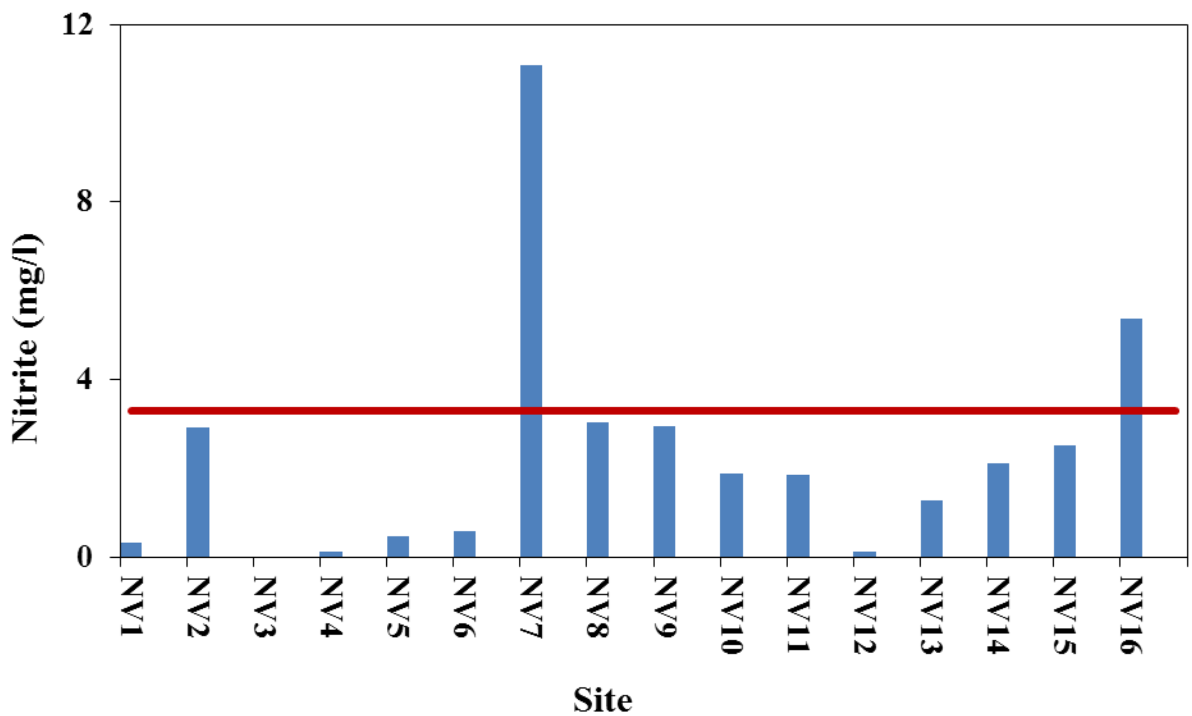


Figure 5.5 Nakivale: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

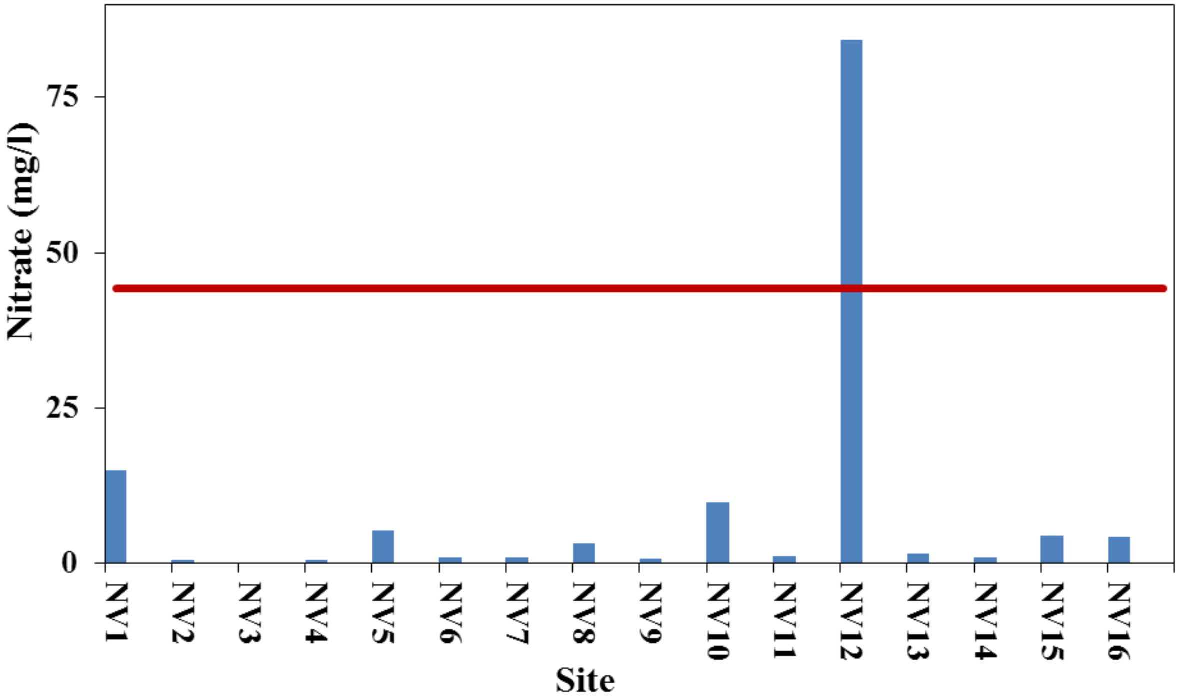


Figure 5.6 Nakivale: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

In Kyaka II, 13 wells have been analyzed. Iron is elevated in 10 wells above the WHO guideline of 300 µg/L, with high values of 22 mg/L in two separate wells (Figure 5.7). Ten wells are above the aesthetic WHO guideline of 100 µg/L manganese, with 4 wells exceeding the WHO health guideline of 400 µg/L (Figure 5.8). There are some isolated wells with elevated Zn (K213) at 11.62 mg/L, where the guideline is a range of 3-4 mg/L. Uranium and gallium are found in K28 at 10 µg/L and K25 18 µg/L, respectively. Gallium does not have a health guideline, but it may be an indicator of leaching solder from the well heads. All but four of the wells in Kyaka II contained elevated levels of fluoride above 1.5 mg/L set by the WHO (Figure 5.9), and two of these sites are approaching the standard. Many are extremely elevated—as high as 10.45 mg/L. The solid red line in the figure shows the current U.S. EPA enforceable standard of 4.0 mg/L while the dashed line shows the WHO health standard of 1.5 mg/L.

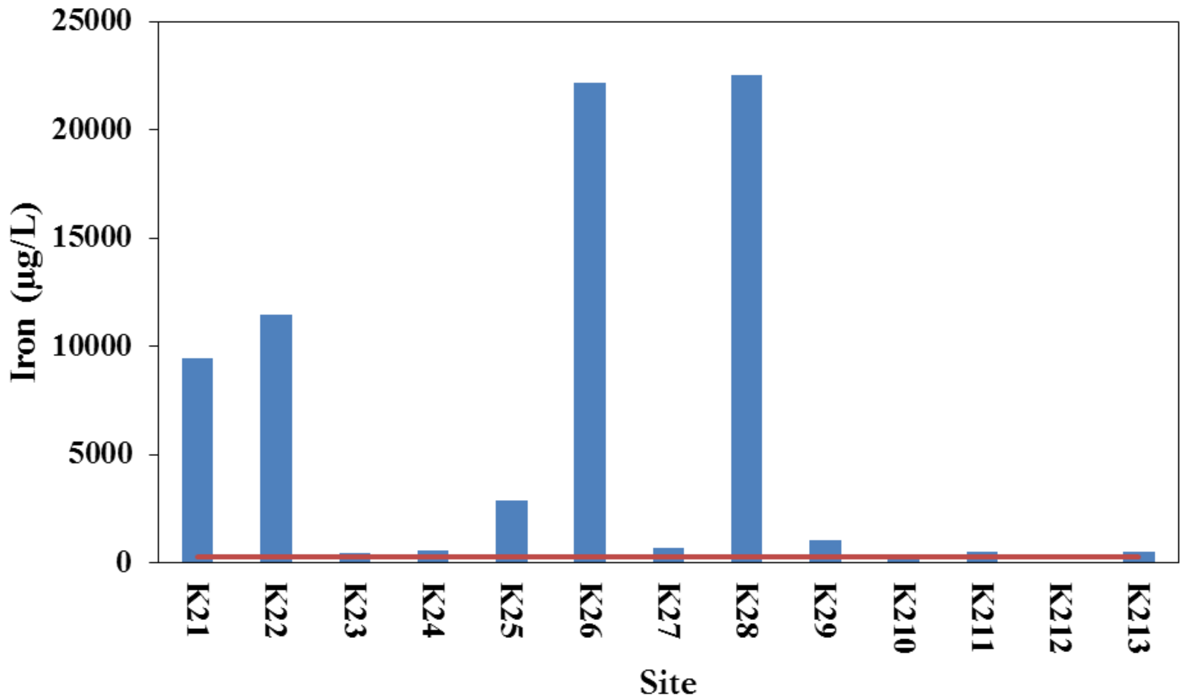


Figure 5.7 Kyaka II: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

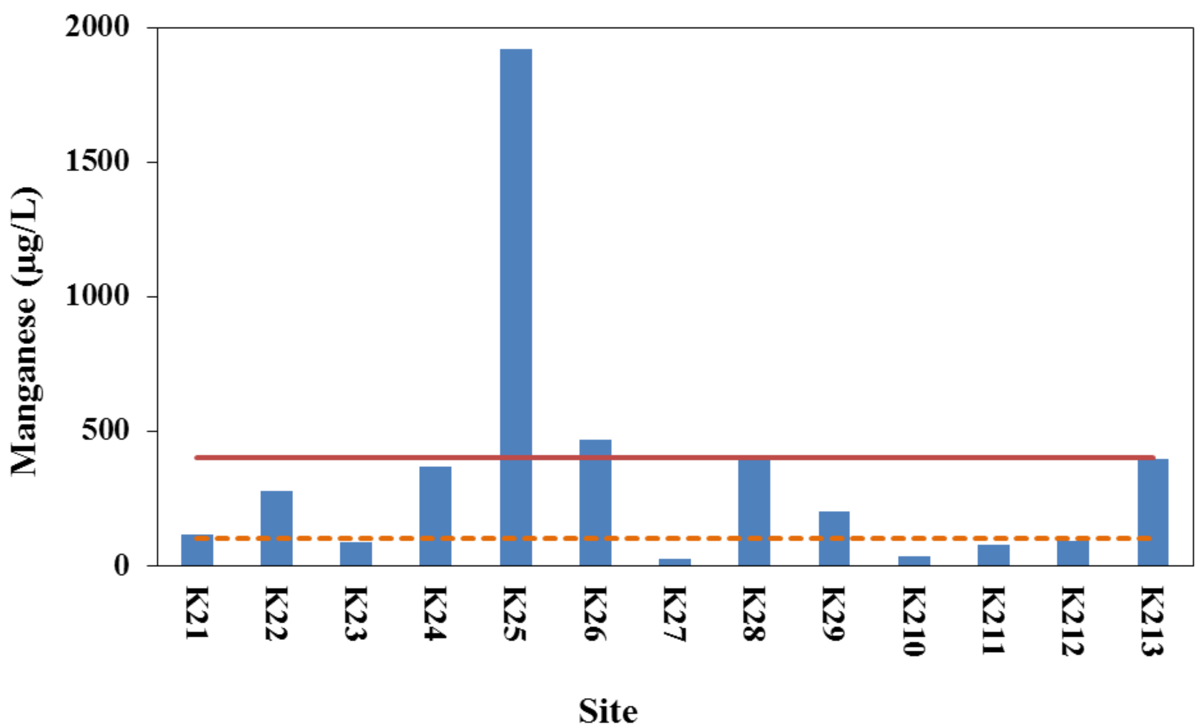


Figure 5.8 Kyaka II: Measured manganese concentrations
WHO aesthetic guideline is 0.1 mg/L (orange dashed line); WHO health guideline is 0.4 mg/L (red line)

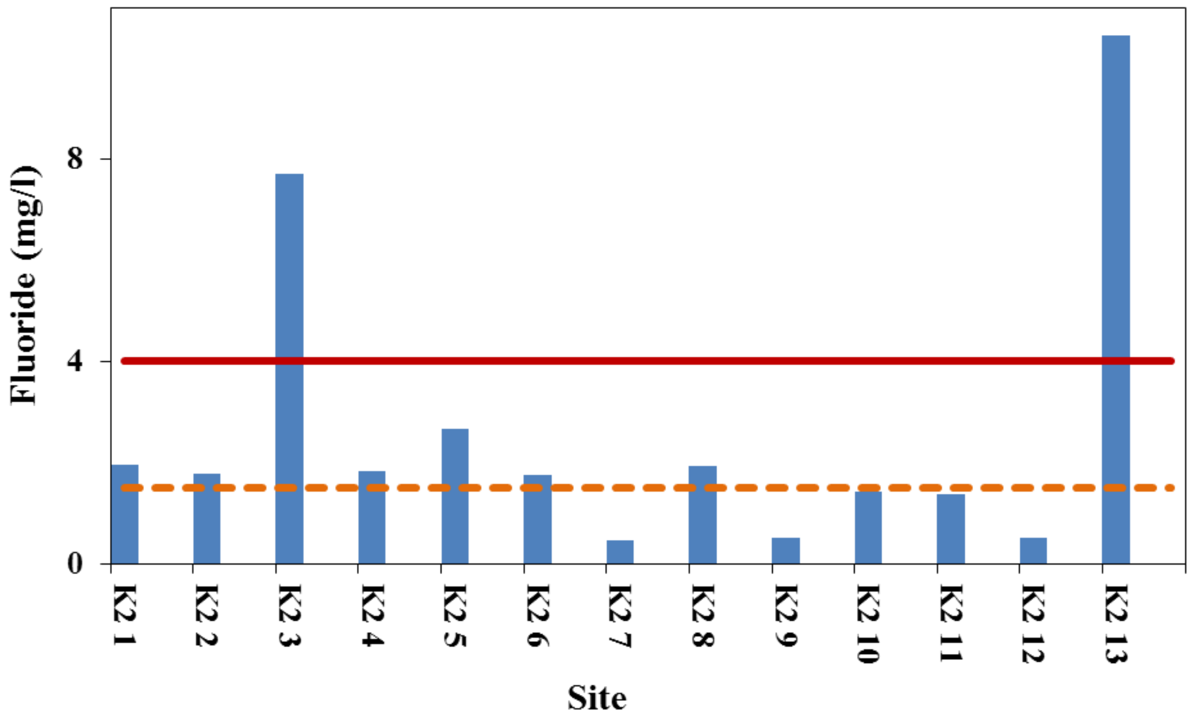


Figure 5.9 Kyaka II: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)

In Kyangwali, 19 sites were visited, while only 17 samples were taken due to well functionality. Iron is elevated in 12 wells above the 300 µg/L WHO aesthetic standard (Figure 5.10). Manganese is elevated above aesthetic standards in 7 wells, while only 2 exceed the WHO health guideline of 400 µg/L (Figure 5.11). Elevated gallium is seen in 10 wells. While this is above background, the source is unknown and there is no health guideline, so it should not be viewed as a problem (Figure 5.12). Zn is another transition metal of concern and is seen elevated above the 3-4 mg/L aesthetic WHO guideline in 3 wells. An additional 8 wells show significant zinc above the background but not at a level of concern (Figure 5.13). An isolated well with an elevated lead measurement is KD19 with 7.13 µg/L Pb. Nitrite is elevated in about half of the sites sampled (Figure 5.14); the highest level seen is 6.89 mg/L, more than double the recommended 3.3 mg/L limit.

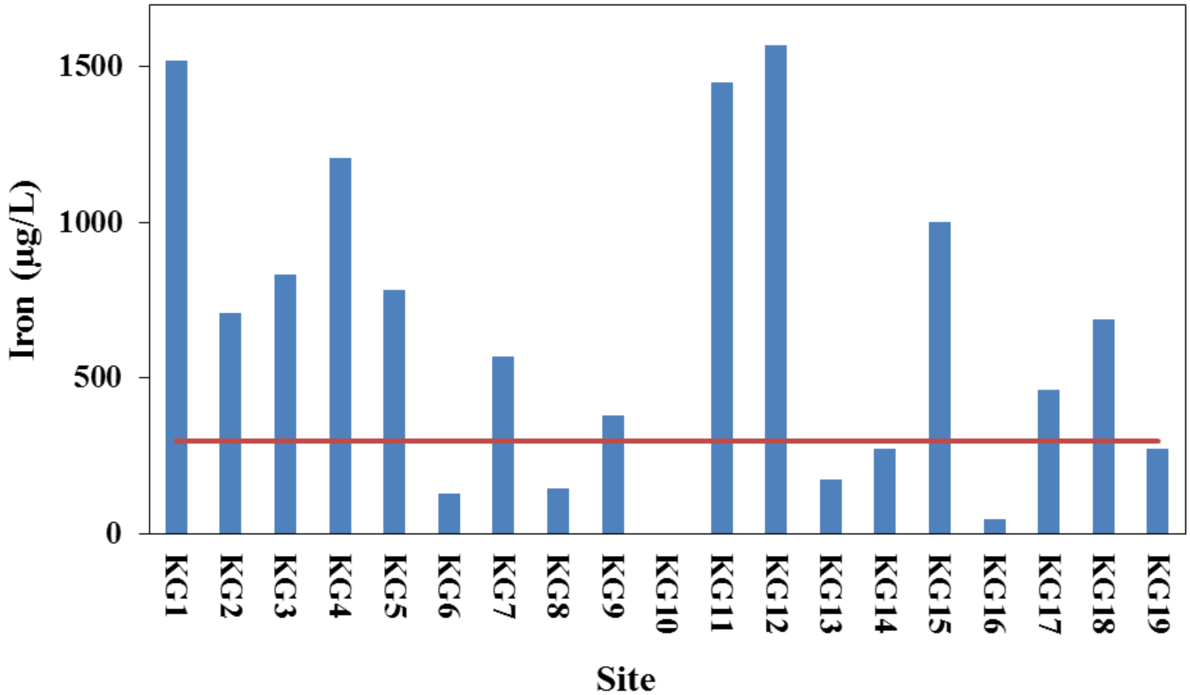


Figure 5.10 Kyangwali: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

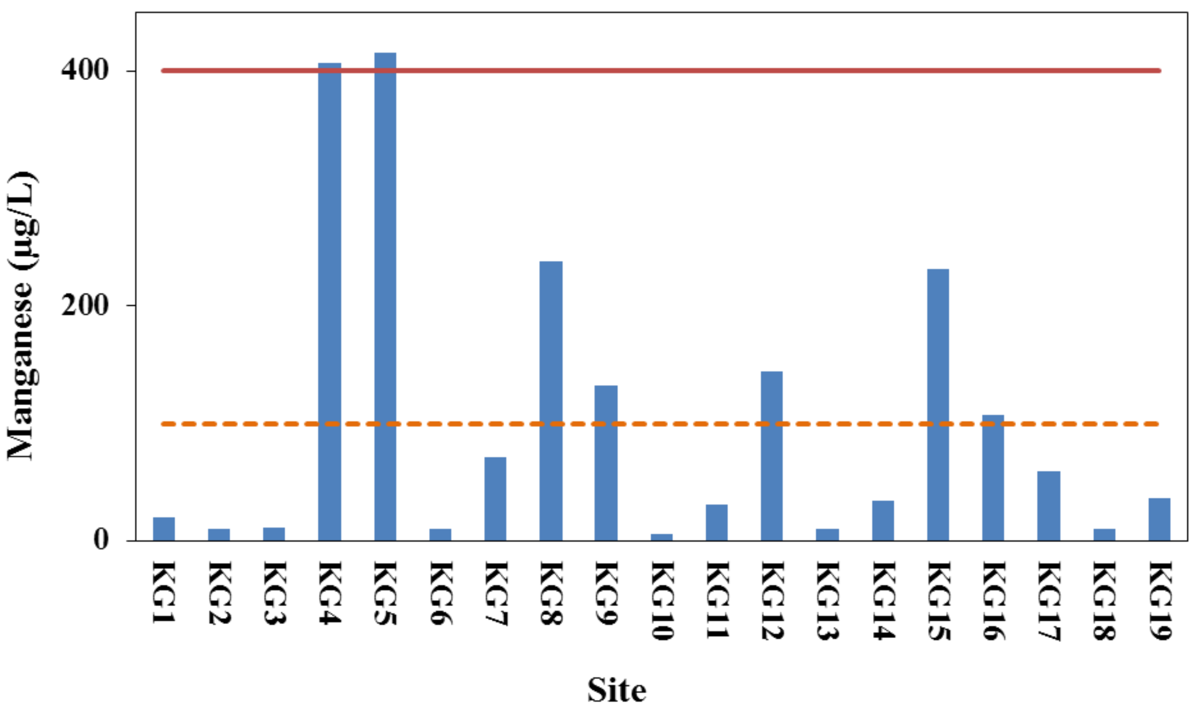


Figure 5.11 Kyangwali: Measured manganese concentrations
WHO aesthetic guideline is 0.1 mg/L (orange dashed line); WHO health guideline is 0.4 mg/L (red line)

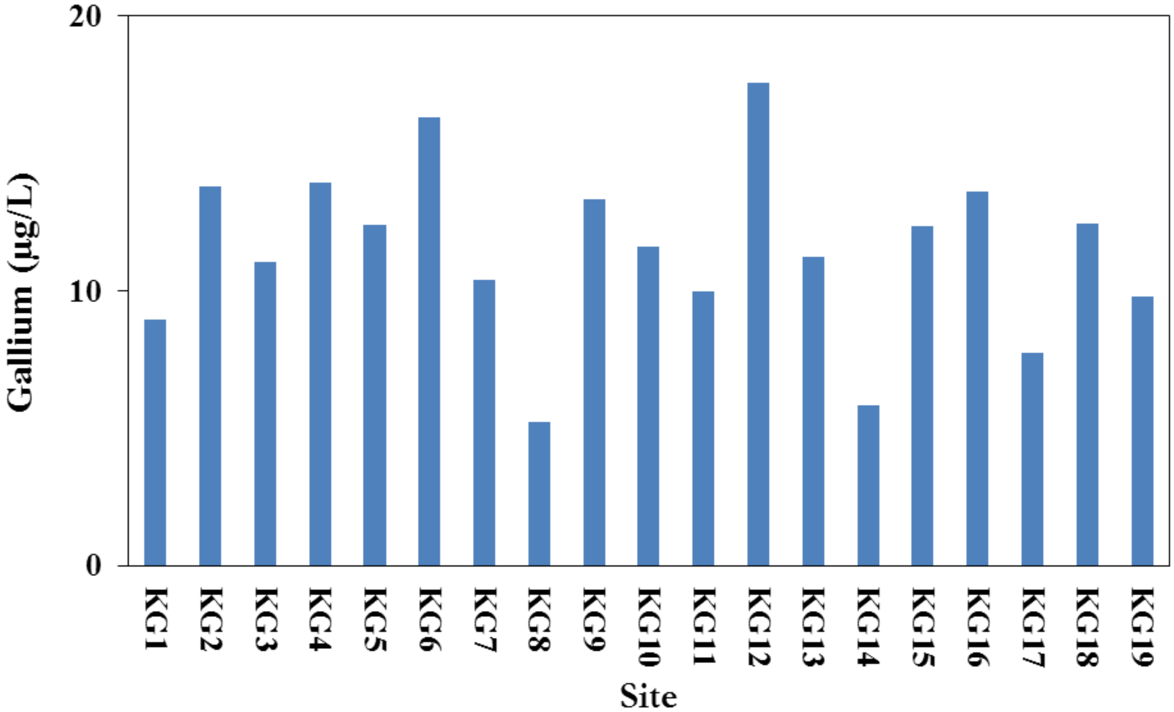


Figure 5.12 Kyangwali: Measured gallium concentrations

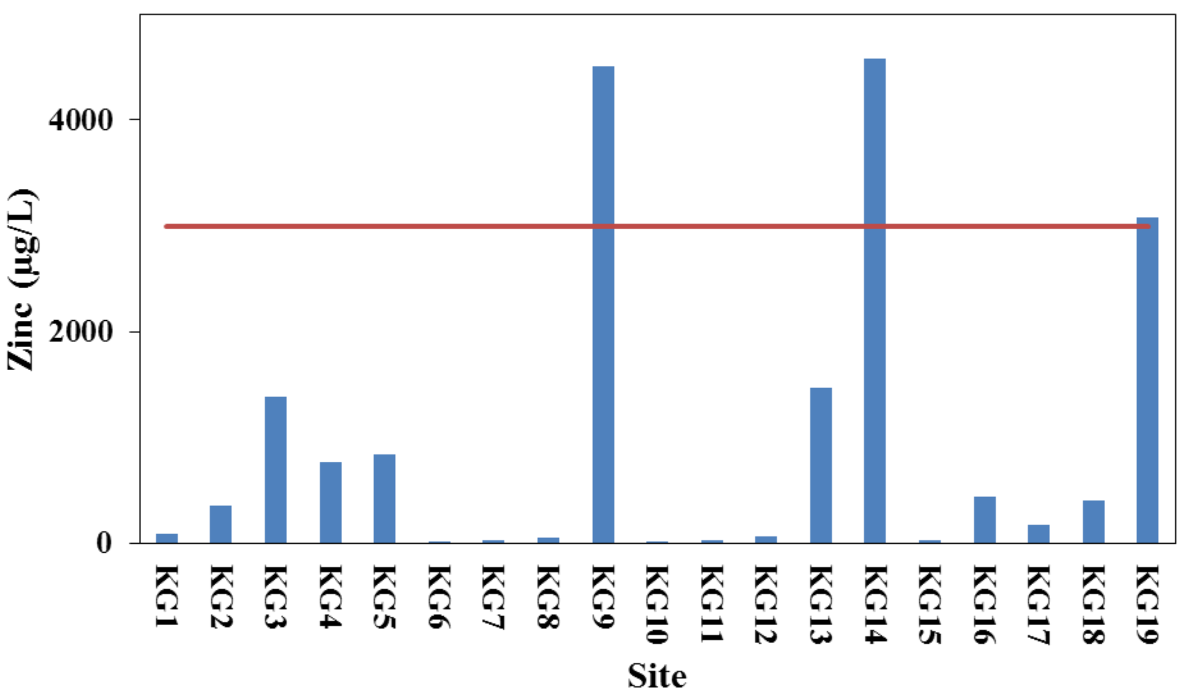


Figure 5.13 Kyangwali: Measured zinc concentrations
WHO aesthetic guideline is 3 mg/L (red line)

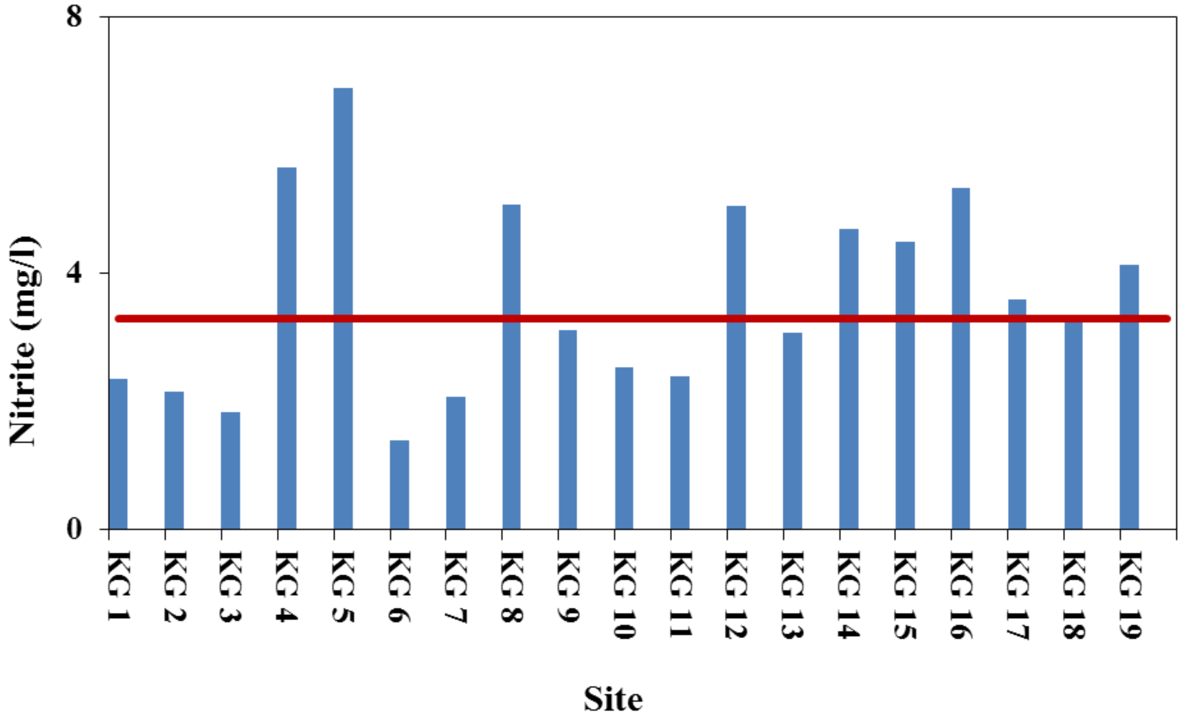


Figure 5.14 Kyangwali: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

In Kiryandongo settlement, 19 sites have been sampled and analyzed. Three wells show elevated vanadium levels above the 15 µg/L guideline suggested by the California OEHHA (http://oehha.ca.gov/water/pals/vanadium.html): KD2, KD3, and KD4 with values of 17.85, 17.55, and 26.68 µg/L, respectively. Similarly to other sites in Uganda, Kiryandongo shows elevated manganese and iron levels. Fifteen wells have Fe measurements above the WHO guideline (Figure 5.15). Nine wells show Mn above the aesthetic WHO guideline, and 5 are above the Mn health WHO guideline (Figure 5.16). Elevated copper is seen in KD4 and KD18 with values of 43.33 and 103.85 µg/L, respectively. The WHO health guideline is 2 mg/L. While these values are far below the guideline, they are elevated relative to the background. Zinc is highly elevated relative to the background; however, no wells exceed the WHO guideline (Figure 5.17). KD16 shows a Ga value of 12.31 µg/L. There is an isolated well (KD7) with an elevated arsenic level of 13.38 µg/L. The WHO guideline for arsenic is 10 µg/L. This well will need retesting to verify this level. Lead is high in KD6, with a measurement of 3.31 µg/L, however, not to action level. An elevated level of 51.64 mg/L of nitrate is seen at one site in Kiryandongo, KD12 (Figure 5.18), but many are well below the 44.3 mg/L nitrate standard. Elevated nitrite is also seen in all the northern Ugandan camps, including Kiryandongo. All sites sampled in the settlement showed nitrite levels above the 3.3 mg/L limit (Figure 5.19); however, nitrite data for the sites KD11, KD15, KD16, and KD17 are unavailable due to a limited volume of each sample reaching the laboratory.

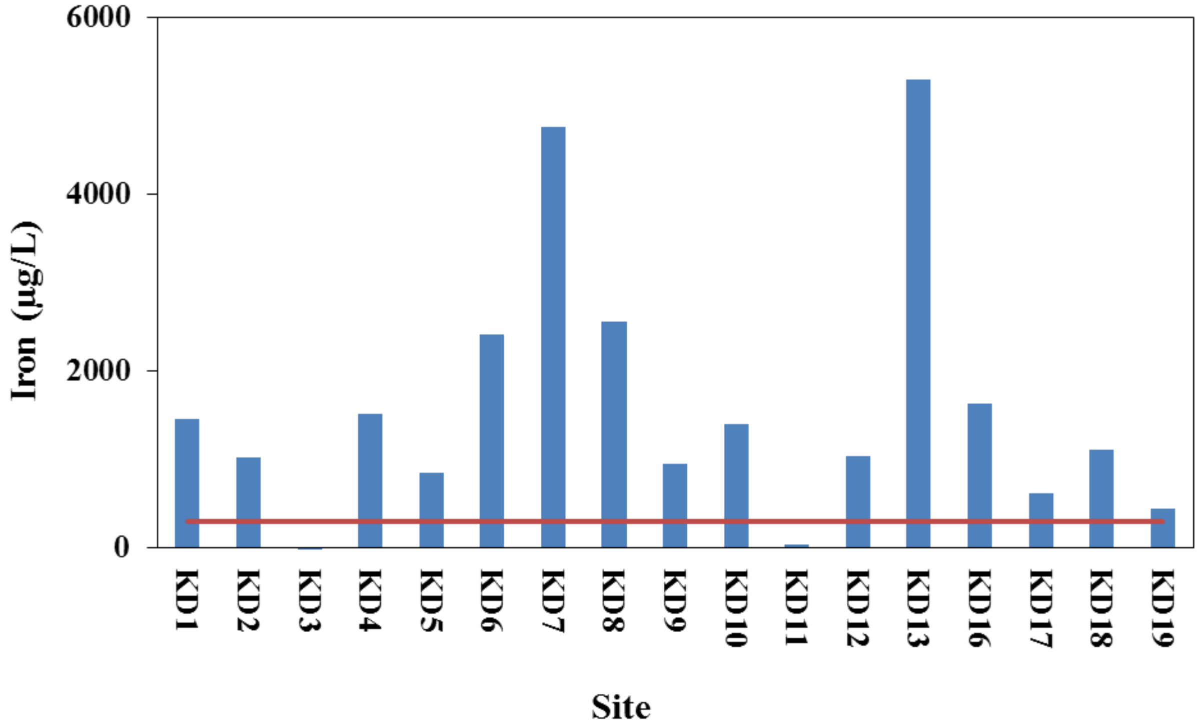


Figure 5.15 Kiryandongo: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

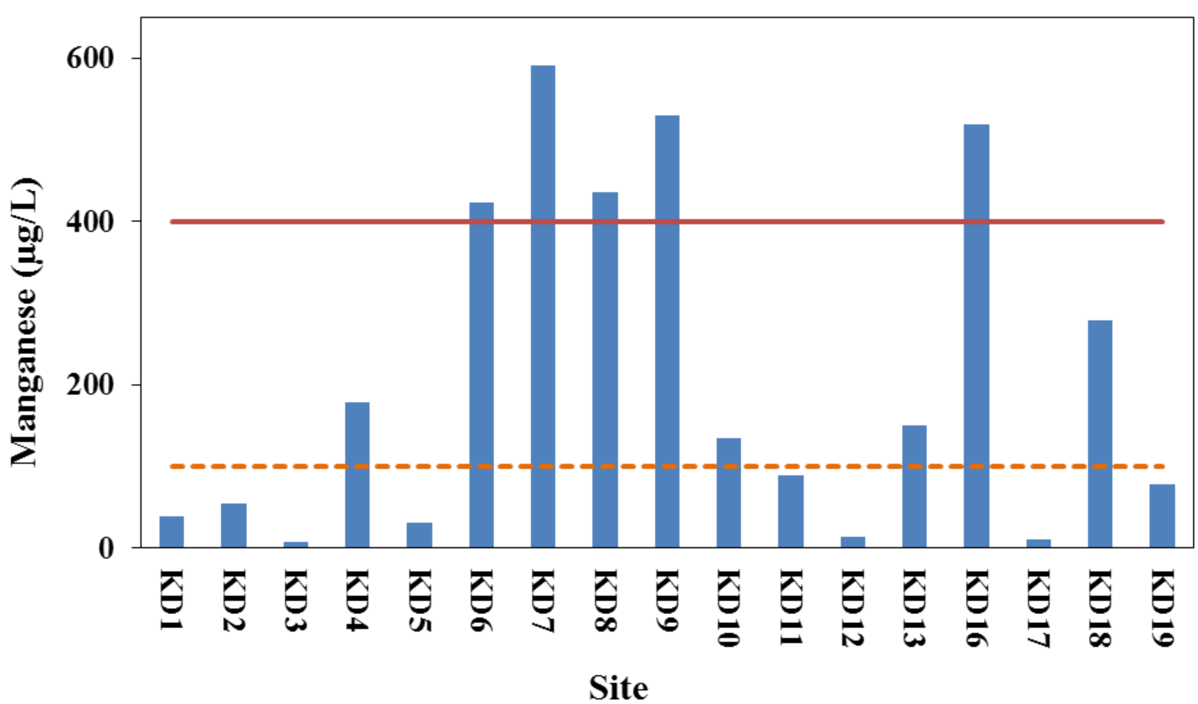


Figure 5.16 Kiryandongo: Measured manganese concentrations
WHO aesthetic guideline is 0.1 mg/L (orange dashed line); WHO health guideline is 0.4 mg/L (red line)

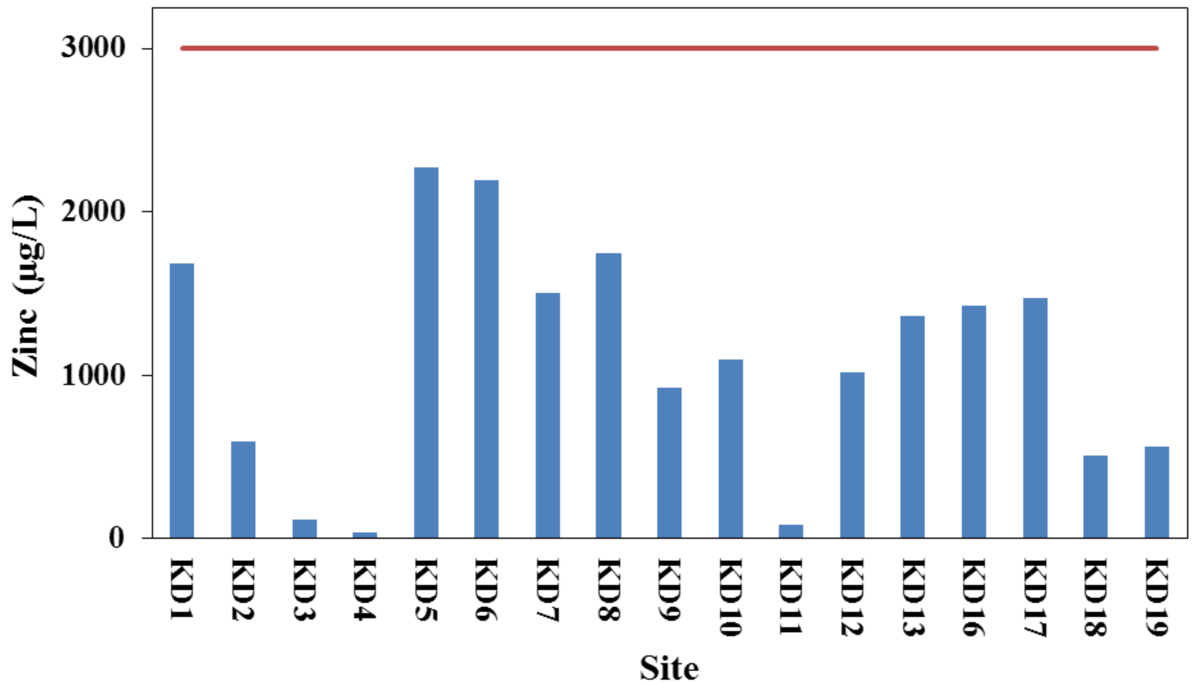


Figure 5.17 Kiryandongo: Measured zinc concentrations
WHO aesthetic guideline is 3 mg/L (red line)

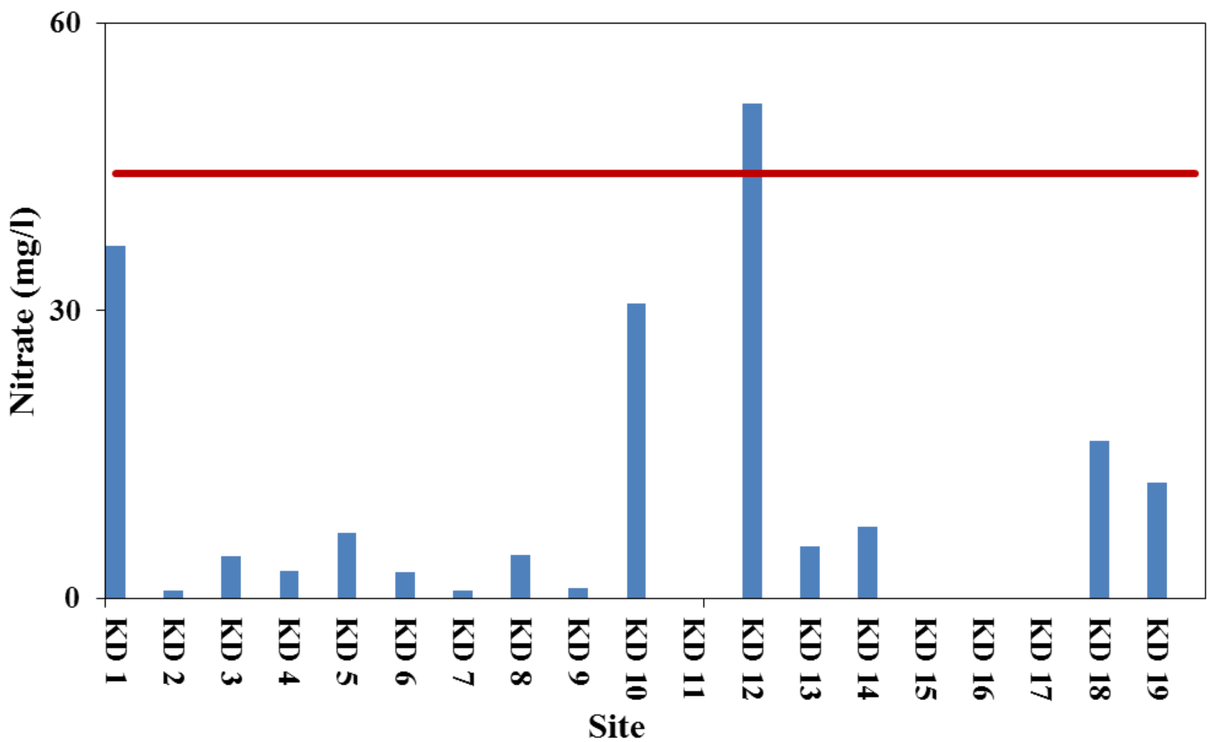


Figure 5.18 Kiryandongo: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

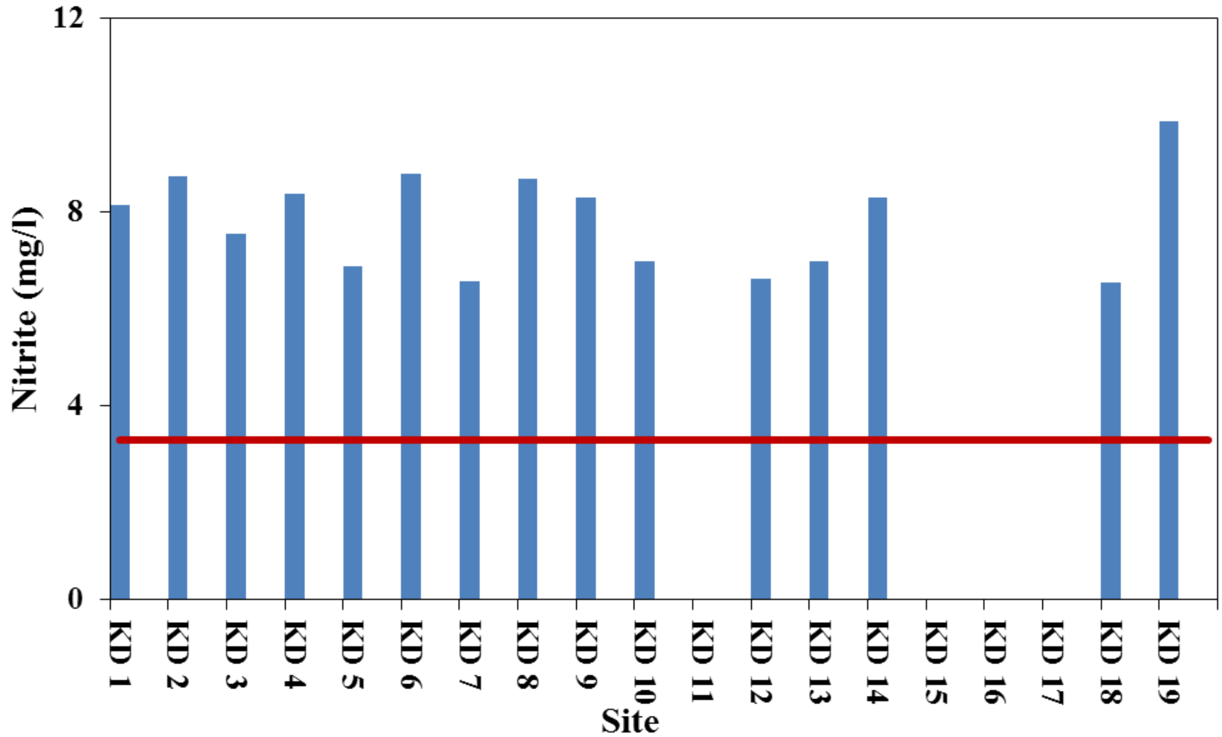


Figure 5.19 Kiryandongo: Measured nitrite concentrations
Nitrite data unavailable for KD11, KD15, KD16, and KD17; U.S. EPA standard is 3.3 mg/L (red line)

Rhino Camp has elevated iron, relative to the WHO guideline, in 7 out of the 8 wells sampled (Figure 5.20). A single elevated vanadium well (RH2) is seen at 15.52 µg/L, which is right at the guideline of 15 µg/L. Gallium is elevated relative to background (Figure 5.21). Isolated elevated values of strontium and lead are seen in RH1 at 1.3 mg/L and RH8 at 5.16 µg/L, respectively. Nitrite levels are above the 3.3 mg/L standard at all sites at Rhino Camp (Figure 5.22). Nitrite levels range from 6.46 mg/L to a maximum of 9.45 mg/L, nearly three times the nitrite standard.

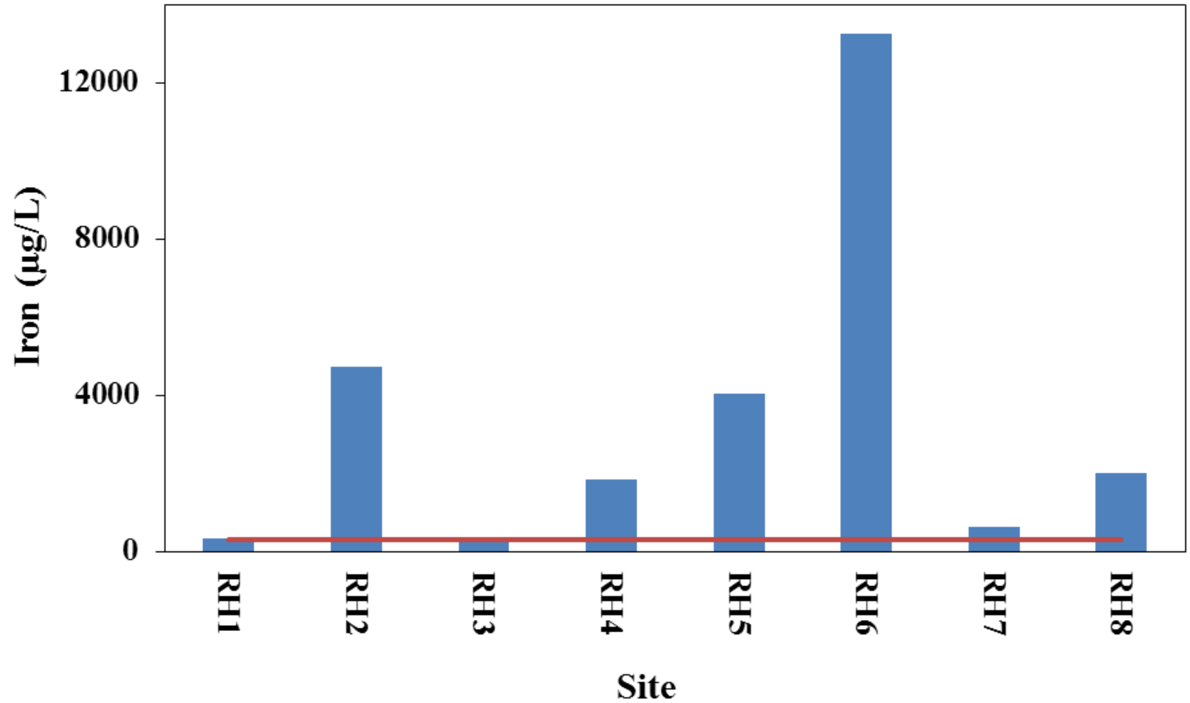


Figure 5.20 Rhino Camp: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

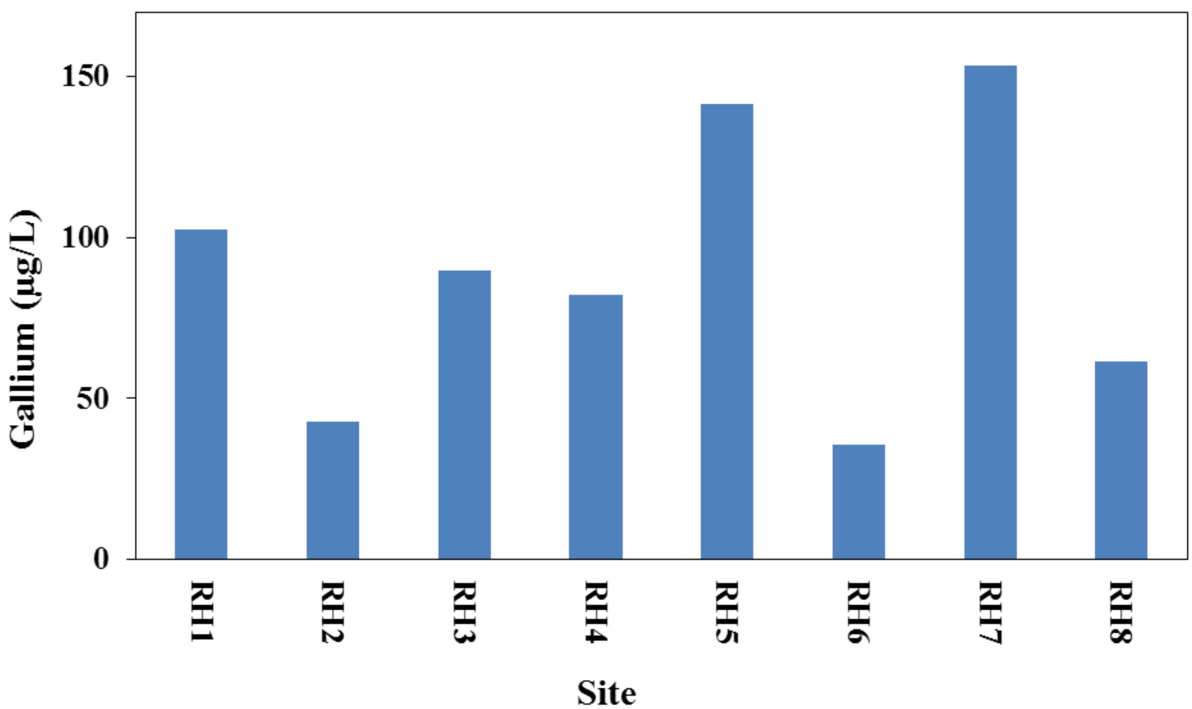


Figure 5.21 Rhino Camp: Measured gallium concentrations

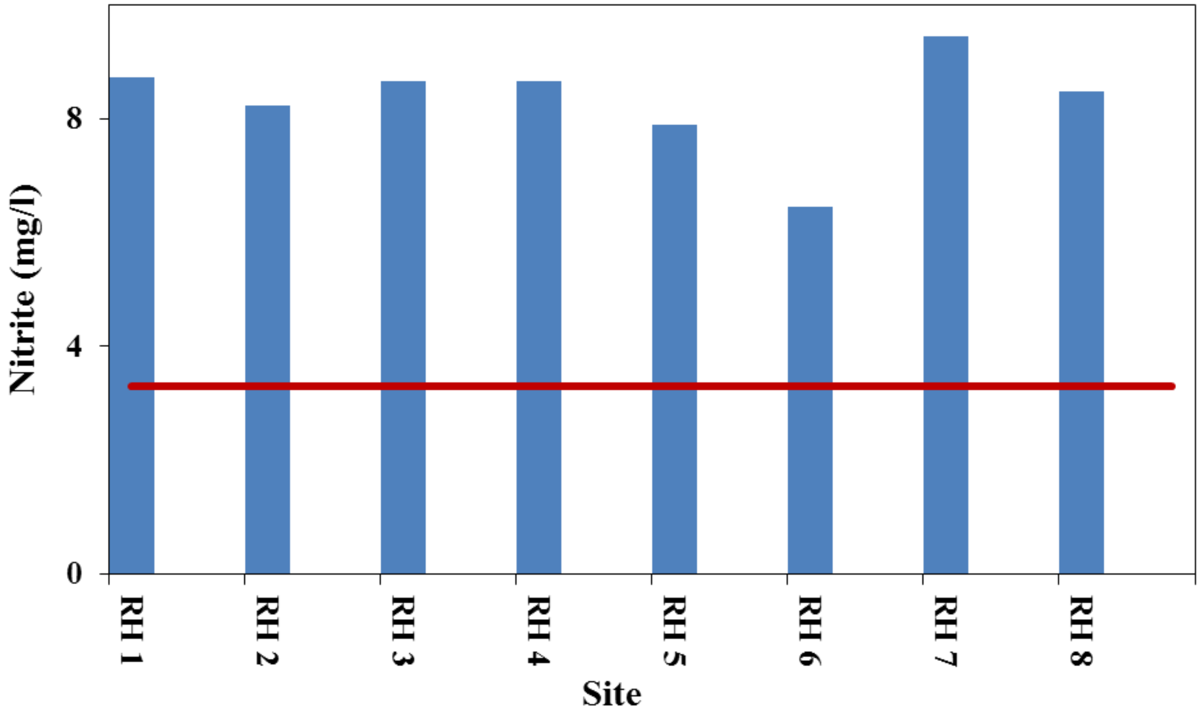


Figure 5.22 Rhino Camp: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

Imvepi settlement abuts Rhino Camp and yields similar results. There are 6 wells above the WHO aesthetic standard for Fe (Figure 5.23) and 3 wells elevated above the manganese aesthetic guideline (Figure 5.24). A single site is elevated in uranium (IV7) at 12.75 µg/L. Gallium levels are elevated above the background (Figure 5.25). Furthermore, as with the other northern Ugandan camps, nitrite levels are elevated at all Imvepi sites (Figure 5.26). Nitrate is also elevated at one site, IV1, with a nitrate level of 68.85 mg/L; nitrate is right around the standard of 44.3 mg/L at site IV5 with 46.07 mg/L of nitrate measured (Figure 5.27).

