Feasibility Study for Creating a Field-based Water Quality Testing Kit for use in Rajasthan India

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Newai Talab: Rajasthan, India

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Executive Summary

Harsh environmental conditions coupled with high population density result in water quality and scarcity issues for the rural villages of Rajasthan, India. Climate change, continued urbanization, and lack of effective water quality testing infrastructure further complicate the already fragile water cycle. The poor drinking water quality results in many potential human health problems including fluorosis, brittle bones, diarrhea, fevers, joint pains and stiffness, kidney stones, headaches, and dehydration related “deep-sleeps”

The Jal Bhagirathi Foundation advocates the reintroduction of traditional rainwater harvesting practices as well as educates villagers on hygiene and sanitation. JBF also provides water quality testing to rural villages. However, the long list of parameters provided by the WHO and the number of villages in the area creates a large sampling and analytical burden for their small laboratory. By selecting a more focused list of parameters tailored to the conditions and health risks in the region we have put together a field water quality testing kit. This kit could potentially provide frequent and accurate water testing to villages, improving the management of their water resources to the benefit of greater public health protection.

The kit, designed around seven of the basic WHO water quality parameters and information on public health in the region, was brought to Jodhpur for testing in rural villages in the surrounding area during the month of July 2013. Salinity, total dissolved solids (TDS), conductivity, E. coli and coliforms, pH, and fluoride were selected as the most important parameters to test as indicators of public health in the Marwarian villages.. The villages of Surani, Jaithmal, Newai and Norwa were selected as field sites to test the feasibility and efficacy of the kit. Samples were collected at all points along the drinking water supply chain of each village. Tests were performed in the field when possible and corresponding samples were brought back to the laboratory for validation. Results show that all drinking water sources are relatively poor quality, but also that the quality varies spatially and temporally suggesting that there are certain times when a particular source is the best option to protect against water borne health risks.

While the kit was sufficiently portable there were challenges in implementing all of the targeted tests in the field and the cost exceeded the desired limit. Complications arose when attempting to perform fluoride and E. coli and coliform measurements. Fluoride concentrations could not be determined due to results that varied an order of magnitude because of methodological problems. E. coli and coliform tests were exposed to elevated temperatures during shipping, resulting in questionable quality and highly variable results. Furthermore, the amount of time and complicated procedure necessary for performing these measurements may make them difficult to perform in the field, although the field method is an easier option than the full laboratory assay. Tests for salinity, TDS, pH and turbidity proved to be effective in the field. All tests provided precision in measurement, but further testing will be needed to assess their accuracy.

This study found that a portable field based testing kit is feasible and may also enable villagers to develop a better understanding of water quality at each source during the year. The instruments used in this study allow measurement of important parameters. While further validation is needed, some tests may be more suited as screens indicating need for further examination and intervention.

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I. Introduction

Rajasthan, India is characterized by sporadic and sparse precipitation, intense solar radiation and heat, saline groundwater, and rocky soil. The Marwar region is also deemed a zone of extreme water scarcity averaging 200 mm of rainfall per year, generally only over a couple of monsoon months (June to August). The remainder of the year is typically devoid of rainfall. In fact, 43 of the last 50 years have been recorded as drought conditions and this has only been exacerbated by climate change, population growth, and the government failure to fulfill their promises of delivering an ample supply of quality drinking water. However, despite the dry and difficult conditions, the region is the most densely populated arid zone in the world. Rajasthan has only 1.15% of the country's total water resources while spanning 10.5% of India's geographic area (JBF website). The majority of people rely on animal husbandry and agriculture as their source of income. But, as one can imagine, a dense population dependent on unpredictable precipitation leads to many problems. Water quality and insecurity issues manifest themselves in the form of disease, infection, and overall poor human health. In Rajasthan, villagers experience frequent kidney stones, fevers, extreme diarrhea, dental discoloration, and brittle bones. Additionally, the geology in this area of the Thar Desert causes the groundwater to have an elevated mineral content with particularly high levels of fluoride, resulting in health problems without advanced treatment. The Rajasthan villages currently employ traditional rainwater harvesting practices of collecting rainwater in open catchment ponds, or talabs, for use throughout the year. Additional storage devices of this rainwater have brought the water closer to the home and minimized the time women and children spend traveling to fetch water. However, in general, the only way that the Rajasthani people judge the quality of their drinking water is salinity; 'sweet' water is considered safe to drink and 'salty' is not. While the government does pump water into select villages from the city of Jodhpur, the villagers consider this water 'salty' and prefer the traditionally sourced water. Regardless, such rudimentary assessment of drinking water quality has lead to health concerns. The Jal Bhagirathi Foundation (JBF) has worked hard to promote the revival of traditional best practices for water collection and storage in over 80 villages throughout the Thar Desert. These efforts include educational initiatives for improved health and sanitation as well as the reintroduction of sustainable management practices. However, there is still a lack of accurate, reliable, and routine testing of the drinking water-- a challenge that this project seeks to address. Improving the understanding of water quality and access to safe drinking water can result in tangible benefits to the health of the Rajanthani people.

II. Project Goals and Objectives

The overall goal of this project was to design and test a field based water quality testing kit tailored to the water resource conditions in rural villages of Rajasthan, India. In order to fulfill this goal we defined four main objectives:

1. Design a field testing kit.
2. Select a set of villages to test the kit within over one month (July 2013).
3. Test efficacy of the field instruments.
4. Based on the test results-- what can be said about quality of villages' water resource management.

III. Background

A. Water quality in Rajasthan

Within the villages people rely on aesthetics (taste, odor, cloudiness, smell) to assess the quality of their drinking water. While aesthetic analysis is an easy and ready assessment, it can be misleading and uninformative. Local opinions regarding which water sources are considered clean, palatable, and safe coupled with traditional aesthetic analysis leaves the villagers with an unclear understanding of the quality of their water.

Currently there are two possible water-testing regimes that may provide the villages with a more comprehensive analysis. There were reports that the Indian government provides kits containing presence or absence tests for pH and microbial contaminants as well as bleaching powder for improving the quality of the talab. However, we were not able to obtain one of these kits to investigate the contents or reliability of the tests. In fact, it seemed that the villagers had not seen a government supplied testing kit in a while, implying that they are not regularly in use, if ever at all.

Bi-annual testing of the village talab water is done by an outsourced lab on site at the JBF headquarters in Jodhpur. However, the lab is severely understaffed. The single technician receives an overwhelming number of samples from the 80 surrounding villages. Each is tested for up to all 52 WHO drinking water quality parameters; a very time consuming and costly endeavor. A more manageable list of parameters catering to the specific health and environmental conditions in Rajasthan would allow for more frequent testing and a better understanding of water quality during the year.

Lack of sufficient water quality data and infrequent testing in a region with intermittent precipitation, a growing population, persistent health issues, and highly variable water quality is motivation for implementing testing infrastructure at the village level.

B. Rajasthan health Issues

Worldwide millions of people die each year from water-related diseases, a large portion due to diarrhea caused by bacterial contamination. Over 80% of these water-related deaths occur among children 0-14 and almost all of the water-related deaths occur in places facing water quality and scarcity issues, like Rajasthan (JBF). Village interviews indicated that the people of Rajasthan routinely suffer from fluorosis, brittle bones, diarrhea, fevers, joint pains and stiffness, kidney stones, headaches, and dehydration related "deep-sleeps". In a society that suffers from malnutrition, poor sanitation and hygiene, and a low standard of living it is hard to pinpoint the root of any of these health issues. Introducing a more frequent water quality monitoring program could help alleviate some of the uncertainty surrounding these health challenges.

C. Drinking water sources

While rainwater harvesting is the major source of drinking water within the Rajasthan villages, there are many methods of collecting, storing, and transporting the water. Additionally, some villages are supplemented with government water piped in from the nearest city, Jodhpur. Some villagers have also constructed devices for harvesting water on their rooftops. These various water sources all combine to form a water supply chain that varies both from village to village as well as between households based on income and accessibility. The components of the water supply chain are outlined below and illustrated in Figure 1.

1. Talab

Each village within our study contained a talab, an open catchment pond of varying size and complexity that is utilized by both the village itself as well as many small neighboring villages. Talab water can be accessed in a few different ways. Traditional practices where women and children spend hours a day fetching water and transporting it back to their homes in jugs on their heads is still very prevalent. This time and labor intensive practice is necessary year-round, particularly for the poorest members of the village. Some women filter the talab water through their dupatta (scarf) to eliminate large particles and algae from entering the collection container. However, this is the only barrier between potentially harmful contaminants. Another, more modern way of collecting and storing talab water is to deliver large volumes of talab water to an at-home storage vessel called a tanka. However, this is a luxury for only the families that can afford it.

Over time talabs require maintenance in the form of dredging, desilting, building of embankments, and designing and rebuilding of more efficient catchment areas. The burden of these projects is carried by the village members but is eased through partnership and development programs supported by JBF and their collaborators.

