SENSORS WITHOUT BORDERS
WATER SAFETY REPORT

2015-2016

SENSORS WITHOUT BORDERS

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SENSING NALGONDA DISTRICT'S WATER SAFETY

Water is the world's singular most precious resource: We rely on it for agriculture, industrialism, and of course, personal consumption. According to an ancient proverb, "Pure water is the world's first and foremost medicine." In the Nalgonda District of Andhra Pradesh, this vital medicine is missing from the lives of many. This report explores Sensors Without Borders' 2016 findings as our group measured the district's water fluoride levels.

INTRODUCTION

Sensing India Water Safey (SIWS) is a comprehensive water quality program conducted by our organization, Sensors Without Borders. For this initiative, we also worked with the field partners, Fluoride and Knowledge Action Network (FKAN), and the TKREC University student chapter of Engineers Without Borders (EWB-TKREC) network. This initiative's goal was to estimate the Nalgonda District's water fluoride levels across various water sources, including public tap, hand pump, bore well, and surface water sources (such as the Krishna river's).

When fluoride enters the body, it deposits itself on bones. Fluoride then replaces calcium and continuously weakens the bone structure. When present in optimal concentrations (0.5-1.0 mg/l), fluoride is beneficial for calcification of dental enamel, especially for children below 8 years of age.

Fluoride is often called a double-edged sword – in small dosages, it has remarkable influence on the dental system by inhibiting the formation of dental cavities. In higher dosages, however, the compound causes dental and skeletal fluorosis.

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Excessive fluoride intake occurs primarily from contaminated drinking water, but may also arise from from food. Crops grown from high fluoride water--such as rice, greens, and grains--may leave residue on the foodstuff. Cooking reduces the amount, but does not eliminate it. In addition, irrigation water tends to contain the highest fluoride levels.

High fluoride intake in concentrations of 1.5-2.0mg first results first in dental fluorosis, which is the disfigurement and weakening of teeth. Higher dosages of 3-6 mg/l leads to severely debilitating skeletal fluorosis. The disease affects the bone and ligaments, and such high intake may result in painful joint issues such as arthritis.

Intakes of 20-40 mg F/day over long periods have resulted in crippling skeletal fluorosis. Because a water source's distribution affects entire districts, high levels have the capacity to create

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an epidemic of stunted children and adults crippled in the arms and legs. Among the groups most affected by pernicious fluorosis, children are the most vulnerable.

Indeed, several generations of individuals with malformed appendages appear in certain parts of India, including the states of Telangana, Andhra Pradesh, Orissa, Uttar Pradesh and NE India. Andhra Pradesh's Nalgonda district is among those most severely affected.

This district's fluoride issue is especially problematic on account of its malnutrition epidemic: High levels of fluoride, coupled with low levels iron and calcium, further retard the formation of healthy bones.

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High water fluoridation creates a massive social cost on the country, particularly as it relates to women's and children's health. A 1999 survey estimates that 66 million people drink high fluoride water (measured by greater than 2 mg/l). This figure is likely significantly higher at the time of this report owing to rising population pressure.

2005-2006 INREM studies show that affected victims have a social cost burden of approximately Rs 5000 per year due to medical cost and wage losses. This would put the overall country burden of fluorosis at several thousand crores annually.

Ground level efforts to change the fluoride issue is inherently difficult. To start, fluorosis symptoms appear gradually, which makes it difficult to convince those affected that they will inevitably face serious long-term consequences, absent a change in water consumption habits. In addition, fluorosis is mostly limited to rural areas: In such regions, outreach efforts tend to be limited compared to urban campaigns, and inhabitants are often the least educated.

At the grassroots level, children are the best targets for a number of reasons. To start, children get affected with dental fluorosis at an early age and, as mentioned, are the hardest hit demographic. Early prevention is the single best tool in combatting the effects of fluorosis. Additionally, getting children involved make them conscious of a problem that they previously didn't deem as serious. When organizations involve children in water testing exercises, they quickly discern that their stained teeth and the conditions of the older people in the community have a common cause: Their unsafe water. This revelation is instrumental in galvanizing children to become "change agents" in the region.

When children realize the gravity of their water situation, they carry their new learning back home and convince their families to change their water drinking habits. Earlier, it was difficult to achieve this outcome. With the advent of easy, practical water testing devices like the Caddisfly, young children can become active participants in their community's water consumption habits. Many regions have not been exposed to such new tools, however, and remain woefully behind as it relates to awareness.

The union of SWB Engineers without Borders (EWB) volunteers aim to bridge this gap between the availability of low cost technology and local knowledge of the problem.

Trained EWB students have used the Caddisfly to undertake a broad water testing exercise in Nalgonda. These volunteers have also conducted capacity building exercises at the local schools, enabling the students to undertake their own water testing reports in the future.

The strategy of involving students as change agents for their region's fluoride water levels is easily deployable anywhere in India. Such an initiative is easily scalable when integrated with other existing programs, such as the government of India's School WASH programme. Additional partnerships, such as with the DFMC and UNICEF, may also prove instrumental in scalability and program sustainability.

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THE TECHNOLOGY

This project utilized a device called the Caddisfly. The company behind the creation of this equipment is a Bangalore-based startup called Ternup, which has since been acquired by a company called Akvo. The Caddisfly device is an accessible, mobile phone-coupled technology that measures water fluoride levels using a mobile phone's camera sensor. Though the device is admittedly not as accurate as government units, it is significantly more portable and cheaper.

The Caddisfly is low cost, portable, reasonably accurate, gives fast results, and is easy to use. These key benefits enable many people to use the device for fluoride level testing. In fact, it's a perfect instrument for the tech savvy younger generation. With a mere half day training course, however, anyone can learn to use a Caddisfly: This includes teachers, municipal workers, auto drivers, farmers, and any group of workers broadly distributed across the village and Mandal level. Any of these constituents may then use the device to measure their local water sources including those for drinking, irrigation, domestic and sanitation.

The Caddisfly's fluoride assay kit turns the smartphone camera into a colorimeter, making it portable, battery powered and widely available in the market. This feature allows for accurate testing to be performed inexpensively on the field. The Caddisfly also contains a test chamber for the water and reagent capsule, which, when mixed together, provides for accurate readings. This step is simple enough for a layman to perform. The Android app developed for the Caddisfly then interprets the color, and gives a more accurate measurement than would be given if using visual judgment alone. Results displayed on the app are comparable with the laboratory-based, expensive, Ion Selective Electrode method. In addition, interpreting the results does not require technical expertise.