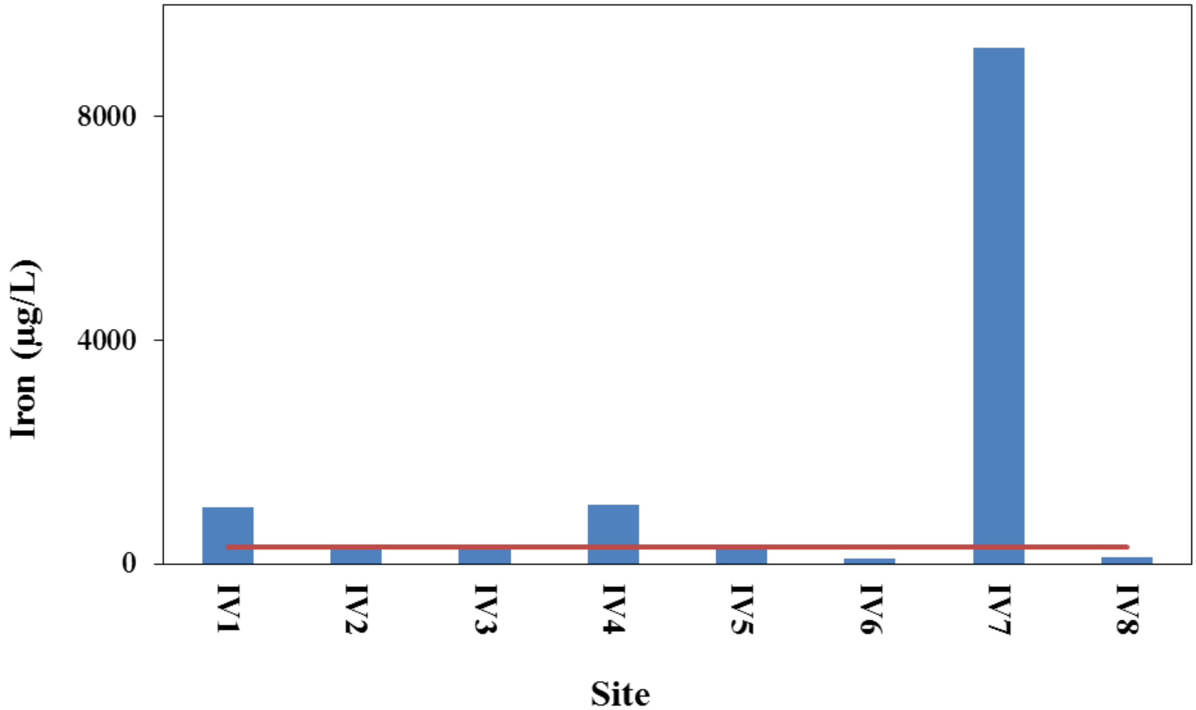


Figure 5.23 Imvepi: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

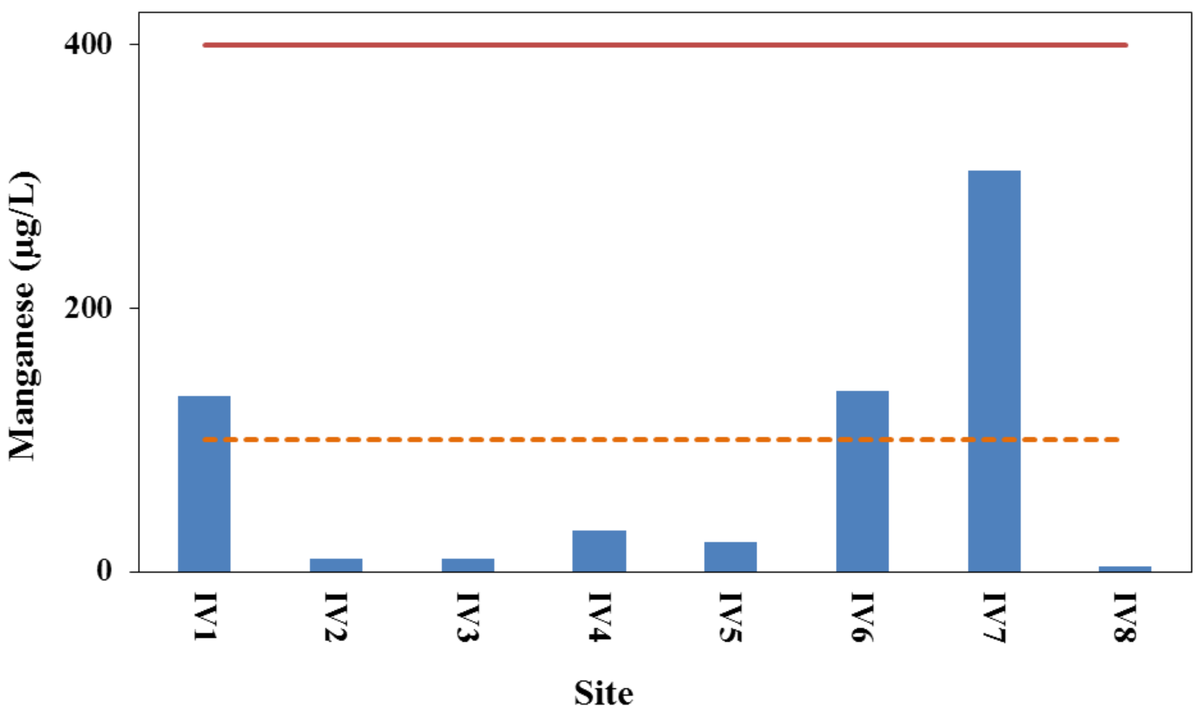


Figure 5.24 Imvepi: Measured manganese concentrations
WHO aesthetic guideline is 0.1 mg/L (orange dashed line); WHO health guideline is 0.4 mg/L (red line)

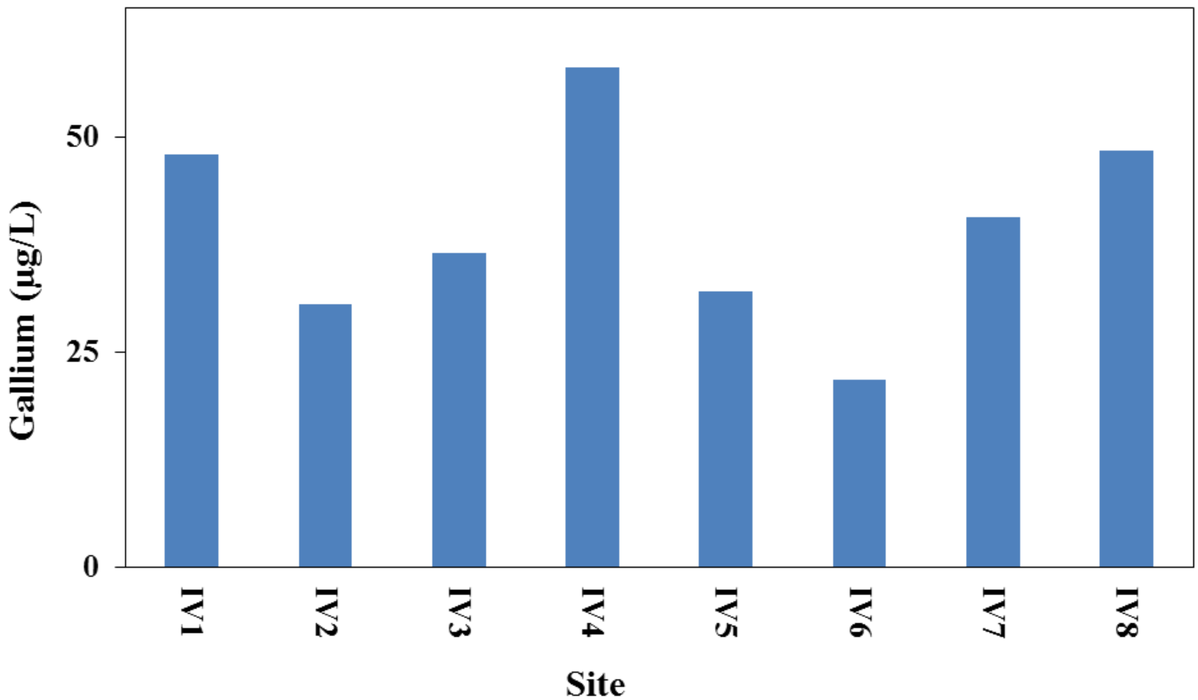


Figure 5.25 Imvepi: Measured gallium concentrations

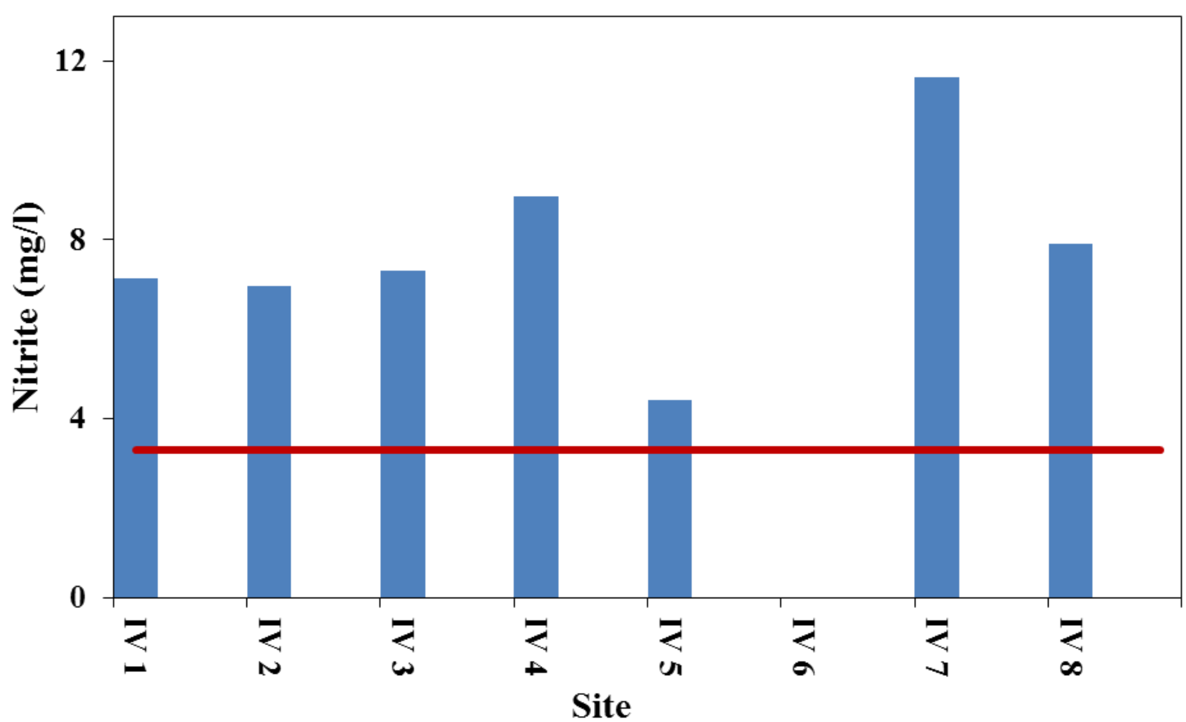


Figure 5.26 Imvepi: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

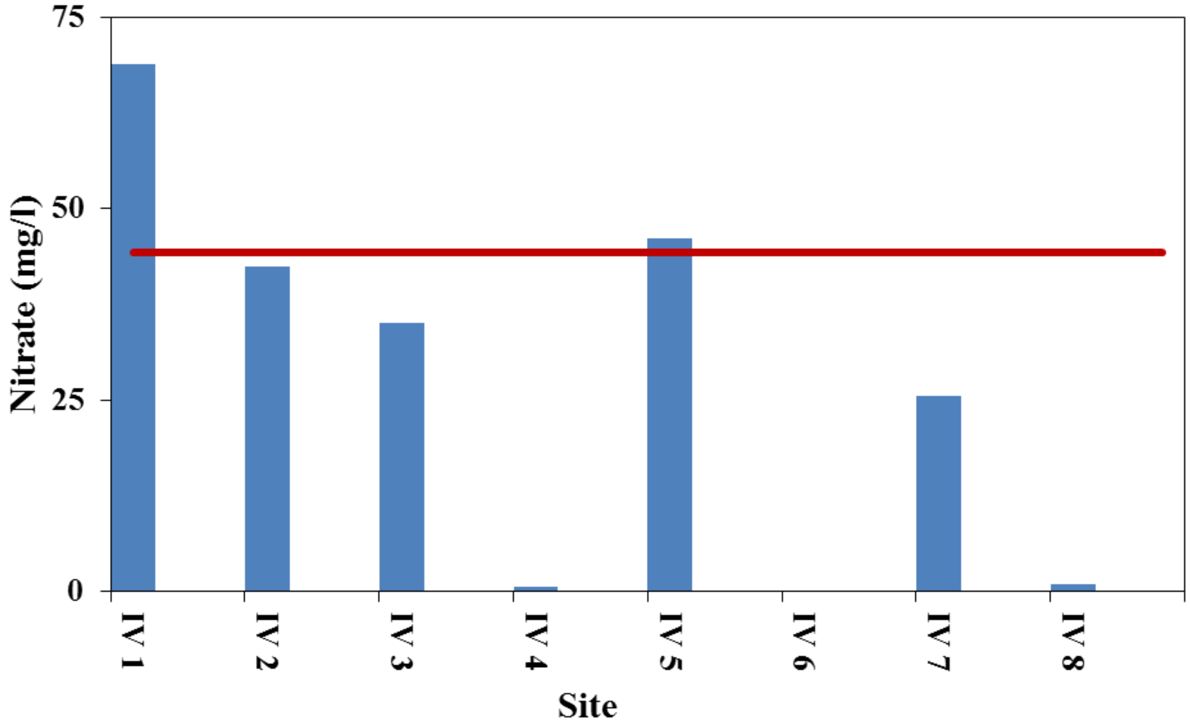


Figure 5.27 Imvepi: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

5.3.2 Kenya

In Kakuma, 11 wells have been sampled. Eight wells contain vanadium concentrations above the 15 µg/L guideline suggested by the California OEHHA (http://oehha.ca.gov/water/pals/vanadium.html) (Figure 5.28). A few isolated wells contain elevated molybdenum: KK5, KK8, and KK24 with values of 14.64, 26.06, and 25.17 µ/L, respectively. Uranium, at an elevated level of 8.31 µg/L, is seen in KK7. Throughout Kakuma, conductivity measurements are generally high with two sites above 1000 µS/cm (Figure 5.29). The U.S. EPA aesthetic guideline for total dissolved solids (TDS) is 500 mg/L, while WHO suggests water with TDS above 1000 mg/L is unpalatable. TDS can be related to conductivity by an empirical factor (http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/interp/interp-01.htm), which sets the suggested range for conductivity between 700 and 1400 µS/cm. The midpoint of this range (1000 µS/cm) is shown in Figure 5.29 and throughout the report for comparative purposes. Fluoride is measured above the 1.5 mg/L WHO standard at all the sampled sites in Kakuma (Figure 5.30). Fluoride values range from 1.75 mg/L at KK7 to 7.31 mg/L at KK11. These results are somewhat expected as elevated fluoride levels have previously been reported. It should also be noted that the U.S. EPA and the United States Department of Health and Human Services (HHS) in cooperation with the Centers for Disease Control (CDC) recently released a recommendation to decrease its enforceable fluoride standard from 4 mg/L to 0.7 mg/L (http://www.hhs.gov/news/press/2011pres/01/20110107a.html). This action clearly expresses concern by the U.S. EPA, HHS, and the CDC regarding the prolonged exposure to fluoride in drinking water at levels even less than 1 mg/L. Two sites in Kakuma show elevated levels of nitrate (KK3 and KK5), with KK3 showing a level of 209.86 mg/L, well above the 44.3 mg/L

U.S. EPA standard for nitrate (Figure 5.31). Nitrite is also elevated at all the sites in Kakuma but one (KK3). At KK7, a concentration of 14.77 mg/L is seen, which is four times the 3.3 mg/L U.S. EPA standard for nitrite (Figure 5.32).

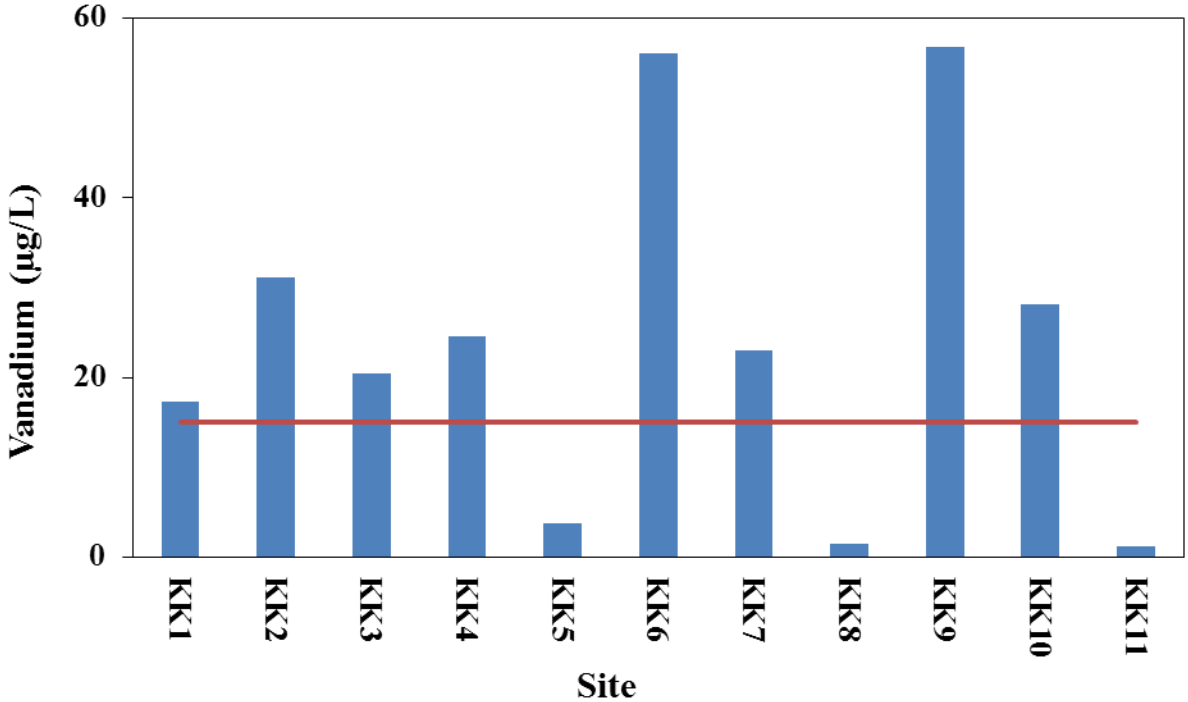


Figure 5.28 Kakuma: Measured vanadium concentrations
OEHHA guideline is 15 µg/L (red line)

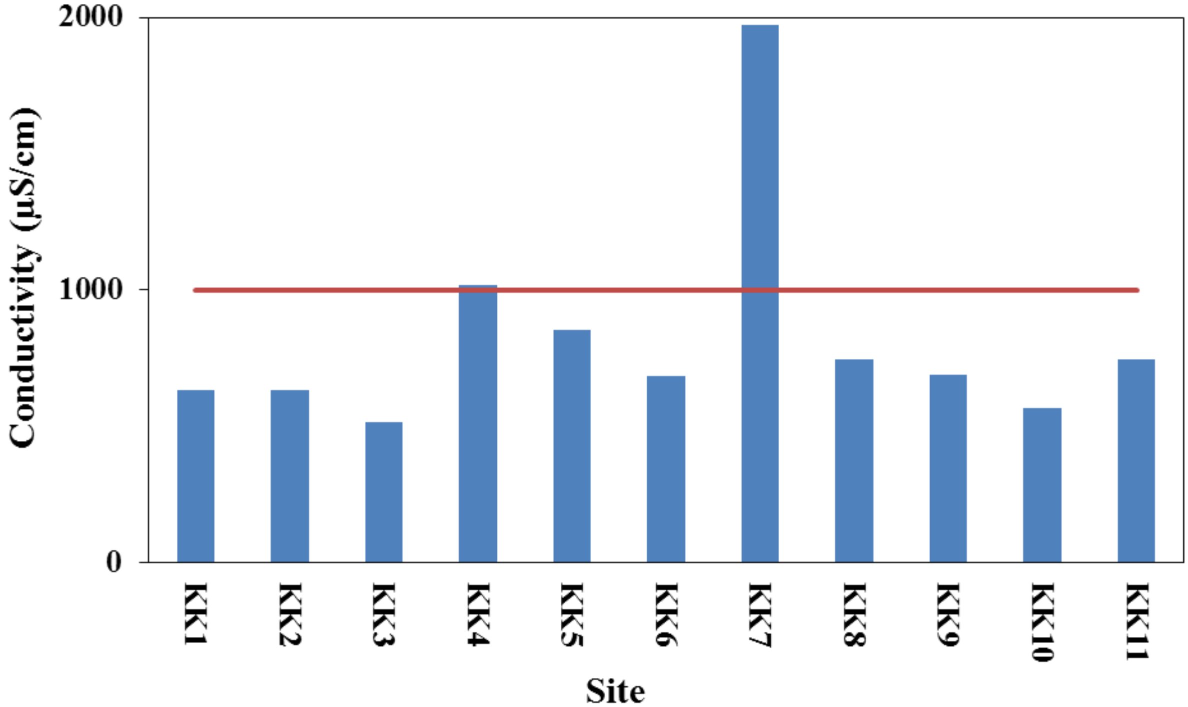


Figure 5.29 Kakuma: Measured conductivity values
Aesthetic guideline is 1000 µS/cm (red line)

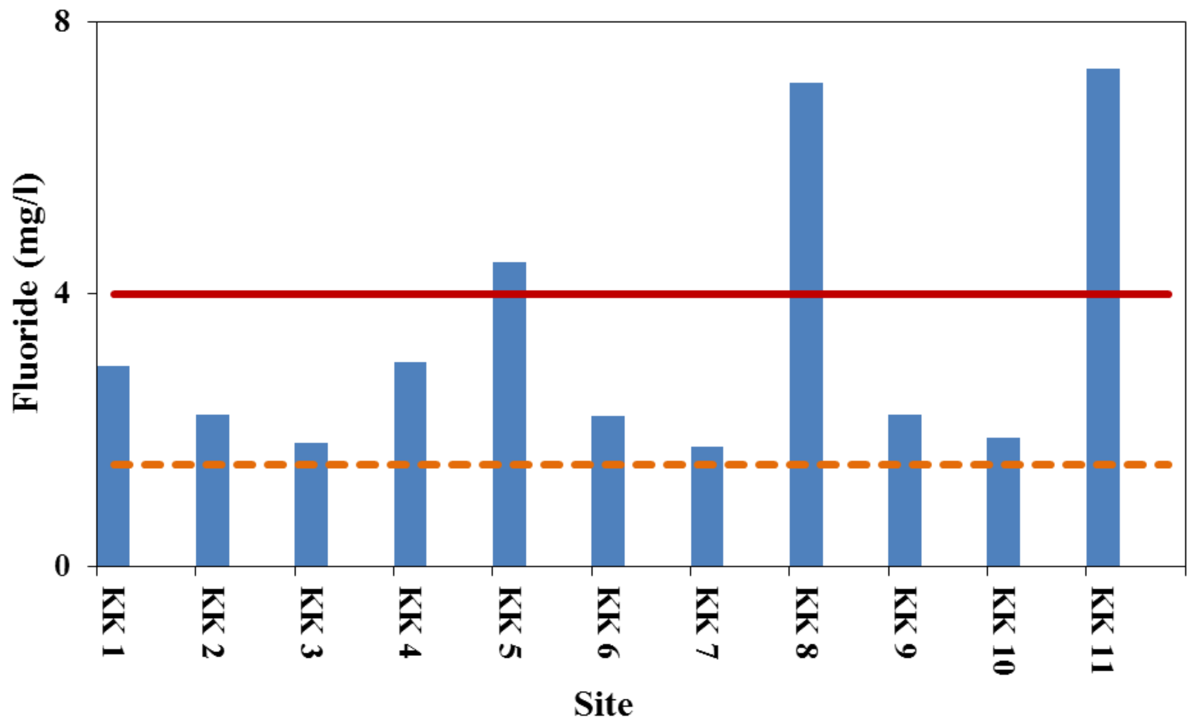


Figure 5.30 Kakuma: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)

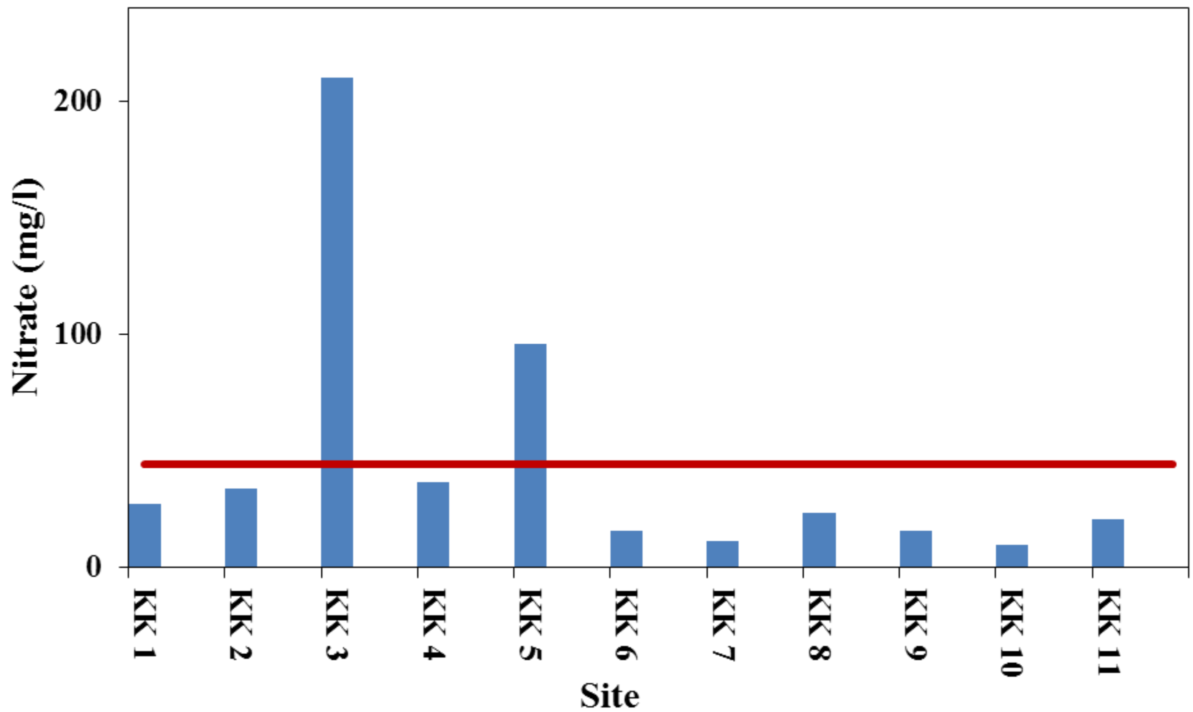


Figure 5.31 Kakuma: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

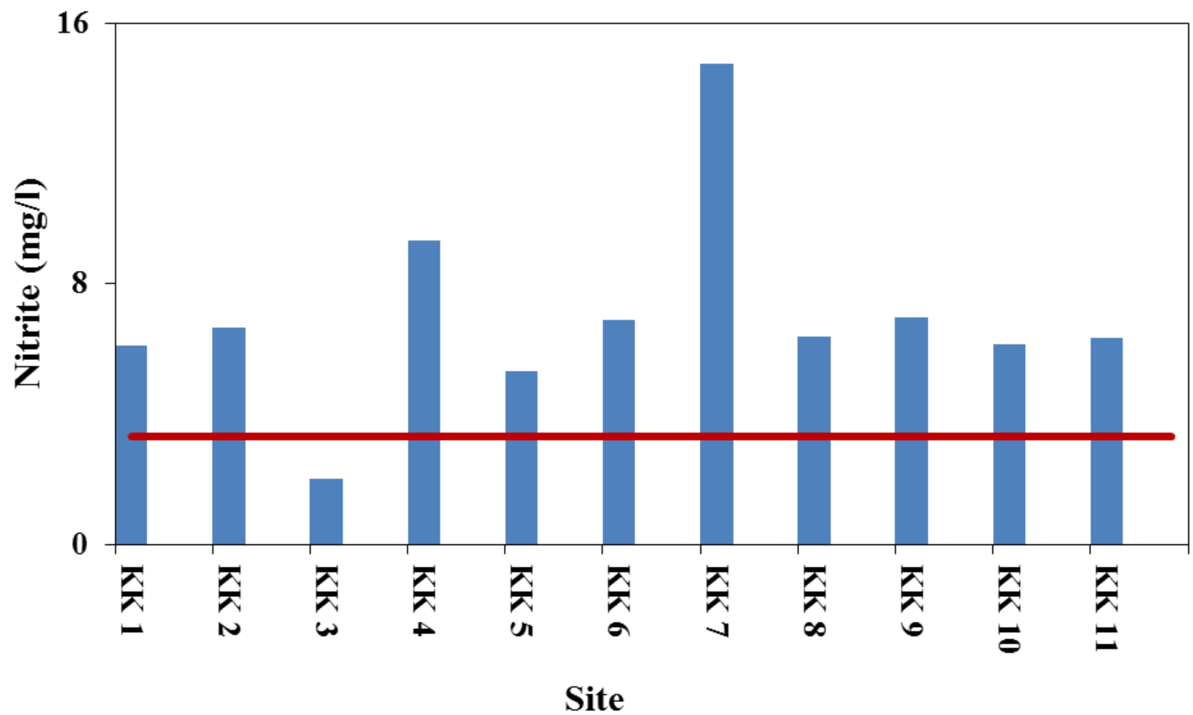


Figure 5.32 Kakuma: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

Water quality in the Dadaab region of Kenya focuses on elevated vanadium concentrations coupled with elevated conductivities. Fifteen sites contain elevated vanadium exceeding the 15 μg/L guideline (Figure 5.33). This is observed to be coupled with the elevated conductivities in Figure 5.34. This plot shows two bimodal populations. Clustering together at high conductivities are very high vanadium concentrations, while moderate conductivities show moderately elevated vanadium. This relationship must be further studied to understand the controlling mechanisms. Overall conductivity is shown in Figure 5.35, with almost all sites sampled at or exceeding 1000 μS/cm. Elevated iron is seen in 9 samples but not to the extent seen across Uganda; however, these values do exceed the aesthetic WHO guideline (Figure 5.36). Four sites (DD5, 9, 10, 14) show elevated chromium levels, which do not exceed standards, but should be measured again. There is elevated zinc across the camps (Figure 5.37) relative to background levels, but it does not exceed the aesthetic WHO guideline. Elevated aluminum could be a potential issue in the Dadaab camps; however, due to contamination, conclusive results cannot be determined at this time. Further testing is required.

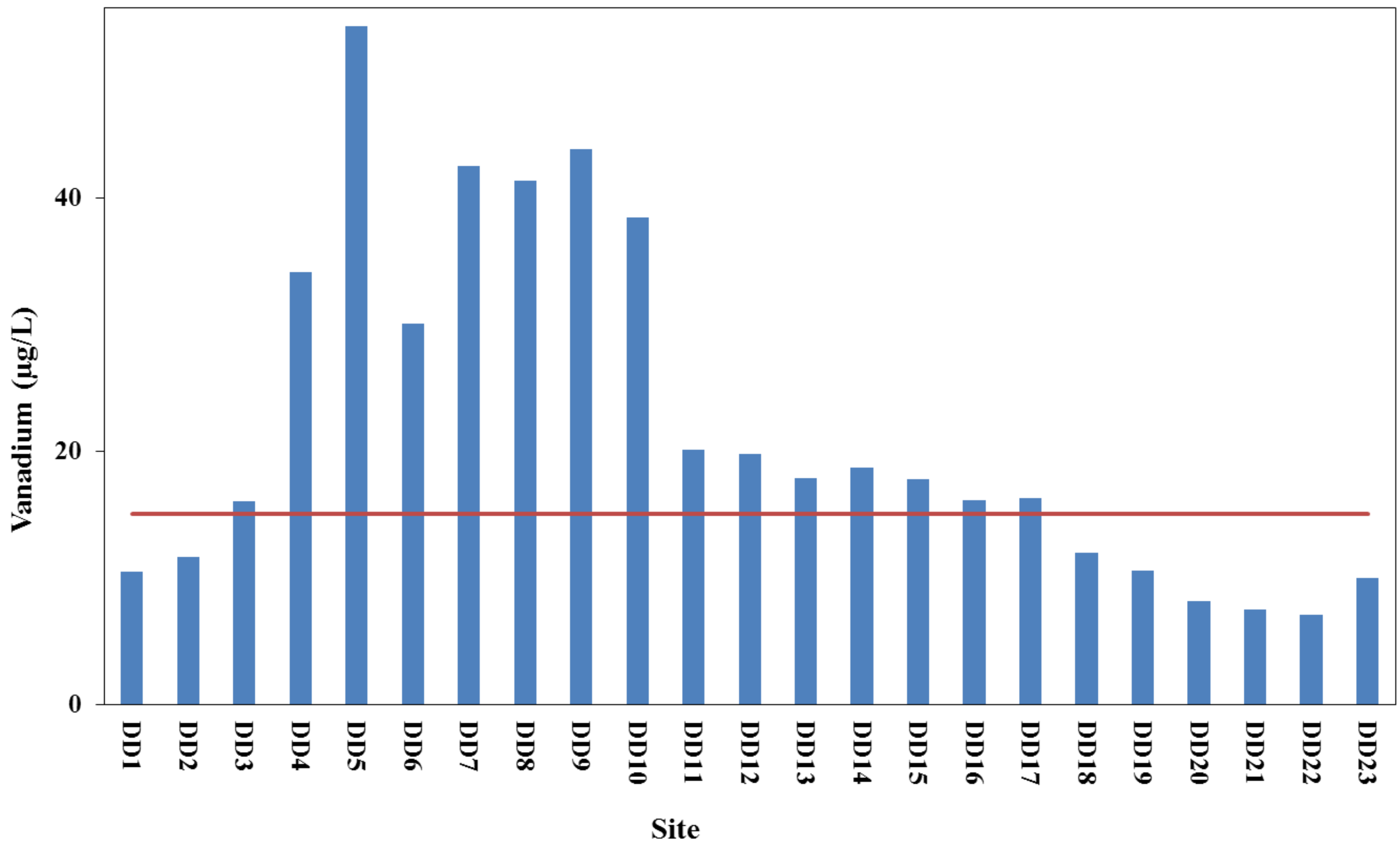


Figure 5.33 Dadaab camps: Measured vanadium concentrations
OEHHA guideline is 15 µg/L (red line)

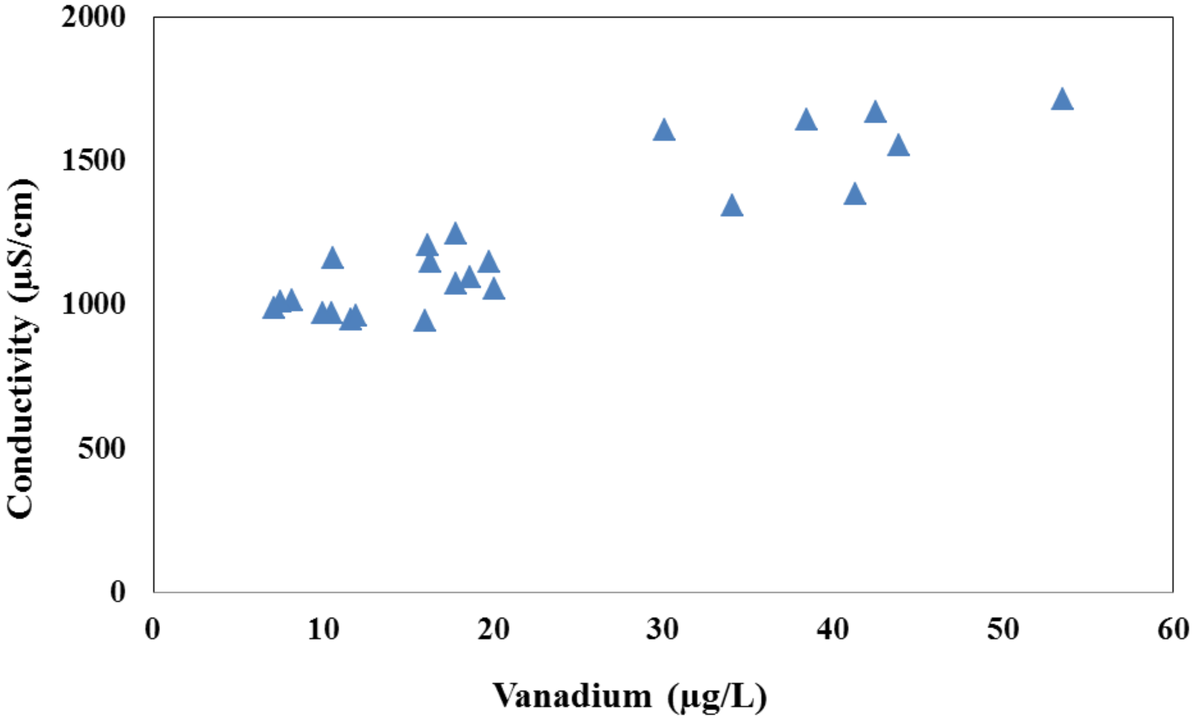


Figure 5.34 Dadaab camps: Conductivity (µS/cm) vs. vanadium (µg/L)

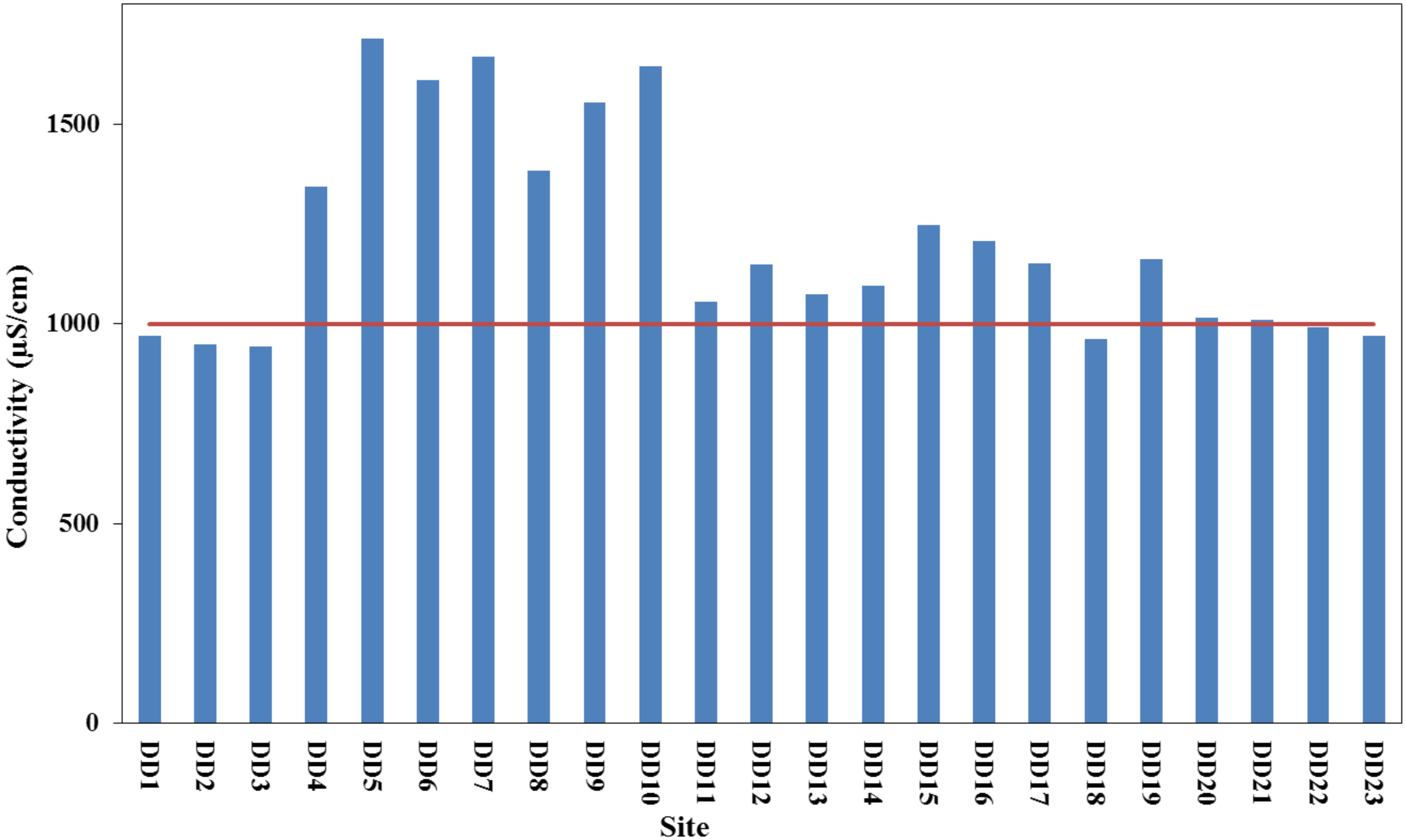


Figure 5.35 Dadaab camps: Measured conductivity values
Aesthetic guideline is 1000 µS/cm (red line)

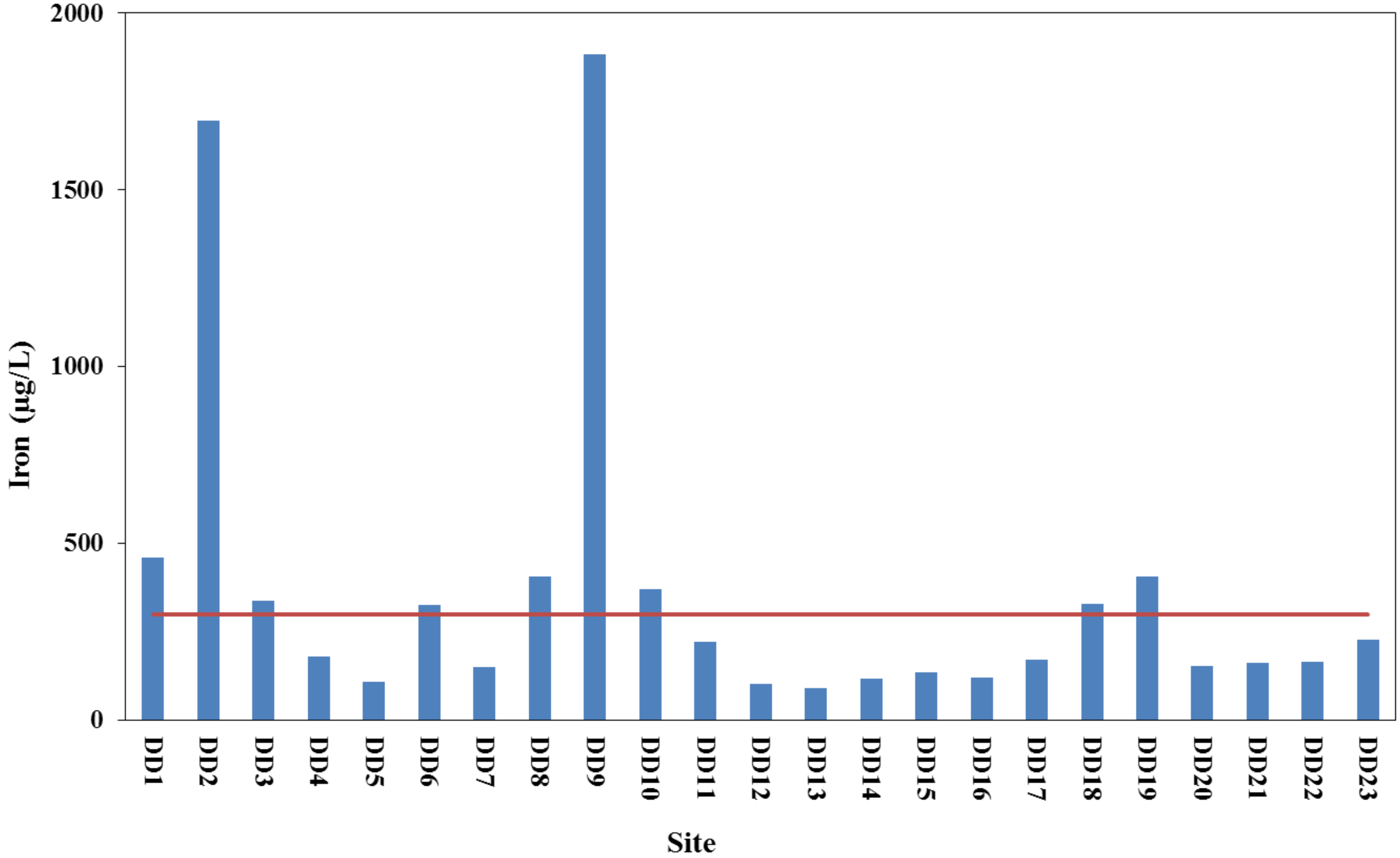


Figure 5.36 Dadaab camps: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

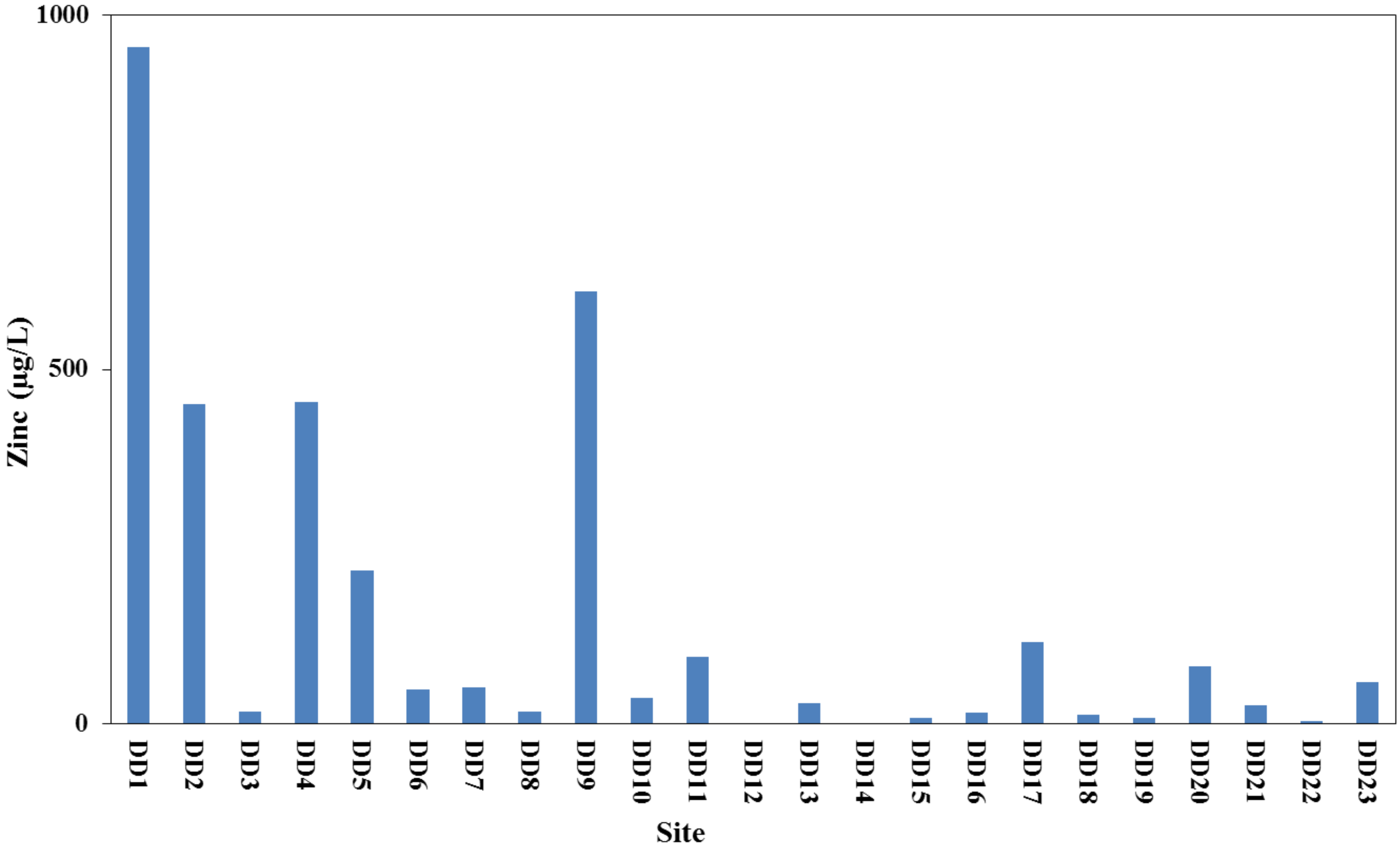


Figure 5.37 Dadaab camps: Measured zinc concentrations
WHO aesthetic guideline is 3 mg/L

Of particular note in the Dadaab region is the lack of iodide found; it has been previously reported that elevated levels of iodide are present at the Dadaab camps. The analyses performed here do not demonstrate this, however. The highest level of iodide detected is 0.13 mg/L (Figure 5.38). While this may be a temporal variation, iodide is not determined to be a particular issue based upon the levels measured at this time. Nitrite, on the other hand, like in Kakuma, shows elevated levels at all sites sampled (Figure 5.39) with concentrations as high as 10 mg/L. Two sites show elevated levels of nitrate, with one site in particular, DD16, having an extremely elevated level of 225 mg/L (Figure 5.40). In addition, the levels of fluoride in the Dadaab camps (Figure 5.41), while not currently above the 1.5 mg/L WHO standard, could possibly become a concern if the U.S. EPA decreases its enforceable standard to 0.7 mg/L. Such an action would clearly demonstrate that major health and environmental organizations believe that fluoride consumption is a health concern at levels much lower than the current WHO level.

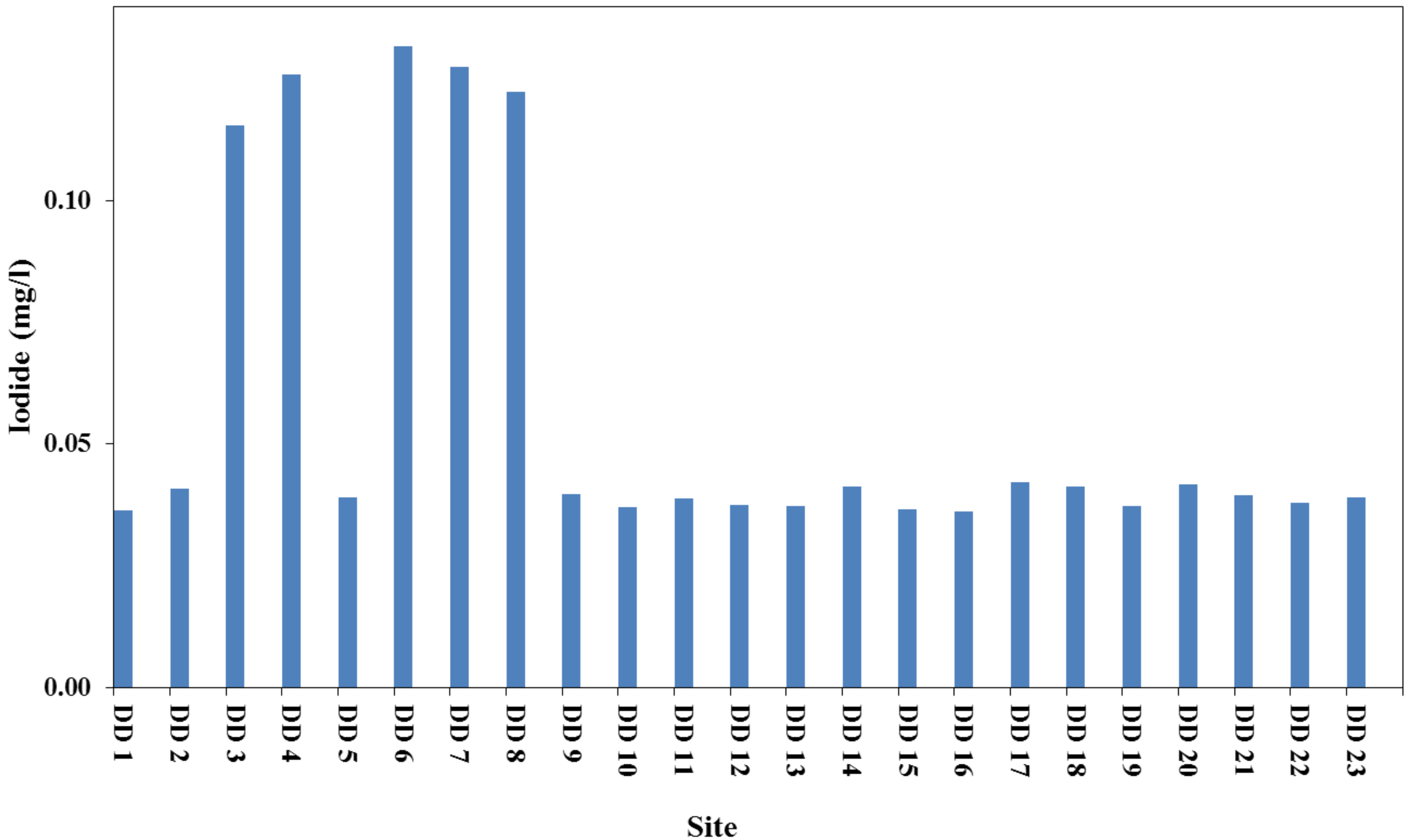


Figure 5.38 Dadaab camps: Measured iodide concentrations
The highest iodide concentration is 0.13 mg/L, which is much lower than expected

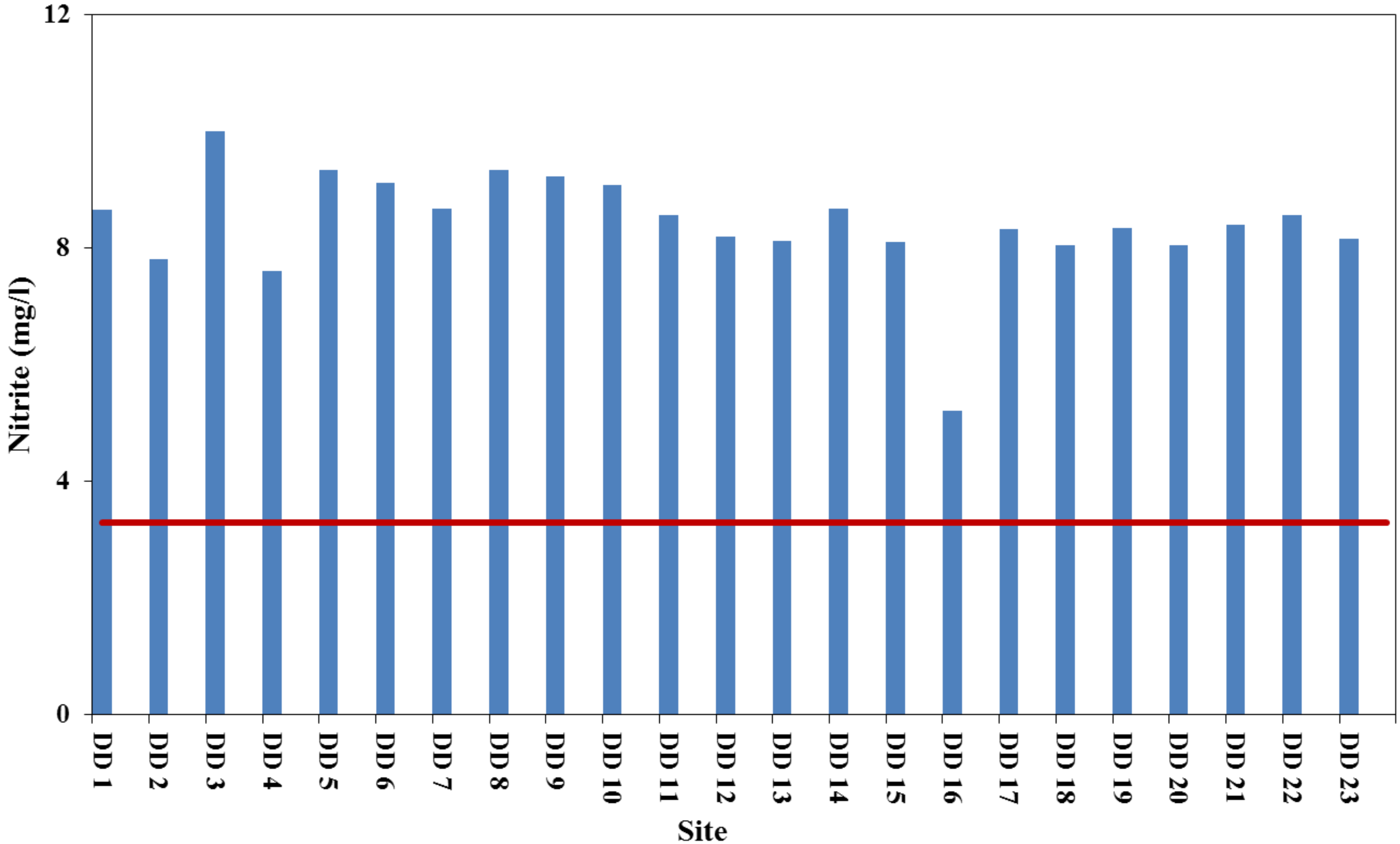


Figure 5.39 Dadaab camps: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

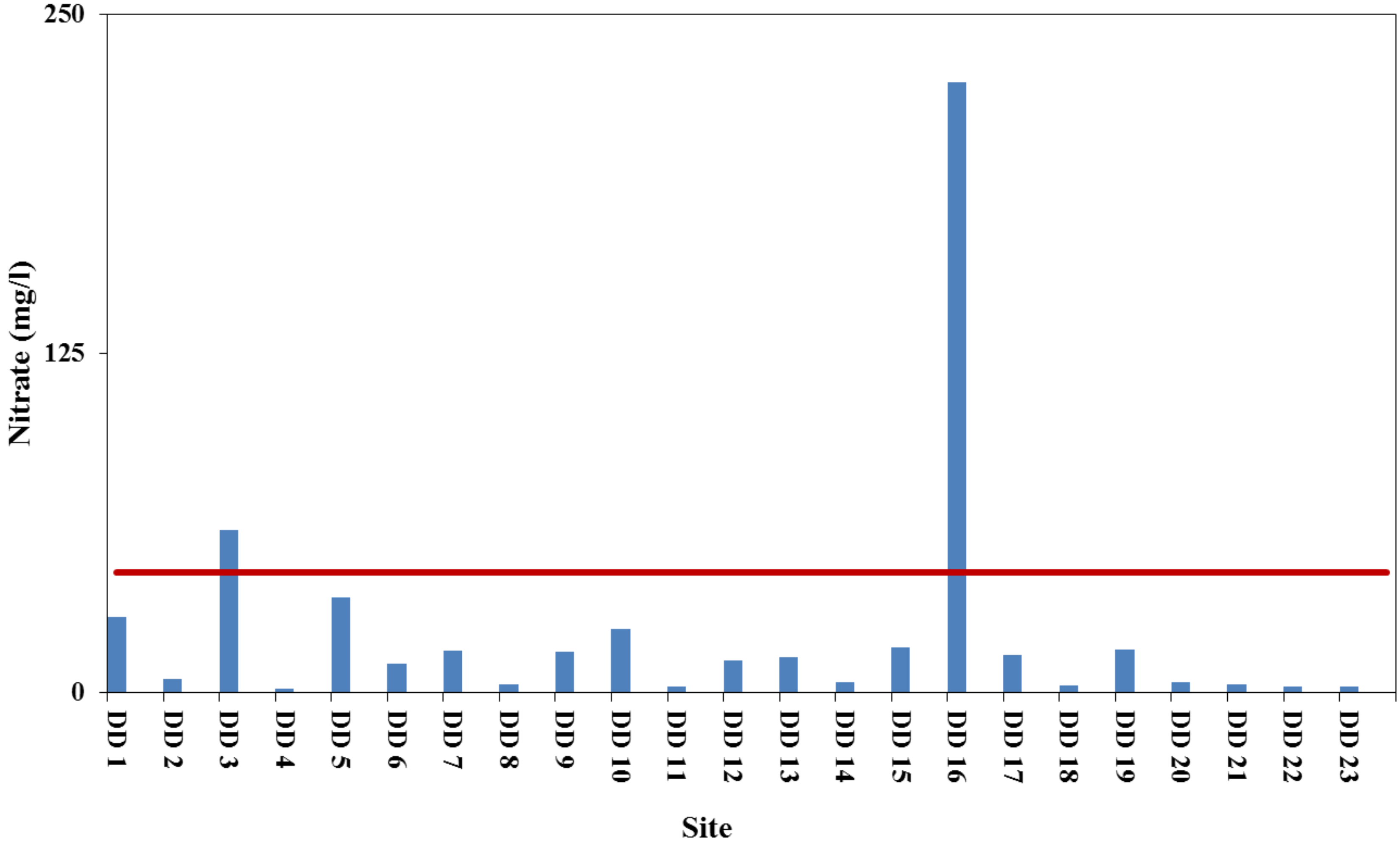


Figure 5.40 Dadaab camps: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

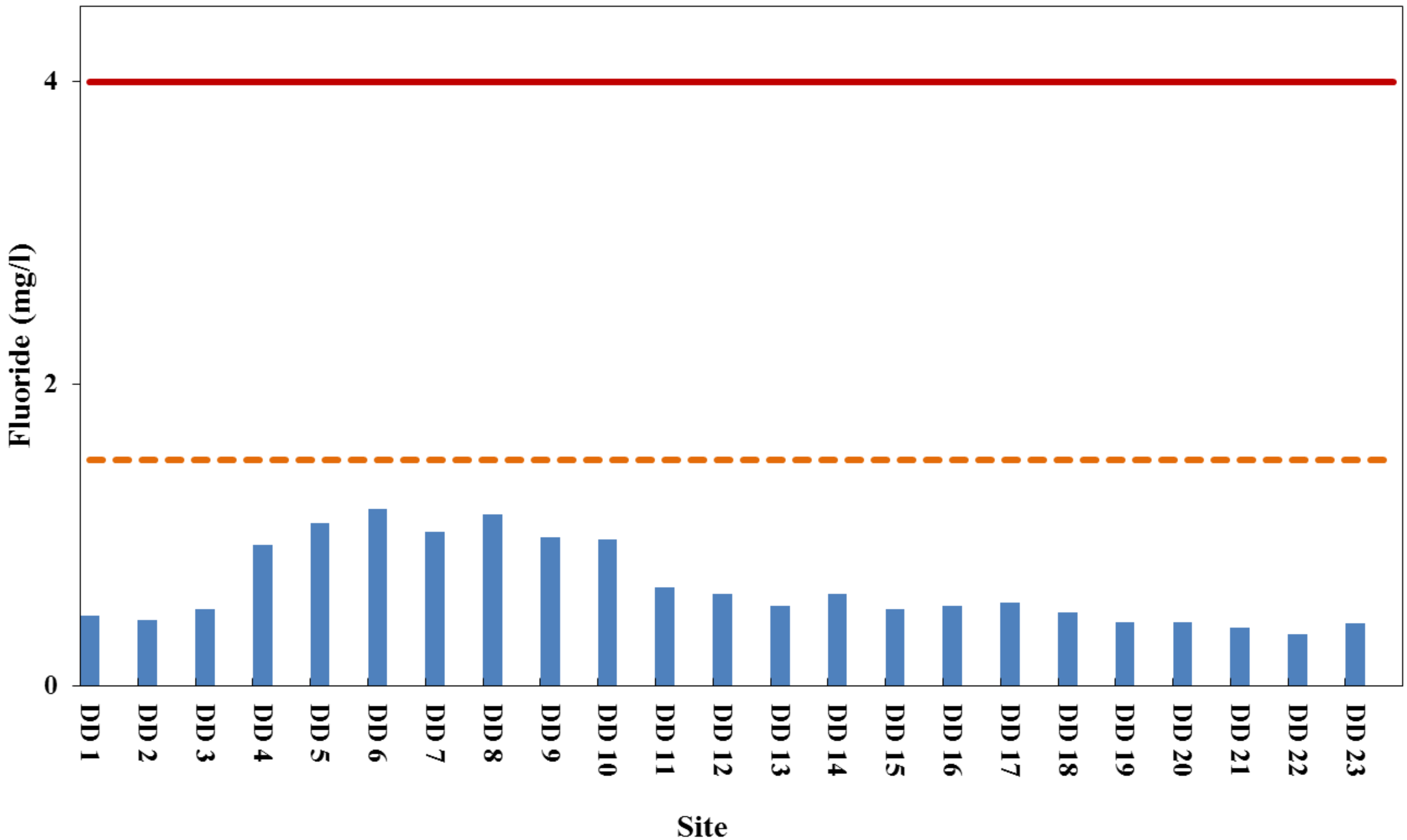


Figure 5.41 Dadaab camps: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)
U.S. EPA may recommend the lowering of its standard to 0.7 mg/L—below many of the fluoride concentrations in the Dadaab camps

5.3.3 Bangladesh

Nayapara has a unique configuration of water distribution points from three centralized water treatment plants. Nine samples have been collected at various stages in the treatment and distribution process. One site has an elevated iron level relative to the WHO aesthetic guideline of 300 µg/L (Figure 5.42). Only a single site in Nayapara, NP7, showed an elevated level of nitrate (Figure 5.43) with a value of 97.7 mg/L, which is well above the 44.3 mg/L U.S. EPA standard for nitrate. No other anions are observed to be elevated.