Because talab water is exposed to weather, human waste, and contamination in the surrounding catchment area, the quality is highly variable both spatially and temporally. Additionally, the talab is often shared with cattle. It is not unusual for drinking water to be collected meters from submerged cattle, further tampering with an already vulnerable water system. JBF encourages villages to develop separate water ponds designated for the cattle called Nadis. However, Nadis are usually quite shallow and therefore dry-up quickly during the 9 months without precipitation. In this case, the cattle are forced into the talab water. Further, there is a lack of a surrounding buffer zone or riparian barrier to provide the talab with natural protection from contaminants and animal fecal matter released into the catchment area.

2. Matki

Each household has at least one matki, a 15L clay earthen pot that is used to store water within the home. The clay material allows water to seep through and evaporate, making the water inside the matki cooler than the outside temperatures.

Some villagers reported using up to 4 matkis per day, varying with the size of the household. None reported ever cleaning the matkis. All collected water is eventually stored in the matki, generally in the kitchen, to allow easy access for daily chores and drinking. Usually the matki is covered with a metal plate in an attempt to prevent contamination. On top of the plate there is a metal cup that is dipped into the matki and used to pour water into the mouth to drink. Anyone invited into the home is invited to drink directly from the matki either using the cup, a ladle, or their hands.

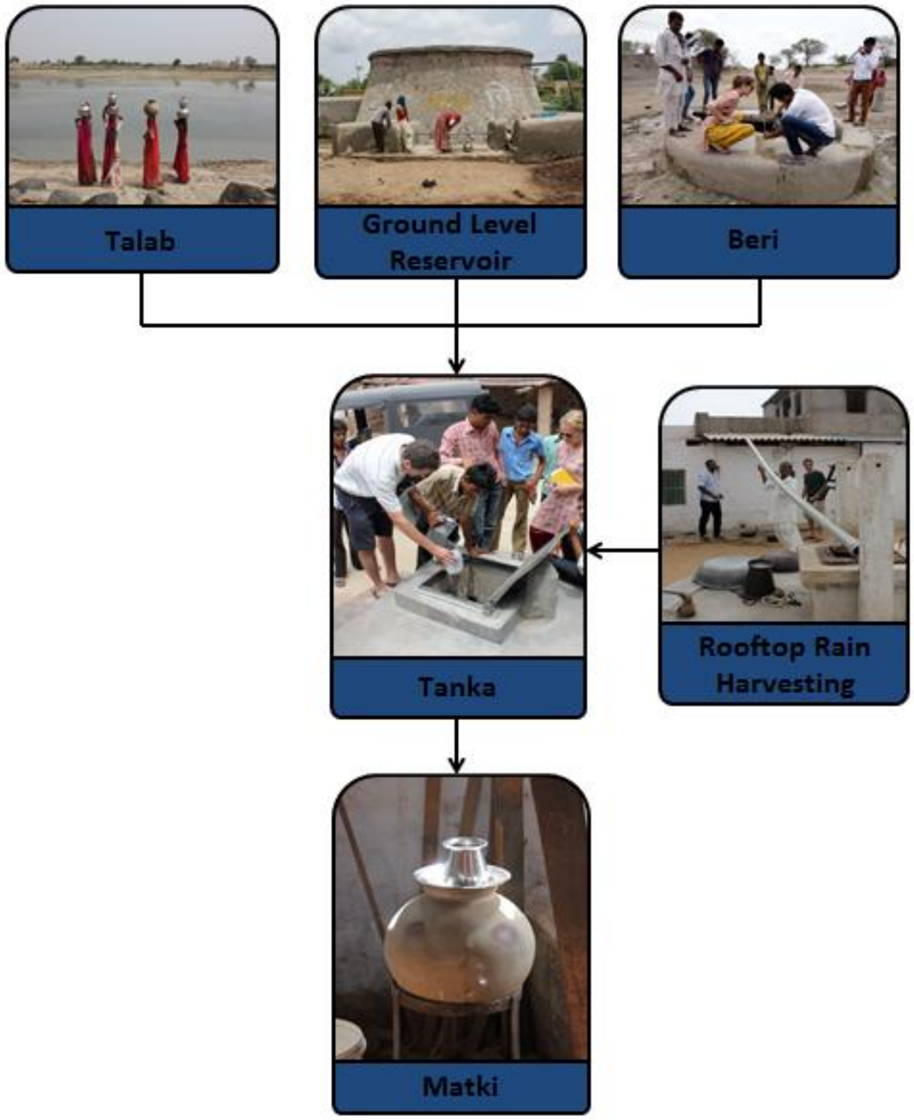
3. Tanka
Villagers can pay to have at-home storage vessels constructed and filled with talab water. These underground storage containers, called tankas, are filled with tanker trucks at the cost of 50 to 100 Rs per load. They vary in their exposure to the elements—some are open, covered with corn, or closed with a metal door. Water is pulled from the tanka as necessary using a rope and plastic container, similar to a well. The capacity of a tanka varies but, when full, most can provide water security for 3-5 months. Tankas minimize the travel and labor of the women in the village as well as water loss due to evaporation and seepage. However, tankas require resources and money to build, maintain, and fill, preventing them from being an option for all households. JBF financially assists villagers with tanka construction, but the cost of filling a tanka eliminates it from being a year round option for all.

4. At Home Rainwater Harvesting
Another technique sometimes employed is at home rooftop rainwater harvesting. This water is collected via PVC pipe put in place at the onset of rain. The pipe connected the edge of the roof to the opening of the tanka. This is an easy way to supplement the tanka with fresh rainwater, particularly during the short window of rainfall. However, we only observed this at one household in one village, Surani.

5. Ground Level Reservoir (GLR)
Traditionally a GLR is a faucet in the center of the village that delivers government supplied water from the nearest city, in this case Jodhpur. However, often times the government supply is unreliable or considered poor-quality (aesthetically) by the villagers. In some cases, the villagers will re-route the GLR piping to deliver talab water through the centralized faucet. This is done both for convenience and because the talab water is regarded by the villagers as higher quality and more palatable. The metal faucet is often covered with grasses and twigs to insulate the tube and prevent the water from getting too hot.

6. Beris
Some of the villages also have an ancient system of recharge wells, or beris, roughly 70 ft deep. When the Talab water is low, water can be collected via rope and container from the recharge wells. This was observed numerous times at the beginning of sampling but after a heavy rain the talabs were flooded and beris were inaccessible. Samples were taken from the Beris when possible.

Figure 1: *Water flow diagram*



D. JBF Initiatives & Village Selection

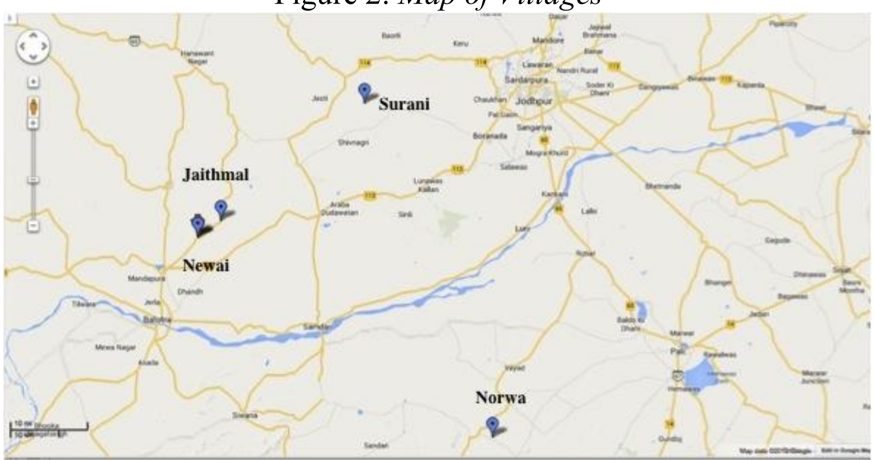
The Jal Bhagirathi Foundation mission is to promote the revival of traditional practices of water collection and storage allowing access to adequate drinking water for both humans and animals. Through this mission they reintroduce sustainable management practices and educational initiatives to improve health and sanitation. JBF has established and maintained strong relationships with all villages included in this study in three main ways. They promote the Water, Sanitation, and Hygiene (WASH) campaign. WASH encourages and educates villagers about decisions promoting sanitation practices, initiates behavioral change, and helps establish better facilities for waste disposal at the household level. Within this project, JBF financially matches household contributions for the construction of at home sanitation facilities. This program is also responsible for the formation of the Jal Sabhas, a community based institution composed of a body of the most responsible and respected members of the village. The formation of the Jal Sabhas helped JBF establish a two-way relationship by empowering locals. The Jal Sabhas are responsible for operating the talab as well as managing other JBF initiatives in the community, engaging in a bottom-up approach. These groups establish waste management rules and regulations within the village. JBF also works with communities to create ecological security programs, which facilitate common property resource management via the development of catchment areas and pasture lands for cattle grazing. Additionally, talab expansion and maintenance programs are supported by JBF. These programs include dredging, desilting, expansion, and maintenance of the talab feeder channels.

The relationships established by JBF with the villages we worked at were crucial for the feasibility of our objectives. They enabled easy access to village water sources and facilitated interaction with the village members, which minimized skepticism from villagers towards us, as foreigners, and our work.