Delving into the technology, fluoride estimation is based on the methodology developed by India's Bhabha Atomic Research Centre. The kit works by bleaching and developing the reagent's zirconium xylenol orange complex mixed with the water sample. The kit also provides a color chart of range 0–3 ppm. To perform the test, the user must mix a 4 ml water sample and 1 ml zirconium xylenol orange reagent. The color changes from pink to yellow, depending on the fluoride concentration in the sample. By comparing the color produced with the color chart, the fluoride content in the water can be quantified. However, it is difficult to correctly estimate the concentration due to human error in visual judgment and differing light conditions. Additional errors occur from the difficulty of accurately measuring liquid quantities is in field conditions.

The Caddisfly is currently being used throughout India and in many other parts of the world. In India, units have been deployed in Jhabua and parts of Karnataka. A pilot was conducted at Jharkhand to train Jal Sahiyas (women water workers) in the use of Caddisfly. Other pilots have been held in Kenya and Burkina Faso. Over the next few months, Caddisfly will be piloted in Punjab and Bolivia.

TRIAL OVERVIEW

Overview

- The TKREC chapter of Engineers Without Borders were trained by FKAN personnel on how to use the Caddisfly. This training session covered initial calibration, mixing techniques, and how to use the Caddisfly mobile app.

- Initially, water sample testing was performed on locations near the FKAN Marriguda headquarters.

- Once the EWB group had achieved some level of expertise, data collection began in the broader community.

- Water testing locations were identified in consort with FKAN personnel.

- A range of water sources were targeted, including public tap, hand pump, bore well, surface water sources such as those supplied by the Krishna river.

- Location of these water sources were often near primary schools, temples, mosques, Angawadi centres, bus stops, and some in farming areas.

- The test was purely quantitative in nature: All readings gave a fluoride value between 0 - 10ppm. An excess of 10ppm was rendered too inaccurate on account of the number of dilutions required to test such high values.

Baseline Observations

- The Nalgonda district of Telengana State, South India, covers an area of approximately 14,200 square kilometres (5,500 sq mi) and is home to 3.5 million people (2012 Census data).

- Nalgonda has 59 sub-districts, 17 towns, 1,135 villages, and 59 CD blocks.

- Nalgonda comprises of 3,327 habitations. Of these,1,440 habitations get surface water from fourteen different water supply schemes. There are an estimated 30,000 water sources in the Nalgonda District.

- Areas in Nalgonda facing fluorosis includethe Pakagudem hamlet in Metichandapur Grama Panchayat, the Idulagudem hamlet under Lenkalapalli Grama Panchayat, and the Gottipally village in Marriguda mandal.

- We chose to focus on the affected mandal of Marriguda, given its particularly endemic fluorosis.

- The SIWS pilot data collection exercise has been conducted primarily in Marrigudem Mandal (Block) that has 16 Gram Panchayats inclusive of 33 Habitations (Total). It has been estimated that the total number of drinking water sources listed by the Dept of RWSS is between 277 - 333 water sources.

Representative Sampling

At present, local governments monitor fluoride levels by deploying field personnel to collect samples from notified or tagged water sources in a given geographical area. This region is usually determined by assessing the population size surrounding a given water source. Next, the authority delivers these samples to a lab. Here, the lab personnel analyze these samples using sophisticated techniques such as ion chromatography.

Due to the efforts of activists and organizations (such as FKAN), the state has has begun to supply uncontaminated water from the Krishna tributary via pipeline. In addition, the state has since demarcated several water sources as “safe” or “unsafe.” To err on the side of caution, however, many drinking water sources--regardless of their actual safety--display a painted red “x” next to a pump or on the tank itself.

Another complication regarding the state’s actions arise from the fact that F- levels can fluctuate significantly given changes in environmental conditions. For example, rainfall during monsoon seasons affect levels, as do changing water usage patterns by local residents and local industries.

Thus, the state’s efforts are laudable but not specific enough to meet the needs of the local residents. For instance, it is entirely appropriate for local residents to avoid drinking from toxic water sources, as identified as sources with levels of F- greater than 1.5ppm), although these water sources are regularly used for domestic purposes including sanitation, other domestic purposes and irrigation (particularly for sources in agricultural areas), a sizable proportion of the non-notified sources whose values are surmised through statistical techniques may well actually be within safe levels (0.5 - 1.5ppm).

Therefore, it is important for all sources, representative and non-representative, to be sampled. Only this degree of thorough sampling is sufficient to get the full picture toxic and non-toxic sources. Doing so will maximize the safety for residents by demarcating unsafe sources, while also maximizing accessibility to precious safe water sources.

Representative sampling is advantageous for a few reasons. First, it provides a meaningful representation of the wider population's parameters. Secondly, it reduces the operational burden required to sample every water source in the area. For instance, it is estimated that there are approx. 330+ unique water sources in Marriguda Mandal and over 30000+ unique water sources in wider Nalgonda District composed of 57 Mandals. It is impractical and cost prohibitive to measure every water source in this region. Representative sampling, however, can provide key insights to decision makers regarding the overall fluoride problem. As a broad example, if the representative sample reveals that half of all pump water sources have excessive levels of fluoride, then a provisional budget may allocate funds to modify half of the region’s sources.

This study’s representative sampling uses statistical modeling techniques such as interpolation, a knowledge of hydrochemical and hydrogeological models, recent past meterological events such as Monsoon-derived rainfall. Accounting for these factors allowed our group to build a reasonably accurate model, which could then be used to construct an overall map of F- levels of every water source within the population.

The obvious disadvantage of this technique is that these models are far less accurate than measuring every water source. Representative sampling also fails to account for complex interactions taking place at significant depths underground, and may also be problematic if the sampled region's water source levels deviate significantly from the broader area's. Representative sampling must also account for any recent changes conducted by local governments. For instance, if the government remedies the water supply in 75% of the villages, then sampling the unaffected 25% will give an inaccurate picture. Sampling must also be conducted frequently: Surveys used to be conducted on a 5 year basis, but are now being conducted more frequently due to community pressures to supply this data on a yearly basis.

Presently, figures from Government of India put more than 100 districts in 20 states affected with high fluoride problems. State-led efforts to monitor fluoride content are conducted intermittently at best: Fluoride sensing should be conducted on a monthly basis ideally. Nodal agencies responsible for monitoring may not be effectively measuring levels, either, if they do not know how to use expensive, state-sponsored supplied kits. Moreover, fluoride levels of non-notified water sources are surmised using statistical techniques, which is the least accurate method of gauging water supply levels of fluoride.

Representative and interpolated water sources greater than 1ppm are cross-marked in red to indicate their toxicity as a drinking water source.

PHOTO CREDIT: NILUTPAL DAS

FINDINGS

A total of 165 water sources were sampled over an approximately 2-week period over the course of the sensing Indian water safety (SIWS) program. To recap, the program included 12 volunteers testing 4 main types of water sources: Hand pump, borewell, water tank, and tap.