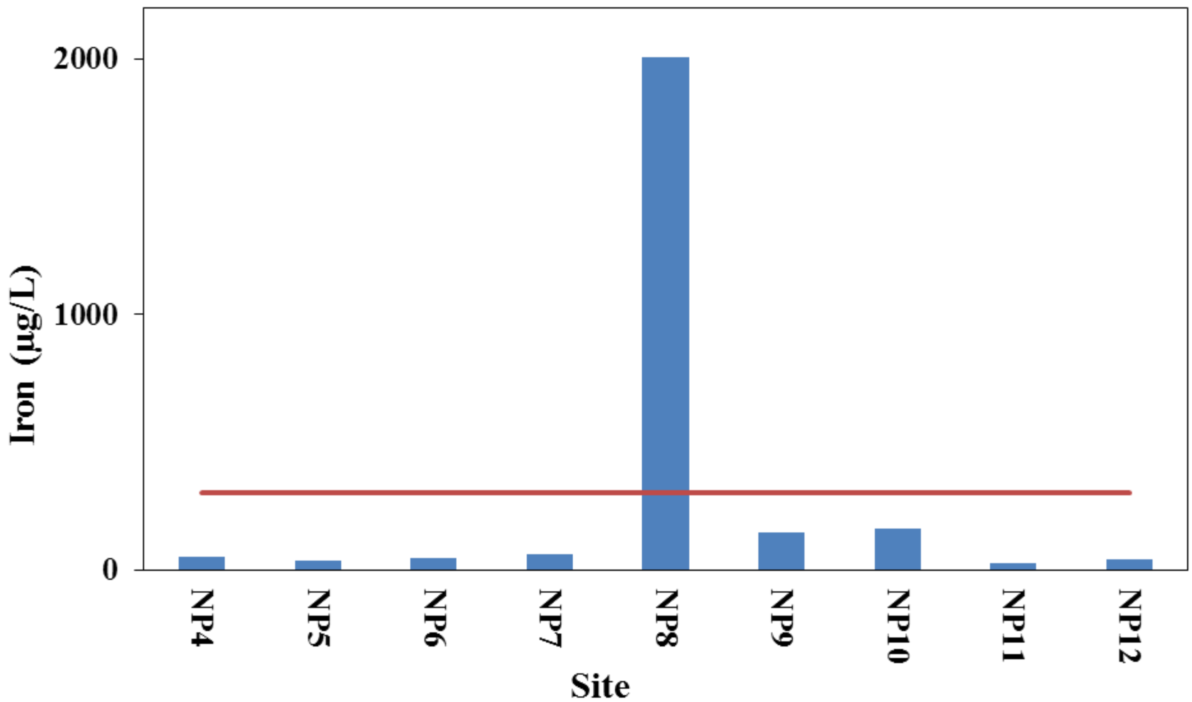


Figure 5.42 Nayapara: Measured iron concentrations WHO aesthetic guideline is 300 µg/L (red line)

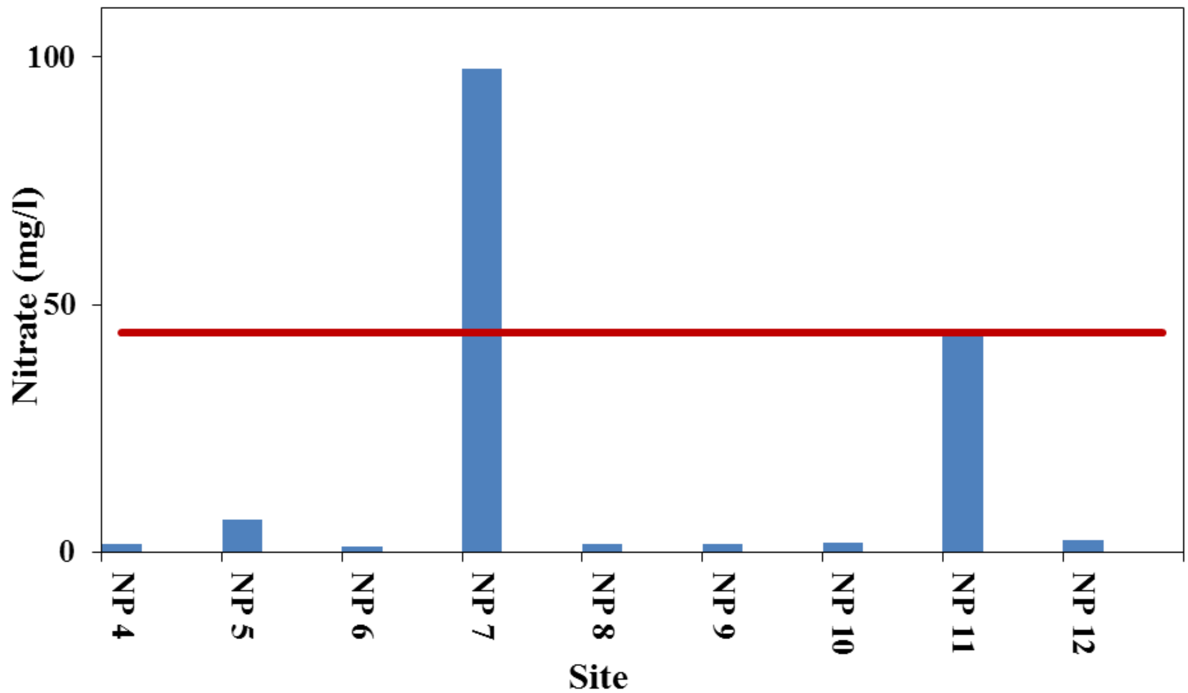


Figure 5.43 Nayapara: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

Kutapalong has 107 tube wells; 38 samples have been analyzed. Overall, iron contamination is a severe problem in Kutapalong. In Figure 5.44, almost all wells are at or above the WHO aesthetic guideline, with many wells far exceeding acceptable or palatable levels. Many of these extremely high iron wells have been abandoned for consumption, and some have even been abandoned for washing, etc. As seen in Uganda, the camps with high iron are also elevated in manganese (Figure 5.45). Thirty wells exceed the WHO aesthetic guideline, and 18 are above the WHO health guideline. An isolated well (KP8) has an elevated arsenic level of 70.99 µg/L. This far exceeds the WHO guideline of 10 µg/L. Two isolated wells, KP4 and KP12, show elevated levels of chromium at 60.06 and 17.61 µg/L, respectively. Cobalt is seen trending with elevated nickel, suggesting contamination by an alloy in the well head. Elevated nickel is shown in Figure 5.46. One well exceeds the 70 µg/L WHO health standard, while many are above background levels. Six wells show elevated gallium; the source and health impacts are unknown. Lead contamination is seen in 5 wells to exceed the WHO guideline of 10 µg/L (Figure 5.47). Interestingly, pH values in Kutapalong are not stable. They show a wide range from highly acidic values of 3.92 to a circumneutral 7.73 (Figure 5.48). This has implications for lead solubility. Figure 5.49 shows the relationship between lead and pH. Lead clearly shows a drastic increase in solubility below pH 5.5; as the pH decreases, more lead is released into solution. One site with a lead level of 215 µg/L (KP8) is not included in this plot. The fact that the lead concentration at this site is so much higher than at any other site suggests a single point source of contamination separate from the pH-controlled increase in lead solubility.

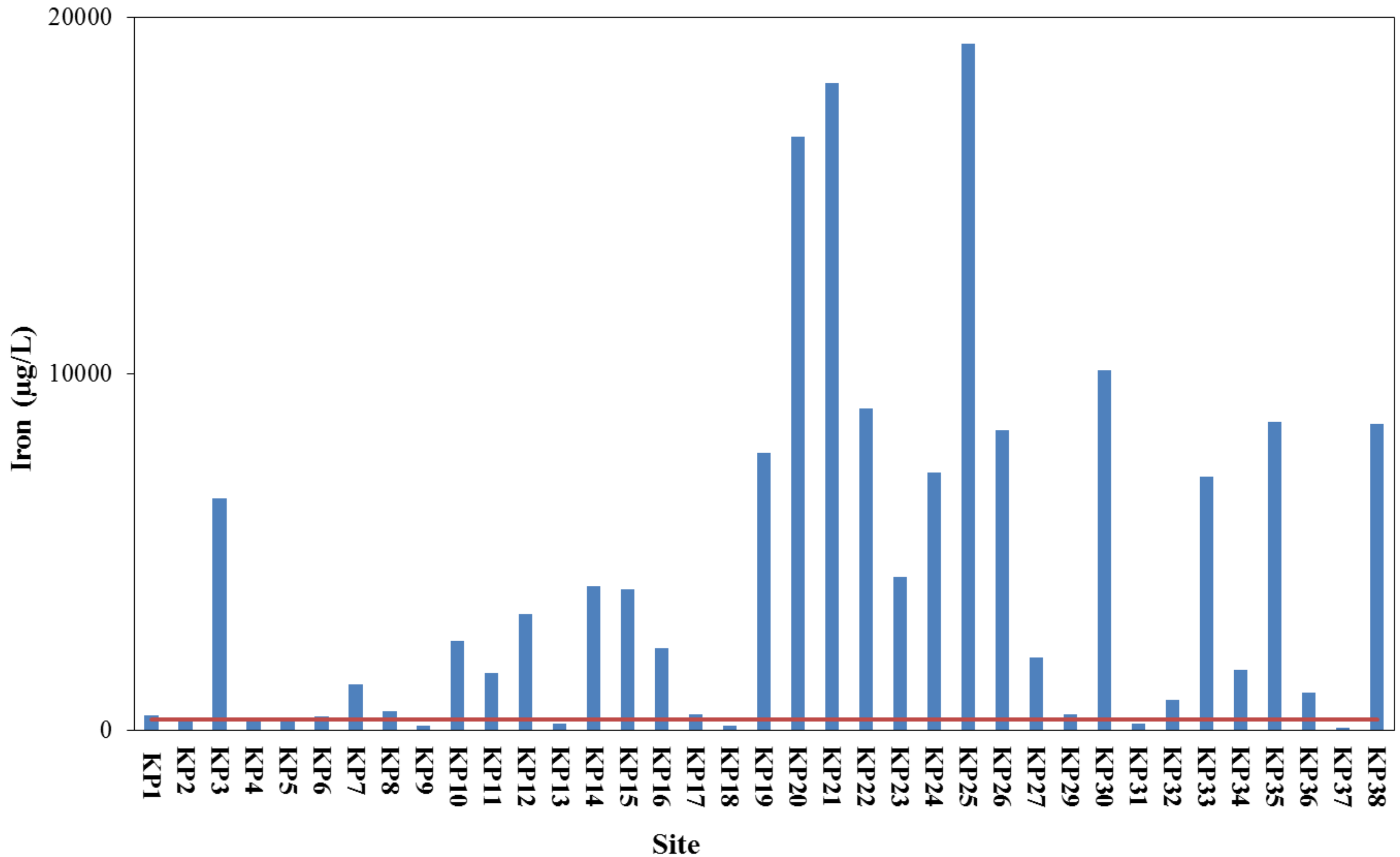


Figure 5.44 Kutapalong: Measured iron concentrations
WHO aesthetic guideline is 300 µg/L (red line)

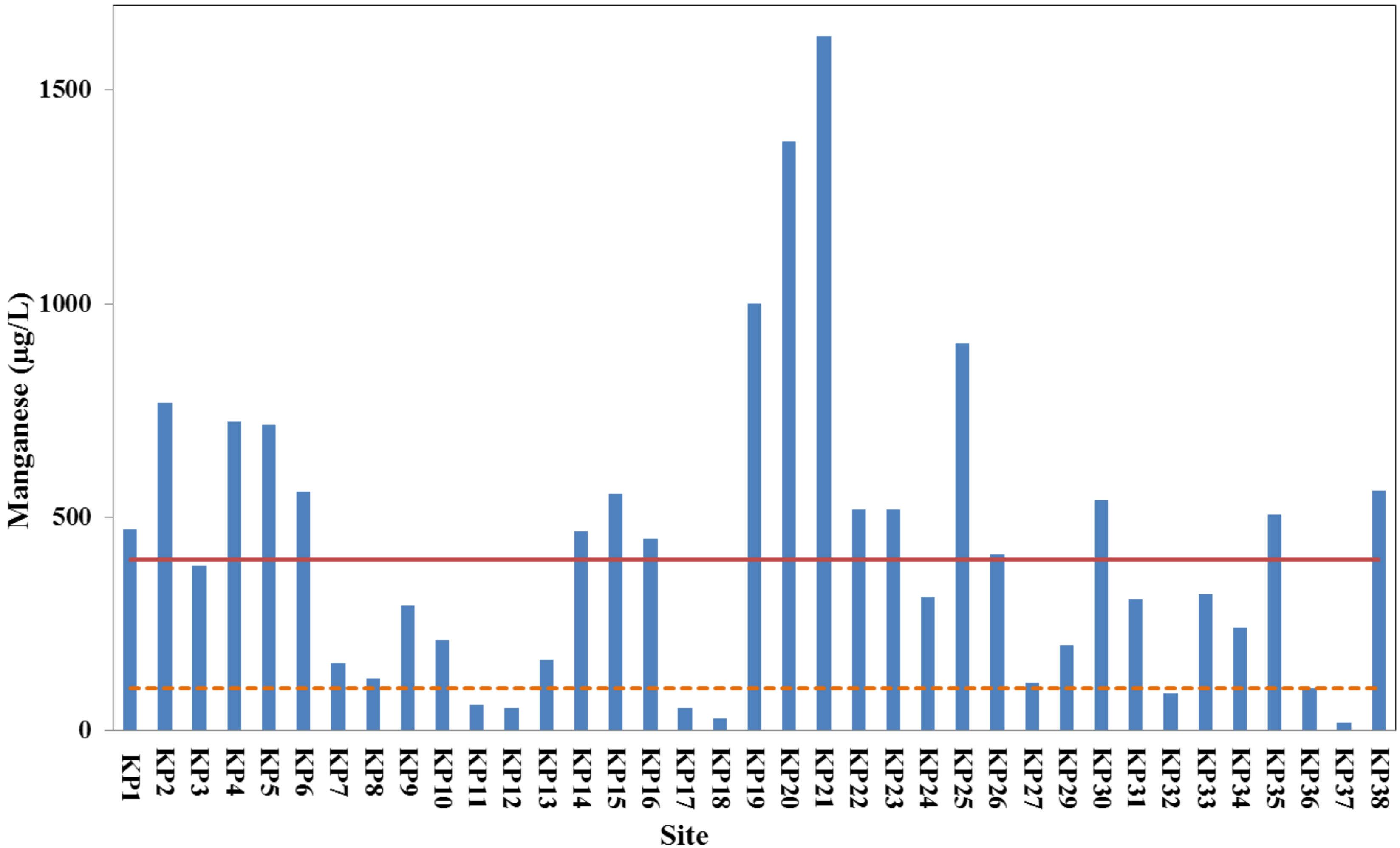


Figure 5.45 Kutapalong: Measured manganese concentrations
WHO aesthetic guideline is 0.1 mg/L (orange dashed line); WHO health guideline is 0.4 mg/L (red line)

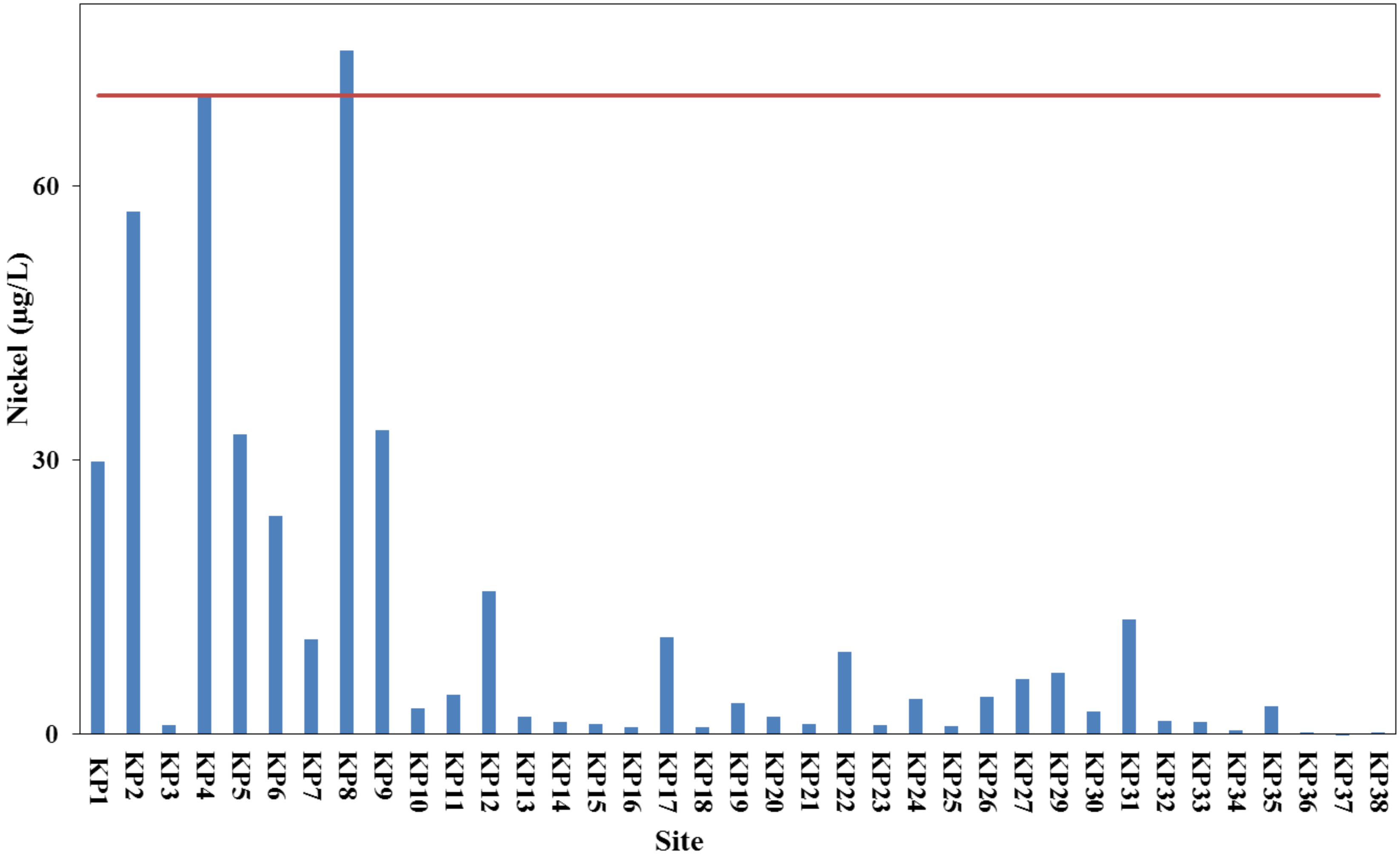


Figure 5.46 Kutapalong: Measured nickel concentrations
WHO health guideline is 70 µg/L (red line)

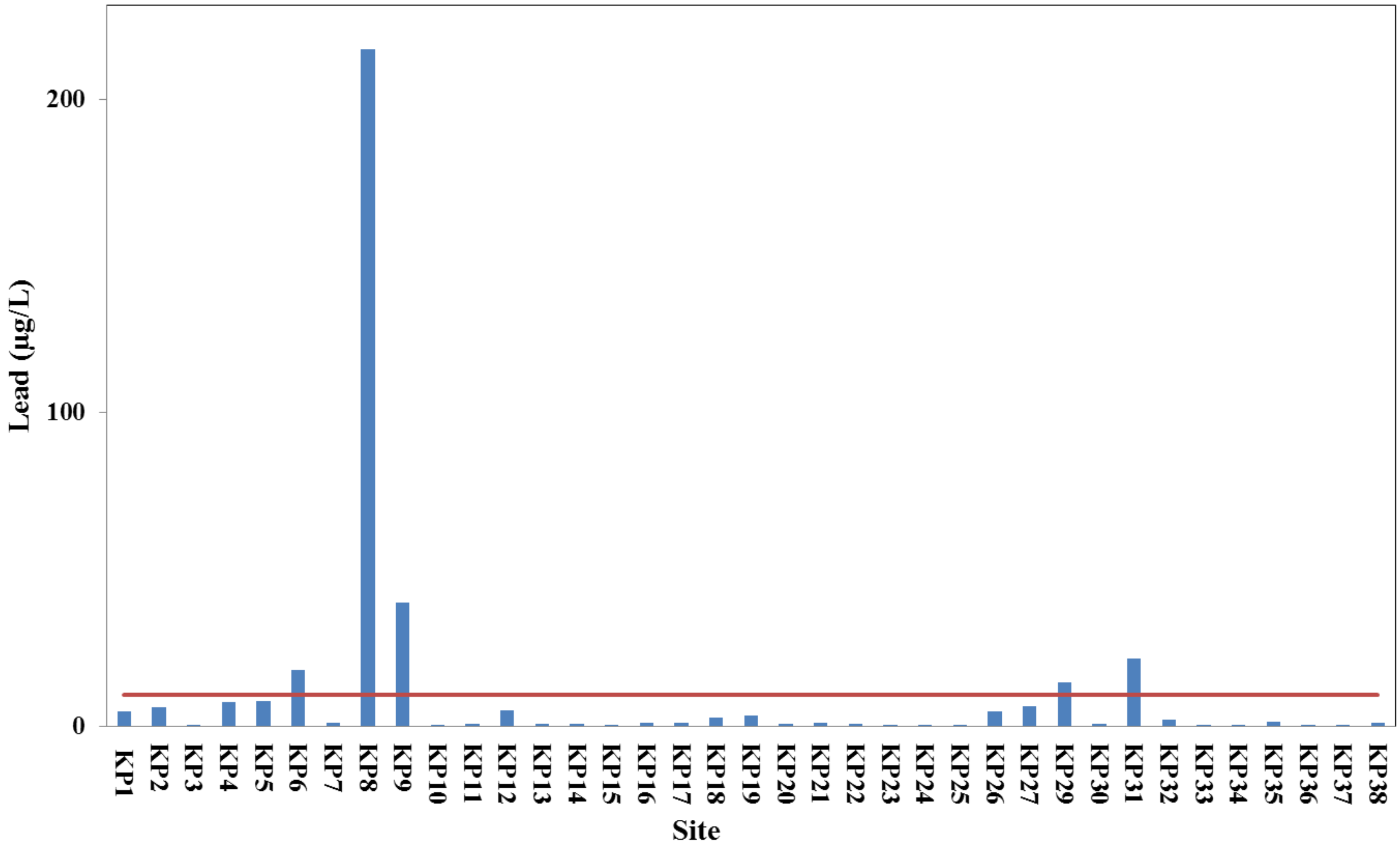


Figure 5.47 Kutapalong: Measured lead concentrations
WHO health guideline is 10 µg/L (red line)

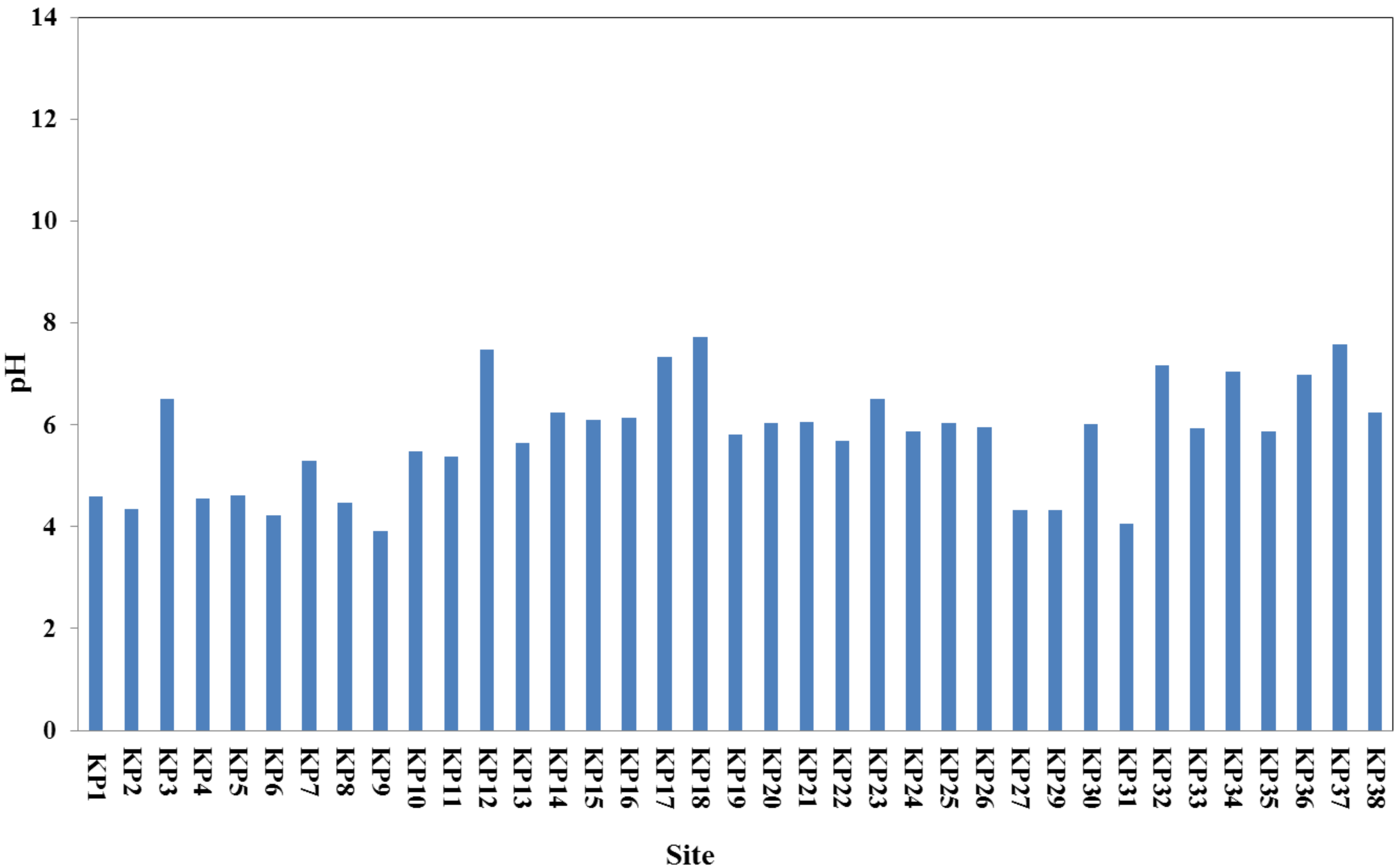


Figure 5.48 Kutapalong: Measured pH values

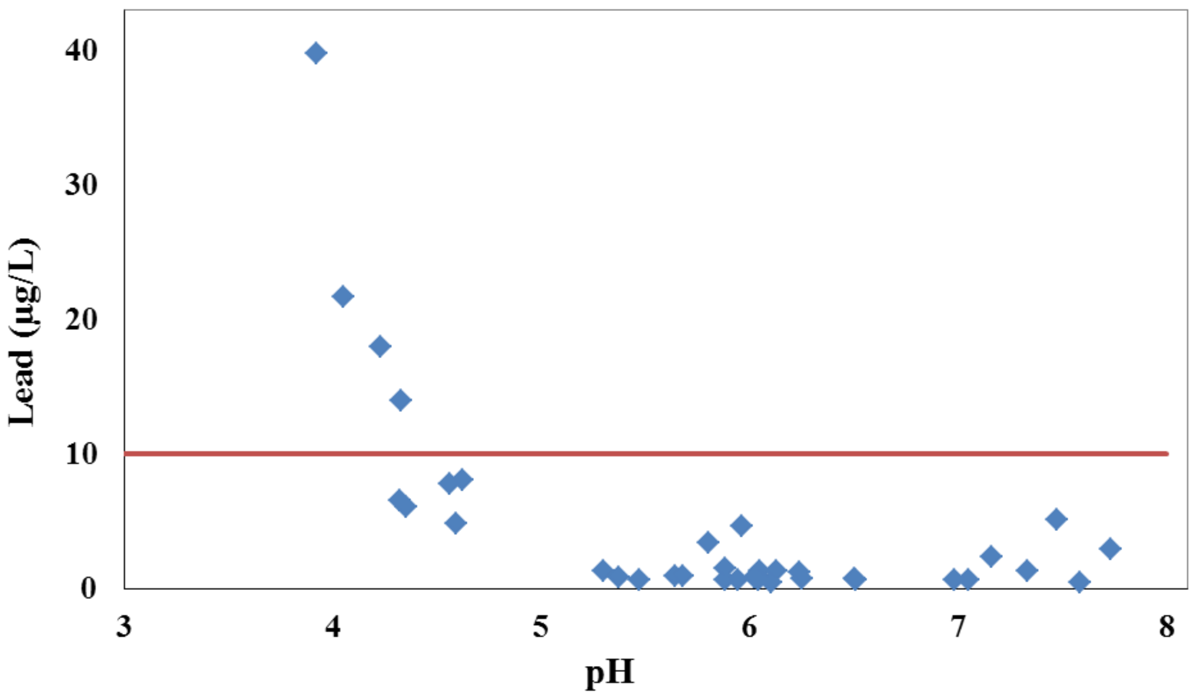


Figure 5.49 Kutapalong: Lead (µg/L) vs. pH
WHO health guideline is 10 µg/L (red line)

Eight sites in Kutapalong show elevated nitrite levels above the U.S. EPA standard of 3.3 mg/L (Figure 5.50), while nearly half show elevated levels of nitrate (Figure 5.51). Interestingly, if plotted together against pH one can see that nitrate and nitrite are inversely related in Kutapalong (Figure 5.52) showing that this redox pair is controlling pH. This occurs with the processes of nitrogen-reducing bacteria. The two anions cross around pH 5.5, showing that nitrate (oxidizing conditions) is more favorable at a pH less than 5.5 and nitrite (reducing conditions) is more favorable at a pH greater than 5.5. A relationship is also evident with lead (Figure 5.49): where oxidizing conditions exist, lead desorbs from solid surfaces caused by the increasingly positive solid surfaces and is thus released; under reducing conditions, lead is more likely to sorb to the less positively charged solid surfaces.

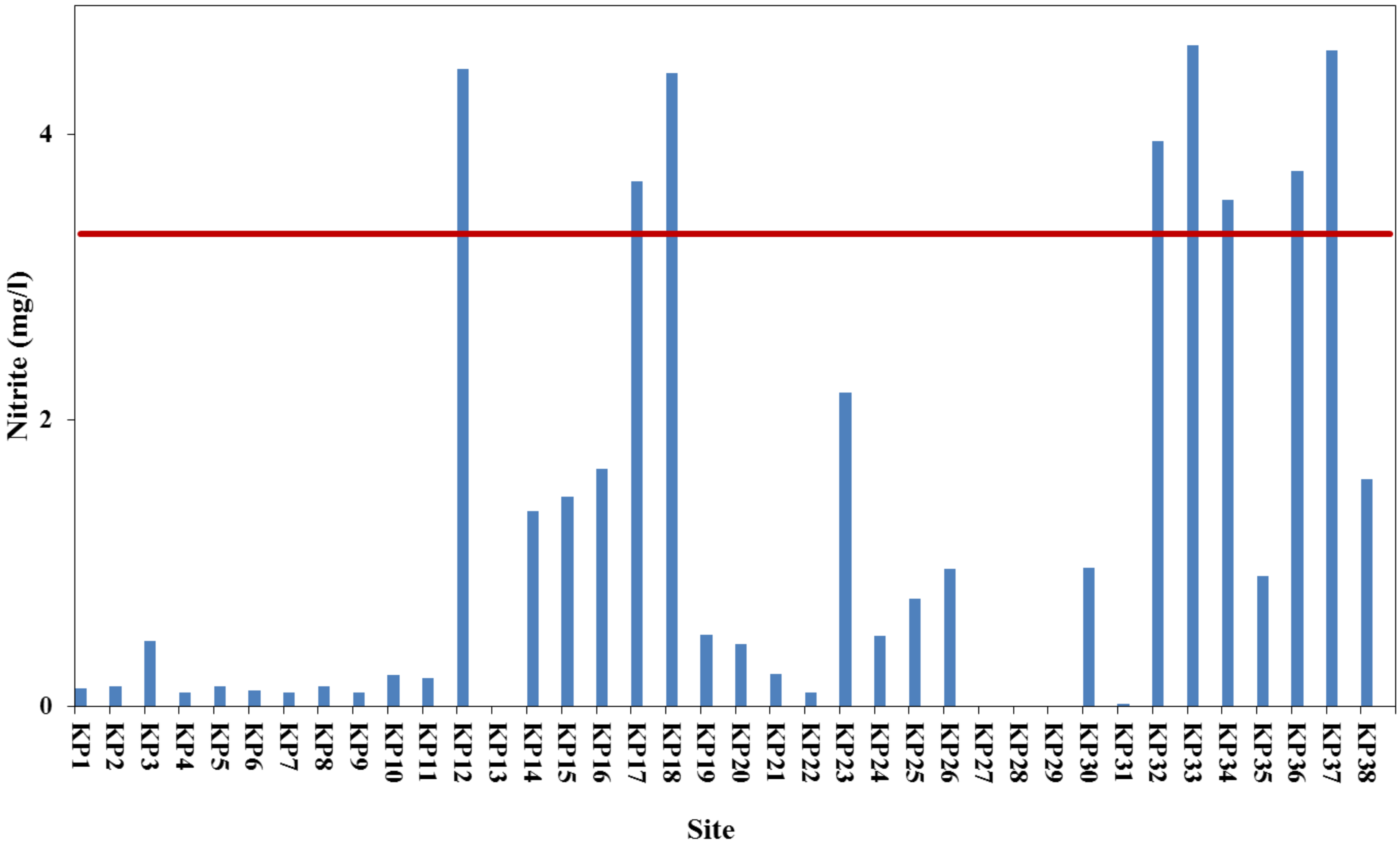


Figure 5.50 Kutapalong: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

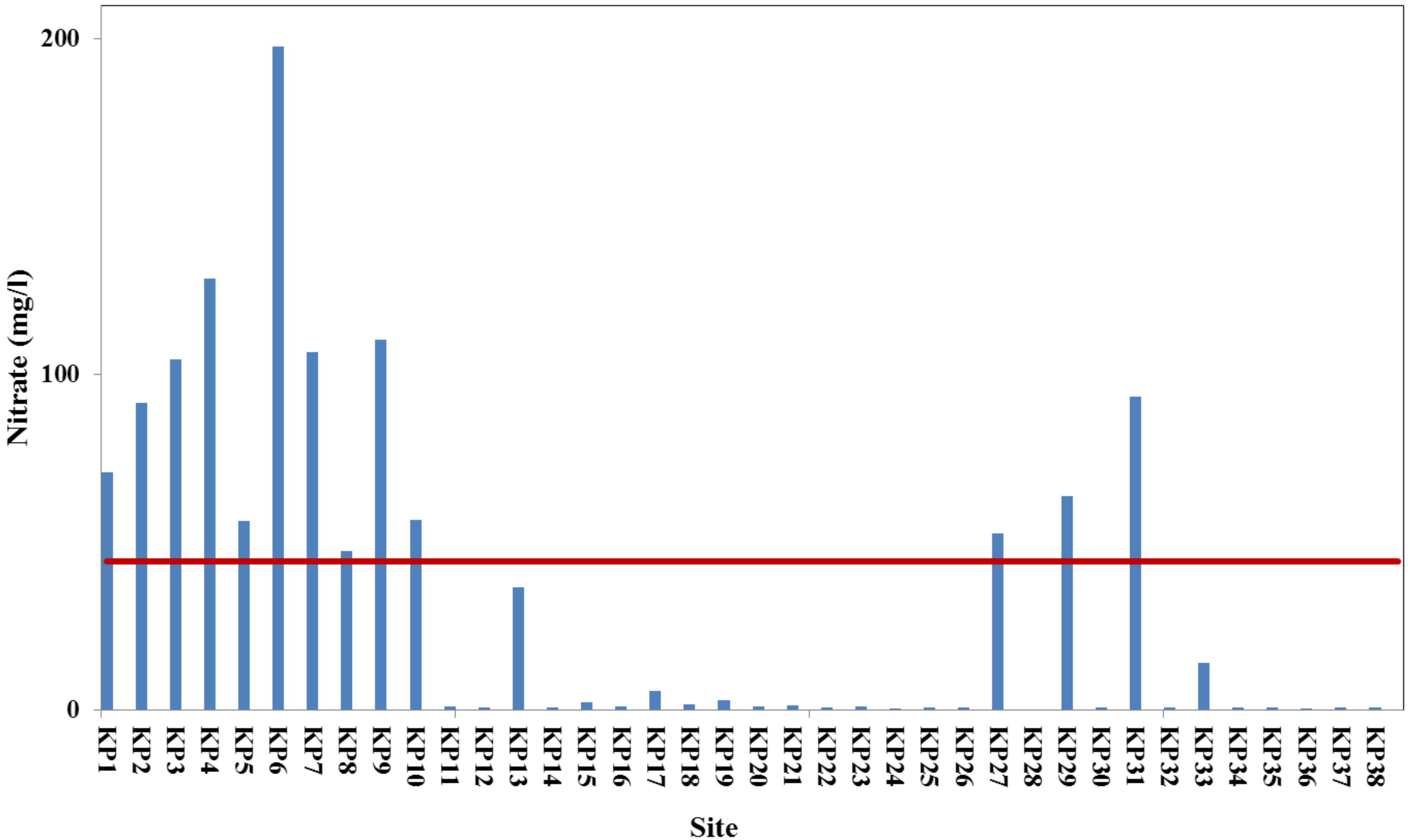


Figure 5.51 Kutapalong: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

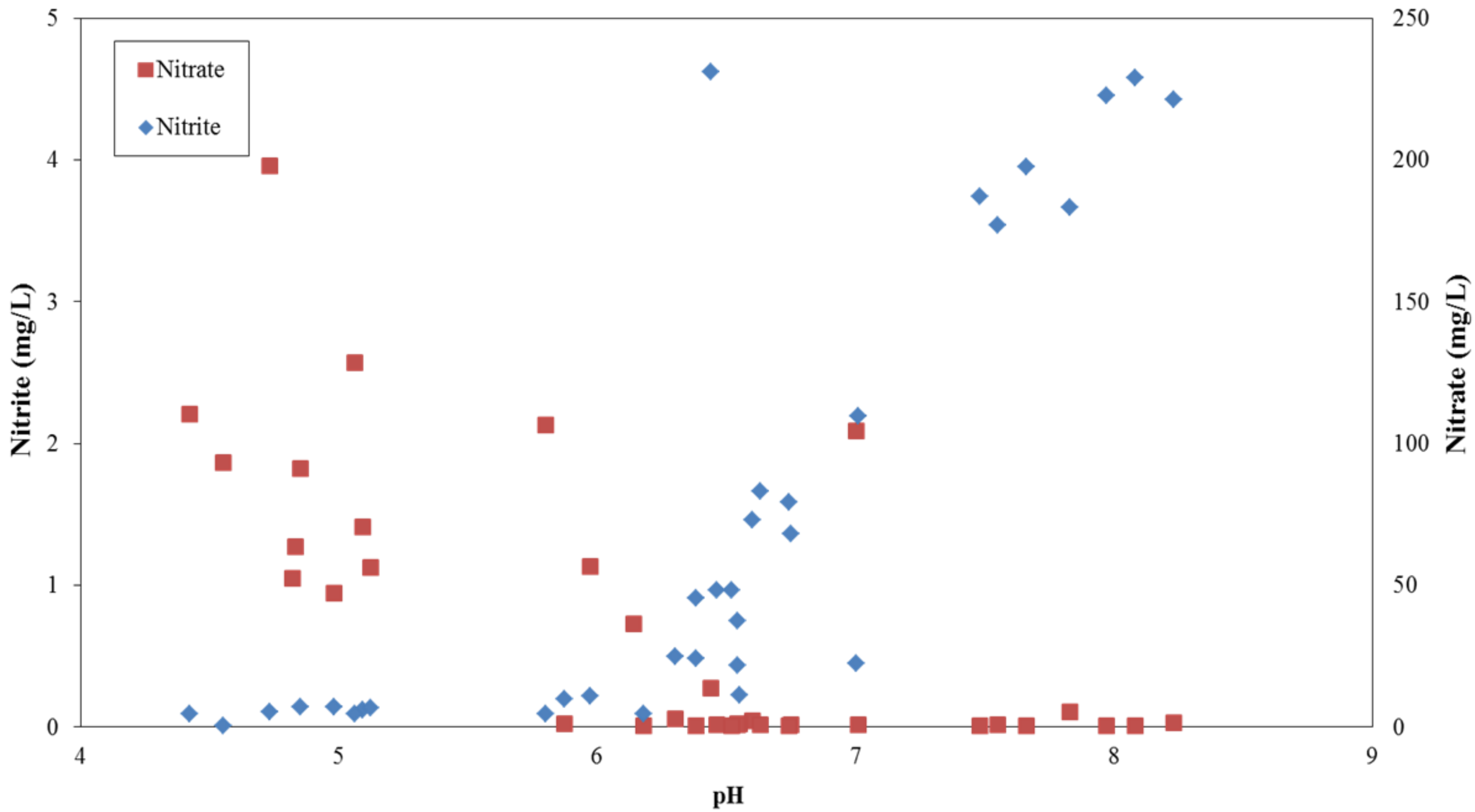


Figure 5.52 Kutapalong: Nitrate/Nitrite (mg/L) vs. pH

5.3.4 Djibouti

In the town of Ali Sabieh, conductivity is elevated above 1000 µS/cm (Figure 5.53), and vanadium concentrations are above the 15 µg/L guideline suggested by the California OEHHA (http://oehha.ca.gov/water/pals/vanadium.html) (Figure 5.54), as seen throughout the entire country. The U.S. EPA aesthetic guideline for total dissolved solids (TDS) is 500 mg/L, while WHO suggests water with TDS above 1000 mg/L is unpalatable. TDS can be related to conductivity by an empirical factor (http://www.ilmb.gov.bc.ca/risc/pubs/aquatic/interp/interp-01.htm), which sets the suggested range for conductivity between 700 and 1400 µS/cm. The midpoint of this range (1000 µS/cm) is shown in Figure 5.53 and throughout the report for comparative purposes. The high conductivity measurements are reinforced by the high chloride values which are above the 250 mg/L U.S. EPA guideline in Ali Sabieh (Figure 5.55) and throughout Djibouti. Isolated sites are high in zinc (AS1) with a value of 1.16 mg/L and selenium (AS1 and AS2) with values of 29.03 and 20.72 µg/L. Elevated nitrate (Figure 5.56) and nitrite (Figure 5.57) are also seen in Ali Sabieh. Nitrate is extremely elevated relative to the U.S. EPA standard of 44.3 mg/L, ranging from 121 mg/L to 154 mg/L. The AS1 nitrate data is invalidated due to a competing peak in the resulting chromatogram and is therefore not shown. Likewise, nitrite values are well above the 3.3 mg/L U.S. EPA standard, ranging from 4.7 mg/L to 5.4 mg/L. Elevated fluoride concentrations above the 1.5 mg/L WHO health guideline are also seen at two of the three sites sampled in Ali Sabieh, reaching as high as 2.3 mg/L (Figure 5.58). It should also be noted that the U.S. EPA and the United States Department of Health and Human Services (HHS) in cooperation with the Centers for Disease Control (CDC) recently released a recommendation to decrease its enforceable fluoride standard from 4 mg/L to 0.7 mg/L (http://www.hhs.gov/news/press/2011pres/01/20110107a.html). This action clearly expresses concern by the U.S. EPA, HHS, and the CDC regarding the prolonged exposure to fluoride in drinking water at levels even less than 1 mg/L.

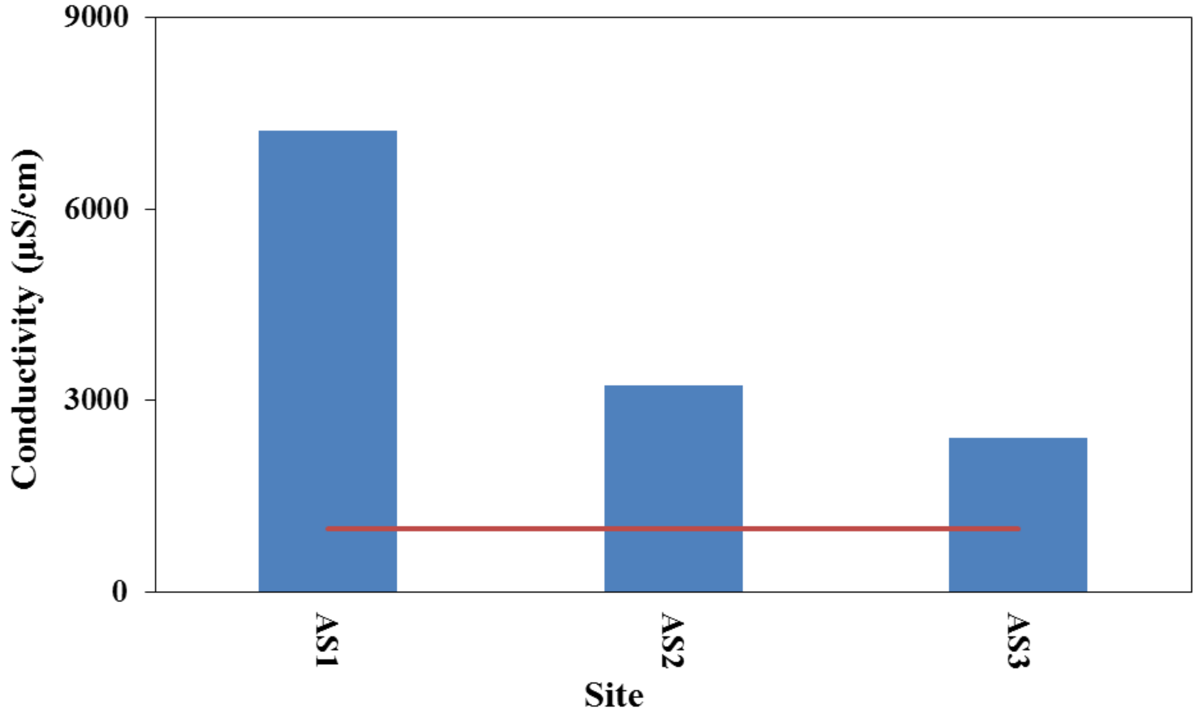


Figure 5.53 Ali Sabieh: Measured conductivity values
Aesthetic guideline is 1000 µS/cm (red line)

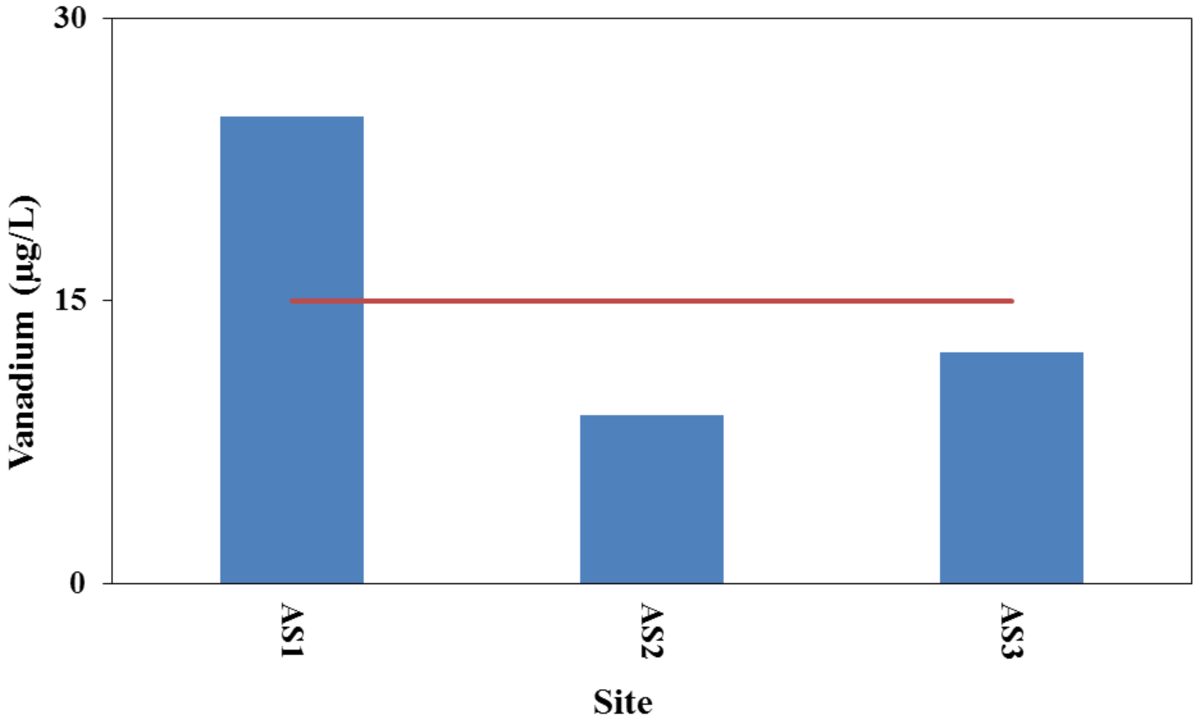


Figure 5.54 Ali Sabieh: Measured vanadium concentrations
OEHHA guideline is 15 µg/L (red line)

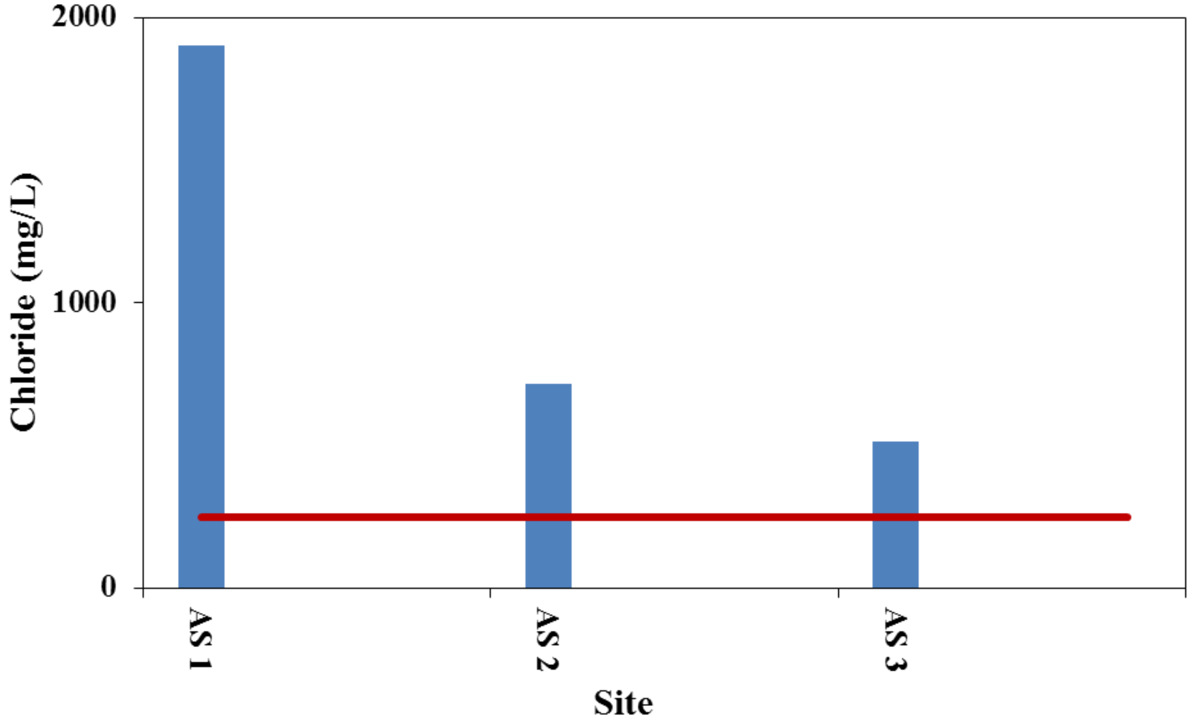


Figure 5.55 Ali Sabieh: Measured chloride concentrations
U.S. EPA guideline is 250 mg/L (red line)

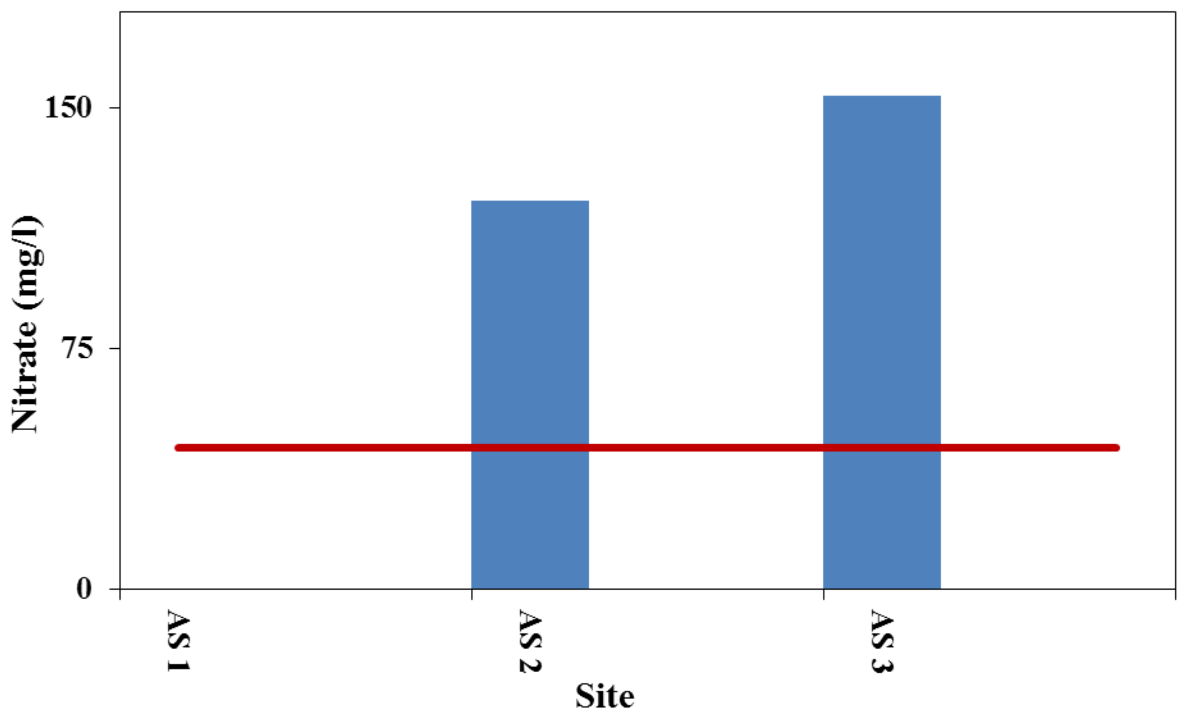


Figure 5.56 Ali Sabieh: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

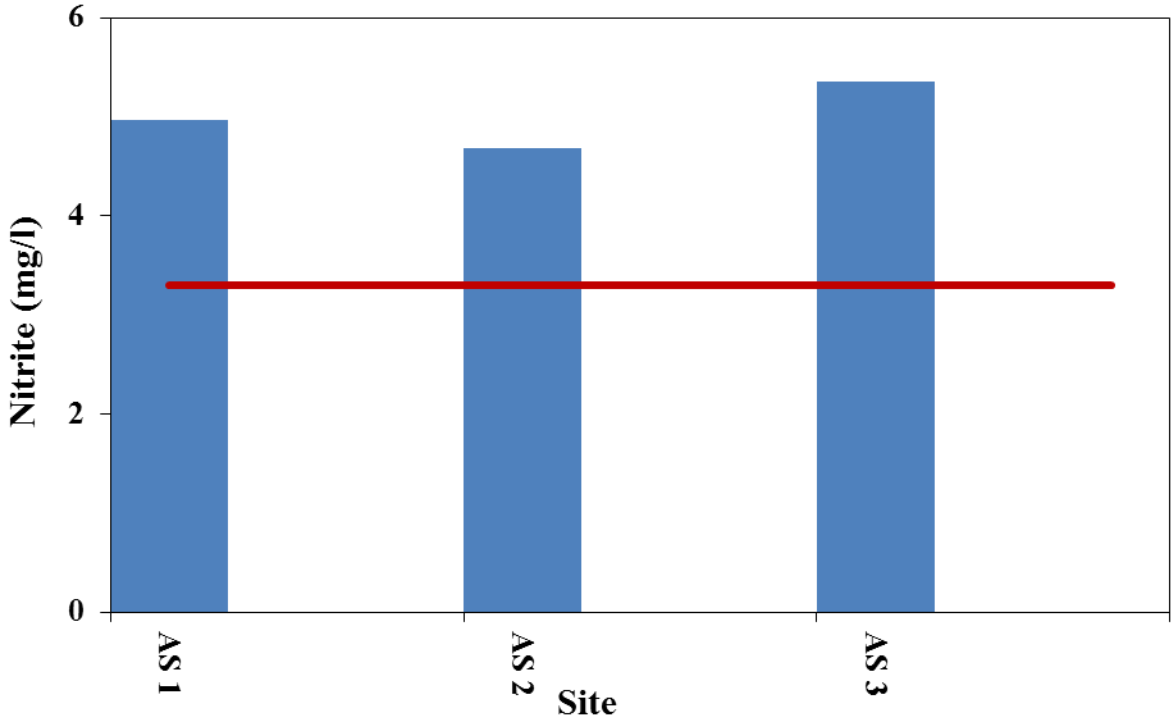


Figure 5.57 Ali Sabieh: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

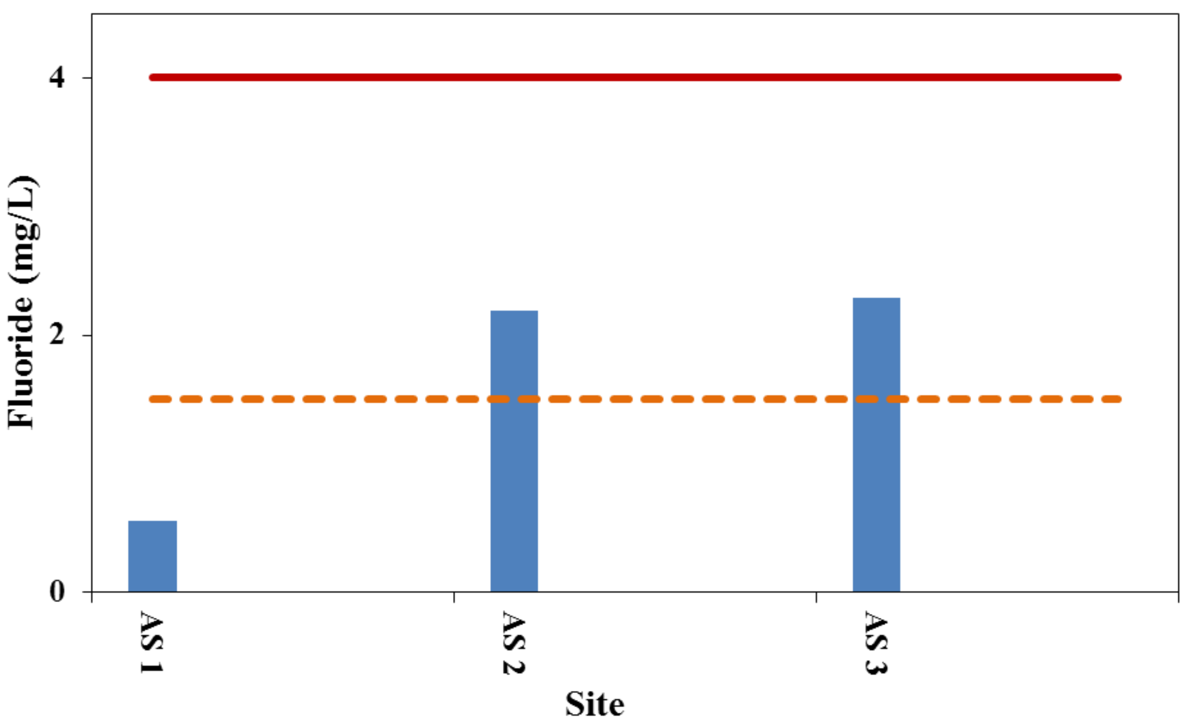


Figure 5.58 Ali Sabieh: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)

In Ali Adde camp, vanadium and conductivity are highly elevated above standards (Figure 5.59 and Figure 5.60). As with Ali Sabieh, these high measured conductivities can be reinforced by the high chloride concentrations detected (Figure 5.61). There are two isolated sites (AA2 and AA5) with elevated zinc levels of 1.54 and 1.79 mg/L, respectively. All but one sample also show elevated levels of nitrite (Figure 5.62) reaching as high as 6.7 mg/L at AA27. Several have elevated levels of nitrate (Figure 5.63) reaching as high as 114.4 mg/L at AA17 in Ali Adde. Elevated levels of fluoride are seen in many sites (Figure 5.64) in Ali Adde with levels as high as 2.3 mg/L. Furthermore, twenty-five of the sites are above the possible future U.S. EPA recommended fluoride level of 0.7 mg/L.