Village selection

Initially, three villages were selected by JBF as locations for weekly tests, samples, and observations. A fourth village, Norwa was added a week into testing. Newai, Jaithmal, Surani, and Norwa, shown in Figure 2, were selected based on proximity to the JBF headquarters in Jodhpur and because they all had established JBF initiatives in place in the following ways:

Figure 2: *Map of Villages*



Newai: Development of the Jal Sabha, basic sanitation and hygiene education, talab expansion and maintenance assistance, and a developed grassland area.

Jaithmal: Development of the Jal Sabha, basic sanitation and hygiene education, talab expansion and maintenance assistance, and a grassland development project.

Surani: Development of the Jal Sabha, WASH campaigns including a financial assistance program for the construction of sanitation facilities and talab expansion and maintenance assistance. Additionally, pasture lands were being developed when we visited. Because of sanitation efforts, villagers in Surani make their own soaps for bathing and hand washing. Some homes even use wastewater seepage sites. Surani is a model village for JBF, as a result they are involved in all of their initiatives.

Norwa: This village was added in order to include a village known to have elevated fluoride concentrations. JBF also works with Norwa to employ hygiene and sanitation practices, ecological security, and talab expansion and maintenance efforts. Norwa's talab is significantly larger than the other villages.

E. WHO Drinking water guidelines

Because drinking water quality is a powerful indicator of overall health, assurance of safe drinking water can provide a foundation for both prevention and control of waterborne diseases. The World Health Organization (WHO) provides guidelines that indicate international norms for water quality. These guidelines provide a baseline for regulation and are used to set standards worldwide across varying economic, cultural, political, biological and social settings. The lab technician at JBF tests for up to all 52 of the recommended WHO parameters found in the table below. Highlighted tests are those that we target in this study.

Table 1: *Tests done by JBF lab technician*

Color (Hazen unit)	Copper as Cu (mg/l)
Odour	Zinc as Zn (mg/l)
Taste	Boron as B (mg/l)
Turbidity (NTU)	Nitrite as NO2 (mg/l)
Surface Temp C	Ammonical N as NH4 (mg/l)
pH	Sulphide as S (mg/l)
E.C. (milli siemen) ms/cm	B.O.D5 (mg/l)
Total Dissolved Solids (mg/l)	C.O.D.
Total Hardness as CaCo3 (Mg/l)	Free CO2 (mg/l)
Total Alkalinity as CaCO3 (Mg/l)	Phosphorus as P (mg/l)
Non Carbonate hardness as CaCO3 (Mg/l)	Dissolved Oxygen as O2 (mg/l)
Caclium as ca (mg/l)	Total organic Nitrogen as NH3 (mg/l)
Magnesium as Mg (Mg/l)	
Sodium as Na (Mg/l)	Coliforms/ml
Potassium as K (Mg/l)	Faecal Coliforms
Chloride as Cl (Mg/l)	E.Coli (MPN/100ml)
Sulphate as SO4 (Mg/l)	Pseudomonas Aeruginosa Bacteria
Silica as SiO2 (Mg/l)	Coliform (MPN/100ml)
Iron as Fe (Mg/l)	E-Coli MFT
Nitrate as NO3 (Mg/l)	E-Coli normal
Fluoride as F (Mg/l)	Coliform Normal
Residual Free chlorine	Coliform MFT

The WHO drinking water quality guidelines for the parameters of focus in this study are identified in Table 2. All standards include both the desirable limit and the permissible limit in absence of an alternative source.

Table 2: *WHO drinking water quality standards (WHO 2011)*

pH	Fluoride	Turbidity	Conductivity	TDS	E. coli	Coliform
6.5-9.5[a]	1.5mg/l	<10 NTU	<800uS	600-1000mg/l[b]	absent	absent

[a]No health-based guideline value for pH is proposed by the WHO; however, they do suggest an optimum pH within this range

[b]No health-based guideline value for TDS is proposed by the WHO; however, they do provide this range for which palatable water should fall within

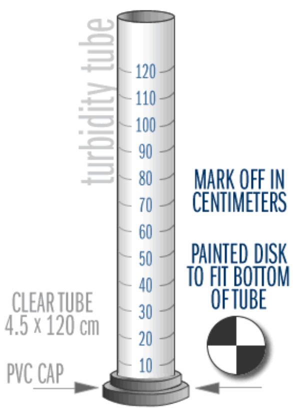
IV. Results: Kit

A. Contents of the Field Based Testing Kit

The field based testing kit was designed to test the water sources along the water supply chain under the environmental and financial constraints of the rural villages surrounding Jodhpur. It is meant to permit routine water quality testing for a small set of critical parameters frequently, rapidly, easily, affordably and accurately. We chose each instrument based on ease of use, reliability during field testing, and portability. To test for the parameters affecting health in the region we included instruments to quantify turbidity, total dissolved solids (TDS), pH, *E. Coli* and Coliforms, conductivity (salinity), and fluoride concentration. Use of most of the instruments is quite intuitive. Some, however, would require training for proper use.

1. Turbidity

Two instruments were chosen for testing the turbidity of the water; a simple secchi disk tube (T-tube) and a more advanced battery operated Hach Field Turbidimeter. Both the T-tube and the turbidmeter are rugged, portable, and easy to use. The T-tube, shown on the left, is a very basic design composed of a large plastic cylinder with a secchi disk at the bottom and a short water dispensing tube at the base. For testing, the T-tube is filled to the top with sample water. The water is slowly released from the dispensing tube while the operator watches the secchi disk from the opening at the top of the cylinder. The water is shut off from the release tube with a small plastic clamp as soon as the pattern of the Secchi disk is no longer visible. The depth of the water is recorded using the measurements printed on the side of the cylinder and is a taken as a measure of water transparency. This depth, in centimeters, is then converted to the corresponding NTU value or range using a table provided by the manufacturer. If this instrument can be validated using the turbidmeter it would provide a very simple way for villagers to monitor the turbidity of their drinking water, which provides an index of the concentration of particles and a rough predictor of the presence of bacteria.



The turbidimeter, shown to the left, utilizes a light source and sensor to measure the scattering of light caused by particles in the water sample. Prior to testing the meter must be calibrated and set to the correct turbidity range. For testing, the water sample is collected in a small vial and inserted into the sample chamber. The screen displays the turbidity measurement in NTUs; a high value (greater than 5) reflects an elevated concentration of particles and may also indicate the presence of microorganisms, as the maximum response of the instrument is in the particle size range also characteristic of bacteria and algae. Some training is required for instrument calibration and to understand interferences, but ultimately this is a reliable method for routine water quality screening. *(Images from lakeaccess.org and labX.com.)*

2. Conductivity

Pocket Pals are handheld meters made specifically for field testing. They are very simple to use, battery powered, factory calibrated and are made to withstand field conditions. We purchased a Hach conductivity Pocket Pal that measures the conductivity between two electrodes at the bottom of the instrument. The conductivity increases as the concentration of ions in solution increases, yielding a measurement directly related to the salt concentration in the sample. This device is used by simply pressing a button to turn it on, then inserting the tip of the instrument into the sample and pressing a button to take a measurement. Readings are given on a small screen on the front of the device. The instrument must be intermittently calibrated with pre-mixed calibration solutions to ensure accuracy of measurements. *(Image from Hach.com)*

3. TDS

Total dissolved solids were measured using an Eco Testr, very similar to the Pocket Pal design, developed by Oakton. This instrument is also designed for field testing, runs on batteries, is factory calibrated, and very simple to use. Testing involves inserting the tip into the sample after the device it turned on then pressing a button to initiate the measurement. Once the value given on the small display screen is steady the reading can be taken. This instrument also measures conductivity, but it converts readings to a parts per million (mg/L) total dissolved solids measurement that is easy to read and understand. Intermittent calibration using pre-mixed calibration solutions, available from Oakton, ensures accuracy of measurements. *(Image from Hach.com)*

4. pH

We also purchased an Oakton pH Eco Testr. Similarly, this instrument is designed for field testing, runs on batteries, is factory calibrated, and very simple to use. The tip contains an ion selective (H+) electrode that is developed to be protected against breakage in the field. A similar procedure is followed; the tip is inserted into the sample once the instrument is on, the measurement button is pressed, a reading is taken when the value displayed is stable. This instrument must also be intermittently calibrated to maintain accuracy of measurement. *(Image from Hach.com)*

5. E. Coli and Coliform Tests

Traditional microbiological tests require precise measurements, sterile technique, and are very time intensive. These protocols not easily transferrable to conditions in the field, but Hygenia Micro-Snap pens, a rapid test for detection of specific bacteria, is somewhat adaptable to performing microbiological assessments in the field. E. coli and coliforms are targeted as indicators of fecal coliforms, the major cause of diarrheal illness in drinking water. For testing, a 10 mL water sample is drawn up using a 30 mL syringe. The water is then filtered through a syringe tip filter and the filter is removed and placed in a petri dish. Enrichment broth is poured over the filter, enabling the growth of bacteria. The petri dish is then placed in a battery powered incubator and left to incubate for seven to eight hours. After incubation, 1-3 mL of the enrichment broth is pipetted into the Micro-Snap pen. The head of the pen is snapped to release a specialized substrate, which is only broken down by the target organism, and the pens are placed back in the incubator for 10 minutes. If the target bacteria are present enzymes will break down the substrate, producing light. This signal is quantified using a handheld luminometer. The luminometer gives a reading of relative light units (RLUs). This value is then converted to colony forming units (CFUs), an estimate of the number of viable target bacteria within the sample, using a table provided by Hygenia. This test involves the use of sterile technique, measurement of specific sample volumes, and adherence to procedures that would require training. Furthermore, an autoclave is needed to sterilize equipment between tests. *(Images from Hygenia.net, UnitedLabPlastics.com)*