SIWS has been carried out in two phases thus far - a pilot phase and a follow-up phase, each with their own objectives.

Enclosed is a summary of observations from the field, captured by different Engineers Without Borders (EWB) citizen science volunteers (CSV). These observations run the gamut from infrastructure-based to sociological observations. They capture the problem, as well as general notes or suggestions on how to remedy the issue at hand.

Problem Description	Observations / Suggestions
Insufficient Number of Sources	In some habitations where the water fluoride content is very high, there is only one Krishna water source. This is not sufficient for the nearly 200 houses dependent on the source.
Unhygienic Water Storage Facilities	The public tank of Krishna water should be covered at the top, while providing good drainage around it. Most tanks observed have no such cover. Algae is also forming due to constant water leaks. One drinking water tank neighbors another covered in sewage water.
Lack of surface water source means reliance on reverse osmosis filtration for drinking water	In areas with an absence of Krishna water, residents use reverse osmosis drinking water. This source tests at .12ppm, which is less than the .5 level recommended by the World Health Organization.
Unused Infrastructure	In one habitation, a newly-built water tank with a 10,000 liter capacity remained unused on account of no piped connection.
Greater Piped Connections	Only one connection between tanks is present in some habitations. A greater number is required.
Changing Behaviors	For example, the Marriguda Police Station has a well-maintained water tank, serviced every two days with Krishna water. In spite of this availability of safe water, locals are hesitant to drink from it due to the region's reputation for high fluoride. Thus, testing this water source in front of the locals and explaining its safety was successful in promoting knowledge and changing consumption habits. Local authority figures should endeavor similar public displays.

Problem Description (Cont'd)	Observations/Suggestions
Interconnection Between Krishna Water Supply and Borewell Pipes	One school had a Krishna water source, but its borewell connection rendered the water usable only for domestic purposes. Despite the availability of this safe water source, the school management wastes 1k-1.5k per day to import filtered mineral drinking water. Modifying the pipeline to provide Krishna for drinking water would result in significant cost savings and yield better water management practices.
Intermittent or No Krishna Water Supply	One Krishna pipeline was laid near a school, but the water supply was nonexistent.

PHOTO CREDIT: NILUTPAL DAS

PILOT OBJECTIVES

This study had several objectives, the first of which was to field test the accuracy of the Caddisfly devices. At present, few organizations are aware of such a low-cost sensor, and most rely

on the cumbersome, expensive equipment usually available to only state officials and scientists. By checking the Caddisfly's veracity and ease of use, Sensors Without Borders paves the way for other third parties to use this device for their own needs.

As explained prior, testing was done by collecting geo-tagged fluoride data across what was expected to be a range of fluoride levels. This was done by measuring these ranges across individual and community-based drinking water sources including public tap, bore well, groundwater, well water, and pumped water.

The second objective was to determine the suitability of drinking water in a region prone to high fluoride levels. Ample problems exist with previous efforts to undergo such testing, including limited scope, outdated data, and unclear results.

The third objective was to design a low-cost study that could be easily replicated by third parties interested in testing other areas of high fluoride. These third parties must be groups *other* than trained scientists; ie, students, residents, teachers, etc. In essence, these groups must be capable of conducting such a study, as they have the most to gain from performing such field work.

The fourth objective was to raise awareness among local groups, namely school children and teachers. From our observation, Angawadis are the perfect field partners for water testing exercises: they are abundant throughout India, they have a vested interest in water safety, and they are reputable members of the community. Other ideal partnerships include with law enforcement, farmers, local shop keepers, university students, and auto drivers.

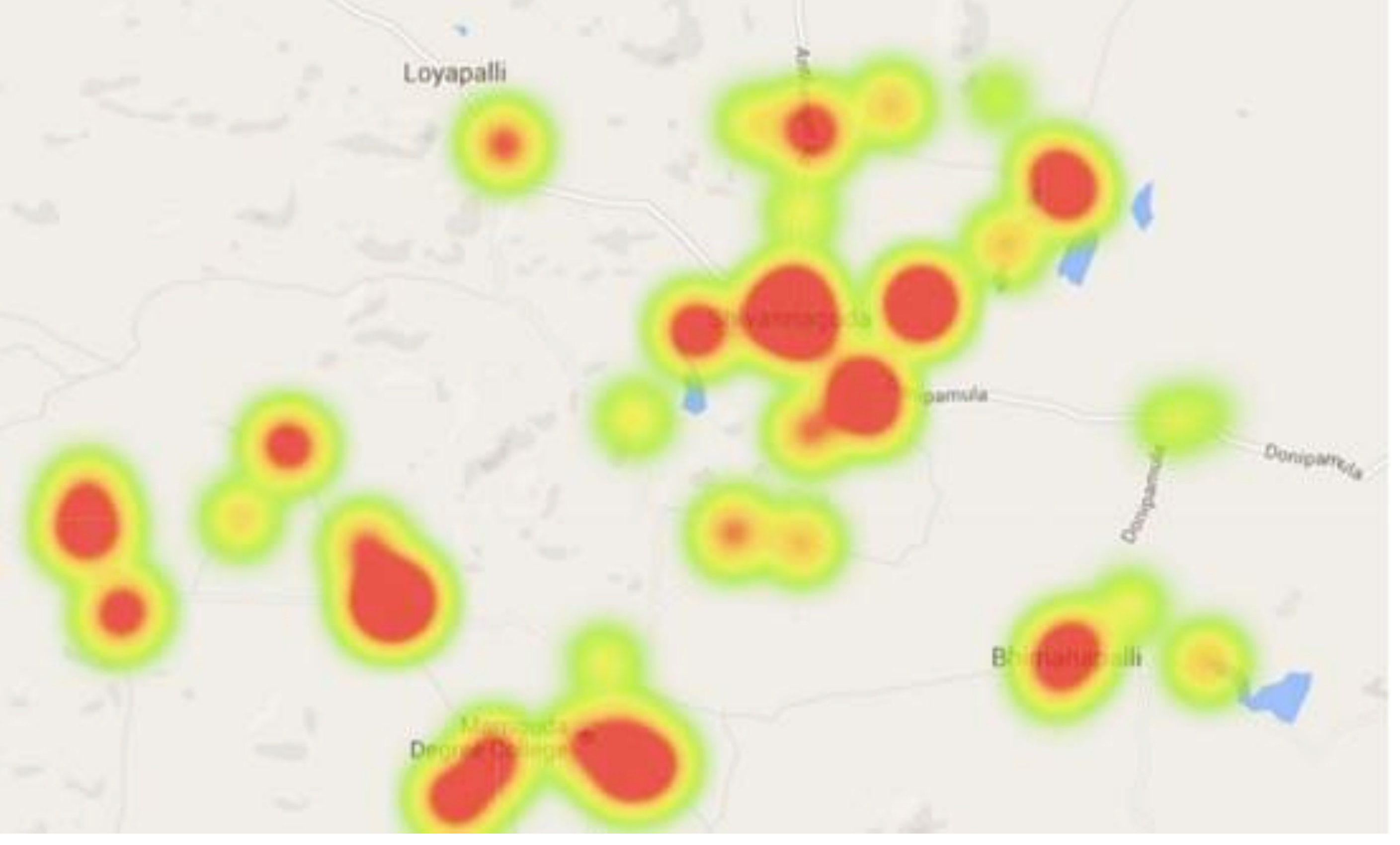
A fifth objective was determining weaknesses in the device and program design. For instance,