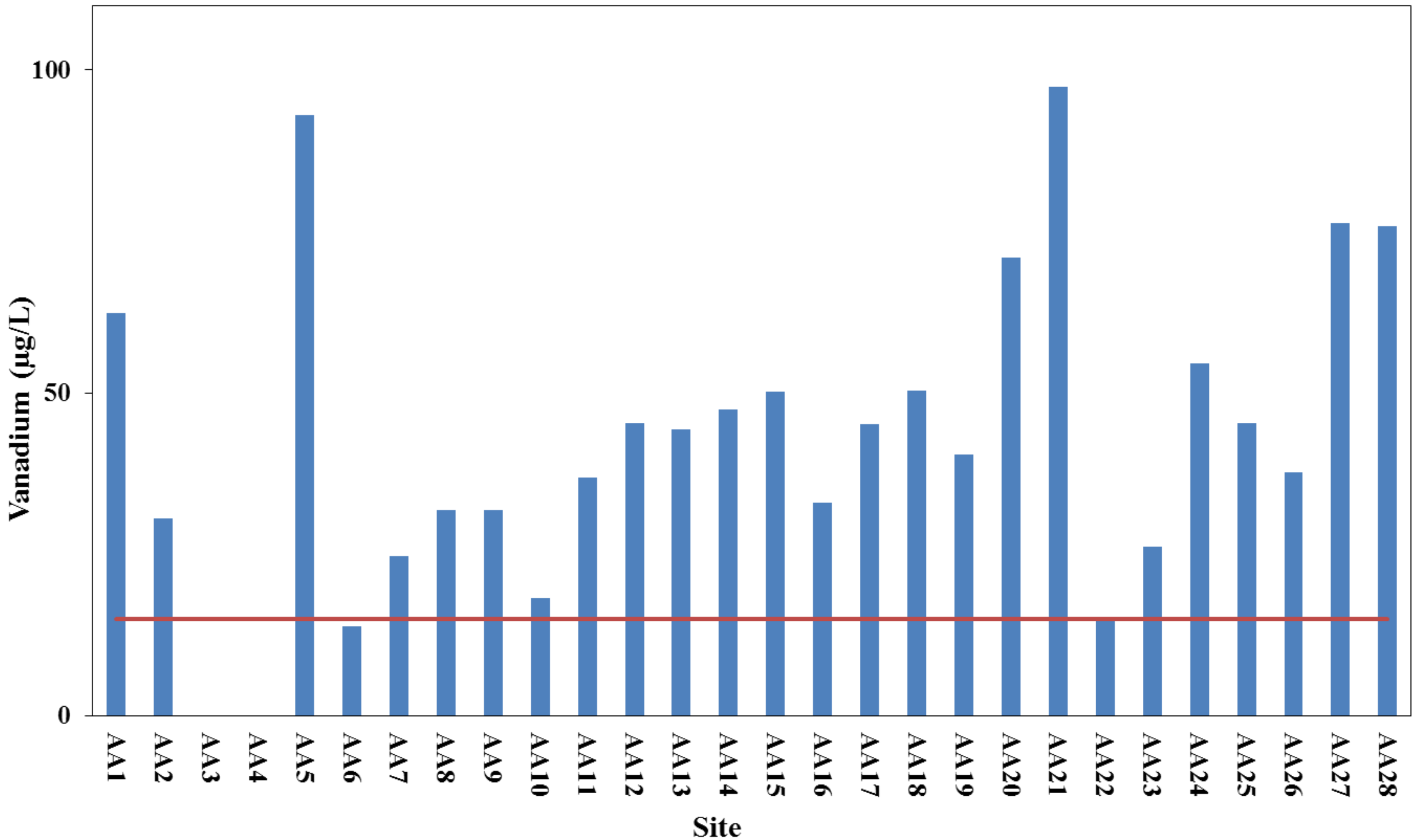


Figure 5.59 Ali Adde: Measured vanadium concentrations
OEHHA guideline is 15 µg/L (red line)

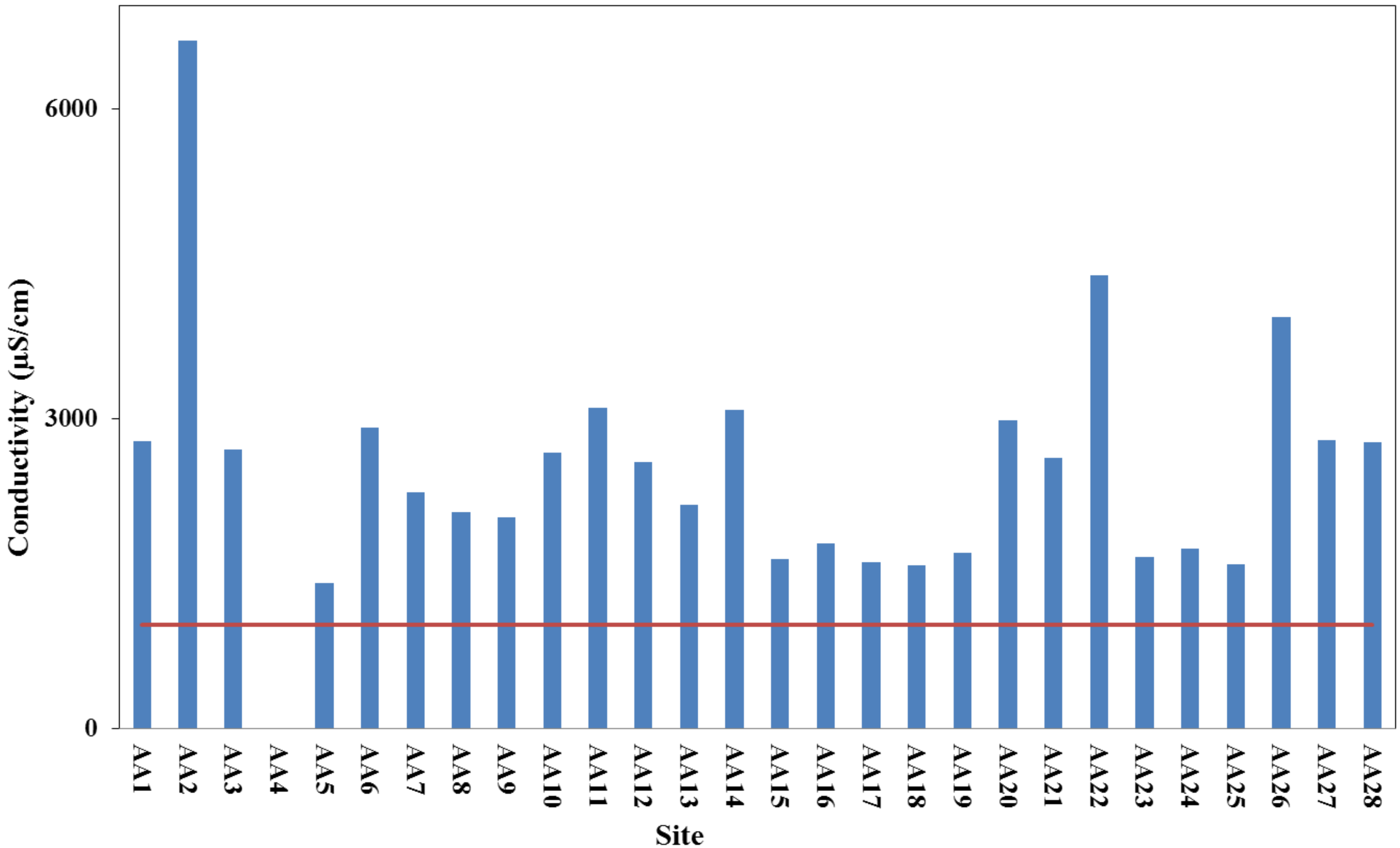


Figure 5.60 Ali Adde: Measured conductivity values
Aesthetic guideline is 1000 µS/cm (red line)

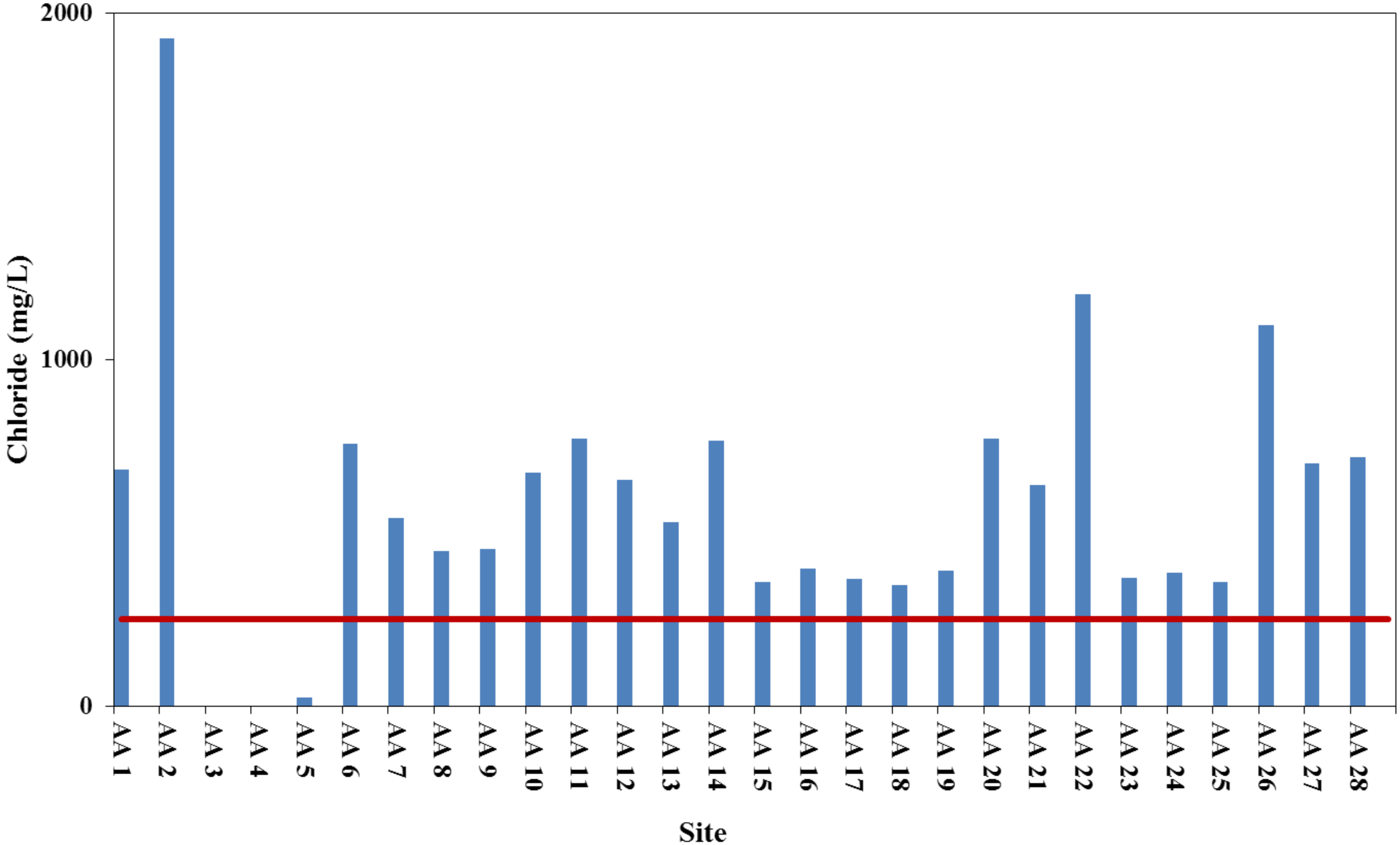


Figure 5.61 Ali Adde: Measured chloride concentrations
U.S. EPA guideline is 250 mg/L (red line)

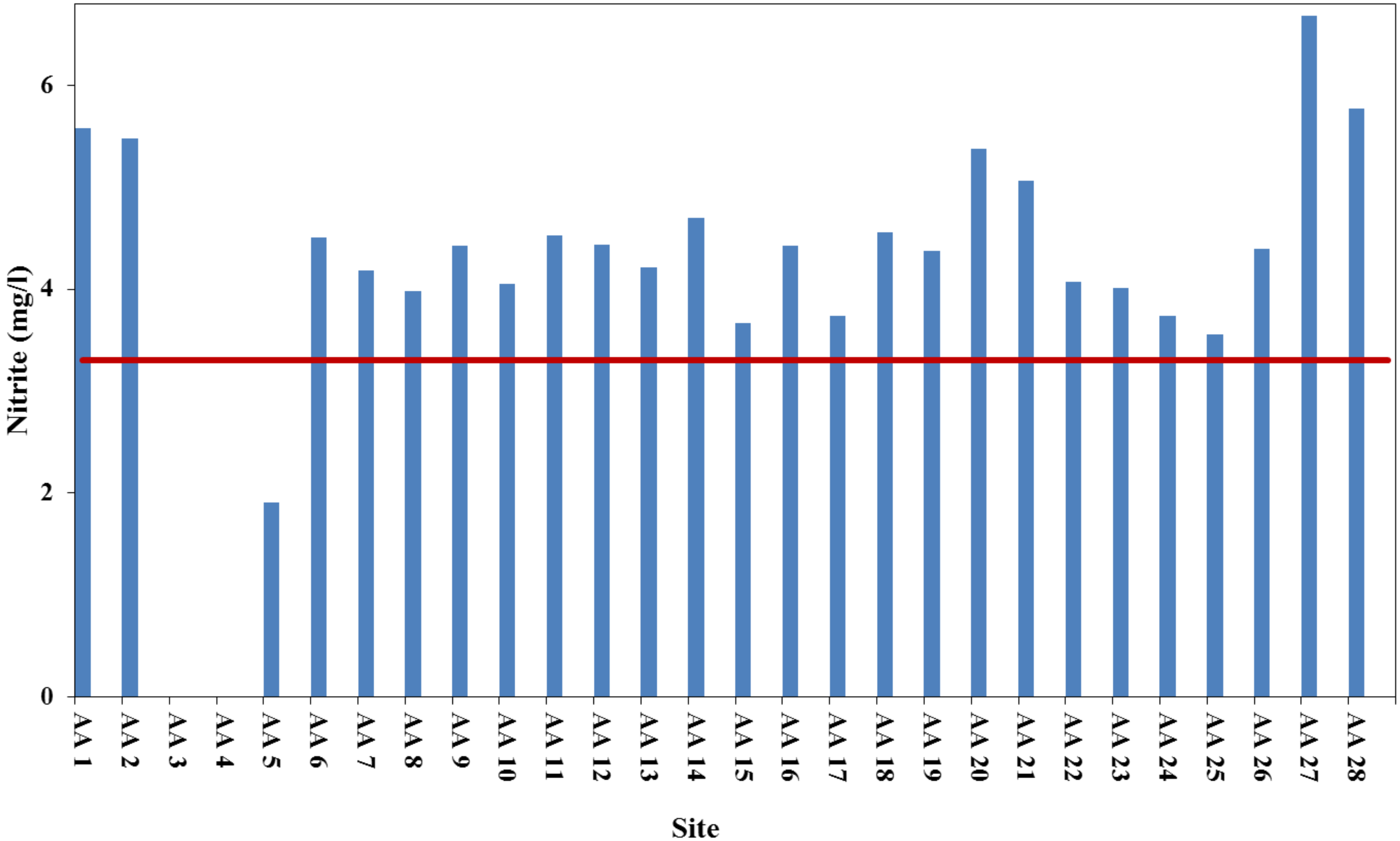


Figure 5.62 Ali Adde: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

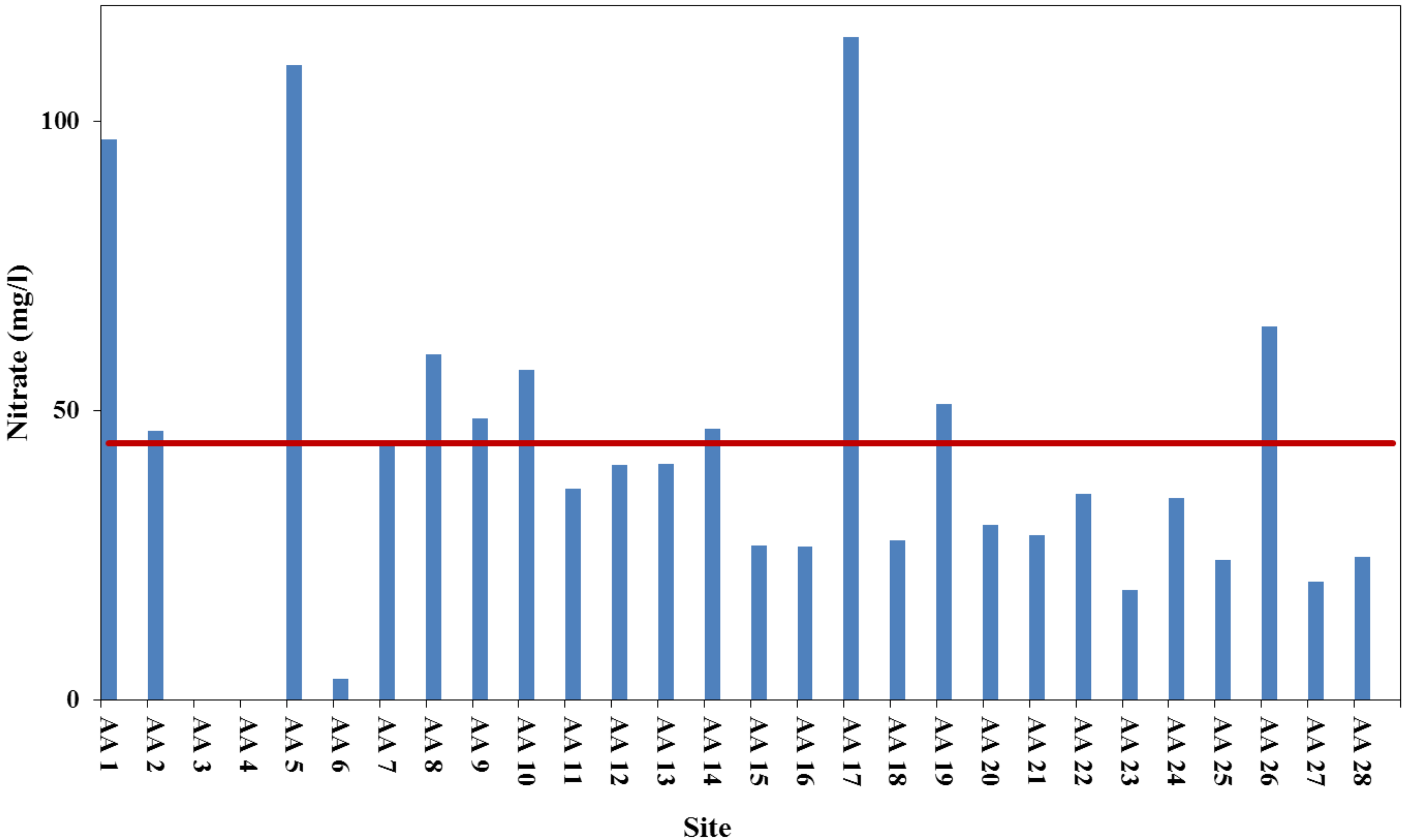


Figure 5.63 Ali Adde: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

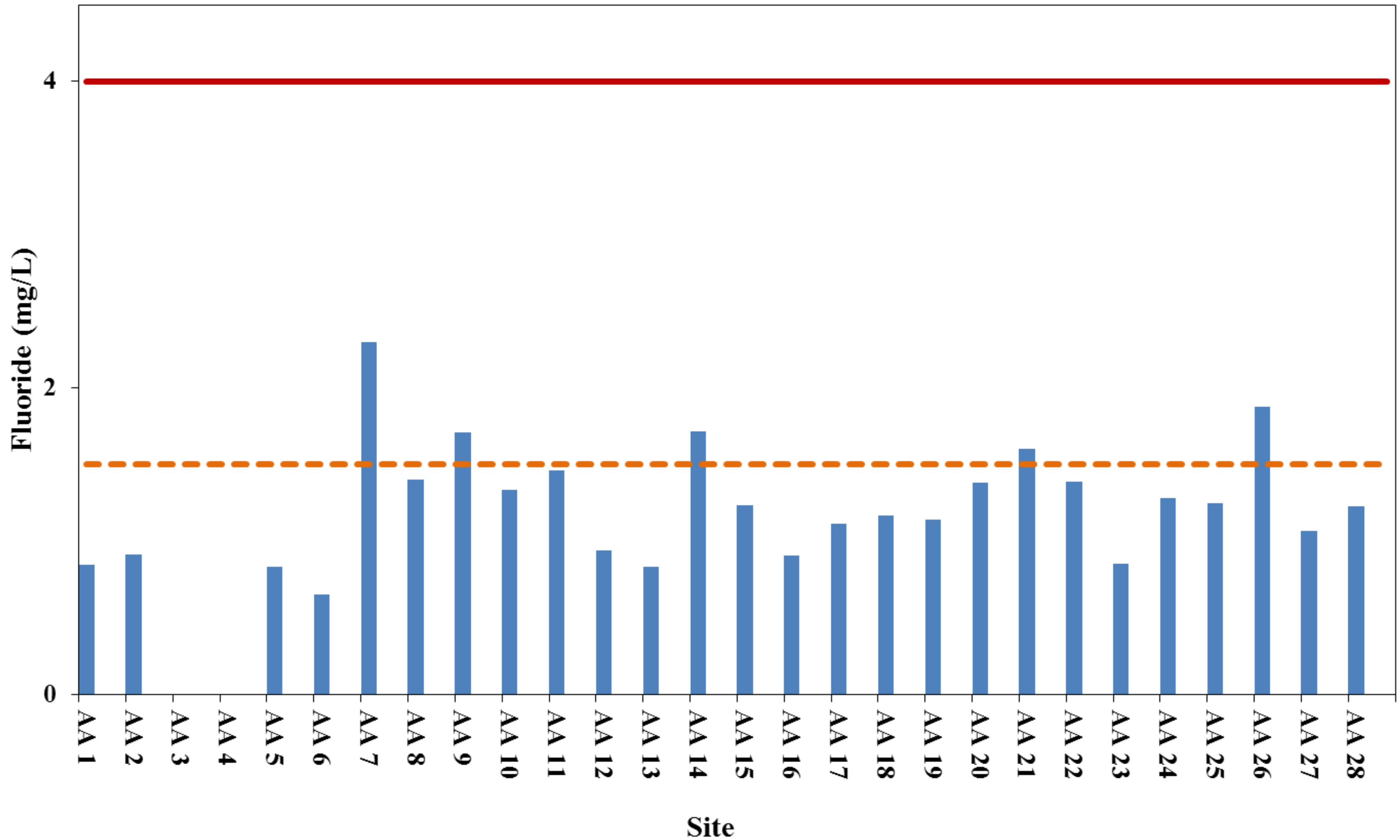


Figure 5.64 Ali Adde: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)

In Holhol, as with the entire country of Djibouti, vanadium and conductivity are elevated well above guidelines (Figure 5.65 and Figure 5.66). Again, the conductivities can be directly related to the high chloride concentrations measured (Figure 5.67). There is one isolated well (HH1) that contains elevated zinc of 4.01 mg/L, which does exceed the WHO aesthetic guideline. Similar to the rest of the country, elevated fluoride (Figure 5.68), nitrate (Figure 5.69), and nitrite (Figure 5.70) are present in Holhol. Fluoride reaches almost 4 mg/L, more than twice the WHO standard. Nitrite reaches almost 8 mg/L at two sites, HH3 and HH7, and is well above the 3.3 mg/L standard at all others. Nitrate concentrations reach 82 mg/L at HH2.

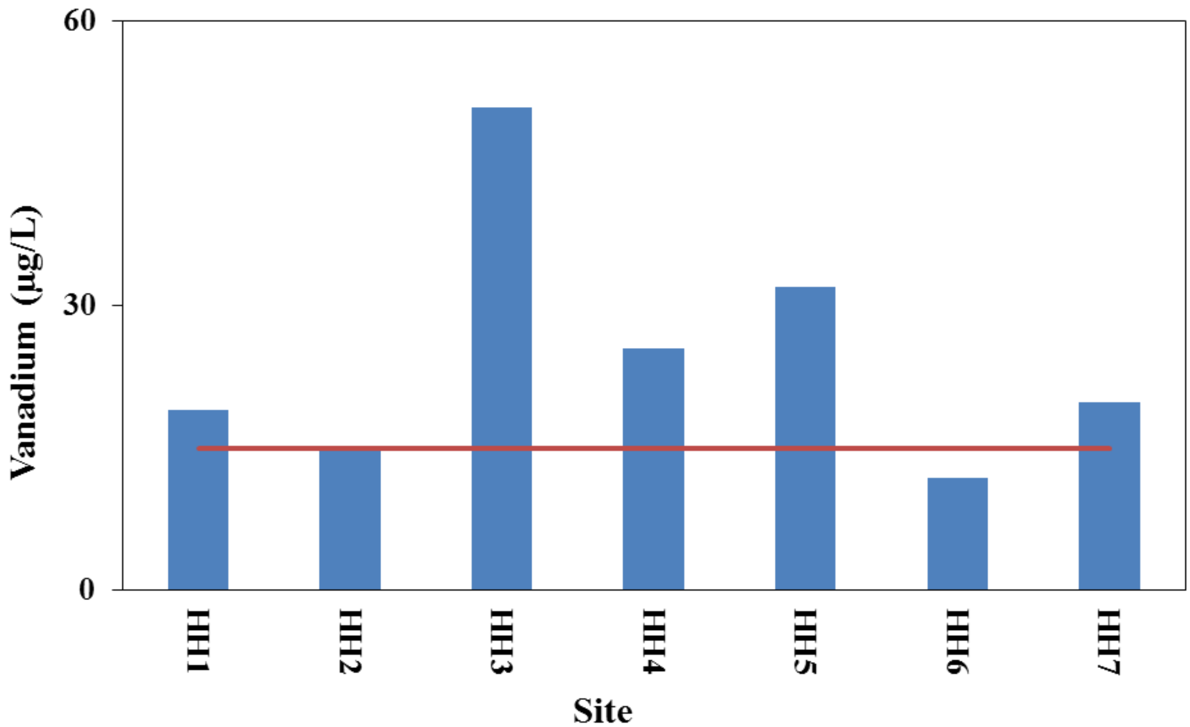


Figure 5.65 Holhol: Measured vanadium concentrations
OEHHA guideline is 15 µg/L (red line)

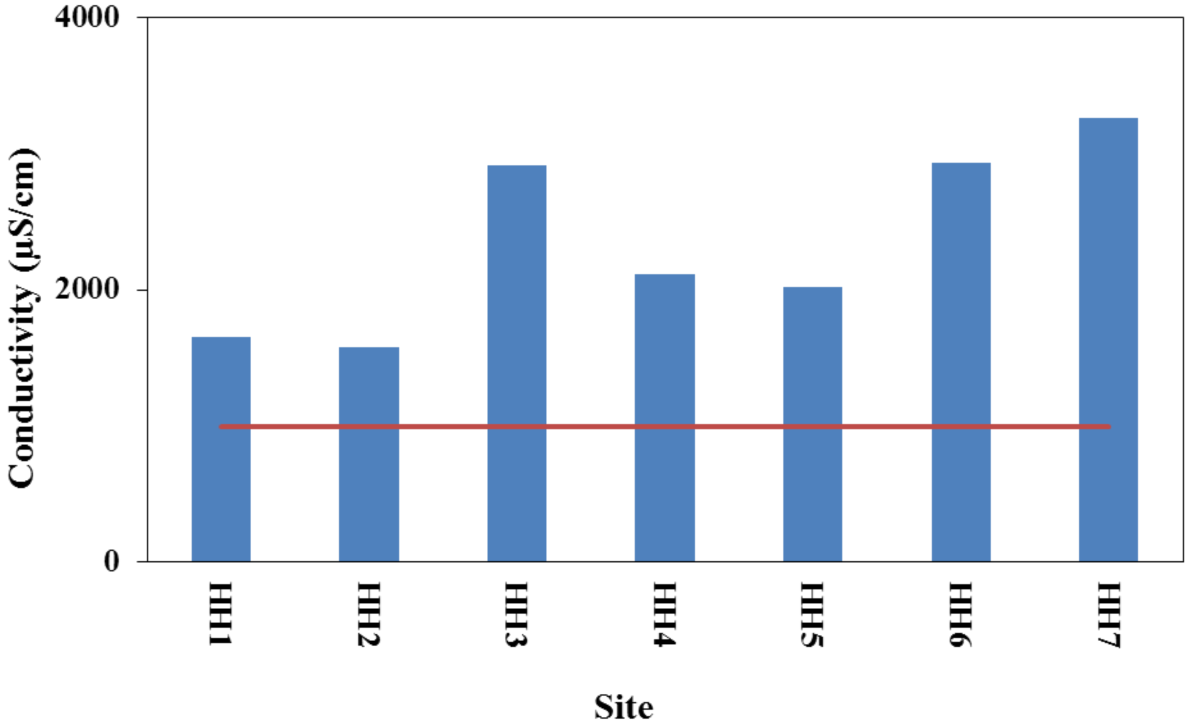


Figure 5.66 Holhol: Measured conductivity values
Aesthetic guideline is 1000 µS/cm (red line)

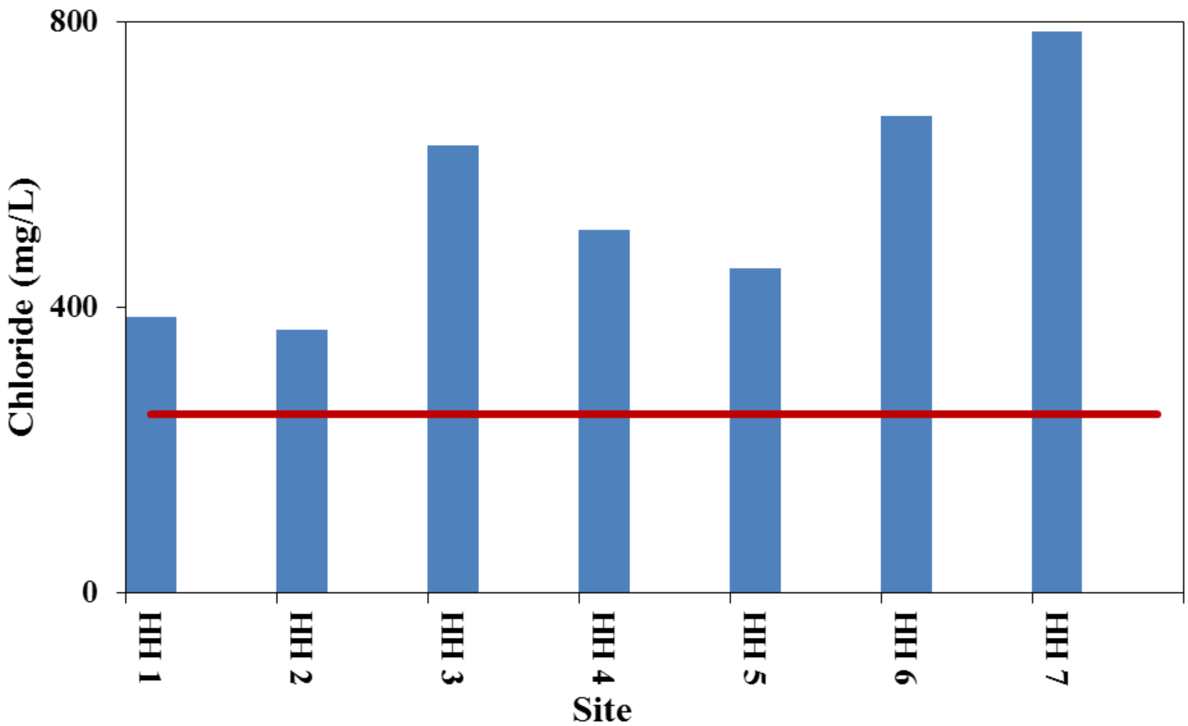


Figure 5.67 Holhol: Measured chloride concentrations
U.S. EPA guideline is 250 mg/L (red line)

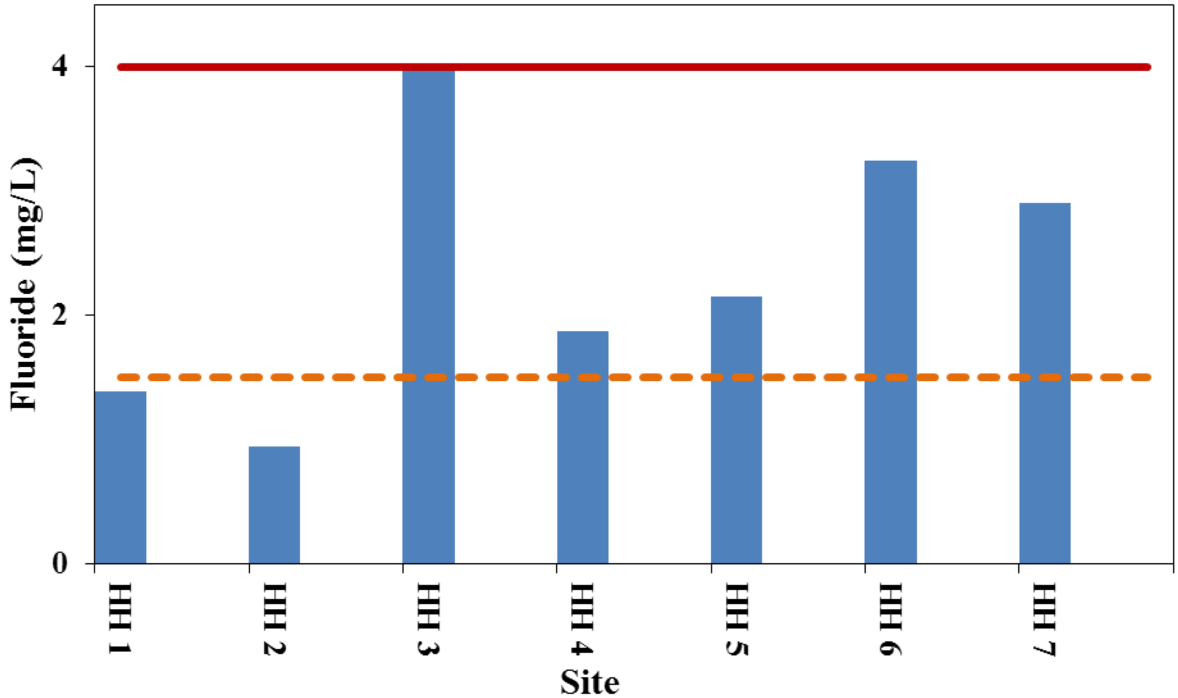


Figure 5.68 Holhol: Measured fluoride concentrations
WHO health guideline is 1.5 mg/L (orange dashed line); U.S. EPA standard is 4.0 mg/L (red line)

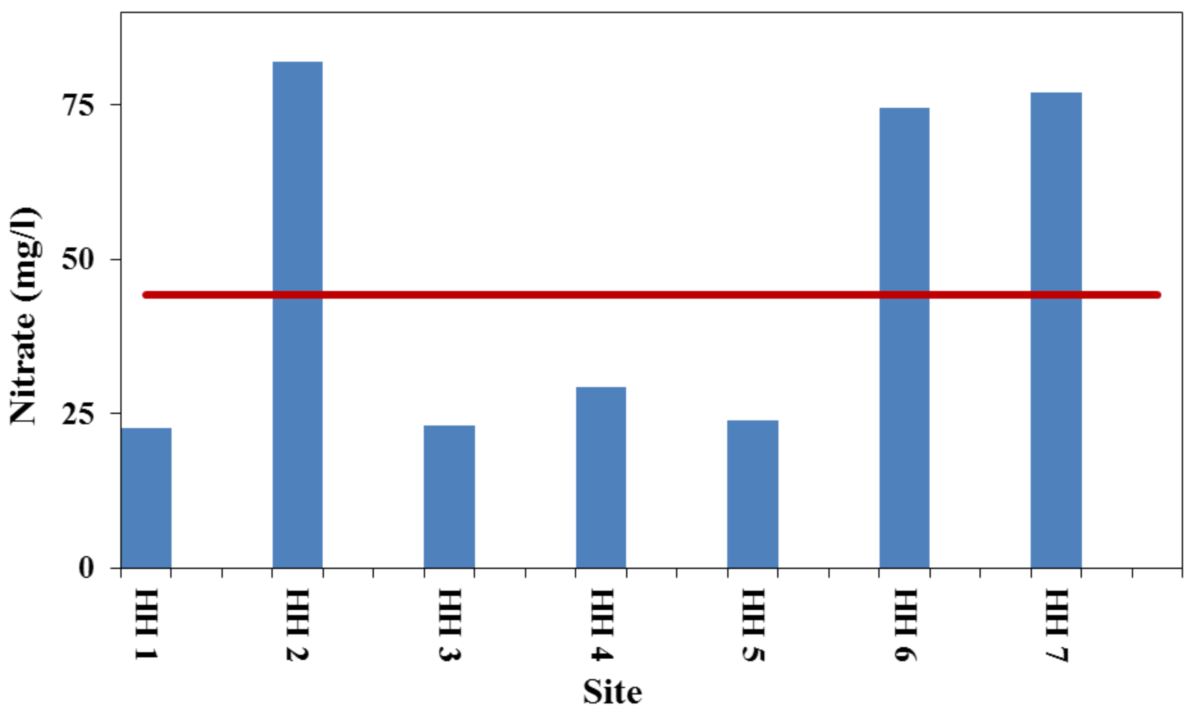


Figure 5.69 Holhol: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

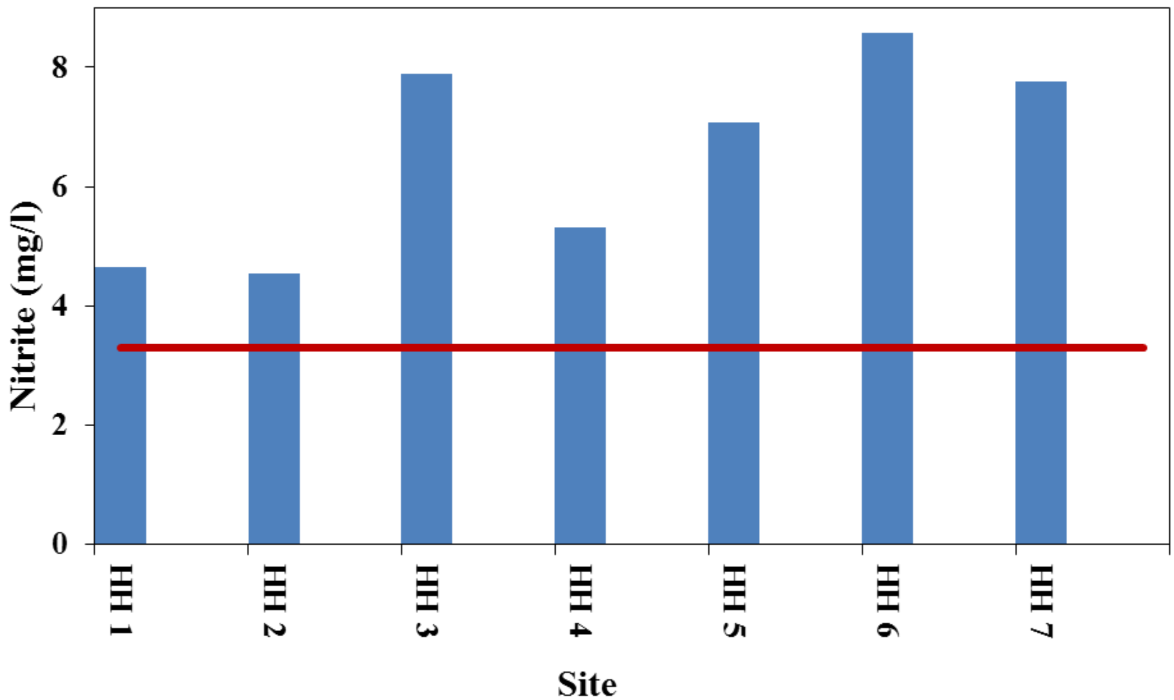


Figure 5.70 Holhol: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

5.3.5 Liberia

Liberia samples have been collected at a range of small sites across the country. There are no real trends apparent in the chemical data. In Gblah at site GB3, isolated elevated values of Mn, Ga, and Pb are measured at 328.5, 129.43, and 16.33 µg/L, respectively. In Dougee camp, elevated chromium of 61.24 µg/L is measured at site DC1, and DC3 has high gallium at 23.39 µg/L. In Solo camp, elevated Mn is seen in 2 sites (SC1 and SC2) at 199 and 212 µg/L, respectively. In PTP camp, at PT3 Mn is seen at 251 µg/L.

Chloride is uniformly low across Liberia. No other trend in anions can be observed. Nitrite levels above the U.S. EPA standard of 3.3 mg/L are seen at few sites across Liberia, as typified by Figure 5.71 from Maryland County, but are generally acceptable otherwise. Slightly elevated nitrate concentrations are seen at a few sites in Little Wlebo (Figure 5.72), but in Gblah nitrate is very elevated at GB3 with a concentration of 127.6 mg/L, which is well above the 44.3 mg/L U.S. EPA standard.

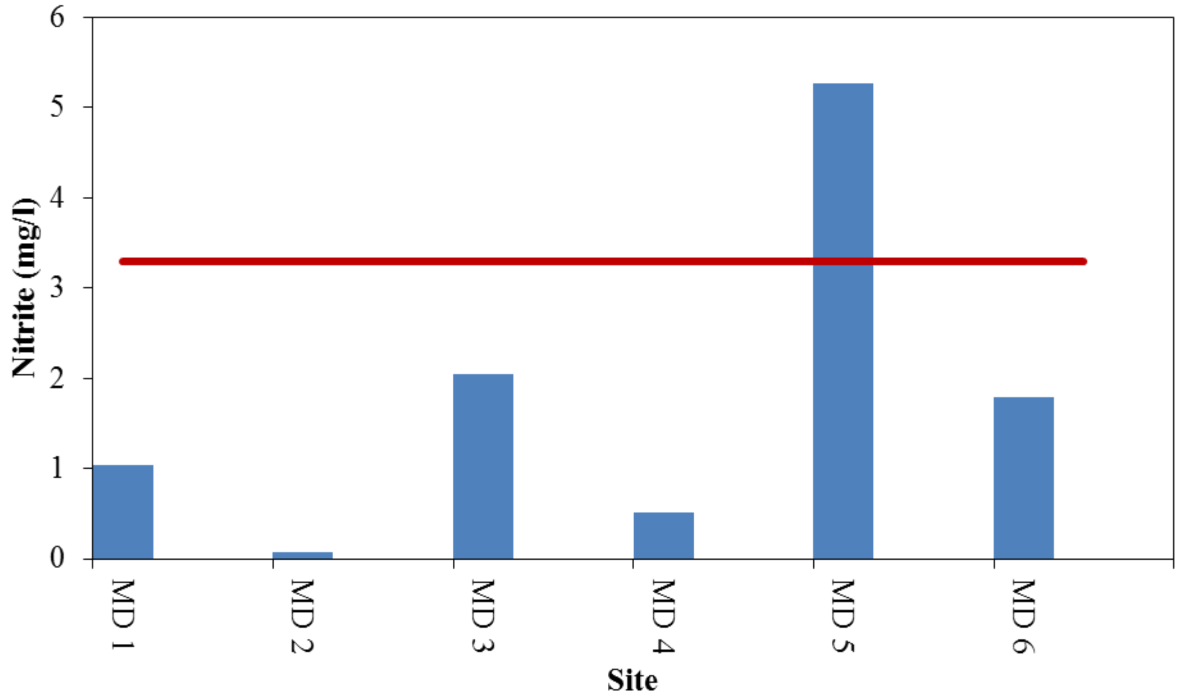


Figure 5.71 Maryland County: Measured nitrite concentrations
U.S. EPA standard is 3.3 mg/L (red line)

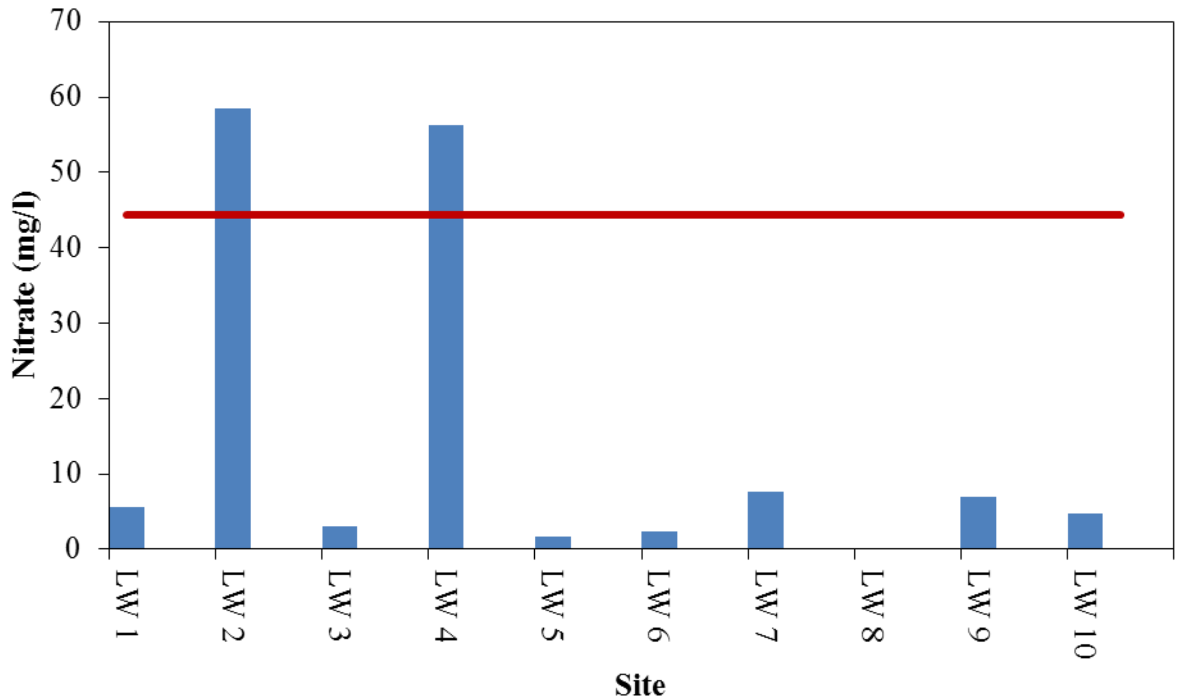


Figure 5.72 Little Wlebo: Measured nitrate concentrations
U.S. EPA standard is 44.3 mg/L (red line)

5.4 Status

The Water Quality Database is well underway. Five countries (Uganda, Kenya, Bangladesh, Djibouti, and Liberia) have been evaluated to date. Nearly every camp has been visited in each country and a statistically large percentage of water points have been visited in each camp. All analyses are complete, and the data have been reported and interpreted. Comprehensive analytical results for each site are provided in Appendix B. These data, combined with field data and observations, have been entered into At-A-Glance report cards for each camp and are presented in Chapter 10 of this report. These cards act as the static output of the current database. They are also the demonstration of a future truly user-friendly online system to be worked on in 2012.

One goal of the WQD project was to identify as yet unmeasured contaminants in specific locations. As discussed above, this has been accomplished in many cases. Additionally, as typified by the lack of iodide in the Dadaab region, many contaminants are shown not to be a problem in specific camps. Recommendations on moving forward with newly determined problems, camps with variable results, and the WQD project as a whole are summarized in Chapter 9 of this report.

Chapter 6: Fluoride Analysis and Remediation

6.1 Rationale

Elevated fluoride concentrations in well waters are a concern in certain regions due to dominant aquifer lithology and sourcing of water. East Africa is a region known to have potential for fluoride levels of concern in groundwater used for consumption. Recently, Nakivale, Uganda, and Kakuma, Kenya, have been shown to have fluoride concentrations well in excess of the 1.5 mg/L WHO health guideline, as well as values in excess of the 4 mg/L U.S. EPA standard.

Fluoride is an ion rarely measured in the water supplies of the developing world. Refugee camps have little need to measure for it under emergency conditions, as its negative health impacts are not acute. Chronic exposure to fluoride is, however, a significant health concern if levels are elevated. Skeletal fluorosis may occur if exposed to drinking water with values exceeding the WHO, CDC, or U.S. EPA recommended levels. Skeletal fluorosis is a debilitating condition and is progressive with longer exposure to fluoride rich waters.

Past studies have shown that hydroxyapatite (HAP), a naturally occurring mineral [$Ca_{10}(PO_4)_6(OH)_2$], has the ability to remove fluoride from aqueous solutions via an exchange interaction. This exchange process involves the fluoride ion (F^-) replacing the hydroxide ion (OH^-) in the apatite structure. It is possible that this process could be utilized and optimized such that it may be applied and implemented at the UNHCR refugee camp sites where fluoride contaminated drinking water is determined to be a serious issue.

6.2 Methods

Once the presence of fluoride is confirmed based on the analysis of those samples collected on site by the research team, the approach to a possible fluoride remediation technique can be partitioned into three main steps: (1) computer modeling of the potential HAP remediation solution at various fluoride concentrations based on those found at contaminated UNHCR sites; (2) bench-scale laboratory experiments to test the efficacy and kinetics of the exchange process and the removal of fluoride from aqueous solution; and (3) design and optimization of a potential fluoride remediation solution which could be implemented at the well sites at the camps.

6.2.1 Computer Modeling

The computer modeling of the fluoride-hydroxyapatite system is performed using the free software Visual MINTEQ. This software, whose code was originally written by the U.S. EPA, is now maintained by Jon Petter Gustafsson of the Royal Institute of Technology in Stockholm, Sweden. The software is intended to model aqueous systems of many types, such as speciation, solubility, and equilibria. Therefore, the parameters of the general fluoride-HAP system (the most basic case of a known fluoride solution with the solid HAP present and available) may be input into the software. The output includes all aqueous phases present at a range of specified pH values. Once it is determined which aqueous species are present in the system, Visual MINTEQ allows for the possibility of solid precipitation. Because the exchange process would produce fluorapatite (FAP), this is added as a possible species to be formed in the system. Formation of FAP would signify the exchange of the HAP with the fluoride and thus its removal from the aqueous phase.

The main input parameter for the modeling software is the initial fluoride concentration. This is varied from 0.05 M up to 0.50 M in increments of 0.05 M. A phosphate buffer is included in solution to sequester H^+ ions at low pH. HAP is included in the system as an "infinite" solid species, meaning any amount of HAP is available to affect the solution. These parameters were then run over a range of pH values from 1 to 14 in 0.1 increments. The specified output desired was fluoride concentration and FAP saturation index. Any other aqueous species present are simply noted for their possible effects on the desired OH^--F^- exchange process. Secondly, the possibility of FAP precipitation is added to the above input parameters, allowing a more realistic scenario. The initial fluoride concentrations and the presence of HAP in the system are kept unchanged.

The overall purpose of the computer modeling step is to determine if the exchange process between the hydroxide in the HAP and the aqueous fluoride ions is thermodynamically favorable. This is accomplished by plotting the model-calculated fluoride concentrations against the range of pH values (noting that groundwater is usually circumneutral, *i.e.*, between 6 and 8) along with the FAP concentrations across the same pH range. The modeling is used as a starting point for the laboratory-based experiments which follow to get a better idea of the chemistry occurring.

6.2.2 Bench-Scale Laboratory Experiments

Two sets of bench-scale laboratory experiments are performed: batch experiments and column experiments. The batch experiments involve placing a known mass, surface area, and particle size of HAP in a single container with a fluoride solution of known concentration to allow the exchange process to take place. Then, shaking during its entirety, the batch tubes are sampled and analyzed for fluoride after set elapsed times. This process allows for the determination of the kinetics, or the "speed," of the exchange process which aids in the optimization process for the design of the chosen remediation technique. This process is repeated for various known fluoride concentrations and is performed in triplicate.

The batch experiments are performed in 50-mL centrifuge tubes for ease of shaking and centrifuging prior to sampling. The initial fluoride concentrations are 0.01 mg/L, 0.10 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 8 mg/L. Each initial concentration is run separately due to space restrictions. The HAP-to-solution ratio used in these initial sets of batch experiments is 1 g HAP to 35 mL solution. Each set of tubes for each initial fluoride concentration is begun simultaneously and performed in triplicate. The tubes are shaken constantly using Labquake test tube rotators. They are sacrificed and sampled at 4 hr, 8 hr, 24 hr, 48 hr, and 72 hr. The tubes are then centrifuged and an aliquot of the solution is analyzed for fluoride on the ion chromatograph (IC). The pH is measured initially and prior to sacrifice at the given time.

The column experiments involve a flow-through process (Figure 6.1). The solution is placed in a stock beaker and is pumped using a low-flow peristaltic pump upwards through a column packed with the media. The column effluent is then collected using an automatic fraction collector (Figure 6.2) which collects samples in plastic vials for a set amount of time.

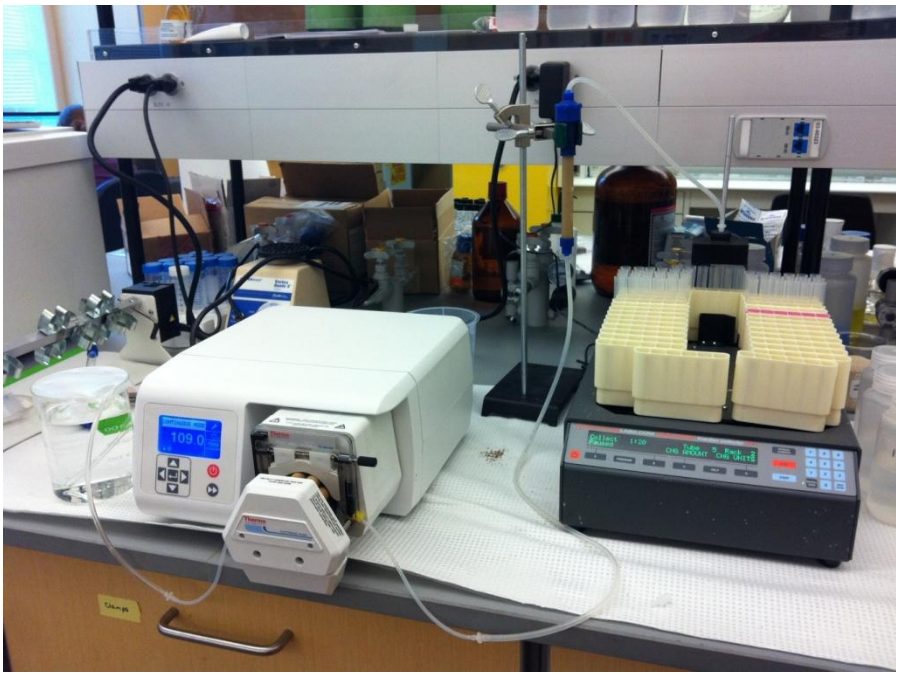


Figure 6.1 Flow-through experimental setup

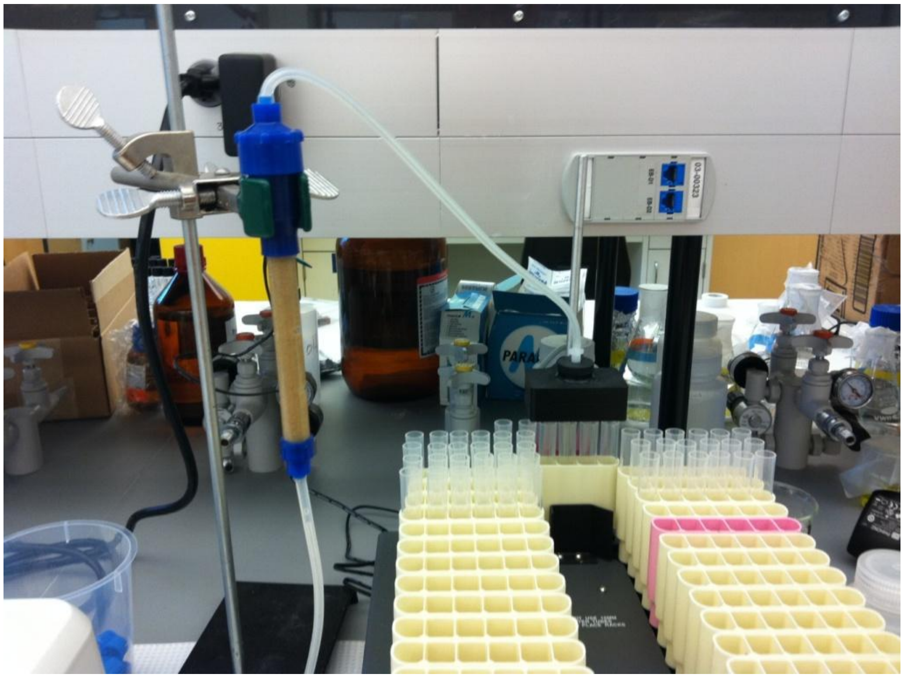


Figure 6.2 Column and automatic fraction collector used for flow-through experiments

Before the fluoride experiments may commence, a tracer experiment is performed to obtain a breakthrough curve for the column from which the pore volume of the column is determined. Data from the flow-through experiments are then normalized based on this pore volume. A potassium bromide tracer is used (5 mg/L Br^-), because it is conservative and unreactive with the column material and ionic strength solution.

Once the tracer is run and the breakthrough curve is obtained, the initial set of column experiments includes a high fluoride concentration, a mid-range fluoride concentration, and a low fluoride concentration, each run at a high flow rate and a low flow rate. The low flow rate is approximately 0.05 mL/min; the high flow rate is approximately 0.5 mL/min.

The buffered fluoride solutions with the standard ionic strength solution (sodium perchlorate) are then pumped through the column. Samples are collected by the fraction collector; certain samples are chosen for IC fluoride analysis. The amount of fluoride sequestered by the solid is then calculated. The partition coefficient can then be determined, *i.e.*, the ratio of fluoride on the solid versus in solution. This is the penultimate goal of the column experiments and will allow for the optimization of the final remediation design.

The combination of both sets of bench-scale experiments, static and flow, together allows for the best design and complete optimization of a potential fluoride remediation technique specifically designed for its application at UNHCR refugee camps.

6.3 Results and Discussion

6.3.1 Computer Modeling

The calculated aqueous fluoride concentrations from an initial fluoride concentration of 0.05 M with the precipitation of FAP possible and HAP available are plotted in Figure 6.3 as a function of pH.

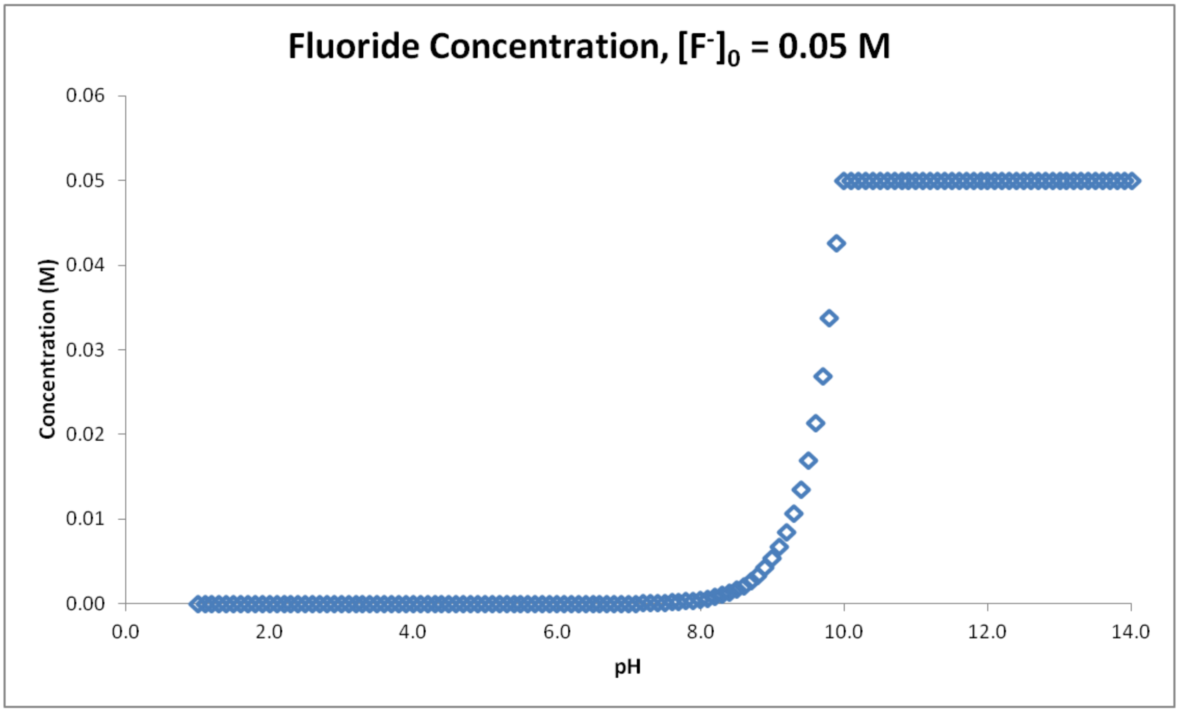


Figure 6.3 Visual MINTEQ output: Aqueous concentration of fluoride (M) vs. pH

The output saturation indices of FAP are plotted versus pH in Figure 6.4. A zero or positive saturation index implies that the solution is saturated and precipitation is likely. A negative saturation index implies that the solution is undersaturated and precipitation is unlikely.