6. Fluoride

An Orion fluoride specific electrode with a reference electrode and a hand held millivolt meter is used to determine the concentration of fluoride. To obtain fluoride measurements a standard curve of known fluoride concentrations that bracket the sample concentration needs to be made. Within the proper concentration range this curve is linear, and linear regression of these points yields a trendline that can be used to determine the unknown concentration of the sample. Each sample is mixed with the appropriate total ionic strength adjustment buffer (TISAB IV) at a 1:1 ratio prior to testing. This TISAB buffer fixes the ionic strength of the solution and buffers the pH to the appropriate range for accurate measurements. TISAB IV is suggested for use when testing waters with high concentrations, up to 100 ppm, of ligands such as iron or aluminum. If ligands complex the fluoride it is not detected by the electrode. It is important to use plastic labware as fluoride can adsorb to glass resulting in inaccurate results. Calibration solutions and samples must also be measured at a constant temperature as changes in temperature can affect measurements. *(Images from ThermoScientific.com)*

7. Cost of field based water quality testing kit

The cost of the kit components may change based on manufacturer, retailer, and educational discounts. As such, the costs shown in Table 3 are subject to change. The estimated total cost of the instruments in the kit is 7,676.46 USD. Additional shipping costs came out to approximately 2,000 USD but this would not be a factor for a kit assembled in India.

Table 3: Cost of Field Testing Kit Instruments

Instrument	# in pack	# packs purchased	Cost
pH Pocket Pal	1	1	$ 65.00
Turbidimeter	1	1	$ 1,010.00
Conductivity Pocket Pal	1	1	$ 74.50
Total Dissolved Solids Pocket Pal	1	1	$ 74.50
Microbiological			
- *E. coli Microsnap Pens*	100	2	$ 650.00
- *Coliform Microsnap Pens*	100	2	$ 600.00
- *Luminometer*	1	1	$ 1,395.00
- *Enrichment Broth*	100	2	$ 250.00
- *Calibration Control Kit*	1	1	$ 300.00
- *Incubator*	1	1	$ 721.75
- *Syringe Filter Membranes 0.045 µm*	100	2	$ 143.62
- *Syringe Filter Holders*	6	3	$ 257.31
- *Sterile Petri Dishes*	500	1	$ 65.80
- *Sterile 30 ml Syringes*	50	4	$ 132.84
- *Sterile Transfer Pipettes*	500	1	$ 34.14
Fluoride			
- *Electrode*	1	1	$ 665.00
- *Reference Electrode*	1	1	$ 240.00
- *Millivolt Meter*	1	1	$ 997.00
Total Cost			$ 7,676.46

V. Results: Tests

1. Village Test Results

For testing, water samples were collected in reusable plastic containers routinely used by JBF. Within each village, water samples and field tests were done at multiple points at the talab, a tanka, and a matki. Additionally, when possible, a sample was taken from the beris. Tanka and matki samples were taken from the same homes each week when possible. All sampling and field testing were done throughout the month of July, 2013. This is the beginning of the transition from dry season to monsoon season, which allowed us to test the water quality both when the talab was at its lowest point and as the volume started to increase.

Surani

Throughout the sampling period, the pH of all sampled drinking water sources fell within the desirable range of 6.5 to 9.5. The talab turbidity was consistently above the permissible range of 10 NTUs (although turbidity is regulated at a much lower level (< 1 NTU) in the U.S.A.) but the turbidity of the matki and GLR were both within the range, with the exception of the GLR on our final visit. Most of the conductivity and TDS measurements were within the desirable limits of 200 µs and 600 ppm respectively. While the conductivity of the GLR was slightly over the desirable limit, it still fell within the permissible limits in the absence of an alternative source. E. coli and coliform tests, while highly variable, indicated the presence of microbial contamination throughout the drinking water supply chain.

Table 4: Summary of *Surani Data*

		pH		Fluoride (ppm)		Turbidity (NTUs)					
Date	Location	pH electrode	pH pp	TISAB IV	TISAB JBF	Turbidimeter	T-tube	Conductivity (uS)	TDS (ppm)	E. coli (CFUs)	Coliform (CFUs)
3-Jul	Talab	8.2	--	0.4	--	358	--	--	--	--	--
11-Jul	Steps	8.5	--	0.2	--	150	90	--	--	--	--
	Tanka withdrawl spot	8.6	--	0.2	--	129	120	--	--	--	--
	Feeder channel	8.1	--	0.3	--	210	120	--	--	--	--
	GLR	7.7	--	0.1	--	2.4	--	--	--	--	--
	Matki A	7.6	--	0.7	5.1	5.7	--	--	--	--	--
	Tanka A	8.4	--	0.7	--	4.8	--	--	--	--	--
	Tanka 2	7.8	--	0.5	--	19.1	--	--	--	--	--
18-Jul	T. Steps	8.5	9.2	0.3	--	85.1	65	143	177	50-500	50-500
	T. Feeder	8.7	9.4	0.3	--	28.2	24	143	177	100-5000	100-5000
	GLR	8.4	9.4	0.1	0.4	6.3	<10	201	250	50-200	100-5000
25-Jul	Feeder	8.5	9.3	--	1.5	75.6	15	157	180	200-5000	1000-5000
	Steps	8.2	9.1	--	1.4	78.2	19	159	180	1000-5000	1000-5000
	GLR	8.3	8.6	--	0.3	47.6	12	221	260	50-5000	1000-10000
	Matki	8.0	--	--	1.3	--	--	--	--	--	--

Jaithmal

Generally, the pH of the drinking water in Jaithmal is within the acceptable range. However, the measurements taken with the electrode show the talab water to have the lowest pH while the measurements taken with the Pocket Pal show the talab water to have the higher pH of the different water sources. The turbidity at the talab was consistently significantly over the permissible limit of 10 NTUs, but acceptable for the GLR, tanka, and matki. With the exception of the tanka, all of the drinking water sources had conductivity and TDS within permissible limits. E. coli and coliforms tests were highly variable but consistently indicated microbial contamination.

Table 5: *Summary of Jaithmal Data*

		pH		Fluoride (ppm)		Turbidity (NTUs)					
Date	Location	pH electrode	pH pp	TISAB IV	TISAB JBF	Turbidimeter	T-tube	Conductivity (uS)	TDS (ppm)	E. coli (CFUs)	Coliform (CFUs)
3-Jul	Talab	7.5	--	0.4	--	Over detect limit	--	--	--	--	--
9-Jul	Talab	7.7	--	0.3	--	652	>240	--	--	--	--
	GLR	8.3	--	0.5	3.3	2.9	--	--	--	--	--
	Beris	7.2	--	0.1	--	20.4	--	--	--	--	--
	Tanka	8.4	--	0.8	5.6	2.6	--	--	--	--	--
	Matki	8.4	--	0.4	--	3.2	--	--	--	--	--
16-Jul	Steps	7.9	9.9	0.2	1.2	370	>240	91	160	50-1000	20-1000
	Opp steps	8.2	10.4	0.2	--	431	>240	127	173	20-1000	100-1000
	GLR	8.3	8.2	0.5	--	4.1	--	259	347	100-500	1000-5000
	Tanka	8.6	8.5	0.7	4.7	7.5	--	796	1047	--	--
23-Jul	Steps	9.2	9.8	--	1.0	617	>240	172	190	100-1000	500-5000
	Opp steps	8.9	9.7	--	1.0	311	185	151	180	500-1000	500-5000
	GLR	8.1	8.2	--	2.9	17.8	<10	313	357	50-5000	5000-10000+
	Tanka	8.3	8.7	--	0.5	7.0	--	866	143	--	--

Newai

Throughout July, the pH of the talab was consistently the highest of the drinking water sources, and the Pocket Pal detected a pH outside of the permissible range. The talab turbidity is consistently above the permissible range and the highest amongst the different sources tested. The turbidity of the tanka and matkis were highly variable, even exceeding the acceptable value a few times. The conductivity and TDS were within the permissible range except for the TDS of the talab, which exceeded the permissible value on the last sampling date. E. coli and coliforms tests were highly variable but consistently indicated microbial contamination.