only by deploying volunteers with the Caddisfly could we determine that an appropriate number of reagents need to be on hand, in addition to the correct type for excessive fluoride levels. Such insight could only be gained from on-the-ground experience.

Fluoride Levels Across Geographic Levels of Interest

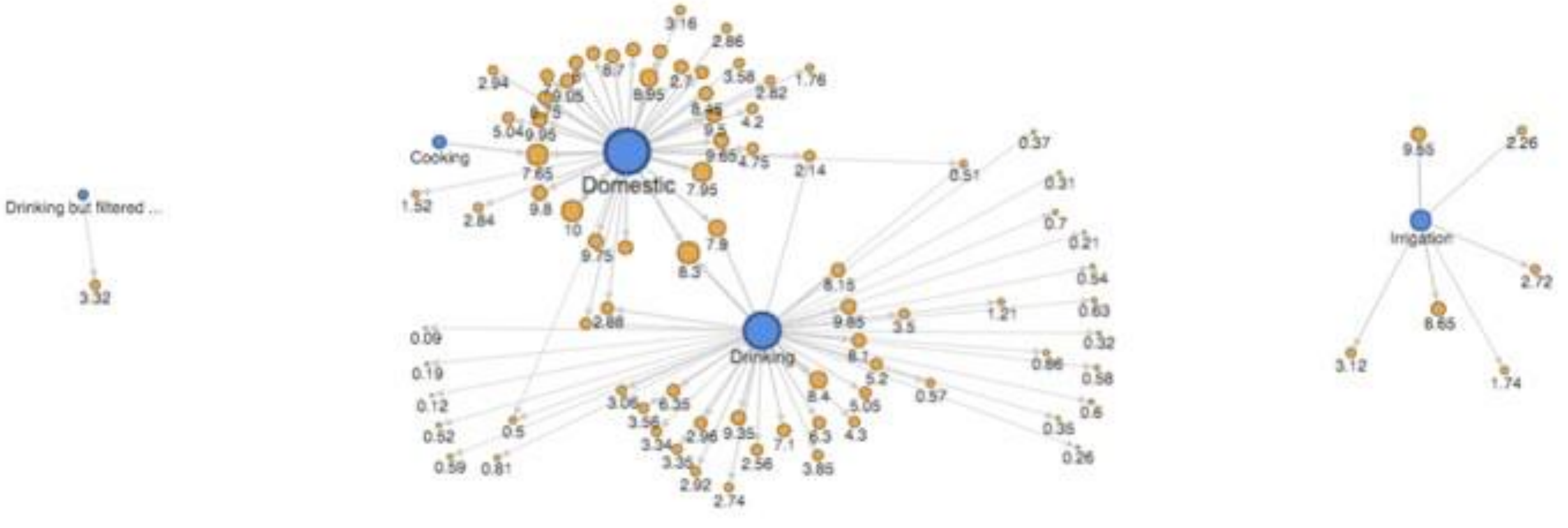
The heat map below shows the geographic region with varying intensity--colors move from green to red to indicate increasingly higher Fluoride values. This kind of map is a useful tool to determine where best to lay new piped infrastructure. This is especially beneficial if a map of existing piped infrastructure can be overlapped onto this heatmap as a way of avoiding duplicate work.

The decision-making authority should also consider groundwater depth and / or population figures as it relates to piping.



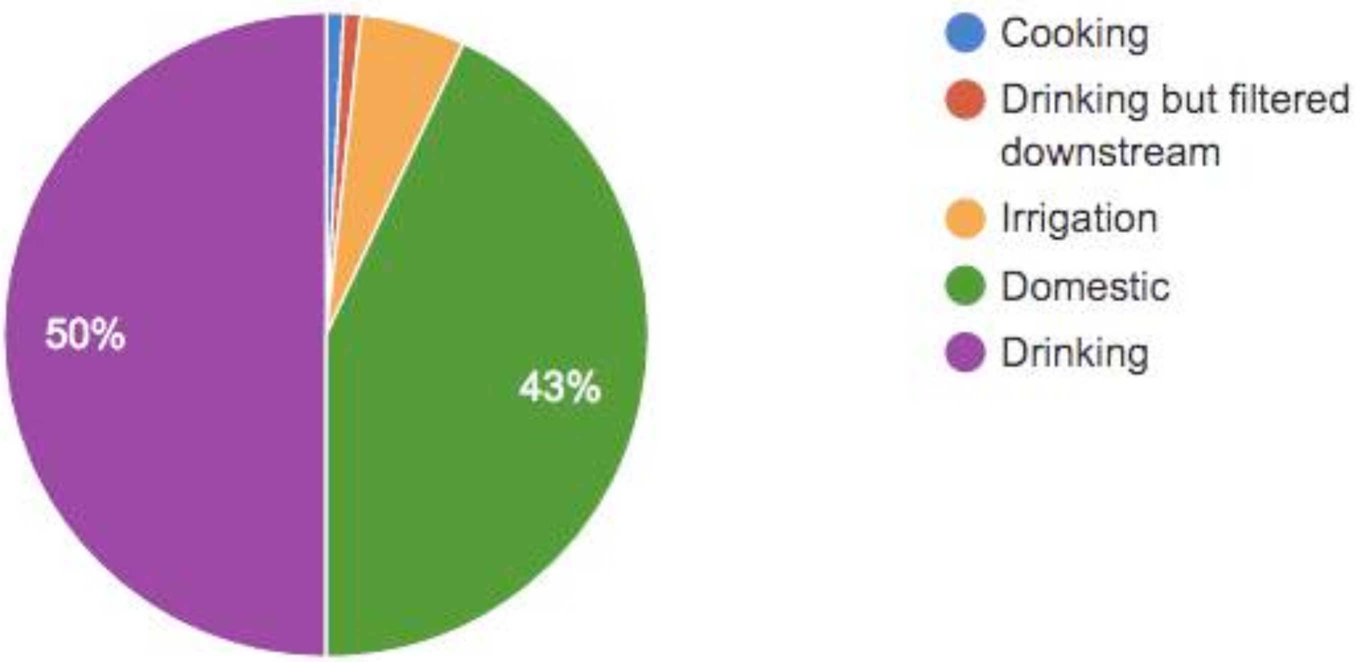
Fluoride Levels Mapped Across Water Source Type

This map reveals the levels found for domestic, drinking, and irrigation water.