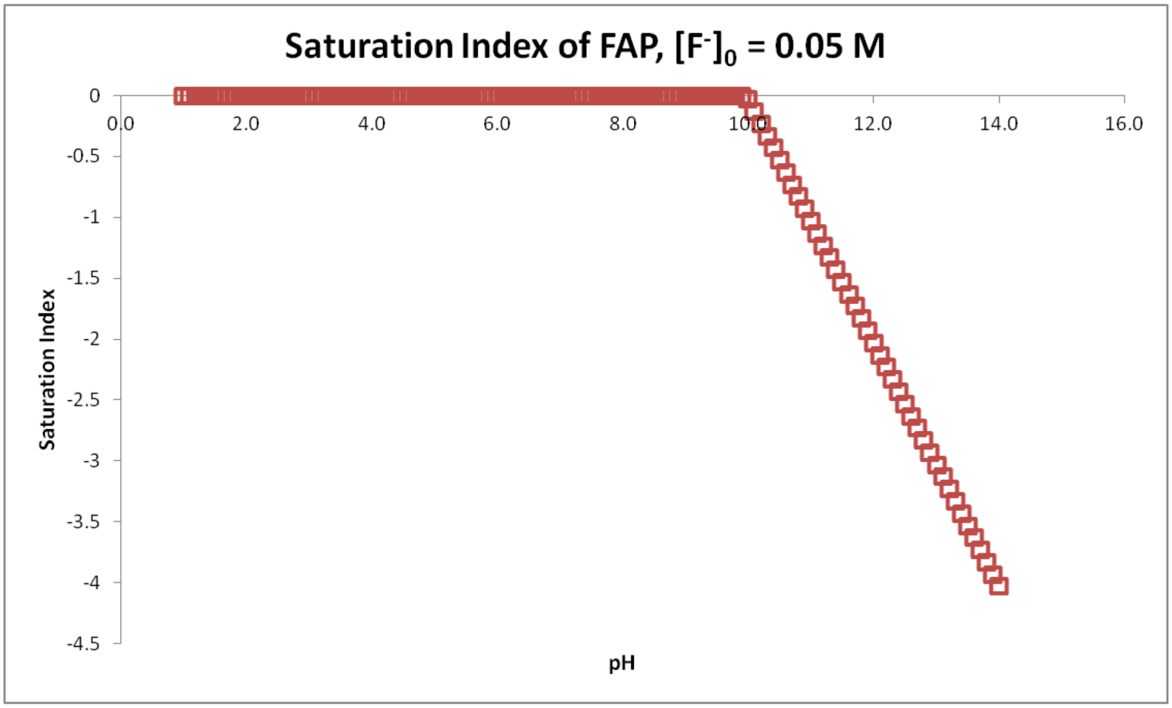


Figure 6.4 Visual MINTEQ output: Saturation index of FAP vs. pH

The model outputs shown in Figure 6.3 and Figure 6.4 clearly illustrate that, in the pH range of most natural waters (*i.e.*, from approximately pH 6 to 8), the precipitation of fluorapatite is thermodynamically feasible and favorable. The modeling effort therefore clearly justifies the fluoride exchange into hydroxyapatite mechanism as a plausible remediation technique.

6.3.2 Bench-Scale Laboratory Experiments

The residual fluoride concentrations for all batch experiments (*i.e.*, all initial fluoride concentrations) are plotted versus the elapsed time in Figure 6.5. The batch tubes were sacrificed and sampled at 4 hr, 8 hr, 24 hr, 48 hr, and 72 hr, as shown.

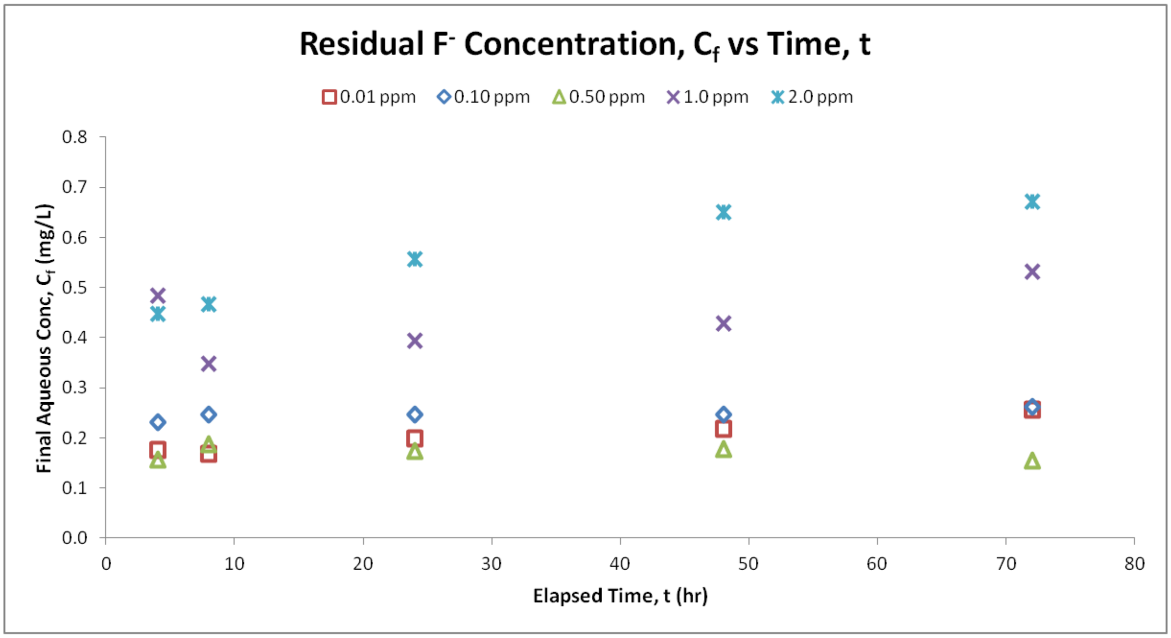


Figure 6.5 Residual aqueous fluoride concentration, C_f (in mg/L), vs. elapsed time (hr)

The solid-phase/aqueous-phase equilibrium plot is shown in Figure 6.6 for the initial fluoride concentrations of 0.5 mg/L, 1.0 mg/L, and 2.0 mg/L. The partitioning coefficient is determined from this plot of fluoride solid phase concentration versus the fluoride concentration remaining in the aqueous phase. The best-fit linear trend line is also plotted with the data. The trend line equation is $y = 69.051x - 2.3677$. The slope, 69.051, is the experimentally-determined partitioning coefficient, K_d.

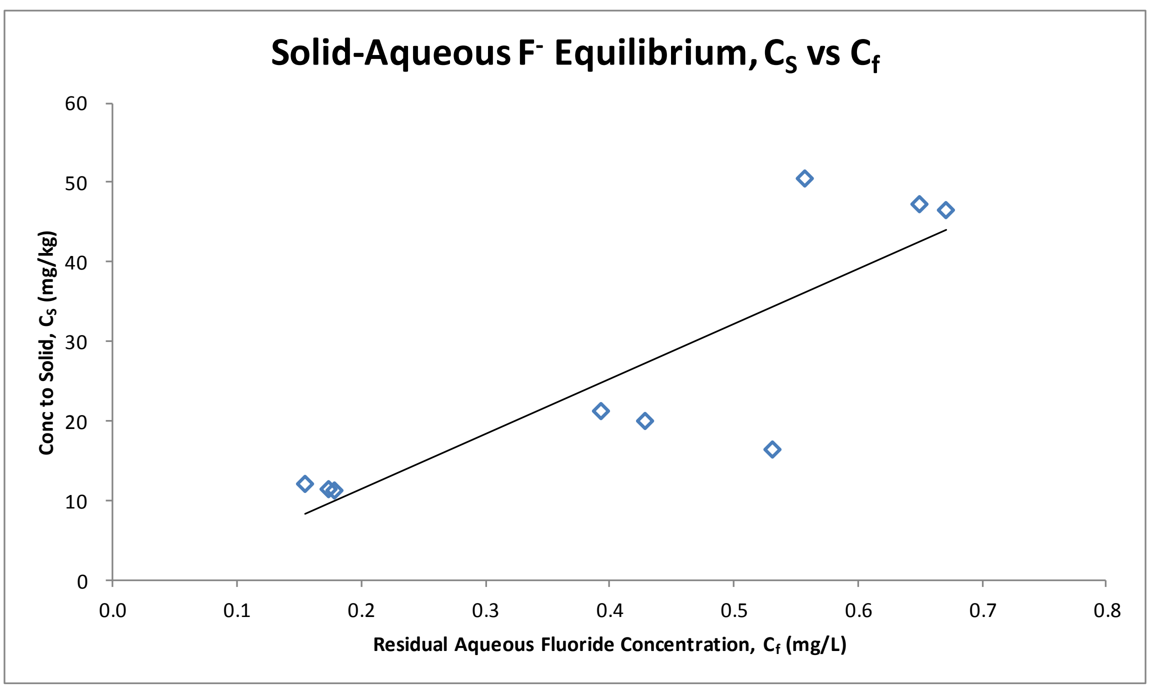


Figure 6.6 Fluoride on the solid vs. residual aqueous fluoride with a linear trendline

The percent of fluoride removed from solution is calculated for each batch reaction as a percent of the initial concentration. A plot of the percent of fluoride removed from solution in the set of experiments with an initial fluoride concentration of 2.0 mg/L is shown in Figure 6.7. The 2.0 mg/L set is shown because it is above the threshold for concern for fluoride in drinking water (currently set at 1.5 mg/L according to the WHO).

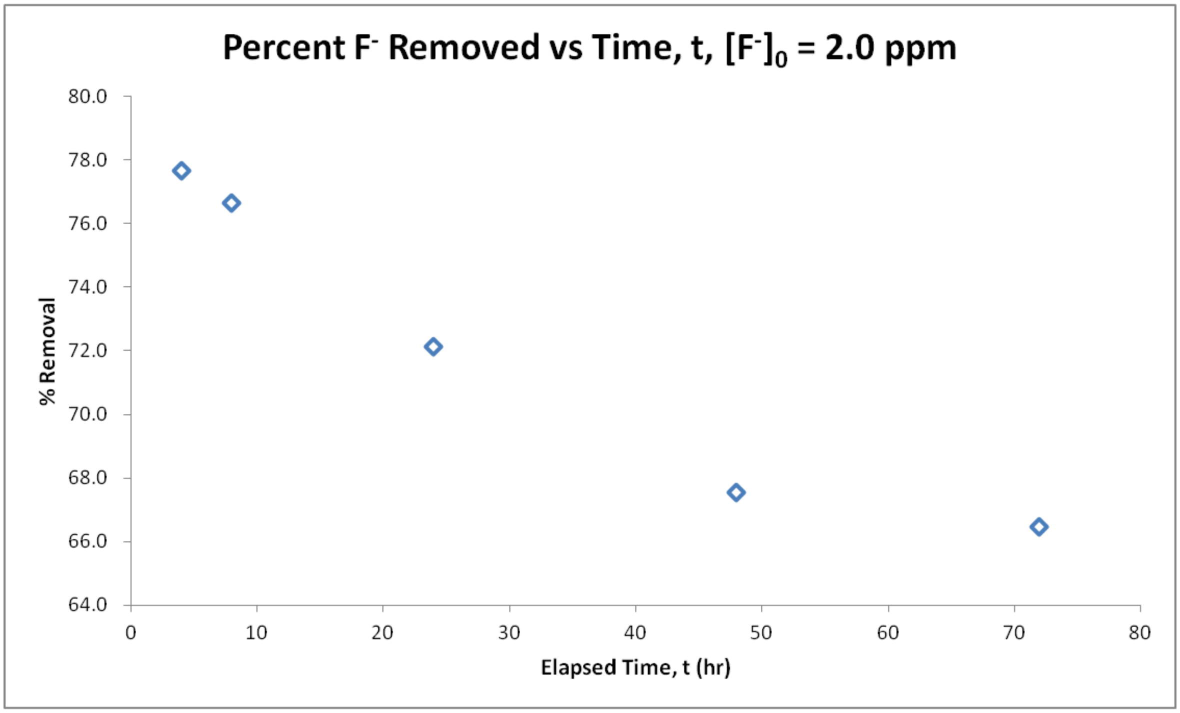


Figure 6.7 Percent fluoride removed from solution (2.0 ppm initial) vs. elapsed time

From Figure 6.5 it may be inferred that the hydroxyapatite used in the experiments contains naturally-occurring fluoride. This is evidenced by the data points representing the lower initial fluoride concentrations, namely 0.01 mg/L and 0.10 mg/L, which are virtually collinear with the 0.5 mg/L initial fluoride concentration data points. This implies that the naturally-occurring fluoride in the HAP is actually released at lower concentrations until equilibrium is met causing a small increase in aqueous fluoride concentrations. Once this equilibrium is achieved, the exchange process which removes aqueous fluoride begins to overcome the process by which the naturally-occurring fluoride is released from the HAP. Thus, a net removal is observed. Because of this fact, it does not make sense to include the 0.01 or 0.10 mg/L data points in Figure 6.6. This phenomenon may be confirmed with future batch experiments similar to those performed here.

The data points for the higher initial fluoride concentrations in Figure 6.5 show a large initial decrease in fluoride concentration. Because the residual concentrations do not entirely level off and become virtually constant, it does not seem that full equilibrium is reached within the 72-hr maximum time frame. This is similarly demonstrated in Figure 6.7 as the percent of the initial fluoride removed does not reach a constant value.

From Figure 6.6, a preliminary partitioning coefficient, K_d, of 69.051 L/kg (or, log K_d of 1.84) has been determined. The partitioning coefficients obtained from both the batch experiments and the flow-through column experiments will be used to optimize the design of a potential remediation technique for the UNHCR sites.

These batch experiments may need to be repeated or varied and considered along with the column flow-through experiments in order to fully optimize a potential fluoride remediation solution. Preliminary results demonstrate, however, that using HAP successfully removes a relatively substantial amount of fluoride from solution when the initial fluoride contamination is at or above the level of concern.

6.4 Status

The preliminary computer modeling of the simplified fluoride and hydroxyapatite system is complete. The first set of batch experiments has been completed. Further batch experiments will likely need to be performed to prove reproducibility in the data and potentially investigate certain unexpected chemical phenomena seen in the data of the first set. The column experiments have begun initial setup and will be performed in the immediate future.

Chapter 7: Iron Remediation

7.1 Rationale

Iron is typically considered a non-toxic metal and is, in fact, necessary for the proper functioning of the human body. However, long-term consumption of high levels of iron, through iron-contaminated drinking water or other sources, can lead to iron poisoning. The occurrence of iron overdose is especially dominant in children under the age of three, but severe cases have been found even in middle aged adults (Fine, 2000).

High concentrations of iron also yield a significant decrease in water quality through the impact that they have on taste. While taste may seem unimportant in terms of other potential threats to water quality in refugee camps, it can in fact be a massive problem. Odor, color, and taste, most importantly, are three characteristics by which people most often judge the drinkability of water. If an otherwise clean water source has demonstrably poor aesthetics, people will not drink the water. This often pushes populations to under-consumption of water, leading to the health problems associated with dehydration. Additionally, many make the conscious decision to consume water from aesthetically clean yet chemically or biologically contaminated waters, such as coliform-impacted surface waters.

Incredibly high levels of iron concentrations (as high as 25 mg/L) were found in several drinking water sources in refugee camps in Uganda (Figure 7.1). Even in places and circumstances where iron concentrations are not high enough to cause the most extreme of the above symptoms, the major concern for the refugee camp drinking water is the fact that high iron concentrations produce a bad taste in the water. This has caused the population to turn to other wells that contain harmful contaminants, such as coliform. Even a reasonable reduction of these iron concentrations might persuade villages to use the safe drinking water wells versus other contaminated sites. Implementation of a very cost effective and easily implemented and maintained system to remove iron from the safe wells would be much more beneficial for a fast response to drinking water needs than would expensively treating the contaminated water.

Figure 7.1 Nakivale: Red staining shows excess iron in drinking water source

7.2 Methods

7.2.1 Current Field Filtration Methods

Of the refugee camps that the SMU team visited, two already have some attempts at iron removal through rock filters. This is encouraging because it shows that the community is concerned about the high iron levels. While the rock filters remove some iron, they do not remove sufficient iron to produce water at a safe level or at a level that has a good taste. These filters are also not easily maintained. The rocks accumulate iron quickly, and cleaning is time-consuming and inefficient. At the two locations observed by the SMU team, the filter barrels were made out of large 18" PVC pipe, such as that shown in Figure 7.2 and in Figure 7.3, or made out of concrete. Both locations had lids.

Figure 7.2 Nakivale: Iron filter on hand-pump drinking water well

Figure 7.3 Nakivale: Filtration system currently in use
Components are a simple PVC tube cemented to the ground and large rocks

Figure 7.3 shows the current configuration of the iron removal system in Nakivale. The red coloration of the water and of the PVC pipe is a good visual indicator of the high iron concentration. Rocks are simply resting at the bottom and quickly accumulate iron, calling for frequent changing and cleaning. This maintenance is performed by volunteers in the community, but several accounts were gathered that these attempts are quite difficult to coordinate because of the frequency with which it must be done and because it is a time-consuming task.

7.2.2 Laboratory Filtration Design

The existing field filtration methods serve as a starting point for laboratory modeling and design of an updated and more effective field filtration method. In the Quicksall lab at Southern Methodist University, some modifications had to be made in order to imitate the filter casing and source wells found in the field. A large barrel is used to provide water into the filter (Figure 7.4). Due to the cost and availability of 18” PVC pipe, and due to the inability to cement a pipe to the ground in the laboratory, a polyethylene tube with a thick polypropylene base glued and screwed into the bottom was used (Figure 7.4). The material and size of the filter housing is not of primary importance but possible variations will be considered before finalizing the design for field application.

Figure 7.4 Laboratory iron filter prototype
Barrel (on table) supplies synthetic groundwater spiked with varying levels of iron to the polyethylene tube (on floor), which serves as the housing for the iron filter

Figure 7.5 Laboratory iron filter housing
Water drains through the pipe at the bottom; filtration will occur on a component attached to the lid

Top designs were modeled in SolidWorks – a powerful computer-aided design (CAD) software made by Dassault Systèmes©. SolidWorks allows engineers to create a three-dimensional drawing of individual parts and assemblies. It also assists in evaluating designs in many useful ways, such as strength tests of parts and assemblies and to locate points of interference.

The design objectives necessary for creating an effective iron filter are as follows:

1) Increase surface area
2) Efficacy of implementation into existing water systems
3) Ease of maintenance
4) Ease of production
5) Compact
6) Low cost

With the design objectives in mind, several designs were considered, but Design 3 was selected as the final design (other top designs can be found in Appendix C).

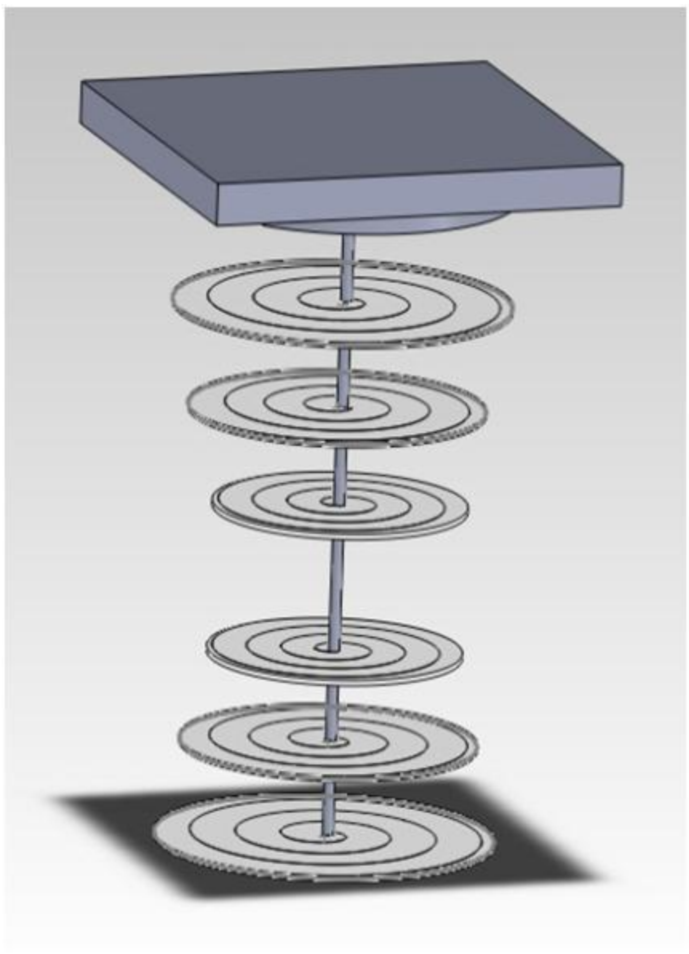


Figure 7.6 Laboratory iron filter: CAD model
CAD model of the main rod and the six polypropylene disks attached to the lid of the system

The basic components of the design are a main rod, six polypropylene spiral disks, six Nylon push-in fasteners (Figure 7.7), and six plastic hex caps and nuts (Figure 7.8). All components are planned for adaptability, so that many materials could be used for each function – this will allow for the flexibility to use available resources (especially for on-site production). The polypropylene disks are three different sizes, and each can be easily cut using a simple hand saw. These sizes are also planned for adaptability, though the ratios of disk to disk should stay constant. The size of the largest disk is determined by the inner diameter of the filter casing, and the other two disks fit inside this outer disk. Each disk is looped through the main rod to the locations shown in Figure 7.9. These disks are attached to each respective part symmetrically below, as shown in the movement simulation in Figure 7.10.

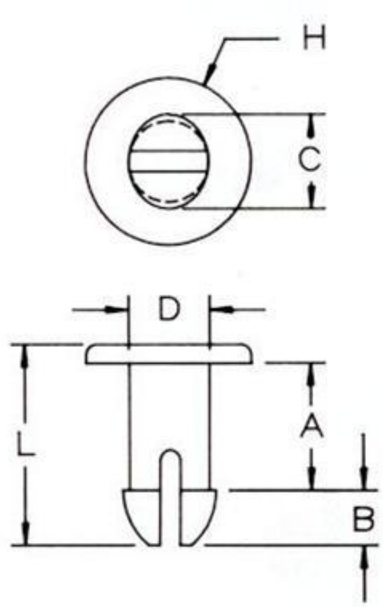


Figure 7.7 Laboratory iron filter components: Nylon push-in fasteners
Nylon fasteners hold the disks in place and allow manageable removal for cleaning

Figure 7.8 Laboratory iron filter components: Plastic metric hex caps and nuts
Hex caps and nuts attach top disks to bottom disks and expand the spirals to create elasticity and movement

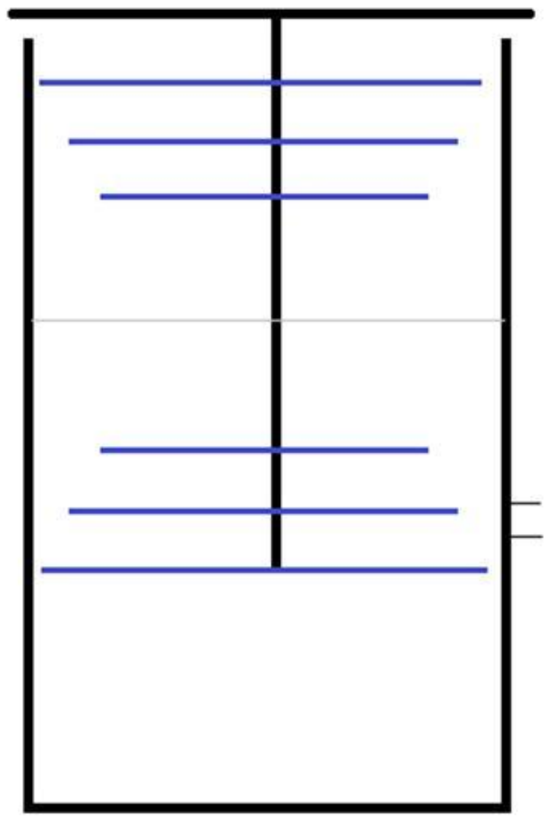


Figure 7.9 Laboratory iron filter: Schematic drawing
The filter is attached to the lid; filter disks are attached to the main rod, running down the middle
The light gray line between the top and bottom disks is where the disks will meet and attach

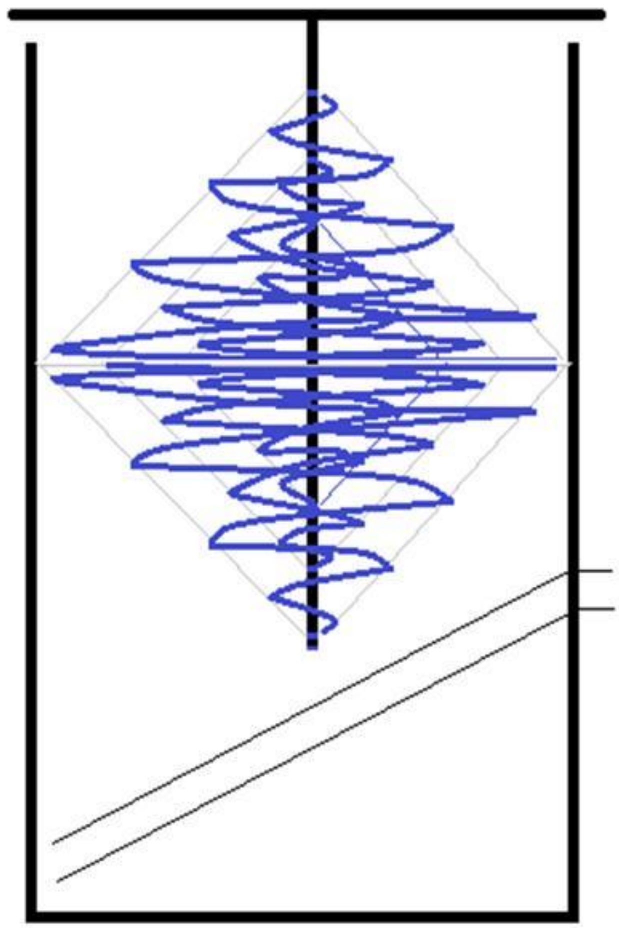


Figure 7.10 Laboratory iron filter: Schematic of filtration disks
Top three disks are attached to their respective spirals on the bottom half
Disks provide increased surface area as well as elasticity and movement to maximize aeration

With the design described above, the objectives have been met, as described below.

1) Increase surface area

Especially in the large quantities found, iron will stick to whatever surface it can find. Stacking these disks creates layers to maximize the surface area within the filter onto which the iron molecules can attach. Simply having only one spiral does not fully utilize the space inside the filter housing; stacking several disks maximizes the space available.

2) Ease of maintenance

The rock filtration design currently in use in the field calls for frequent changing of many parts, which are difficult to remove and replace when the rocks need to be changed. The disks on the new design can collapse for easy cleaning, and the whole system is easy to replace because it is simply attached to the lid. The disks can easily be removed and assembled to the main rod.

3) Efficacy of implementation into existing water systems

When implementing the design to an existing water source, the design is faced with varying tank sizes, varying tank heights, and various filter materials. It is extremely important, then, to intrinsically plan adaptability into the aeration model design. A standard design and set of materials and measurements is available, based off the Nakivale refugee camp filter dimensions in Uganda. From this standard design, however, modifications may be made to better fit other structures.

- Diameter size. The stacked disks can be made to have bigger or smaller diameters, based on the size of the filtration tank at the site of desired implementation. This allows the design to be usable even for non-standard sizes of existing filtration tanks. This is especially important in working with refugee camps because every camp uses distinct water distribution systems and has access to different materials, so variability is a necessity.

- Thickness/coils. Disk thicknesses or disk coil repetitions can be increased or decreased for varying heights of filter tanks to account for more or less distance to cover. More spiral repetitions and thinner disks can expand more and thus are more suitable for higher filter tanks (assuming a fixed inner diameter). Another way to account for very tall tanks would be to add another stacked disk.

- Lid attachment. It is important to consider a design that requires little to no changes to the existing structure. Thus, a design that attaches solely at the lid provides excellent flexibility.

4) Ease of production

The whole system can be machined by a simple hand saw, or a similar tool. The main components can be made out of almost any material, as long as it has comparable properties and does not rust. No heavy machining is necessary, and the idea is that the structure could be produced and assembled on site.

5) Compact

Taking apart the assembly allows for a very compact system. The disks and mesh can be easily taken apart from the main rod, and the disks can be compacted out of the spiral form. This is great for shipping or even storing.

6) Low cost

Although polypropylene is not the cheapest material available, the life-span is excellent. Also, the ease of production cuts down significantly on machining, shipping, and overhead costs. The design is relatively simple and calls for few parts, so the cost of raw materials per system will be quite low, especially if buying supplies in bulk.

The field model with a purely rock filter may be tested in the future for comparative purposes, but laboratory testing will primarily focus on the new design.

7.3 Results

The primary focus has been on design optimization, material research, and prototype production. Careful consideration of each of the design objectives described in the previous section was especially involved. Prototype production has proved successful in terms of ease, material availability, and feasibility. For cost reasons, the final material selected for the prototype was polypropylene (Figure 7.11), but materials with similar properties, including most nylons, would also work. The main rod can easily be made from any material that will not rust, depending on custom costs and availability.

Figure 7.11 Laboratory iron filter: Disk prototype
Polypropylene spirals in expanded position, made in the SMU Quicksall lab
Disks will have three sizes in order to stack and maximize space usage

7.4 Status

Design and prototype production are complete, and the testing phase will begin immediately after final modifications and laboratory space are solidified. The testing procedure has been established, and variables and standards for each repetition of testing have been predetermined. Water fed into the system will be a synthetic groundwater prepared based upon the chemical constituents measured in samples collected by the SMU team. Pre- and post-filtration iron concentrations will be measured with the Quicksall laboratory's inductively coupled plasma-mass spectrometer (ICP-MS).

7.5 Interpretation

The field data clearly indicate that an iron removal system is required for camps in Kenya and Uganda. The solution must be cheap, effective, and easily produced and maintained in order for implementation to be feasible in the desired camps. The team is hopeful that the recommended design will meet these requirements and that camp implementation will become a reality.

Chapter 8: Analysis of Trace Metals on Suspended Particulate Matter

8.1 Rationale

Toxic, trace metals may exist in the drinking water supply either as dissolved constituents or bound to suspended particulate matter (SPM). Often this particulate matter is so fine-grained that it will not readily settle out and will be ingested along with the truly dissolved components. In some refugee camps, the water is very turbid and ingestion of SPM is expected. Thus, it is imperative that the concentrations of trace metals adsorbed onto these suspended solids are analyzed. In this study, SPM in water from refugee camps will be tested for trace metals.

8.2 Methods

Methods are currently under development, but the preliminary procedure is as follows. Unacidified, unfiltered raw water samples are collected at each sampling location. It is necessary to remove the suspended particulate matter from each sample and use acid digestion to dissolve the SPM for laboratory analysis. In the lab, 5-10 mL of each raw water sample is filtered with 0.45 µm filter paper using a reusable filter holder. The filter paper is removed from the filter holder and placed into a 30 mL Teflon vial. 15 mL of reverse aqua regia (RAR) is added. RAR is made up of 1 part concentrated HCl and 3 parts concentrated HNO_3 (all acids are trace metal grade from Fisher Scientific). Under a vented hood, the vials are placed on a hot plate (Figure 8.1), which keeps the RAR temperature at ~75°C. The samples are digested until all of the liquid has evaporated (Figure 8.2). If necessary, the samples are re-disgested a second or a third time. Digestion of each sample can take up to 10 hours. The digested samples are then re-dissolved in 5% HNO_3 and analyzed with ICP-MS.

Figure 8.1 Teflon vials on the hot plate for digestion

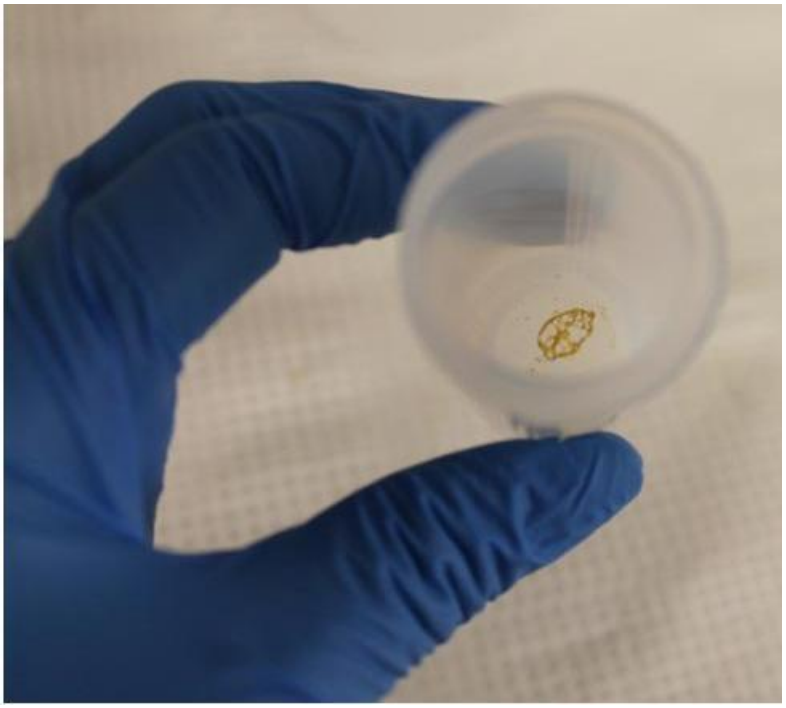


Figure 8.2 Digested sample evaporated to dryness

8.3 Status

Each sample has a different composition of suspended particulate matter. As a result, the methods developed should work for samples containing different compositions of solids. Research on methods is currently being conducted to ensure that the procedure adopted will be suitable for a wide array of samples.

Chapter 9: Recommendations

9.1 Water Quality Database

9.1.1 Continuance of 2011 Sites

It is recommended that water point monitoring in Kenya, Uganda, Bangladesh, Djibouti, and Liberia continue for 2012. It is highly encouraged that replicate, time-series samples be taken from sites analyzed in 2011. Demonstration of reproducibly clean, safe water or contaminated water is necessary before remediation can be deemed either unnecessary or justified, respectively. Further, active changes may be occurring seasonally or over longer time periods. It is therefore important to track trending changes. For the countries in their second year, most sampling can be performed by UNHCR and/or implementing partner (IP) staff, and samples can then be shipped to SMU for analysis. This would be a net decrease in costs by saving on travel. Costs can be further cut by analyzing samples in regional labs rather than shipping samples to SMU. Such partnerships can be built for each location by working with UNHCR country offices, IPs, and governmental agencies.

9.1.2 Expansion of Field Sites

It is recommended that the WQD expands minimally in 2012. It is the goal of the overall project to slowly migrate to cover more countries and camps globally. It is therefore important to add additional sites each year. Countries should eventually be removed from active sampling, likely after their second year. Until this occurs, however, it is important to keep the project manageable. The team, therefore, suggests the addition of a maximum of two to four new countries. A blend of countries from Africa and Asia is preferred with the specific list co-identified by SMU and UNHCR. Sampling in these countries would be similar to the process in 2011 for the countries from that year.

9.1.3 Specific Chemical Recommendations

While the current WQD output is static and presented as a series of camp-specific At-A-Glance cards in Chapter 10, the future goal is to integrate these visuals as an online system of reporting. The following are some of the major findings with recommendations on how to address them.

Iodide

It was the original intent of this agreement to fully identify the extent of iodide contamination in the Dadaab region. The team then planned to work towards a remediation solution through lab-based development followed by field testing. It is the finding of this study, however, that iodide levels in the Dadaab camps are not elevated. It is unclear at this time why prior studies disagree with the findings here. It could show great temporal variability. It is suggested, therefore, that these measurements be repeated over the course of the year to definitively show iodide concentrations with time. It is further suggested that no remediation study is needed at this time. It would not be prudent to invest resources in such a study without clear, reproducible evidence of contamination.

Vanadium

Vanadium was found in consistently high levels in Djibouti and in numerous wells in the Dadaab region. The latter showed a strong trend with conductivity while the former did not. The source of the vanadium in these drinking waters likely varies, as demonstrated by the fact that one region showed correlation to conductivity and another did not. It is suggested that field measurements be repeated and spatially plotted to assist in the determination of extent and potential cause of contamination. Additionally, lab-based remediation solutions should be pursued in similar fashion to the fluoride project already underway.

Aluminum

Aluminum values in the Dadaab region, Djibouti, and isolated wells in other locations were highly elevated. Aluminum is, however, an abundant post-collection sample contaminant. While these values are of concern, the high potential for anomalous values leads the SMU team to suggest that any aluminum value should be reproduced before remediation actions are suggested. Samples should therefore be taken again and cross checked for large scale variances. If numbers are reproduced, then remediation can be addressed at that time.

Manganese

Manganese was not a globally observed contaminant; however, it was widely abundant in Kutapalong, Bangladesh. Numerous values are high enough for concern, and confirmation and remediation are both suggested. Reproducing the results is necessary to confirm both the presence but, more likely, the absolute magnitude and full spatial extent of contamination. Much of Kutapalong was sampled but more wells exist. Extensive regular and rigorous sampling is prudent given the current manganese data. Concurrently, it is suggested that a manganese remediation program be initiated in the laboratory for eventual implementation in the field. This project would operate in similar fashion to that of the current fluoride project.

Other Isolated Issues

Nickel was observed in isolated wells. Values were higher than standards in some cases. At this time, reproducing results is all that is necessary. If values are consistently high, working towards a remediation solution or even closing a small number of wells may be necessary.

Zinc is only a concern at highly elevated levels, and such levels were observed in very few wells. It is only recommended to repeat results at this time.

Isolated wells had elevated uranium. It is likely these values are real and naturally occurring. It is the current recommendation to reproduce such values and hold further recommendations until values are shown to be consistent.

A small number of wells were shown to have high values of lead. The source of such lead is likely anthropogenic. It is suggested that the data be reproduced then a decision can be made on addressing the problem. A well-head solution could be developed, or wells could be closed.

Only two wells in the entire study were shown to have arsenic levels elevated above health standards. It is the recommendation to first reproduce these findings, then to close wells as necessary. If the number of wells was larger, it would be the suggestion to work towards a remediation solution; however, with so few elevated it is likely far more cost effective to close the wells once they are reproducibly shown to be contaminated.

9.2 Fluoride Analysis and Remediation

9.2.1 Laboratory Experiments

Modeling and preliminary batch experiments have demonstrated that fishbone-derived hydroxyapatite can be successfully used to remove fluoride from solution when the initial fluoride contamination is at or above the level of concern. It is therefore recommended that batch experiments be repeated to better quantify removal efficiencies and clearly identify the processes and mechanisms of fluoride retention. Column experiments are also necessary to test fluoride removal efficacy under dynamic flow, which best mimics field conditions.

9.2.2 Field Sampling and Testing

As mentioned previously, elevated fluoride concentrations have been measured in several camps across Uganda, Kenya, and Djibouti. Continued field analysis of fluoride is recommended, particularly in Southern Uganda and Kakuma, Kenya. Seasonal variation is a potential, and some sites are near the health limit. Further spatial mapping is also necessary to cover the full range of possible contamination in Southern Uganda, as only portions of Nakivale and Kyaka II were sampled due to time constraints.

It is recommended that, once a final solution regime is designed and prototyped in the lab, it be scaled to field testing. Implementation of a batch or flow reactor at one to two test sites is highly encouraged during 2012. Once installed, fluoride levels should be monitored monthly to track efficacy of removal closely. This data will yield models for long term predictability of material lifespan.

9.3 Iron Remediation

9.3.1 Prototype Production

Iron concentrations above established standards have been measured in several camps in Uganda, Kenya, and Bangladesh. The iron removal project to develop a remediation strategy for such sites is well underway. The design phase has been completed using a CAD program called SolidWorks to evaluate possible options for achieving remediation and to then identify the best design. The first draft prototype based upon this design is expected to be completed by February 15.

9.3.2 Testing Phase

Lab testing of the prototype is recommended, and the testing phase will begin immediately following the completion of the prototype. To determine the extent of iron removal relative to the available surface area, testing will consist of the following:

a) Filtering varying concentrations of iron in synthetic groundwaters similar in composition to those in the wells of concern
b) Increasing spiral repetitions
c) Possible chemical enhancements to assist iron removal
d) Using different materials, such as different types of cheaper plastics at several thicknesses

All treated water will be sampled and analyzed at SMU with an inductively coupled plasma mass spectrometer (ICP-MS) to determine iron concentration.

9.3.3 Standardization and Cost Analysis

Once ratio of surface area to iron removal has been determined and the minimum surface area needed to achieve the desired results is established, the next phase recommended is standardization and cost analysis, including:

a) Standardizing production method for mass production
b) Pricing of best materials, locally and abroad
c) Writing up production guidelines and maintenance procedures, in English and in local languages

9.3.4 Other Considerations

While most of the water sources with high iron concentrations are predominantly hand pumps and cylindrical water filtration tanks, it is important to realize that these might change in the future. Many camps are already moving to central water taps instead of hand pumps, and hopefully even more improvements will be made in many of these camps. It is necessary, then, to begin to design ways to modify the design to adapt to vastly different water distribution systems, or to present a new design for these altogether. This would not be to meet the present need, but it must be considered for future adaptation and research.

9.3.5 Field implementation

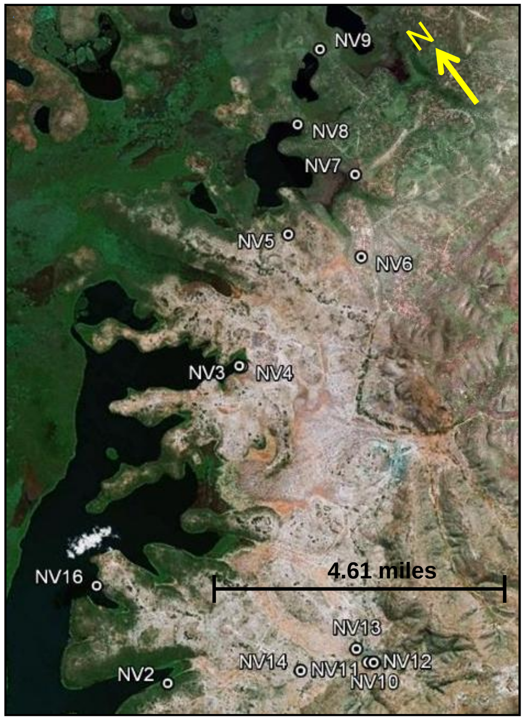
Upon completion of the testing and cost analysis phases, field implementation at the pilot scale is recommended. It is essential to then monitor the pilot test regularly to track efficacy. Results will be used to project future efficacy and total lifespan. It is noted that other such pilots have been put in place by other UNHCR partnerships, but these are currently ineffective based on the recently measured removal efficiencies.

9.4 Suspended Sediment

It is recommended that the SMU team continue analyses of suspended sediment from water points. While iron oxide sediment in water is of little health concern and aesthetically alters taste less than dissolved iron, other health issues may be present. This work could show a significant level of heavy metals associated with the iron oxide sediment. While these metals are not dissolved in the drinking water, ingestion of iron oxide sediment laden waters that have high associated metals still delivers those metals to the body. This could be a very effective route for heavy metal enrichment that is not well tracked, as most water samples are filtered before chemical analysis. This simple project could yield excellent data relating to long term water recipient health.

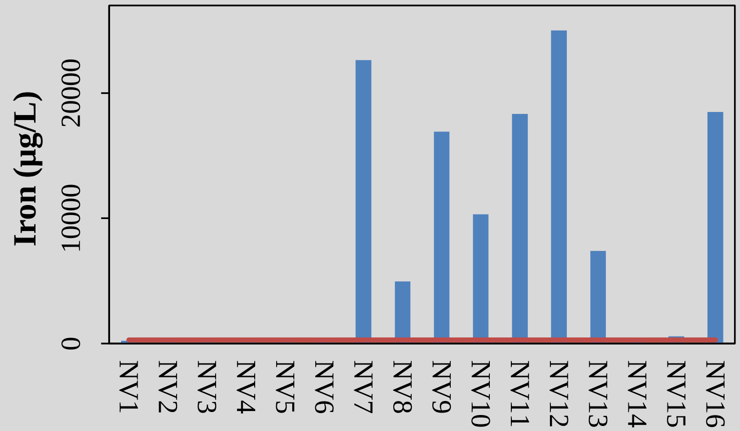
Chapter 10: Individual Camp At-A-Glance

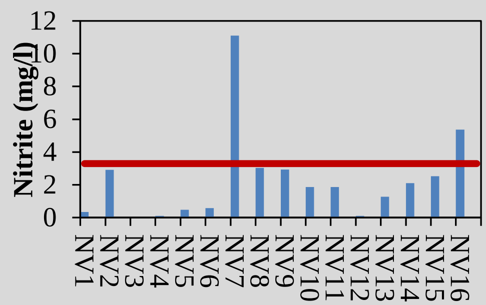
Nakivale Camp
Uganda

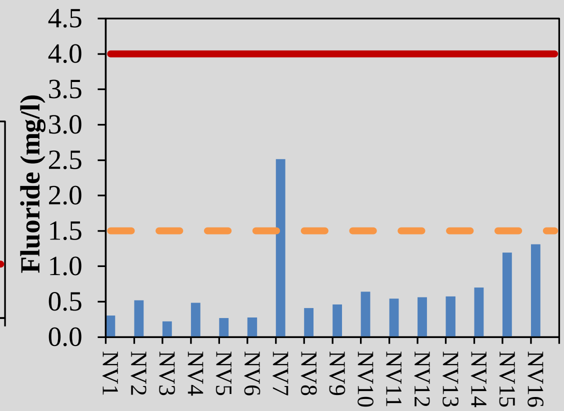


Site	Cond. (µS)	pH
*NV1	735	±9.59
NV2	NM	NM
NV3	677	8.88
NV4	759	7.78
NV5	285	7.56
NV6	277.4	7.9
NV7	3220	8.26
NV8	300.9	7.65
NV9	292.2	7.8
NV10	2500	7.09
NV11	2500	7.7
NV12	2600	7.18
NV13	1760	7.82
NV14	1200	8.06
NV15	666	8.43
NV16	1000	7.49

*Not shown on map







Field Observations:

- Surface water and groundwater were used as drinking water
- High iron content in water from boreholes caused some wells to be abandoned
- Sand and gravel filters were being used to try to reduce iron content

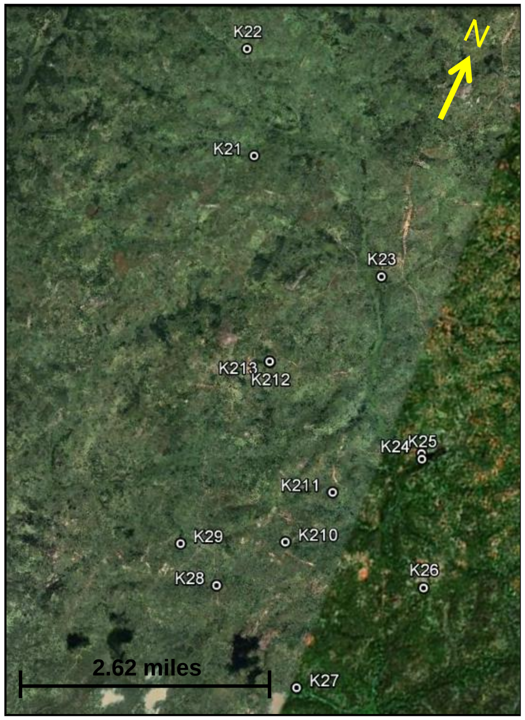
Camp Summary:

- High conductivity values measured
- Very high iron (above WHO aesthetic std)
- High manganese measured
- Elevated fluoride, nitrite, and chloride
- Elevated nickel in NV1 (lake)

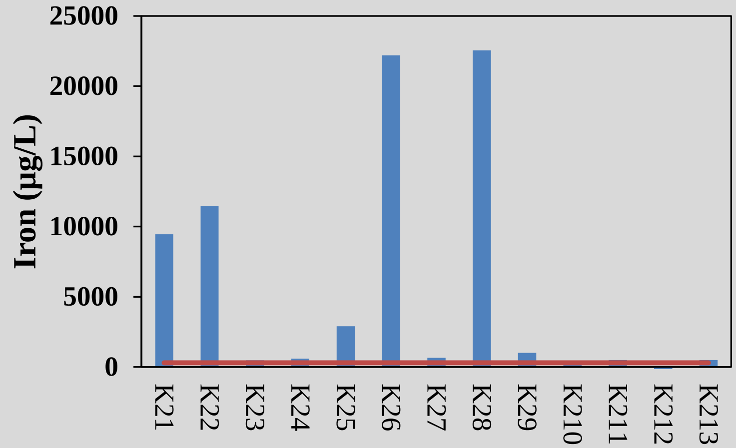
Recommendations:

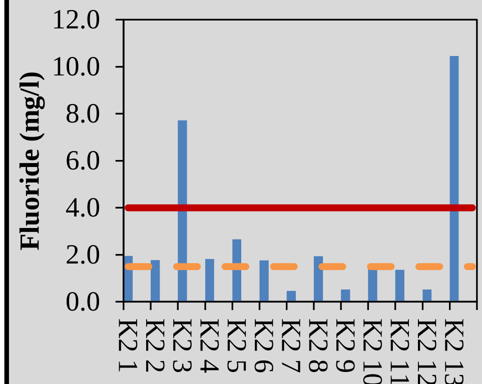
- Continue remediation study for iron
- The geographic expression of some contaminations should be mapped
- Longitudinal studies for analytes with elevated levels should be pursued to establish trends

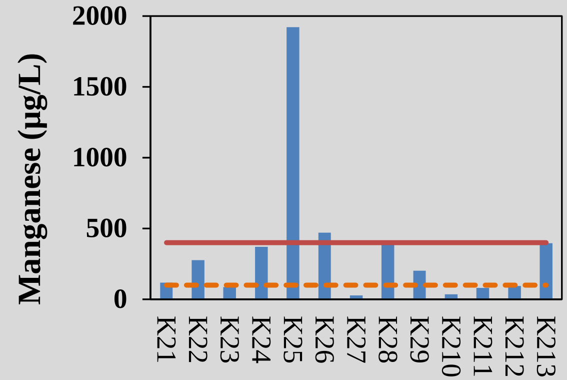
Kyaka II Camp
Uganda



Site	Cond. (µS)	pH
K21	189.4	7.43
K22	217	7.69
K23	470	8.25
K24	161.6	7.84
K25	243.5	7.88
K26	344	8.63
K27	47.7	6.53
K28	307	8.2
K29	67.2	6.16
K210	85.5	6.97
K211	144	7.72
K212	97.7	6.77
K213	283.2	6.79







Field Observations:

- Surface water trucked to tanks in dry season
- Several water sources were difficult to access
- Turbidity varied spatially
- Wells were well-cared for

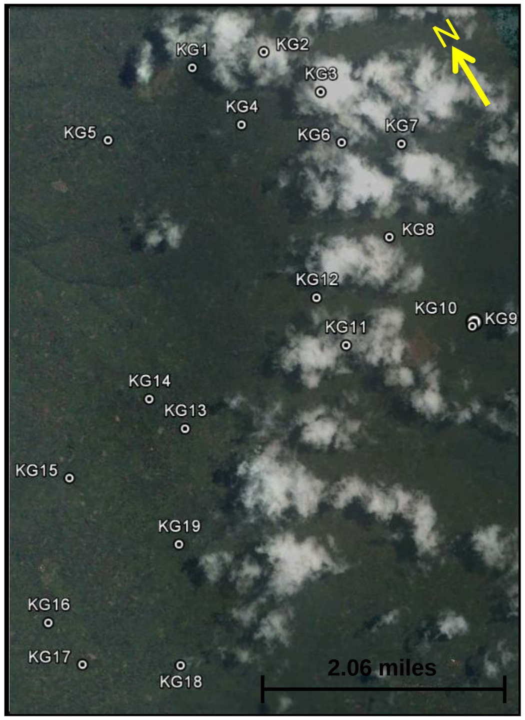
Camp Summary:

- Very high iron (above WHO aesthetic std)
- 4 wells above WHO health std for manganese
- 1 well (K213) above WHO health std for zinc
- Elevated uranium, fluoride, and nitrite

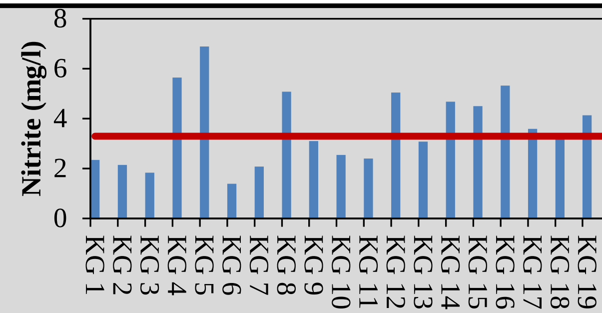
Recommendations:

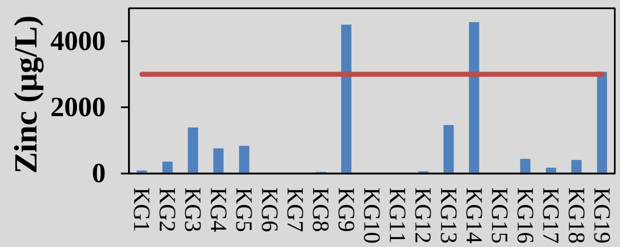
- A lab-based remediation study for manganese should be pursued
- Continue remediation study for iron
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends

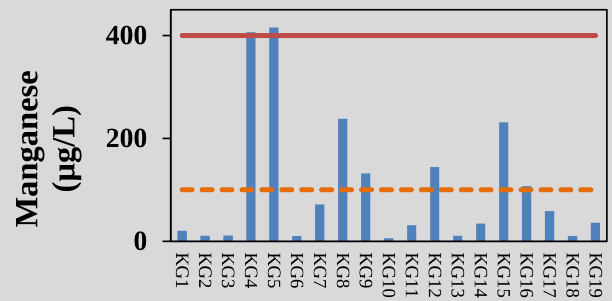
Kyangwali Camp
Uganda



Site	Cond. (µS)	pH
KG1	246	7.24
KG2	187.2	7.83
KG3	136.5	6.81
KG4	408	7.74
KG5	608	7.2
KG6	163.6	6.66
KG7	137.2	6.8
KG8	408	8.1
KG9	197	7.15
KG10	167.5	6.6
KG11	171.5	6.9
KG12	385	8.6
KG13	211.2	7.12
KG14	323	7.9
KG15	367	7.46
KG16	444	7.35
KG17	380	7.4
KG18	229.1	7.35
KG19	308	7.7







Field Observations:

- Old piping was causing some discoloration of the water in some wells
- Shallow wells became cloudy after rainfall events
- Discoloration and mud were observed in the cement pours surrounding the wells

Camp Summary:

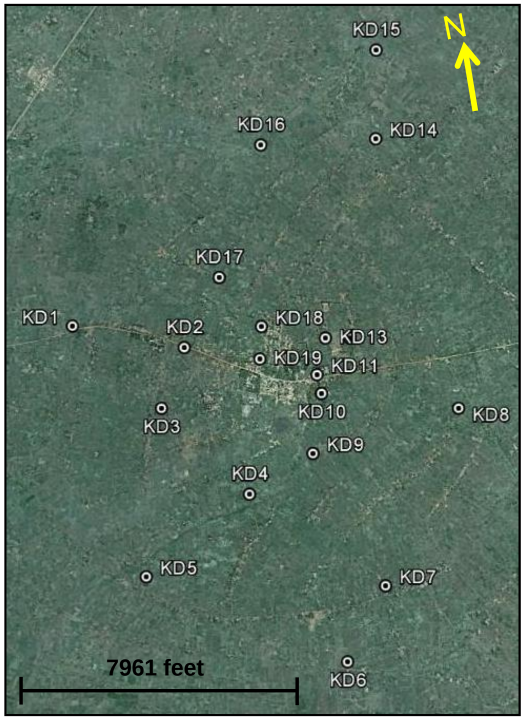
- 12 wells above WHO aesthetic std for iron
- 2 wells above WHO health std for manganese
- Elevated lead at KG 19
- Elevated zinc, fluoride, and nitrite levels

Recommendations:

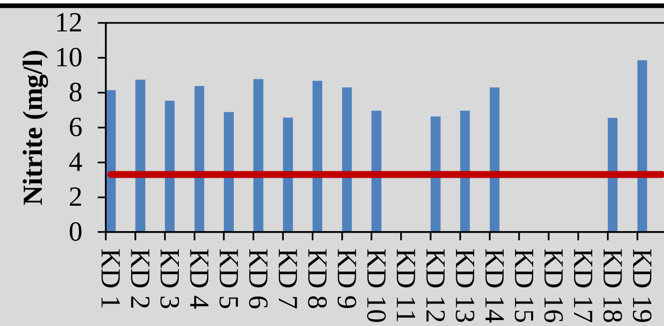
- Continue remediation study for iron
- A lab-based remediation study for manganese should be pursued
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends

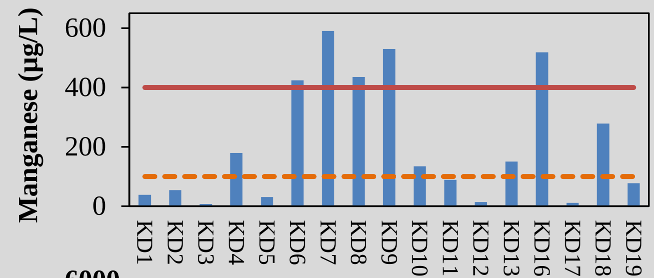
Kiryandongo Camp

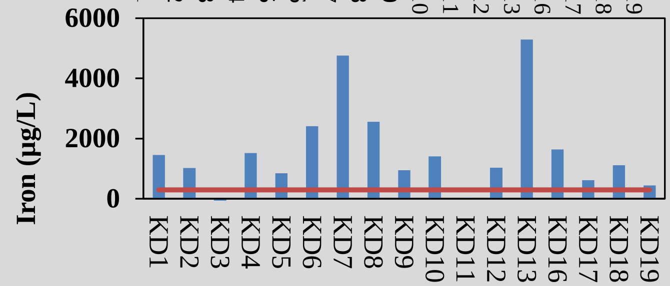
Uganda



Site	Cond. (µS)	pH
KD1	677	8.3
KD2	923	8.1
KD3	661	8.5
KD4	719	8.3
KD5	777	8.3
KD6	1660	8
KD7	1000	7.75
KD8	1300	8.3
KD9	686	8.6
KD10	591	8.1
KD11	773	8.5
KD12	699	8.1
KD13	714	7.6
KD14	669	8.3
KD15	NM	NM
KD16	NM	NM
KD17	1160	8.3
KD18	612	8.2
KD19	805	8.1







Field Observations:

- Iron discoloration of water was evident in some wells
- Mechanized bore holes led to taps for water distribution
- Some wells did not have protection from animals

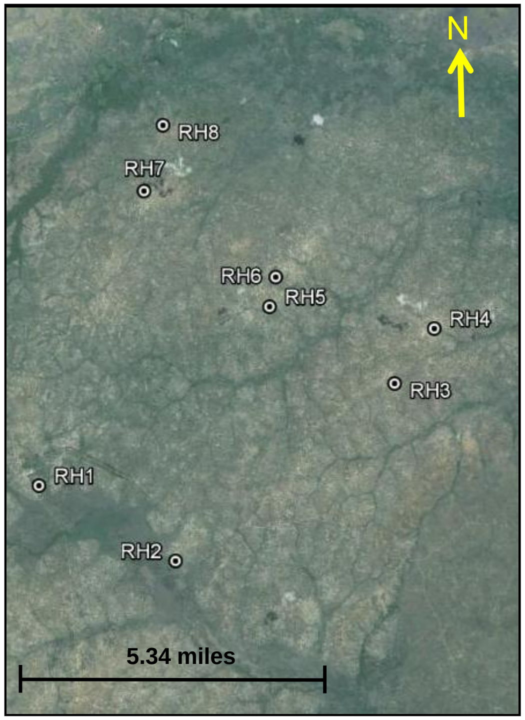
Camp Summary:

- Elevated vanadium in wells KD1, KD2, KD3
- 5 wells above WHO health std. for manganese
- 15 wells above WHO health std. for iron
- Elevated nitrite, copper, zinc, arsenic, lead, gallium, nickel and strontium levels
- 1 well was above the health standard for arsenic

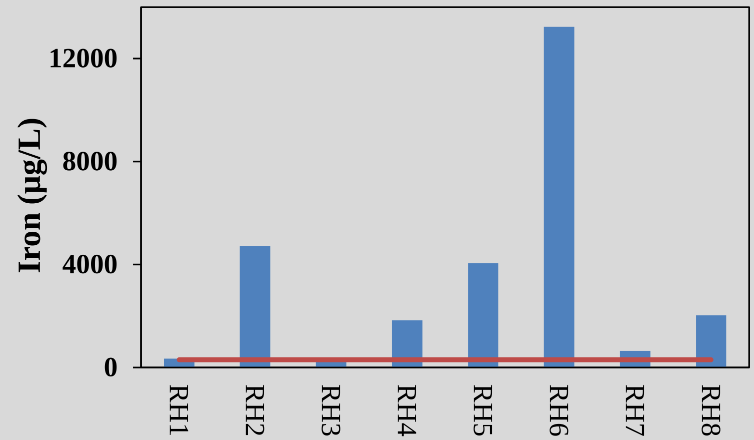
Recommendations:

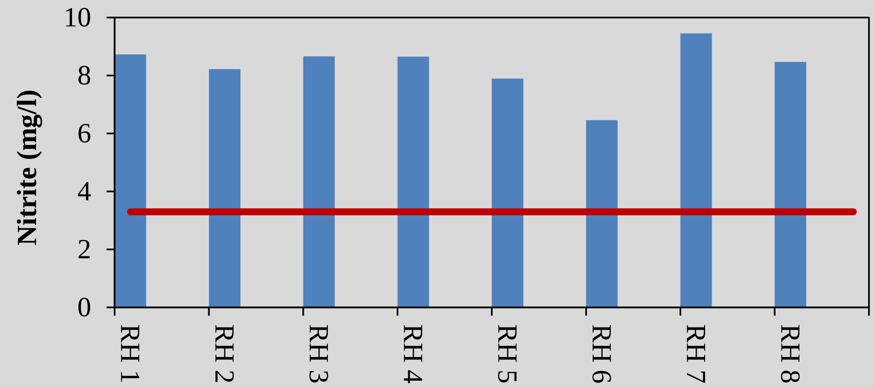
- Confirmation studies for analytes at elevated levels (copper, zinc, lead, etc)
- Possible decommission of well if arsenic results are reproducible
- Continue remediation study for iron
- A lab-based remediation study for manganese should be pursued

Rhino Camp
Uganda



Site	Cond. (µS)	pH
RH1	782	8.1
RH2	740	8.2
RH3	709	8.05
RH4	738	7.9
RH5	662	7.7
RH6	596	7.5
RH7	800	7.6
RH8	721	7.9



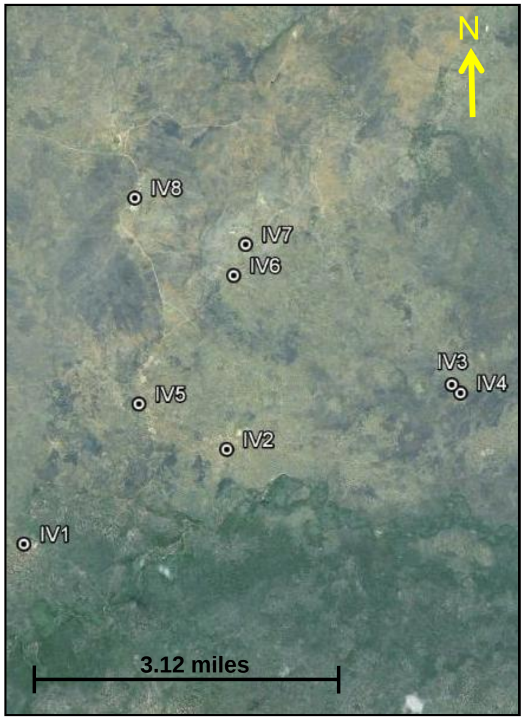


Field Observations:
- One of the boreholes was abandoned due to *e. coli* contamination
- Iron discoloration of water and concrete aprons was observed at some of the sites
- Poorly protected wells
- Comments on “salty taste”

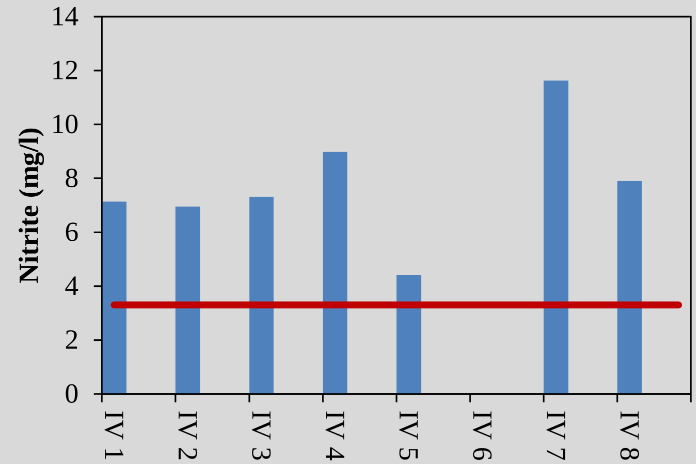
Camp Summary:
- 7 wells above WHO aesthetic std for iron
- Nitrite levels were consistently elevated
- Elevated nitrite, vanadium, and lead

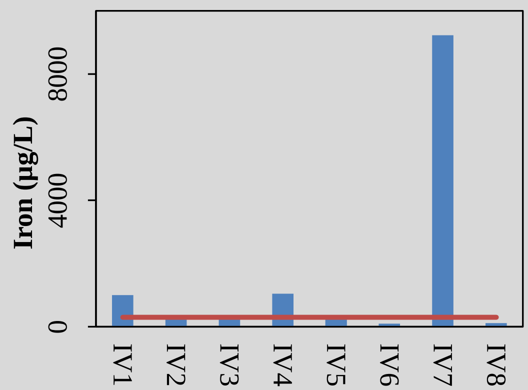
Recommendations:
- Confirmation studies for analytes at elevated levels
- Continue remediation study for iron
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends

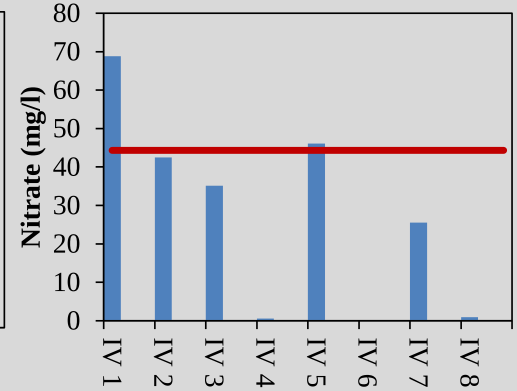
Imvepi Camp
Uganda



Site	Cond. (µS)	pH
IV1	680	8.05
IV2	654	7.9
IV3	612	8.1
IV4	736	8.6
IV5	409	7.9
IV6	720	7.9
IV7	1138	7.8
IV8	639	8.1







Field Observations:

- Both hand pumps and tap stands were in use
- Iron discoloration of the water was evident in some of the wells
- Some wells needed to be protected from defecation by animals

Camp Summary:

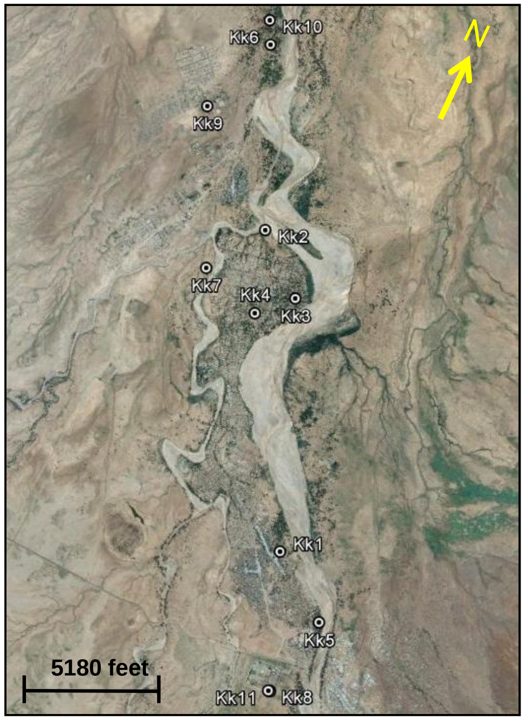
- 6 wells above WHO aesthetic std for iron
- 3 wells above WHO aesthetic std for manganese
- Elevated nitrite, gallium and uranium

Recommendations:

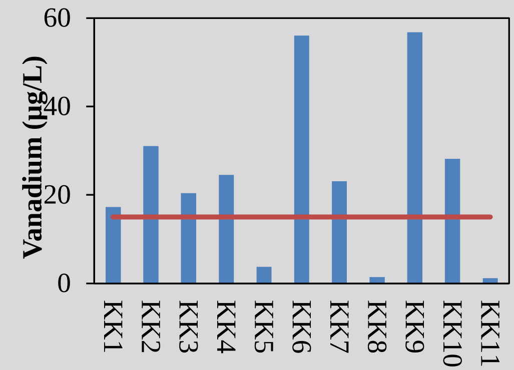
- Confirmation studies for analytes at elevated levels
- Continue remediation study for iron
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends

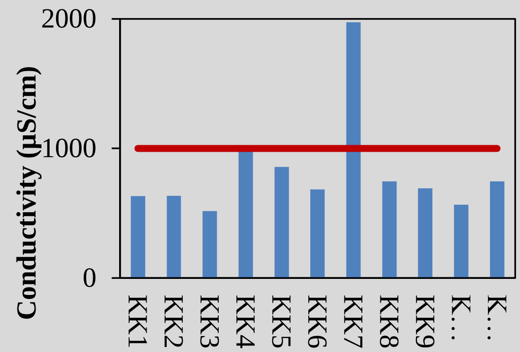
Kakuma Camp

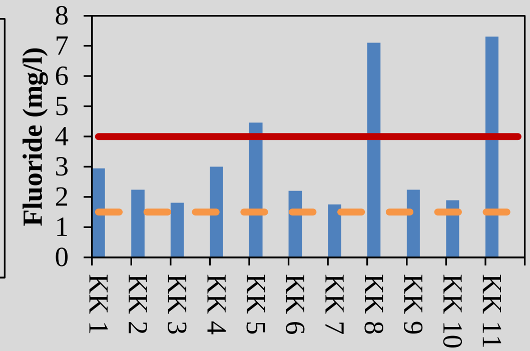
Kenya



Site	Cond. (µS)	pH
KK1	632	8.5
KK2	633	8.3
KK3	517	8
KK4	1019	7.1
KK5	856	8.85
KK6	683	8.47
KK7	1973	7.73
KK8	745	9.5
KK9	691	8.39
KK10	565	8.15
KK11	746	8.9







Field Observations:

- Water system was well designed and efficient
- All the water was derived from boreholes
- Heavy erosion due to flash flooding
- Erosion control measures are in place to protect boreholes
- Boreholes were being re-drilled to increase total capacity

Camp Summary:

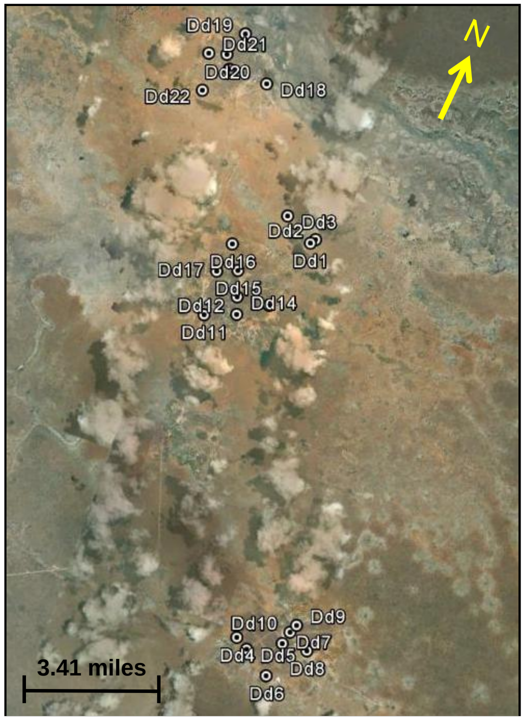
- 8 wells elevated above 15ug/L std for vanadium
- High fluoride levels
- Elevated nitrite, molybdenum, and Uranium
- A few wells with elevated nitrate

Recommendations:

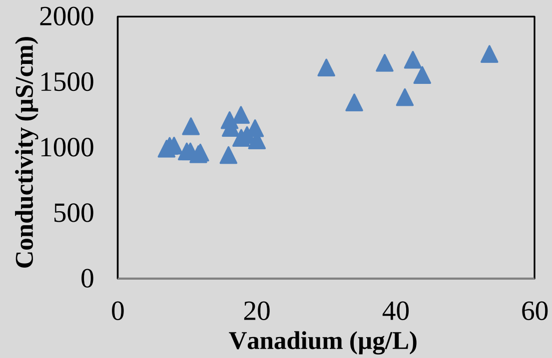
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends
- Continue field analyses and remediation study for fluoride

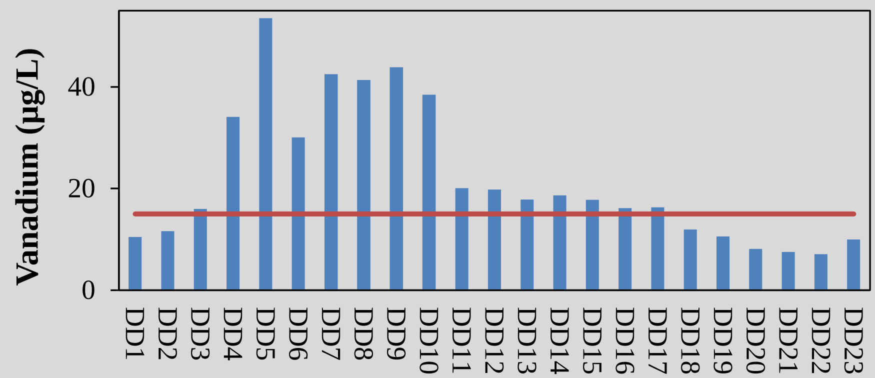
Dadaab Camp

Kenya



Site	Cond. (µS)	*Column II*	
		Site	Cond. (µS)
DD1	970	**DD13**	1074
DD2	948	**DD14**	1094
DD3	942	**DD15**	1248
DD4	1344	**DD16**	1208
DD5	1713	**DD17**	1150
DD6	1609	**DD18**	962
DD7	1669	**DD19**	1161
DD8	1383	**DD20**	1014
DD9	1554	**DD21**	1011
DD10	1645	**DD22**	990
DD11	1055	**DD23**	970
DD12	1148		





Field Observations:

- Dadaab camp complex extending including Ifo 2 camp
- Numerous temporary tents
- Elevated water tanks eliminated the need for trucking
- Auto-dosing facilities for chlorine addition
- Solid waste close to boreholes

Camp Summary:

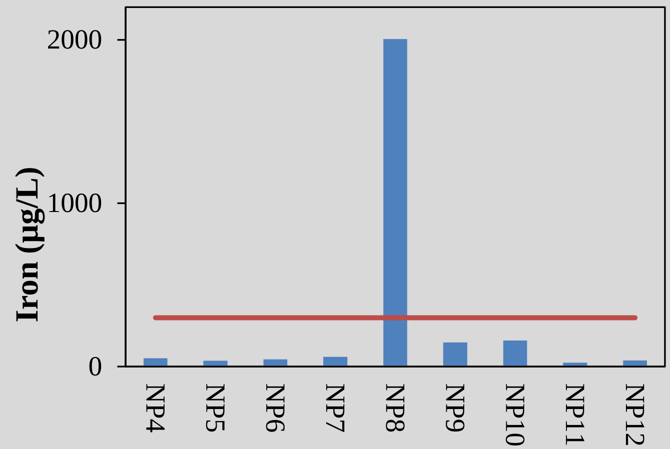
- 15 elevated above 15ug/L guideline for vanadium
- Vanadium concentration correlates with conductivity
- Elevated nitrite, lead, chromium, and zinc
- Iodide NOT present in elevated levels

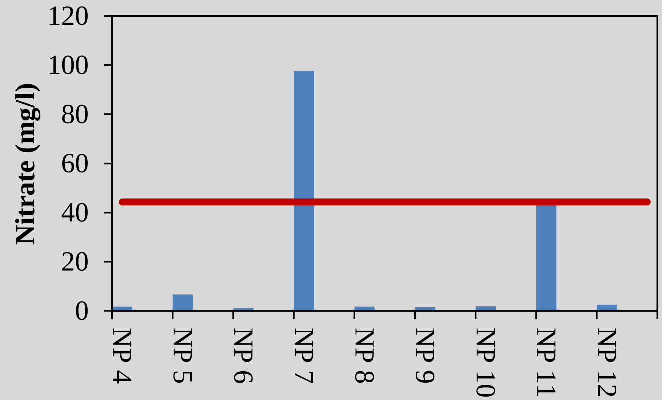
Recommendations:

- Lab-based remediation study for vanadium should be pursued
- Iodide and aluminum measurements should be repeated to determine if remediation study is vital
- Confirmation studies for other analytes with elevated levels

Nayapara Camp
Bangladesh

Site	Cond. (μS)	pH
NP1	NM	NM
NP2	NM	NM
NP3	NM	NM
NP4	104	7.48
NP5	89	7.32
NP6	113	4.42
NP7	121	7.38
NP8	102	6.81
NP9	97	7.49
NP10	95	7.19
NP11	86	7.19
NP12	99	7.24
NP13	94	7.01





Field Observations:

- Population density caused sanitation issues
- Internal reservoir as a main water source
- 3 on-site treatment facilities: water undergoes coagulation, flocculation, chlorination
- Water was turned on for only 1 hour per day
- Water wastage due to the absence of tap heads (removed due to theft)

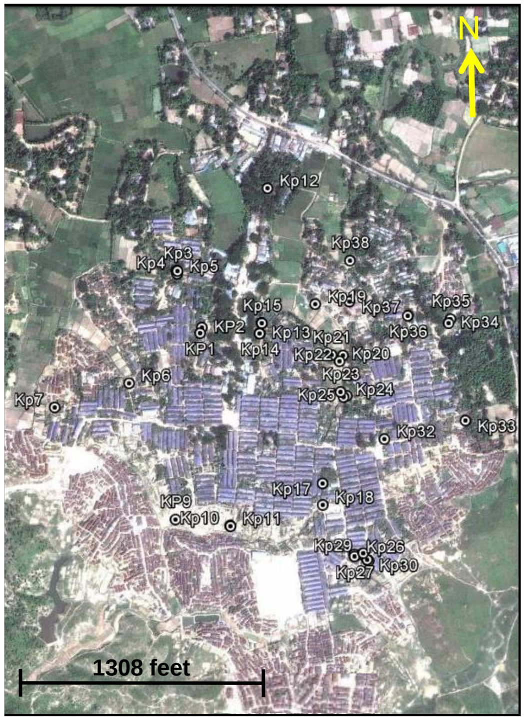
Camp Summary:

- Well NP8 has iron levels above WHO aesthetic std
- 1 well with high nitrate

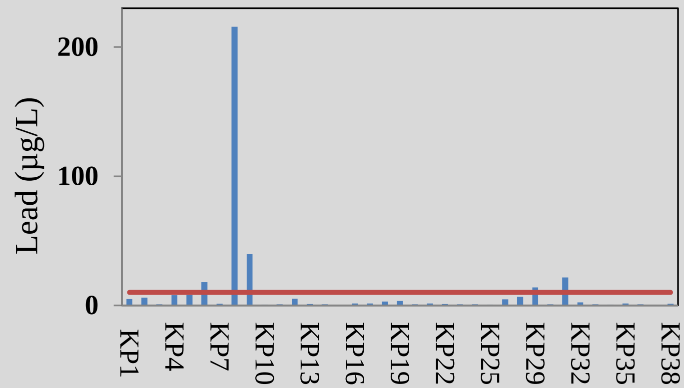
Recommendations:

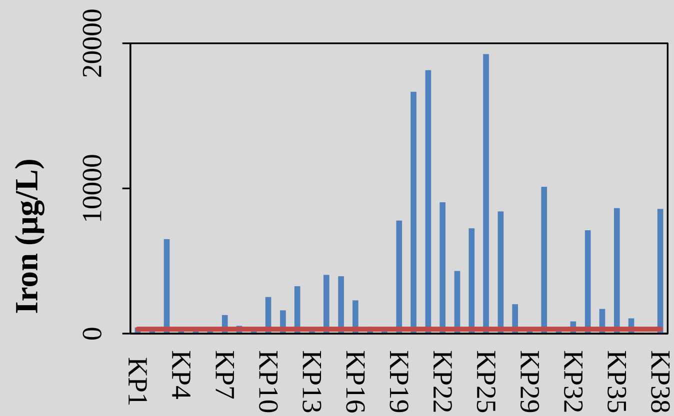
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends
- Study of water supply and use is required

Kutapalong Camp
Bangladesh



Site	pH	Site	pH
KP1	4.59	KP21	6.05
KP2	4.35	KP22	5.68
KP3	6.5	KP23	6.51
KP4	4.56	KP24	5.88
KP5	4.62	KP25	6.04
KP6	4.23	KP26	5.96
KP7	5.3	KP27	4.32
KP9	3.92	KP28	NM
KP10	5.47	KP29	4.33
KP11	5.37	KP30	6.02
KP12	7.47	KP31	4.05
KP13	5.64	KP32	7.16
KP14	6.25	KP33	5.94
KP15	6.1	KP34	7.05
KP16	6.13	KP35	5.88
KP17	7.33	KP36	6.98
KP18	7.73	KP37	7.58
KP19	5.8	KP38	6.24
KP20	6.04		





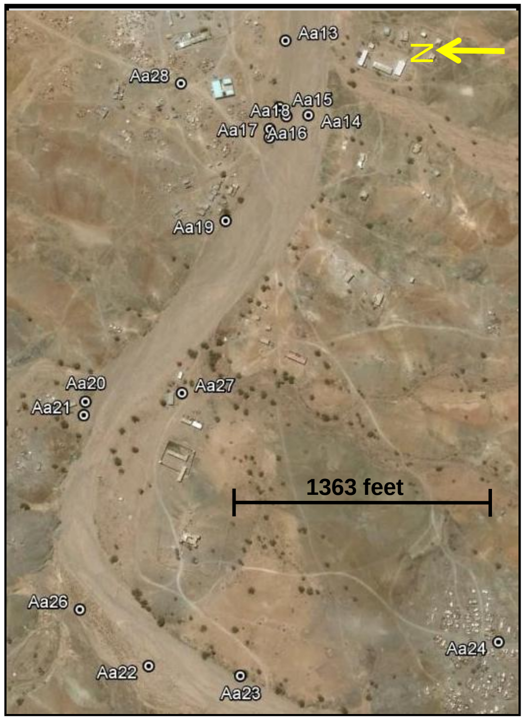
Field Observations:
- Unassisted refugees in surrounding areas
- Excellent water coverage, 107 tube wells
- Some wells next to rice fields that used fertilizers
- Iron contamination was evident across the camp and, as a result, some wells were abandoned

Camp Summary:
- 5 wells above WHO health standard for lead
- 26 wells above WHO aesthetic standard for iron
- 18 wells above WHO health standard for manganese
- Elevated chromium, nickel, iron, and cobalt
- 1 well above health level standard for arsenic
- Lead conc. trends with pH

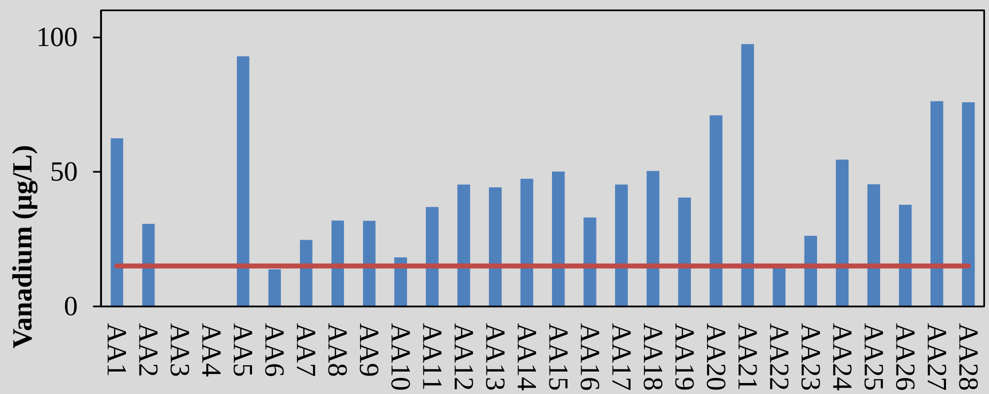
Recommendations:
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends
- A lab-based remediation study for manganese should be pursued
- Closure of well if similar arsenic results are obtained

Ali Adde Camp

Djibouti



Site	Cond. (µS)	pH	Site	Cond. (µS)	pH
AA1	2776	7.45	**AA15**	1642	7.61
AA2	6660	6.95	**AA16**	1791	7.48
AA3	2695	7.04	**AA17**	1612	7.61
AA4	NM	NM	**AA18**	1575	7.74
AA5	1405	7.72	**AA19**	1700	8.18
AA6	2914	7.41	**AA20**	2978	7.48
AA7	2283	7.57	**AA21**	2622	7.48
AA8	2095	7.56	**AA22**	4384	7.82
AA9	2046	7.43	**AA23**	1664	7.57
AA10	2674	7.9	**AA24**	1737	8.42
AA11	3100	7.37	**AA25**	1590	7.98
AA12	2575	7.62	**AA26**	3981	7.5
AA13	2167	7.6	**AA27**	2792	7.7
AA14	3088	7.4	**AA28**	2775	7.7



Field Observations:

- Solar panels (power to water pump) damaged by children throwing rocks
- There were numerous instances of donkeys resting too close to the wells
- In-home ceramic filter

Camp Summary:

- All but 3 above 15µg/L guideline for vanadium
- Conductivities are extremely high
- Elevated nitrite and fluoride levels
- Nitrate is elevated with isolated samples excessively elevated

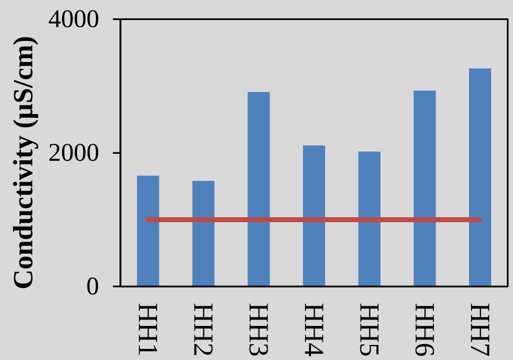
Recommendations:

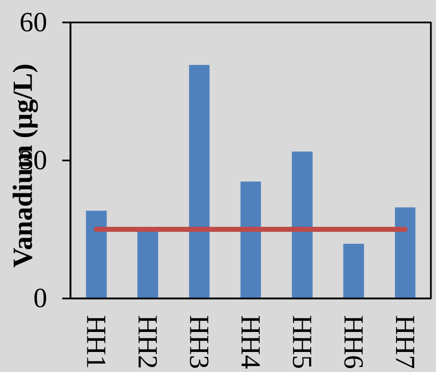
- Lab-based remediation solutions for vanadium should be pursued
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends

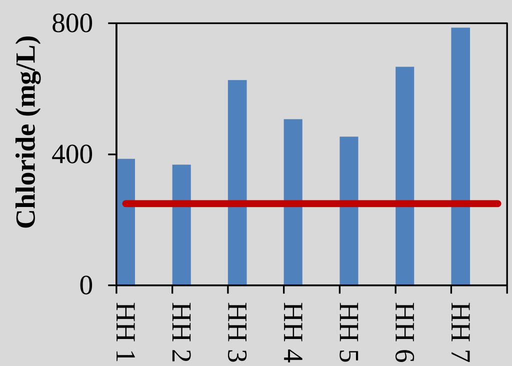
Holhol Camp

Djibouti

Site	Cond. (µS)	pH
HH1	1657	7.58
HH2	1580	7.79
HH3	2912	8.34
HH4	2110	8.27
HH5	2017	7.63
HH6	2931	7.54
HH7	3263	7.79







Field Observations:

- It was a previously-occupied camp
- Solar panels did not seem to be in the correct position for maximum exposure to the sun
- Solar panels should be used as power supply for the adjacent pump to save on energy and costs
- All samples collected here also had conductivity values above the1000 µS/cm guideline

Camp Summary:

- All but 1 well above 15µg/L Vanadium guideline
- Chloride levels above health standard for all wells
- Elevated fluoride and nitrite levels
- Nitrate is elevated with isolated samples excessively elevated

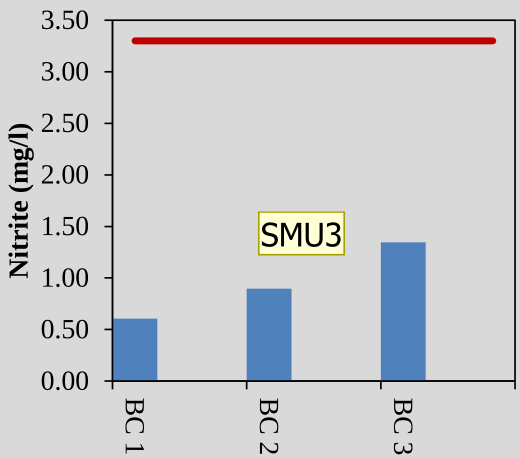
Recommendations:

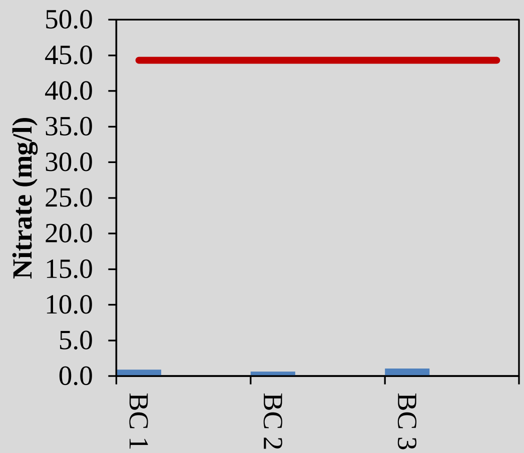
- Lab-based remediation study for vanadium should be pursued
- Temporal and geographic studies for analytes with elevated levels should be pursued to establish trends

Bahn Camp

Liberia

Site	Cond. (µS)	pH
BC1	36	5.44
BC2	51	5.69
BC3	71	5.72





Field Observations

- A total of 3 samples were collected
- Water was pumped and stored in large storage bags or one of the holding tanks
- The pH values were slightly lower than normal (normal range is 6-9) with a minimum of about 5.44

Camp Summary:

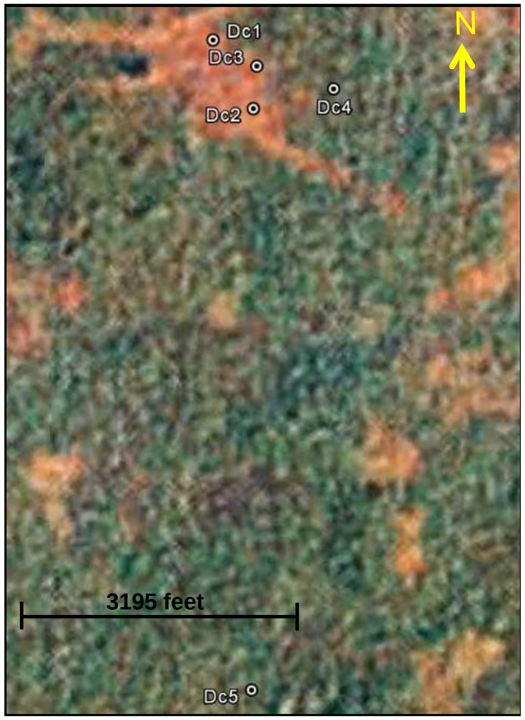
- Nitrate and nitrite values are uniformly low
- Conductivities are consistently low

Recommendations:

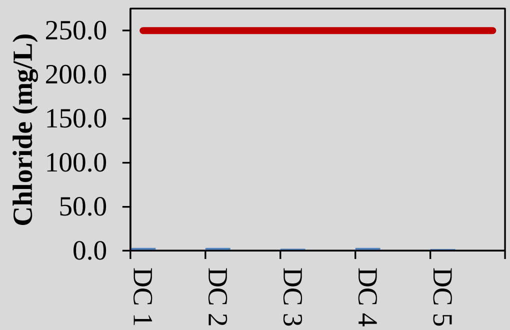
- Temporal and geographic studies for analytes to establish trends of no contamination

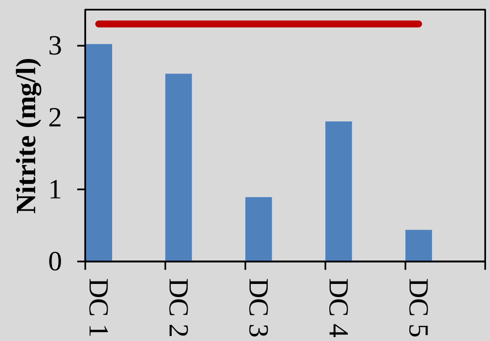
Dougee Camp

Liberia



Site	Cond. (µS)	pH
DC1	348	6.42
DC2	319	6.18
DC3	121	5.73
DC4	287	6.1
DC5	53	6.9





Field Observations:

- At half capacity of population
- Plans of a new well to be constructed close to the creek adjacent to the camp
- Self-made well was preferred by residents, but treated with aquatabs in situ
- Residents not obedient to WASH recommendations

Camp Summary:

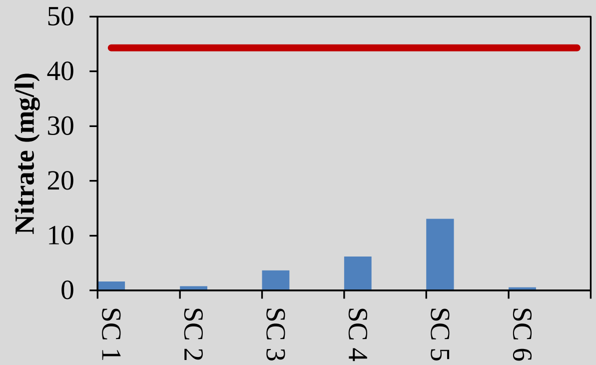
- Nitrate and nitrite values are uniformly low
- Conductivities are consistently low

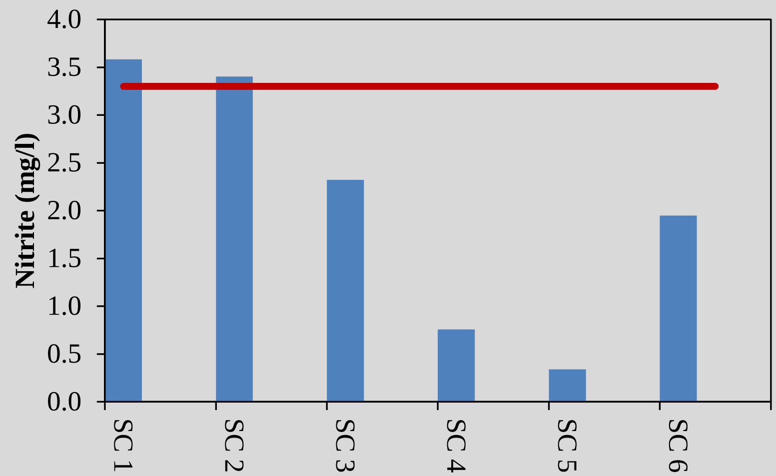
Recommendations:

- Temporal and geographic studies for analytes to establish trends of no contamination

Solo Camp
Liberia

Site	Cond. (µS)	pH
SC1	447	6.48
SC2	576	6.42
SC3	178	5.87
SC4	99	5.57
SC5	87	5.58
SC6	224	6.52



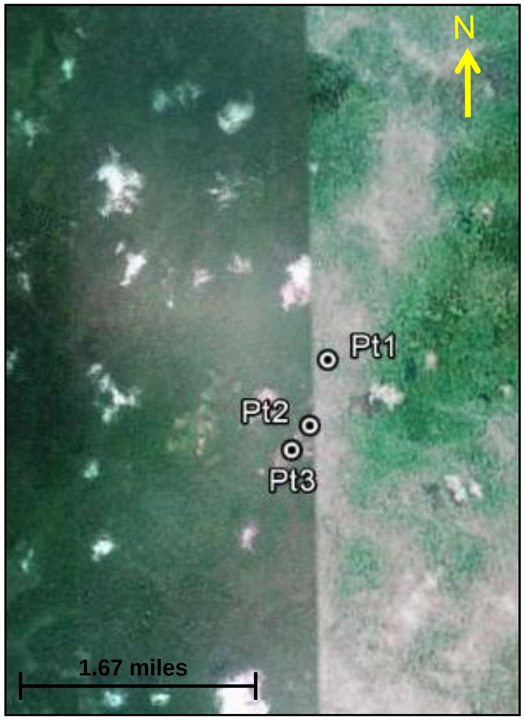


Field Observations:
- Largest tank of the camps visited
- The water from one of the hand pumps became turbid after pumping for a long time
- Good water yield

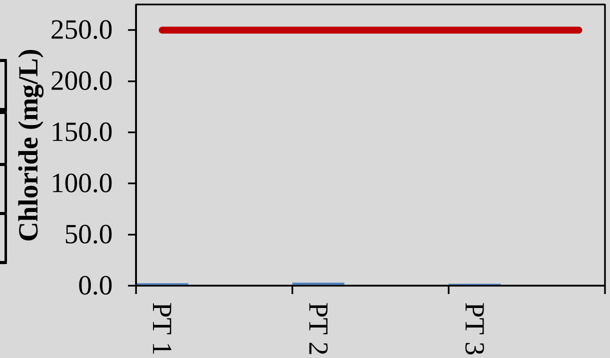
Camp Summary:
- Nitrate values are uniformly low
- Isolated nitrite values are elevated
- Conductivities are consistently low

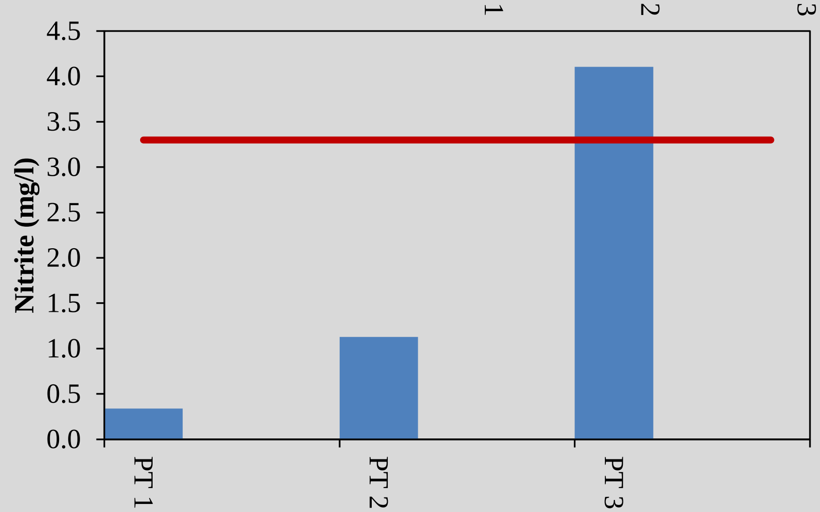
Recommendations:
- Temporal and geographic studies for analytes to establish trends of no contamination
- Nitrite values should be confirmed and geographically mapped

PTP Camp
Liberia



Site	Cond. (µS)	pH
PT1	125	5.66
PT2	160	5.87
PT3	1218	6.96





Field Observations:

- The refugees constructed a hand dug which they used as potable water despite warnings that it might be contaminated
- On-site chlorination of water from the well using aquatabs was mandated to lower risk of disease

Camp Summary:

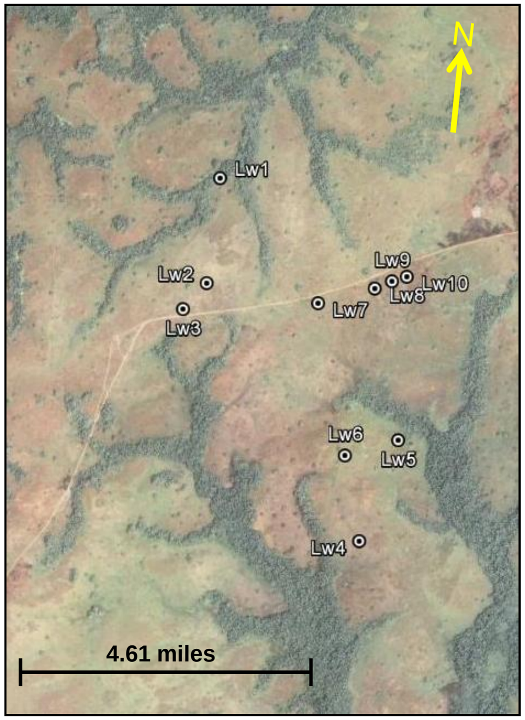
- Low chloride and nitrate concentrations
- Nitrate concentration above health standard in one of the wells

Recommendations:

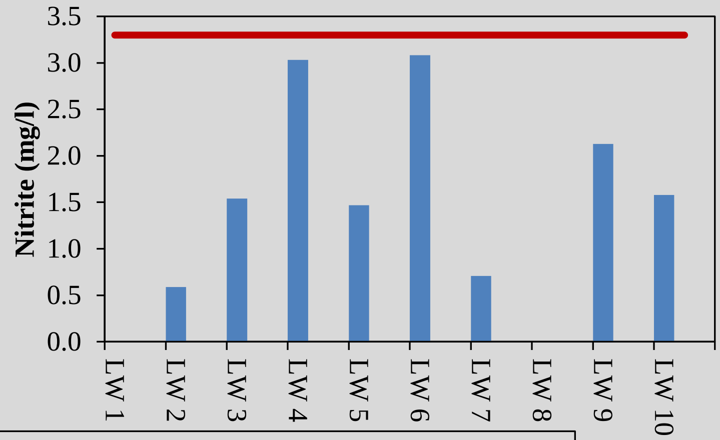
- Temporal and geographic studies for analytes to establish trends of no contamination
- Nitrite values should be confirmed and geographically mapped

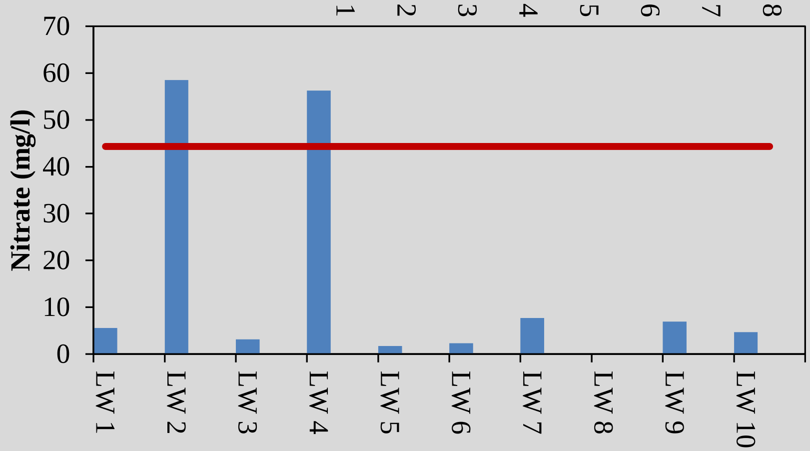
Little Wlebo Camp

Liberia



Site	Cond. (µS)	pH
LW1	49	7.68
LW2	122	5.98
LW3	223	6.47
LW4	497	6.68
LW5	168	6.15
LW6	439	6.59
LW7	263	6.3
LW8	76	5.6
LW9	104	5.72
LW10	95	5.54





Field Observations:

- Flood trenches were covered (to prevent disease and odor) unlike other camps visited in Liberia
- A de-sludging facility to treat waste from latrines was at the design stage
- The camp was well maintained overall

Camp Summary:

- Elevated nitrite levels in some of the wells
- Nitrate levels above health standard for two wells
- Low chloride and fluoride concentrations

Recommendations:

- Temporal and geographic studies for analytes to establish trends of no contamination
- Nitrite and nitrate values should be confirmed and geographically mapped

Appendix A: GPS Data

A.1 Uganda

Nakivale camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
NV1	-	-
NV2	S0 49.355	E30 53.496
NV3	S0 46.174	E30 56.806
NV4	S0 46.198	E30 56.830
NV5	S0 45.000	E30 58.413
NV6	S0 45.841	E30 59.102
NV7	S0 44.816	E30 59.675
NV8	S0 43.768	E30 59.386
NV9	S0 43.049	E31 00.244
NV10	S0 50.711	E30 56.089
NV11	S0 50.710	E30 56.089
NV12	S0 50.666	E30 56.026
NV13	S0 50.418	E30 55.991
NV14	S0 50.239	E30 55.165
NV15	S0 50.190	E30 54.601
NV16	S0 47.654	E30 53.413

Rhino Camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
RH1	N3 05.509	E31 14.826
RH2	N3 04.333	E31 16.888
RH3	N3 06.972	E31 20.269
RH4	N3 07.796	E31 20.888
RH5	N3 08.167	E31 18.382
RH6	N3 08.615	E31 18.483
RH7	N3 09.951	E31 16.498
RH8	N3 10.945	E31 16.802

Kiryandongo camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
KD1	N1 56.736	E32 09.058
KD2	N1 56.575	E32 09.570
KD3	N1 56.306	E32 09.432
KD4	N1 55.860	E32 09.795
KD5	N1 55.532	E32 09.269
KD6	N1 55.028	E32 10.161
KD7	N1 55.361	E32 10.379
KD8	N1 56.146	E32 10.815
KD9	N1 56.015	E32 10.112
KD10	N1 56.289	E32 10.185
KD11	N1 56.378	E32 10.174
KD12	N1 56.529	E32 10.346
KD13	N1 56.543	E32 10.232
KD14	N1 57.440	E32 10.573
KD15	N1 57.852	E32 10.623
KD16	N1 57.475	E32 10.034
KD17	N1 56.882	E32 09.770
KD18	N1 56.631	E32 09.941
KD19	N1 56.482	E32 09.916

Imvepi camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
IV1	N3 12.445	E31 15.757
IV2	N3 13.245	E31 17.551
IV3	N3 13.782	E31 19.537
IV4	N3 13.707	E31 19.612
IV5	N3 13.656	E31 16.787
IV6	N3 14.767	E31 17.636
IV7	N3 15.035	E31 17.745
IV8	N3 15.452	E31 16.784

Kyangwali camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
KG1	N1 12.120	E30 46.161
KG2	N1 11.987	E30 46.637
KG3	N1 11.567	E30 46.848
KG4	N1 11.622	E30 46.273
KG5	N1 11.955	E30 45.430
KG6	N1 11.200	E30 46.813
KG7	N1 11.003	E30 47.164
KG8	N1 10.489	E30 46.799
KG9	N1 09.699	E30 47.013
KG10	N1 09.718	E30 47.041
KG11	N1 09.984	E30 46.201
KG12	N1 10.359	E30 46.174
KG13	N1 09.998	E30 44.983
KG14	N1 10.286	E30 44.862
KG15	N1 10.070	E30 44.139
KG16	N1 09.281	E30 43.560
KG17	N1 08.927	E30 43.635
KG18	N1 08.615	E30 44.216
KG19	N1 09.333	E30 44.583

Kyaka II camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
K21	N0 23.374	E31 04.085
K22	N0 24.300	E31 03.631
K23	N0 22.761	E31 05.621
K24	N0 21.374	E31 06.576
K25	N0 21.327	E31 06.599
K26	N0 20.244	E31 07.047
K27	N0 18.979	E31 06.308
K28	N0 19.560	E31 05.285
K29	N0 19.786	E31 04.836
K210	N0 20.158	E31 05.719
K211	N0 20.738	E31 05.950
K212	N0 21.629	E31 04.963
K213	N0 21.634	E31 04.958

A.2 Kenya

Kakuma camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
KK1	N3 43.288	E34 51.062
KK2	N3 45.286	E34 50.223
KK3	N3 44.917	E34 50.576
KK4	N3 44.729	E34 50.353
KK5	N3 42.939	E34 51.466
KK6	N3 46.507	E34 49.814
KK7	N3 44.905	E34 49.936
KK8	N3 42.405	E34 51.303
KK9	N3 45.954	E34 49.555
KK10	N3 46.666	E34 49.750
KK11	N3 42.406	E34 51.314

Dadaab camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
DD1	N0 08.334	E40 20.079
DD2	N0 08.441	E40 20.158
DD3	N0 08.717	E40 19.421
DD4	S0 00.180	E40 21.451
DD5	S0 00.348	E40 21.735
DD6	S0 00.743	E40 22.324
DD7	N0 00.026	E40 22.418
DD8	N0 00.057	E40 22.969
DD9	N0 00.496	E40 22.575
DD10	N0 00.312	E40 22.493
DD11	N0 06.111	E40 18.443
DD12	N0 06.354	E40 19.101
DD13	N0 06.775	E40 19.690
DD14	N0 06.713	E40 18.984
DD15	N0 07.252	E40 18.809
DD16	N0 07.749	E40 18.503
DD17	N0 07.084	E40 18.382
DD18	N0 11.238	E40 18.035
DD19	N0 12.095	E40 17.240
DD20	N0 11.548	E40 17.014
DD21	N0 11.440	E40 16.638
DD22	N0 10.642	E40 16.778
DD23	N0 11.261	E40 17.170

A.3 Bangladesh

Kutapalong camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
KP1	N21 12.737	E92 09.785
KP2	N21 12.742	E92 09.786
KP3	N21 12.792	E92 09.762
KP4	N21 12.792	E92 09.761
KP5	N21 12.790	E92 09.762
KP6	N21 12.693	E92 09.718
KP7	N21 12.670	E92 09.648
KP8	-	-
KP9	N21 12.573	E92 09.764
KP10	N21 12.569	E92 09.816
KP11	N21 12.568	E92 09.816
KP12	N21 12.866	E92 09.846
KP13	N21 12.738	E92 09.841
KP14	N21 12.738	E92 09.841
KP15	N21 12.747	E92 09.843
KP16	N21 12.747	E92 09.843
KP17	N21 12.607	E92 09.902
KP18	N21 12.588	E92 09.903
KP19	N21 12.765	E92 09.893
KP20	N21 12.715	E92 09.917
KP21	N21 12.720	E92 09.909
KP22	N21 12.720	E92 09.920
KP23	N21 12.688	E92 09.918
KP24	N21 12.683	E92 09.921
KP25	N21 12.684	E92 09.924
KP26	N21 12.545	E92 09.933
KP27	N21 12.543	E92 09.934
KP28	N21 12.545	E92 09.940
KP29	N21 12.546	E92 09.942
KP30	N21 12.541	E92 09.946
KP31	N21 12.539	E92 09.947
KP32	N21 12.647	E92 09.960
KP33	N21 12.664	E92 10.037
KP34	N21 12.749	E92 10.020
KP35	N21 12.753	E92 10.021
KP36	N21 12.755	E92 09.981
KP37	N21 12.767	E92 09.925
KP38	N21 12.803	E92 09.925

Nayapara camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
NP1	N20 57.715	E92 14.859
NP2	N20 57.652	E92 14.888
NP3	N20 57.651	E92 14.900
NP4	N20 57.317	E92 14.997
NP5	N20 57.331	E92 15.062
NP6	N20 57.380	E92 15.069
NP7	N20 57.466	E92 15.075
NP8	N20 57.466	E92 15.075
NP9	N20 57.554	E92 14.940
NP10	N20 57.524	E92 14.865
NP11	N20 57.523	E92 14.866
NP12	N20 57.510	E92 14.940
NP13	N20 57.552	E92 15.015

A.4 Djibouti

Holhol camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
HH1	N11 18.196	E42 54.625
HH2	N11 18.186	E42 54.632
HH3	N11 17.923	E42 54.661
HH4	N11 17.919	E42 54.760
HH5	N11 17.870	E42 54.801
HH6	N11 17.836	E42 54.781
HH7	N11 17.846	E42 54.879

Ali Sabieh	Coordinates (GPS)	
	LATITUDE	LONGITUDE
AS1	N11 09.188	E42 42.368
AS2	N11 08.930	E42 42.042
AS3	N11 08.976	E42 42.099

Ali Adde camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
AA1	N11 08.206	E42 52.900
AA2	N11 08.149	E42 52.905
AA3	-	-
AA4	N11 08.185	E42 52.747
AA5	N11 08.110	E42 52.811
AA6	N11 09.386	E42 52.082
AA7	N11 07.909	E42 53.883
AA8	-	-
AA9	N11 07.923	E42 53.866
AA10	N11 07.839	E42 53.743
AA11	N11 07.848	E42 53.657
AA12	N11 07.825	E42 53.525
AA13	N11 07.824	E42 53.505
AA14	N11 07.809	E42 53.433
AA15	N11 07.834	E42 53.443
AA16	N11 07.829	E42 53.434
AA17	N11 07.846	E42 53.416
AA18	N11 07.845	E42 53.424
AA19	N11 07.892	E42 53.342
AA20	N11 08.032	E42 53.188
AA21	N11 08.034	E42 53.176
AA22	N11 07.995	E42 52.945
AA23	N11 07.914	E42 52.929
AA24	N11 07.684	E42 52.940
AA25	N11 07.684	E42 52.940
AA26	N11 08.052	E42 53.001
AA27	N11 07.945	E42 53.188
AA28	N11 07.922	E42 53.473

A.5 Liberia

Fishtown	Coordinates (GPS)	
	LATITUDE	LONGITUDE
FT1	N4 25.472	W7 49.082

Gblah	Coordinates (GPS)	
	LATITUDE	LONGITUDE
GB1	N7 00.522	W8 40.418
GB2	N7 00.461	W8 40.371
GB3	N7 00.503	W8 40.472

Bahn camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
BC1	N7 01.861	W8 43.933
BC2	N7 01.920	W8 43.964
BC3	N7 01.986	W8 43.925

Dougee camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
DC1	N6 15.983	W8 31.204
DC2	N6 15.852	W8 31.128
DC3	N6 15.932	W8 31.121
DC4	N6 15.886	W8 30.976
DC5	N6 14.753	W8 31.143

Tian Town	Coordinates (GPS)	
	LATITUDE	LONGITUDE
TT1	N6 15.776	W8 29.150
TT2	N6 15.842	W8 29.258
TT3	N6 15.961	W8 29.316

Solo camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
SC1	N6 08.666	W8 14.927
SC2	N6 08.605	W8 14.875
SC3	N6 08.510	W8 14.842
SC4	N6 08.751	W8 14.498
SC5	N6 08.796	W8 14.481
SC6	N6 08.694	W8 14.612

PTP camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
PT1	N6 01.875	W8 02.994
PT2	N6 01.459	W8 03.119
PT3	N6 01.306	W8 03.239

Maryland Country	Coordinates (GPS)	
	LATITUDE	LONGITUDE
MD1	N4 21.923	W7 32.009
MD2	N4 21.806	W7 32.348
MD3	N4 21.656	W7 35.490
MD4	N4 21.686	W7 35.443
MD5	N4 22.364	W7 35.318
MD6	N4 27.172	W7 44.183

Little Wlebo camp	Coordinates (GPS)	
	LATITUDE	LONGITUDE
LW1	N4 27.204	W7 44.960
LW2	N4 26.984	W7 44.963
LW3	N4 26.925	W7 45.006
LW4	N4 26.489	W7 44.588
LW5	N4 26.706	W7 44.531
LW6	N4 26.662	W7 44.637
LW7	N4 26.969	W7 44.728
LW8	N4 27.012	W7 44.614
LW9	N4 27.031	W7 44.580
LW10	N4 27.044	W7 44.551

Appendix B: Full Water Analyses

B.1 Uganda

Nakivale

Nakivale camp	Temperature (°C)	Conductivity (uS/cm)	pH	ORP (mV)
NV1	27.2*	735	9.59*	-138.2
NV2	NM	NM	NM	NM
NV3	21.7	677	8.88	-97.0
NV4	23.6	759	7.78	-23.3
NV5	23.1	285	7.56	-28.4
NV6	21.8	277.4	7.90	-64.6
NV7	23.9	3220	8.26	-47.6
NV8	21.4	300.9	7.65	-51.4
NV9	20.2	292.2	7.80	-54.6
NV10	22.8	2500	7.09	-40.2
NV11	23.6	2500	7.70	-81.0
NV12	24.0	2600	7.18	-111.2
NV13	24.7	1760	7.82	-110.4
NV14	24.9	1200	8.06	-109.9
NV15	25.5	666	8.43	-106.9
NV16	23.8	1000	7.49	-101.6

Nakivale camp	7Li μg/L	9Be μg/L	23Na μg/L	24Mg μg/L	27Al μg/L	39K μg/L	44Ca μg/L	51V μg/L	52Cr μg/L	55Mn μg/L	56Fe μg/L
NV1	10.78	-0.78	61869.93	26292.84	44.97	13529.99	11958.29	0.77	28.60	191.36	226.92
NV2	4.33	-0.78	61365.29	26057.86	66.98	13263.28	12462.31	0.37	0.59	405.35	147.23
NV3	2.76	3.93	57429.79	24312.56	-112.12	13073.06	11881.51	1.38	2.42	393.29	248.60
NV4	7.44	-0.77	56631.92	23418.90	102.97	11922.40	13541.22	0.38	0.54	215.42	251.89
NV5	2.74	1.56	17938.57	6781.52	-93.37	7122.57	5289.17	0.14	0.58	250.66	166.63
NV6	4.39	-0.79	19309.60	7511.40	-91.37	9594.56	8772.94	0.15	1.09	196.43	297.80
NV7	20.27	1.56	347740.33	136426.98	-126.73	24257.07	27259.36	0.24	0.05	275.71	22633.42
NV8	-2.06	-0.78	21392.44	8133.03	-100.94	8685.07	6929.25	2.74	1.17	606.13	4966.28
NV9	-0.47	1.59	15486.28	8465.67	-114.87	7165.40	7313.83	1.81	1.65	561.59	16915.70
NV10	5.99	-0.79	220159.97	74794.80	-114.41	2754.35	64173.74	0.25	0.94	349.57	10317.35
NV11	1.15	3.92	222668.04	75536.28	-107.63	3750.37	65705.12	0.34	0.90	440.82	18338.35
NV12	10.92	-0.79	193921.44	96515.44	-122.43	11461.45	78384.65	0.29	-0.07	189.83	25008.43
NV13	131.45	1.56	256917.59	35966.98	-111.62	9668.33	19793.88	0.14	-0.03	119.30	7400.64
NV14	45.22	1.54	171187.80	12691.03	-120.95	6222.18	9946.54	0.14	2.50	66.40	232.82
NV15	24.83	1.55	89736.56	8627.84	-126.79	6205.03	10333.39	0.06	0.04	135.87	569.56
NV16	1.13	-0.77	36933.12	23691.25	-125.69	20273.20	36546.86	0.23	0.00	1770.17	18480.73

Nakivale camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
NV1	0.27	45.67	3.13	-3.75	4.52	0.48	NM	15.25	17.93	305.99	5.58
NV2	0.06	0.86	1.99	7.07	4.91	0.31	NM	20.86	18.21	316.20	2.94
NV3	0.11	0.75	1.86	-0.76	5.09	0.44	NM	14.36	17.22	294.92	2.60
NV4	0.11	3.37	1.77	17.55	4.24	0.47	NM	17.87	16.67	286.69	0.01
NV5	0.10	2.36	2.70	66.06	1.97	0.31	NM	5.53	10.95	95.69	0.02
NV6	0.11	0.92	2.92	37.83	1.81	0.37	NM	10.75	11.72	98.40	-0.05
NV7	0.09	0.64	0.64	1.94	6.04	0.30	NM	128.72	13.16	1471.24	1.12
NV8	2.78	3.94	0.46	9.14	5.40	0.76	NM	12.77	10.18	129.30	1.20
NV9	2.47	10.69	0.82	9.06	3.34	1.52	NM	16.68	10.04	121.71	1.15
NV10	1.27	2.02	0.95	15.33	3.22	0.23	NM	81.82	2.44	1796.28	0.12
NV11	0.91	2.62	2.20	54.65	3.31	0.28	NM	84.92	2.43	1842.38	0.13
NV12	0.93	5.66	0.60	41.96	1.71	0.42	NM	81.95	3.83	1896.13	0.00
NV13	0.22	1.45	1.22	99.39	1.41	0.07	NM	33.25	23.42	342.26	1.54
NV14	0.07	1.26	27.96	80.70	2.02	0.10	NM	23.65	17.95	181.30	2.58
NV15	0.04	0.65	1.55	44.27	6.76	0.22	NM	10.40	19.58	88.41	4.69
NV16	0.78	0.19	0.37	-3.13	8.99	2.41	NM	18.70	16.12	550.11	1.27