Table 6: *Summary of Newai Data*

		pH		Fluoride (ppm)		Turbidity (NTUs)					
Date	Location	pH electrode	pH pp	TISAB IV	TISAB JBF	Turbidimeter	T-tube	Conductivity (uS)	TDS (ppm)	E. coli (CFUs)	Coliform (CFUs)
3-Jul	Talab	8.9	--	0.5	--	30.8	--	--	--	--	--
10-Jul	Talab	9.2	--	0.6	3.6	54	19	--	--	--	--
	Tanka A	8.2	--	0.4	--	2.4	--	--	--	--	--
	Matki A	8.6	--	0.4	--	3.9	--	--	--	--	--
	Tanka B	8.6	--	0.5	--	15.5	--	--	--	--	--
	Matki B	8.4	--	0.5	3.0	11.7	--	--	--	--	--
18-Jul	Talab A	9.2	9.6	0.7	3.4	81.9	40	447	565	50-500	200-500
	Talab B	9.0	9.4	0.7	--	75.5	35	449	573	100-200	500-5000
	Matki	8.6	8.4	0.5	--	8.5	--	353	443	100-200	100-10000+
24-Jul	Talab A	9.2	9.9	--	3.1	108	35	528	617	200-5000	1000-5000
	Talab B	8.9	9.8	--	3.1	98.1	30	545	623	20-1000	1000-10000
	Tanka	8.1	8.4	--	1.7	42.3	--	257	300	--	--
	Matki	8.3	8.4	--	2.1	--	--	376	450	100-5000	5000-10000

Norwa

We only sampled at Norwa two times, the first sample date fell at the end of the dry season and the second just after the first rain with the talab significantly filled. As can be seen in the table above, the pH of the all of the locations is within the desirable range. Turbidity measurements are all above desirable limits with the exception of the GLR, which was very clear. All water sources produced conductivity measurements above the permissible limit except for the talab after it filled. Three TDS measurements were below the permissible limits, all taken from various locations around the talab. Fluoride and microbiological tests were unreliable and inconsistent. However, measurements taken at this location indicate that fluoride is potentially above the desirable limit, and the E. coli and coliforms tests indicate strong microbial contamination.

Table 7: *Summary table for Norwa*

		pH		Fluoride (ppm)		Turbidity (NTUs)					
Date	Location	pH electrode	pH pp	TISAB IV	TISAB JBF	Turbidimeter	T-tube	Conductivity (uS)	TDS (ppm)	E. coli (CFUs)	Coliform (CFUs)
19-Jul	Talab	8.1	9.4	1.1	--	51.6	120	1407	1720	200-500	1000-5000
	GLR	7.8	7.6	0.3	--	3.4	--	6853	8600	20-200	1000-10000+
	Beris	8.1	7.7	1.3	5.9	51.1	21	1782	2213	200-1000	1000-10000
26-Jul	Talab	7.5	8.7	--	0.4	198.7	100	316	387	1000-5000	1000-10000
	GLR	7.0	7.5	--	1.2	6.1	<10	5560	6500	0-1000	500-5000
	Matki (Beris)	8.0	8.0	--	5.6	21.2	--	1783	2107	500-1000	500-5000
	Feeder	7.7	8.1	--	1.3	140.0	--	991	1147	500-5000	50-5000

2. Parameters

Conductivity and TDS

Results, displayed in Appendix D and E, show that the conductivity and the TDS Eco Testr produced precise readings for each sample location. The electrode brought to validate these results did not work after shipping, as a result we were unable to determine the accuracy of the hand-held devices.

pH

The pH of the water sources was tested in the field using the pocket pal and validated in the laboratory with a standard pH probe. Results obtained from the pH pocket pal, provided in Appendix A, show that this instrument gives precise results. The average standard deviation for all readings is 0.0, with the largest standard deviation being 0.2.

The pocket pal was validated using a pH probe. The standard deviation for probe measurements is, 1.6 millivolts, resulting in no significant deviation in pH measurements. The average difference in pH measurements between the pocket pal and probe is 0.7. In six locations the pocket pal reports a difference of 1, and the greatest difference between the probe and the pocket pal is 2.6.

Turbidity

Results obtained using the Hach Turbidimeter, displayed in Appendix C, show that this instrument provided precise results at each sample location. Locations with a turbidity greater than 300 NTUs often had larger variation in measurement. The average standard deviation for all measurements was 4.23 NTUs.

The T-tube results, given in Appendix C, also gave precise results. Locations with greater turbidity tend to have greater variation between measurements. The average standard deviation across all measurements was 0.8 cm. The T-tube results were not validated by the Hach Turbidimeter. The data obtained is on average off by 54 NTUs from the more accurate turbidimeter measurements.

Fluoride

The fluoride concentration was determined in the lab using an ion selective electrode. The results obtained from the fluoride electrode, shown in Appendix B, are precise. However, the two different TISAB IV solutions yielded results that are an order of magnitude different

E. coli and Coliform

The Hygenia E. coli and coliform pens reported highly variable results for each sampling location. The reported values of colony forming units (CFUs), shown in Appendix F, span a range of one to two orders of magnitude at each location. Despite this variation in the results of almost all of the tests indicate microbial presence above the detection threshold of the test of 10 RLUs.

V. Discussion

A. Kit Contents

The cost of the field based kit, estimated at $7,676.46, was higher than we initially planned. This potentially impacts longer term goals. The kit was purchased and put together at Northwestern University and shipped to India for testing. Complications arose during shipping that added additional costs as well as impacted test results and validation.

Conductivity, TDS, pH, and Turbidity.

The conductivity, TDS, pH, and turbidity measurements are simple and reliable tests. The instruments brought to measure these parameters performed well. They were easy to use, portable, gave quick results, and could effectively be deployed in the field.

Fluoride

Fluoride determination was performed as a lab test due to failure of our portable millivolt meter. This complication may have arisen due to shipping issues. Fluoride measurements also require a 1:1 mix of sample and TISAB buffer. This adds material requirements and requires precise measurements that may complicate performing this test in the field. Additionally, the buffer requires a laboratory setting for mixing. The solution can also be purchased, but is relatively expensive and will increase testing costs.

Hygenia Micro-Snap pens

The Hygenia Micro-Snap pens were the most unreliable. While these require much less time to perform than the traditional most probable number (MPN) test they did not perform well as a field measurement. These tests were essentially done in the lab due to the need for long incubation times (6-8 hours). Refrigeration is also required to maintain the quality of the substrate in the pens as well as the enrichment broth. The need for sterile technique further complicates this procedure and strategies to avoid contamination need to be employed in the field. Access to an autoclave is required to clean the equipment & supplies between tests. Although, due to the naturally high temperatures in the region, the incubator would not be necessary, at least during the warmer months.

B. Village Test Results

The tests performed in this study indicate that the water quality in these villages is highly variable but overall, relatively poor, at least over the period of our testing. As can be seen in the results many of the testing locations turbidity and conductivity were above desirable limits set by the WHO. E. coli and coliforms tests, while highly variable, indicate the presence of fecal contamination in all sources. The results of this rough determination of water quality indicate potential health concerns.

Water in the talab was generally of poorer quality than the storage sources further along the water supply chain. Talabs frequently had the highest turbidity while tankas, matkis and GLRs had the lowest turbidity. However, the GLR had the highest conductivity and TDS. Matkis and tankas are filled from the talab, but frequently have the best water quality. Water sits in them for extended periods of time, allowing particles to settle out, resulting higher water quality. However, the matki water frequently comes into direct contact with potentially dirty hands and utensils which could be why they show a spiked E. coli and coliform count compared to the other sources.   Tankas and matkis also frequently had lower conductivity and TDS. This may be due to the fact that the tanka water was filled earlier in the year when the talab was less saline.

The village of Norwa appeared to have the lowest water quality of all villages selected. This village was added to the testing regime because it was known to have elevated fluoride concentrations. However, it also had elevated TDS and conductivity measurements at all sampling locations.

C. Efficacy

The results for the conductivity and TDS Eco Testrs were precise. Due to complications with the instrument brought to validate conductivity and TDS we were unable to evaluate the efficacy of these instruments. However, these tests are relatively simple and reliable, and the equipment used in this study is trusted as established as field instruments.

The pH Pocket Pal also delivered precise results. There was an average difference in measurements of 0.7, but this may just be due to natural variation in measurements taken in the field. Generally, the Pocket Pal readings were higher than the pH electrode values tested in the lab, but still fell within or near the acceptable pH range for drinking water. All things considered, we recommend these instruments for use in a mobile field based testing kit but also recommend further testing and validation.

The Hach portable turbidimeter is expected to be very accurate because the protocol is the same as that used in a laboratory. The average standard deviation in measurements was 4.2-- relatively small when considering turbidity. Therefore, we recommend this instrument as a precise, accurate, and reliable way to measure turbidity in the field. The efficacy of the T-tube was assessed using the Hach turbidimeter. The deviation of measurements of the Hach turbidimeter on average was 54 NTUs. These measurements were consistently quite different than those obtained using the turbidimeter. Therefore, based on our tests. we are not confident of the accuracy of the T-tube. However, further development of this method could prove its usefulness in a field based water quality testing kit, even if just as a screening mechanism.

Fluoride measurements were highly variable due to the use of two different buffer solutions. The TISAB IV solution, suggested for waters with high ligand concentrations, sets the ionic strength as well as buffers the pH of the solution for measurement. It was assumed that talabs would have high ligand concentrations due to the method of water collection. As can be seen in Tables 4 – 7 when a different recipe for the TISAB IV solution was used fluoride measurements were an order of magnitude higher. To determine the concentration of fluoride at these villages, the accuracy of measurements with the two different TISAB solutions will have to be investigated further.