Data Points per Water Usage

This map shows the breakdown of the water samples taken, as it relates to its usage. From the pie chart below, it is evident that drinking water samples comprised of 50% of the overall data set. Domestic came in second, at 43%.



Using this pie chart with the network node diagram on the previous page, 13, it is evident that several drinking water sources are in excess of 2 ppm. We encourage decision-makers in the region to revisit these sites to retest, and if the data corroborates our findings, to raise awareness among the locals to avoid such sources. In tandem, we hope the local government may remedy this water source by filtering it, or repiping the source to provide safe Krishna water.

Calibrating Using Reference Sensors

- Ten samples were obtained for the purpose of comparing the water sample values determined by the Caddisly, with the results yielded from traditional reference methods.
- Seven samples were sent to CARE Lab, Hyderabad. This station uses the gold standard reference method of Ion Chromatography to determine accuracy.
- Three of the tested samples were standard solutions of 1.5ppm, 1ppm and 0.5ppm. As can be seen below (see table below), there is a significant difference across all values ranging from 20 -

25% error. This deviation may arise from either the inaccuracies in the reference analysis method, or in the preparation of standard solutions.

Standard Solution Values (ppm)	CARE Lab Values
2	1.5
1	0.8
0.5	0.4

- Based on the high degree of error, it was deemed that further testing was required. The samples were then sent to the Nalgonda Govt. Lab. If the government lab reflected the same values and deviations as the CARE lab with both the Caddisfly sample and the water solution, then the problem would obviously be a mislabeling of the water solution's values.
- After retesting, it was found that the reference water solution sample obtained from the market was in fact mislabeled, and contained different fluoride levels than advertised.
- Upon obtaining a new, brand-name water solution, the Caddisfly readings then showed much greater accuracy.

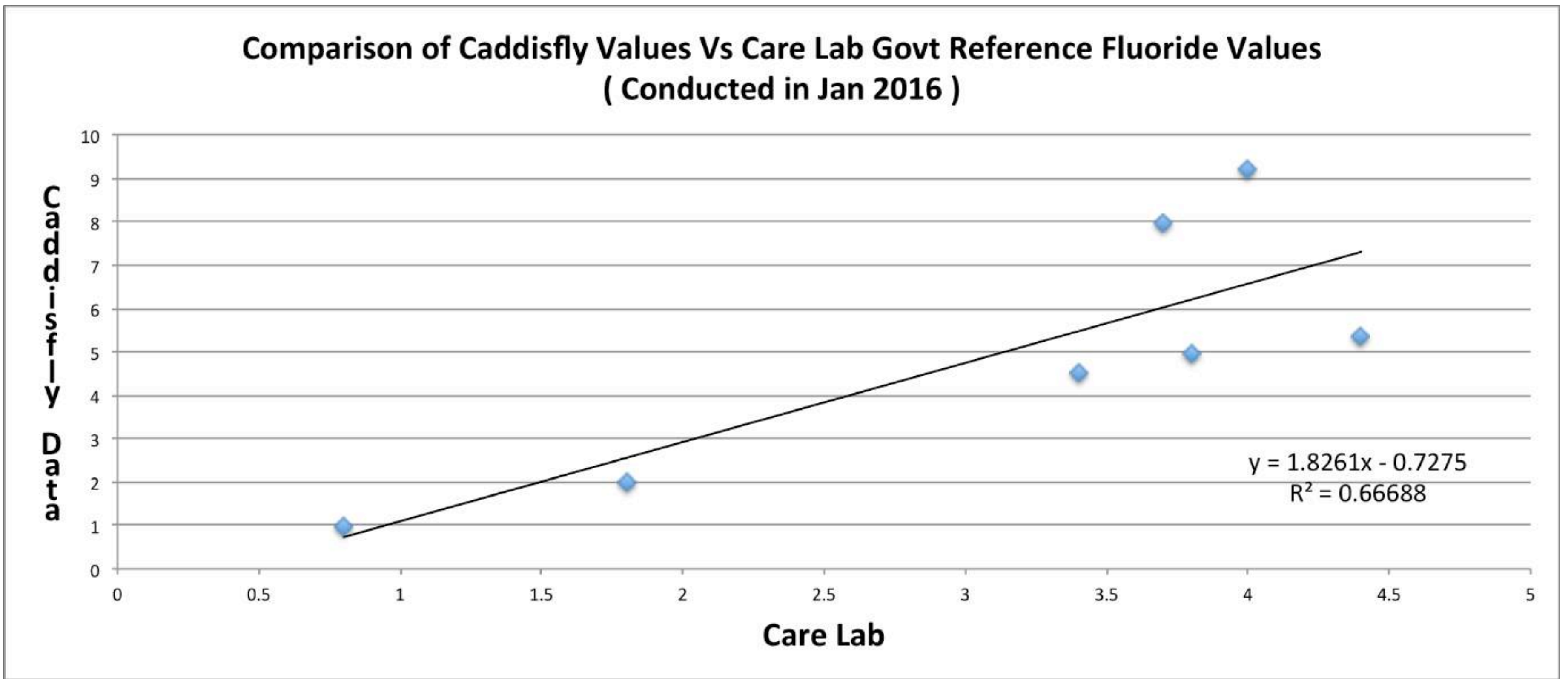
Comments on the Accuracy of the Caddisfly

Overall R-squared is 0.67 for the initial accuracy tests using CARE Lab analysis.