Nakivale camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
NV1	0.03	0.05	0.00	42.58	0.44	0.00	0.83	0.83	0.81	-0.08	0.03
NV2	-0.03	0.02	-0.01	45.30	0.36	0.00	0.38	0.40	0.41	-0.07	0.00
NV3	0.48	0.13	-0.01	47.65	0.44	0.00	0.44	0.45	0.43	-0.07	0.12
NV4	0.03	0.34	-0.02	39.21	0.39	-0.01	0.62	0.61	0.60	-0.07	0.01
NV5	-0.02	0.16	-0.03	18.27	0.26	-0.01	0.73	0.71	0.72	-0.07	0.00
NV6	0.32	2.41	-0.02	16.18	0.23	-0.01	3.09	3.41	3.20	-0.07	0.00
NV7	5.58	0.24	0.03	56.13	1.29	0.00	0.25	0.27	0.26	-0.07	33.83
NV8	0.46	0.18	-0.04	49.78	0.54	0.03	0.40	0.42	0.41	-0.03	0.02
NV9	0.15	0.18	-0.03	29.98	0.37	0.00	0.24	0.28	0.26	-0.01	0.02
NV10	0.63	0.24	0.29	30.82	1.39	0.00	0.39	0.40	0.40	-0.07	0.18
NV11	0.42	0.21	0.24	30.87	1.96	0.00	1.23	1.24	1.24	-0.07	0.14
NV12	0.38	0.15	0.21	16.88	2.03	0.00	0.38	0.40	0.39	-0.08	0.48
NV13	0.41	0.11	10.93	13.58	1.82	0.00	0.54	0.56	0.53	-0.07	0.03
NV14	1.26	0.35	8.52	19.36	1.42	0.00	0.62	0.61	0.62	-0.08	0.03
NV15	0.07	0.17	2.03	64.47	1.17	0.01	0.55	0.59	0.57	-0.08	0.03
NV16	0.12	0.18	-0.02	86.01	1.01	0.00	0.37	0.39	0.37	-0.08	0.60

Nakivale camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
NV1	0.30	0.14	4.69	0.33	14.90
NV2	0.52	0.05	92.19	2.92	0.50
NV3	0.22	0.07	16.73	NM	NM
NV4	0.48	0.05	86.93	0.11	0.45
NV5	0.27	0.05	29.08	0.48	5.16
NV6	0.28	0.04	29.70	0.57	0.82
NV7	2.52	0.67	441.72	11.10	0.85
NV8	0.41	0.05	29.70	3.03	3.26
NV9	0.46	0.05	19.82	2.94	0.71
NV10	0.64	0.05	424.60	1.87	9.72
NV11	0.54	0.04	415.99	1.86	1.12
NV12	0.56	0.05	320.23	0.11	84.33
NV13	0.57	0.04	176.38	1.26	1.53
NV14	0.70	0.04	120.49	2.10	0.89
NV15	1.19	0.05	30.01	2.52	4.41
NV16	1.31	0.04	79.22	5.37	4.28

Kyaka II

Kyaka II camp	**Temperature (°C)**	**Conductivity (uS/cm)**	**pH**	**ORP (mV)**
K21	21.9	189.4	7.43	-118.5
K22	22.8	217	7.69	-169.2
K23	22.1	470	8.25	-144.6
K24	23.9	161.6	7.84	-147.6
K25	23.4	243.5	7.88	-137.6
K26	24.9	344	8.63	-136.6
K27	22.8	47.7	6.53	-149.3
K28	22.8	307	8.20	-56.2
K29	21.6	67.2	6.16	-130.1
K210	22.3	85.5	6.97	-168.8
K211	20.7	144	7.72	-150.6
K212	22.1	97.7	6.77	-157.3
K213	21.5	283.2	6.79	28.2

Kyaka II	7Li	9Be	23Na	24Mg	27Al	39K	44Ca	51V	52Cr	55Mn	56Fe
camp	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
K21	4.31	-0.77	11466.99	5008.12	93.25	5008.69	4836.85	0.12	1.07	117.31	9459.36
K22	2.72	-0.77	15301.55	3693.81	100.17	9808.59	4638.95	0.11	-0.22	276.61	11471.68
K23	1.12	-0.77	41390.11	7978.05	-80.09	9646.01	15789.45	1.11	-0.18	86.55	472.18
K24	-2.01	-0.77	16433.07	2746.63	-46.48	10841.85	2080.25	0.20	0.46	370.14	597.17
K25	0.91	-0.62	15393.89	6057.46	-64.97	19213.52	5244.87	0.16	0.56	1921.21	2903.92
K26	2.65	1.52	17165.15	5643.51	-74.99	7151.12	8066.80	0.08	0.28	469.29	22192.10
K27	2.64	-0.75	4837.85	560.99	140.51	3724.54	1199.61	0.59	0.11	27.15	659.99
K28	9.98	-0.56	18125.58	15063.57	-14.22	18937.56	3448.48	0.16	0.37	405.95	22547.93
K29	1.09	-0.75	5377.28	595.57	21.53	6930.76	2361.19	1.21	1.14	200.75	1017.02
K210	4.22	-0.76	10749.52	918.29	205.61	3572.93	1236.29	7.27	0.76	35.57	147.11
K211	1.15	1.58	10061.28	2863.47	89.99	10058.91	3006.30	1.11	0.36	79.35	491.11
K212	-0.45	-0.76	10574.01	905.96	130.19	7791.01	2089.83	0.82	0.67	92.57	-604.81
K213	10.01	5.82	15185.84	4847.86	127.77	4179.18	10242.97	2.37	8.34	395.98	504.14

Kyaka II camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
K21	0.11	7.35	0.18	62.39	2.99	0.29	NM	-5.72	0.54	56.58	1.22
K22	0.75	1.13	0.68	134.31	7.87	0.33	NM	-5.71	1.17	65.76	0.91
K23	0.31	1.80	2.05	0.97	7.07	0.24	NM	-1.38	1.29	235.25	4.93
K24	1.12	1.57	0.96	-4.85	0.90	0.33	NM	-3.11	10.86	25.48	0.63
K25	8.06	1.87	1.31	26.77	18.00	0.85	NM	1.20	3.66	73.03	1.16
K26	0.30	0.91	1.23	88.25	3.28	0.07	NM	-1.26	1.62	137.69	0.86
K27	0.26	2.28	1.50	6.79	1.73	0.17	NM	1.05	3.41	15.38	0.37
K28	0.54	4.39	4.36	201.80	6.60	0.12	NM	-4.13	4.95	41.97	1.74
K29	1.80	3.64	2.19	46.15	8.42	0.47	NM	-1.15	6.21	24.84	0.58
K210	0.26	2.91	0.88	-3.53	6.91	0.13	NM	3.88	2.69	18.87	0.69
K211	0.53	2.02	2.19	-1.09	5.40	0.21	NM	-0.16	7.18	48.71	0.80
K212	0.40	5.58	2.79	23.36	5.66	0.04	NM	1.05	3.45	32.07	0.40
K213	0.41	10.33	2.13	11623.35	5.24	0.41	NM	1.69	4.24	88.48	1.65

Kyaka II camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
K21	0.65	0.31	0.33	31.20	0.12	0.00	0.27	0.27	0.24	0.57	0.02
K22	0.42	0.86	0.38	78.68	0.14	0.01	0.35	0.37	0.33	0.48	0.04
K23	0.86	0.20	0.39	70.75	0.15	0.01	0.14	0.16	0.15	0.38	0.84
K24	0.72	0.43	0.34	8.51	-0.01	0.01	0.37	0.38	0.37	0.71	0.07
K25	0.20	0.15	0.26	182.57	0.02	0.02	0.31	0.30	0.30	0.26	0.47
K26	0.38	0.31	0.25	32.48	0.02	0.00	0.29	0.28	0.26	0.25	1.58
K27	0.47	0.24	0.16	15.79	-0.04	0.01	0.53	0.47	0.50	0.60	0.39
K28	0.87	0.23	0.13	63.05	0.01	0.02	0.88	0.91	0.90	0.18	10.09
K29	0.38	0.27	0.12	82.61	-0.05	0.04	0.53	0.50	0.52	0.49	0.25
K210	0.18	0.36	0.11	65.57	-0.05	0.10	0.86	0.76	0.86	0.66	0.40
K211	0.12	0.27	0.08	51.33	-0.08	0.01	0.70	0.72	0.73	0.48	0.13
K212	0.42	0.38	0.08	52.79	0.02	0.02	0.53	0.46	0.49	0.54	0.15
K213	0.26	0.32	0.09	48.56	-0.04	0.01	2.33	2.25	2.31	0.24	4.10

Kyaka II camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
K21	1.95	0.05	3.54	2.18	1.82
K22	1.77	0.06	6.28	1.86	7.13
K23	7.72	0.06	28.12	3.50	2.23
K24	1.82	0.06	9.19	2.14	1.77
K25	2.66	0.15	7.29	3.20	1.89
K26	1.76	0.17	6.19	3.46	1.93
K27	0.46	0.05	4.50	0.55	3.12
K28	1.93	0.05	9.34	2.62	32.91
K29	0.52	0.07	4.38	0.85	4.04
K210	1.43	0.07	5.28	0.93	3.10
K211	1.36	0.06	5.68	1.43	1.54
K212	0.52	0.07	4.97	0.55	8.51
K213	10.45	0.15	7.35	3.49	2.83

Kyangwali Camp

Kyangwali camp	Temperature (°C)	Conductivity (uS/cm)	pH	ORP (mV)
KG1	23.7	246	7.24	-132.2
KG2	23.7	187.2	7.83	-151.7
KG3	23.2	136.5	6.81	-146.6
KG4	23.6	408	7.74	-112.5
KG5	23.7	608	7.20	-114.9
KG6	21.4	163.6	6.66	-144.9
KG7	23.1	137.2	6.80	-168.0
KG8	23.5	408	8.10	-129.9
KG9	22.9	197	7.15	-130.6
KG10	23.0	167.5	6.60	-149.2
KG11	23.5	171.5	6.90	-148.3
KG12	23.9	385	8.60	-154.0
KG13	23.9	211.2	7.12	-136.9
KG14	24.0	323	7.90	-130.2
KG15	24.6	367	7.46	-140.2
KG16	24.2	444	7.35	-138.7
KG17	23.8	380	7.40	-137.0
KG18	-138.7	229.1	7.35	-138.7
KG19	23.4	308	7.70	-138.6

Kyangwali camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
KG1	-0.45	1.53	15814.76	8967.58	-72.38	2954.88	5791.53	0.53	-0.11	20.34	1521.61
KG2	-2.02	3.83	10352.11	5781.87	-72.47	6259.16	5026.85	1.39	0.85	10.27	711.00
KG3	4.31	-0.77	8839.24	4254.60	30.50	3011.41	3505.20	2.98	-41.28	10.90	833.55
KG4	7.43	-0.77	17932.17	15533.62	-63.44	3032.53	14257.45	0.10	0.08	406.37	1208.31
KG5	-0.46	-0.78	71975.64	13716.20	-36.66	2949.13	13819.67	2.42	0.30	415.27	784.54
KG6	2.70	1.54	9118.62	5103.14	-61.58	3660.07	4133.53	3.88	0.32	10.14	127.76
KG7	4.27	-0.77	9102.35	4324.53	-39.35	3131.57	3961.58	2.03	1.31	71.50	568.58
KG8	5.91	-0.78	16321.17	13922.17	-84.97	2842.06	16643.55	0.59	-0.16	238.34	144.74
KG9	-0.46	-0.78	10587.50	8355.94	-36.51	51885.91	8888.25	3.77	-0.09	131.92	381.22
KG10	4.36	-0.78	10350.46	6661.45	-92.81	40533.86	5026.47	2.12	-0.22	5.90	-0.46
KG11	4.23	-0.76	9419.10	6579.29	-63.94	4355.21	4477.92	0.84	-0.01	30.76	1448.44
KG12	4.31	-0.78	13568.83	17388.52	-70.72	4299.18	12569.80	0.25	0.13	144.47	1569.54
KG13	-2.02	-0.77	11496.35	7831.33	-47.88	7153.69	5821.05	3.11	0.30	10.79	175.74
KG14	-2.03	-0.77	18278.22	11644.52	-75.72	3157.74	8861.13	8.89	0.17	34.16	273.83
KG15	2.69	-0.76	29406.31	16312.75	-72.50	1582.90	7255.15	1.47	0.02	230.98	1001.08
KG16	1.12	-0.77	43646.83	17239.93	-48.72	2616.42	9644.31	5.43	-0.08	107.31	46.83
KG17	2.73	-0.78	34114.59	12752.27	9.26	4509.40	7749.76	1.49	-0.03	58.76	460.62
KG18	2.73	-0.78	19852.17	8136.99	-62.34	6023.05	6214.41	2.64	-0.07	10.16	689.09
KG19	4.29	-0.77	15422.63	10659.69	-82.87	2872.60	9018.04	3.21	-0.11	35.95	274.26

Kyangwali camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
KG1	6.21	1.05	3.15	90.18	8.94	0.07	NM	-1.07	0.16	152.10	0.26
KG2	0.16	2.16	13.73	354.64	13.80	0.04	NM	-2.80	0.29	171.20	0.53
KG3	0.24	4.96	13.19	1387.68	11.06	0.08	NM	-0.57	1.24	116.79	0.15
KG4	0.32	1.03	3.61	763.88	13.95	0.03	NM	-3.94	3.15	200.47	0.45
KG5	3.35	1.65	2.63	834.93	12.39	0.09	NM	4.72	4.46	411.15	2.37
KG6	0.09	2.70	5.92	17.22	16.32	-0.03	NM	0.97	0.46	140.29	0.83
KG7	0.81	4.05	2.59	28.86	10.39	-0.07	NM	0.56	0.97	103.01	0.28
KG8	0.07	2.01	0.60	51.39	5.22	0.05	NM	2.32	1.75	171.79	0.32
KG9	0.51	1.66	4.59	4509.27	13.34	0.13	NM	0.46	2.32	174.52	0.12
KG10	0.16	1.74	0.99	0.69	11.60	-0.05	NM	7.87	1.76	170.25	-0.04
KG11	0.16	34.65	11.20	28.37	10.00	0.05	NM	7.34	0.34	98.67	0.09
KG12	0.19	2.25	3.92	65.58	17.58	0.11	NM	4.89	2.04	204.61	0.21
KG13	0.15	2.93	17.29	1463.85	11.25	-0.02	NM	5.77	0.96	168.30	0.17
KG14	0.15	1.48	2.41	4581.56	5.82	0.11	NM	0.66	0.55	221.71	0.30
KG15	1.49	1.80	6.60	33.23	12.37	0.08	NM	1.47	1.47	194.78	0.43
KG16	0.56	1.71	4.05	443.55	13.61	-0.06	NM	6.47	1.48	252.50	0.31
KG17	0.22	2.42	11.44	169.94	7.74	-0.10	NM	1.29	0.77	186.30	0.71
KG18	0.09	2.16	6.56	408.99	12.47	-0.02	NM	-2.53	0.56	206.99	0.04
KG19	0.08	0.72	52.66	3075.21	9.82	0.03	NM	0.05	0.88	183.52	0.18

Kyangwali camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
KG1	0.04	0.24	0.02	85.62	-0.11	0.00	0.28	0.29	0.27	0.03	0.00
KG2	0.12	0.23	0.02	132.19	-0.11	0.00	1.12	1.18	1.15	0.03	0.00
KG3	0.21	0.30	0.02	103.04	-0.10	0.00	3.60	3.95	3.80	0.04	0.01
KG4	0.23	0.28	0.03	133.69	-0.10	0.00	0.39	0.40	0.40	0.01	0.10
KG5	0.12	0.21	0.01	115.27	-0.05	0.00	0.40	0.41	0.39	0.02	0.23
KG6	0.20	0.19	0.00	154.58	-0.09	0.00	1.12	1.17	1.13	0.01	0.00
KG7	0.12	0.22	-0.01	97.20	-0.11	0.00	0.54	0.58	0.55	0.01	0.00
KG8	0.05	0.17	0.00	48.61	-0.03	0.00	0.62	0.65	0.62	-0.02	0.18
KG9	-0.05	0.06	0.00	124.02	0.11	0.00	3.38	3.68	3.54	-0.02	0.01
KG10	-0.07	-0.01	0.00	106.66	-0.03	0.00	0.02	0.03	0.01	-0.03	-0.01
KG11	0.41	0.23	-0.02	92.73	-0.11	0.00	0.45	0.47	0.46	-0.03	0.00
KG12	0.37	0.17	0.03	161.32	-0.05	0.00	0.95	1.03	0.96	-0.02	0.10
KG13	0.80	0.29	-0.03	102.99	-0.09	0.00	0.70	0.71	0.73	-0.02	0.01
KG14	0.07	0.34	-0.04	52.74	-0.11	0.00	3.31	3.69	3.46	-0.02	0.05
KG15	0.10	0.24	-0.04	114.46	-0.11	0.00	0.31	0.33	0.31	-0.03	0.04
KG16	0.17	0.22	-0.04	127.55	0.00	0.00	1.05	1.15	1.09	-0.03	0.11
KG17	0.68	0.27	-0.04	71.99	-0.07	0.00	0.60	0.64	0.62	-0.02	0.10
KG18	0.26	0.25	-0.04	117.52	-0.12	0.00	1.32	1.40	1.35	-0.03	0.01
KG19	0.08	0.29	-0.03	92.99	-0.05	0.00	6.83	7.56	7.13	-0.04	0.02

Kyangwali camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
KG 1	0.58	0.06	1.77	2.35	41.71
KG 2	0.44	0.06	1.54	2.15	9.85
KG 3	0.44	0.06	1.60	1.83	6.04
KG 4	2.27	0.06	1.59	5.65	2.50
KG 5	1.42	0.07	4.67	6.89	2.03
KG 6	0.41	0.06	2.67	1.38	32.83
KG 7	0.50	0.06	1.15	2.08	5.68
KG 8	2.06	0.06	6.50	5.08	3.41
KG 9	0.55	0.06	2.27	3.10	3.44
KG 10	0.46	0.06	1.96	2.54	3.53
KG 11	0.46	0.06	1.29	2.40	2.91
KG 12	1.62	0.06	3.99	5.04	3.16
KG 13	0.37	0.06	1.62	3.08	2.89
KG 14	0.45	0.06	2.29	4.68	8.15
KG 15	1.25	0.06	3.31	4.50	27.12
KG 16	0.82	0.07	9.58	5.32	27.72
KG 17	0.41	0.06	3.44	3.59	27.55
KG 18	0.47	0.06	2.89	3.26	20.67
KG 19	0.69	0.06	7.95	4.14	7.81

Kiryandongo Camp

Kiryandongo camp	Temperature (°C)	Conductivity (uS/cm)	pH	ORP (mV)
KD1	25.1	677	8.30	-135.4
KD2	24.3	923	8.10	-133.9
KD3	24.4	661	8.50	-142.7
KD4	23.9	719	8.30	-139.7
KD5	24.3	777	8.30	-143.7
KD6	24.4	1660	8.00	-131.6
KD7	24.3	1000	7.75	-128.0
KD8	25.1	1300	8.30	-122.3
KD9	24.2	686	8.60	-147.6
KD10	24.2	591	8.10	-136.9
KD11	24.0	773	8.50	-152.9
KD12	24.7	699	8.10	-140.8
KD13	25.2	714	7.60	-137.5
KD14	24.5	669	8.30	-146.3
KD15	NM	NM	NM	NM
KD16	NM	NM	NM	NM
KD17	24.6	1160	8.30	-131.1
KD18	24.7	612	8.20	-140.1
KD19	24.5	805	8.10	-143.9

Kiryandongo camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
KD1	2.69	-0.77	12948.81	28381.37	-11.39	2983.84	18949.11	5.93	3.25	38.13	1452.92
KD2	2.72	-0.77	14619.21	58228.14	-34.18	2311.51	27524.73	17.85	0.79	54.32	1022.69
KD3	1.12	1.54	9936.00	39589.82	-125.15	857.88	16498.19	17.55	0.94	7.54	-75.45
KD4	13.80	1.55	8188.36	31060.78	-125.31	1455.36	28655.09	26.68	0.38	179.08	1522.64
KD5	12.24	-0.77	10321.33	33989.52	-136.11	1131.14	27109.48	7.65	2.84	30.75	850.30
KD6	10.59	1.55	42096.44	86499.97	-107.28	9312.54	50276.71	0.27	0.00	423.46	2413.67
KD7	6.00	-0.79	36892.68	44351.98	571.11	2278.76	25454.11	1.35	2.33	590.17	4762.29
KD8	5.88	-0.77	38660.97	46800.17	-121.89	1211.81	41596.85	0.12	0.13	435.15	2558.51
KD9	13.85	-0.78	14342.75	30649.79	-129.07	1173.98	28127.39	0.11	-0.06	529.52	949.77
KD10	4.24	-0.76	21870.75	26693.31	-57.03	1535.96	16730.60	0.29	0.27	134.65	1407.22
KD11	9.23	-0.79	32303.83	39095.91	-143.55	448.76	27148.09	0.23	2.51	88.70	34.05
KD12	10.70	-0.78	20526.36	27983.25	-113.72	1416.54	19704.52	0.35	0.02	13.29	1034.29
KD13	9.08	-0.78	27998.89	34029.78	-74.74	1365.10	15821.34	0.18	0.97	149.72	5294.12
KD16	2.73	-0.78	21088.57	19808.54	-109.67	1019.87	26049.83	0.15	-0.16	518.11	1637.74
KD17	10.67	-0.78	22773.99	58057.54	-116.99	1429.61	38032.79	7.10	-0.06	10.51	614.57
KD18	12.19	-0.77	13560.14	28433.70	-133.14	576.46	21533.23	0.23	0.33	278.47	1114.43
KD19	12.34	-0.78	21702.91	36560.30	-113.77	1526.26	29084.59	0.77	0.91	77.59	439.92

Kiryandongo camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
KD1	0.52	25.39	6.57	1683.00	7.88	0.07	NM	0.15	0.81	287.32	0.36
KD2	1.26	9.38	5.07	596.17	7.27	1.71	NM	8.70	1.25	336.81	0.20
KD3	0.04	0.94	0.79	118.62	0.69	3.90	NM	4.23	0.32	181.51	0.10
KD4	0.45	2.59	43.33	35.76	0.14	2.65	NM	6.22	0.92	185.45	0.05
KD5	0.10	3.73	1.69	2273.30	0.02	0.31	NM	3.55	0.60	116.14	0.33
KD6	1.99	3.61	2.02	2191.76	2.31	0.75	NM	11.31	4.81	594.58	0.93
KD7	3.77	11.98	4.93	1500.71	1.37	13.38	NM	13.15	2.01	438.78	1.28
KD8	0.60	3.80	1.67	1744.67	5.31	0.20	NM	15.86	1.39	1159.11	1.71
KD9	2.42	7.31	0.52	927.29	1.50	1.35	NM	3.87	0.66	314.07	2.90
KD10	0.68	5.97	5.63	1094.69	0.84	0.22	NM	0.96	0.92	234.66	0.93
KD11	1.45	26.68	1.67	82.02	2.20	1.03	NM	14.94	1.04	450.70	5.48
KD12	0.09	2.16	3.06	1019.94	0.28	0.39	NM	12.15	0.81	349.89	2.02
KD13	0.23	2.43	2.55	1365.65	1.41	0.07	NM	9.43	0.50	213.81	0.43
KD16	0.11	0.40	0.76	1423.23	12.37	1.35	NM	0.26	0.87	590.42	0.86
KD17	0.05	2.44	0.69	1469.98	0.04	0.33	NM	3.55	4.85	458.68	0.45
KD18	1.47	5.59	103.85	512.03	0.47	0.11	NM	8.66	0.30	276.07	0.81
KD19	1.61	7.86	2.06	564.33	3.95	0.46	NM	11.15	2.85	458.09	3.07

Kiryandongo camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
KD1	0.24	0.82	-0.05	74.93	0.58	0.00	1.13	1.15	1.12	-0.06	1.46
KD2	0.11	0.21	-0.05	70.47	0.48	0.00	1.28	1.30	1.30	-0.08	1.89
KD3	0.01	0.26	-0.05	6.44	0.31	-0.01	0.35	0.37	0.38	-0.08	0.37
KD4	0.12	0.27	-0.01	1.36	0.21	-0.01	1.06	1.06	1.06	-0.08	0.30
KD5	0.04	0.55	-0.01	0.41	0.42	-0.01	0.38	0.44	0.40	-0.08	0.05
KD6	1.84	0.52	0.25	22.90	0.60	0.01	3.30	3.03	3.31	0.02	2.28
KD7	0.46	0.24	0.11	11.60	0.54	0.02	0.90	0.95	0.89	0.06	1.10
KD8	0.10	0.36	0.25	53.24	0.72	0.00	0.36	0.40	0.37	-0.07	0.58
KD9	0.03	0.22	0.07	15.06	0.19	0.00	1.83	1.95	1.86	-0.08	1.34
KD10	0.09	0.36	0.04	8.23	0.24	0.00	0.69	0.72	0.66	-0.05	0.48
KD11	-0.10	0.00	0.19	21.42	0.21	0.01	0.25	0.27	0.25	-0.09	1.77
KD12	-0.01	0.28	0.04	3.34	0.40	0.00	0.41	0.42	0.40	-0.08	0.61
KD13	0.07	0.35	-0.06	13.20	0.30	0.00	0.40	0.41	0.41	-0.04	0.14
KD16	0.11	0.33	0.10	121.40	0.21	-0.01	0.34	0.34	0.31	-0.07	0.05
KD17	-0.01	0.37	0.82	0.58	0.34	0.00	0.77	0.82	0.81	-0.06	0.87
KD18	-0.02	0.29	0.01	4.71	0.13	0.02	0.21	0.20	0.20	-0.08	0.40
KD19	0.00	0.25	0.33	38.61	0.21	0.03	0.81	0.87	0.81	-0.09	0.72

Kiryandongo camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
KD 1	0.18	0.05	22.99	8.13	36.78
KD 2	0.23	0.05	31.09	8.74	0.86
KD 3	0.14	0.05	16.77	7.54	4.39
KD 4	0.10	0.05	2.32	8.38	2.87
KD 5	0.11	0.05	31.19	6.88	6.81
KD 6	0.17	0.05	107.92	8.78	2.72
KD 7	0.18	0.04	75.07	6.57	0.87
KD 8	0.18	0.05	153.19	8.68	4.55
KD 9	0.25	0.05	2.10	8.30	1.07
KD 10	0.23	0.05	5.98	6.97	30.72
KD 11	0.21	0.05	12.66		
KD 12	0.33	0.05	78.38	6.63	51.64
KD 13	0.21	0.05	36.14	6.97	5.39
KD 14	0.19	0.05	20.23	8.30	7.47
KD 15	NM	NM	NM		NM
KD 16	NM	NM	NM		NM
KD 17	0.09	0.05	58.86		NM
KD 18	0.15	0.05	13.09	6.55	16.42
KD 19	0.18	0.05	13.49	9.86	12.06

Rhino Camp

Rhino Camp	Temperature (°C)	Conductivity (uS/cm)	pH	ORP (mV)
RH1	30.7	782	8.10	-138.6
RH2	29.1	740	8.20	-111.1
RH3	30.1	709	8.05	-130.9
RH4	31.0	738	7.90	-122.3
RH5	29.7	662	7.70	-121.2
RH6	30.1	596	7.50	-139.3
RH7	29.5	800	7.60	-115.3
RH8	30.2	721	7.90	-108.7

Rhino camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
RH1	-2.03	-0.77	33118.30	8669.48	-100.84	5637.16	32518.44	3.10	-0.17	9.69	342.47
RH2	-0.46	-0.78	49527.59	13828.06	-136.97	6650.87	21819.57	15.52	1.17	28.37	4727.41
RH3	-0.45	3.84	30989.14	8260.51	-106.13	7295.74	27537.67	4.76	28.21	10.22	311.56
RH4	1.13	-0.77	32387.07	9567.44	-124.94	7996.98	29421.36	4.03	1.53	16.19	1835.53
RH5	-2.04	-0.77	25407.05	10771.55	-87.11	5957.57	27098.06	5.42	0.11	28.65	4057.87
RH6	-3.64	-0.78	54670.69	7548.95	-112.66	4670.71	9163.03	0.30	0.47	197.55	13238.89
RH7	-3.57	1.53	38276.30	21574.89	-110.92	7599.78	25624.90	0.98	0.04	21.24	641.87
RH8	2.82	-0.80	60015.22	14109.89	-113.24	5738.40	18496.30	0.27	0.09	76.86	2021.85
Rhino camp	**59Co µg/L**	**60Ni µg/L**	**65Cu µg/L**	**66Zn µg/L**	**69Ga µg/L**	**75As µg/L**	**78Se µg/L**	**82Se µg/L**	**85Rb µg/L**	**88Sr µg/L**	**95Mo µg/L**
RH1	0.12	1.06	3.53	205.40	102.61	0.08	NM	0.87	3.14	1363.47	0.37
RH2	0.04	0.95	0.92	0.10	42.66	0.12	NM	-0.78	6.95	465.91	4.64
RH3	0.11	4.88	3.73	121.11	89.83	0.22	NM	1.89	6.25	348.90	4.41
RH4	0.10	3.62	1.07	756.95	82.31	0.47	NM	2.10	7.14	381.26	0.59
RH5	0.21	1.39	2.80	1133.10	141.26	0.24	NM	-0.26	5.84	486.31	0.37
RH6	0.70	3.87	2.07	343.04	35.66	0.17	NM	3.77	6.60	228.50	1.54
RH7	0.17	0.91	3.52	213.80	153.53	0.10	NM	4.10	3.70	999.64	0.49
RH8	0.12	0.71	2.23	354.32	61.41	0.33	NM	1.76	2.78	784.60	0.36

Rhino camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
RH1	-0.02	0.28	-0.06	1014.56	0.09	0.00	0.22	0.24	0.24	-0.08	4.07
RH2	0.07	0.17	-0.05	420.80	0.10	-0.01	0.12	0.13	0.12	-0.08	4.05
RH3	0.01	0.24	-0.05	876.30	0.01	0.00	0.51	0.55	0.55	-0.08	2.58
RH4	0.01	0.20	-0.05	802.62	0.08	0.00	0.83	0.89	0.86	-0.08	3.06
RH5	0.03	0.26	-0.05	1387.30	0.05	0.00	0.74	0.80	0.74	-0.08	2.15
RH6	0.10	0.26	-0.03	347.23	0.11	0.01	0.26	0.27	0.27	-0.06	0.43
RH7	0.02	0.29	-0.05	1481.60	0.08	0.00	0.44	0.48	0.45	-0.08	1.44
RH8	0.08	0.20	-0.06	592.78	0.03	0.00	5.07	5.30	5.16	-0.08	0.38

Rhino camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
RH 1	0.15	0.06	2.62	8.73	29.86
RH 2	0.22	0.15	2.50	8.22	0.86
RH 3	0.16	0.06	25.39	8.66	0.60
RH 4	0.20	0.16	1.47	8.65	1.57
RH 5	0.14	0.14	2.82	7.90	1.43
RH 6	0.31	0.06	5.48	6.46	8.96
RH 7	0.10	0.06	30.57	9.45	2.09
RH 8	0.13	0.06	2.66	8.47	0.76

Imvepi Camp

Imvepi camp	Temperature (°C)	Conductivity (uS/cm)	pH	ORP (mV)
IV1	28.6	680	8.05	-120.9
IV2	29.6	654	7.90	-117.5
IV3	28.5	612	8.10	-121.2
IV4	28.5	736	8.60	-119.9
IV5	29.8	409	7.90	-134.2
IV6	30.8	720	7.90	-117.7
IV7	31.0	1138	7.80	-110.8
IV8	28.2	639	8.10	-130.5

Imvepi camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
IV1	1.12	-0.77	32613.71	24904.44	33.57	7366.07	20588.82	3.97	0.74	133.05	1003.51
IV2	10.70	-0.78	34063.08	20378.31	-67.51	7139.93	18820.74	1.55	0.13	9.65	278.51
IV3	-2.04	-0.78	61935.77	12577.86	-58.04	3457.39	11941.35	8.17	0.14	9.38	336.14
IV4	2.72	-0.77	77483.22	14317.18	-51.14	3963.52	15381.52	4.32	0.22	31.25	1047.49
IV5	1.12	1.53	22392.98	11705.55	-20.79	5541.48	10248.24	1.14	0.20	22.54	353.84
IV6	15.75	1.59	41355.65	26270.23	-84.25	10154.91	20333.00	0.39	0.99	137.62	91.56
IV7	12.24	1.55	94411.45	40523.73	-3.13	21396.75	36899.85	0.85	0.59	304.28	9226.03
IV8	12.13	-0.77	30316.31	27198.87	-35.86	10001.24	14821.04	11.30	0.40	4.38	112.42

Imvepi camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
IV1	1.06	4.51	9.13	23.44	47.96	0.12	NM	0.05	1.76	616.54	0.60
IV2	0.05	1.71	5.07	-2.27	30.46	0.04	NM	1.19	3.23	516.48	1.19
IV3	0.09	1.87	0.98	191.05	36.53	0.13	NM	-3.57	6.17	398.02	1.27
IV4	0.27	6.77	1.32	53.66	58.03	0.63	NM	2.31	6.55	433.99	1.25
IV5	0.18	2.83	4.49	107.61	31.94	0.08	NM	1.67	1.99	328.07	8.82
IV6	0.51	10.26	0.64	118.73	21.74	0.05	NM	3.21	7.49	454.39	2.67
IV7	0.81	3.20	3.69	1905.02	40.60	0.07	NM	7.56	2.62	731.65	4.12
IV8	0.06	1.23	5.85	202.77	48.31	0.05	NM	5.86	0.58	511.31	0.94

Imvepi camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
IV1	0.73	0.26	-0.04	454.22	-0.06	0.00	0.74	0.80	0.80	-0.01	0.35
IV2	0.17	0.15	-0.04	284.55	-0.09	0.00	0.31	0.31	0.34	-0.04	0.67
IV3	0.10	0.22	-0.04	339.57	-0.12	0.02	0.32	0.36	0.33	-0.04	3.58
IV4	0.12	0.20	-0.02	533.31	-0.08	0.01	0.29	0.34	0.33	-0.04	7.18
IV5	0.15	0.22	-0.04	293.56	-0.07	0.00	0.50	0.55	0.54	-0.05	0.43
IV6	-0.04	0.01	0.02	203.11	-0.11	0.02	0.10	0.08	0.08	-0.06	0.28
IV7	0.78	0.21	-0.02	375.03	0.06	0.00	0.45	0.47	0.47	-0.02	12.75
IV8	0.15	0.26	-0.04	444.76	-0.06	0.00	0.34	0.37	0.36	-0.02	1.46

Imvepi camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
IV 1	0.34	0.01	1.83	7.14	68.85
IV 2	0.38	0.01	2.67	6.96	42.45
IV 3	0.62	0.01	-0.26	7.32	35.14
IV 4	0.66	0.10	0.18	8.98	0.57
IV 5	0.43	0.01	4.62	4.42	46.07
IV 6	0.43	0.01	22.49	0.00	NM
IV 7	0.69	0.01	21.73	11.64	25.53
IV 8	0.43	0.01	5.21	7.90	0.97

B.2 Kenya

Kakuma

Kakuma camp	Temperature (°C)	Conductivity (uS/cm)	pH	ORP (mV)
KK1	30.1	632	8.5	-256
KK2	30.8	633	8.3	-75
KK3	29.5	517	8.0	-40
KK4	32.2	1019	7.1	-8
KK5	32.6	856	8.9	-111
KK6	29.9	683	8.5	-85
KK7	30.3	1973	7.7	-40
KK8	31.8	745	9.5*	-141
KK9	30.9	691	8.4	-80
KK10	30.2	565	8.2	-58.5
KK11	25.0	746	8.9	-103.5

Kakuma camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
KK1	5.91	-0.78	79789.59	6863.82	-56.90	2779.35	7730.60	17.30	2.59	2.80	43.31
KK2	16.91	-0.77	65808.11	13094.60	26.84	1261.31	10231.89	31.05	1.42	10.61	144.50
KK3	-2.00	1.53	56516.61	8645.85	-17.66	1433.87	10566.46	20.40	1.40	5.36	117.89
KK4	16.64	-0.76	134696.71	11761.08	-17.70	5635.17	10589.63	24.52	1.76	16.99	54.37
KK5	2.67	-0.76	131039.05	3208.93	-14.47	2882.72	4437.85	3.74	0.88	14.24	30.53
KK6	1.13	1.55	96463.82	9703.79	-1.03	1527.43	7525.99	56.05	4.31	5.64	96.40
KK7	16.84	-0.77	319878.84	29145.17	-48.84	2299.03	13573.98	23.07	0.67	104.60	57.33
KK8	2.65	-0.75	137970.88	526.11	32.03	1870.69	1300.87	1.41	1.35	12.09	93.86
KK9	4.27	-0.77	101569.07	10132.96	88.19	6037.10	8101.16	56.79	1.73	13.32	193.99
KK10	-0.45	-0.76	66351.29	10501.64	-3.90	1674.48	9696.33	28.16	1.02	4.97	85.81
KK11	4.26	1.54	142397.61	413.96	-40.90	1681.31	1178.99	1.20	1.01	3.21	44.95

Kakuma camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
KK1	0.06	4.81	3.23	51.98	0.27	0.78	NM	3.15	2.71	220.74	10.45
KK2	0.12	6.65	3.70	50.25	1.28	1.17	NM	6.19	2.53	293.74	5.99
KK3	0.20	22.99	6.21	31.11	0.98	0.15	NM	7.85	0.91	300.06	6.97
KK4	0.11	10.44	5.23	46.93	2.20	1.18	NM	5.99	4.71	292.54	4.76
KK5	0.08	1.18	1.24	9.27	0.32	0.31	NM	13.09	5.45	110.65	14.64
KK6	0.10	5.05	2.08	15.47	1.26	1.48	NM	8.34	0.65	243.60	7.11
KK7	0.21	5.49	2.25	1547.92	4.02	0.36	NM	9.73	2.02	849.17	2.98
KK8	0.14	4.26	2.76	71.35	0.44	0.25	NM	14.60	0.85	13.38	26.06
KK9	0.16	5.62	4.47	27.13	1.47	1.40	NM	9.76	1.16	246.03	7.14
KK10	0.06	0.76	67.88	42.92	1.70	0.44	NM	7.74	0.55	296.33	7.42
KK11	0.05	0.99	2.21	12.51	0.27	0.21	NM	10.65	0.89	12.90	25.17

Kakuma camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
KK1	0.06	0.06	-0.04	2.19	-0.06	0.00	0.54	0.56	0.56	-0.04	0.94
KK2	0.10	0.01	-0.05	11.72	-0.04	0.00	1.10	1.16	1.14	-0.04	1.71
KK3	0.01	2.09	-0.05	8.17	-0.06	-0.01	1.61	1.66	1.59	-0.05	0.60
KK4	0.63	0.11	-0.01	19.83	-0.01	0.00	0.45	0.47	0.48	-0.05	1.38
KK5	0.12	0.04	0.05	2.81	0.13	0.00	0.27	0.28	0.28	-0.04	0.91
KK6	0.14	0.06	-0.05	11.12	0.01	0.00	0.44	0.43	0.44	-0.05	1.53
KK7	-0.05	0.01	-0.04	36.59	0.16	0.00	2.17	2.30	2.22	-0.06	8.31
KK8	0.03	0.07	-0.03	3.96	0.06	0.00	1.20	1.23	1.19	-0.04	0.20
KK9	0.33	0.35	-0.04	13.11	0.05	0.00	0.70	0.71	0.70	-0.03	1.55
KK10	0.17	0.05	-0.05	15.47	0.00	0.00	0.55	0.55	0.56	-0.05	1.00
KK11	0.07	0.10	-0.04	2.75	0.05	0.00	0.45	0.45	0.46	-0.05	0.21

Kakuma camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
KK 1	2.95	0.02	7.49	6.11	27.01
KK 2	2.23	0.02	5.91	6.64	33.75
KK 3	1.81	0.02	4.65	2.02	209.86
KK 4	3.00	0.02	18.38	9.31	36.35
KK 5	4.46	0.02	43.07	5.30	95.96
KK 6	2.20	0.01	15.06	6.90	15.59
KK 7	1.75	0.10	68.60	14.77	11.49
KK 8	7.10	0.02	19.40	6.37	23.34
KK 9	2.23	0.02	15.65	6.96	15.77
KK 10	1.89	0.02	8.10	6.12	9.90
KK 11	7.31	0.02	20.00	6.35	20.49

Dadaab Camps

Dadaab camp	Temperature (°C)	Conductivity (uS/cm)
DD1	36.0	970
DD2	36.3	948
DD3	36.1	942
DD4	36.2	1344
DD5	36.0	1713
DD6	37.1	1609
DD7	37.5	1669
DD8	37.8	1383
DD9	35.9	1554
DD10	36.2	1645
DD11	37.1	1055
DD12	36.2	1148
DD13	36.7	1074
DD14	36.7	1094
DD15	36.4	1248
DD16	36.9	1208
DD17	36.4	1150
DD18	34.7	962
DD19	36.1	1161
DD20	36.4	1014
DD21	36.6	1011
DD22	36.8	990
DD23	37.1	970

Dadaab camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
DD1	24.54	-0.76	148399.78	26157.64	925.92	17365.66	19524.27	10.50	3.74	51.29	458.39
DD2	18.29	-0.76	141045.12	27317.36	2372.99	17219.81	20335.72	11.64	4.08	100.83	1696.63
DD3	1.11	-0.76	126471.80	30725.36	368.01	16157.20	19099.81	15.99	0.92	20.95	336.60
DD4	10.49	-0.76	326777.89	8878.87	383.25	9129.11	5206.51	34.08	2.00	21.65	178.42
DD5	19.72	-0.76	361865.97	20845.92	152.60	15000.62	11116.17	53.54	10.91	10.55	107.54
DD6	7.22	1.50	374587.01	13862.99	437.01	8955.74	8683.05	30.08	3.08	16.70	326.18
DD7	13.79	-0.77	372224.36	23908.54	106.41	11357.47	12173.21	42.52	8.16	6.40	149.46
DD8	9.04	-0.77	330183.57	8403.54	498.50	7539.68	6845.94	41.34	4.04	19.63	406.95
DD9	26.12	-0.76	379648.81	20185.12	3617.02	16895.65	12808.31	43.84	13.59	249.93	1883.91
DD10	13.83	-0.77	368902.22	25231.21	344.82	15215.29	11946.18	38.45	10.08	29.05	370.85
DD11	8.90	1.53	168992.91	32619.21	239.10	20730.23	17545.69	20.06	5.80	12.12	222.39
DD12	7.39	3.82	185074.12	36091.81	40.89	28683.31	19453.90	19.78	7.86	5.93	102.60
DD13	9.07	-0.78	182384.16	36103.86	129.98	20554.08	22326.25	17.83	5.21	6.54	91.40
DD14	7.47	1.55	171968.54	36203.71	66.06	19988.28	19545.44	18.66	27.37	6.38	118.19
DD15	5.79	1.53	182142.35	43288.14	98.08	22475.30	24292.63	17.78	9.33	6.68	133.79
DD16	7.56	-0.78	171239.26	39073.49	47.47	20983.13	25685.50	16.14	6.58	4.84	121.42
DD17	7.45	-0.77	180634.43	40355.10	288.23	21477.47	22430.65	16.29	8.31	11.89	172.06
DD18	1.11	-0.76	106973.51	33417.78	356.44	16988.01	27805.13	11.94	5.25	21.62	329.62
DD19	4.23	1.53	130910.01	39763.54	479.26	19793.79	35159.51	10.57	4.00	32.26	406.93
DD20	-3.63	1.55	145204.43	29672.64	86.05	18248.24	27578.01	8.15	1.54	10.09	152.56
DD21	7.30	-0.76	138255.44	29563.30	144.92	18964.42	26925.03	7.50	2.90	15.17	162.75
DD22	1.13	1.55	148243.30	27353.99	95.33	18769.27	25293.86	7.09	1.48	9.21	164.57
DD23	7.41	-0.77	139576.99	28173.85	216.03	17910.19	26131.63	9.96	3.22	15.14	227.04

Dadaab camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
DD1	0.49	3.28	9.56	954.46	23.09	0.23	NM	7.75	2.73	679.52	2.19
DD2	1.08	9.57	7.19	450.83	27.27	0.39	NM	6.43	4.93	704.68	2.21
DD3	0.28	12.19	2.68	17.38	24.26	0.18	NM	3.88	2.05	595.18	3.14
DD4	0.19	0.90	3.74	453.65	7.17	0.44	NM	14.94	1.34	402.20	8.00
DD5	0.10	1.78	1.19	216.60	11.65	0.72	NM	12.63	1.61	758.28	7.03
DD6	0.20	1.35	3.25	48.59	14.26	0.52	NM	13.85	1.78	761.72	10.45
DD7	0.10	2.19	1.14	51.99	20.73	0.34	NM	18.23	1.28	1364.28	7.58
DD8	0.23	1.13	1.53	17.85	10.64	0.45	NM	10.22	1.33	456.47	8.46
DD9	1.93	5.83	5.53	610.26	23.70	0.26	NM	14.04	4.01	1229.16	6.01
DD10	0.31	1.00	1.57	36.36	19.57	0.23	NM	18.07	1.64	1289.59	5.94
DD11	0.14	1.83	1.49	94.37	23.30	0.36	NM	7.32	2.18	593.75	2.73
DD12	0.07	0.76	0.79	0.63	27.62	0.54	NM	11.14	2.79	732.84	2.75
DD13	0.06	0.42	1.45	29.95	22.59	0.32	NM	4.89	2.05	703.58	2.66
DD14	0.08	3.04	1.12	-2.10	20.72	0.44	NM	3.13	1.85	615.85	4.66
DD15	0.10	3.12	0.94	8.33	21.69	0.67	NM	8.75	2.21	717.15	1.92
DD16	0.10	2.21	0.78	16.33	15.47	0.35	NM	7.23	2.26	731.26	1.69
DD17	0.14	0.70	1.74	115.66	22.43	0.28	NM	14.39	2.36	712.96	2.54
DD18	0.24	4.41	1.48	13.56	1.57	0.30	NM	2.88	2.84	504.71	1.30
DD19	0.29	1.96	1.98	8.67	10.49	0.20	NM	9.25	3.24	630.59	1.00
DD20	0.11	0.66	0.83	81.73	19.01	0.38	NM	12.40	2.26	686.95	1.57
DD21	0.13	0.65	2.19	26.57	20.92	0.18	NM	7.98	2.54	760.80	1.40
DD22	0.08	0.52	0.66	4.80	26.81	0.04	NM	9.89	2.10	885.68	3.67
DD23	0.15	0.67	1.28	59.47	12.69	0.29	NM	10.03	2.62	610.41	1.47

Dadaab camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
DD1	0.18	0.12	-0.03	216.85	0.08	0.00	1.82	1.87	1.84	0.12	1.67
DD2	0.12	0.07	0.00	247.14	0.05	0.01	1.47	1.54	1.47	0.57	1.65
DD3	0.12	0.04	-0.04	222.25	0.06	0.01	0.56	0.52	0.52	0.06	2.36
DD4	0.03	0.06	-0.04	63.39	0.15	0.00	0.67	0.69	0.68	-0.01	2.81
DD5	0.01	0.05	-0.04	101.67	0.23	0.00	0.36	0.36	0.38	-0.05	3.81
DD6	0.05	0.05	-0.03	125.22	0.24	0.00	0.91	0.92	0.91	0.03	2.46
DD7	0.02	0.04	-0.04	183.92	0.35	0.00	0.41	0.39	0.36	-0.03	3.83
DD8	0.10	0.04	-0.03	95.27	0.27	0.00	0.71	0.71	0.73	0.05	2.93
DD9	0.04	0.08	0.00	206.75	0.29	0.01	2.32	2.44	2.35	0.22	4.55
DD10	0.09	0.05	-0.03	174.49	0.25	0.00	0.57	0.55	0.57	0.04	4.29
DD11	0.03	0.06	-0.04	212.66	0.11	0.00	0.86	0.87	0.86	0.04	2.48
DD12	2.66	0.04	-0.04	254.27	0.18	0.00	0.24	0.25	0.26	-0.03	2.48
DD13	0.12	0.03	-0.05	211.15	0.04	0.00	0.27	0.27	0.27	-0.03	2.49
DD14	0.04	0.01	-0.04	195.14	0.03	0.00	0.27	0.30	0.28	-0.03	2.40
DD15	0.07	0.05	-0.04	200.72	0.14	0.00	0.27	0.27	0.26	-0.01	2.50
DD16	0.04	0.02	-0.04	143.29	0.16	-0.01	0.27	0.30	0.28	-0.04	2.28
DD17	0.11	0.02	-0.04	206.28	0.17	0.00	2.88	3.14	2.99	0.00	3.56
DD18	0.07	0.05	-0.04	13.75	0.26	0.00	0.48	0.49	0.48	0.06	1.85
DD19	0.13	0.06	-0.03	97.09	0.70	0.00	1.04	1.06	1.03	0.10	1.92
DD20	0.01	0.02	-0.05	175.73	0.20	0.00	0.39	0.38	0.37	-0.01	1.74
DD21	0.06	0.05	-0.04	192.99	0.07	0.00	0.59	0.60	0.59	-0.01	1.86
DD22	-0.02	0.03	-0.05	247.86	0.04	0.00	0.29	0.30	0.29	-0.02	2.24
DD23	0.01	0.02	-0.05	118.35	0.05	0.00	0.54	0.53	0.54	0.01	1.88

Dadaab camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
DD 1	0.47	0.04	26.57	8.66	27.77
DD 2	0.44	0.04	27.13	7.81	5.13
DD 3	0.51	0.12	22.00	10.00	60.02
DD 4	0.94	0.13	46.03	7.61	1.59
DD 5	1.08	0.04	122.16	9.34	35.21
DD 6	1.17	0.13	93.24	9.11	10.91
DD 7	1.02	0.13	109.09	8.67	15.52
DD 8	1.14	0.12	52.36	9.34	3.13
DD 9	0.99	0.04	86.85	9.23	15.03
DD 10	0.97	0.04	105.60	9.08	23.58
DD 11	0.65	0.04	20.74	8.55	2.51
DD 12	0.61	0.04	49.50	8.19	11.98
DD 13	0.54	0.04	26.28	8.12	13.20
DD 14	0.61	0.04	28.20	8.68	3.86
DD 15	0.51	0.04	60.85	8.10	16.87
DD 16	0.53	0.04	61.72	5.21	225.03
DD 17	0.55	0.04	43.06	8.32	13.98
DD 18	0.49	0.04	18.40	8.04	2.77
DD 19	0.42	0.04	56.76	8.34	15.85
DD 20	0.42	0.04	29.42	8.04	3.80
DD 21	0.39	0.04	24.86	8.40	2.95
DD 22	0.34	0.04	22.83	8.56	2.19
DD 23	0.42	0.04	22.98	8.15	2.32

B.3 Bangladesh

Nayapara Camp

Nayapara camp	Temperature	Conductivity	DO	pH	ORP
	(°C)	(uS/cm)	(%)		(mV)
NP1	NM	NM	NM	NM	NM
NP2	NM	NM	NM	NM	NM
NP3	NM	NM	NM	NM	NM
NP4	27.45	104	81.9	7.48	203.9
NP5	26.95	89	68.0	7.32	364.8
NP6	26.60	113	72.1	4.42	294.9
NP7	27.27	121	65.9	7.38	319.5
NP8	26.84	102	59.6	6.81	265.1
NP9	27.12	97	77.1	7.49	561.2
NP10	26.95	95	62.0	7.19	141.7
NP11	26.39	86	65.6	7.19	141.1
NP12	28.02	99	62.9	7.24	130.8
NP13	26.63	94	65.4	7.01	127.9

Nyapara camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
NP4	-2.00	0.00	6800.36	4302.77	44.74	3397.10	2773.69	0.72	2.64	2.61	50.5752445
NP5	-2.00	40.63	6478.20	4227.94	253.53	2425.02	3019.15	0.74	11.08	2.94	36.4613869
NP6	-2.02	20.47	6883.86	4806.28	147.65	2232.45	3307.07	0.38	0.48	16.51	43.9989695
NP7	-2.01	20.38	7635.30	5019.34	216.05	2818.43	9719.10	0.65	1.30	10.99	59.0660443
NP8	-2.01	0.00	6845.59	4162.89	178.56	2694.73	5319.93	0.28	2.92	25.95	2004.19398
NP9	-2.02	0.00	6038.23	4222.92	166.77	2352.46	5926.00	0.99	3.51	5.32	148.183164
NP10	-2.05	0.00	14867.28	6481.59	705.25	4079.76	44791.34	2.15	1.97	18.93	159.344612
NP11	-2.01	0.00	5388.51	3923.35	43.73	1223.22	3224.62	0.70	0.17	1.28	24.7622363
NP12	-2.01	0.00	6194.67	4172.31	40.52	2204.46	3322.80	0.33	0.36	38.05	38.2619552

Nyapara camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
NP4	-0.20	3.02	6.34	36.96	0.41	0.98	-0.35	2.04	2.44	29.51	0.36
NP5	-0.31	3.37	10.92	160.92	0.45	0.69	0.31	0.97	2.64	29.92	0.40
NP6	-0.23	1.37	9.91	161.23	0.55	0.96	0.65	1.84	3.06	72.14	0.44
NP7	-0.35	1.62	37.18	208.93	0.69	0.86	0.65	1.40	3.33	42.85	0.66
NP8	-0.02	2.59	14.24	68.30	0.58	0.67	0.53	2.91	3.09	34.26	0.81
NP9	-0.32	0.90	4.12	172.52	0.85	0.89	-0.25	-0.33	2.66	36.65	0.60
NP10	-0.30	2.15	38.56	731.83	1.60	1.17	-0.25	7.16	3.57	84.93	2.42
NP11	-0.40	0.70	2.81	29.21	0.37	0.50	-0.47	2.69	2.23	27.72	0.41
NP12	-0.25	0.76	2.47	24.04	0.29	0.74	-0.35	4.41	2.74	31.17	1.31

Nyapara camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
NP4	0.07	0.08	0.06	2.28	-0.26	0.03	1.78	1.86	1.80	0.14	0.03
NP5	0.04	0.04	0.03	2.77	-0.25	0.01	1.04	1.14	1.07	0.10	0.02
NP6	0.03	0.07	0.02	3.18	-0.26	0.01	1.76	1.81	1.80	0.08	0.17
NP7	0.04	0.06	0.02	3.97	-0.22	0.00	2.90	2.83	2.89	0.07	0.03
NP8	0.06	0.09	0.02	4.18	-0.18	0.00	0.89	0.93	1.00	0.05	0.02
NP9	0.02	0.04	0.03	5.33	-0.16	0.01	1.29	1.25	1.30	0.06	0.02
NP10	0.07	0.06	0.00	11.82	0.17	0.01	1.03	1.05	0.95	0.03	0.07
NP11	0.03	0.05	0.00	2.93	-0.26	0.00	0.75	0.68	0.66	0.03	0.02
NP12	0.06	0.06	0.01	2.13	-0.26	0.00	0.85	0.82	0.77	0.04	0.02

Nayapara Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
NP4	0.15	0.01	4.13	1.18	1.71
NP5	0.20	0.02	4.38	1.16	6.66
NP6	0.15	0.01	6.04	0.99	1.19
NP7	0.13	0.02	8.11	0.03	97.71
NP8	0.09	0.01	2.88	0.85	1.73
NP9	0.19	0.01	5.36	1.15	1.55
NP10	0.15	0.04	3.48	1.18	1.80
NP11	0.15	0.02	4.19	1.16	43.43
NP12	0.15	0.01	4.24	1.30	2.50

Kutapalong Camp

Kutapalong camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
KP1	26.62	276	20.3	4.59	124.8
KP2	26.48	429	15.5	4.35	137.1
KP3	26.87	178	14.1	6.50	-39.7
KP4	27.16	329	17.1	4.56	183.5
KP5	26.75	308	34.4	4.62	195.9
KP6	27.22	376	43.0	4.23	235.0
KP7	26.88	72	15.3	5.30	156.9
KP8	26.80	124	31.4	4.48	242.3
KP9	28.48	401	51.2	3.92	285.4
KP10	27.81	45	17.0	5.47	99.5
KP11	27.25	37	21.0	5.37	143.1
KP12	26.85	304	16.8	7.47	118.0
KP13	26.37	69	18.3	5.64	100.8
KP14	26.36	101	31.8	6.25	21.3
KP15	26.18	123	17.9	6.10	23.9
KP16	26.15	105	18.2	6.13	32.9
KP17	27.25	257	16.6	7.33	-58.5

Kutapalong camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
KP18	28.78	306	27.3	7.73	115.0
KP19	26.47	217	18.6	5.80	28.1
KP20	26.57	156	19.2	6.04	0.7
KP21	26.27	187	17.7	6.05	18.0
KP22	26.46	160	20.5	5.68	55.3
KP23	26.39	161	26.7	6.51	-26.8
KP24	26.38	91	22.1	5.88	65.1
KP25	26.46	106	17.1	6.04	6.0
KP26	26.56	104	19.7	5.96	31.0
KP27	27.14	200	41.4	4.32	343.0
KP28	NM	NM	NM	NM	NM
KP29	26.87	220	45.5	4.33	295.0
KP30	26.54	111	17.3	6.02	32.5
KP31	27.18	307	32.1	4.05	276.9
KP32	27.60	257	33.0	7.16	-85.8
KP33	26.57	99	26.2	5.94	41.1
KP34	25.98	215	27.7	7.05	-83.3
KP35	26.45	180	52.2	5.88	37.9
KP36	26.50	236	37.1	6.98	-74.9
KP37	26.46	287	23.3	7.58	82.7
KP38	26.71	140	18.8	6.24	-25.9

Kutapalong camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
KP1	-2.02	0.00	23793.95	8153.62	567.15	7179.60	3414.95	1.82	5.33	472.75	423.87
KP2	38.39	20.48	46785.86	14936.59	680.83	7241.57	12559.49	0.83	1.35	768.80	242.16
KP3	18.13	0.00	26282.73	3661.46	65.18	3291.43	2072.14	0.11	6.40	386.20	6502.20
KP4	38.34	0.00	38440.27	11371.13	529.44	11156.91	3123.08	0.29	60.06	724.59	343.79
KP5	38.13	0.00	28839.60	8701.19	431.04	8225.68	2898.65	0.17	1.56	716.30	236.13
KP6	18.07	0.00	45611.31	6268.45	1166.04	7303.45	2059.02	0.20	1.18	559.60	384.27
KP7	-2.02	0.00	6864.37	2300.08	61.05	2922.53	2545.09	0.71	0.57	158.91	1281.71
KP8	-2.01	20.33	15091.91	1611.62	332.17	3925.83	1258.68	0.20	0.81	120.46	534.89
KP9	18.25	0.00	38544.76	8113.18	3357.14	6375.52	2255.29	0.14	0.46	292.29	134.21
KP10	-2.01	0.00	3322.39	916.26	38.47	2231.92	886.39	0.11	0.53	211.29	2511.47
KP11	-2.03	0.00	2760.76	1093.80	28.18	1712.19	939.06	0.22	-0.10	60.03	1609.22
KP12	-2.02	0.00	71957.37	1959.78	49.23	4360.53	2799.22	0.66	17.61	53.29	3253.57
KP13	-2.04	0.00	477.91	201.17	40.21	284.32	138.47	0.06	0.70	164.99	177.75
KP14	18.34	0.00	14115.11	1916.47	13.14	3024.26	1439.12	0.05	0.35	467.90	4042.29
KP15	-2.07	0.00	13419.50	3533.71	18.80	3224.76	2412.05	0.17	1.14	554.06	3945.77
KP16	18.14	0.00	12648.54	3153.50	28.99	2180.79	1255.28	0.25	0.08	448.88	2290.77
KP17	18.19	40.96	58253.56	6052.86	268.42	5132.05	9743.73	0.49	0.66	52.60	451.34