The results obtained from the Hygenia Micro-Snap pens were extremely variable. Data from a single location spanned at least an order of magnitude. Due to this imprecision we cannot currently recommend these as an instrument to determine bacterial quality. However, we believe that further testing of this method is warranted due to the fact that they produce results significantly faster than traditional methods and the required time may possibly be reduced under field conditions. The prolonged exposure of these tests to high temperatures while retained by customs could be the reason for the poor precision in this study. Due to limited availability of laboratory materials and time, we were unable to validate the results with another method to determine if the accuracy of the measurements of microbial content.

Based solely on precision and manageability, we strongly recommend the inclusion of the pH Pocket Pal, TDS and conductivity Eco Testrs, and the field turbidmeter in a regularly used field based water quality testing kit. Further investigation into a Fluoride selective field electrode is necessary. The Micro-Snap pens also need further testing and modifications but at this point we can not recommend them for the field based kit. Instead, after further insight is drawn, we suggest that they not be routinely used but only deployed as necessary due to the energy, temperature, and material requirements. Following this study, additional testing is needed in order to verify the accuracy of all instruments.

D. Future

Overall the field based testing kit was easy to use and manageably portable, but there are some issues that may arise when attempting to implement it as a regular testing strategy in villages. First, a better method for transportation would be desirable. All of the instruments themselves could easily fit into a large cooler however, with the addition of all of the necessary daily consumables such as deionized water, beakers, syringes, pipettes, tweezers, etc, the contents become harder to handle and impossible for a single person, particularly when performing multiple tests in a day. On a daily basis two large coolers, the incubator, and a backpack were necessary for transporting the kit from village to village. This was only manageable because we were using a jeep. However, in the future the size of the regular testing kit should allow easy transportation on a readily available vehicle, such as a motorcycle. We would like to be able to reduce the contents of the kit down to a single backpack. This could be possible if we are able to employ regular testing of small indicator parameters and follow up with the more material extensive instruments only as necessary.

Most of the equipment physically worked well in the stressful environmental conditions of rural India, with the exception of the Mico-Snap pens. The protocol of the pens and the enrichment require constant refrigeration and the manufacturer warns that long exposure to high temperatures can compromise the accuracy of the pens. Addressing the energy and temperature requirements of the Micro-Snap pens will be necessary to confirm that they are a viable option for a field based testing kit. But, perhaps the pens are not regularly necessary and will only be deployed to the field once a baseline parameter, such as turbidity, signals that further testing is required. This could also address the fact that the Micro-Snap pens are very material intensive and require sterilization between tests. Furthermore, although the Micro-Snap pens produce results much faster than traditional microbial tests, we would like to see an even faster method. Depending on the necessary sensitivity of the measurement, the time can be dropped down to an hour making the test much more feasible in the field but, the required sensitivity needs to be further explored.

VIII. Summary:

We believe that a field based testing kit is possible for routine water quality testing. However, there are a number of challenges related to ease of use and cost. With the help of JBF we were able to perform tests at villages that were very hospitable and welcoming with committed villagers that showed overwhelming interest. However, while we are able to confirm the precision of most of the contents of the kit, we were not able to validate the accuracy of any of the instruments. Of all of the instruments assessed fluoride and microbiological tests proved to be the most problematic.

Based on our preliminary results it is evident that all drinking water sources are of poor quality, but the quality does improve at various places along the water supply chain. The GLR water, while saline, was the cleanest drinking water source during the time of our sampling. When regularly used, this field based water quality testing kit would help inform villagers of this quality change across their supply chain, and provide insightful information about the optimal time frame for each drinking water source. This will allow villagers to take advantage of the cleanest drinking water throughout the year.

This project serves as a powerful first step for future work that will educate the Rajasthani people about methods of testing their drinking water and will ultimately help protect against harmful water related health effects.

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Appendix A: pH data

Limits
Desirable 6.5-9.5
Over limit

Measurements												
			pH probe (mV)				pH: Probe	pH: Pocket Pal			
	Date	**Location**	1	2	3	avg		1	2	3	avg
Newai	3-Jul	Talab	-101	-101.2	-100.9	-101.0	**8.9**				
Jaithmal	3-Jul	Talab	-10	-9.6	-9.5	-9.7	**7.5**				
Surani	3-Jul	Talab	-52.9	-53.1	-53.8	-53.3	**8.2**				
Jaithmal	9-Jul	Talab	-22.9	-22.8	-22.6	-22.8	**7.7**				
		GLR	-61.6	-62.1	-62.7	-62.1	**8.3**				
		Beris	11.5	11.7	11.1	11.4	**7.2**				
		Tanka	-67.1	-68.3	-67.9	-67.8	**8.4**				
		Matki	-67.4	-68.1	-67.9	-67.8	**8.4**				
Newai	10-Jul	Talab	-114.3	-115.5	-115.5	-115.1	**9.2**				
		Tanka A	-54.5	-53	-52.8	-53.4	**8.2**				
		Matki A	-77.3	-78.2	-78	-77.8	**8.6**				
		Tanka B	-77.4	-77.3	-77.1	-77.3	**8.6**				
		Matki B	-67.8	-67.3	-67.3	-67.5	**8.4**				
Surani	11-Jul	Steps	-72.1	-73.4	-73.1	-72.9	**8.5**				
		Tanka withdrawl spot	-81.8	-81.2	-81.9	-81.6	**8.6**				

		Feeder channel	-45.6	-45.5	-45.4	-45.5	**8.1**				
		GLR	-23.5	-23.4	-23.3	-23.4	**7.7**				
		Matki A	-45.9	-47.1	47.3	-15.2	**7.6**				
		Tanka A	-65.3	-64.5	-65.1	-65.0	**8.4**				
		Tanka 2	-27.8	-26.6	-27.1	-27.2	**7.8**				
Jaithmal	16-Jul	Steps	-35	-32.4	-32	-33.1	**7.9**	9.9	9.9	9.9	**9.9**
		Opp steps	-55.8	-56.5	-54.4	-55.6	**8.2**	10.4	10.4	10.4	**10.4**
		GLR	-56	-57.4	-57.7	-57.0	**8.3**	8.3	8.2	8.1	**8.2**
		Tanka	-81.3	-76.8	-76.4	-78.2	**8.6**	8.5	8.5	8.5	**8.5**
Newai	18-Jul	Talab A	-116.3	-117.4	-117.3	-117.0	**9.2**	9.7	9.6	9.6	**9.6**
		Talab B	-107.1	-106.8	-107	-107.0	**9.0**	9.4	9.4	9.4	**9.4**
		Matki	-80.3	-79.7	-79.8	-79.9	**8.6**	8.4	8.4	8.4	**8.4**
Surani	18-Jul	T. Steps	-71.1	-71.1	-71.4	-71.2	**8.5**	9.2	9.2	9.2	**9.2**
		T. Feeder	-84.3	-84.9	-84.7	-84.6	**8.7**	9.5	9.4	9.4	**9.4**
		GLR	-65.4	-64.1	-65.2	-64.9	**8.4**	9.5	9.4	9.3	**9.4**
Norwa	19-Jul	GLR	-24.9	-25.7	-26.6	-25.7	**7.8**	7.8	7.5	7.6	**7.6**
		Talab	-44.9	-44.4	-44.6	-44.6	**8.1**	9.4	9.4	9.4	**9.4**
		Beris	-44.1	-44.8	-44.9	-44.6	**8.1**	7.7	7.7	7.7	**7.7**
Jaithmal	23-Jul	Steps	-4.1	-5.4	-5.8	-5.1	**7.3**	9.9	9.8	9.8	**9.8**
		Opp steps	-19.3	-20.6	-21	-20.3	**7.5**	9.7	9.7	9.7	**9.7**
		GLR	-60.3	-61	-61.4	-60.9	**8.1**	8.3	8.2	8.2	**8.2**
		Tanka	-73.6	-73.4	-73.6	-73.5	**8.3**	8.7	8.7	8.7	**8.7**
Newai	24-Jul	Talab A	-126.8	-126.8	-127.1	-126.9	**9.2**	9.9	9.9	9.9	**9.9**
		Talab B	-106	-106.2	-106.2	-106.1	**8.9**	9.8	9.8	9.8	**9.8**

		Tanka	-57.7	-57.9	-58	-57.9	**8.1**	8.5	8.4	8.3	**8.4**
		Matki	-69.5	-69.8	-69.6	-69.6	**8.3**	8.4	8.4	8.4	**8.4**
Surani	25-Jul	Feeder	-83.4	-83.7	-83.5	-83.5	**8.5**	9.3	9.3	9.3	**9.3**
		Steps	-65.1	-65.3	-65.4	-65.3	**8.2**	9.1	9.1	9.1	**9.1**
		GLR	-68.1	-67.6	-67.6	-67.8	**8.3**	8.6	8.6	8.5	**8.6**
		Matki	-50.4	-50.5	-50.9	-50.6	**8.0**	--	--	--	**--**
Norwa	26-Jul	Talab	-19.4	-19.4	-19.8	-19.5	**7.5**	8.8	8.6	8.6	**8.7**
		GLR	-18.2	-19.3	-20.3	-19.3	**7.5**	7.5	7.5	7.5	**7.5**
		Matki-Beris	-52.6	-53.1	-53.5	-53.1	**8.0**	8.0	8.0	8.0	**8.0**
		Feeder	-34.5	-34.1	-34.3	-34.3	**7.7**	8.2	8.1	8.1	**8.1**