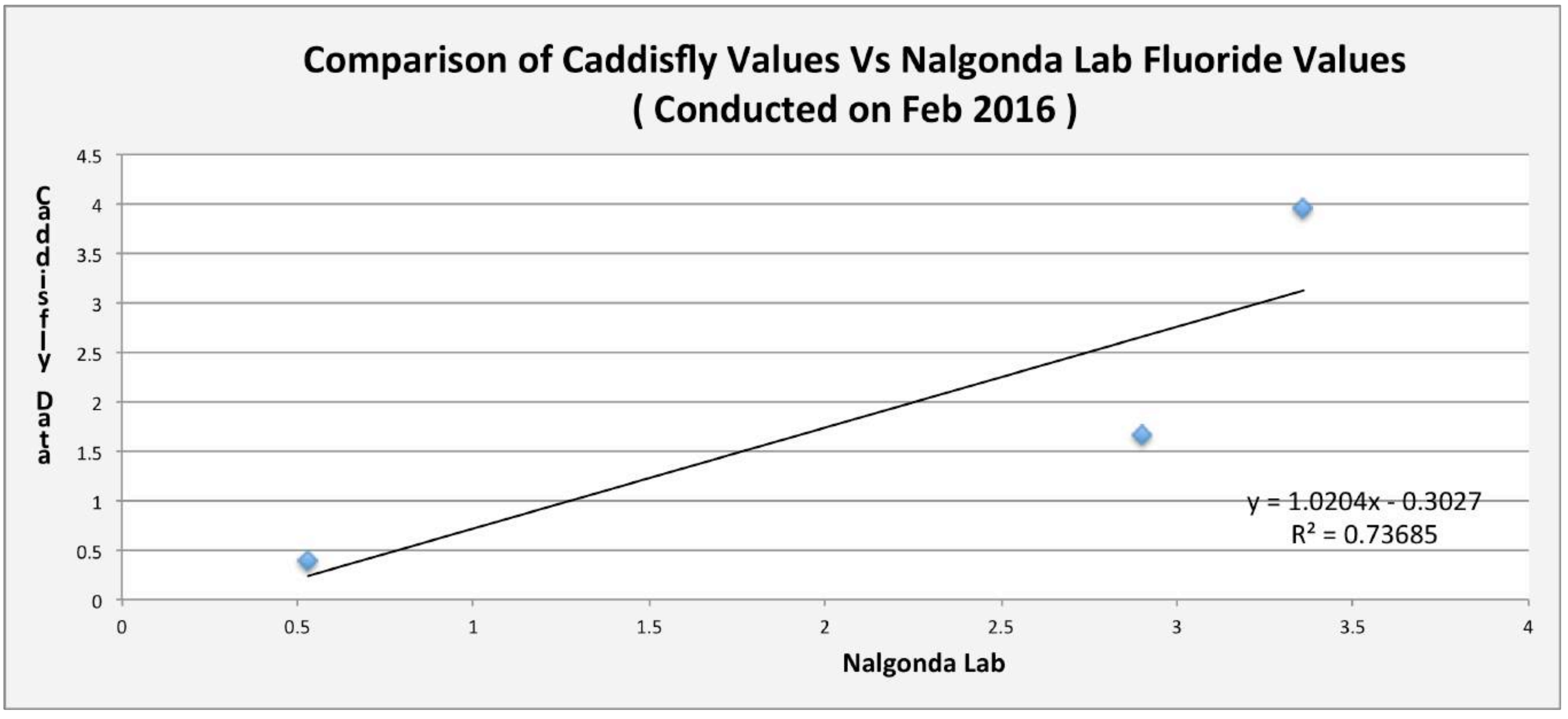
Also, the overall R-squared is 0.74 for the initial accuracy tests using Nalgonda Lab analysis.

This is approaching decent accuracy. However, It can be seen from the figures below that while the Caddisfly is very accurate up to 2ppm range, it is far less accurate at higher fluoride values.

It must be remembered that since toxic levels of fluoride are considered above 2ppm (as per WHO standard), the accuracy of the Caddisfly at these lower levels still make it a useful instrument for a threshold analysis (either > 2ppm or < 2ppm). This is especially true for the Nalgonda District's water testing, on account of their lowered safety threshold of 1ppm due to nutritional deficiencies of low Calcium and Iron. The Caddisfly, then, is a highly suitable device for the region's water testing.



The chart above shows the initial test and the deviation in values between the CARE lab and the Caddisfly data in January, 2016. The chart below shows the re-test at the Nalgonda Lab in February, 2016.



Total Cost of Ownership Analysis

Though the Caddisfly is less expensive and easier to use than standard reference machines, it still carries some capital and operating costs. In addition, reagents are a variable cost that rises with the number of data points. Put another way, the more water sources a group desires to test, the more they will need to spend on reagents. All of these expenses should be considered by any group wishing to undergo similar field work.

In addition, even volunteer citizen scientists donating their labor may still carry boarding and lodging costs.

Based on the expenses incurred to deploy volunteers in this pilot phase, we have obtained estimates for the corresponding line items described below.

Some assumptions are made here:

The lifetime of the Caddisfly device is capped at 6 (six) months.

The estimate is in Indian Rupees: those considering a pilot phase overseas may need to readjust these costs to reflect local prices, especially in food, lodging, transport, and stipend.

In some cases, there was no lodging cost during our trial on account of accommodation being generously organized by FKAN using the local government facilities. However, this might not be the case in every data collection exercise.

DP = Data Point corresponds to the use of the Caddisfly in regard one water source.

Logic Rules (LR)

LR 1	1 Caddisfly Day = 10 DPs / Day	Based on our data collection, we determined that the reasonable number of data points (water samples) that can be collected per day for each device is 10.
LR 2	1 Caddisfly Day = 2 Man Days (2-person team)	Each Caddisfly should be operated by a 2-person team for reasons of accuracy, documentation, and general safety.

Logic Rules Cont'd

LR 3	5 DPs / Man Day	Using LR 1 and LR 2, this logic rule implies it is possible to collect around 5 data points per Man Day (1 Caddisfly Day, then, is 2 Man Days).
LR 4	Man Power Cost / Man-Day (Rs. 150: See Below)	Man Day Cost = total HR-related costs (such as stipend, transport, lodging, etc, also clarified below)
LR 5	Man power cost / data point	As explained by LR 3

Using the 5 logic rules specified above, we can then determine the cost per man day (yielding 5 data points per man and 10 per day) for volunteers supplied with lodging, and without:

Line Item	Remarks	Cost per Man Day (Without Stipend+Lodging)	Cost per Man Day (With Stipend +Lodging)
Stipend	Our study incentivized volunteers with a Rs. 100 stipend, as we felt this would maximize the number of points collected per day. However, groups can use other non-monetary incentives such as certificates.	0	100
Transport	The least expensive is state-run buses, though private transport may be necessary to get shuttled between water sources.	50	50
Lodging	Local field partners and govts may provide this line item to volunteers	0	100

Cost per Man Day Cont'd

Line Item	Remarks	Cost per Man Day (Without Stipend+Lodging)	Cost per Man Day (With Stipend +Lodging)
Food	It is assumed that 3 square meals a day can be provided for Rs. 100. It is worth reiterating that this figure should be adjusted depending on local conditions, as this cost may vary considerably.	150	150
	Cost per Man Day	200	400

The next assessment offers 6 scenarios, each describing a different number of data points collected per day and a varying stipend plus boarding cost. Those considering undergoing a similar trial should choose the scenario that best reflects the geographical context, budget, and number of volunteers available. There are also three additional costs that have been factored into the assessment described herein: device acquisition costs, device operation costs, and device manpower/HR costs associated with the data collection.