Kutapalong camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
KP18	18.13	0.00	69179.89	2298.80	53.46	3187.57	1710.83	0.38	0.69	27.46	135.37
KP19	18.21	20.50	7298.49	8351.06	219.52	3568.15	3130.32	0.07	1.04	1001.66	7786.95
KP20	18.13	0.00	6397.46	2561.41	20.45	2399.08	1989.58	0.15	0.23	1380.71	16651.54
KP21	18.09	0.00	7262.11	3498.18	59.74	2157.09	1627.31	0.15	0.14	1627.58	18147.18
KP22	18.14	0.00	12693.88	3223.39	486.21	4179.95	2152.01	0.22	0.34	519.09	9036.11
KP23	18.33	41.28	20640.73	4374.27	41.14	2536.63	2178.70	0.07	0.71	518.21	4305.60
KP24	18.21	0.00	5510.02	1468.59	16.27	2610.48	1278.70	0.11	0.61	313.55	7243.99
KP25	-2.02	0.00	4305.19	1906.03	10.88	2377.68	1080.51	0.08	-0.21	908.67	19258.14
KP26	58.65	0.00	8649.48	2899.04	588.06	4212.54	8756.87	0.39	0.57	412.76	8412.10
KP27	-2.02	0.00	24291.14	2304.17	1383.23	4425.35	1729.30	0.05	0.70	112.37	2030.89
KP29	18.12	0.00	27373.48	2155.07	1467.91	2746.76	752.11	0.22	0.47	200.70	446.23
KP30	-2.03	0.00	5302.76	2436.65	36.73	1891.56	1848.41	0.15	0.27	539.55	10110.27
KP31	-2.01	0.00	27993.90	3148.82	2836.45	6407.78	1285.99	0.08	1.21	308.19	195.94
KP32	-2.03	0.00	47413.23	4274.99	73.12	5135.23	1821.38	0.16	0.25	87.56	844.78
KP33	-2.06	0.00	6027.98	2058.23	173.33	1536.16	1439.93	0.22	0.71	320.86	7126.52
KP34	58.80	0.00	34238.53	6051.47	24.90	3095.67	1847.54	0.13	0.88	241.81	1693.74
KP35	18.26	20.56	18198.36	2506.83	149.33	3009.82	5845.12	0.38	0.73	506.95	8636.89
KP36	-2.03	0.00	36951.10	5726.59	75.35	5005.28	2003.59	0.27	0.42	100.33	1044.30
KP37	-2.08	0.00	55744.83	2521.62	15.63	6403.82	656.99	0.19	0.17	19.27	64.28
KP38	-2.04	41.40	14809.20	2027.35	26.14	1608.50	1059.53	0.14	0.23	562.77	8595.91

Kutapalong camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
KP1	19.53	29.89	5.65	178.52	59.73	0.65	-0.58	6.61	24.01	151.46	1.49
KP2	16.36	57.20	43.44	414.14	28.29	0.74	0.87	2.92	21.01	130.16	0.71
KP3	-0.24	1.01	0.61	26.96	1.12	0.62	-0.58	4.64	2.69	45.10	0.24
KP4	19.64	69.69	8.82	91.05	30.31	0.60	0.87	7.90	33.22	93.02	0.63
KP5	21.35	32.83	6.24	166.54	26.12	2.16	1.09	5.27	23.79	78.54	0.09
KP6	20.94	23.96	13.84	257.55	58.39	1.05	0.87	3.55	27.81	82.50	0.08
KP7	3.88	10.38	3.80	184.56	4.12	0.24	-0.13	-0.32	9.01	26.67	0.51
KP8	8.18	74.87	18.63	58.17	19.67	70.99	0.53	0.11	11.44	20.14	0.08
KP9	24.16	33.30	6.22	87.25	101.15	2.95	3.35	17.29	20.24	117.38	0.08
KP10	1.84	2.83	1.19	31.90	2.19	0.24	-0.25	1.83	6.73	11.19	0.17
KP11	2.45	4.34	1.35	24.54	3.14	0.39	-0.13	2.07	6.24	10.56	0.18
KP12	20.58	15.68	2.82	55.95	0.35	4.03	-0.47	-3.56	2.58	16.85	0.53
KP13	0.48	1.96	3.90	40.38	1.77	0.37	0.54	0.77	7.66	33.45	0.11
KP14	-0.10	1.38	0.76	72.14	0.78	0.32	-0.36	3.82	3.73	30.13	0.06
KP15	0.28	1.15	0.25	28.75	1.62	0.35	-0.37	-1.89	5.73	49.45	0.12
KP16	0.11	0.77	1.21	25.53	1.10	0.62	-0.02	-1.19	5.63	39.00	0.16
KP17	25.86	10.68	11.75	295.31	0.91	0.41	-0.69	-2.28	1.51	36.86	0.57

Kutapalong camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
KP18	-0.35	0.83	5.16	313.62	0.23	0.20	0.20	0.97	1.23	34.35	0.68
KP19	1.81	3.38	2.78	35.28	4.19	0.94	-0.47	0.11	8.90	124.19	0.35
KP20	0.67	1.91	2.74	15.50	1.23	0.24	-0.25	1.84	3.35	34.54	0.25
KP21	0.28	1.18	1.74	156.40	2.06	0.38	-0.58	0.97	2.87	102.23	0.13
KP22	3.64	9.02	1.60	487.81	6.93	0.50	-0.25	1.40	10.00	48.16	0.12
KP23	-0.03	1.06	2.00	73.63	0.90	0.44	0.77	-0.98	1.39	59.98	0.13
KP24	1.60	3.85	1.55	20.85	2.40	0.67	0.20	0.98	7.05	21.89	0.21
KP25	1.07	0.86	0.61	9.31	1.13	0.27	-0.02	3.35	4.08	22.23	0.02
KP26	2.24	4.07	2.33	589.93	2.66	1.99	-0.02	-2.93	5.08	51.30	0.69
KP27	4.77	6.05	3.34	39.31	23.40	0.77	1.32	11.40	13.26	31.90	0.07
KP29	7.02	6.74	17.68	40.32	23.22	0.69	1.54	8.74	9.99	33.99	0.13
KP30	0.85	2.48	2.18	24.00	1.88	0.58	0.43	0.98	3.84	38.90	0.08
KP31	10.83	12.64	6.79	128.45	56.04	2.45	4.54	12.62	23.58	57.49	0.20
KP32	-0.41	1.48	2.84	103.37	0.68	0.53	0.65	0.98	2.05	33.50	0.21
KP33	0.41	1.30	1.69	35.22	2.06	0.27	0.78	5.63	4.51	36.01	0.15
KP34	-0.42	0.42	1.07	40.62	0.46	0.20	0.09	0.33	1.32	47.36	0.24
KP35	0.51	3.04	30.20	129.83	2.70	0.77	-0.25	-3.37	7.44	53.47	0.52
KP36	-0.41	0.19	0.61	40.50	0.86	0.17	-0.58	3.81	1.81	44.54	0.02
KP37	-0.41	-0.10	0.42	19.03	0.55	0.00	-0.60	0.78	1.37	16.74	0.05
KP38	-0.36	0.19	6.35	32.16	1.03	0.13	0.43	-0.77	1.38	35.16	0.10

Kutapalong camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
KP1	0.09	0.17	0.15	473.93	-0.23	0.16	4.81	4.89	4.88	0.05	0.16
KP2	0.12	0.16	0.34	217.87	-0.16	0.12	6.09	5.88	6.06	0.01	0.28
KP3	0.03	0.02	0.00	9.33	-0.27	0.00	0.76	0.75	0.74	0.01	0.00
KP4	0.01	0.08	0.78	253.33	-0.24	0.23	7.70	7.75	7.81	0.00	0.31
KP5	-0.03	0.03	0.37	206.23	-0.23	0.17	7.94	7.90	8.07	0.00	0.22
KP6	0.10	0.15	0.71	473.63	-0.24	0.22	17.55	17.88	17.96	0.00	0.37
KP7	0.03	0.14	0.08	31.73	-0.23	0.05	1.28	1.35	1.31	-0.01	0.04
KP8	-0.05	0.01	0.16	156.47	-0.26	0.11	209.15	218.58	215.76	-0.02	0.13
KP9	-0.04	0.15	0.20	818.23	-0.19	0.18	38.95	38.53	39.71	-0.02	0.96
KP10	0.00	0.06	0.03	19.57	-0.24	0.04	0.71	0.72	0.70	-0.01	0.01
KP11	-0.01	0.08	0.30	27.63	-0.23	0.20	0.91	0.95	0.92	0.02	0.09
KP12	-0.04	0.07	0.01	3.65	-0.24	-0.01	4.86	5.13	5.11	0.12	0.03
KP13	-0.03	0.00	0.00	14.33	-0.25	0.03	1.06	1.01	0.99	-0.03	0.02
KP14	-0.03	0.06	0.00	5.60	-0.26	0.00	0.71	0.66	0.75	-0.03	0.00
KP15	-0.01	0.01	0.00	12.41	-0.27	0.01	0.46	0.47	0.47	-0.03	0.01
KP16	0.00	0.03	0.00	8.85	-0.26	0.01	1.37	1.31	1.40	-0.03	0.00
KP17	-0.05	0.05	0.01	6.80	-0.18	0.00	1.36	1.48	1.40	-0.01	0.05

Kutapalong camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
KP18	-0.03	0.07	-0.01	3.38	-0.20	0.00	2.80	2.98	2.94	0.02	0.09
KP19	-0.02	0.02	0.00	34.00	-0.26	0.03	3.16	3.56	3.45	-0.04	0.01
KP20	0.03	0.07	0.00	11.51	-0.26	0.00	0.90	0.86	0.85	-0.03	0.00
KP21	0.15	0.01	0.00	13.80	-0.25	0.02	1.38	1.35	1.39	-0.04	0.20
KP22	0.09	0.01	0.02	53.66	-0.26	0.02	0.94	1.00	0.94	-0.02	0.02
KP23	-0.01	0.10	0.00	6.70	-0.26	0.00	0.74	0.79	0.71	-0.03	0.00
KP24	0.00	0.01	0.02	17.52	-0.26	0.00	0.69	0.71	0.71	-0.03	0.01
KP25	0.34	0.01	0.00	8.46	-0.26	0.00	0.67	0.62	0.65	-0.03	0.00
KP26	0.00	0.03	0.01	18.04	-0.19	0.00	4.62	4.92	4.71	-0.03	0.00
KP27	-0.02	0.09	0.23	185.04	-0.25	0.14	6.53	6.43	6.54	-0.03	0.18
KP29	0.01	0.08	0.12	197.10	-0.26	0.10	13.67	13.87	13.96	-0.04	0.23
KP30	-0.02	0.02	0.00	14.47	-0.27	0.00	0.85	0.90	0.85	-0.05	0.00
KP31	0.12	0.24	0.29	443.00	-0.26	0.23	21.26	20.88	21.71	-0.04	0.56
KP32	0.22	0.12	0.02	5.87	-0.27	0.00	2.34	2.38	2.35	-0.02	0.00
KP33	0.00	0.02	0.01	13.32	-0.28	0.00	0.76	0.80	0.72	-0.02	0.01
KP34	-0.04	0.00	0.02	3.40	-0.26	0.00	0.74	0.70	0.67	-0.04	0.00
KP35	0.00	0.04	0.01	22.32	-0.21	0.00	1.57	1.49	1.56	-0.04	0.04
KP36	0.00	0.04	0.02	6.35	-0.25	0.00	0.72	0.69	0.71	-0.01	0.01
KP37	0.10	0.01	0.00	3.94	-0.27	0.00	0.45	0.48	0.46	-0.03	0.00
KP38	0.05	0.04	0.01	7.30	-0.26	0.00	1.27	1.25	1.24	-0.01	0.01

Kutapalong Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
KP1	0.16	0.02	49.72	0.12	70.65
KP2	0.12	0.01	98.82	0.14	91.34
KP3	0.14	0.03	3.26	0.45	104.35
KP4	0.11	0.01	90.27	0.09	128.49
KP5	0.10	0.02	67.64	0.13	56.25
KP6	0.13	0.01	54.02	0.11	197.87
KP7	0.03	0.02	4.91	0.09	106.50
KP8	0.04	0.06	9.78	0.14	47.31
KP9	0.10	0.04	67.78	0.09	110.27
KP10	0.04	0.02	2.28	0.22	56.66
KP11	0.02	0.01	1.83	0.20	1.02
KP12	0.10	0.02	4.61	4.46	0.66
KP13	0.05	0.03	7.61	0.00	36.37
KP14	0.05	0.02	2.10	1.37	0.69
KP15	0.08	0.02	4.07	1.46	2.30
KP16	0.07	0.02	2.46	1.66	0.99
KP17	0.06	0.03	4.11	3.67	5.50

Kutapalong Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
KP18	0.17	0.02	5.31	4.42	1.64
KP19	0.05	0.02	27.50	0.50	2.79
KP20	0.07	0.02	17.12	0.43	1.11
KP21	0.07	0.02	29.65	0.22	1.16
KP22	0.07	0.02	21.06	0.09	0.52
KP23	0.12	0.02	2.58	2.19	0.81
KP24	0.05	0.02	4.85	0.49	0.47
KP25	0.05	0.03	2.04	0.75	0.70
KP26	0.05	0.02	1.84	0.96	0.71
KP27	0.07	0.02	34.53	-0.01	52.39
KP29	0.04	0.04	37.03	-0.01	63.76
KP30	0.05	0.02	1.85	0.97	0.56
KP31	0.06	0.02	45.11	0.01	93.22
KP32	0.13	0.10	4.02	3.95	0.56
KP33	0.07	0.02	3.81	4.62	13.92
KP34	0.08	0.06	3.72	3.54	0.67
KP35	0.05	0.02	28.93	0.91	0.66
KP36	0.12	0.04	3.77	3.74	0.47
KP37	0.16	0.04	4.14	4.58	0.63
KP38	0.11	0.02	4.19	1.58	0.54

B.4 Djibouti

Ali Adde

Ali Adde Camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
AA1	30.90	2776	68.5	7.45	176.5
AA2	32.05	6660	41.2	6.95	-11.8
AA3	29.13	2695	53.0	7.04	130.0
AA4	NM	NM	NM	NM	NM
AA5	33.29	1405	99.0	7.72	141.5
AA6	30.32	2914	27.7	7.41	146.5
AA7	32.67	2283	66.0	7.57	129.0
AA8	30.70	2095	44.5	7.56	139.0
AA9	31.26	2046	51.0	7.43	151.0
AA10	27.00	2674	68.0	7.90	135.0
AA11	32.50	3100	64.9	7.37	142.0
AA12	31.40	2575	66.5	7.62	156.0
AA13	30.69	2167	55.0	7.60	137.0
AA14	32.76	3088	66.0	7.40	142.0
AA15	31.80	1642	66.0	7.61	145.0
AA16	32.00	1791	54.9	7.48	126.5
AA17	32.08	1612	60.5	7.61	127.0
AA18	31.08	1575	54.6	7.74	119.2
AA19	29.22	1700	70.0	8.18	115.5
AA20	29.73	2978	43.1	7.48	140.0
AA21	30.79	2622	56.6	7.48	137.0
AA22	28.31	4384	40.0	7.82	140.0
AA23	29.23	1664	54.0	7.57	128.5
AA24	27.86	1737	78.5	8.42	111.1
AA25	29.23	1590	75.0	7.98	115.9
AA26	31.95	3981	72.4	7.50	120.0
AA27	30.41	2792	80.3	7.70	470.0
AA28	29.39	2775	74.5	7.70	590.0

Ali Adde	7Li	9Be	23Na	24Mg	27Al	39K	44Ca	51V	52Cr	55Mn	56Fe
camp	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
AA1	18.28	0.00	288756.97	83297.25	96.87	1659.34	48431.39	62.45	0.41	3.46	56.90
AA2	79.44	0.00	594858.62	340069.49	546.78	759.30	117925.74	30.67	1.53	26.29	860.51
AA5	38.95	0.00	169483.81	28597.23	99.93	-402.11	19408.48	92.96	2.66	2.59	45.84
AA6	18.35	0.00	408614.43	60899.77	1419.12	11711.25	53050.78	13.82	1.38	10.66	127.96
AA7	18.14	0.00	310777.52	48425.40	143.04	4693.19	28947.78	24.70	1.77	3.96	53.71
AA8	-2.05	0.00	284054.06	43685.26	43.62	5953.50	32490.51	31.96	0.65	2.24	35.34
AA9	-2.02	0.00	282879.78	41031.41	64.29	5556.79	27728.23	31.83	0.92	1.77	29.04
AA10	18.38	0.00	371884.32	61167.28	344.61	7576.85	38242.75	18.27	3.47	5.42	114.84
AA11	18.28	0.00	411450.35	81323.74	52.85	4504.60	43789.83	36.92	1.07	1.20	74.25
AA12	38.41	0.00	324957.21	68631.09	630.86	6115.06	47472.39	45.31	1.66	6.48	81.67
AA13	-2.04	0.00	262457.16	54843.29	814.54	5376.47	37915.30	44.32	1.33	43.19	142.40
AA14	58.42	0.00	433382.18	80711.97	72.74	4524.35	35642.87	47.42	1.27	5.75	28.70
AA15	-2.01	0.00	213708.18	34132.67	19.34	3283.23	22116.73	50.14	2.44	0.99	28.55
AA16	-2.01	20.33	228918.51	40420.74	146.57	3556.04	25498.64	33.08	1.32	5.90	80.29
AA17	-2.02	0.00	197744.13	33433.23	46.11	2540.08	21974.13	45.25	4.33	2.13	72.58
AA18	18.10	0.00	205807.69	34327.99	31.05	2391.07	22253.13	50.35	7.02	2.43	40.87
AA19	18.30	0.00	242237.29	36268.75	234.58	4958.83	25123.69	40.49	6.76	3.74	65.00
AA20	18.09	0.00	394896.68	77930.27	312.75	2383.82	39035.44	71.02	2.20	7.07	117.22
AA21	-2.03	0.00	377719.93	70156.14	262.36	3009.32	36911.10	97.47	2.72	5.12	92.81
AA22	18.06	0.00	597903.03	129210.26	90.41	2545.75	58157.79	15.35	8.63	2.67	53.71
AA23	18.61	0.00	211709.75	29605.46	208.01	2077.52	29521.87	26.22	1.69	15.29	40.54
AA24	-2.01	0.00	231824.95	37522.73	53.46	3501.28	23278.46	54.54	2.06	1.67	20.86
AA25	-2.01	0.00	202035.29	34283.90	89.34	3071.89	22587.51	45.39	2.51	2.05	31.65
AA26	58.81	0.00	515149.46	124492.41	345.92	1720.26	51558.16	37.74	1.98	3.74	124.93
AA27	-2.02	0.00	302676.68	87333.23	205.67	1177.42	49715.78	76.24	1.34	6.04	117.64
AA28	18.31	0.00	304141.99	89146.95	36.78	575.51	50305.49	75.86	1.15	1.17	28.68

Ali Adde	59Co	60Ni	65Cu	66Zn	69Ga	75As	78Se	82Se	85Rb	88Sr	95Mo
camp	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
AA1	-0.36	0.48	1.67	218.39	0.37	0.46	8.42	83.10	1.77	3163.62	3.99
AA2	-0.12	4.10	3.89	1544.05	1.44	0.70	16.80	284.13	3.31	9786.92	10.20
AA5	-0.34	3.63	53.55	280.13	0.67	1.51	3.16	50.89	0.88	1259.29	5.54
AA6	-0.19	2.83	12.06	1787.51	7.07	0.39	3.48	110.54	3.23	2660.74	4.46
AA7	-0.32	0.79	2.44	125.13	4.17	1.24	5.45	79.45	1.91	1979.49	10.94
AA8	-0.36	0.87	4.18	46.60	9.67	1.85	6.57	65.91	1.54	2174.79	11.68
AA9	-0.33	1.52	2.51	70.42	5.07	1.36	8.03	60.54	1.51	1889.18	11.49
AA10	-0.31	0.75	2.73	357.50	6.55	0.99	8.35	99.95	2.89	2667.93	11.60
AA11	-0.40	0.59	1.24	88.13	5.39	1.01	10.44	112.75	1.09	3287.46	9.82
AA12	-0.27	1.61	10.77	678.73	10.91	1.22	6.36	103.08	1.34	2867.37	6.76
AA13	-0.12	3.47	37.12	917.33	10.48	1.30	4.60	85.09	1.55	2412.60	6.33
AA14	-0.34	1.63	2.91	131.94	6.91	0.93	7.46	114.11	2.04	3207.69	12.68
AA15	-0.39	0.35	1.35	13.49	4.44	0.98	5.43	57.02	0.77	1482.94	10.19
AA16	-0.31	1.14	1.62	39.46	6.41	0.48	4.64	62.06	0.78	1685.66	8.12
AA17	-0.37	1.65	52.70	81.31	4.42	1.29	6.02	55.53	0.76	1478.79	8.86
AA18	-0.31	1.27	2.89	120.89	4.78	1.26	3.10	53.80	1.13	1445.37	9.32
AA19	-0.34	2.42	6.28	205.34	4.83	1.25	5.38	63.12	2.59	1519.40	9.94
AA20	-0.28	2.06	4.05	374.06	2.86	0.84	8.89	109.20	1.65	2899.92	10.02
AA21	-0.34	1.53	5.89	249.20	1.87	1.52	6.39	109.93	0.98	2481.81	12.58
AA22	-0.28	1.14	19.85	70.14	8.74	1.02	7.98	175.95	2.76	5593.12	14.01
AA23	-0.35	1.67	2.29	306.12	6.01	0.96	3.99	56.89	1.01	1527.27	3.72
AA24	-0.38	0.77	3.51	44.78	5.73	0.98	5.00	56.48	1.21	1643.02	9.65
AA25	-0.39	0.65	1.78	147.72	4.48	1.07	5.98	60.36	0.99	1504.48	8.92
AA26	-0.37	1.13	55.11	414.05	5.80	0.58	10.10	156.67	1.38	4944.82	10.43
AA27	-0.20	1.01	2.66	182.39	0.50	0.29	8.38	109.92	2.18	3581.33	4.17
AA28	-0.40	0.68	6.82	221.34	0.31	0.44	11.47	103.29	1.83	3599.31	4.17

Ali Adde	107Ag	111Cd	133Cs	137Ba	202Hg	205Tl	206Pb	207Pb	208Pb	232Th	238U
camp	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
AA1	0.01	0.01	0.06	3.39	-0.17	0.11	0.50	0.51	0.52	-0.02	1.41
AA2	0.19	0.14	0.38	12.33	-0.09	0.17	1.35	1.32	1.37	0.07	2.12
AA5	0.00	0.05	0.02	4.95	-0.18	0.07	2.18	2.05	2.14	-0.03	0.36
AA6	-0.01	0.23	0.04	53.46	-0.02	0.11	1.47	1.58	1.52	-0.04	1.38
AA7	0.02	0.06	0.07	32.61	-0.17	0.09	0.81	0.85	0.79	-0.02	1.01
AA8	-0.02	0.02	0.04	78.03	-0.21	0.09	1.16	1.22	1.18	-0.04	1.22
AA9	-0.02	0.05	0.07	42.93	-0.20	0.09	1.02	1.02	1.01	-0.04	1.00
AA10	-0.03	0.05	0.08	52.34	-0.09	0.09	0.97	0.88	0.93	-0.03	1.52
AA11	-0.05	0.02	0.03	43.94	-0.21	0.11	0.41	0.49	0.47	-0.04	1.84
AA12	-0.01	0.03	0.02	86.96	-0.14	0.10	1.05	1.03	0.98	-0.03	1.44
AA13	-0.03	0.11	0.03	80.31	-0.06	0.07	1.55	1.56	1.63	-0.03	1.19
AA14	0.03	0.10	0.10	57.32	0.04	0.11	0.74	0.71	0.72	-0.03	2.19
AA15	-0.02	0.05	0.03	33.41	-0.23	0.07	0.54	0.56	0.58	-0.03	0.83
AA16	-0.01	0.05	0.04	49.20	-0.22	0.08	0.53	0.61	0.59	-0.02	0.99
AA17	-0.05	0.07	0.02	35.88	-0.22	0.08	3.84	3.99	3.88	-0.05	0.68
AA18	-0.01	0.07	0.03	36.73	-0.23	0.08	0.92	0.86	0.87	-0.05	0.74
AA19	0.11	0.08	0.05	39.25	-0.21	0.08	0.85	0.86	0.86	-0.04	0.78
AA20	0.00	0.13	0.09	21.37	-0.17	0.11	0.91	1.03	0.89	-0.03	1.20
AA21	-0.02	0.04	0.05	13.75	-0.18	0.11	3.28	3.35	3.31	-0.04	1.18
AA22	-0.03	0.06	0.05	74.05	-0.21	0.15	1.21	1.22	1.19	-0.03	1.81
AA23	0.00	0.03	0.07	48.57	-0.22	0.08	0.54	0.62	0.58	-0.04	0.58
AA24	11.19	0.05	0.03	45.43	-0.23	0.09	0.92	0.92	0.84	-0.04	0.85
AA25	0.04	0.04	0.02	34.10	-0.19	0.09	0.77	0.78	0.76	-0.04	0.69
AA26	0.03	0.06	0.06	45.81	-0.16	0.13	0.83	0.86	0.78	-0.05	1.68
AA27	0.07	0.03	0.10	4.41	-0.23	0.11	1.00	0.99	0.90	-0.02	1.52
AA28	0.03	0.04	0.10	2.78	-0.23	0.12	0.84	0.87	0.79	-0.05	1.52

Ali Adde Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
AA 1	0.85	0.02	682.38	5.58	96.83
AA 2	0.91	0.23	1925.39	5.48	46.49
AA 5	0.84	0.02	25.74	1.90	109.70
AA 6	0.65	0.02	757.93	4.50	3.69
AA 7	2.30	0.02	542.23	4.18	44.69
AA 8	1.40	0.02	448.97	3.98	59.63
AA 9	1.71	0.02	454.73	4.43	48.68
AA 10	1.33	0.02	673.79	4.05	56.96
AA 11	1.46	0.02	772.41	4.52	36.51
AA 12	0.94	0.02	652.04	4.43	40.55
AA 13	0.83	0.06	530.17	4.22	40.78
AA 14	1.72	0.02	765.00	4.70	46.81
AA 15	1.24	0.02	358.35	3.67	26.73
AA 16	0.91	0.02	398.31	4.42	26.43
AA 17	1.11	0.02	366.05	3.74	114.45
AA 18	1.17	0.02	350.58	4.56	27.59
AA 19	1.14	0.02	392.35	4.37	51.18
AA 20	1.38	0.02	770.75	5.38	30.18
AA 21	1.60	0.02	637.25	5.06	28.43
AA 22	1.39	0.02	1187.51	4.07	35.57
AA 23	0.85	0.02	371.04	4.01	18.98
AA 24	1.28	0.02	384.45	3.74	34.91
AA 25	1.25	0.02	357.01	3.56	24.13
AA 26	1.88	0.02	1100.65	4.40	64.57
AA 27	1.07	0.02	701.30	6.69	20.41
AA 28	1.23	0.02	717.30	5.77	24.69

Holhol Camp

Holhol camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
HH1	31.00	1657	63.3	7.58	257.9
HH2	28.15	1580	43.0	7.79	255.4
HH3	27.57	2912	67.0	8.34	239.5
HH4	28.95	2110	75.5	8.27	222.4
HH5	33.40	2017	88.0	7.63	232.2
HH6	31.70	2931	42.5	7.54	235.5
HH7	30.59	3263	63.5	7.79	223.5

Holhol camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
HH1	119.26	0.00	277609.79	22250.37	2858.00	20522.61	40679.47	19.03	2.92	25.03	238.63
HH2	-2.02	0.00	227402.99	18818.03	561.94	8500.03	25926.43	14.82	3.41	41.63	79.35
HH3	18.25	0.00	623974.29	21656.38	42.02	6057.16	6034.69	50.79	1.69	4.50	110.17
HH4	-2.03	0.00	366528.76	24979.10	110.81	5602.06	17540.28	25.41	1.12	3.48	63.96
HH5	-2.06	0.00	366068.33	18997.71	373.20	6024.82	17806.99	31.91	2.47	4.80	95.00
HH6	59.89	0.00	574539.94	24565.48	316.19	6399.67	14906.75	11.89	0.63	5.09	77.10
HH7	-2.02	0.00	619836.81	37775.31	123.13	6547.96	24683.69	19.79	0.48	2.46	48.38

Holhol camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
HH1	0.45	8.01	40.14	4006.11	4.73	3.92	3.90	55.20	6.41	1018.56	19.11
HH2	0.22	3.18	6.35	680.20	9.66	2.92	4.01	46.98	3.34	1230.78	13.46
HH3	-0.31	1.30	3.23	27.56	2.96	4.70	5.93	70.78	1.71	676.90	26.98
HH4	-0.32	1.04	5.13	72.09	6.67	1.85	4.36	57.82	2.03	1083.09	16.10
HH5	-0.32	1.57	4.35	317.66	6.20	2.26	5.33	58.78	2.50	929.71	14.66
HH6	-0.09	1.47	5.46	348.72	3.71	2.50	6.85	80.16	5.14	934.64	36.21
HH7	-0.33	0.52	2.43	120.76	5.11	2.18	9.72	105.03	4.38	1382.81	27.01

Holhol camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
HH1	0.56	0.64	0.54	32.04	0.17	0.68	2.36	2.59	2.54	2.94	1.48
HH2	0.56	0.56	0.52	76.33	-0.18	0.56	1.53	1.51	1.52	1.68	1.17
HH3	0.12	0.06	0.13	23.83	-0.24	0.15	0.76	0.83	0.79	0.87	1.97
HH4	0.11	0.07	0.14	54.55	-0.22	0.11	0.94	0.93	0.98	0.62	0.83
HH5	0.06	0.13	0.13	53.06	-0.19	0.11	0.82	0.91	0.88	0.50	1.12
HH6	0.08	0.15	0.17	27.17	-0.18	0.12	0.81	0.94	0.81	0.36	2.11
HH7	1.07	0.05	0.21	41.14	-0.21	0.13	1.03	1.12	1.07	0.27	2.14

Holhol Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
HH 1	1.38	0.02	386.64	4.65	22.62
HH 2	0.94	0.02	368.21	4.53	82.02
HH 3	3.97	0.07	627.03	7.88	23.09
HH 4	1.87	0.02	507.55	5.31	29.34
HH 5	2.15	0.02	454.10	7.06	23.93
HH 6	3.24	0.02	667.50	8.57	74.58
HH 7	2.90	0.02	786.91	7.77	77.00

Ali Sabieh

Ali Sabieh	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
AS1	24.67	7222	13.0	7.55	132
AS2	28.69	3230	56.4	7.55	162
AS3	NM	2424	48.0	7.49	163.4

Ali Sabieh	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
AS1	80.15	0.00	1032264.27	213958.82	797.54	9398.09	119115.64	24.77	1.00	46.64	77.64
AS2	-2.01	0.00	432161.13	140577.69	67.29	2742.24	29768.47	8.93	0.74	2.48	27.19
AS3	-2.02	20.52	299989.58	96174.36	17.35	1427.37	25040.45	12.27	0.52	0.90	25.73

Ali Sabieh	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
AS1	0.35	4.30	6.81	1157.87	13.79	0.81	29.03	285.80	2.14	7936.81	4.23
AS2	-0.34	0.94	1.86	56.79	1.31	0.29	20.72	140.05	4.33	2543.65	9.06
AS3	-0.28	0.13	0.45	21.82	1.49	0.55	10.18	89.79	1.46	1969.08	9.72

Ali Sabieh	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
AS1	0.27	0.07	0.21	112.61	-0.14	0.20	0.85	0.83	0.87	0.25	4.35
AS2	0.02	0.03	0.18	9.19	-0.25	0.12	0.62	0.58	0.57	0.20	2.73
AS3	0.03	0.03	0.10	10.97	-0.24	0.12	0.45	0.41	0.42	0.18	2.16

Ali Sabieh Town	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
AS 1	0.55	0.35	1902.04	4.97	
AS 2	2.19	0.02	718.19	4.69	120.90
AS 3	2.29	0.02	512.72	5.36	153.62

B.5 Liberia

Gblah

Gblah	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
GB1	30.50	72	64.5	5.35	160.1
GB2	30.22	53	85.5	5.53	170.0
GB3	30.21	239	65.5	4.84	213.2

Gblah	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
GB1	13.09	5.04	8952.43	9834.03	33.23	4882.07	1797.40	0.66	0.64	50.63	65.33
GB2	12.80	4.93	7641.53	9327.05	57.12	2605.72	1628.72	0.39	0.73	10.03	88.91
GB3	-3.21	-2.12	22750.90	12800.36	433.01	12479.01	4501.76	0.19	0.50	382.50	57.17

Gblah	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
GB1	1.69	2.47	20.91	29.73	19.15	2.87	1.05	-1.11	13.20	27.54	2.19
GB2	0.32	0.86	19.98	29.15	5.86	1.64	0.90	-3.53	5.89	21.56	1.12
GB3	8.25	4.31	19.79	62.09	129.43	4.79	7.59	16.68	32.18	169.22	0.74

Gblah	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
GB1	0.47	0.13	3.65	177.46	0.23	0.20	3.57	3.37	3.49	0.79	0.19
GB2	0.26	0.08	3.87	53.12	0.17	0.10	2.88	2.83	2.88	0.44	0.09
GB3	0.18	0.18	4.13	1207.91	0.27	0.32	15.97	14.78	16.33	0.26	1.86

Gblah and Fishtown	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
GB 1	0.12	0.02	3.84	0.25	24.32
GB 2	0.06	0.01	2.81	0.24	15.94
GB 3	0.09	0.12	10.16	-0.1	127.59
FT 1	0	0.01	7.38	1.05	3.67

Bahn Camp

Bahn camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
BC1	27.39	36	49.1	5.44	210.4
BC2	29.50	51	36.3	5.69	190.1
BC3	25.60	71	34.5	5.72	191.0

Bahn camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
BC1	12.63	-2.09	5381.70	9549.77	119.57	3990.04	3955.56	0.95	1.07	98.75	131.43
BC2	-3.18	-2.10	8427.42	9575.02	4.26	2340.92	1810.53	0.74	1.54	8.44	28.93
BC3	12.87	-2.13	8797.68	10700.71	-17.15	3361.42	2496.95	1.67	4.47	8.45	22.21

Bahn camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
BC1	1.51	2.35	57.73	235.35	5.49	1.00	0.93	-2.52	9.23	19.27	0.54
BC2	0.09	0.50	1.87	13.07	5.79	0.49	0.61	-4.71	2.50	26.59	0.53
BC3	0.15	2.39	3.11	11.87	7.29	0.61	0.13	-2.16	1.31	39.08	0.40

Bahn camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
BC1	0.49	0.19	3.70	47.76	0.17	0.20	3.71	3.80	3.75	0.34	0.28
BC2	0.08	0.03	3.32	50.89	0.08	0.02	0.45	0.45	0.46	0.09	0.05
BC3	0.08	0.00	2.97	66.10	0.08	0.01	0.61	0.63	0.62	0.07	0.06

Bahn Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
BC 1	0.04	0.01	1.38	0.6	0.89
BC 2	0.03	0.01	2.32	0.9	0.62
BC 3	0.05	0.01	1.81	1.35	1.05

Dougee Camp

Dougee camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
DC1	26.44	348	45.0	6.42	195.0
DC2	26.16	319	30.0	6.18	157.0
DC3	26.18	121	40.0	5.73	181.9
DC4	25.26	287	28.3	6.10	157.8
DC5	24.03	53	68.0	6.90	143.0

Dougee Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
DC 1	0.02	0.01	3.13	3.02	1.54
DC 2	0.09	0.02	3.24	2.61	14
DC 3	0.06	0.01	2.18	0.89	12.03
DC 4	0.08	0.01	3.19	1.95	1.31
DC 5	0.01	0.01	1.98	0.44	0.95

Dougee camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
DC1	-3.19	-2.10	2467.70	25845.19	65.14	1078.17	2970.56	3.19	61.24	14.76	102.11
DC2	23.48	-2.11	11434.18	12497.18	324.94	5145.28	15021.06	5.75	2.92	17.88	182.62
DC3	2.16	-2.14	6307.33	8893.42	110.32	3905.30	1843.72	1.15	4.10	17.52	91.19
DC4	7.49	-2.12	6601.00	15368.40	86.77	3294.70	5571.41	3.85	5.06	71.95	133.33
DC5	7.52	-2.13	3122.72	9155.73	-14.84	1032.10	1479.08	0.23	0.51	9.93	164.16

Dougee camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
DC1	0.36	22.94	8.97	164.27	2.67	0.89	0.37	-2.13	2.47	18.73	0.26
DC2	0.25	3.70	15.75	373.64	7.08	0.57	0.13	-1.33	3.60	144.41	0.51
DC3	0.97	3.97	11.81	55.49	23.39	0.62	0.38	-1.52	15.59	76.93	0.12
DC4	0.71	6.14	5.47	284.61	7.50	0.78	0.05	-1.99	5.36	83.94	0.24
DC5	0.17	1.22	3.51	38.88	2.16	0.69	0.05	-1.83	3.77	21.41	0.14

Dougee camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
DC1	0.07	0.08	2.43	22.18	0.14	0.02	2.67	2.80	2.70	0.05	0.01
DC2	0.08	0.05	3.62	67.33	0.17	0.01	1.36	1.40	1.36	0.05	0.08
DC3	0.09	0.09	3.94	212.79	0.04	0.10	1.93	2.03	1.96	0.03	0.01
DC4	0.50	0.08	2.67	65.10	0.06	0.02	2.29	2.35	2.27	0.04	0.01
DC5	0.03	0.07	2.40	19.76	0.06	0.01	1.41	1.51	1.49	0.02	0.01

Tian Town

Tian Town	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
TT1	27.71	70	50.0	5.40	179.0
TT2	27.00	401	57.5	6.17	167.7
TT3	27.20	96	33.8	5.55	209.0

Tian Town	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
TT1	-3.18	-2.10	2011.45	7656.55	41.30	26784.37	1943.25	0.22	0.87	14.99	63.50
TT2	12.64	-2.09	13682.93	14084.03	113.37	6571.99	5477.69	0.96	2.97	63.03	295.33
TT3	2.17	-2.14	2670.01	8224.65	42.22	440.41	2577.34	0.24	0.53	15.50	60.51

Tian Town	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
TT1	0.35	0.58	14.37	26.68	6.75	0.27	0.69	-0.76	3.92	14.86	0.08
TT2	0.10	1.31	6.14	34.02	13.07	0.43	1.14	-2.68	5.24	123.87	0.21
TT3	0.56	1.78	33.23	664.58	2.67	0.33	0.25	-0.69	1.84	37.27	0.06

Tian Town	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
TT1	0.05	0.05	1.29	60.74	0.02	0.04	4.32	4.11	3.85	0.00	0.10
TT2	0.11	0.03	0.92	122.00	0.04	0.03	1.10	1.21	1.16	0.02	0.16
TT3	0.04	0.06	0.58	22.86	0.06	0.01	1.84	1.91	1.80	0.00	0.01

Tian Town	**FLUORIDE (mg/L)**	**IODIDE (mg/L)**	**CHLORIDE (mg/L)**	**NITRITE (mg/L)**	**NITRATE (mg/L)**
TT1	0.03	0.01	2.63	0.27	5.65
TT2	0.21	0.08	12.12	2.21	23.24
TT2	0.02	0.01	2.38	0.05	22.39

Solo Camp

Solo camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
SC1	25.78	447	23.8	6.48	47.3
SC2	26.32	576	16.6	6.42	61.5
SC3	25.58	178	35.0	5.87	120.5
SC4	25.53	99	46.5	5.57	200.8
SC5	25.20	87	55.0	5.58	210.0
SC6	25.35	224	78.0	6.52	137.0

Solo Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
SC 1	0.28	0.01	1.61	3.58	1.64
SC 2	0.16	0.02	1.14	3.4	0.75
SC 3	0.05	0.01	2.94	2.32	3.62
SC 4	0.07	0.01	1.97	0.76	6.16
SC 5	0.04	0.01	2.19	0.34	13.07
SC 6	0.13	0.01	2.67	1.95	0.53

Solo camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
SC1	18.27	-2.13	10304.03	16962.71	49.88	4720.15	12068.24	0.35	1.15	199.41	698.54
SC2	17.98	-2.10	9299.48	16506.84	9.55	5089.33	7924.72	0.75	0.62	212.43	409.23
SC3	-3.18	-2.10	4477.11	10005.95	36.02	1545.34	4736.49	1.03	3.60	41.59	87.99
SC4	-3.18	-2.10	1975.37	7969.16	-3.30	571.20	3106.12	0.19	0.67	16.06	58.33
SC5	2.12	-2.10	3465.14	8414.14	47.22	1165.08	2070.77	1.06	1.98	21.13	47.07
SC6	12.90	-2.13	9792.11	10966.28	237.34	3796.50	12459.09	4.56	3.88	25.53	137.97

Solo camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
SC1	0.77	0.95	3.82	34.12	6.91	0.62	-0.20	-1.18	5.36	340.12	0.23
SC2	0.61	0.56	3.26	28.74	9.71	0.29	0.04	-0.03	3.84	229.14	0.08
SC3	0.33	0.50	15.02	61.32	5.16	0.41	-0.12	0.69	3.72	95.49	0.09
SC4	0.36	0.28	7.02	21.03	3.04	0.23	0.09	0.37	2.14	44.29	0.11
SC5	0.47	1.19	5.39	29.35	8.75	0.12	0.04	-1.17	4.17	63.75	0.03
SC6	0.24	1.50	51.68	864.89	9.74	0.47	0.17	0.21	2.40	165.24	0.35

Solo camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
SC1	0.06	0.67	0.65	62.52	0.05	0.02	2.79	2.79	2.71	0.00	0.08
SC2	0.02	0.02	0.66	90.66	0.02	0.01	0.63	0.74	0.69	-0.01	0.05
SC3	0.04	0.05	0.22	46.91	0.01	0.02	1.24	1.35	1.27	0.00	0.01
SC4	0.01	0.04	-0.20	27.14	0.01	0.01	1.39	1.44	1.41	-0.02	0.00
SC5	0.06	0.04	-0.01	79.52	0.01	0.02	0.99	1.05	0.97	-0.01	0.00
SC6	0.04	0.11	-0.17	90.21	0.18	0.01	2.14	2.08	2.16	-0.01	0.05

PTP Camp

PTP camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
PT1	23.62	125	55.5	5.66	116.4
PT2	24.90	160	48.7	5.87	159.1
PT3	25.67	1218	20.1	6.96	109??

PTP camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
PT1	-3.14	-2.07	3244.08	7561.07	84.99	361.66	968.21	0.52	0.56	19.22	647.44
PT2	-3.19	-2.10	5702.91	9485.37	-4.32	1802.44	2661.49	5.71	6.79	15.31	77.04
PT3	23.39	-2.11	14059.69	19045.39	-3.82	5231.70	34702.57	0.24	0.41	351.45	210.72

PTP camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
PT1	1.21	5.84	10.38	57.84	4.40	0.35	0.12	-0.91	2.63	13.21	0.06
PT2	0.15	2.67	37.18	96.27	8.84	0.39	0.00	2.64	4.34	78.53	0.12
PT3	0.14	0.27	20.35	34.45	3.42	0.54	-0.04	0.21	7.45	1116.61	0.31

PTP camp	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
PT1	0.06	0.11	-0.54	39.94	-0.01	0.02	3.41	3.42	3.42	-0.01	0.01
PT2	0.06	0.09	-0.78	80.67	0.01	0.01	2.30	2.26	2.30	-0.02	0.00
PT3	0.16	0.04	-0.63	32.63	0.00	0.01	1.47	1.51	1.48	-0.02	0.09

PTP Camp	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
PT 1	0.03	0.01	2.61	0.34	0.81
PT 2	0.05	0.01	3.08	1.13	0.67
PT 3	0.23	0.01	1.87	4.1	0.46

Maryland County

Maryland County	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
MD1	29.39	3141	72.5	7.26	169.0
MD2	30.00	325	59.6	6.20	179.4
MD3	28.94	408	26.8	6.26	38.9
MD4	27.38	321	26.5	5.68	110.5
MD5	28.89	2690	34.3	11.28	-136.5
MD6	28.41	260	46.0	6.31	207.3

Maryland County	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
MD 1	0.09	0.02	517.18	1.03	1.87
MD 2	0.02	0.02	24.49	0.07	35.52
MD 3	0.05	0.02	34.55	2.05	2.73
MD 4	0.07	0.13	37.33	0.51	44.3
MD 5	0.64	0.43	6.01	5.27	1.83
MD 6	0.08	0.01	4.37	1.79	10.54

Maryland County	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
MD1	2.15	-2.12	228964.87	35519.64	125.62	9150.09	5630.62	0.71	0.80	19.21	309.90
MD2	12.73	4.91	11182.35	9678.06	357.05	2819.64	4180.14	0.51	0.78	19.94	43.05
MD3	2.02	-2.00	16696.71	9842.26	137.97	1900.98	8967.50	0.98	1.63	17.15	1458.49
MD4	2.11	11.85	17702.80	11110.15	135.42	1748.46	9194.95	0.72	0.70	46.91	1209.49
MD5	7.44	-2.10	21505.89	6344.16	5553.34	26114.98	35150.24	3.35	0.40	7.80	82.93
MD6	2.16	-2.13	3028.98	7807.67	42.52	847.30	9775.08	0.63	7.12	7.65	66.04

Maryland County	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
MD1	0.18	0.99	4.93	71.75	3.46	0.50	0.29	50.01	6.90	199.69	0.27
MD2	0.19	1.77	8.82	595.52	3.06	0.21	-0.53	5.71	7.70	82.42	0.17
MD3	0.08	0.71	4.34	233.57	0.84	0.43	0.66	6.51	4.13	105.24	0.16
MD4	0.67	1.16	5.69	159.16	2.44	0.15	0.98	6.41	4.87	59.07	1.04
MD5	0.15	17.58	6.51	92.59	13.11	2.54	4.20	7.34	113.02	581.45	3.18
MD6	0.08	4.21	60.89	162.71	1.29	0.17	0.42	1.36	2.05	57.85	0.22

Maryland County	107Ag µg/L	111Cd µg/L	133Cs µg/L	137Ba µg/L	202Hg µg/L	205Tl µg/L	206Pb µg/L	207Pb µg/L	208Pb µg/L	232Th µg/L	238U µg/L
MD1	0.20	0.04	-0.87	30.71	0.17	0.12	1.23	1.25	1.21	0.00	0.06
MD2	0.04	0.05	-0.70	27.91	0.08	0.04	1.10	1.13	1.10	-0.02	0.02
MD3	0.01	0.01	-0.93	7.25	0.07	0.02	0.55	0.61	0.57	0.17	0.04
MD4	0.00	0.04	-1.04	20.92	0.34	0.04	1.51	1.61	1.52	-0.02	0.05
MD5	0.01	0.14	1.88	59.41	0.01	0.01	3.21	3.40	3.28	-0.03	0.00
MD6	0.06	0.10	-1.25	12.80	0.02	0.01	2.46	2.58	2.46	-0.03	0.02

Little Wlebo Camp

Little Wlebo camp	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
LW1	27.60	49	76.1	7.68	144.5
LW2	28.46	122	82.0	5.98	168.0
LW3	28.54	223	61.2	6.47	164.1
LW4	28.75	497	68.5	6.68	157.1
LW5	28.04	168	58.6	6.15	164.3
LW6	28.47	439	42.0	6.59	40.8
LW7	28.10	263	32.0	6.30	39.8
LW8	27.81	76	50.0	5.60	211.0
LW9	28.05	104	61.6	5.72	189.9
LW10	27.99	95	53.5	5.54	214.6

Little Wlebo	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
LW 1	0.05	0.07	7.7	0.01	5.55
LW 2	0.04	0.01	6.61	0.59	58.48
LW 3	0.14	0.01	5.6	1.54	3.14
LW 4	0.08	0.01	3.22	3.03	56.27
LW 5	0.02	0.01	4.2	1.47	1.69
LW 6	0.12	0.01	4.23	3.08	2.29
LW 9	0.02	0.01	6.79	2.13	6.92
LW 10	0.04	0.01	6.32	1.58	4.68

Little Wlebo camp	7Li µg/L	9Be µg/L	23Na µg/L	24Mg µg/L	27Al µg/L	39K µg/L	44Ca µg/L	51V µg/L	52Cr µg/L	55Mn µg/L	56Fe µg/L
LW1	12.87	-2.13	4019.49	7101.92	141.48	526.15	2804.98	0.17	0.66	12.82	124.18
LW2	-3.21	-2.12	2304.11	6994.69	22.40	1538.09	2991.31	0.08	0.27	4.28	39.96
LW3	7.54	4.97	2520.13	8691.89	2.54	13.85	6789.51	0.27	0.99	5.01	42.10
LW4	12.94	-2.14	5114.23	12351.13	125.87	518.53	23833.12	0.74	1.18	9.67	52.04
LW5	7.56	-2.14	2615.58	6991.61	130.72	459.19	5301.66	0.75	1.46	11.05	54.38
LW6	7.54	-2.13	7899.12	10947.69	18.69	1914.35	12559.36	0.51	0.31	5.82	33.42
LW7											
LW8											
LW9	7.68	-2.17	5196.87	6326.23	298.40	-42.44	4751.74	0.46	0.88	44.33	281.70
LW10	-3.21	-2.12	3657.03	6541.66	120.30	-272.82	1736.66	0.19	0.49	14.66	124.81

Little Wlebo camp	59Co µg/L	60Ni µg/L	65Cu µg/L	66Zn µg/L	69Ga µg/L	75As µg/L	78Se µg/L	82Se µg/L	85Rb µg/L	88Sr µg/L	95Mo µg/L
LW1	0.13	1.80	15.36	274.43	0.76	1.05	0.54	12.32	2.57	12.55	0.13
LW2	0.14	0.50	10.78	98.54	0.73	0.23	0.29	1.11	0.53	35.73	0.03
LW3	0.11	0.75	17.34	116.35	1.38	0.19	-0.45	1.77	2.93	70.38	0.17
LW4	0.11	1.24	33.32	237.01	1.20	0.27	0.67	4.00	0.87	219.77	0.33
LW5	0.21	1.98	16.37	311.82	1.44	0.46	0.17	3.01	5.22	43.62	0.25
LW6	0.17	0.71	58.32	198.95	1.45	0.08	0.71	2.27	1.31	55.55	0.22
LW7											
LW8											
LW9	0.38	0.96	15.83	70.02	1.27	0.01	-0.08	2.72	-0.25	34.73	0.38
LW10	0.20	0.73	9.41	35.01	0.70	0.08	0.29	2.41	0.60	13.46	-0.03

Little Wlebo	107Ag	111Cd	133Cs	137Ba	202Hg	205Tl	206Pb	207Pb	208Pb	232Th	238U
camp	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
LW1	0.01	0.09	-1.42	7.11	0.02	0.04	3.47	3.61	3.51	-0.01	0.06
LW2	0.11	0.02	-1.57	6.85	-0.03	0.02	1.13	1.05	0.97	-0.03	0.03
LW3	0.34	0.07	-1.66	12.08	-0.04	0.03	1.87	1.82	1.75	-0.04	0.04
LW4	0.00	0.04	-1.67	11.86	0.09	0.01	1.63	1.60	1.56	-0.04	0.06
LW5	-0.01	0.05	-1.47	12.17	0.07	0.01	2.25	2.29	2.21	-0.04	0.06
LW6	0.01	0.03	-1.60	12.23	0.00	0.01	1.71	1.72	1.74	-0.04	0.02
LW7											
LW8											
LW9	0.04	0.12	-1.87	11.15	0.05	0.01	1.28	1.25	1.24	0.01	0.02
LW10	0.00	0.05	-1.78	5.80	-0.03	0.02	1.33	1.28	1.29	-0.01	0.03

Fishtown

Fishtown	Temperature (°C)	Conductivity (uS/cm)	DO (%)	pH	ORP (mV)
FT1	28.85	89	68.0	5.33	250.8

Fishtown	7Li	9Be	23Na	24Mg	27Al	39K	44Ca	51V	52Cr	55Mn	56Fe
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
FT1	12.87	-2.13	3445.10	6590.98	29.35	-585.64	1622.34	0.17	0.35	8.22	55.34

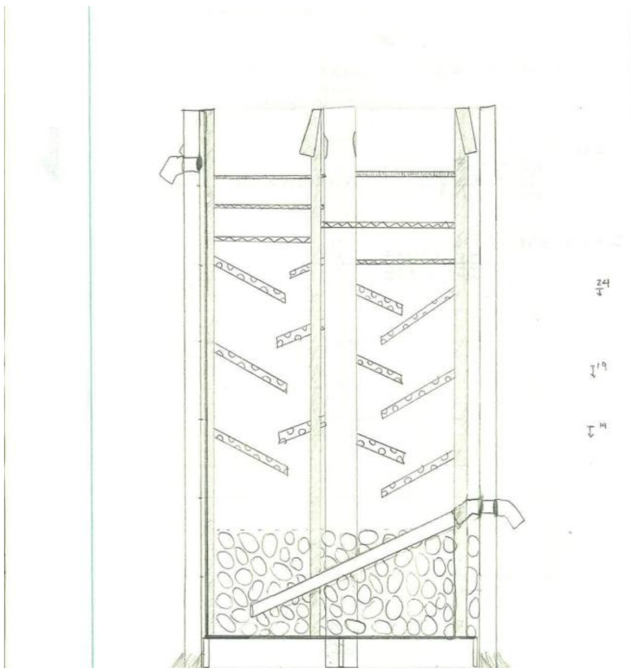
Fishtown	59Co	60Ni	65Cu	66Zn	69Ga	75As	78Se	82Se	85Rb	88Sr	95Mo
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
FT1	0.10	1.00	7.50	83.24	0.64	0.19	0.62	2.75	-0.55	11.25	0.02

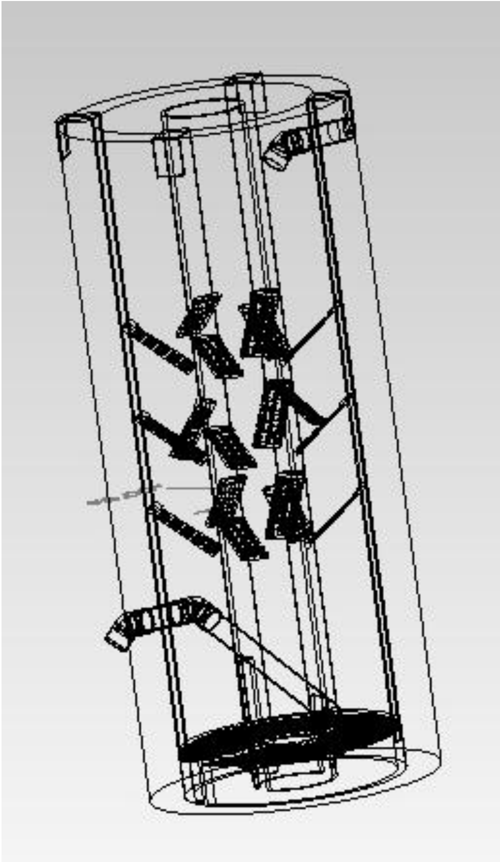
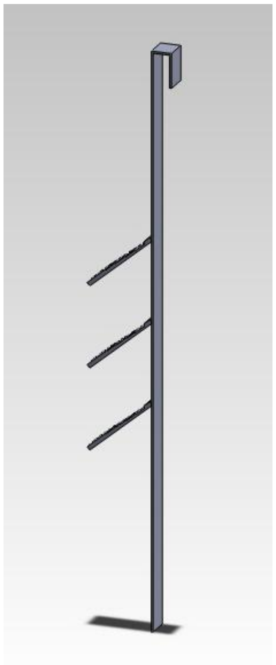
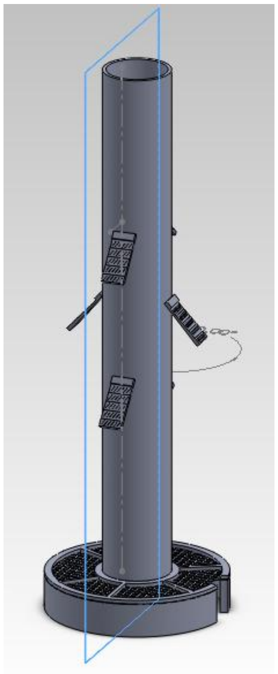
Fishtown	107Ag	111Cd	133Cs	137Ba	202Hg	205Tl	206Pb	207Pb	208Pb	232Th	238U
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
FT1	-0.03	0.08	-1.88	5.69	-0.04	0.01	2.06	2.10	2.05	-0.03	0.02

Gblah and Fishtown	FLUORIDE (mg/L)	IODIDE (mg/L)	CHLORIDE (mg/L)	NITRITE (mg/L)	NITRATE (mg/L)
GB 1	0.12	0.02	3.84	0.25	24.32
GB 2	0.06	0.01	2.81	0.24	15.94
GB 3	0.09	0.12	10.16	-0.1	127.59
FT 1	0	0.01	7.38	1.05	3.67

Appendix C: Supplemental Drawings for Iron Remediation

C.1 Design 1



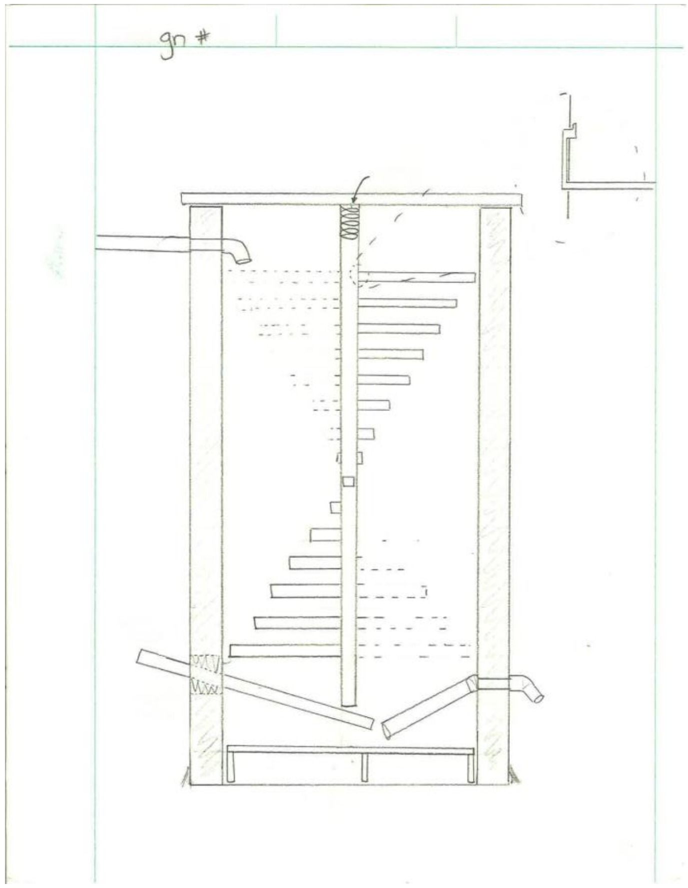
Pros for Design 1:

- Generally adaptable to wells already built
- Can be accomplished with various types of materials (most likely plastics or aluminum)
- Can be built as either one unity (by welding or gluing parts) OR connecting and building for compact storage and transportation.
- No pump needed
- Uses their design of pebbles at the bottom

Cons for Design 1:

- Could get heavy
- Does not allow snug lid
- Intricate machining needed

C.2 Design 2



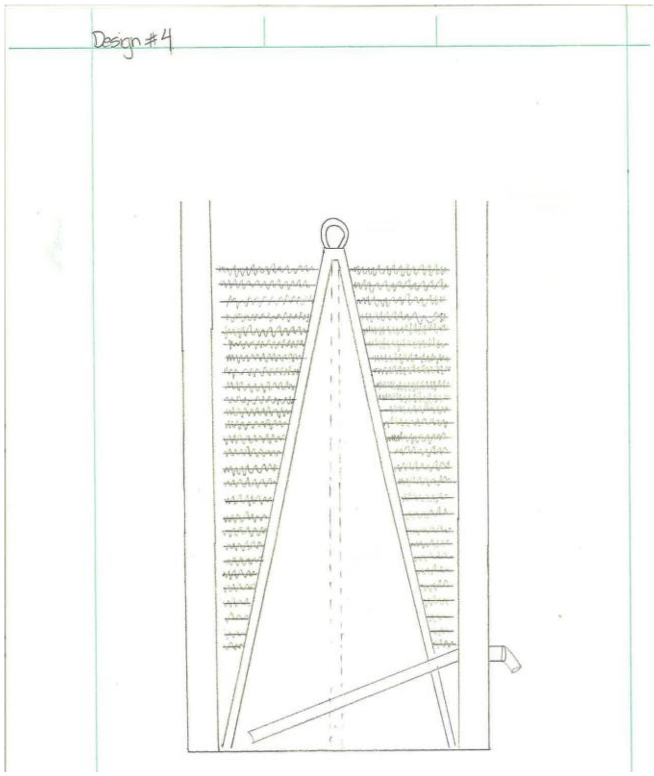
Pros for Design 2:

- Generally adaptable to wells already built
- Can be accomplished with various types of materials (most likely plastic)
- Can be built as either one unity (by gluing parts) OR connecting and building for compact storage and transportation.
- Can move from well to well because size only depended on the lid
- No rocks (easier cleaning)
- Easy production and transport

Cons for Design 2:

- Potentially fragile because only held on by spring (and possibly hooked tubing)
- Would need to add foot pump to already-existing wells (design might work without pump too)
- Many moving parts

C.3 Design 4



Pros of Design 4:

- Extremely effective
- Disposable parts
- Fits generally any size and shape

Cons of Design 4:

- Not cost sustainable
- Many parts and requires more involved maintenance
- Dependent on continual buying of new parts, or very difficult cleaning