Appendix B: Fluoride data

Limits

Desirable	1.0	mg/L
Max in absence of alternative source	1.5	mg/L

Over limit
Over Max

	Date	Location	mV: TISAB JBF Recipe 1	2	3	avg	ppm
Newai	3-Jul	Talab	--	--	--	--	**--**
Jaithmal		Talab	--	--	--	--	**--**
Surani		Talab	--	--	--	--	**--**
Jaithmal	9-Jul	Talab	--	--	--	--	**--**
		GLR	44.4	44.3	44.6	44.4	**3.3**
		Beris	--	--	--	--	**--**
		Tanka	31.6	30.8	30.4	30.9	**5.6**
		Matki	--	--	--	--	**--**
Newai	10-Jul	Talab	42.8	42.7	42.8	42.8	**3.6**
		Tanka A	--	--	--	--	**--**
		Matki A	--	--	--	--	**--**
		Tanka B	--	--	--	--	**--**
		Matki B	47.4	47.4	47.3	47.4	**3.0**
Surani	11-Jul	Steps	--	--	--	--	**--**
		Tanka withdrawl spot	--	--	--	--	**--**

		Feeder channel	--	--	--	--	**--**
		GLR	--	--	--	--	**--**
		Matki A	33.3	33.3	33.8	33.5	**5.1**
		Tanka A	--	--	--	--	**--**
		Tanka B	--	--	--	--	**--**
Jaithmal	16-Jul	Steps	72.2	71.6	71.7	71.8	**1.2**
		Opp steps	--	--	--	--	**--**
		GLR	--	--	--	--	**--**
		Tanka	35.5	35.3	34.9	35.2	**4.7**
Newai	18-Jul	Talab A	44.5	44.2	44.1	44.3	**3.4**
		Talab B	--	--	--	--	**--**
		Matki	--	--	--	--	**--**
Surani	18-Jul	T. Steps	--	--	--	--	**--**
		T. Feeder	--	--	--	--	**--**
		GLR	97.4	98.2	97.7	97.8	**0.4**
Norwa	19-Jul	GLR	--	--	--	--	**--**
		Talab	--	--	--	--	**--**
		Beris	29.6	29.4	29.4	29.5	**5.9**
Jaithmal	23-Jul	Steps	73.6	72.9	72.8	73.1	**1.0**
		Opp steps	73.3	73.3	72.8	73.1	**1.0**
		GLR	47.9	47.8	47.4	47.7	**2.9**
		Tanka	90.5	90.9	91.4	90.9	**0.5**
Newai	24-Jul	Talab A	46.8	46.4	46.3	46.5	**3.1**
		Talab B	46.4	46.3	46.3	46.3	**3.1**
		Tanka	60.6	60.4	61.1	60.7	**1.7**
		Matki	55.6	55.4	55.3	55.4	**2.1**
Surani	25-Jul	Feeder	64.1	63.8	63.8	63.9	**1.5**
		Steps	65.3	65.7	65.4	65.5	**1.4**
		GLR	103.1	103.8	103.6	103.5	**0.3**

		Matki	68	67.5	67.3	67.6	**1.3**
		Talab	95.8	95.3	95.2	95.4	**0.4**
		GLR	68.9	68.5	68.8	68.7	**1.2**
Norwa	26-Jul	Matki-Beris	32.4	32	31.8	32.1	**5.6**
		Feeder	68.4	67.9	67.8	68.0	**1.3**

Appendix C: Turbidity data

Limits

Desirable	5	NTU
Permissible in absence of alternative source	10	NTU
Over limit		
Over Max		

			Turbidimeter (NTU)			
	Date	**Location**	**1**	**2**	**3**	**avg**
Newai	3-Jul	Talab	31.5	30.1	30.8	**30.8**
Jaithmal	3-Jul	Talab	1000+	1000+	1000+	**Over detect limit**
Surani	3-Jul	Talab	359	357	358	**358**
Jaithmal	9-Jul	Talab	649	660	648	**652.3**
		GLR	3.02	2.66	2.98	**2.9**
		Beris	20.2	20.5	20.4	**20.4**
		Tanka	2.49	2.78	2.44	**2.6**
		Matki	3.15	3.28	3.03	**3.2**
		Talab wd 2	--	--	--	--
		Talab opp	--	--	--	--
Newai	10-Jul	Talab	56.1	53.7	52.2	**54.0**
		Tanka A	2.61	2.37	2.11	**2.4**
		Matki A	3.70	3.62	4.39	**3.9**
		Tanka B	17.2	14.6	14.6	**15.5**
		Matki B	11.8	11.6	11.7	**11.7**
		Talab wd 2	--	--	--	--
		Talab opp	--	--	--	--
Surani	11-Jul	Steps	153	148	150	**150.3**

		Tanka withdrawl spot	133	125	129	**129.0**
		Feeder channel	210	210	209	**209.7**
		GLR	2.57	2.1	2.44	**2.4**
		Matki A	6.46	5.16	5.54	**5.7**
		Tanka A	5.15	4.47	4.77	**4.8**
		Tanka B	20.5	18.6	18.1	**19.1**
		Talab wd 2	--	--	--	--
		Talab wd 3	--	--	--	--
Jaithmal	16-Jul	Steps	440	336	335	**370.3**
		Opp steps	441	415	436	**430.7**
		GLR	4.65	3.92	3.59	**4.1**
		Tanka	7.76	7.47	7.28	**7.5**
Newai	18-Jul	Talab A	82.2	81.0	82.6	**81.9**
		Talab B	73.3	77.0	76.2	**75.5**
		Matki	9.08	6.30	10.0	**8.5**
Surani	18-Jul	Feeder channel	86.5	89.0	79.7	**85.1**
		Steps	29.8	30.8	24.1	**28.2**
		GLR	6.17	6.29	6.40	**6.3**
Norwa	19-Jul	GLR	3.15	3.50	3.43	**3.36**
		Talab	54.3	48.4	52.1	**51.6**
		Beris	52.8	48.0	52.5	**51.1**
Jaithmal	23-Jul	Steps	645	588	619	**617.3**
		Opp steps	301	310	322	**311**
		GLR	29.7	13.2	10.4	**17.8**
		Tanka	7.97	6.20	6.79	**7.0**
Newai	24-Jul	Talab A	108	108	108	**108**

		Talab B	99.8	99.4	95.2	**98.1**
		Tanka	44.1	40.9	42	**42.3**
Surani	25-Jul	Feeder	74.6	75.5	76.7	**75.6**
		Steps	75.0	77.1	82.5	**78.2**
		GLR	49.6	49.9	43.2	**47.6**
Norwa	26-Jul	Talab	196	200	200	**198.7**
		GLR	7.38	4.82	6.01	**6.07**
		Matki-Beris	25.1	17.9	20.5	**21.2**
		Feeder	147	140	133	**140**

			Turbidity Tube (cm)					
	Date	**Location**	**1**	**2**	**3**	avg	**Extra Data**	**Turbidity (NTU)**
Newai	3-Jul	Talab	--	--	--	--		**--**
Jaithmal		Talab	--	--	--	--		**--**
Surani		Talab	--	--	--	--		**--**
Jaithmal	9-Jul	Talab	3.1	3.1	3.05	3.1		**>240**
		GLR	--	--	--	--		**--**
		Beris	--	--	--	--		**--**
		Tanka	--	--	--	--		**--**
		Matki	--	--	--	--		**--**
		Talab wd 2	2.2	2.9	2.6	2.6		**>240**
		Talab opp	2.95	2.5	2.6	2.7		**>241**
Newai	10-Jul	Talab	39.6	39.7	34.5	36.5	32.2	**19**
		Tanka A	--	--	--	--		--
		Matki A	--	--	--	--		--
		Tanka B	--	--	--	--		**--**

		Matki B	--	--	--	--		**--**
		Talab wd 2	41.3	35.4	40.9	38.9	38	**17**
		Talab opp	25.7	24.3	28.6	26.1	25.9	**30**
Surani	11-Jul	Steps	14.2	13.7	13.8	13.9		**90**
		Tanka withdrawl spot	10.25	10.4	10.4	10.4		**120**
		Feeder channel	10.06	9.8	10.8	10.2		**120**
		GLR	--	--	--	--		**--**
		Matki A	--	--	--	--		**--**
		Tanka A	--	--	--	--		**--**
		Tanka B	--	--	--	--		**--**
		Talab wd 2	14.1	13.85	13.15	13.7		**90**
		Talab wd 3	10.6	11.9	10.15	10.9		**100**
Jaithmal	16-Jul	Steps	6.1	5.6	3	4.9		**>240**
		Opp steps	5.6	5.8	5.8	5.7		**>240**
		GLR	--	--	--	--		**--**
		Tanka	--	--	--	--		**--**
Newai	18-Jul	Talab A	19.5	19.6	20.2	19.8		**40**
		Talab B	23.2	23.6	23.8	23.5		**35**
		Matki	--	--	--	--		**--**
Surani	18-Jul	Feeder channel	15.2	15.2	15.25	15.2		**65**
		Steps	27.6	32.6	32.4	31.1	31.8	**24**
		GLR	60+	--	--	60+		**<10**
Norwa	19-Jul	GLR	--	--	--	--		**--**
		Talab	10.7	9.4	10.2	10.1		**120**