The six scenarios for which we have analysed costs are the following :

- Scenario 1 : 10 DPs / Caddisfly Day + No Stipend + Boarding Costs
- Scenario 2 : 15 DPs / Caddisfly Day + No Stipend + Boarding Costs
- Scenario 3 : 20 DPs / Caddisfly Day + No Stipend + Boarding Costs
- Scenario 4 : 10 DPs / Caddisfly Day + Stipend + Boarding Costs
- Scenario 5 : 5 DPs / Caddisfly Day + Stipend + Boarding Costs
- Scenario 6 : 20 DPs / Caddisfly Day + Stipend + Boarding Costs

TCO Analysis: Cost per Data Point (DP)

Note on "Data Points": It is collected over the unit lifetime (assuming 10 DPs / Caddisfly Data)

SNO	Item	Remarks	Data Points	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5	Scen. 6
1	Device acquisition costs	Assuming Caddisfly must be replaced within 6 months of constant use. Device cost is 12,000/kit with no salvage value.	Scenario 1: 180 days: (LR 3) = 180 X 10 =1800 Scenario 2: 180 days: (LR3) = 180 X 15 = 2700 Scenario 3: 180 days: (LR3) = 180 X 20 = 3,600	8	5	4	8	5	4
2	Device operation costs (including consumables)	The reagent is the main cost, though one must also purchase distilled water to clean device between tests. Calibration water is another factor, though cost is minimal.	NA	20	20	20	20	20	20
			SUBTOTAL 1 (device related costs / DP)	28	25	24	28	25	24
			SUBTOTAL 2 (device related costs / DP including 20% maintenance)	*33*	*31*	*29*	*33*	*31*	*29*
3	Manpower Costs	See section Manpower Costs (cost per man) below							
			Manpower Cost per DP based on Logic Rule 5:	30	20	15	70	28	35
			SUBTOTAL 3 (manpower cost plus 10% contingency expense)	33	22	17	77	53	39
			Grand Total (Sub 2 plus Sub 3)	**66**	**53**	**46**	**110**	**84**	**68**

Limitations

1. Major gaps during the field test application

- Our water testing was conducted in only one Mandal within the district. This single district's levels may not be representative of the fluoride levels across other areas.
- The community was not adequately brought in to the process of quality support mechanism. As such, there is a reduced chance that the locals will feel a sense of good quality health and ownership of their water supply.
- It is our understanding that the population's knowledge is poor regarding the connection between drinking contaminated water and subsequent health risks.

- Lack of cleanliness around the source is also due to a lack of sense of ownership. This is because it is a shared resource, with no single owner wishing to bear responsibility.

- Our CSVs reported broken pipes and signs of contamination around the drinking water pipes.

- Even when people know that long-term health consequences arise from drinking contaminated water, their actual behavior seldom changes.

- The community needs to see water quality as a basic right. This will improve the likelihood that they will assert themselves and accept external assistance as a positive change, as opposed to an unwelcomed threat.

Missing Data

Understanding the problem of missing data requires an explanation of all moving parts during the data collection and its ultimate storage. As mentioned, the Caddisfly is composed of an Android phone, coupled with a mixing chamber. It uses the phone's camera sensor and a pre-determined calibration curve to detect color changes obtained from the mixing of the reagent with the contaminated sample. The Caddisfly's app then couples the result with additional data including field context, GPS coordinates and attendant meta data (such as including the username). In tandem, the Akvo App works with the Caddisfly device and its application to connect the Akvo database with the Caddisfly App data.

The connection to the cloud takes place over the phone's wireless technologies, such as the GPRS / 3G connection, or WiFi. In the absence of such a connection, the data is stored offline on the phone itself, and will reconnect and send data once the Internet becomes available.

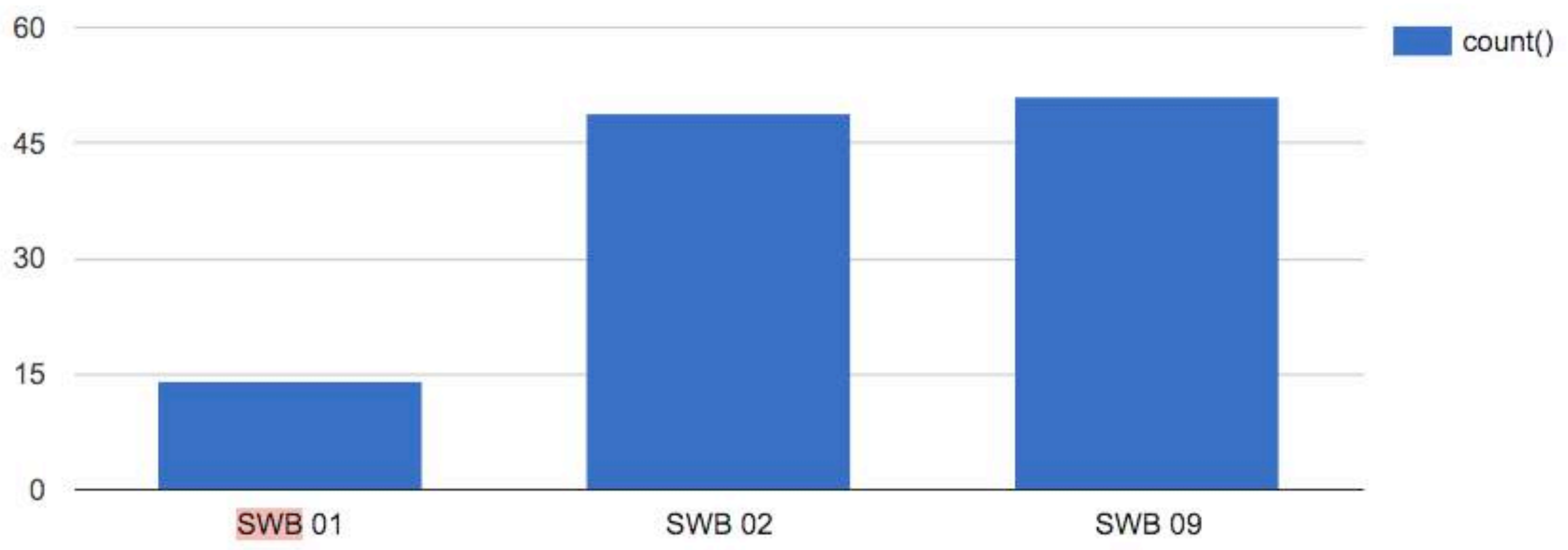
The issue our group encountered is described thus: Our CSVs showed a total of 160 data points and used 6 Caddisfly devices in total. However, the Akvo data ultimately downloaded reflected only 115 of these data points. These data points appeared from only 3 devices in total - "SWB 1", "SWB 2" and "SWB 9".