		Beris	29.8	34.6	35.8	33.4		**21**
Jaithmal	23-Jul	Steps	3.7	4.2	4.2	4.0		**>240**
		Opp steps	7	7.2	7.2	7.1		**185**
		GLR	60+	--	--	60+		**<10**
		Tanka	--	--	--	--		**--**
Newai	24-Jul	Talab A	22.2	22.2	21.8	22.1		**35**
		Talab B	25.5	25.6	25.4	25.5		**30**
		Tanka	--	--	--	--		**--**
Surani	25-Jul	Feeder	41.2	41.8	41.6	41.5		**15**
		Steps	34.4	34.6	34.6	34.5		**19**
		GLR	48.2	--	--	48.2		**12**
Norwa	26-Jul	Talab	11	11.2	11.2	11.1		**100**
		GLR	60+	--	--	60+		**<10**
		Matki-Beris	--	--	--	--		**--**
		Feeder	--	--	--	--		**--**

Appendix D: Conductivity data

Limits

Desirable	200	uS
Permissible in absence of alternative source	800	uS
Over limit		
Over Max		

Conductivity (uS)

	Date	Location	1	2	3	avg
Jaithmal	16-Jul	Steps	80	97	97	**91**
		Opp steps	125	127	128	**127**
		GLR	256	257	263	**259**
		Tanka	797	799	791	**796**
Newai	18-Jul	Talab A	444	442	449	**447**
		Talab B	444	449	454	**449**
		Matki	349	355	355	**353**
Surani	18-Jul	T. Steps	142	140	147	**143**
		T. Feeder	140	144	144	**143**
		GLR	198	201	204	**201**
Norwa	19-Jul	GLR (1:10)	682	686	688	**6853**
		Talab (1:2)	705	703	703	**1407**
		Beris (1:2)	885	894	894	**1782**
Jaithmal	23-Jul	Steps	168	176	172	**172**
		Opp steps	150	152	152	**151**
		GLR	309	315	315	**313**
		Tanka	864	869	865	**866**
Newai	24-Jul	Talab A	520	538	526	**528**
		Talab B	545	545	544	**545**
		Tanka	256	258	258	**257**

		Matki	375	376	376	**376**
Surani	25-Jul	Feeder	156	157	157	**157**
		Steps	157	160	161	**159**
		GLR	219	222	222	**221**
Norwa	26-Jul	Talab	313	316	319	**316**
		GLR (1:10)	552	557	559	**5560**
		Matki-Beris (1:2)	891	892	892	**1783**
		Feeder	496	495	496	**991**

Appendix E: Total Dissolved Solids (TDS) data

Limits		
Desirable	600	mg/L
Permissible in absence of alternative source	1000	mg/L
Over limit		
Over Max		

TDS (ppm)

	Date	Location	1	2	3	avg
Jaithmal	16-Jul	Steps	160	160	160	**160**
		Opp steps	170	180	170	**173**
		GLR	320	350	370	**347**
		Tanka	1040	1050	1050	**1047**
Newai	18-Jul	Talab A	560	550	580	**565**
		Talab B	570	570	580	**573**
		Matki	440	440	450	**443**
Surani	18-Jul	T. Steps	170	180	180	**177**
		T. Feeder	170	180	180	**177**
		GLR	250	240	260	**250**
Norwa	19-Jul	GLR (1:10)	840	870	870	**8600**
		Talab (1:2)	870	860	850	**1720**
		Beris (1:2)	1110	1110	1100	**2213**
Jaithmal	23-Jul	Steps	190	190	190	**190**
		Opp steps	180	180	180	**180**
		GLR	350	360	360	**357**
		Tanka	150	140	140	**143**
Newai	24-Jul	Talab A	610	620	620	**617**
		Talab B	620	630	620	**623**
		Tanka	300	300	300	**300**

		Matki	450	450	450	**450**
Surani	25-Jul	Feeder	180	180	180	**180**
		Steps	180	180	180	**180**
		GLR	260	260	260	**260**
Norwa	26-Jul	Talab	380	390	390	**387**
		GLR (1:10)	640	650	660	**6500**
		Matki-Beris (1:2)	1030	1060	1070	**2107**
		Feeder	570	580	570	**1147**

Appendix F: E. Coli and Coliform data

			E. Coli						
			1		2		3		
	Date	Location	RLU	CFU	RLU	CFU	RLU	CFU	Overall
Jaithmal	16-Jul	Steps	9	50-100	22	200-500	45	500-1000	50-1000
		Opp steps	31	200-500	5	20-50	50	500-1000	20-1000
		GLR	17	100-200	25	200-500	no data	--	100-500
		Tanka	--	--	--	--	--	--	--
Newai	18-Jul	Talab A	21	200-500	29	200-500	8	50-100	50-500
		Talab B	18	100-200	20	100-200	no data	--	100-200
		Matki	16	100-200	14	100-200	18	100-200	100-200
Surani	18-Jul	T. Steps	26	200-500	19	100-200	10	50-100	50-500
		T. Feeder	62	1000-5000	66	1000-5000	20	100-200	100-5000
		GLR	14	100-200	10	50-100	13	100-200	50-200
Norwa	19-Jul	GLR	5	20-50	13	100-200	11	50-100	20-200
		Talab	28	200-500	28	200-500	30	200-500	200-500
		Beris	30	200-500	49	500-1000	28	200-500	200-1000
Jaithmal	23-Jul	Steps	16	100-200	50	500-1000	53	500-1000	100-1000
		Opp steps	42	500-1000	39	500-1000	38	500-1000	500-1000
		GLR	12	50-100	79	1000-5000	95	1000-5000	50-5000
Newai	24-Jul	Talab A	21	200-500	51	500-1000	68	1000-5000	200-5000
		Talab B	5	20-50	58	500-1000	53	500-1000	20-1000
		Matki	19	100-200	40	500-1000	61	1000-5000	100-5000
Surani	25-Jul	Feeder	23	200-500	73	1000-5000	79	1000-5000	200-5000
		Steps	74	1000-5000	77	1000-5000	80	1000-5000	1000-5000
		GLR	93	1000-5000	8	50-100	38	500-1000	50-5000
Norwa	26-Jul	Talab	134	1000-5000	80	1000-5000	85	1000-5000	1000-5000
		GLR	0	0	1	0-10	38	500-1000	0-1000

	Matki-Beris	45	500-1000	51	500-1000	122	1000-5000	500-1000
	Feeder	77	1000-5000	92	1000-5000	47	500-1000	500-5000

			Coliform						
			1		2		3		
	Date	Location	RLU	CFU	RLU	CFU	RLU	CFU	Overall
Jaithmal	16-Jul	Steps	6	20-50	42	500-1000	36	500-1000	20-1000
		Opp steps	17	100-200	16	100-200	51	500-1000	100-1000
		GLR	177	1000-5000	259	5000-10000	no data	--	1000-5000
		Tanka	--	--	--	--	--	--	--
Newai	18-Jul	Talab A	26	200-500	35	200-500	24	200-500	200-500
		Talab B	no data	--	108	1000-5000	50	500-1000	500-5000
		Matki	15	100-200	398	10000+	490	10000+	100-10000+
Surani	18-Jul	T. Steps	23	200-500	10	50-100	17	100-200	50-500
		T. Feeder	19	100-200	32	200-500	63	1000-5000	100-5000
		GLR	17	100-200	61	1000-5000	45	500-1000	100-5000
Norwa	19-Jul	GLR	no data	--	470	10000+	126	1000-5000	1000-10000+
		Talab	122	1000-5000	73	1000-5000	61	1000-5000	1000-5000
		Beris	271	1000-5000	245	5000-10000	188	5000-10000	1000-10000
Jaithmal	23-Jul	Steps	49	500-1000	44	500-1000	80	1000-5000	500-5000
		Opp steps	63	1000-5000	57	500-1000	67	1000-5000	500-5000
		GLR	248	5000-10000	664	10000+	544	10000+	5000-10000+
Newai	24-Jul	Talab A	128	1000-5000	68	1000-5000	121	1000-5000	1000-5000
		Talab B	186	5000-10000	182	5000-10000	140	1000-5000	1000-10000
		Matki	255	5000-10000	236	5000-10000	243	5000-10000	5000-10000
Surani	25-Jul	Feeder	121	1000-5000	176	1000-5000	78	1000-5000	1000-5000

		Steps	74	1000-5000	97	1000-5000	80	1000-5000	1000-5000
		GLR	84	1000-5000	201	5000-10000	142	1000-5000	1000-10000
Norwa	26-Jul	Talab	104	1000-5000	63	1000-5000	256	5000-10000	1000-10000
		GLR	62	1000-5000	116	1000-5000	44	500-1000	500-5000
		Matki-Beris	80	1000-5000	65	1000-5000	55	500-1000	500-5000
		Feeder	10	50-100	79	1000-5000	131	1000-5000	50-5000