The table below represents the number of data points collected from these three devices.

This shortage may be explained by either of two reasons :

1. The citizen scientist volunteers did not upload the missing 45 DPs to their Caddisfly devices, either because they forgot to do so or did not know how.

2. The Caddisfly / Akvo apps may have issues with data transference.



A 30% shortfall in data is a significant issue: It increases the cost, required manpower, and margin of error sizably, Anyone using the Caddisfly for a similar operation should undergo the following precautions:

1. Undergo extensive volunteer training, specifically in data point collection, storage, and uploading.

2. During said training, check each volunteer's ability to transfer the data successfully.

3. Ensure the phone possesses wireless capability while in the field, so as to perform routine checks that the data is being transferred and stored adequately.

4. Or, take a break in the afternoon specifically for the purpose of transferring the day's data collection to the Akvo app, and subsequently, a backup device such as a pen drive.

5. Fully test the data functionality before undergoing fieldwork. This should be done by the trainer before the arrival of the volunteers, so as not to waste precious labor and time.

6. Carry backup Caddisflies into the field if the number of devices exceed the number of available volunteers.

7. Rotate the volunteers and the devices periodically, such as in half day intervals. Any issue of missing data can then be pinpointed more easily on a volunteer, or attributed to the device itself.

8. Collect, label, and store each water sample during fieldwork itself. Any missing data can then be rectified by re-testing the specific sample. For this, it's best to purchase several hundreds of small, plastic storage bottles, and designate one volunteer responsible for its collection and hauling.

   Note: it's best to keep these bottles in the same temperatures and conditions as the source it self, when possible, so as to avoid degradation of the fluoride.

Reagent Level Errors

Determining fluoride levels requires mixing reagent with the water. Errors occur when too much or too little reagent is mixed. As such, it is imperative that volunteers know to mix the prescribed amount as carefully as possible so as to avoid this error.

Recommendations

1. Suggestions

a. *Orientation and Training:*

Some of the technical aspects should be explained and simplified to volunteers. For example, the idea of colormetric change to determine levels of fluoride was ill understood by our field deployers. Understanding such points can minimize error, such as the reagent level problem described on the previous page. Moreover, we recommend that field partners such as Engineers Without Borders, provide extensive orientation and training to all volunteers related to the use of the Caddisfly, its software, the dilution process, and how to send data over the network.

Although the Caddisfly is still significantly easier to use than any other fluoride detection device on the market, it is still complex enough to require said orientation. The community survey table below also articulates the user complexity.

b. Recalibration

Each new batch of reagent requires device recalibration, given that no two batches will be precisely the same. This leads to slightly different color changes upon mixing the reagent with the contaminated sample at a given fluoride level. Thus, calibration curves need to be developed with standard fluoride solutions at different ppm values, respective to its particular batch of reagent.

c. Field Personnel Risks

By-and-large, our data deployers were welcomed during the data collection process. However, in the habitation of Batlapalli, our EWB personnel were not welcome by locals due to the fact that there have been unfulfilled promises on the part of the state in providing access to surface water. This led to resentment. Such unkept promises may have been due to the fact that Batlapalli is uphill, making surface water piping particularly difficult. Regardless, anyone undergoing fieldwork should have a clear understanding of local context before the data collection process begins. This information is best provided by the local community partner.

d. Accompanying Government Data

We have access to extensive government data, but the details regarding water levels are not as useful without GPS coordinates to geolocate said points. Absent these coordinates, we could not correlate our gathered data with government data. The ability to cross-compare the data would have been exceptionally useful for supplementary monitoring and to yield benefits of hotspot localization.

Until government machinery collects data with GPS coordinates, our recommendation is to have a government official accompany field deployers, or at least to be able to help correlate these two data sources. Thus, those doing field work may want to work out a partnership arrangement beforehand. This should be arranged well in advance, as some officials mandate permission, a few meetings, and clearing a host of other bureaucratic protocols.

2. Increasing access to safe water presently marked as unsafe

Our study found that some water sources marked as unsafe are actually adequate for drinking purposes. While this is a better problem to have than the opposite (unsafe water sources being marked as safe), it is still an inefficient allocation of water.

Having access to a larger number of safe water sources reduces the net impact of fluorosis in the longer term. This is because at present, people drink from a water source marked as unsafe due to ease of access. They may, however, be willing to travel the extra distance to a nearby water source considered safe. This is especially true if the if the distance to a Krishna water source--a well-understood safe supply--is seen as being too great. The greatest impact will be among the cross-section of people who live furthest from safe water sources and / or are too poor to afford for-sale reverse osmosis water sources nearby.

3. Reducing the net cost burden

To lower costs for Marriguda's population for the pilot and Nalgonda district for the follow-up phase, we must reducing the populace's reliance on reverse osmosis water.

In the face of irregular government provided supply, a crop of private water providers have grown to cover this gap. These suppliers usually charge for filtered reverse osmosis water, and is often the only clean water source available. However, access to this supply comes at a cost estimated to be Rs 6 / litre. This price tag puts it out of reach to the poorest sections within an already impoverished population.

Reverse osmosis water is often inaccessible and inconvenient, given the limited number of such providers. For instance, even if they can bear the financial cost, poor farmers tending to their fields in scorching hot weather seldom have the energy to travel the distances required to access RO-filtered water. Further, reverse osmosis water is a preferable source but not an ideal one: this is because it is completely devoid of minerals important to the healthy growth of the human body.

4. Follow-up phase objective :

In the follow-up phase, our goal is to research the health impact of high fluorosis intake, specifically in terms of new fluorosis cases. We attribute these intakes due to a lack of access to water schemes supplied in Marriguda Mandal.

This lack of access will be contrasted with data from a sampling of the Nalgonda District's other 56 Mandals, specifically those with large swathes covered by the pipeline network. We will contrast the new intake cases in regions with limited access, with the reduced intake of fluorosis cases from regions with better piping infrastructure.

At its core, the campaign will promote school children engaging in the water testing of their local sources. We will try to build momentum around this exercise by doing awareness raising among the Anganwadi workers and Panchayats.

The campaign picks up its threads from what it achieved in this first year, notably the testing of 120 data points in 5 different locations by a group of Engineers Without Borders citizen scientist volunteers.

Gallery